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GEOGRAPHY, GEOLOGY, AND MINERAL RESOURCES OF PART OF SOUTHEASTERN IDAHO

BY

GEORGE ROGERS MANSFIELD

WITH

DESCRIPTIONS OF CARBONIFEROUS AND TRIASSIC FOSSILS

BY

G. H. GIRTY

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CONTENTS

ILLUSTRATIONS

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ABSTRACT OF PAPER

The creation of the western phosphate reserve by Executive action in 1908 was followed by systematic exploration of the area by the United States Geological Survey. Most of the ground in Idaho thus far examined is described in this paper. The exploration and history of the region is sketched from the time of the early fur traders and immigrants to the time of its agricultural settlement and the beginning of its mineral development. The work of the Hayden surveys is briefly outlined and the character of the later geologic studies is described.

Chapter II, on geography, which is preceded by a summary, shows the relation of southeastern Idaho to the larger physiographic regions of the United States. The chapter outlines the physiographic development of the region and describes in some detail its mountains and valleys. The climate, vegetation, animal life, natural resources, industries, and transportation facilities are briefly considered.

The sedimentary rocks of southeastern Idaho have a total thickness of approximately 46,000 feet. They have been divided into 41 formations, ranging in age from Lower Cambrian to Recent. These formations are listed and briefly described in a table in Chapter III. The chapter as a whole is devoted to a detailed description of the distribution, lithology, thickness, paleontologic character, and age of the respective formations.

The igneous rocks of the region may all be referred to three groups—hornblende andesite porphyry, rhyolite, and basalt. The distribution, mode of occurence, and character of these rock types are described in some detail. Six and possibly nine epochs of igneous activity are recognized. The origin of the igneous rocks, their modes of eruption, and their succession are briefly considered, together with the causes of igneous activity, in Chapter IV. The relations of the igneous rocks to the sedimentary rocks and their age are indicated.

In Chapter V the broader structural features, as outlined on the general geologic map of the region (pl. 1), are first described and the types of structure present are mentioned. The chapter as a whole is principally concerned with a detailed description of the individual structural features named on the general map but shown with greater refinement on the large-scale maps of the respective quadrangles (pls. 2–7 and 9) and in the geologic-structure sections (pls. 11, 12). Extended treatment is given to the Bannock overthrust. The epochs of mountain-building, the conditions of deformation, and other related topics are briefly reviewed.

Chapter VI, which is preceded by a summary, is devoted to the interpretation of the geologic record as set forth in the preceding chapters. The events of the respective geologic periods in southeastern Idaho are described in some detail, and comparisons are made both with neighboring regions and with more distant fields.

About three-quarters of Chapter VII, on mineral resources, which is preceded by a summary, is devoted to a detailed account of the physical and chemical character of phosphate rock, the classification and the legal method of acquiring phosphate lands, descriptions of individual phosphate-bearing townships, including estimates of tonnage for each township and for the entire western field, an account of the western phosphate industry, and a statement regarding the production, marketing, and utilization of phosphate rock. Considerable attention is given to water resources, both surface and underground, including a presentation of their character and utilization. In addition to these resources, about 16 minor mineral resources or mineral occurences are described in some detail.

Chapter VIII, which is preceded by a summary, contains a series of essays on themes that have grown out of intensive physiographic and geologic studies of southeastern Idaho. The subjects are considered under the five headings of physiographic, stratigraphic, igneous, structural, and economic problems. Extended treatment is given to the Tertiary peneplanation in Idaho, the origin of the Permian phosphate, the origin of the Rex chert, Triassic and Jurassic physiography and sedimentation, overthrust faulting, circumferential shortening, tension faulting, and the building of the northern Rockies. For each subject the data available for southeastern Idaho and other data are brought to bear upon the discussion of broader fields, some of which involve the consideration of fundamental geologic problems.

The appendix, by G. H. Girty, describes in detail many new species of Carboniferous and Triassic fossils.

GEOGRAPHY, GEOLOGY, AND MINERAL RESOURCES OF PART OF SOUTHEASTERN IDAHO

By George Rogers Mansfield

Chapter I. INTRODUCTION

WESTERN PHOSPHATE RESERVE

The western phosphate reserve, part of which is described in the following report, was created on December 9, 1908, when the Secretary of the Interior withdrew from all kinds of entry 4,541,300 acres of land in Idaho, Utah, and Wyoming. Not all this land was supposed to contain phosphate, but the withdrawal included all areas in which, according to the best evidence then available, valuable phosphate beds might be present. The examination, which has not yet been completed, began in June, 1909, and continued through successive field seasons including 1916, after which it was discontinued in favor of investigations more closely associated with the conduct of the war. The field work has led to the restoration of some of the withdrawn lands and to the withdrawal of others so that, as shown in the chapter on mineral resources, the present acreage of the reserve, which now includes some land in Montana, is much less than at first.

The reserve as now constituted is a group of detached areas in the four States named, some of which have been classified as phosphate land and restored to entry under the public-land laws, the phosphate being reserved to the Government and made subject to development under the provisions of the leasing law. By far the greater part of these areas remains unexamined and unclassified. In addition, some phosphate lands in the general region have passed into private hands. In a broad sense and for the purposes of the present discussion these also may be considered part of the western phosphate reserve.

PURPOSE AND SCOPE OF INVESTIGATION

The original purpose of the work was merely to study the phosphate deposits, describe their occurrence, estimate their quantity, so far as practicable, and classify the public land. The investigation was later extended to include other features of geographic and geologic interest and to complete the areal mapping of the Fort Hall Indian Reservation and of seven quadrangles with some adjacent territory in southeastern Idaho. More detailed study has been made of the Idaho field than of other parts of the reserve, both because of the large body of high-grade phosphate rock that it contains and because the stratigraphic and structural features of the region are of unusual interest.

A number of geologists have been engaged in the work, and several semidetailed reports and minor papers, which are listed in the bibliography at the end of the volume, have already been published. The Fort Hall Indian Reservation is the subject of a separate report. (See bibliography, p. 403.) The purpose of the present paper is to describe the larger area.

LOCATION AND EXTENT OF AREA

This area comprises approximately 2,200 square miles in the southeast corner of Idaho, with narrow adjoining strips of Utah and Wyoming. It extends about 25.5 miles along the northern boundary of Utah and includes about 68 miles of the western boundary of Wyoming. The seven quadrangles with which the report is chiefly concerned are the Montpelier 30-minute quadrangle at the south and the Slug Creek, Crow Creek, Lanes Creek, Freedom, Henry, and Cranes Flat 15-minute quadrangles farther north. Their geographic positions are given in the following table:

Table 1.—*Geographic positions of seven quadrangles in southeastern Idaho*

Quadrangle	Latitude	Longitude
	° ′ ° ′	° ′ ° ′
Montpelier	42 00–42 30	111 00–111 30
Slug Creek	42 30–42 45	111 15–111 30
Crow Creek	42 30–42 45	111 00–111 15
Lanes Creek	42 45–43 00	111 15–111 30
Freedom	42 45–43 00	111 00–111 15
Henry	42 45–43 00	111 30–111 45
Cranes Flat	43 00–43 15	111 30–111 45

The locations of these quadrangles are shown on the accompanying index map (fig. 1), on which are also shown other areas or features mentioned in this report.

The region includes much of Bear Lake County and parts of Bannock, Caribou, Bingham, and Bonneville Counties, Idaho; Rich County, Utah; and Lincoln County, Wyo. It also includes parts of the Cache and Caribou National Forests.

EARLY EXPLORATION AND HISTORY

A concise historical summary, applicable in large part to this region, is given by Gannett.[1] Veatch's historical account of southwestern Wyoming,[2] which is also in considerable measure applicable to this region, is so complete with its annotated bibliography that only a brief supplementary statement is necessary here.

As far back as the later part of the eighteenth century this region was frequented by fur traders and trappers. The waters of the Green, Bear, and Snake Rivers abounded in valuable fur-bearing animals, and in the broad valleys the fur companies had their annual meetings with the trappers for trade. Here, too, occurred many bloody Indian conflicts. Irving[3] gives an interesting picture of the life and activities of the trappers, traders, and Indians in his graphic account of the attempts of parties outfitted by John Jacob Astor to found a trading post at the mouth of Columbia River and in his charming story of the adventures of Captain Bonneville. Bancroft[4] presents a very different picture of Bonneville and his expedition. He denounces Bonneville and censures Irving for his favorable presentation of the captain.

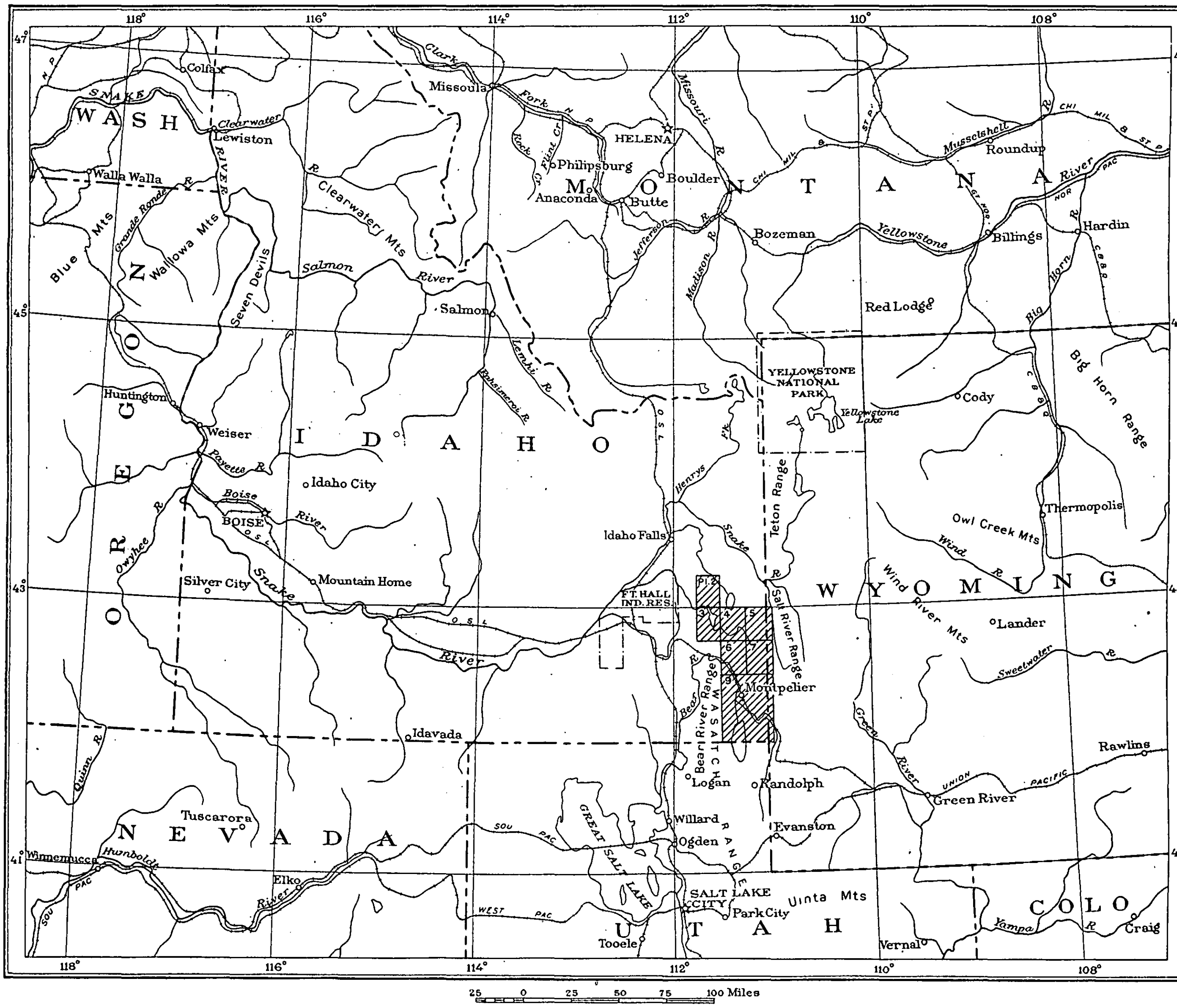


FIGURE 1.—Index map showing the location of areas in southeastern Idaho described in this report and of related areas

The Astorians passed along Snake River on their way to the Columbia. They met with reverses at the hands of the Indians and endured many hardships. One of their parties, in returning under Robert Stuart,

[1] Gannett, Henry, U. S. Geol. and Geog. Survey Terr., Eleventh Ann. Rept. for 1877, pp. 708–710, 1879.

[2] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 9–32, 1907.

[3] Irving, Washington, Astoria, 2 vols., Philadelphia, 1836; The adventures of Captain Bonneville, U. S. Army, in the Rocky Mountains and the Far West, Pawnee ed., vols. 1 and 2, New York and London, 1898.

[4] Bancroft, H. H., Works, vol. 28, pp. 568–575, 1884.

entered Bear River Valley.[5] After misadventure with a party of Indians they made their way over to Salt River (possibly by way of Georgetown Canyon, Crow Creek, and Star Valley) and thence to Snake River. Here they were set upon by the same Indians and suffered the loss of their horses.

The agents of the fur companies and the trappers were familiar with the country, but their knowledge largely died with them. The names of some of them, as Sublette and Portneuf, are, however, preserved in the present nomenclature of the region.

The first exploration that really contributed to the world's knowledge of this territory was that of Bonneville in 1832–1835. He obtained a year's leave from the Army, outfitted his expedition with private means, and set out to explore the Rocky Mountains and to trade with the Indians and trappers. In November, 1833 (?), he entered Bear River Valley from Hams Fork and encamped at the outlet of a lake, which he describes as 30 miles long and from 2 to 3 miles in width, "completely embedded in low ranges of mountains and connected with Bear River by an impassable swamp."[6] This lake, which is without doubt the present Bear Lake, appears on Bonneville's map as "Little Snake Lake." On a later visit to the lake he notes[7] that "the outlets are so muddy and so surrounded by swamps and quagmires" that he was obliged to construct canoes of rushes with which to explore them.

> The mouths of all the streams which fall into this lake from the west are marshy and unconsiderable; but on the east side there is a beautiful beach, broken occasionally by high and isolated bluffs, which advance upon the lake and heighten the character of the scenery. The water is shallow but abounds in trout and other small fish.

Bonneville's map,[8] which is reproduced in part in Figure 2, was the first map to show any of the geographic features of the region.

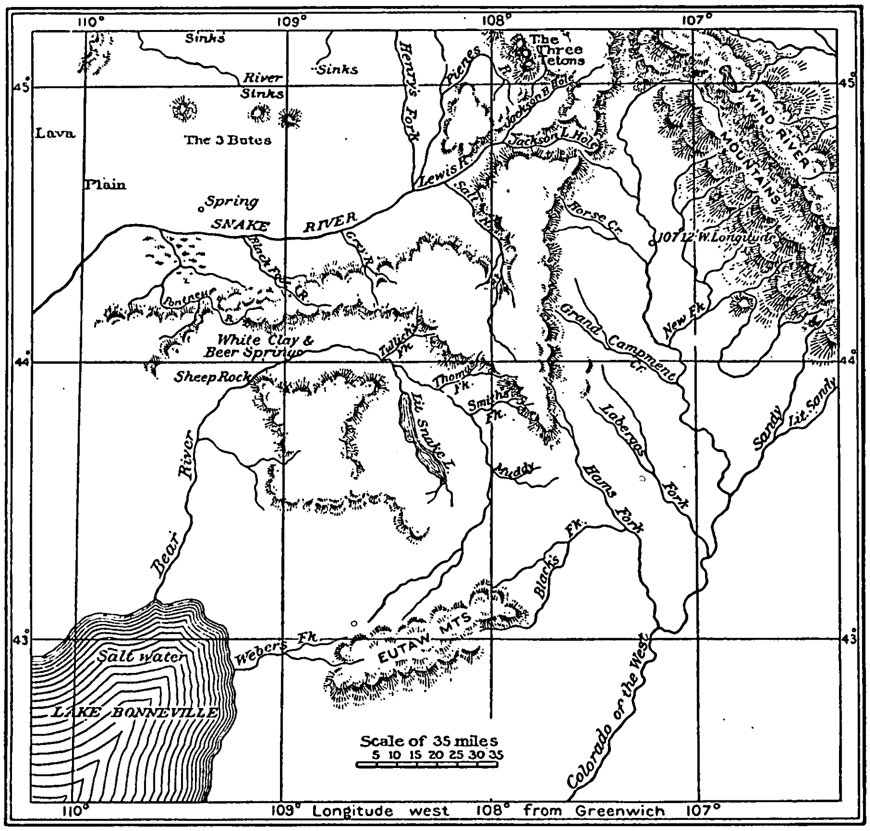


FIGURE 2.—Part of a map by Captain Bonneville accompanying his journal of adventures in the Far West, 1837 (from Professional Paper 56, fig. 1)

Nathaniel J. Wyeth, a trader from Boston, who in 1834 built Fort Hall near the junction of Snake and Portneuf Rivers,[9] shared with Bonneville in buffalo hunting and its attendant festivities in the headwaters of the Blackfoot.

Frémont[10] in 1843 entered the valley of Bear River from the Green River Basin by way of Hams Fork and struck the emigrant route to Columbia River. He noted the attractive and fertile appearance of Bear Lake Valley and the fact that the emigrants paused there to feed and refresh their stock before

[5] Irving, Washington, Astoria, vol. 2, pp. 134–141.

[6] Irving, Washington, The adventures of Captain Bonneville, U. S. Army, in the Rocky Mountains and the Far West, vol. 1, pp. 310–312.

[7] Idem, vol. 2, p. 90.

[8] In Irving, Washington, The Rocky Mountains, or Scenes, incidents, and adventures in the Far West: from the journal of Capt. B. L. E. Bonneville, vol. 1, Philadelphia, 1837. The map in the Pawnee edition is not a copy of the original.

[9] Young, F. G., editor, The correspondence and journals of Capt. Nathaniel J. Wyeth 1831–1836: Sources of Oregon History, vol. 1, pts. 3–6, Oregon Univ. Dept. Economics and History Contr., pp. 146–147, 227, Eugene, Oreg., 1889.

[10] Frémont, J. C., Report of the exploring expedition to the Rocky Mountains in the year 1842 and to Oregon and north California in the years 1843–44, pp. 132–139, Washington, 1845.

proceeding with their tedious journey across the Snake River Plains. Frémont's map includes the region here described. Veatch[11] notes that on this map the meridians are about 10 miles too far east, though the parallels are approximately in the correct position. The general geographic features along Frémont's route are well shown, and the map is the first important contribution to the detailed knowledge of the geography of the region. Frémont's report also includes a map of Bear River valley from "Muddy Creek" (Bridger Creek, Wyo.) to the "Beer Spring" (Soda Springs, Idaho), and analyses of the waters of some springs at that place.

A larger-scale map[12] of the region traversed by Frémont was published in 1850 by his assistant, Charles Preuss, for whom the Preuss Range, one of the most prominent mountain groups in this region, is named.

The old emigrant road to Oregon entered Bear River Valley from the divide at the head of Hams Fork of Green River. Thence it followed along Bear River to Thomas Fork, which it ascended for 2 or 3 miles, then turned west across the southern end of the Preuss Range near the present settlement of Alton. From this point it continued northwestward across the mountains and reentered Bear River valley a few miles south of the present city of Montpelier. Thence it followed the valley in a general northwesterly direction to and beyond Soda Springs. (See fig. 3.) A commemorative monument has been erected on this route at Main and Second Streets in Montpelier.

In the late fifties Government parties were engaged in the selection of routes and the construction of wagon roads through parts of this region. Among the roads thus constructed is that now known as the "old Lander trail" or "Landers cut-off." It was planned

> especially and emphatically [as] an emigrant road, so located as to avoid the tolls of bridges, alkali plains, and deleterious poisonous waters, and to furnish fuel, water, and grass to the ox-team emigration. * * * The overland emigrants reach the mountain sections in the latter part of July, and pass over the adjacent sand plains during July and August. The chief difficulties and obstacles which they encounter arise from the extreme dryness and heat of the artemisian [sagebrush] deserts. The passage of the line as located nearer to the base of the snow-capped mountains, in a more elevated region, richly grassed, and along the great summer trails of the Indians, is favorable to their health, the preservation of their stock, and gives them abundance of pasturage, with water at short intervals from mountain streams.[13]

This road, which enters the Freedom quadrangle in Star Valley, ascends Stump Creek, called Smoking Creek on Wagner's map,[14] crosses into the head of Lanes Creek, skirts the southern end of Grays Lake, then turns westward across Blackfoot River and down Ross Fork in the Fort Hall Indian Reservation into

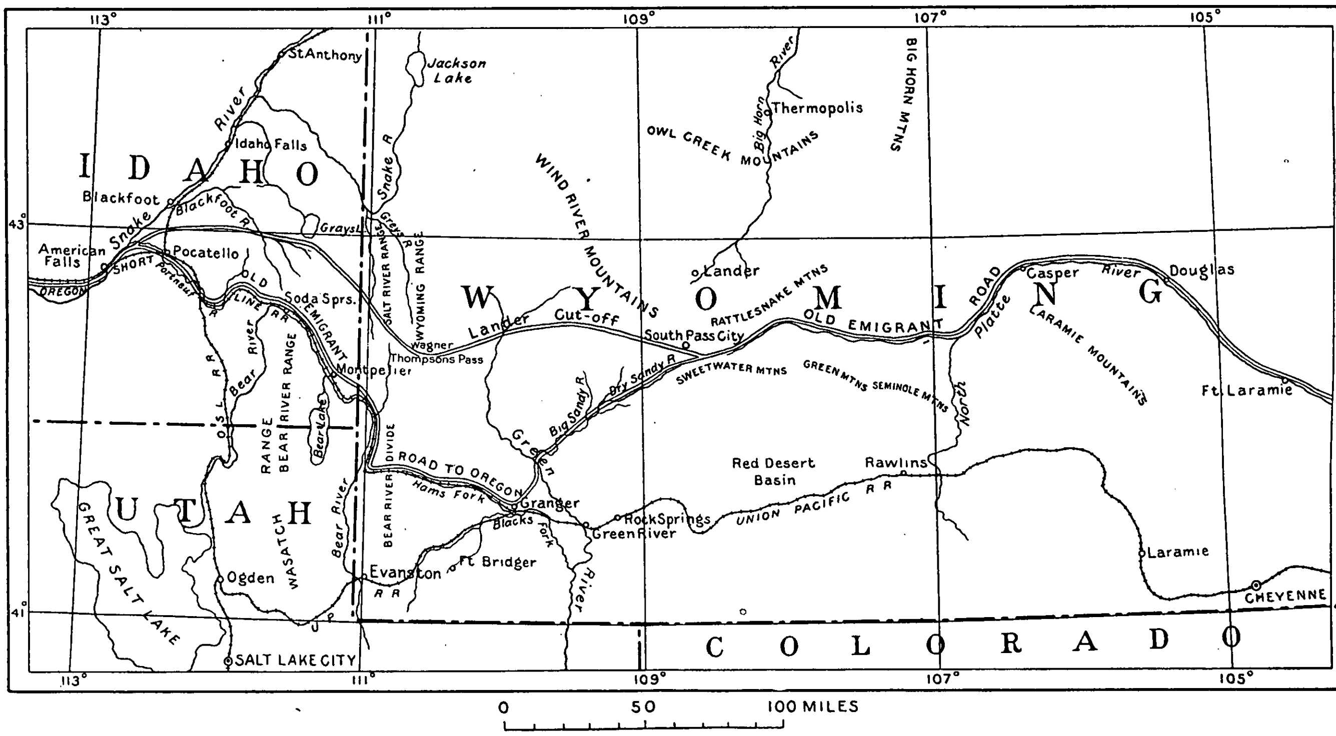


FIGURE 3.—Map of old emigrant road and Lander cut-off in Wyoming and southeastern Idaho

[11] Veatch, A. C., op. cit., p. 17.

[12] Preuss, Charles, 30th Cong., 2d sess., House Com. Rept. 145, vol. 2, [1850].

[13] Report of Supt. F. W. Lander upon the central division of the Fort Kearney, South Pass, and Honey Lake wagon road, constructed under the direction of the Department of the Interior, 1857-1858, 1859: 35th Cong., 2d sess., S. Ex. Doc. 36, vol 10, p. 64, 1859. (Map by W. H. Wagner.)

[14] Idem.

Snake River Valley. Parts of this road in the Freedom and Lanes Creek quadrangles are now impassable for vehicles, but other parts are well used.

Wagner's map, which is on the scale of 10 miles to the inch, includes all the quadrangles here described except the Cranes Flat and furnishes more topographic detail than any of its predecessors.

Before 1872 Bear Lake County was supposed to belong to Utah. It was first settled by a colony of Mormons under C. C. Rich, and was called Rich County. The establishment of the boundary of Idaho by survey threw the greater and better portion of Rich County into Idaho, together with its industrious and thrifty population, and it was considered as part of Oneida County until its separate organization in January, 1875. The first settlers were agriculturists, but their early efforts at farming were failures owing to frost and grasshoppers, which together took the greater part of their crops for several years. By making hay and raising stock the settlers prospered, and little by little overcame the worst of their difficulties.[15]

In 1870 gold was discovered in the Caribou Range east of Grays Lake, in what is now T. 4 S., R. 44 E., about 10 miles east of the Cranes Flat quadrangle. These deposits, first worked as placers, are said to have yielded $250,000 annually for 10 years;[16] in recent years, however, they have been worked but little.

THE HAYDEN SURVEY

In 1871 Hayden [17] explored Bear River and Bear Lake Valleys. He noted the craters north of Soda Springs and described one of them, probably the one in sec. 34, T. 6 S., R. 41 E., in the Henry quadrangle, now called Little Crater. He pointed out their relatively recent age and made a number of other geologic observations, to some of which reference will be made later. In the same year Peale [18] visited Soda Springs and made notes on some of the springs in the vicinity.

Actual geologic investigation and mapping were undertaken in 1877 by parties of the Hayden Survey in charge of Peale [19] and St. John.[20] Henry Gannett did the topographic work of Peale's party, and G. R. Bechler made the topographic map for St. John's party. The work of Peale and Gannett includes all the region here described except the Cranes Flat quadrangle, which lies in the field mapped by St. John's party. This work, though of reconnaissance grade, was of a high standard, and many of the broader stratigraphic and structural features of the region were disclosed, besides numerous details on a variety of subjects. For much of the region covered by these surveys the reports of Peale and St. John still constitute the principal sources of information.

LATER GEOLOGIC STUDIES

The explorations of the United States Geological Survey in this region began in 1906 with the work of Weeks and Ferrier on the phosphate beds. This was continued by Weeks in 1907. The detailed mapping, on which this report is largely based, began in 1909 and is described below.

Paleontologic studies in the general region have been carried on by Walcott, Girty, and J. P. Smith, and stratigraphic studies by Richardson. Further reference to their work is made in the body of this report, and their published contributions are listed in the bibliography.

FIELD WORK

The topographic field work in the quadrangles here described was done in the years 1909 to 1916 by field parties of the United States Geological Survey. Those who participated in establishing the topographic control were G. T. Hawkins, D. S. Birkett, L. F. Biggs, F. L. Whaley, F. A. Danforth, O. G. Taylor, C. F. Urquhart, and H. H. Hodgeson. The topographic mapping was done by Albert Pike, J. L. Lewis, A. E. Murlin, C. G. Anderson, W. O. Tufts, and M. A. Knock. The general excellence of the topographic maps, both in accuracy and physiographic expression, has greatly facilitated the geologic mapping.

The geologic field work was carried on in the same years by a number of geologists and assistants. Work began in the Montpelier quadrangle in 1909 before topographic maps were available, and hence, in that year and at certain places in other years the geologic parties combined topographic with geologic mapping. Hoyt S. Gale had general charge of the work in 1909. From 1910 until the midseason of 1912 R. W. Richards was in charge. For the rest of the period cited the writer has carried forward the investigation with several field parties. The following geologists and assistants have participated in the mapping: P. V. Roundy, E. H. Finch, E. L. Jones, jr., C. L. Breger, E. L. Troxell, J. H. Bridges, William Peterson, J. W. Merritt, and Robert Ferron. Valuable field assistance was also rendered by E. C. Ragar, J. W. Clark, Lester Bagley, Ezra Campbell, Clifford Thornton, Fred Campbell, Lewis Campbell, and V. R. D. Kirkham.

Most of the geologic field work in the Montpelier quadrangle was done on the scale of 1:42,240 or of 1:96,000; but T. 11 S., Rs. 44 and 45 E., and parts of Tps. 13 and 14, R. 43 E., were done on the scale of 1:31,680 and some work was done on the scale of the

[15] Bancroft, H. H., Works, vol. 31, History of Washington, Idaho, and Montana, p. 548, San Francisco, 1890.

[16] Bancroft, H. H., op. cit., p. 533.

[17] Hayden, F. V., U. S. Geol. Survey Terr. Fifth Ann. Rept., pp. 150-156, 161, 1872.

[18] Peale, A. C., U. S. Geol. Survey Terr. Fifth Ann. Rept., p. 193, 1872.

[19] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 511-646, 1879.

[20] St. John, Orestes, Report on the geological field work of the Teton division: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 323-508, 1879.

published map, 1:125,000. Parts of Tps. 12 and 13 S., R. 45 E., were mapped on the scale of 1:1,000. In the six quadrangles to the north most of the work was done on the scale of 1:31,680 or of 1:48,000, but a little has been done on the scale of the published maps, 1:62,500.

The outcrop of the phosphate beds has been mapped practically throughout by plane-table methods, largely by stadia but partly by intersection. The same is true in considerable measure of the boundary between the Rex chert and the Woodside and of the *Meekoceras* zone, which forms the boundary between the Woodside shale and the Thaynes group. All these formations are more or less associated with the phosphate beds and must be considered in the classification of the land. The other boundaries were in part mapped by plane-table methods but usually by successive ridge or canyon traverses and the use of large-scale dissected maps. Where the plane table was not used locations were determined by sights with pocket compass or by identification of position on the topographic maps. This last method was commonly easy because of the accuracy and detail of these maps, which in some places even showed the position of conspicuous individual ledges. All the geologic boundaries have in large measure been followed out upon the ground, but some sketching has been necessary. The boundaries of the Tertiary and Quaternary formations are in some places less accurately shown than are those of the older formations.

Particular attention has been given to the phosphate beds. Existing prospects have been examined and sampled and numerous trenches dug by the Survey parties for obtaining measurements, samples for analysis, and stratigraphic data. In 1912 a special allotment of $300 was provided for this purpose and an additional force of men was employed for about 10 days at the close of the field season.

Other features of the field work included physiographic and geologic observations, measurement of stratigraphic sections, taking numerous photographs, collection of many lithologic specimens and fossils, and sampling certain spring waters.

ACKNOWLEDGMENTS

The field maps, notes, and collections of each geologic field party have been available for study, and the results, so far as practicable, are included in this report. Special reference should be made to the work of Hoyt S. Gale and his party in 1909, from whose published and unpublished data much of the mapping of the Montpelier quadrangle south of Montpelier Canyon and east of Bear Lake Valley has been taken.

The work of the writer in the region began in 1910 under the leadership of R. W. Richards, with whom he continued in pleasant collaboration for two and a half years, until Mr. Richards's duties took him into other fields. In addition to the notes and collections of Mr. Richards several joint published papers and an unpublished manuscript on the Montpelier quadrangle have been available for use in this report. The author is indebted to Mr. Richards for his kindness and for numerous helpful suggestions.

The author owes much to P. V. Roundy, his able assistant, for the three field seasons 1914, 1915, and 1916. To his keen observation and careful measurement and to his faithful and accurate mapping many of the stratigraphic and cartographic details here presented are due. Although he did considerable field work in each of the quadrangles studied and dealt with all the geologic formations involved, special mention should be made of his studies in the rocks formerly called the Beckwith and Bear River formations, which he was largely instrumental in subdividing into their present units. His contagious enthusiasm and his never-failing kindness added much to the pleasure of the work.

To G. H. Girty, who spent some time during five field seasons with the parties in Idaho, the writer is indebted for field determinations and distinctions among Carboniferous and Triassic formations, which would have been impossible without his aid. Besides his own extensive collections from this field Mr. Girty has examined a large amount of material submitted by other members of the different parties. His contributions, with the illustrations on the Carboniferous and Triassic faunas, are embodied in the chapter on stratigraphy and in an appendix that contains descriptions of new species. These contributions add much to the value of the work.

The work of E. H. Finch, who spent parts of three seasons, and of E. L. Jones, jr., who spent part of one field season in the Idaho phosphate work, deserves special mention. These men contributed useful data to the mapping of the Crow Creek, Freedom, Lanes Creek, and Henry quadrangles, besides assisting in the sampling of the phosphate.

The late J. H. Bridges in 1910 mapped portions of Tps. 8 and 9 S., R. 42 E., and of T. 10 S., R. 43 E. In collaboration with R. W. Richards he prepared a paper on the sulphur deposits of the region.

J. P. Smith and T. W. Stanton each spent a few days in examination of parts of the region. Mr. Smith assisted in the study of the beds that contain Triassic ammonites. Mr. Stanton has kindly determined numerous fossils from the Jurassic and Cretaceous formations and has supplied Plate 31, which illustrates typical Jurassic fossils.

The assistance of W. H. Dall, F. H. Knowlton, Edwin Kirk, and L. D. Burling in determining fossils is gratefully acknowledged. Mr. Kirk has kindly supplied Plate 20, which illustrates typical Cambrian and Ordovician fossils.

The numerous chemical analyses, except those otherwise credited, were made in the laboratories of the United States Geological Survey. Special acknowledgment is due to F. W. Clarke, formerly chief chemist, and to George Steiger, at present in charge, for helpful suggestions. The analyses in subsequent pages are credited to the respective analysts.

W. T. Schaller, E. S. Larsen, jr., and the late J. F. Hunter have made mineralogic or petrographic determinations at the request of the writer. O. E. Meinzer, W. G. Hoyt, J. F. Deeds, and G. C. Stevens have revised or rewritten parts of the manuscript relating to water resources.

To his colleagues on the Geological Survey the writer is indebted for encouragement and for helpful suggestions and discussions.

Prof. Eliot Blackwelder has been kind enough to loan his annotated bibliography on phosphate, which the writer has found of much value in the study of the origin of phosphate.

The officers of the Caribou National Forest, past and present, and particularly G. G. Bentz, former supervisor, have permitted the free use of their field facilities and have extended many personal courtesies.

The following owners of phosphate lands or officials of operating phosphate, transportation, or power companies have permitted examination of their respective properties, have given information or supplied maps, or have otherwise rendered valuable assistance in the prosecution of the investigation: J. J. Taylor, superintendent of the San Francisco Chemical Co.'s mine near Montpelier; Robert J. Shields, of the Utah Fertilizer & Chemical Manufacturing Co., of Salt Lake City, with properties in Georgetown Canyon and vicinity; C. E. Nighman, superintendent of the Anaconda Copper Mining Co.'s phosphate properties near Soda Springs, Idaho (to Mr. Taylor, Mr. Shields, and Mr. Nighman the writer's thanks are due for many personal courtesies); Louis A. Jeffs, president of the Western Phosphate Co., of Salt Lake City, with property at Paris, Idaho; Joseph Nibley, president of the American Phosphate Corporation, with property near Montpelier leased from the San Francisco Chemical Co.; L. W. Bach, vice president of the Bear Lake Phosphate Co., of Paris, Idaho; R. H. Sales, chief geologist of the Anaconda Copper Mining Co. at Butte, Mont.; E. L. Larison, superintendent of the acid and fertilizer plants of the Anaconda Copper Mining Co. at Anaconda, Mont.; Markham Cheever, general superintendent and chief engineer of the Utah Power & Light Co., of Salt Lake City, with power plant and lines in Bear Lake County, Idaho; C. R. Higson, of the Utah Power & Light Co.; and R. B. Reasoner, division engineer of the Oregon Short Line Railroad at Pocatello, Idaho.

Many personal courtesies, too numerous to mention separately, have been extended to the writer during the progress of the work by residents of the region. These courtesies are also gratefully acknowledged.

Chapter II. GEOGRAPHY

SUMMARY OF GEOGRAPHIC FEATURES

The region considered in this paper lies chiefly in the northern Rocky Mountain province but includes also part of the Basin and Range province, and both areas are interfingered along their borders with projections of the Snake River lava plain. These physiographic units are briefly described and their relations to each other and to the region here discussed are indicated.

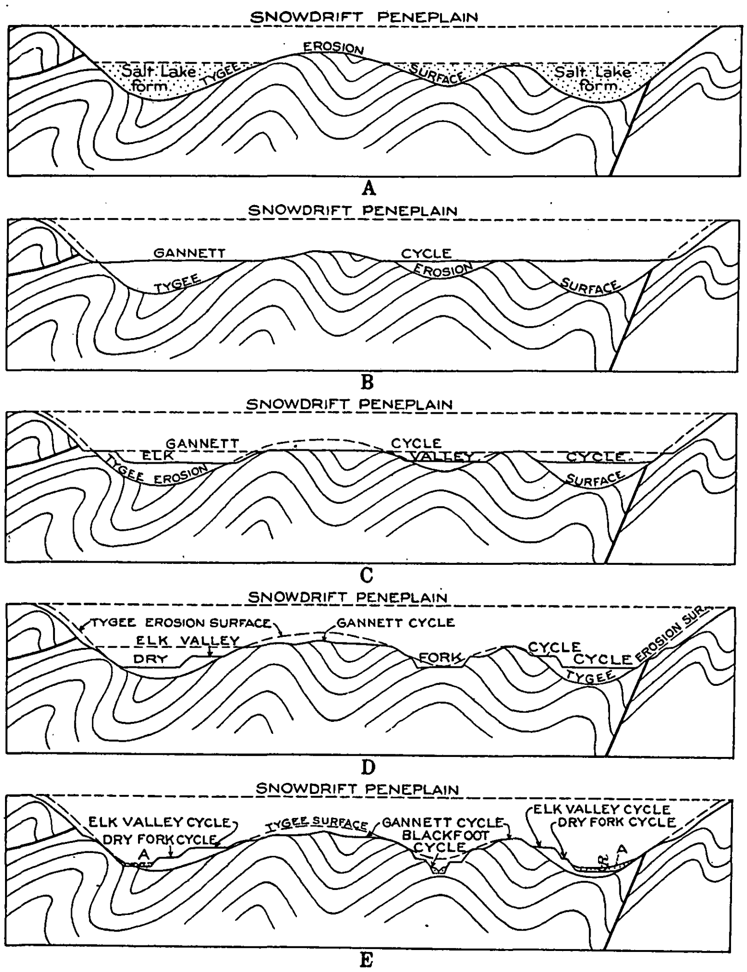


FIGURE 4.—Stages in physiographic development in southeastern Idaho and adjacent regions: A, Tygee erosion and Salt Lake deposition; B, Gannett erosion; C, Elk Valley erosion; D, Dry Fork erosion; E, Blackfoot erosion, aggradation (A), and reexcavation (*R*)

Other studies of the mountains of the West show that complex physiographic development has been the general rule and that similar stages of development may be expected in neighboring regions. The record of southwestern Wyoming is reviewed for comparison with that in southeastern Idaho.

In southeastern Idaho (see fig. 4) the highest ridge tops, at elevations of about 9,000 feet, probably represent remnants of a peneplain, developed in a region of complexly folded and faulted sedimentary rocks. The peneplain was dissected, and after the excavation of broad and deep valleys, which, with the lower neighboring uplands, were then extensively aggraded, the region was uplifted and again subjected to erosion through several succeeding partial cycles. About 1,000 feet below the peneplain stand remnants of a late mature erosion surface, above which unreduced remnants of the earlier dissected peneplain or of an intervening erosion surface now rise in some places as high as 500 feet. Two later erosion surfaces stand at altitudes, respectively, about 300 and 600 feet lower. These surfaces form more or less well defined rock terraces above the present early mature canyons, which themselves range in depth from a few hundred to 1,000 feet or more. Older valleys, which represent some of these earlier erosion surfaces, now hang here and there 400 feet or more above the present valley bottoms.

Some of the broader valleys or intermont basins have been reexcavated in the buried valleys which succeeded the peneplain. Others are in part of structural origin or have been eroded in rocks with favorable structure. Still other valleys owe their present transverse courses to superposition succeeding the aggradational cycle which came after the peneplain. All have been more or less aggraded, partly because of former arid climatic conditions and, in the lower valleys, partly because of obstruction by basaltic flows. Moister climatic conditions, which probably accompanied the later glacial stage, quickened the streams, notably Bear River, which rises in the glaciated Uinta Mountains, and permitted youthful dissection of the aggraded material with the development of canyoned courses and graded reaches in some of the streams. Bear Lake, which occupies a reexcavated valley of structural origin in the southwestern part of the region, was developed to nearly twice its present size. Its highest level, maintained by alluvial fans, did not long persist, but superposition of its outlet upon buried ledges preserved the level of the lake long enough to develop shore lines, which may now be recognized at many places. Since glacial time little erosion has been accomplished.

The mountains and valleys of southeastern Idaho are inadequately named and differentiated. Some principles of nomenclature and definitions are therefore presented. Most of the mountains of the Rocky Mountain province in this region belong to the Idaho-Wyoming Chain, which, with some of its subdivisions, is here described, and new names are applied where necessary. Other members of the province which enter the region are the Bear River Plateau and Wasatch Range with their subdivisions and associated valleys. These members are also briefly described. In addition several members of the Basin and Range province and extensions of the Snake River lava plain are distinguished and described.

The climate is semiarid, and the annual rainfall is about 14 inches. The mean annual temperature is about 41°, but strong contrasts occur between summer and winter temperatures, and marked extremes of temperature, both monthly and annual, are experienced. The prevailing westerly winds and the other climatic features are modified to some extent by local physiographic conditions. The growing season averages 87 days but varies greatly in different parts of the region.

PHYSIOGRAPHIC PROVINCES

LARGER PHYSIOGRAPHIC DIVISIONS

According to a map prepared in 1916 by a committee of the Association of American Geographers,[1] in collaboration with members of the United States Geological Survey, the United States has been divided into units of greater or less magnitude, according to structural or other differences. The subdivisions are of three orders—major divisions, provinces, and sections. In general these are given geographic names, but for a few the proper name is replaced by some distinctive term. Thus we have the Intermontane Plateaus (major division), the Basin and Range province, and the Nevada Basin section.

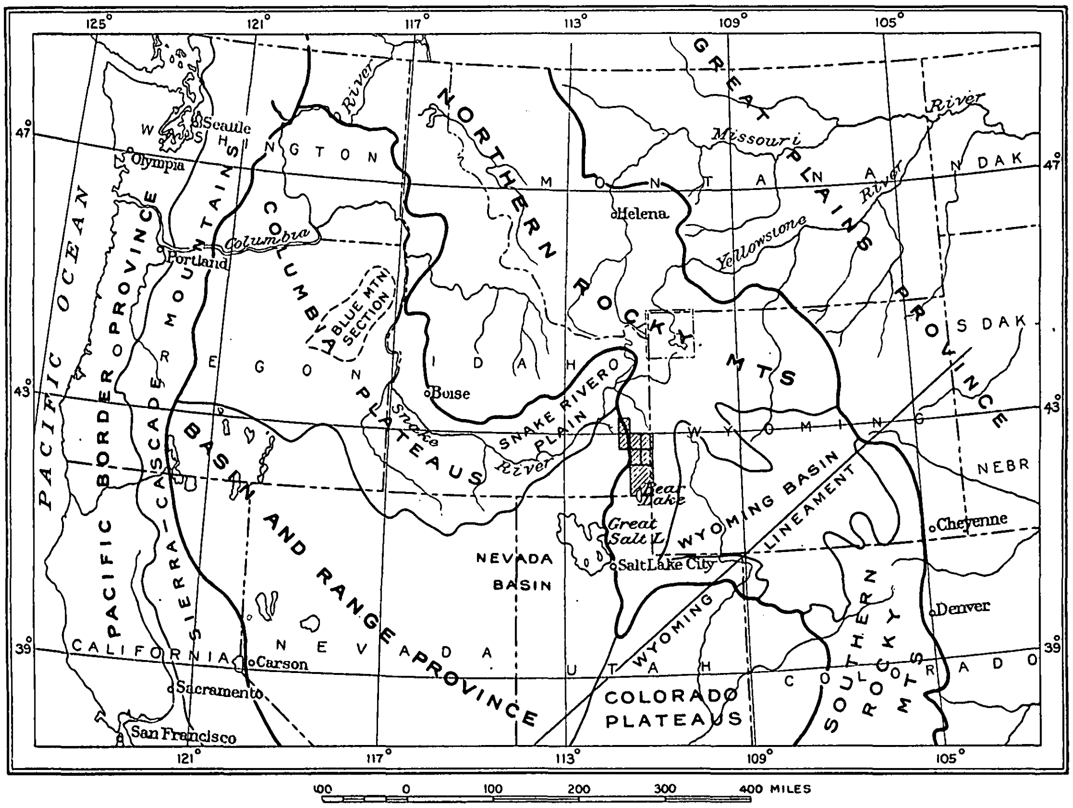


FIGURE 5.—Physiographic provinces in southeastern Idaho and adjacent regions and the "Wyoming lineament"

The vegetation responds actively to the climatic conditions and differs in character and distribution with exposure to sun and wind and with the distribution of moisture and of temperature. There is timber for local use, but much of it is relatively inaccessible.

Agriculture and grazing are the chief industries, but phosphate mining gives promise of extensive early development. Some water is available for irrigation and for power.

The Oregon Short Line Railroad crosses the southwestern part of the region, and Montpelier, Idaho, is the principal shipping point. Much of the country is sparsely settled and remote from railways but is accessible by roads or trails. Electric power is available from plants erected on Bear Lake and Bear River.

DIVISIONS REPRESENTED

The region of the seven quadrangles here described lies chiefly in the Rocky Mountain system and forms part of the Northern Rocky Mountain province, but it is adjacent to the Nevada Basin section of the Basin and Range province of the Intermontane Plateaus and to the Snake River section of the Columbia Plateau province. Locally it partakes of the characteristics of each of these sections. These physiographic units will therefore be briefly described, in order that the relationship of this region to these units may be more clearly indicated. (See fig. 5.)

[1] Fenneman, N. M., Physiographic divisions of the United States: Assoc. Am. Geographers Annals, vol. 6, pp. 19-98, pl. 1, 1917.

ROCKY MOUNTAIN SYSTEM

Near its central part in south-central Wyoming the mountain belt gives way to plateaus with somewhat isolated low mountains, which are practically continuous with the great plains at the northeast and with the high plateaus at the southwest. The plateau area thus serves to divide the Rocky Mountain system into three well-defined provinces, namely, the Northern Rocky Mountain province, the Wyoming Basin, which includes the plateaus, and the Southern Rocky Mountain province. This paper is concerned only with the first of these subdivisions.

> The Northern Rocky Mountain province embraces all contiguous mountains in the United States north and west of central Wyoming to the Cascade Mountains in northern Washington. For about 75 miles south of the international boundary the Rocky Mountain system borders on the Cascade Range. Throughout its remaining 2,500 miles the boundary is marked almost everywhere by a contrast of mountains on one side and plateau on the other. For the greater part of this distance the contrast is sufficiently sharp to be visible in the field within a single view. * * * The area within the line is all mountainous, the valleys being so narrow as to be plainly incidental to the mountain character. * * *
>
> The province as thus outlined embraces several scores of separate ranges and many important valleys bearing distinct names. The ranges differ in topography, structure and physiographic history, but all together form a continuous expanse of mountain country extending northward far into Canada. * * *
>
> Going north at the west foot of the Wasatch the province boundary is marked by a perfectly clear and abrupt topographic break separating the Wasatch Mountains from the Great Basin. * * * It follows the valley of Bear River northward to latitude 42° 40′. Thence it continues north along the course of Blackfoot River at the western base of the Blackfoot Mountains. At a point south of Idaho Falls the line thus described intersects the boundary of the Snake River Plains.[2]

The southern boundary of the Northern Rocky Mountain province corresponds in a general way with the line called by Ransome[3] the "Wyoming lineament," except that this line passes through the Wyoming Basin, which is regarded by the committee mentioned above as a separate province.

INTERMONTANE PLATEAUS

The Intermontane Plateaus[4] include all the territory west and south of the Rocky Mountain system in which mountains are either wanting or isolated in relatively small ranges separated by desert plains. A northern division of these plateaus that lies almost wholly in Canada and Alaska consists largely of worn-down mountains.

Columbia Plateau province.—The Columbia Plateau province is a subdivision of the Intermontane Plateaus characterized by a substratum of nearly horizontal lava flows.

The Snake River Plain is a part of the Columbia Plateau distinguished by its very young lava plains.

Basin and Range province.—The Basin and Range province is that part of the Intermontane Plateaus which is characterized by isolated, subparallel mountain ranges that rise abruptly above desert plains. It lies west and north of the Colorado Plateaus and extends from southern Oregon to the interior of Mexico, its dominant features differ in development from place to place.

The northern part of this region is roughly coextensive with the area of internal drainage which John C. Frémont named the Great Basin. This name, however, has generally been used in geographic and and geologic writings with primary reference to the characteristic surface features of the country rather than with regard to the actual limits of drainage basins.

> The most central and significant feature of the Great Basin seems to be the accumulated waste from its higher parts, building plains in its lower parts. This is related on the one hand to the structure of the province and on the other to its climate. Along streams entering the basin from other provinces, such deposits do not begin until the proper limits of this province are reached. Again, where such deposits are found along stream courses leading outward from this province to through-flowing streams, their presence indicates ineffective drainage in that portion of the stream basin where they are found. This inability of the running waters to forward the waste derived from higher slopes is a much more important fact in the character of the country than the mere fact that the water is, at some remote point, evaporated or that it ultimately reaches the sea.[5]

Almost equally distinctive are the isolated, nearly parallel mountain ranges, which are presumably fault blocks. The consolidated older beds and lavas that constitute these mountains are only locally horizontal. In general they are deformed and locally very much so.[6]

The Nevada Basin section is that part of the Basin and Range province which contains elevated desert plains and approximately equal areas of mountain and plain.[7] It constitutes the largest section of the province. Davis gives the following picture of the region:[8]

> The low ranges with sprawling, fading spurs and wide open valley mouths are regarded as the residual reliefs of the earlier cycle, undisturbed or only slightly disturbed by the later faulting, and not greatly modified by continued erosion. The high ranges, with strong slopes, simple base lines on at least one side, and relatively narrow valley mouths, are regarded as uplifted and tilted blocks of the previously eroded region, now well entered upon a new cycle of erosion. The intermont depressions, more or less aggraded, appear to be relatively depressed areas now covered with waste from higher areas.

[2] Fenneman, N. M., op. cit., pp. 80–82.

[3] Ransome, F. L., The Tertiary orogeny of the North American Cordillera and its problems: Problems of American Geology, pp. 294, 295, New Haven, 1915.

[4] Fenneman, N. M., op. cit., pp. 41, 42, 83–93.

[5] Fenneman, N. M., op. cit., p. 90.

[6] Idem, p. 89.

[7] Idem, p. 42.

[8] Davis, W. M., The Wasatch, Canyon, and House Ranges, Utah: Harvard Coll. Mus. Comp. Zoology Bull., vol. 49, p. 54, 1905.

RELATIONS OF AREA TO PROVINCE BOUNDARIES

The west boundary of the Northern Rocky Mountain province as outlined above follows Bear River northward through the Logan and Preston quadrangles and thence presumably continues northward through the Henry, Portneuf, and Paradise Valley quadrangles along the west base of the Blackfoot Mountains. (See pl. 15.) It is here proposed to modify that boundary by drawing it eastward through the gap of Bear River west of Soda Springs and thence northward to the valley of Meadow Creek in the Henry quadrangle. From that locality it is drawn northwestward through the valley of Willow Creek and along the east side of the Blackfoot Mountains. This arrangement places Reservoir Mountain and Wilson and Pelican Ridges, all of which are believed to be fault blocks, in the Basin and Range province.

The boundary of the Snake River Plain section of the Columbia Plateau province, which is necessarily generalized on the small-scale map, becomes intricate when followed in detail on large-scale maps. Most of the large valleys that drain into the Snake are occupied in greater or less degree by lava, which merges with that of the Snake River Plain outside the mountains. These valley extensions of the lava plain are properly arms or branches of it and as such they interlock with extensions of the Basin and Range province on the one hand and of the Northern Rocky Mountain province on the other. The Willow Creek and Blackfoot lava fields are examples of this interlocking tendency that fall within the area here described.

PHYSIOGRAPHIC DEVELOPMENT

OTHER STUDIES

Geologists who have worked in different parts of the western mountains and plateaus have found evidence of widespread peneplanation, or late mature erosion, succeeded by crustal disturbances and renewed erosion, usually interrupted by further earth movements or influenced by climatic changes, the whole series indicating a complex physiographic development. Thus Ransome[9] in the Sierra Nevada; Smith and Willis[10] in the Cascade Mountains; Robinson[11] in the Grand Canyon district; Atwood and Mather[12] and Ball[13] in Colorado; Baker,[14] Rich,[15] Westgate and Branson,[16] and Blackwelder[17] in Wyoming; Lindgren,[18] Calkins,[19] and Umpleby[20] in Idaho; Willis[21] in Montana; and Dawson[22] in British Columbia have all recognized and described in greater or less detail such a chain of physiographic events. The sequence in all these places has not been identical, and geologists are not fully agreed upon the time of occurrence of some of the events or upon their relative significance. It is clear, however, that the earth movements, climatic changes, and erosive agencies that produced the physiographic features were regional rather than local in their activity and that in districts relatively near each other similar physiographic development, subject to local modifying influences, may be expected. The region nearest to southeastern Idaho for which a fairly detailed record has been worked out is central-western Wyoming. This record is reviewed below for comparison with that of southeastern Idaho.

RECORD OF WESTERN WYOMING

Aside from unconformities the oldest recognized erosion surface in western Wyoming probably lies near the west end of the Owl Creek Mountains, where, according to Blackwelder,[23] an old sub-Eocene land surface has recently been exhumed by the denudation of the soft Eocene clays and yet has not been seriously disfigured during the process. This surface is "postmaturely hilly upon the harder rocks" and has a relief of over 1,000 feet but is generally worn down to plains on the weaker Cretaceous and Jurassic beds.

The oldest surface developed as a part of the present topography is a peneplain with monadnock ridges that is well preserved in the Wind River Mountains, where it has been described by Westgate and Branson[24] as the Summit peneplain and by Blackwelder[25] as the "Wind River peneplain," the product of the "Fremont cycle." The central part of the Wind River Range is really a broad dissected plateau 20 to 30

[9] Ransome, F. L., The Great Valley of California: California Univ. Dept. Geology Bull., vol. 1, pp. 371–428, 385–387, 1896.

[10] Smith, G. O., and Willis, Bailey, Contributions to the geology of Washington: U. S. Geol. Survey Prof. Paper 19, pp. 38, 70, 1903.

[11] Robinson, H. H., A new erosion cycle in the Grand Canyon district, Ariz.: Jour. Geology, vol. 18, pp. 742–763, 1910.

[12] Atwood, W. W., and Mather, K. F., The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colo: Jour. Geology, vol. 20, pp. 385–409, 1912.

[13] Spurr, J. E., Garrey, G. H., and Ball, S. H., Geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, 1908.

[14] Baker, C. L., Notes on the Cenozoic history of central Wyoming (abstract): Geol. Soc. America Bull., vol. 23, pp. 73, 74, 1912.

[15] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, pp. 601–632, 1910.

[16] Westgate, L. G., and Branson, E. B., The later Cenozoic history of the Wind River Mountains, Wyo.: Jour. Geology, vol. 21, pp. 142–159, 1913.

[17] Blackwelder, Eliot, The Cenozoic history of the Laramie region, Wyo.: Jour. Geology, vol. 17, pp. 429–444, 1909; Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, pp. 97–117, 193–217, 307–340, 1915.

[18] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, pp. 77, 78, 1900; A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, p. 14, 1904.

[19] Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, pp. 14, 19, 1909.

[20] Umpleby, J. B., An old erosion surface in Idaho: its age and value as a datum plane: Jour. Geology, vol. 20, pp. 139–147, 1912. See also criticism by Blackwelder, idem, vol. 20, pp. 410–414, 1912, and reply by Umpleby, idem, vol. 21, pp. 224–231, 1913.

[21] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston Ranges, Mont.: Geol. Soc. America Bull., vol. 13, pp. 348, 349, 1902.

[22] Dawson, G. M., On the later physiographical geology of the Rocky Mountain region in Canada, with special reference to changes in elevation and to the history of the glacial period: Canada Roy. Soc. Proc. and Trans., vol. 8, sec. 4, p. 13, 1891.

[23] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geology, vol. 32, p. 106, 1915.

[24] Westgate, L. G., and Branson, E. B., op. cit., pp. 144–147.

[25] Blackwelder, Eliot, op. cit., pp. 193–195, 310.

miles wide, surmounted by a narrow axial range of sharp peaks. Tabular remnants indicate the character and position of the original surface, which cuts indiscriminately hard and soft Archean and Paleozoic rocks. This peneplain in the Wind River Range attains elevations of 11,300 to more than 12,000 feet and in adjacent regions to the west other surface remnants of supposedly the same age reach elevations of 10,500 to 11,000 feet.

Below this peneplain Westgate and Branson[26] distinguish and describe four erosion surfaces or "plains." They also recognize two glacial stages, but the plains were all developed before the earlier glacial stage.

Blackwelder, from the study of a considerably larger territory, distinguishes in addition to the peneplain at least four cycles of erosion and three stages of glaciation. Three of the four cycles are more or less associated with glacial phenomena, but one is older than the oldest glacial drift. The latest cycle, which is probably complex in detail, is represented by the inner valleys with existing flood plains and their immediate terraces. It was closely associated with the last glacial stage.[27]

The first erosion stage after the peneplain, called by Blackwelder the Union Pass cycle, produced a "post-mature" surface upon resistant Archean and Paleozoic rocks near the west end of the Wind River Range, notably below the highest peneplain. It is represented by broad, shallow, and well-graded valleys at elevations of 9,000 to 9,500 feet. In the Teton Range, in the vicinity of the north fork of Teton River, Blackwelder thinks that the plain may have been tilted upward toward the east, so that it now rises from about 6,000 feet, the plateau level, to 9,500 feet at the base of the more rugged peaks. Although the surface produced in the Union Pass cycle was doubtless broadly planed on weak Mesozoic and Tertiary rocks, only late mature topography was developed on the harder rocks near the headwaters of the streams.

The surface features developed in the next or Black Rock cycle lie several hundred feet lower than the valleys that were developed in the Union Pass cycle. Remnants of this surface lie 500 to 1,000 feet above the present streams. This surface is marked here and there by the accumulation of thick gravels upon it, whereas the earlier or later partly developed plains carry only a thin veneer of such material. Patches of the oldest recognized glacial deposits lie here and there upon remnants of this surface.

The next or Circle erosion cycle is represented by broad terraces cut at many places across upturned beds 100 to 400 feet above the bottoms of the present stream valleys. This terrace blends into the earlier moraines of some of the glaciers. Suggestions of additional partial erosion cycles between this and the one preceding are visible here and there, but they have not yet been worked out.

The last of the cycles described by Blackwelder is the Lenore, which is represented by the inner trenches of streams cut 100 feet or more below the terraces that mark the preceding cycle. Although these valleys are relatively narrow in their upper reaches they are well graded, and the flood plains are broad enough locally to accommodate ranches. They expand considerably downstream. The moraines of the latest glacial stage were deposited in these valleys.

RECORD OF SOUTHEASTERN IDAHO

GENERAL CHARACTER

The present surface of that portion of southeastern Idaho included in the region here described has been produced mainly by the agencies of so-called normal erosion that followed the intermittent uplift or warping of the earth's crust. Glaciers had no direct part in the sculpture of the surface, though local glaciers did exist here and there in the Bear River Range to the west and in the Salt River Range to the east. Likewise the activity of the wind has been greatly subordinate to that of streams, and its chief observed effects were the accumulation of soil at favorable places, especially in portions of the lava fields. The effects of gravity in conjunction with those of frost, changes in temperature, or favorable geologic structure are much in evidence throughout the region in the form of talus piles and waste slopes and locally of landslides. Climatic change, though not a dominant control in this region, has exercised a clearly distinguishable influence, especially in the later stages of topographic development. Extrusions of lava both within and without the region, have also played a noteworthy part in the production of the present surface features.

The intermittent character of the crustal movements has given rise to a series of erosion cycles, none of which, with a single possible exception, was carried through to completion and some of which were so short that they may be regarded simply as brief episodes in the topographic development of the country. Episodes or partial cycles recorded in some localities have been unrecorded in others or their records have been obliterated by subsequent erosion. No attempt is made to correlate or describe these shorter episodes. Such an attempt would be ineffective without further and more detailed field study and might even then be fruitless.

TOPOGRAPHIC PROFILES

In order to study the relationship of the various topographic features to each other 23 profiles, representing typical areas, were constructed. These profiles were all drawn to true scale and in one of two general directions, either parallel with the trend of the ranges and hills or at right angles to that trend.

[26] Westgate, L. G., and Branson, E. B., op. cit., p. 159.
[27] Blackwelder, Eliot, op. cit., pp. 309–340.

Instead of making straight cuts, as in profiles for geologic structure sections, they follow divides and are thus irregular, but they show the relative evenness or irregularity of crest lines in main or subordinate ridges, and, where they cross valleys or canyons, they show the modifications produced in older topographic features by later erosion. Plate 10 illustrates a selected group of these profiles, the locations of which are shown on Plates 4 to 6, 8, and 9.

One of the conspicuous features in these profiles is the number of relatively level areas or levels that appear in many of them. The largest number recognized in any one profile is eight. (See E–E′, pl. 10.) They range in altitude from nearly 9,400 feet to somewhat less than 6,000 feet and indicate that the physiographic history of the region, when considered in detail, is highly complex.

Some of the levels have been developed through the occurrence of layers of hard rock. In many places erosion has differentiated the hard from the soft layers, so that the hard rocks form prominent ledges, ridges, or knobs. These features are closely related to the erosion cycles and commonly mark the position of the erosion surface at the time of interruption of the given cycle, as shown by the 8,200-foot level east of White Dugway Creek (E–E′) or by the 7,000-foot level near Bear River (A′–A″), west and east of Crow Creek (E′–E″), or near Stump Canyon (K–K′). (See pl. 10.) The presence of weaker rocks at many of these levels, however, indicates that the levels are not wholly due to differential erosion, but that actual interruptions of the erosional processes have occurred, resulting in the establishment of partial cycles of erosion.

LEVELS AND EROSION CYCLES

A given erosion surface was not everywhere developed at the same level during the same cycle of erosion. Rock terraces in valleys should stand at higher levels in the upper courses of streams than farther downstream, because of the graded slope of the former valley floor, of which the terraces are remnants. Corresponding terraces stand at different levels in different valleys, depending upon their relative position in the courses of the respective streams and upon the different conditions that may have influenced the grade of the respective streams, such as length of course, area of drainage basin, and stream piracy. Moreover, the vigorous cutting in a newly established cycle may remove much of the evidence of a previous partial cycle, especially if the earlier cycle was relatively short. Thus, as in alluvial terraces, a single rock terrace at one locality may correspond to two or more similar terraces at another locality. Similarly a terrace developed on hard rock may persist at one locality, whereas a corresponding terrace developed on weak rock at another locality may be in part or entirely obliterated by subsequent erosion.

EROSION CYCLES RECOGNIZED

After due allowance is made for the conditions just outlined there are nine erosion cycles or episodes in the physiographic development of southeastern Idaho that deserve mention. These cycles, with one exception, are illustrated on Plate 10 and are described under the following headings: Pre-Wasatch erosion surface, post-Wasatch erosion and deformation (Snowdrift cycle), Tygee erosion surface, Gannett cycle, Elk Valley cycle, Dry Fork cycle, Blackfoot cycle, St. Charles glacial episode, and postglacial erosion.

PRE-WASATCH EROSION SURFACE

In the Bear Lake Plateau and in the southern part of the Aspen Range an ancient erosion surface emerges beneath the frayed edge of the Wasatch formation (early Eocene). The geologic aspects of this surface and of the other physiographic features next described are discussed in Chapter VI.

Two profiles were drawn at places where the margin of the Wasatch formation was favorably exposed. The first illustrates the conditions in the Bear Lake Plateau, and the second those in the southern part of the Aspen Range. (See B–B′ and C–C′, pl. 10.) In order that the profiles may readily be followed on the maps they have been drawn to true scales. This method has the disadvantage, especially in the first profile, which is on a smaller scale than the other, of making the surface irregularities, which are considerable, appear relatively slight. There is also the further disadvantage that the ancient surface as shown in the profiles probably suffers distortion from the fact that the profiles necessarily follow irregular rather than straight lines. Nevertheless, the profiles probably give a fair idea of the general character of the surface of the country at the time when the Wasatch beds were laid down.

In the Bear Lake Plateau, so far as may be judged from the first profile, the altitude of the ancient surface, as it emerges from cover, ranges from 6,150 to 7,500 feet. Thus the maximum relief of that part of the country at the time of its burial was probably at least 1,350 feet. Individual valleys, as indicated by the dotted line, appear to have ranged in depth from 400 to 1,000 feet. A considerable part of the surface however, seems to have been worn relatively smooth.

In the Aspen Range the surface, as indicated by the second profile, was considerably rougher than that in the Bear Lake Plateau. This roughness is doubtless in part due to the fact that it was developed on older and harder rock formations. It may also have stood at that time, as it does to-day, at a somewhat higher elevation than the Bear Lake Plateau. Its present elevation, as it emerges from cover, ranges from 6,250 to 8,050 feet. Thus its maximum relief was probably at least 1,800 feet. Individual valleys were as much as 1,000 feet deep. A comparison of the ancient surface, as shown by the dotted line, with the modern surface shows that the roughness of the ancient surface was of nearly the same order as that of the present surface, which may be called early mature.

After the deposition of the Wasatch beds there was gentle folding in the Bear Lake Plateau, with somewhat sharper flexure in the portion occupied by the Boundary Hills. The old erosion surface beneath these beds shared in that deformation. In the profile of that area, which has already been described, gentle flexure of the ancient surface is suggested. The corresponding profile for the Aspen Range affords a similar suggestion, but probably a considerable part if not all of the hypothetical flexure is due to the fact that the profile as drawn first ascends and then descends irregularly part of the west flank of the range.

Exposures of the Wasatch formation on the west side of Bear Lake indicate that the surface on which it rests has an average inclination eastward of about 4½°. The general slope of the upland in that district is about 2½° E. Both slopes, if produced, would be cut by the Bear Lake fault.

suggested, or have merged with that surface beyond the area of Wasatch deposition. The Wasatch formation may therefore be regarded as a deposit in a downwarped area in a region that was undergoing general erosion. The downwarped area itself was progressively subjected to erosion as soon as successive parts of it were filled to the base-level of deposition. The Miocene deformation, to which fuller reference is made in Chapter VI, elevated the old erosion surface and it has since been so eroded that only remnants of it now remain. These remnants are described below.

The Preuss Range in the vicinity of Meade Peak (pls. 6, 8, and 9) and Snowdrift Mountain (pl. 34 and fig. 6) present relatively even crest lines that stand at altitudes of 9,200 to nearly 10,000 feet and are suggestive of peneplanation. A few summits in Dry Ridge and Sublette Ridge, and in Webster Ridge north of Draney Creek also reach altitudes of 9,000 feet or more and may perhaps be correlated with Snowdrift Mountain as possible remnants of a former peneplain.

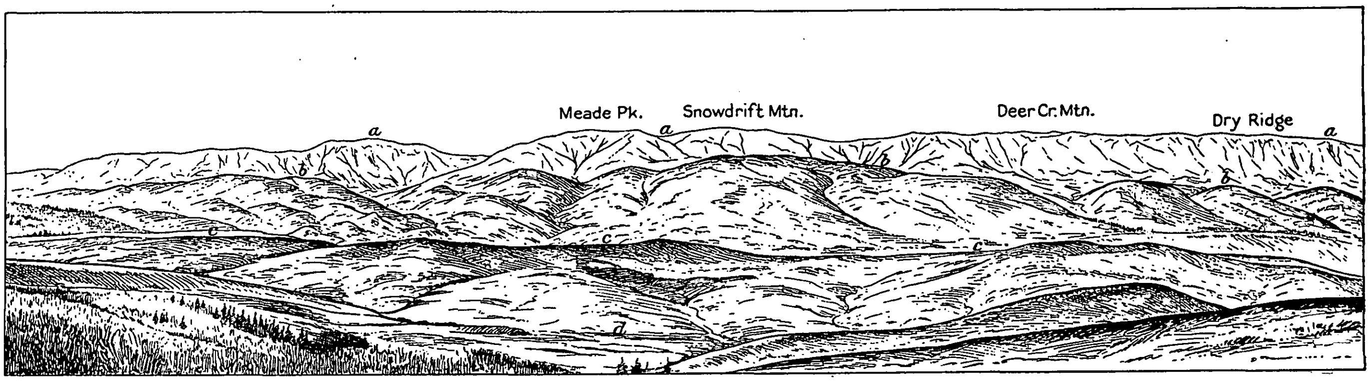


FIGURE 6.—Sketch of the Preuss Range from a point on the divide near the road between Ephraim and Elk Valleys, Crow Creek quadrangle. *a*, Snowdrift peneplain; *b*, Gannett cycle; *c*, Elk Valley cycle; *d*, Ephraim Valley (Dry Fork cycle)

In the Bear Lake Plateau (pl. 9), immediately north of the exposures of the Wasatch, the upland surface probably corresponds fairly closely with that upon which the Wasatch formation was deposited, but farther north this ancient surface is supposedly truncated at a faint angle by a later erosion surface and becomes indistinguishable.

POST-WASATCH EROSION AND DEFORMATION (SNOWDRIFT CYCLE)

The order of physiographic events subsequent to Wasatch deposition is not clearly understood. Erosion, interrupted by deformation, appears to have prevailed until Pliocene time, but no deformation of note occurred until about the middle of the Miocene. This long erosion interval, which covered most of Eocene, Oligocene, and perhaps more than half of Miocene time, was doubtless sufficient to reduce the country approximately to base-level. The erosion surface developed on the Wasatch beds may thus have truncated the pre-Wasatch erosion surface, as above

The Salt River Range along the east side of Star Valley and a few miles east of the region described in this report, rises to altitudes of 10,000 to 11,000 feet. From favorable points of view in southeastern Idaho the Salt River Range presents a fairly even sky line, strongly suggestive of peneplanation. (See fig. 7.) Similarly in the Bear River Range, which lies mostly to the west of this region, numerous summits reach altitudes greater than 9,000 feet, and one of these summits lies in the southwest corner of the Montpelier quadrangle. If a former peneplain is presumed to have developed over these two ranges and the intervening territory here described, Snowdrift Mountain and the other summits mentioned would closely approach the level of that peneplain. The cycle in which the supposed peneplain was developed and the peneplain itself may therefore be called respectively the Snowdrift cycle and the Snowdrift peneplain. The Snowdrift peneplain is now gently arched and reaches its maximum elevation in the vicinity of Meade Peak, as shown in profiles A′–A″ and G–G′, Plate 10.

TYGEE EROSION SURFACE

The Salt Lake formation, which is described on pages 110 to 112, was deposited in broad valleys that were probably formed both by erosion and by deformation after the development of the Snowdrift peneplain. The surface on which the Salt Lake formation was laid down is designated for convenience the Tygee erosion surface, from Tygee Valley in the Crow Creek quadrangle, where the Salt Lake formation occupies considerable areas. The relation of Tertiary sediments to Tertiary planation in Idaho and adjacent regions is a subject of disagreement among geologists. A discussion of this subject is given in Chapter VIII. (See pp. 354 to 361.) The present occurrences of the Salt Lake formation indicate that the relief at the time of its deposition was greater than 1,000 feet. It is probable that the maximum relief of the region at that time was even greater than that of to-day.

The Tygee cycle was presumably the one in which the larger topographic features of the present, such as the mountain ranges and intermont valleys, were outlined. Subsequently by aggradation many of these valleys became filled and the lower hills were overspread by the Salt Lake formation.

Many of the main valleys of to-day appear to have been reexcavated in old valleys, which were of equal or even greater dimensions, as indicated by the unremoved masses of the Salt Lake formation in the bottoms or lower parts of Bear River, Slug, Tygee, Star, and other valleys. In other places the old surface was so deeply buried that later drainage bore little relation to it. Thus the present course of Bear River across the folded sedimentary rocks south of the Preuss Range in the Montpelier quadrangle and at the north end of the Bear River Range west of Soda Springs is probably due to its superposition through Pliocene (?) or older cover.

Renewed deformation, mainly in the form of a broad uplift, subjected the whole region to renewed erosion. The Salt Lake formation, though nearly horizontal at many places, locally has steep dips, but these may have been acquired in later crustal disturbances.

No upland surfaces now remain that can with assurance be correlated with the Tygee erosion surface although some of the residuals above the Gannett erosion surface, described below, may be related to the first-named surface. This fact lends support to the view held by some that the Tertiary beds, which here form the Salt Lake formation, were laid down prior to the general peneplanation of the region (Snowdrift cycle), but the discussion mentioned above shows that the attractive hypothesis presented in this view remains unproved.

Similarly the relations of the Tygee erosion surface to the Gannett erosion surface are not clear. The highest known remnants of the Salt Lake formation lie somewhat below the level of the Gannett erosion surface, and hence that surface is not known to truncate those beds at any place. Yet the relations of that surface to the lower members of the erosional series are such that there appears to be no room for such extended intervals of erosion and deposition as those represented by the Tygee erosion surface and the succeeding Salt Lake formation. The Tygee erosion cycle is therefore tentatively placed between the Snowdrift cycle and the Gannett cycle.

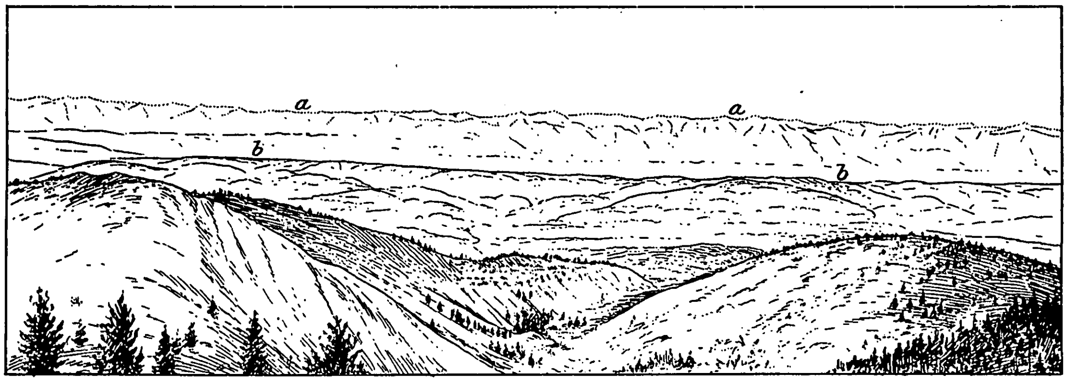


FIGURE 7.—Sketch of the Salt River Range from the hill in the NW. ¼ sec. 24 (unsurveyed), T. 8 S., R. 45 E., Crow Creek quadrangle. *a*, Snowdrift peneplain in Salt River Range; *b*, Elk Valley erosion surface in Gannett Hills

GANNETT CYCLE

About 1,000 to 1,500 feet below the Snowdrift peneplain lies a widespread erosion surface which might locally be called a peneplain but which generally ranges in topographic development from late maturity to old age. As this surface is well developed in the Gannett Hills, the cycle in which it was produced may be called the Gannett cycle and the surface itself the Gannett erosion surface. (See figs. 6 and 7 and pl. 13, *A*.) Intermediate stages between this surface and the Snowdrift peneplain are suggested by some of the profiles, but the records of these intermediate stages are scattered and poorly preserved and can not be deciphered without further and more detailed study. Possibly some of these records may relate to the Tygee erosion surface.

The elevation and character of the Gannett erosion surface depend in considerable measure upon the character of the rocks upon which it was developed. Thus in the Aspen Range and parts of Dry and Webster Ridges, in which the rocks are older and more consolidated, its maximum relief is nearly 1,000 feet, but in the Gannett Hills, where the rocks are younger and less consolidated, it is barely half as great. The local relief of the old surface is commonly 200 to 500 feet.

The most extensive areas of the Gannett erosion surface now preserved are in the southern part of the Gannett Hills, and in parts of the Preuss, Aspen, and Webster Ranges. Most of the higher mountains preserve portions of this surface, but in the lower mountains it is absent or represented by only a few summits.

The Gannett surface has its maximum altitude in the vicinity of the Bear Lake and Bannock county line, where its rounded or flat-topped hills reach altitudes of 8,300 to 8,600 feet. (See pl. 8. No attempt has been made to map these surfaces in detail.)

ELK VALLEY CYCLE

The Elk Valley cycle is marked by the development of broad and relatively shallow valleys below the Gannett erosion surface. Practically all the broad valleys of the region are bordered by gentle upper slopes or flats developed during this cycle. In some areas of relatively weak rocks, as in the northern part of the Gannett Hills, and in some of the lower ridges composed of harder rocks, the upper smooth and relatively even surfaces are ascribed to this cycle.

Elk Valley, in the southeastern part of the Crow Creek quadrangle, is bordered by a somewhat dissected terrace 300 feet or more above the valley bottom, and nearly a corresponding distance below the Gannett erosion surface, which there forms the hilltops. (See pl. 8.) This dissected terrace gives its name to the erosion cycle in which it was produced.

Similarly at the south end of Sage Valley, in the same quadrangle, a terrace representing part of an old valley floor stands 350 to 500 feet above a flat that represents a valley floor of the succeeding cycle. Sage Valley itself, like Dry and Slug Valleys, is probably in greater part the product of later erosion cycles but was partly excavated in the Elk Valley cycle.

These terrace remnants and the corresponding upland remnants may be described as late mature. Figure 7 shows the late mature upland of the northern Gannett Hills against the background of the Salt River Range, which represents the Snowdrift cycle.

In the Elk Valley cycle the main drainage of the region, as it now exists, may first be clearly recognized. Sage Valley and many of the main valleys to-day contain remnants of the easily eroded Salt Lake formation. There is a noteworthy contrast between the amount of erosion accomplished by the main streams in these broad valleys and that accomplished by their tributaries or even by the main streams themselves where they cross the ridges. The discrepancy may be explained in part by the greater effect of the streams where the rock structure is favorable. The remnants of the Salt Lake formation, however, suggest that the broad valleys are an inheritence from an earlier erosion period, as stated above. In regions adjacent on the northwest flows of lava are interbedded with the Salt Lake formation and constitute part of the filling. Each successive uplift has enabled the main streams to remove rapidly the weak Pliocene beds while their tributaries were making only moderate progress in the hard rocks on either side.

Some valleys, such as Dry Valley, do not furnish any exposures of the Salt Lake formation, though portions of that formation may now be concealed by later deposits. The presence of that formation, however, in so many of the valleys and in patches of greater or less extent on the uplands indicates that it was formerly a widespread and thick blanket deposit and that its extensive removal has almost certainly reopened valleys of great antiquity.

The transverse course of Bear River, mentioned above, had already been established at the beginning of the Elk Valley cycle, during which it meandered broadly in a relatively shallow valley. Similarly Blackfoot River south of Wooley Ridge and also Tincup River and Stump Creek in the Caribou Range were probably established in their transverse courses at the beginning of the Elk Valley cycle. They, too, developed broad and shallow valleys during this cycle. (See A′–A″, J–J′, I′–I″, and K–K″, pl. 10.)

DRY FORK CYCLE

Below the terraces and uplands of the Elk Valley cycle and above the present stream valleys lies a group of high-level valleys or terraces ascribed to the Dry Fork cycle, named from Dry Fork Valley, near the center of the Slug Creek quadrangle (pl. 6). Dry Fork Valley, Elk Valley proper, Ephraim Valley, and the lower flat south of Sage Valley are perhaps the best preserved examples of high-level valleys developed in this cycle. (See pl. 8.) Some of the rock terraces in Georgetown Canyon and the left fork of Twin Creek also belong to this cycle. The depth of cutting below the level of the Elk Valley terraces was usually about 300 feet and the stage of physiographic development late mature. Plate 13, *B*, gives a view of Dry Fork Valley, and Plate 8 shows parts of the Elk Valley and Sage Valley districts in which both the Elk Valley and Dry Fork cycles are well represented. In addition to the high-level valleys certain parts of the lower uplands, as those in the northern part of the Gannett Hills and in Schmid Ridge, are ascribed to the Dry Fork cycle.

Surfaces produced in the Elk Valley and Dry Fork cycles now constitute the uplands throughout much of the region where the altitudes are less than 8,000 feet. A few summits as low as 7,500 feet, such as some of those in Slug Ridge, may represent reduced remnants of the Gannett erosion surface, but in general this surface, though probably somewhat warped, does not lie much below 8,000 feet.

In the Fort Hall Indian Reservation the older topographic features except certain rocky remnants were ascribed to the Putnam cycle.[28] More extended study of the general region makes it probable that the Putnam cycle represents both the Elk Valley and Dry Fork cycles as here defined.

BLACKFOOT CYCLE

The rejuvenation of the region by uplift at the close of the Dry Fork cycle enabled the streams to cut their present sharp-featured canyons to depths of 500 to 1,000 feet below their former valley floors. The canyon of Blackfoot River at the Narrows in the Lanes Creek quadrangle gives its name to the cycle and is a fine example of this topographic form.

At least three episodes may be recognized, namely: Canyon cutting; aggradation, involving both climatic change and volcanic phenomena; and the St. Charles glacial episode.

Canyon cutting.—During the first episode the region was submaturely dissected by canyons, which in some weaker rocks advanced to maturity but in harder rocks did not progress much beyond a late youthful stage. Bear River intrenched its meandering course to a depth probably greater than 1,000 feet, partly in the filling of former buried valleys and partly in hard rock, and thus produced the winding canyon that now separates the Preuss Range from the Bear Lake Plateau. Similarly Stump Creek west of Auburn, Blackfoot River at the Narrows, and Tincup River in the Caribou Range intrenched their courses and developed their present transverse canyons. Other less conspicuous examples might be cited.

Some of the canyons, as those of Crow Creek and Spring Creek in the Crow Creek quadrangle, contain low points, 100 to 200 feet above the present valley bottoms, that are suggestive of pauses in the downcutting, but no systematic terracing in this epoch has been recognized. Many of the streams simply intrenched their courses and continued the excavation of valleys developed in the previous cycle. In some places, as probably along the east side of Slug Valley and Bear Lake, earlier faults which had brought the weak Salt Lake formation into contact with older and harder rocks were developed as scarps by the erosion of that formation.

In Georgetown Canyon the inner valley is about 1,000 feet deep, but the old valley floor, which represents the Gannett cycle, is also 1,000 to more than 1,900 feet below the summits of the inclosing ridges, which rise approximately to the level of the Snowdrift peneplain. Lower terraces here and there represent the Elk Valley and Dry Fork cycles. (See pl. 16, *A*, and *B*.) Thus the canyon as a whole is 2,000 to nearly 3,000 feet deep, the maximum depth for the region.

The canyons and valleys of the Blackfoot cycle are usually joined by their tributaries at grade. Locally, however, there are tributaries that hang 200 to nearly 500 feet above the floors of the main valleys. These hanging valleys are not of glacial origin but represent valleys of the earlier cycle, which because of the relative deficiency of their drainage areas and because of semiarid climatic conditions could not be deepened at the same rate as the main valleys. An excellent example, which is found on the north side of Middle Sulphur Canyon in the Slug Creek quadrangle, has been described elsewhere.[29] (See pl. 35, *B*.) Other examples occur in the hills in T. 12 S., Rs. 43 and 45 E., in the Montpelier quadrangle. (See pl. 14, *A*.) Some of these features, which occur on the valley wall of Bear River and have slopes somewhat suggestive of cirque form, represent the heads of small valleys of the previous cycle that have lost their lower courses during the widening of Bear Lake and Bear River valleys.

During the process of canyon cutting numerous stream adjustments occurred, usually on a small scale. Perhaps the most striking example is Dry Fork Valley in the Slug Creek quadrangle. (See pl. 6.) This valley was once apparently drained by the high-level valley of which remnants are preserved in secs. 12 and 13, T. 9 S., R. 43 E. Branches of the present Dry Fork, and finally Dry Fork itself, have successively tapped the high-level valley three times, beginning near its lower end and proceeding thence upstream. The present Dry Fork Valley has been lowered a little more than 100 feet since its final diversion, probably in large part by agencies of solution and of melting snow. Presumably the advantage enjoyed by Dry Fork over its high-level competitor lay in the fact that Dry Fork excavated its course in the main along the relatively weaker and less consolidated sandy beds in the middle part of the Wells formation, whereas its competitor's course lay in the massive cherty limestone beds that form the lower part of the same formation. Part of the old valley floor and one of the elbows of capture are shown in Plate 14, *B*.

Other examples of stream readjustment worthy of mentioning occur along the east side of Snowdrift Mountain and Freeman Ridge, in the Crow Creek quadrangle. Northward along the east side of Snowdrift Mountain appear remnants of old subsequent valleys of the Elk Valley cycle. (See pl. 8.) These valleys have been tapped and in part appropriated and lowered by the headwater erosion of such eastward-flowing streams as Deer Creek, the South Fork of Sage Creek, and Sage Creek.

The streams that excavated the valleys of the Blackfoot cycle were probably of greater volume than

[28] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pp. 15-16, 1920.

[29] Mansfield, G. R., An unusual type of lateral hanging valley: Geog. Soc. Philadelphia Bull., vol. 9, No. 4, pp. 40-47, 1911.

those of to-day, for the present streams are in some degree incompetent, notably Bear River south of the Preuss Range. The degree of incompetence of this stream is so marked in comparison with that of most of the smaller streams that probably its course has been affected above the place where it enters this territory by some agency that was not operative or was less effective in the development of the other streams. The fact that Bear River rises in the Uinta Mountains, which were formerly extensively and strongly glaciated, whereas the other streams are of local origin and were practically free from glacial influences, may account for the discrepancy.

Aggradation.—After the excavation of the valleys of the Blackfoot cycle the renewal of volcanic activity in the northwestern part of the region produced flows of basalt that flooded parts of some of the valleys, and thus raised the temporary base-levels and produced conditions favorable for aggradation. About the same time the climate became more arid, and the streams which had been degrading their valleys began to aggrade them. Alluvial deposits were spread over the valley floors, and alluvial fans were developed in many of the valleys. Fine examples of these fans, now more or less dissected, occur at the mouth of Georgetown Canyon, in the Montpelier quadrangle, and in Dry Valley, in the Slug Creek quadrangle. Bear River valley, where it is crossed by the line of profile A′–A″ (pl. 10), appears to have been aggraded nearly 400 feet, as shown by its restoration in the profile. Near Soda Springs its basaltic bed is somewhat aggraded, for borings in the river channel in that vicinity show 20 feet or more of fill that overlies basalt.

The accumulation of hill-wash deposits here and there upon the basalt and of wind-blown soil, such as that which covers in considerable quantity areas south and southwest of the Blackfoot River Reservoir, may have taken place in large part during this time of greater aridity.

St. Charles glacial episode.—The episode of aridity and aggradation was succeeded by moister climatic conditions, probably coincident with the last glacial stage and a renewal of downcutting, but was not accompanied by any significant change of level. Thus this episode, which takes its name from St. Charles Canyon in the Montpelier quadrangle, may be regarded as part of the Blackfoot cycle, though it has been separated for convenience of treatment.

Local glaciers occurred in the Salt River Range to the east and in the Bear River Range to the west, but within the territory here described no evidence of glaciation has been found. Morainelike ridges occur in the head of a small valley in the northeast corner of T. 11 S., R. 46 E., in the Montpelier quadrangle. Although these ridges were not seen by the writer, they are more probably the result of landslides. (See p. 115.) A local glacier did, however, advance in the Bear River Range down the valley of St. Charles Creek to a point about 2 miles west of the border of the Montpelier quadrangle, where its relatively fresh terminal moraine now occupies the floor of the valley. Thus the epochs of valley cutting and aggradation had been completed by the time that this glacier was developed.

Bear Lake, which, if it existed before, had perhaps smaller volume than to-day, was then expanded to its maximum extent at a level about 33 feet higher than the present level indicated on the map, as shown by shore lines east of Bear Lake. Other shore lines at levels respectively about 22 and 11 feet higher than the present level show successive stages in the reduction of the lake with the lowering of its outlet.

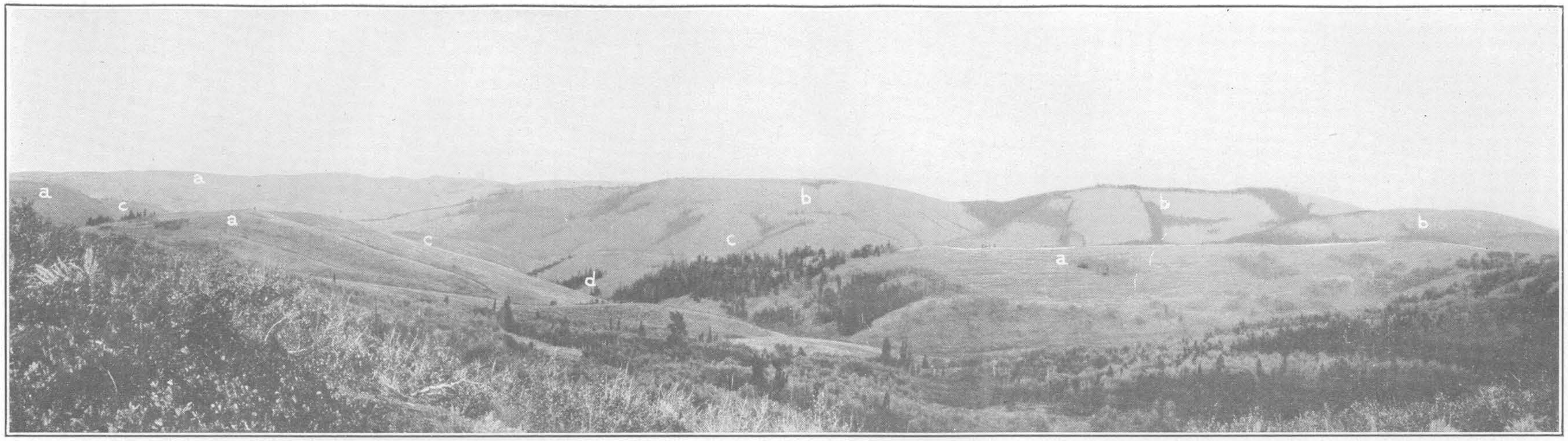
Effects of lava flows on erosion.—Undoubtedly some ponding of the waters occurred back of the lava flows, and Grays Lake, Pelican Slough, Blackfoot Marsh (now occupied by the Blackfoot River Reservoir), and possibly the marshes of Upper Valley in the Lanes Creek quadrangle are remnants of such water bodies. In Bear River Valley basalt extends up the river to a point about 5 miles southeast of Soda Springs, but from present evidence it seems probable that the formation of Bear Lake was due to other causes discussed below. (See pp. 31 and 32.)

Although the basaltic flows might have been expected to cause reversals, or at least pronounced changes of drainage, no noteworthy changes of the general drainage scheme appear to have been produced by them. The streams flowed over the basalt and cut new canyons, or where they were crowded against their former valley walls they cut canyons partly in the basalt and partly in the sedimentary rocks, as at the southeast end of Outlet Ridge in the Cranes Flat quadrangle and at the bend of Bear River west of Soda Springs.

During the persistence of the moister climatic conditions the streams resumed downcutting, dissecting the alluvial fans and cutting canyons in the basalt. The late basaltic flows and also some of the earlier flows of basalt and rhyolite that are interbedded with the Salt Lake formation served as temporary base-levels, which influenced in greater or less degree the downcutting of the streams upvalley from these flows. Thus the lower courses of Bear River, Blackfoot River, Willow Creek, and Outlet Valley are all cut to a greater or less extent in basalt, and the downcutting of these streams and their tributaries within the territory here described has been controlled by the rate at which these major streams could deepen their canyons and extend them into this territory.

Blackfoot River Valley throughout much of its course is divided into graded reaches and basaltic gorges. The upper gorge at the northern tip of the Aspen Range is still youthful. The gorge below the Blackfoot River Reservoir (pl. 14, *C*) reached an

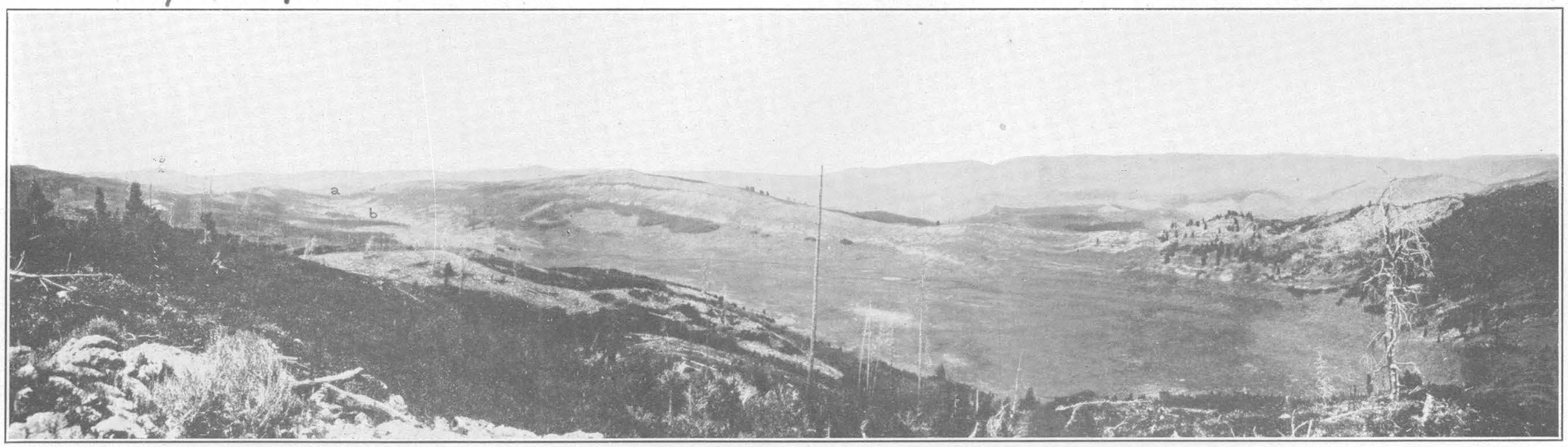
Mansfield (503-505)



A. VIEW IN THE GANNETT HILLS EASTWARD FROM A POINT NEAR THE ROAD ON THE DIVIDE BETWEEN EPHRAIM AND ELK VALLEYS, CROW CREEK QUADRANGLE

a, Gannett erosion surface; b, older erosion remnants; c, Elk Valley erosion surface; d, young valley of Dry Fork cycle

Richards 179-181

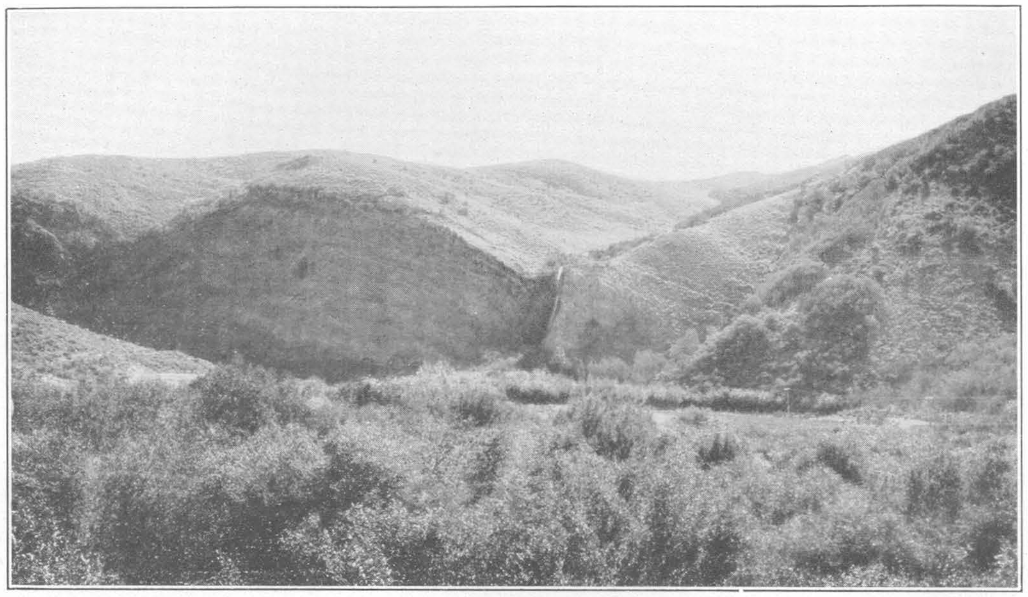


B. DRY FORK VALLEY FROM A LITTLE KNOLL ON THE SOUTHWEST MARGIN OF THE VALLEY, SLUG CREEK QUADRANGLE

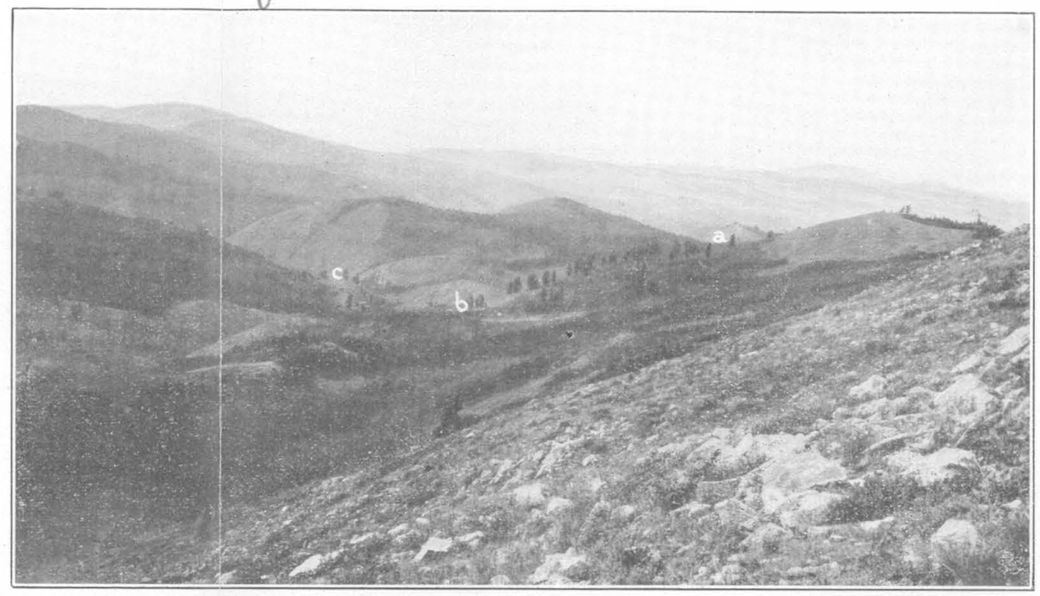
a, Former outlet; b, young valley of Blackfoot cycle, which now drains it

Mansfield, 519.

Mansfield, 501.

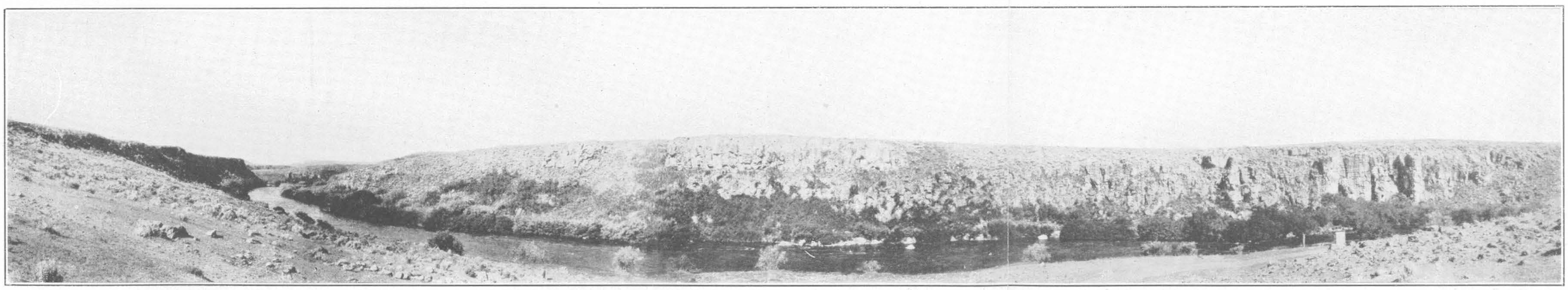


A. HANGING VALLEY OF DRY FORK VALLEY AGE ON THE SOUTH SIDE OF MONTPELIER CANYON, IN SECS. 32 AND 33, T. 12 S., R. 45 E., MONTPELIER QUADRANGLE



B. OUTLET REGION OF DRY FORK VALLEY, SLUG CREEK QUADRANGLE

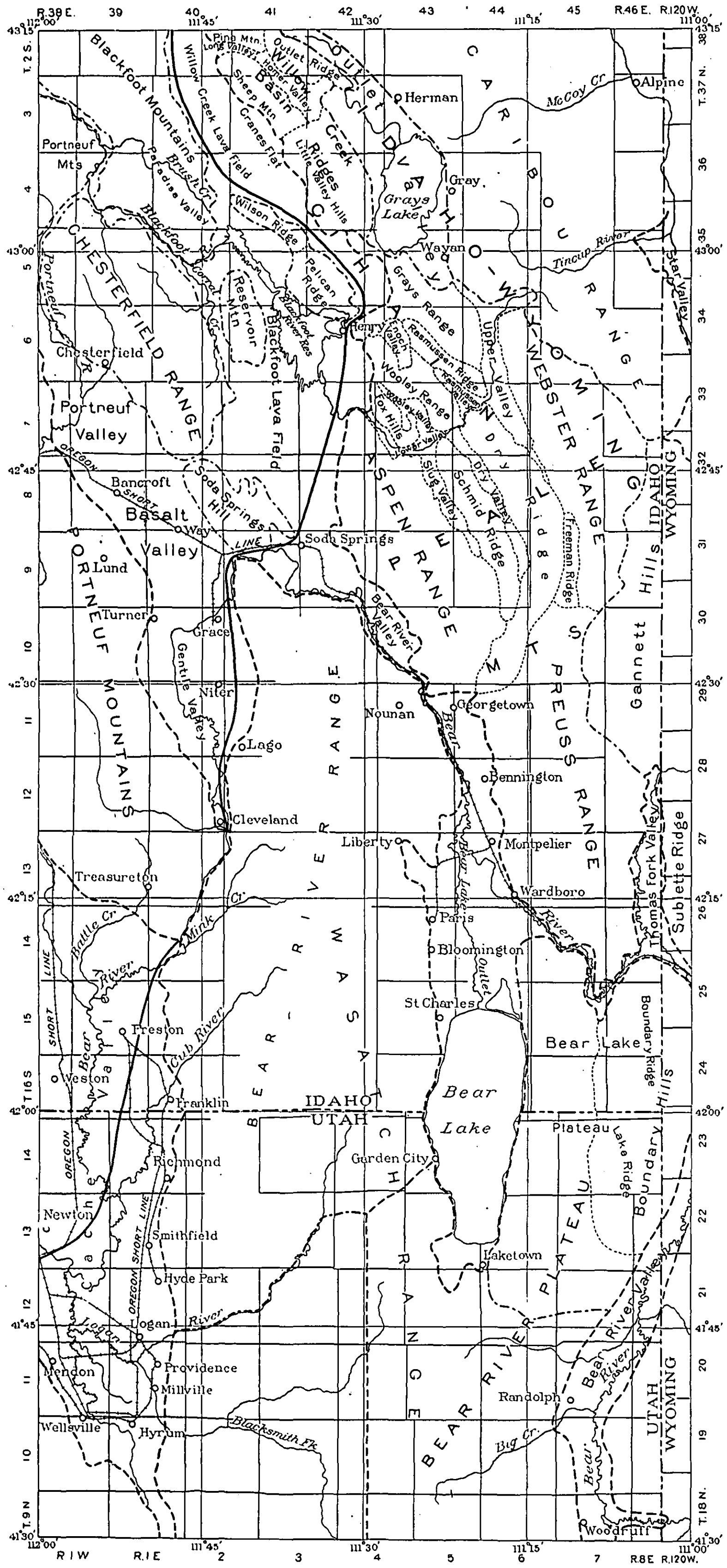
a, Former outlet; b, elbow of capture; c, present outlet, Blackfoot cycle



C. CANYON OF BLACKFOOT RIVER BELOW THE DAM IN SECS. 11 AND 12, T. 5 S., R. 40 E., CRANES FLAT QUADRANGLE

Shows several basalt flows with columnar and ball and socket structure; recent cutting in local fill at the left; and U. S. Geological Survey stream-gaging station at the right

Roundy 75-79.



MAP OF SOUTHEASTERN IDAHO AND ADJACENT REGIONS, SHOWING THE PRINCIPAL PHYSIOGRAPHIC FEATURES

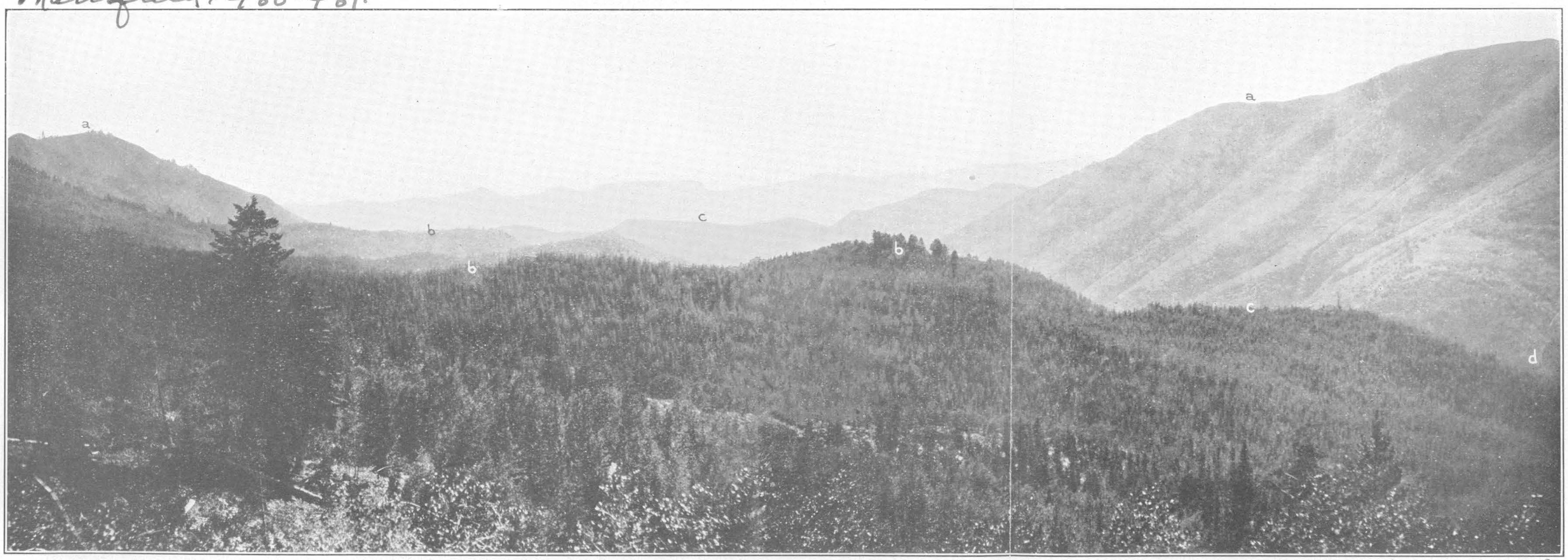
The heavy solid line is the boundary between the Rocky Mountain (right) and Basin and Range provinces

Mansfield, 482-484.

A. ROCK TERRACES IN GEORGETOWN CANYON, SLUG CREEK AND CROW CREEK QUADRANGLES

View northeast from the head of Phosphoria Gulch. a, Snowdrift peneplain; b, Elk Valley surface; c, young valley of Blackfoot cycle

Mansfield, 480-481.



B. ROCK TERRACES IN GEORGETOWN CANYON, SLUG CREEK QUADRANGLE

View southwest from the head of Phosphoria Gulch. a, Gannett erosion surface (?); b, Elk Valley erosion cycle; c, Dry Fork cycle; d, Blackfoot cycle early mature stage and is again being intrenched. A low terrace a few feet above the present stream marks the former valley floor. This intrenchment may be due to uplift but is more probably due to the removal of aggraded filling or of a lower basaltic layer farther downstream and the consequent lowering of the temporary base level. Willow Creek Valley and Outlet Valley have similar alternating graded reaches and canyons.

The canyon development on these streams is largely outside the immediate region described in this report. The reexcavation of the aggraded valleys has been relatively shallow but has reached a late mature stage or even old age in the graded reaches of the larger streams. Elsewhere the alluvial fans and valley fillings are only submaturely dissected, as shown by the fans near Georgetown, in the Montpelier quadrangle, and in Dry Valley in the Slug Creek quadrangle. The submature dissection of the older alluvium is well shown in the geologic map of the Lanes Creek quadrangle. (See pl. 4.) The Blackfoot cycle corresponds in the main with the Gibson cycle of the Fort Hall Indian Reservation,[30] but the St. Charles glacial episode was not distinguished there.

POSTGLACIAL EROSION

Since glacial time the amount of erosion has been slight. The climate has been less moist, though not so arid as in the earlier aggradational stage. Except in the graded reaches most of the streams are actively degrading their courses. In the Fort Hall Indian Reservation this epoch was distinguished as the Spring Creek cycle,[31] in which broad flats, the Fort Hall bottoms, were developed along Snake River below the Gibson terrace and at a somewhat steeper inclination. The cycle is ascribed in part at least to climatic change and its effects die out upstream. From a broader view of the erosional development of the region than was possible when the earlier paper was prepared, and on account of the function of lava sheets as temporary base levels for up-valley erosion, the writer is now inclined to regard this "cycle" as merely the latest episode of the Gibson cycle, or of the Blackfoot cycle, as it is called in the present paper.

CORRELATION WITH WYOMING

If the tentative nature of the correlation is recognized it may be worth while to compare the physiographic development of southeastern Idaho as above outlined with that of western Wyoming, as determined by Blackwelder and by Westgate and Branson, and reviewed above. Blackwelder[32] has tabulated the two records for western Wyoming, and to his table may now be added the record for southeastern Idaho. (See Table 2.)

[30] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho, U. S. Geol. Survey Bull. 713, pp. 16, 17, 1920.

[31] Idem, p. 17.

[32] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geology, vol. 23, p. 310, 1915.

TABLE 2.—*Tentative correlation of erosion cycles in western Wyoming and southeastern Idaho*

Epoch	Western Wyoming			Southeastern Idaho	
	Westgate and Branson	Blackwelder		Mansfield	
				Erosion cycles	
	Stages	Erosion cycle (largely interglacial)	Glacial stages	This paper	Bulletin 713
Recent	Late glacial and terraces	Postglacial		Postglacial	Spring Creek
			Pinedale	Blackfoot cycle (St. Charles glacial episode)	Gibson
		Lenore			
	Early glacial		Bull Lake		Putnam
Pleistocene	Plain No. 1	Circle		Dry Fork	
			Buffalo		
	Plain No. 2	Black Rock		Elk Valley	
	Plains Nos. 3 and 4	Union Pass		Gannett	
Pliocene		Fremont (Wind River Summit peneplain)		Deposition of Salt Lake formation	
Miocene	Reduction to peneplain by middle Tertiary	Middle Miocene deformation		Tygee cycle?	
				Middle Miocene deformation	
Eocene		Aggradation of earlier valleys		Snowdrift peneplain	

No attempt has been made to force an agreement between the erosional stages of western Wyoming, as worked out by Blackwelder, and those of southeastern Idaho, yet the rather close parallelism of salient features, as worked out independently in the two fields, does strongly suggest such an agreement.

The Snowdrift peneplain is much less perfectly preserved than the Summit peneplain of the Wind River Range. In the Wind River Range there are no Pliocene rocks, and that period was one of erosion. Peneplanation is thought by Blackwelder to have been synchronous in western Wyoming and in Idaho and to have occurred in post-middle Miocene time. The evidence for southeastern Idaho seems to favor an earlier date. (See pp. 358 and 359.)

The Gannett erosion surface agrees well in character with the corresponding surface of the Union Pass cycle of Blackwelder, though it is somewhat lower.[32a] Similarly the Elk Valley cycle may correspond with Blackwelder's Black Rock cycle, but nothing comparable to the thick gravel deposits noted by Blackwelder as characteristic of this cycle has been observed in southeastern Idaho. Indeed, aside from the poorly consolidated Cretaceous and Tertiary conglomerates and their weathered derivatives, no high-level gravels have been noted by the many geologists who have examined parts of the Idaho field, though no specific search has been made for them.

The Dry Fork cycle probably corresponds well with the Circle cycle of Blackwelder, for a rock terrace cut in folded resistant limestones lies above the present canyon of the Blackfoot at the Narrows in the Lanes Creek quadrangle, though this terrace is not as smoothly developed as the example figured by Blackwelder.

The Blackfoot and Lenore cycles agree in being represented by the present early mature inner canyons that are distributed throughout both regions.

Only the latest of the glacial stages described by Blackwelder is represented in southeastern Idaho, though the volume and erosive power of Bear River was probably affected by glacially derived waters in the earlier stages as well as in the last. The St. Charles epoch did not directly affect the region under consideration.

In southeastern Idaho, as in western Wyoming, postglacial erosion has accomplished little. The lava flows in the main valleys, which serve as temporary base-levels, have controlled the grades up valley from the respective flows and have delayed general downcutting. In the Fort Hall Indian Reservation, farther northwest, adjacent to Snake River, the Spring Creek cycle or episode has been recognized.

[32a] Recent unpublished field work by W. C. Alden indicates that its age is more probably Pliocene than Pleistocene. (See Table 2.)

MOUNTAINS AND VALLEYS OF SOUTHEASTERN IDAHO

PRINCIPLES OF NOMENCLATURE

The lack of suitable geographic names and the looseness in the application of some of the names in common use adds to the difficulty of preparing a detailed description of the geographic features of southeastern Idaho. The confusion that exists in current terms of mountain nomenclature forms an additional difficulty. The terms mountain or mountains, ridge, and range are used more or less interchangeably and often without implication of order of magnitude. Some names, like that of the Blue Ridge in the eastern United States, are well established in literature and usage, and a change, even in the interest of a more systematic classification, would be inexpedient.

New names that may be proposed, however, should conform to certain guiding principles that may be equally useful under similar circumstances in other areas. Three such principles are here suggested—order of magnitude; relative length, continuity, and arrangement of divides; and physiographic rather than geologic unity. These principles, of course, can not be followed blindly, and some adjustments may be necessary in different areas.

The terms mountain, range, mountains (group name), chain, and system form a series in an ascending order of magnitude. Thus we have in the Crow Creek quadrangle (pl. 7) Snowdrift Mountain, a part of the Preuss Range, which in turn is a member of the Peale Mountains (a new name defined below). These mountains and other similar mountain groups form the Idaho-Wyoming chain, which occupies the border region of these two States and constitutes a notable member of the Rocky Mountain system.

On the other hand the terms mountain, ridge, and spur form a series in descending order of magnitude, but the term ridge may under certain circumstances be given equivalent rank with mountain or even range. Similarly the term peak, which is here regarded as subordinate in rank to mountain, is in common usage frequently given equivalent rank.

Length is usually considered in nomenclature and is implied in such terms as ridge or range. The term mountain, on the other hand, in spite of certain usage to the contrary, carries no specific suggestion of length but suggests rather a greater or less degree of regularity of form without undue extension in any particular direction. The pyramid or cone might be taken as the ideal form, but comparatively few of the so-called mountains except volcanic cones and some strongly glaciated peaks approach this ideal closely.

Spurs are usually lateral with respect to ridges and lateral or radial with respect to individual mountains. Similarly ridges are usually lateral or radial with respect to individual mountains and lateral or parallel with respect to ranges. The term peak ordinarily refers to a conspicuous but subordinate part of a mountain, but if the peak is unusually high, distinct, or conspicuous among its fellows its name may be given to the whole mountain. In either usage of the term a certain sharpness of outline is implied.

Continuity of divide is regarded as a noteworthy principle. A high divide that is interrupted by a broad and deep depression or pass is separated into distinct topographic units (ridges or ranges), which may affect the life, industries, or habits of people who occupy or traverse the region. This relation is especially notable if the divide is intercepted by a through valley. The separate parts of the divide may fall into different political units and in economic use may require separate designation or management. Interruptions of greater or less magnitude may serve to distinguish correspondingly large or small physiographic units. Thus smaller through canyons or passes separate neighboring ridges or individual mountains, whereas larger passes or valleys may similarly distinguish neighboring ranges.

The principle of physiographic unity is closely connected with that of continuity of divide. However uniformly the geologic structure may continue across deep passes or through valleys, these topographic features rather than the geologic structure are what the traveler ordinarily sees. For him as well as for the resident the valleys and passes afford passage through the mountains and separate respective ridges and ranges from each other. In larger-scale units, however, where groups of ranges are to be distinguished geologic structure should be given greater weight, for in large measure it determines the character of the physiographic features, upon the similarity or dissimilarity of which the larger groups are based. Thus, on the principle of continuity of divides Blackfoot River would form a suitable northern boundary for the Peale Mountains, but in consideration of the geologic structure the group is made to include Wooley Range and Grays Range, which lie north of the Blackfoot.

DEFINITIONS

The following definitions, which it is believed embody the principles above outlined, form the basis of the nomenclature employed in the descriptions that follow, but names already published on the maps are not changed, even if they do not agree with the definitions.

Mountain: An eminence, more or less isolated; roughly conical or irregular in shape or even linear, if not of undue length; and sufficiently high to be a relatively commanding feature of the landscape. The isolation may be complete, as in China Hat (pls. 3 and 33, *C*), or only partial, as in Limerock Mountain (pl. 2) or Red Mountain (pl. 9).

Ridge: A linear and relatively even-topped or gently sloping subdivision of a mountain; or a linear and relatively even-topped mountain. Snowdrift Mountain (pls. 8 and 34), is more properly a ridge. Dry Ridge (pls. 6 and 8) also furnishes a good example.

Peak: A commanding and somewhat sharpened summit in a mountain or ridge—for example, Meade Peak at the south end of Snowdrift Mountain (pls. 9 and 34).

Spur: A mountain subdivision of lower order than a ridge, even topped or gently or steeply sloping, and generally trending at a large angle from the parent ridge—for example, the spurs along the east side of Snowdrift Mountain that descend toward Crow Creek.

Range: A group of mountains or ridges that has greater length than breadth and that contains a single continuous divide; terminated by through valleys or by pronounced depressions in the divide and bounded laterally by valleys or by a succession of valleys and cols—for example, Aspen Range. (See pls. 3, 4, 6, 9, and 15.)

Mountains: When used with a name, a group of associated ranges with intermontane valleys or a large group of individual mountains that have similar structural characteristics—for example, Peale Mountains (pl. 15) and Adirondack Mountains, in New York.

Chain: A large group of ranges or of mountain groups and intermontane valleys, in which the geologic structure is generally similar; a major subdivision of a mountain system—for example, the Idaho-Wyoming Chain.

Hills: A group of eminences of perhaps considerable altitude but of relatively lower elevation than neighboring mountain groups; the group may be subdivided into ranges and ridges—for example, Gannett Hills. (See pls. 5, 8, 9, 10, and 15.)

Plateau: A land form of considerable altitude, more or less dissected, but which contains larger or smaller areas of flat surface at generally accordant levels—for example, Bear River Plateau.

IDAHO-WYOMING CHAIN

Most of the mountains and valleys included in the region described in this report are members of the Idaho-Wyoming Chain, an extensive mountain group, composed in the main of folded and faulted sedimentary rocks of northerly or northwesterly trend, that occupies an area of approximately 12,300 square miles. The chain extends from the Green River Basin on the east to the Snake River Plain and the northern extension of the Basin and Range province on the west and from the Uinta Mountains on the south to the volcanic plateau of the Yellowstone on the north. The portion of the chain included in the region described in this paper forms part of its western border and consists of numerous ranges and intermontane valleys of different dimensions and altitudes. The ranges and ridges are from 5 to nearly 50 miles long, and from 2 to

20 miles wide, and rise from about 7,000 to nearly 10,000 feet above the sea. The valleys as a rule are narrower and shorter and range in altitude from about 5,800 to nearly 7,500 feet. The broader and lower valleys, which are 5,800 to 6,500 feet above sea level, indicate the altitude of the base above which the ranges actually rise.

The drainage of the southern and southwestern parts of the chain in this region flows through Bear River to the Great Basin. Bear Lake, which is fed by springs and by small streams chiefly from the Bear River Range, is tributary to Bear River. The rest of the region is drained by branches of Snake River, of which the largest are Blackfoot River, Willow Creek and its tributary (Grays Lake Outlet), and Salt River.

The general map (pl. 15) shows the position and boundaries of the principal members of the chain, as described below. Some of these members extend into adjacent quadrangles, which are therefore also shown.

STAR VALLEY

A broad intermontane valley, known as Star Valley, lies along the east side of the Crow Creek and Freedom quadrangles and heads against the divide above Smith Fork of Bear River at about latitude 42° 30′. Near Auburn, in the Freedom quadrangle, it is nearly 6 miles wide but becomes narrower southward. Northward it is nearly closed off by low hills in the northeastern part of T. 33 N., R. 119 W., through which Salt River has carved the Narrows that now connect Upper Valley with Lower Valley.

Salt River, which drains Star Valley, is one of the principal affluents of the upper Snake, but above the latitude of Auburn its waters are largely diverted for irrigation, and it is usually dry except in winter and at flood seasons. The broad, aggraded, and youthfully dissected floor of Star Valley is dotted with settlements and is one of the richest agricultural districts of the region.

Along its eastern border lies the submaturely dissected Salt River Range, which has been locally glaciated, especially on the east side, and maintains an altitude at many places greater than 10,000 feet. The Salt River Range contributes several streams of considerable volume to Star Valley. Crow Creek, Stump Creek, and Tincup River are the principal streams that enter the valley from the west in this region.

CARIBOU RANGE

St. John [33] defines the Caribou Range as the highland belt that lies between the Willow Creek basin and the lower valley of Snake River and of Salt River. It occupies parts of the Cranes Flat, Lanes Creek, and Freedom quadrangles (pls. 2, 4, 5) but also includes considerable territory on the north and northwest. It is one of the larger ranges of the Idaho-Wyoming Chain and probably exceeds 50 miles in length and 15 miles in width.

The southern boundary of the Caribou Range is the transverse canyon of Stump Creek west of Auburn (pl. 5). The eastern boundary within this region is Star Valley, and the west boundary follows Stump Creek and Chippy Creek into Grays Lake and Outlet Valley and thence through Grays Lake Outlet into the valley of Willow Creek.

Considerable areas of the old Gannett erosion surface are preserved in the higher parts of the range. (See pl. 32, *B*.) Summits rise to a maximum altitude of 8,602 feet in the northeastern part of unsurveyed T. 6 S., R. 45 E., in the Freedom quadrangle. Stump Peak, about 2 miles to the southeast in the same ridge, is only 2 feet lower. The lower ridges preserve remnants of the late-mature Elk Valley and Dry Fork erosion surfaces, which together with the Gannett surface are submaturely dissected by the early mature canyons of the Blackfoot cycle, which here range from about 600 to nearly 2,000 feet in depth. Stump Peak stands about 2,700 feet above the level of Star Valley at Thayne.

The Caribou Range is in general well wooded and supplies numerous permanent streams, of which Tincup River, in the Lanes Creek and Freedom quadrangles, is the largest within this area. It cuts nearly across the mountains and affords the only roadway through them in this district. The drainage to the east is received by Salt River. The drainage to the west flows into several streams, among which Stump Creek, Lanes Creek, and Grays Lake Outlet are the largest. The easterly and northerly slopes of the Caribou Range, like those of most of the mountains in this region, are better watered and have more timber than the southerly and westerly slopes, because snows linger in the lee of the ridges.

GRAYS LAKE AND OUTLET VALLEY

Grays Lake, which is doubtless the remnant of a former larger body of water, occupies a valley 3 miles or more wide opposite the highest part of the Caribou Range. Only a small part of the lake lies within the area studied. It fluctuates in volume with the seasons and is bordered by extensive marshes, "margined by fields of tule and treacherous bog," [34] the haunt of large numbers of waterfowl.

The valley extends southeastward into the Lanes Creek quadrangle, about 4 miles beyond the lake. It is occupied largely by ranches and is drained by Gravel Creek.

Northwest of Grays Lake the outlet wanders through a broad valley called Outlet Valley, which, where it enters the Cranes Flat quadrangle (pl. 2), is about 4 miles wide and is underlain by basalt. The

[33] St. John, Orestes, Report of the Teton division: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 360, 1879.

[34] St. John, Orestes, op. cit., p. 350.

stream occupies a trench 20 to 50 feet deep below the general surface of the lava plain and is bordered by basaltic cliffs. In secs. 9 and 10, T. 3 S., R. 42 E., the trench deepens to a canyon nearly 200 feet deep, because there the stream impinges on more easily eroded sedimentary rocks and thence follows for a few miles the contact of these rocks with the basalt.

The altitude of Outlet Valley in the Cranes Flat quadrangle is more than 6,400 feet. Water is scarce. The abrupt basaltic slopes that border the valley on the southwest are unfavorable for dry farms, and ranches are few. Conditions are more favorable in the northward extension of the valley, where there is considerable meadow land and where there are gentle slopes or bench lands suitable for dry farming. Some homesteads have already been taken up.

HOMER AND LONG VALLEYS

Homer and Long Valleys form the northwestward continuation of the depression that is occupied in part by Outlet Valley, but they are separated from that valley and from each other by low divides. Homer Creek, which rises in the Little Valley Hills, drains Homer Valley and most of the northeastern slope of Sheep Mountain and cuts between Pine Mountain and Outlet Ridge to join Grays Lake outlet. The southwest side of the valley is occupied by long, gentle slopes or benches, youthfully dissected. Long Valley is drained by an unnamed stream that enters Willow Creek just beyond the northwest corner of the Cranes Flat quadrangle. In both valleys some water is available for irrigation, and there is opportunity for dry farming. The elevation is about 6,300 feet.

Homer Valley is occupied throughout by a basaltic area of irregular width. In Long Valley, except near the lower end, basalt is not exposed.

WILLOW CREEK BASIN RIDGES

The name Willow Creek Basin Ridges was applied by St. John[35] to the group of ridges that occupies much of the Cranes Flat quadrangle and adjacent parts of the Henry and Lanes Creek quadrangles and that lies in general between Grays Lake Outlet and the headwaters of Willow Creek. The name is here restricted, for reasons that will later appear, to include only Pine Mountain, Outlet Ridge, Sheep Mountain, and the Little Valley Hills. These ridges are the ones that actually lie between the two streams named. None of them rises high enough to preserve any of the Gannett erosion surface, but the other two erosion surfaces are represented.

Pine Mountain and Outlet Ridge.—Pine Mountain, which retains its local name, lies mostly north of the region considered in this paper and occupies the upland between Willow Creek and Grays Lake Outlet. On the southeast it is separated from Outlet Ridge, with which it is structurally continuous, by the canyon of Homer Creek. On the southwest it is separated from Sheep Mountain, to which it is also structurally related, by Long Valley. Within this region it is composed chiefly of sedimentary rocks, though flanked by lava at the west. Farther north, according to St. John, the sedimentary rocks terminate beneath lava, which forms the crest and descends in rugged benches toward the north and northeast.

Outlet Ridge, which takes its name from Grays Lake Outlet, its termination at the southeast, is in the main composed of strongly folded sedimentary rocks, but at Sugarloaf Mountain, its highest summit, it is capped by hard igneous rocks that form a steep cliff on the southwest. The interesting structure of this ridge is described in Chapters IV and V. The southwest slopes of the ridge are rather abrupt and bare, but on the northeast they are locally more gentle and though in places wooded they are in part utilized for dry farms.

Sheep Mountain.—The ridge south of Homer and Long Valleys is locally called Sheep Mountain. The northwestern part of the ridge, including the highest summit and nearly half of the mountain, is a basaltic cone that is surmounted by a group of cinder cones and is more fully described in Chapter IV. The rest of the mountain is composed of sedimentary rocks whose complex structure gives rise to somewhat varied topographic features.

The northeastern slope is generally abrupt and heavily brushed or timbered. The western slope is more gentle and has scantier vegetation. The steep northeastern slope is probably not itself a fault scarp, but its top follows in part the edge of a thrust-fault block, the beds in which are somewhat more resistant to erosion than those of the underlying block and have protected these weaker beds. Where the mountain is capped by basalt, this rock conceals the fault block and protects the underlying beds.

Little Valley Hills.—The name Little Valley Hills has been given to the group of hills and ridges that surrounds Little Valley and that extends southeastward from the broad sag in sec. 26, T. 3 S., R. 41 E., to the county line, where the hills stop abruptly at a deep gap through which flows a stream that rises in the low basaltic rim east of the hills and is tributary to Meadow Creek on the west side.

The Little Valley Hills include the southern part of the ridge that St. John called the "Willow Creek Ridge" and the northern part of his "Grays Lake Ridge."[36] He drew the division line between these two ridges at the place where basalt overspreads the upland between Meadow Creek and Outlet Valleys. This line would be a suitable line of division geologically, but the sag in T. 3 S., R. 41 E., is more easily recognizable topographically. Since St. John's time

[35] St. John, Orestes, op. cit., pp. 351-360.

[36] St. John, Orestes, op. cit.

Sheep Mountain has been distinguished by a separate name. The area now included in the Little Valley Hills is more of a physiographic and structural unit than St. John's "Grays Lake Ridge," the southern half of which is distinct from the northern half. Moreover, the southern half has already been given the local name of Little Gray Ridge, under which it is described later. Thus St. John's name becomes inappropriate and is therefore dropped.

The Little Valley Hills are composed of both sedimentary and igneous rocks of complex geologic structure. These features are described later.

The steep northeastward-facing slope noted in Sheep Mountain is continued along the main ridge of the Little Valley Hills. The slope southwest from this ridge is as varied as in Sheep Mountain and is submaturely dissected. The west base of the hills is believed to be outlined in part, at least, by a fault the eroded scarp of which is locally steepened by the undercutting of Meadow Creek.

The eastern part of the group consists of hills composed largely of basaltic flows more or less broken by faults into tilted blocks, of which the scarps and slopes are still relatively fresh.

PEALE MOUNTAINS

The largest mountain group of the subdivisions of the Idaho-Wyoming Chain represented in this region, is named in honor of Dr. A. C. Peale, chief of the Green River division of the Hayden surveys, who first sketched in broad outlines the geology of these mountains. The group includes the Preuss Range and its numerous subdivisions, Webster Range, and the outlying Grays Range, together with a group of lesser ridges separated from those first named by Blackfoot River and Lanes Creek but structurally continuous with them. The northern boundary of the group thus follows the southern and eastern border of Meadow Creek Valley and of its tributary at the north end of Little Gray Ridge. This boundary is marked by pronounced topographic depressions and by a noteworthy interruption of the geologic structure. The principal subdivisions of the Peale Mountains are briefly described below. Together they occupy an area 65 miles in length and about 25 miles in maximum breadth.

PREUSS RANGE

As described by Peale,[37] the Preuss Range includes the ridges and valleys south of Blackfoot River, east of Bear Lake Valley, north of the Bear Lake Plateau, and west of Thomas Fork and of Diamond Creek and Upper Valley. Diamond Creek was called by him the East Fork of the Blackfoot, but on Gannett's map[38] it is shown as the North Fork of the Blackfoot. Under this general grouping the Preuss Range, as here described, includes the Aspen Range (Aspen Ridge of Peale), Schmid and Dry Ridges, Snowdrift Mountain, and the Preuss Range proper, which forms the southern extension of all the others and occupies more than a fourth of the Montpelier quadrangle. If the Preuss Range proper were compared to the wrist, the other members would correspond to the fingers of a gigantic hand. The Webster Range and the subordinate Freeman Ridge, which was excluded by Peale and is here separately described, really forms another huge finger of the same hand. The Preuss Range, for which the name Preuss Mountains would be more appropriate, occupies an area about 47 miles in length and about 16 miles in maximum breadth. Its highest and most rugged portion is the junction area of the different members or the back of the hand as above suggested. Here ridges and summits are composed chiefly of folded and faulted resistant limestones that form part of a great overthrust block. The maximum height is attained by Meade Peak, which has an altitude of 9,953 feet.

Aspen Range.—From the north side of lower Georgetown Canyon the Aspen Range extends northwestward about 22 miles to Blackfoot River, and its maximum breadth is nearly 9 miles. In the higher, southeastern part considerable areas of the late-mature Gannett erosion surface that are preserved in the vicinity of the divides range in altitude from 7,800 to 8,300 feet, though individual summits rise to altitudes greater than 8,500 feet. (See pl. 6.) The Elk Valley and Dry Fork surfaces also occupy considerable areas along lower divides and at altitudes that range from approximately 7,000 to nearly 7,500 feet. All these surfaces are submaturely dissected by the early mature to youthful streams of the Blackfoot cycle. One of the larger undissected areas of the Dry Fork surface is afforded by Dry Fork Valley itself. (See pl. 13, *B*.) In the northern part of the range the rocks are less resistant and the valleys of the Blackfoot cycle are late mature. Some of the large ones, such as those of Trail and Johnson Creeks, are extensively aggraded. Alluvial fans and spring deposits only youthfully dissected lie along the west base of the range. Springs are still actively depositing material, though at a greatly reduced rate, at the Swan Lakes, in T. 9 S., R. 43 E., where the extensive deposits are now largely covered with soil and are undergoing dissection (pl. 60, *A*); near Sulphur Canyon, in T. 9 S., Rs. 42 and 43 E., where sulphur has been mined (p. 62); at Formation Spring, in T. 8 S., R. 42 E., where a remarkable series of nearly perfect basins and terraces, largely extinct, are still freshly preserved and where older spring deposits cover an area of approximately 2 square miles; and at Woodall and neighboring springs, in T. 7 S., R. 42 E., where spring deposits occupy another area about 2½ square miles in extent.

The west flank of the Aspen Range is traversed near the base by an old thrust fault, buried at least in part

[37] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 556-558, 582-590, and atlas, 1879.
[38] Idem, atlas, pl. 10.

by Tertiary and later beds and locally offset by normal faults. Some foothills in front of the fault are still occupied by Tertiary beds, but others are partly or entirely free from them. The present west slope of the range is determined in the main by erosion rather than by faulting.

The streams of the Aspen Range are all small, and many of them sink into the ground before reaching the mouths of their canyons. Trail and Wood Canyons, in the north-central part of the range, afford roadways across to Slug Valley and Lower Valley. Elsewhere the range is too high and steep to permit construction of roadways except at prohibitive cost. Numerous trails of mostly indifferent character make much of the range accessible to horsemen and to the numerous bands of sheep, which utilize it for grazing.

The Aspen Range is generally well wooded with groves of aspen and brush. The higher slopes support some timber. It contains rich and extensive beds of phosphate rock. (See pl. 21, *A*, and 29, *B*.)

Schmid Ridge.—Schmid Ridge, which is named from the Schmid ranch, in sec. 5, T. 9 S., R. 44 E., extends about 15 miles southeastward from Blackfoot River to the headwaters of Slug Creek, which loop around the south end in T. 10 S., R. 44 E. Its maximum width is about 2½ miles and its maximum altitude is 7,923 feet, near the south end. According to the principles of nomenclature outlined above, this ridge is really composed of three units, for it is crossed near the middle by two through valleys about a mile apart. It is, however, structurally a single unit, and for the present a single name for it will suffice.

Schmid Ridge ranges in altitude from 7,000 to about 7,900 feet but does not rise high enough to preserve the Gannett erosion surface, except possibly here and there a reduced remnant, though the Elk Valley and Dry Fork surfaces, now maturely dissected, are clearly shown. The southwest side of the ridge, especially in the northern part, is determined by a fault. The fault scarp, which was probably uncovered during the Blackfoot cycle by the erosion of Tertiary beds that were displaced by the fault (see p. 167), is now youthfully eroded. (See pl. 40, *C*.)

Numerous springs, which supply small permanent streams, occur in the ridge. Most of these springs sink in the ground before reaching the main streams in Slug and Dry Valleys. The through valleys above mentioned constitute an interesting drainage feature. They carry drainage from Dry Valley into Slug Creek. The diversion of Dry Valley drainage was accomplished by each one of the through valleys before the close of the aggradational epoch of the Blackfoot cycle, for both the through valleys are somewhat aggraded. Their transverse courses were in part determined in the Dry Fork cycle and may have been inherited from that cycle, as suggested by the terrace-like character of their upper valley walls. Lower Dry Valley is cut across a resistant group of beds, the Rex chert member of the Phosphoria formation, whereas Lower Slug Valley is excavated in weaker rock. Slug Creek has with little doubt always possessed as now the advantage of a greater effective drainage basin. Dry Valley is much obstructed by alluvial fans, now youthfully or submaturely dissected, whereas in Slug Valley the fans are much less developed. Both Slug Creek and the creeks in Dry Valley are incompetent, but Slug Creek is especially so. The incompetence of the creeks in Dry Valley may be explained in part by the double diversion of the upper waters as previously mentioned. For Slug Creek, however, such an explanation is inapplicable, and causes must be sought in climatic change and in the general aggradation of the Blackfoot and its tributaries, including the valleys of Slug and Dry Creeks, as a result of basaltic obstruction in the main valley.

Schmid Ridge supports numerous groves of aspen, especially on its eastern and northeastern slopes, and is utilized for grazing. It contains rich and abundant phosphate deposits.

Dry Ridge.—Although the local name Dry Ridge may not originally have been applied to any elevations south of Deer Creek Mountain, it is here given to the upland which has in general a ridgelike form and which extends in a curving course from the junction point of Georgetown Canyon and the Left Fork of Twin Creek northeastward and then northwestward between Dry Valley and Diamond Creek to the Blackfoot, a distance of about 27 miles. The maximum width is about 4½ miles.

The southern part of the ridge, which is composed of folded and faulted massive older limestones, is somewhat more irregular than the other parts and includes the highest summit, 9,082 feet in altitude, and several lesser elevations. North of Deer Creek Mountain the structure becomes somewhat more simple, and the ridge maintains a more even crest, which at altitudes that range from about 8,300 to 8,900 feet, forms one of the conspicuous features of the landscape. (See fig. 6.) The higher portions of the crest probably approximate the level of the Snowdrift peneplain or are not greatly reduced from that level. Considerable areas of the Gannett erosion surface and of the two succeeding erosion surfaces are also preserved. These areas are now maturely dissected by the early mature or youthful canyons of the Blackfoot cycle, which here range in depth from a few hundred to 1,000 feet or more.

Except the unnamed subsequent stream in the northeast corner of the Slug Creek quadrangle, the west slope of Dry Ridge has no permanent streams. The drainage of the northern and central parts of this slope is received by Dry Valley but is diverted in part to Slug Valley, as previously explained and goes to Blackfoot River. The drainage of the southern part of this slope goes into the Left Fork of

Twin Creek and thence to Bear River. Most of the water of the Left Fork is derived from large springs in sec. 33 (unsurveyed), T. 10 S., R. 44 E. The east slope has a number of permanent streams, of which the upper waters of Diamond Creek, a tributary of the Blackfoot, and of Deer Creek, a branch of Crow Creek, are the largest. Large springs in sec. 35 (unsurveyed), T. 10 S., R. 44 E., add much to the flow of Twin Creek in Georgetown Canyon.

The west base of Dry Ridge along Dry Valley is bordered by a fine succession of alluvial fans, to some of which reference has already been made. The east base along parts of Diamond Valley is marked by an abrupt slope, which is due to the erosion of gently upturned resistant limestone. In the northeast corner of the Slug Creek quadrangle a sharply cut subsequent valley has been excavated in Dry Ridge. The west side of this valley is formed by a remarkably fine dip slope of the Rex chert. (See pl. 29, *A*.)

Dry Ridge supports considerable groves of aspen and some timber and is utilized for grazing. It contains extensive and rich phosphate deposits, but at present these are relatively inaccessible. The ridge is not traversed by roads, but there are trails in most of the canyons.

Snowdrift Mountain.—Snowdrift Mountain, which is connected by a branching divide with Dry Ridge, extends from Deer Creek on the northeast to the upper waters of Montpelier Creek on the southwest, a distance of about 10 miles. The local name, which designates the main crest, is here extended to include the mountain mass between Georgetown Canyon on the west and Crow Creek and upper Preuss Creek on the east. The maximum width of this mass is nearly 6 miles.

The crest of Snowdrift Mountain ranges in altitude from about 9,000 feet at the north to 9,953 feet at Meade Peak, near the south end. The crest presents a relatively even sky line, as shown in Plates 34 and 38, *A*, and is the type locality of the Snowdrift peneplain. On both flanks of the mountain remnants of the Gannett, Elk Valley, and Dry Fork surfaces are preserved, though these are now maturely dissected by the youthful to early mature valleys of the Blackfoot cycle, 500 feet or more in depth. Plates 16, *A*, and *B*, show dissected Gannett and Elk Valley surfaces in Georgetown Canyon, and there are suggestions also of other intermediate levels, as previously explained. (See E–E′ and F–F′, pl. 10.)

The crest of the mountain for much of its length is developed along the axial region of a sharply folded anticline, composed of massive beds of limestone. An interesting series of basins has been developed along this crest by the combined action of solution and nivation,[39] or the action of melting snow. The exterior walls of the basins rise about 50 to 75 feet above the basin floors, and but for the gaps here and there, which allow views of the adjacent lower country, the traveler passing through these basins would hardly realize that he was on top of a high mountain. Small sink holes occur in places along the top of the ridge.

The drainage from the west flank of Snowdrift Mountain is inconsiderable, though there are a number of small permanent streams. The east flank, however, supports a number of fair-sized permanent streams, of which Wells Canyon deserves mention because it contains a road that crosses the mountain near its north end and affords communication between Georgetown Canyon and Crow Creek and by way of that creek with Star Valley. Several large streams that head near the south end of the mountain are Crow Creek, which flows into Salt River; Preuss Creek, which flows into Thomas Fork; and Montpelier and Threemile Creeks, which flow into Bear River. The south fork of Georgetown Canyon also heads in the same district.

Snowdrift Mountain supports considerable brush and timber. It is in part used for grazing, but the slope draining to Montpelier Creek, which supplies water for the city of Montpelier, is kept free from stock. Phosphate deposits of great volume and richness lie along both flanks of the mountain, but those of the west side are more readily accessible.

Preuss Range proper.—The main part of the Preuss Range extends southward from Snowdrift Mountain (its northern extension) and Dunns Canyon to Bear River, a distance of about 23 miles. It lies between Bear Lake Valley on the west and the valleys of Thomas Fork and Preuss Creek on the east, and has a maximum width of about 12 miles. It occupies nearly a fourth of the Montpelier quadrangle. Its highest altitude, 9,390 feet, is near the head of Dunns Canyon at the north. Southward the altitude diminishes to about 6,600 feet at Bear River, west of Pegram. The higher elevations at the north approximate the level of the Snowdrift peneplain. Farther south the Gannett, Elk Valley, and Dry Fork surfaces occupy successively the upland. (See A′–A″, pl. 10.) The incised meandering valley of Bear River is cut in the Dry Fork erosion surface, which with the older surfaces is submaturely dissected by canyons of the Blackfoot cycle that range in depth from a few hundred to about 2,000 feet.

The largest stream is Montpelier Creek, shown on Bonneville's map (fig. 2), as Tullich's Fork and on the Hayden maps as Davis Creek. This stream with its tributaries drains much of the northern part of the range and furnishes both the water supply of the city of Montpelier and water for irrigation. Its canyon provides roadways eastward across the range to Thomas Fork and upper Bear River and northward to Crow Creek and Star Valley. Bennington and Maple Can-

[39] Matthes, F. E., Glacial sculpture of the Big Horn Mountains, Wyo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 179–185, 1900.

yons on the northwest and Dunns Canyon on the north border supply water for irrigating ranches between Montpelier and Georgetown. The old aggraded valley of Sheep Creek at the south is occupied by the settlement of Alton and scattering ranches, and affords a roadway and access to the southeastern part of the range.

Ranches are scattered at favorable places here and there in the range. There is little timber except in the northern part, but much of the range is utilized for grazing. Metalliferous-mineral prospects, some of which have assumed the proportions of actual mines, have been opened at a number of places. These workings are described on pages 345 to 348. The western part of the range is underlain by rich beds of phosphate rock at depths regarded as accessible under the regulations of the United States Geological Survey. These are exposed and are being worked in Montpelier Canyon.

WEBSTER RANGE

The Webster Range is closely related to the Preuss Range; it extends in a curving course from the upper waters of Lanes Creek, in T. 5 S., R. 44 E., in the Lanes Creek quadrangle, southeastward and southward as far as Deer Creek near the boundary of Tps. 9 and 10 S., R. 45 E., in the Crow Creek quadrangle, a distance of about 25 miles. It lies between Lanes and Diamond Creeks on the west and Crow, Tygee, and Stump Creeks on the east and has a maximum width of about 8 miles in the vicinity of Webster Canyon, in the Freedom quadrangle, from which the range takes its name. The highest summit, here called Draney Peak, from the Draney ranch, is near the northern border of the Crow Creek quadrangle and attains an altitude of 9,151 feet. Throughout most of its length the range maintains an altitude of 8,000 feet or more, but it is somewhat lower at the north end.

Draney Peak and other unnamed summits in its vicinity probably rise approximately to the level of the Snowdrift peneplain or are not very much reduced below that level. Much of the range preserves the Gannett erosion surface, but the Elk Valley and Dry Fork surfaces are also represented, and all are submaturely dissected by canyons of the Blackfoot cycle that range in depth from a few hundred to 1,400 feet.

Freeman Ridge, a subsidiary member of the range at the southwest that takes its name from Freemans Pass, is 8½ miles long but only a mile wide except at the south end. It is separated from the main range by a succession of subsequent valleys and cols and is divided into smaller units by several passes, of which Freemans Pass is the lowest. It is a conspicuous topographic feature and is structurally continuous with Snowdrift Mountain. Topographically, however, it is separated from Snowdrift Mountain by the deep through valley of Deer Creek.

The Webster Range is well drained by permanent streams, and there are numerous springs. On the west side Timothy and Bacon Creeks and Browns Canyon, all of which are tributaries of the Blackfoot, deserve mention. The upper part of Browns Canyon contains evidence of recent occupation by beavers. On the east side the drainage is gathered by Stump, Tygee, and Crow Creeks and carried to Salt River. The principal smaller streams are Boulder, Horse, and Spring Creeks (tributary to Stump Creek) and Smoky and Sage Creeks (tributary to Crow Creek).

The range bears considerable timber and in its southern part contains extensive and rich beds of phosphate rock. These beds are relatively inaccessible under present conditions of communication and transportation. No roads cross the range, but there are trails in many of the canyons and the range is utilized for grazing.

GRAYS RANGE

Grays Range, the northernmost member of the Peale Mountains, is named from Grays Lake, which lies east of its northern part. It extends from the gap at the county line in the southeastern part of the Cranes Flat quadrangle southeastward to the Blackfoot, a distance of about 17 miles. It lies between Meadow Creek, Enoch, and Rasmussen Valleys on the west and the valleys of Gravel, Chippy, and Lanes Creeks on the east. If the hills north of Enoch Valley and the Little Blackfoot are included the range has a maximum width of about 7 miles. The highest summit is Lanes Butte, 8,320 feet in altitude, in sec. 3, T. 6 S., R. 43 E. From the vicinity of this peak the altitude diminishes both to the northwest and the southeast to about 7,000 feet.

The northern part of the range as far south as the gap in the SE. ¼ sec. 28, T. 5 S., R. 43 E., has been called Little Gray Ridge. This member is nearly 7 miles long and forms a narrow upland prong between the valleys of Meadow Creek and Grays Lake.

Rasmussen Ridge, another subsidiary of Grays Range, takes its name from the adjacent Rasmussen Valley and is separated from the main range by the valleys of Sheep Creek and of a small creek that heads against that creek. Rasmussen Ridge is 9 miles in length and about 2 miles in a maximum width.

The western extension of the range includes a group of nearly parallel hills that stretch southwestward as far as Henry. Each of these hills might be considered as a small topographic unit, but they are connected with each other and with the main range by low divides.

The range as a whole preserves in its higher portions considerable areas of the Gannett surface, but the Elk Valley and Dry Fork surfaces are also well represented. (See I–I′, pl. 10.) These surfaces are now submaturely dissected by canyons of the Blackfoot cycle that range in depth from a few hundred to about 1,000 feet.

Of the numerous streams and springs Davis Creek and Sheep Creek deserve mention. Sheep Creek has been considerably obstructed by the work of beavers. Chubb Springs, at the northwest, and the springs along the east base of the range are also noteworthy.

Grays Range is generally well wooded. It is crossed by a well-traveled road at the south end of Little Gray Ridge and is entered by secondary roads at the west and northeast. It is utilized for grazing and contains rich and extensive beds of phosphate rock. These beds are accessible from neighboring valleys but are remote from existing railways.

WOOLEY RANGE

The Wooley Range, named from the included Wooley Valley, extends from Blackfoot River northwestward to the Little Blackfoot, a distance of nearly 10 miles. Together with the subsidiary Fox Hills it has a maximum width of nearly 6 miles. The highest summit, 7,800 feet in altitude, is in the southeastern part, but the range as a whole maintains an altitude of 7,000 feet or more.

The Fox Hills, which are named from the neighboring Fox ranch and which are here considered part of the Wooley Range, might almost be given separate rank. They are separated from the main range by the broad Wooley Valley and by a col at the head of that valley. They are as a whole somewhat lower than the main range.

The Wooley Range has irregular form and its geologic structure forms a continuation of that of parts of the Aspen Range and of Schmid and Dry Ridges.

The higher portions of the range preserve remnants of the Gannett erosion surface. The Elk Valley and Dry Fork surfaces are also present. All three surfaces are dissected by canyons of the Blackfoot cycle, the type locality of which lies at the southeastern tip of the range. (See I–I′ and J–J′, pl. 10.)

The drainage of the range all goes directly or indirectly to the Blackfoot. Enoch Valley and parts of Grays Range are drained westward by the Little Blackfoot. Wooley and Rasmussen Valleys are drained southward and southeastward respectively by unnamed streams, which might well be given the names of the valleys that they occupy. The course of the stream that may be called Rasmussen Creek is noteworthy. Its upper portion, which has a northwesterly trend, was probably diverted during the Blackfoot cycle from a previous course into Enoch Valley.

The Fox Hills are relatively bare, but the lee slopes of the main range, which also are moister and better shaded, are well wooded. The range as a whole is utilized for grazing and contains valuable beds of phosphate rock, which under present conditions of transportation are relatively inaccessible.

GANNETT HILLS

The name Gannett Hills has been given to the submaturely dissected upland that extends southward from the transverse canyon of Stump Creek, in the southeastern part of the Freedom quadrangle, to Thomas Fork Canyon, in the northeastern part of the Montpelier quadrangle, a distance of about 27 miles. It lies between Star Valley and Fish Creek on the east and the valleys of Tygee, Sage, Crow, and Preuss Creeks on the west. Its maximum breadth is about 14 miles. The name is given in honor of the late eminent geographer Henry Gannett, who as a topographer of the Hayden Survey mapped much of the country described in this report. Although the altitude of the Gannett Hills is relatively high—7,000 to more than 8,000 feet—their geologic structure is more open than that of the neighboring mountains; they lack the pronounced trend of those mountains and are considerably lower. Thus the term hills seems appropriate. The higher portions of the hills lie to the south, and Red Mountain, in sec. 18, T. 11 S., R. 46 E. (unsurveyed), which has an altitude of 8,799 feet, is the highest summit. (See pl. 32, *C*.)

The Gannett Hills contain the type locality of the Gannett erosion surface, which is well preserved there. In the vicinity of the boundary between the Crow Creek and Montpelier quadrangles the altitude of the hilltops of the Gannett surface is about 8,300 to 8,400 feet, and the old valley bottoms are 300 to 400 feet lower. This relation is well shown at the boundary of the quadrangle south of Elk Valley and northward (see E′–E″, pl. 10; pl. 13, *A*), where the flat-topped hill at 8,017 feet and some corresponding elevations farther north appear to mark an old valley floor.

Elk Valley is the type locality of the erosion surface that bears that name. The surface appears as a dissected terrace 250 feet or more below the old Gannett Valley bottom, which now forms the upper terrace along Elk Valley. (See pl. 8.) The floor of Elk Valley represents the Dry Fork surface, as previously described. These surfaces are all well shown in other parts of the Gannett Hills. The floor of Elk Valley stands higher than some other Dry Fork areas, notably Sage Valley, because of the long roundabout course of its outlet, Spring Creek, and because of the more resistant character of the rocks traversed by that creek. The early mature canyons of the Blackfoot cycle range generally from 200 to 500 feet in depth, but where they undercut the older erosion surfaces, as in the head of Giraffe Creek, they may reach depths of 1,000 feet or more.

The drainage of the Gannett Hills flows chiefly into Crow Creek and thence into Salt River. The streams on the east side flow directly into Star Valley and Salt River. The largest is Spring Creek (Beaver Creek of the Hayden reports), which drains Elk Valley. White Dugway Creek, which drains Ephraim Valley, and

Horse Creek are the other principal tributaries of Crow Creek from these hills. South of the divide, which marks the boundary between Bear Lake and Caribou Counties, the drainage goes into Thomas Fork and thence to Bear River. Giraffe Creek is the largest stream.

The Gannett Hills are relatively bare, except on lee slopes in the higher areas. They are utilized for grazing and in Star Valley are fringed with dry farms. Salt deposits on Crow Creek are worked in a small way, as described in Chapter VII, page 338.

SUBLETTE RIDGE

From Thomas Fork Canyon the Sublette Ridge extends southward along the east border of the Montpelier quadrangle to the vicinity of Cokeville, Wyo., a distance of about 23 miles. The ridge forms the western member of a mountainous upland about 8 miles wide that lies between Thomas and Smith Forks of Bear River. Only about half of the ridge lies in the Montpelier quadrangle.

The crest of the ridge for the first 15 miles is high and rocky and for nearly half this distance exceeds 9,000 feet in altitude; the highest summit (9,314 feet) is south of Raymond Canyon. Thus the ridge locally rises approximately to the level of the Snowdrift peneplain. Along its west flank, which rises rather abruptly to a maximum of about 3,250 feet above the floor of Thomas Fork Valley, projecting points at lower levels may represent the Gannett, Elk Valley, and Dry Fork surfaces, but these surfaces have not been identified. Toward the north end the crest of the ridge probably represents the Gannett erosion surface, and the lower surfaces, maturely dissected, appear in rock terraces to the west, just south of Thomas Fork Canyon. The south end of the ridge for about 8 miles is lower and less continuous.

Most of the streams of the west flank are short and small. Raymond Canyon, however, cuts through the ridge and contains a fine stream. (See pl. 54.)

The western slopes are relatively bare. A fine set of alluvial fans affords opportunities for ranches, for which some water is available. Valuable beds of phosphate rock, which are described in Chapter VII, occur in the Sublette Ridge. These beds are relatively accessible by easy hauls to the Oregon Short Line Railroad at Border.

THOMAS FORK VALLEY

Between the Preuss Range on the west and the Sublette Ridge on the east lies Thomas Fork Valley, which has a maximum breadth of about 3 miles near Bear River. The valley extends northward for about 15 miles but becomes gradually narrower in that direction. Its elevation ranges from about 6,100 feet near Bear River to about 6,250 feet at the north end. The highly incompetent Thomas Fork occupies only a narrow, irregular belt in its aggraded floor.

Thomas Fork Valley is one of the richer agricultural districts of the region and is largely taken up with ranches, for whose irrigation water is generally available. The population is scattered, but two small settlements, Geneva at the north, and Raymond near the middle, deserve mention. The valley has an outlet to the Oregon Short Line Railroad at Border station, on the State line.

BEAR RIVER PLATEAU

GENERAL FEATURES

The name Bear River Plateau, which is still applicable, was given by the Fortieth Parallel Survey to the upland that extends from the junction area of the Uinta and Wasatch Ranges northward between the Wasatch Range on the west and Bear River on the east. The upland is underlain chiefly by a thick set of generally flat-lying Tertiary beds, although near the margins here and there the older, folded sedimentary rocks are exposed. According to G. B. Richardson,[40] the western border of the plateau coincides in part with the boundary between the Randolph and Logan quadrangles. Along that line the frayed edge of the Tertiary beds exposes the folded Paleozoic beds. In the northwestern part of the Randolph quadrangle, however, the boundary turns northeastward across Hodges Canyon to Garden City on Bear Lake. (See pl. 15.)

The altitude of the Bear River Plateau in the Randolph quadrangle is greatest near the western border, where it locally exceeds 8,900 feet. The late-mature surface, now uplifted or tilted and again maturely dissected, slopes gently eastward to altitudes of 6,500 to 7,000 feet along its eastern border.

BEAR LAKE PLATEAU

The region east of Bear Lake was described as the Bear Lake Plateau by Peale,[41] who considered it as geologically the northward continuation of the Bear River Plateau of the Fortieth Parallel Survey. There is no good line of separation, but the map in this paper follows Gannett's map [42] in showing the Bear Lake Plateau as beginning in about latitude 41° 45′, specifically along parts of Laketown Canyon and Sage Creek, in the Randolph quadrangle. It includes the Boundary Hills, which north of Peale's station 107 form a ridge along the State line. (See Gannett's map; altitude 7,083 feet, sec. 13, T. 13 N., R. 7 E., Randolph quadrangle, Utah.) The Boundary Hills include Lake Ridge in the Randolph quadrangle and Boundary Ridge in the Montpelier quadrangle. The northern limit of the Bear Lake Plateau and the included Boundary Hills is the transverse canyon of Bear River, in the Montpelier quadrangle. As thus

[40] Personal communication.

[41] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 582, 583; 1879.

[42] U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., atlas, pl. 10, 1879.

outlined the Bear Lake Plateau has a maximum length of about 30 miles and a breadth of 15 miles. Nearly half of it lies within the Montpelier quadrangle.

Along the borders of the plateau the irregular edge of the gently inclined Tertiary beds exposes the sharply folded older beds. The surface of the plateau responds to the gentle synclinal structure of the Tertiary beds and is higher along the western border, where the maximum altitude of the plateau—7,881 feet—is attained, and again in Boundary Ridge, where the beds are more sharply upturned. At these places the surface of the plateau approaches the level of the Gannett erosion surface. (See A-A′, pl. 10.) Elsewhere the Elk Valley and Dry Fork surfaces are well preserved, though all are now submaturely dissected by canyons of the Blackfoot cycle that range in depth from a few hundred to nearly 1,000 feet. Where the upturned Mesozoic beds are exposed, the streams show a considerable adjustment to the structure, and strike ridges and valleys are developed. Where the streams are working in the more nearly horizontal Wasatch beds they have developed consequent drainage, according to the arrangement of the respective gentle slopes of the plateau surface. The deep-red color of the Wasatch beds, where they are exposed, adds a picturesque quality to the scenery.

The drainage of the plateau all goes to Bear River or to Bear Lake. Indian Creek is the only notable stream on the west side in the Montpelier quadrangle. Pegram and Sweetwater Creeks drain the central portion and Poison, Boyd, and Snow Creeks the east side.

The Bear Lake Plateau is generally free from timber but is utilized for grazing. A few ranches are scattered here and there, but water is relatively scarce. Along the west border north of Bear Lake lie valuable beds of phosphate that are fairly accessible. These beds are described in Chapter VII. Hot springs, some of which are utilized, lie along the fault that marks the west base of the plateau. Others along the same general line occur under the waters of Mud Lake (pl. 17, *A*) and of two other small lakes farther north and supply part of the waters of those lakes.

BEAR LAKE VALLEY

On Gannett's map [43] Bear Lake Valley is made to include Bear Lake and Bear River Valley as far north as Soda Springs. Peale's description [44] refers chiefly to the portion of the valley south of Bennington. This broad depression, however, continues northward beyond Bennington to the vicinity of Novene, near the north border of the Montpelier quadrangle, where Bear River escapes through a narrows. The south end of the valley is in the vicinity of Laketown, in the Randolph quadrangle, Utah. As thus defined Bear Lake Valley extends practically due north a distance of about 45 miles. It is in general rather straight sided and about 7 miles wide, but toward both north and south ends it becomes narrower and is 3 to 4 miles wide.

Bear Lake Valley is, in part at least, of structural origin, as described more fully on pages 149 and 150. The west side of the valley slopes gently eastward and is marked by the usual reentrants that have been formed by long-continued stream erosion. The east side, however, in the vicinity of Bear Lake rises abruptly from the valley floor, has a relatively simple base line, and truncates obliquely successive beds of varying character. There seems therefore little doubt that this part of the valley wall is determined by a fault (the Bear Lake fault, p. 167).

The relative freshness of the fault scarp, particularly the faceted or blunted spurs (pl. 36, *B*), and the hot springs along the base of the scarp, all point to a recent date for the fault. On the other hand, the Pliocene (?) beds still preserved on both sides of the valley indicate that that depression is probably not recent and suggest that the present scarp may have been produced during the Blackfoot cycle by the removal by erosion of weak Pliocene (?) beds that formerly rested against a fault scarp. The facetted spurs and hot springs suggest renewed movement and refreshment of the scarp late in that cycle or in recent time. North of Dingle the form of the valley side changes and the fault dies out or at least fails to dominate the topography.

The entrance of Bear River near Dingle on the east and of Mill Creek near Ovid on the west causes broad reentrants that notably increase the width of the valley. On the other hand, from Bennington northward to Georgetown broad alluvial fans project westward into the valley, and these have forced Bear River against the opposite wall. The fans were formed after the excavation of the valleys of the Blackfoot cycle and during the epoch when the climate was more arid than now, for without apparent change of level they are undergoing dissection and have already reached a late youthful stage.

The flat floor of the valley north of Bear Lake, together with remnants of former shore lines above the present lake level, indicate a former expansion of Bear Lake toward an outlet 1½ miles west of Bennington. Although these shore lines have not been traced in detail they are well shown at a numbei of places on the east and west side of Bear Lake, as between North Eden and Indian Creeks on the east and in the vicinity of Fish Haven and of Ovid on the west.

At the mouth of North Eden Canyon just south of the Montpelier quadrangle a fine delta has been built into Bear Lake. (See pl. 17, *B*.) Here two clearly defined former levels of the lake are shown. The canyon has cut the waste slopes at its mouth to

[43] U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pl. 10, 1879.
[44] Peale, A. C., op. cit., p. 587.

a depth of 10 to 15 feet. The upper level or older terrace of the delta forms a flat floor continuous with the flood plain of North Eden Canyon. West of the road at different distances this upper terrace gives way to the lower terrace of the delta about 10 feet below. These features are illustrated in Figure 8.

Measurements by hand level were made at five places farther north with the following results:

Elevations of shore lines above surface of Bear Lake, September 4, 1920

[Measurements by V. R. D. Kirkham]

Locality No.	Position	Water level to crest of beach	Top of terraces above beach			Remarks
			No. 1	No. 2	No. 3	
		Feet	*Feet*	*Feet*	*Feet*	
1	SW. ¼ NE. ¼ sec. 13, T. 16 S., R. 44 E. (unsurveyed).	6	11	22	33	
2	SW. ¼ SE. ¼ sec. 12, T. 16 S., R. 44 E., (unsurveyed).	6	12	22	33	
3	SE. ¼ SE. ¼ sec. 36, T. 15 S., R. 44 E.	6	12	22	------	Terrace No. 2 lies at base of bluff about 25 feet high.
4	SW. ¼ NE. ¼ sec. 25, T. 15 S., R. 44 E.	6	11	22	------	Second terrace at base of bluff 20 feet high.
5	NW. ¼ SW. ¼ sec. 13, T. 14 S., R. 44 E,	------	------	22	------	Marsh to top of terrace.

lowered. In September, 1920, it was certainly 3 or 4 feet below the level in 1909 which itself was probably as much as 3 feet below the crest of the present beach.

The altitude of the two principal former shore lines above described may therefore be placed approximately at 5,940 and 5,950 feet respectively and the third shore line at 5,960 feet. The third shore line has not been identified elsewhere than east of Bear Lake, though the flat on which Dingle Cemetery is located, which seems somewhat higher, may perhaps be correlated with this shore line. The 5,950-foot shore line, which on the whole seems more pronounced, is indicated in part in Plate 9. On the west side of Bear Lake valley the towns of Fish Haven, St. Charles, Bloomington, Paris, and Ovid are located on the terrace that corresponds to this shore line.

The lower end of Bear Lake Valley near Georgetown is excavated chiefly in weak Tertiary beds that are exposed beneath a thin layer of fan gravels along the river below Wooleys and in gravel pits east of Georgetown station. Bear River itself, instead of flowing through the broad gap filled with Tertiary beds 1 mile east of Novene, has cut a gorge at Novene in more resistant Triassic rocks. Its course thus appears to

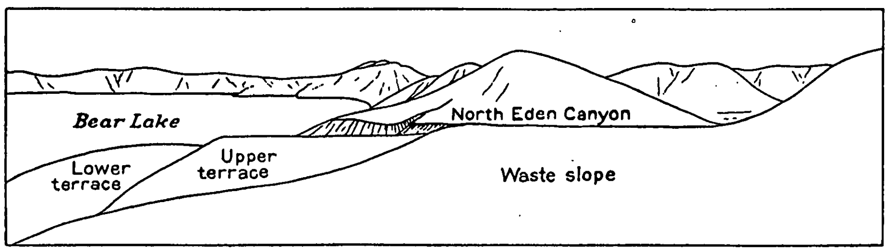


FIGURE 8.—Sketch of the North Eden delta from a point just south of the mouth of North Eden Canyon, Randolph quadrangle

The measurements show two well-defined shore lines and a third less well defined at heights of 11, 22, and 33 feet, respectively, above the present beach crest. At localities 3 and 4, the 33-foot terrace, if it was formerly present, has been eroded away in the development of a bluff 20 feet or more in height. Locality 4 is a point just south of Indian Creek, where conditions are similar to those at the North Eden delta. At locality 5, just west of the end of the secondary road that leads to the cemetery south of Dingle, the level of the marsh probably accords fairly well with that of the beach crest of Bear Lake, as the 5,950-foot contour on the map is somewhat too generalized at that place. The 22-foot level, which there marks the top of Bear River delta, apparently corresponds to the upper terraces at the delta of Indian Creek and North Eden Canyon.

The level of Bear Lake, when surveyed in 1909, was 5,924 feet. Since the construction of a canal between Bear Lake and Bear River for the regulation of the river and the establishment of a pumping station on the turnpike between Mud Lake and Bear Lake, the level of Bear Lake has been artificially raised and

have been determined early in the Blackfoot cycle or in the Dry Fork cycle by superposition upon the Triassic rocks from the weaker Tertiary beds, which at that time doubtless overlay that entire district.

The excavation of Bear Lake Valley was determined by the cutting of this gorge. The weak Tertiary filling of the earlier valley, a valley that dates from the Tygee cycle, was removed over wide areas while the river was engaged in sawing through the Triassic rocks at the outlet. Both gorge and valley were excavated to considerably greater depths than at present, for both are now aggraded with a filling of unknown thickness. A boring 192 feet deep, made by the Utah Power & Light Co. near its pumping station on Bear Lake, the deepest in the valley, did not cut through the filling. A cross section of Bear River Valley above Dingle, in which the old valley bottom is restored (A′-A″, pl. 10), shows that the filling at that place may be as much as 400 feet thick. Bear River now flows over this filling in a beautifully meandering course.

After the excavation of the valley a change to more arid climatic conditions induced the aggradation of the valley and the development of the broad alluvial fans north of Bennington. At about the same time and probably before the completion of the aggradational epoch outflows of basalt flooded Bear River Valley to a point about 5 miles southeast of Soda Springs. This part of the region has not been mapped topographically or studied in detail geologically. The data now available seem to indicate that the top of the basalt at its southern border is not high enough to have raised the waters of Bear River to the former higher levels of Bear Lake. Measurements at the point where the river enters the basaltic area in the northwest corner of sec. 34, T. 9 S., R. 42 E., show that the basalt rises about 140 feet above the surface of the river. A profile survey of Bear River [45] shows that the altitude of the water surface at that place is about 5,782 feet. Thus the altitude of the top of the basalt is about 5,922 feet, which closely approximates that of the present lake level. Hand-level observations show that the altitude of the basalt increases little, if any, northeastward along the river. Thus it is probable that the basalt has had no part or at least has played only a subordinate part in the development of Bear Lake.

On the other hand, the alluvial fans west and northwest of Bennington without doubt formerly extended across the valley at sufficient heights to impound water at the levels of the shore lines above described and perhaps temporarily even higher. The loose materials of these fans would relatively soon be washed away, so that no shore lines of any permanence would be likely to be produced while the river was cutting an outlet through them. However, should the river cut through the fan material into harder rocks or be superposed on buried ledges, its downcutting would be retarded and there might be opportunity for the development of shore lines. North of Wooleys the river has cut through fan gravels into Tertiary beds that are somewhat more consolidated than the gravels, and in the SE. ¼ SW. ¼ sec. 11, T. 11 S., R. 43 E., a Triassic ledge that was formerly buried by fan material is now exposed at about the level of the 5,950-foot shore line. The river has cut its trench between this ledge and a more extensive Triassic mass on the southwest.

The epoch of aridity and fan building was suceeded by moister climatic conditions, which are here tentatively correlated with the later stage of Pleistocene glaciation. Thus Bear Lake with its former expanded stages probably corresponds to some extent in time and development with Lakes Bonneville and Lahontan in Utah and Nevada.

Bear Lake Valley receives most of the drainage of the Montpelier quadrangle and of the northern half of the Randolph quadrangle. The larger affluents are mentioned in describing the inclosing uplands. Bear Lake occupies the upper part of the valley. The north end is separated by a long, narrow, and curved sand bar from Mud Lake, formerly a shallow roughly triangular body of water about 1½ miles on each side but now increased in area and made more irregular in outline as a result of its connection by canal with Bear River. (See pl. 17, *A*.) North of Bear Lake much of the valley for 6 miles or more is occupied by marshes. These marshes are drained by the outlet of Bear Lake, not mapped by the Hayden Survey, which joins Bear River about 3 miles below Montpelier.

Bear Lake has been well described by Peale: [46]

> It is evident that the existing lake is but the remnant of one that was much larger. The view of the lake from the Bear Lake Plateau is beautiful; the water has an exquisite blue tint, which is equaled by few bodies of water in any part of the world. The shape of the lake is somewhat peculiar, both the north and south ends being about square-cornered. The length is 19 miles, and the greatest width about 8 miles. The average width of the main body is about 6 miles. Toward the south it narrows to 4 miles. * * * The depth of the lake, as given in the report of 1871, * * * is 175 feet at the deepest portion, with an estimated average depth of 40 to 60 feet.

Hayden's description [47] gives a more vivid picture of the lake. He says:

> It is a beautiful lake, set like an emerald among the mountains. Not even the waters of Yellowstone Lake present such vivid coloring. No sea-green hue could be more delicate; and as the waves rolled high by the force of the winds, the most vivid green seemed to shade to a beautiful, delicate blue.

Bear Lake Valley has fertile soil and is well watered. It is the largest and richest agricultural district in the region here described. It contains numerous ranches and towns of which the largest is Montpelier, which had a population of 2,984 according to the census of 1920. It is traversed in part by the Oregon Short Line Railroad and by a branch of the same railroad between Montpelier and Paris. The phosphate beds on both sides of the valley promise to form the basis of an active industry. Electric power for lighting and for industrial purposes is available throughout the valley from the power lines of the Utah Power & Light Co. (See pl. 9.)

BEAR RIVER VALLEY

The more striking physiographic features of Bear River Valley above and below Bear Lake Valley have been mentioned in the above discussion and in earlier pages. The river, where its valley is flooded by basalt, follows in general the contact between that rock and the sedimentary beds. For part of its course this contact lies along weak Tertiary rocks, but at the bend near Alexander, where the river turns south, it is walled by basalt on the north and impinges on hard sedimentary rocks on the south.

The east side of Bear River Valley below Novene and above the basalt-flooded area is occupied by extensive alluvial fans and by spring deposits.

[45] U. S. Geol. Survey Water-Supply Paper 350, pl. 1, *C*, 1914.

[46] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 587, 1879.

[47] Hayden, F. V., U. S. Geol. Survey Terr. Fifth Ann. Rept., p. 156, 1872.

The streams from the Aspen Range either sink into the ground before reaching the river or are in large part diverted for purposes of irrigation. At Soda Springs, however, Soda Creek, a fine stream fed chiefly by springs, enters Bear River from the north. In the vicinity of Soda Springs, also, there are numerous springs more or less mineralized, some carbonated and others sulphureted.

Bear River Valley affords one of the natural gateways from western Wyoming and northern Utah to Snake River and the northwest. It was selected as a route for travel by the trappers and emigrants and later was followed by the railroad until now it has become part of a great transcontinental route, along which ebbs and flows the commerce of many States.

Although the Bear River bottoms are provided with water and fertile soil, the cold air which they receive at night from neighboring uplands is generally unfavorable for crops, and little besides wild hay may be grown upon them. Adjacent slopes that are somewhat elevated from the bottoms are extensively farmed.

WASATCH RANGE

Location and extent.—The westernmost mountain group of the southern part of the Northern Rocky Mountain province is the Wasatch Range, which, according to the United States Geographic Board,[48] extends from the mouth of San Pitch River in San Pete County, Utah, northward to the bend of Bear River near Soda Springs and includes as its northward extension the Bear River Range. The Wasatch Range as such does not enter the territory here described, but its subsidiary, the Bear River Range, lies along the western border of the Montpelier quadrangle and its foothills extend into the southwestern part of the Slug Creek quadrangle.

Bear River Range.—As shown on the maps of the King and Hayden surveys the name of Bear River Range seems not to be applied to any of the Wasatch Range south of Logan River in Utah. Geologically and physiographically, however, the range is continuous southward as far as the vicinity of Huntsville, Utah, about latitude 41° 15′, where it apparently joins the main Wasatch Range, which ends in a prong on the west side of Cache Valley and south of Bear River (King's map). If the name is extended as above suggested the Bear River Range would have a length of about 95 miles and a maximum width of about 22 miles along the line between Tps. 15 and 16 S., in Idaho. Toward the north it grows narrower and terminates in a single, broad, rounded summit known as Sheep Rock just south of the sharp bend of Bear River near Soda Springs. The highest peaks in the part of the range that lies in Idaho are Paris Peak (altitude, 9,572 feet) at the head of Paris Canyon in the Preston quadrangle, and Sherman (Soda) Peak (altitude, 9,669 feet) at the head of Skinner Creek, in the same quadrangle. Naomi Peak, in the Logan quadrangle, reaches an altitude of 9,980 feet.

Peale[49] describes part of the range as follows:

> The waters of Logan Fork flow southward in the central portions of the mountains. The best-defined range here is on the west, a succession of sharp peaks extending northward from Logan Canyon. This range presents a steep and rugged front toward Cache Valley. On the east side the mountains are plateau-like, and this is the general character toward the north.

The Bear River Range lies largely outside the area thus far studied. It is partly shown in the Logan, Randolph, Preston, and Montpelier quadrangles. Large areas of it have not yet been mapped topographically and little detailed geologic work has as yet been done upon it. Present data, however, indicate that probably its erosional history is similar to that of the region already described. The higher portions exceed 9,000 feet in altitude, and although individual peaks rise here and there, extensive areas, when viewed from the east, present a relatively even sky line (see pls. 17, *A*, and 21, *C*), that probably corresponds with the level of the Snowdrift peneplain. Other levels that apparently conform to the lower erosion surfaces already described may also be recognized. All are now submaturely dissected by canyons of the Blackfoot cycle that range in depth from a few hundred to more than 1,500 feet.

The development of strike ridges and valleys is not so marked a feature of the Bear River Range as of the Preuss Range. The simpler structure and more resistant beds of much of the Bear River Range probably account for this difference between the two ranges.

The outlying Nounan Valley, which is roughly a strike valley, is a reexcavated part of an old filled valley of the Tygee cycle.

In the higher parts of the range west of the Montpelier and Randolph quadrangles numerous cirques, lakelets, and moraines bear evidence of local glaciation. In St. Charles Canyon, as previously noted, the youthful moraines that stretch across the somewhat aggraded floor of the canyon testify to the relative recency of the St. Charles glacial episode.

The larger streams of the part of the Bear River Range here described are Fish Haven, St. Charles, Bloomington, Paris, Mill, Stauffer, Co-op, and Skinner Creeks. Bloomington and Paris Canyons, in the Montpelier quadrangle, and the canyon of Swan Creek, about a mile to the south, contain large springs from which the creeks emerge full grown. (See pl. 58, *B*.) These canyons all drain into Bear Lake Valley. North of Bern the drainage of the Bear River Range is received by Nounan Valley, which is tributary to Bear River at two places, one of which is 1½ miles south of Novene, in the Mont-

[48] U. S. Geog. Board Fifth Rept., p. 345, 1921.

[49] Peale, A. C., op. cit., p. 598.

pelier quadrangle, and the other opposite Cavanaugh, in the Slug Creek quadrangle. Stauffer, Co-op, and Skinner Creeks flow into Nounan Valley.

The Bear River Range is relatively rugged and in its higher parts carries considerable timber. It is utilized for grazing. Metalliferous prospects have been opened here and there in the range as described in Chapter VII, but no successful metal mines have yet been developed. The eastern foothills west of Bear Lake Valley contain rich beds of phosphate rock, which have been mined in Paris and Slight Canyons and which give promise of supporting large operations. These are described in a later chapter.

INDEPENDENT FEATURES

WILSON AND PELICAN RIDGES

If the boundaries of the physiographic provinces are drawn as suggested on page 11, Wilson and Pelican Ridges constitute the easternmost members in this region of the Basin and Range province. Wilson Ridge, which is named from Wilson Creek at its northwest end, and Pelican Ridge, which is named from Pelican Slough at the southeast, are fault-block ridges that are closely related structurally. They are prominent topographic features whose summits rise 1,000 to 1,500 feet above the valley floors on either side. (See pls. 2 and 3.) Their combined length is about 12 miles, but they are separated from each other by a deep gap which has been eroded along the transverse fault that has produced the offset in the ridges. The ridges are composed of sedimentary rocks, but the gap is occupied by basalt. The gap affords a passage for the road from Grays Lake to the Blackfoot dam, a part of Landers Cutoff.

The ridges do not rise high enough to preserve any of the Gannett erosion surface, but the Elk Valley and Dry Fork surfaces are well shown. These surfaces are now submaturely dissected by canyons of the Blackfoot cycle, locally 500 feet or more in depth.

Pelican Ridge is in part underlain by beds of phosphate rock, at present relatively inaccessible. These beds may prove a valuable resource. Phosphate rock of doubtful commercial value also occurs at several places along the base of each flank of Wilson Ridge.

RESERVOIR MOUNTAIN

Reservoir Mountain is an isolated mass that rises to a maximum height of nearly 1,000 feet above the level of the plain on either side and is named from the Blackfoot River Reservoir, which lies to the east. It was included by Peale[50] in the mountain group that he called the Soda Springs Hills, but it is quite distinct from the other mountains and deserves a separate name. The mountain is only about 8 miles long and 3 miles wide, but it is a conspicuous topographic feature. The eastern face is fairly abrupt and even. There is little accumulation of rock waste at its base, but there is an interesting group of remnant craters about a mile in extent. The western slope is more gentle and irregular. The mountain is a fault block and has complex geologic structure. (See pp. 146 and 164.)

The Elk Valley and Dry Fork erosion surfaces, which are preserved on the uplands, are now submaturely dissected by canyons of the Blackfoot cycle that reach a maximum depth of about 700 feet.

The eastern slope has only temporary streams, but the western slope is drained by several small permanent streams that empty into Corral Creek, a tributary of the Blackfoot that has a broad aggraded valley which is probably underlain by basalt. A good spring for camping occurs in the NE. ¼ sec. 29, T. 6 S., R. 41 E.

There is little timber, but the mountain is utilized for grazing. It is probably underlain by beds of phosphate rock of future commercial value, though they are at present relatively inaccessible.

BLACKFOOT MOUNTAINS

St. John[51] described the Blackfoot Range, now called the Blackfoot Mountains, as "parallel with and lying a few miles to the northeast of the canyoned course of Blackfoot River." Bechler's map[52] shows the Blackfoot Range as including practically all country southeast of the Snake River Plains between Blackfoot River and the present Willow and Meadow Creeks as far south as the forty-third parallel. According to this definition the Blackfoot Mountains would include Wilson Ridge and should include the closely related Pelican Ridge. On the principle of continuous divides, however, the main range would end at Wilson Creek. (See pl. 2.) This creek occupies the site of a former deep valley or gap filled with basalt and later partly reexcavated. It thus appropriately terminates the range.

Only a small portion of the Blackfoot Mountains as here defined enters the region described in this report. (See pl. 15.) The geologic structure of the group is complex and is discussed in part in Chapter V. The group as a whole is relatively low for it rises only 600 to 1,000 feet above the level of Cranes Flat to the east. No detailed geologic or physiographic study of it has yet been made, but probably it corresponds in erosional development with Wilson and Pelican Ridges and Reservoir Mountain.

The larger part of the drainage of the Blackfoot Mountains is tributary to Blackfoot River, but some enters Willow Creek.

Beds of phosphate rock, probably rich and extensive, occur in parts of the Blackfoot Mountains. These beds lie mostly outside the region studied, but mention is made in Chapter VII of the beds thus far examined.

50 Peale, A. C., op. cit., p. 596.

51 St. John, Orestes, Report of the geological field work of the Teton division: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 338, 1879.

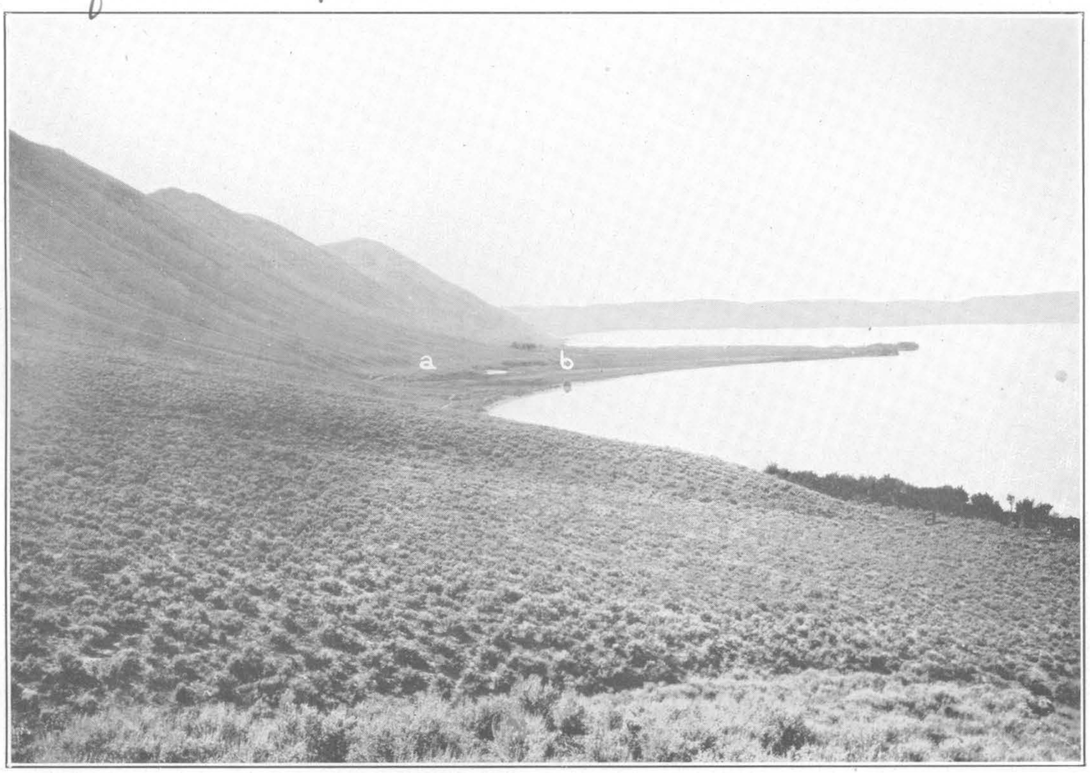
52 U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., atlas, pl. 9, 1878.

Gale. 471.

A. VIEW SOUTHWESTWARD ACROSS MUD LAKE AND THE NORTH END OF BEAR LAKE FROM THE RIDGE EAST OF HOT SPRINGS, MONTPELIER QUADRANGLE

Background, Bear River Range with Snowdrift peneplain (?) and younger erosion surfaces, and village of St. Charles at former shore line of Bear Lake; foreground, escarpment of Bear Lake fault and subaqueous springs

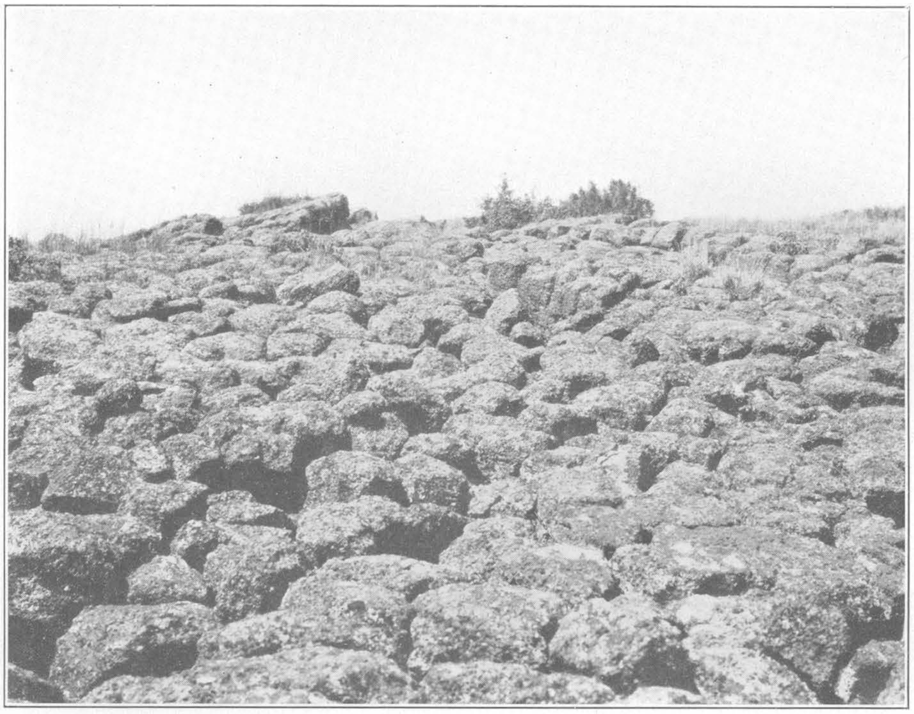
Mansfield, 124.



B. NORTH EDEN DELTA FROM A HILL NEAR THE ROAD ABOUT A MILE NORTH OF THE STATE LINE, MONTPELIER AND RANDOLPH QUADRANGLES

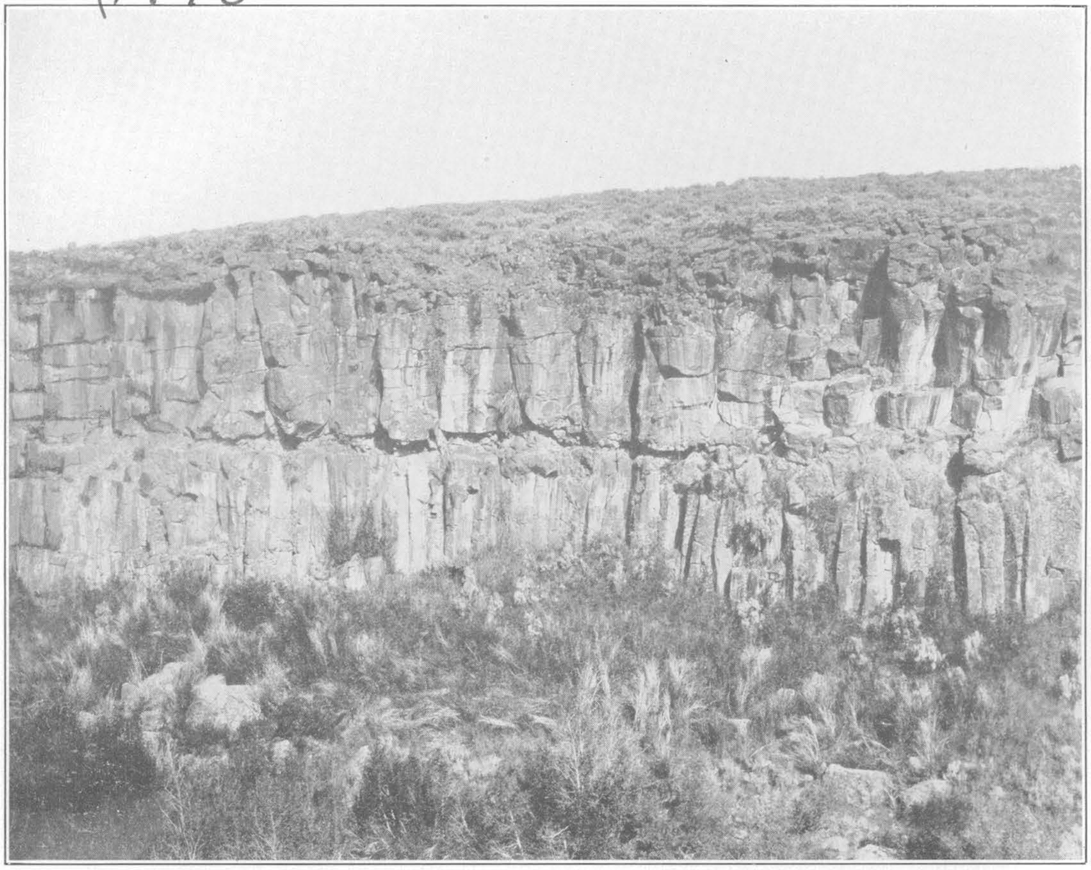
a, b, Former shore lines of Bear Lake

Umpleby, 176.



A. CHARACTERISTICALLY WEATHERED SURFACE OF PRISMATICALLY JOINTED BASALT, HENRY QUADRANGLE

Mansfield, 146.



B. CLIFF OF BASALT, HENRY QUADRANGLE

Exposing two flows with columnar jointing, north side of Blackfoot Gorge, sec. 14, T. 7 S., R. 42 E.

CHESTERFIELD RANGE

Only the southeastern foothills of the Chesterfield Range enter the region described in this report. The range as a whole is nearly 25 miles long and 10 miles wide. It extends northwestward from Tenmile Pass, in the southeastern corner of the Portneuf quadrangle (see pl. 15), to the broad sag west of Morgan, in the southwestern part of the Paradise Valley quadrangle, and is named from the town of Chesterfield at its west base. It forms the northern part of the mountain group called by Peale [53] the Soda Springs Hills, but its topographic and geologic isolation make a separate designation more appropriate.

The range is described by Peale as "somewhat plateau-like," but it is composed of several ridges of sedimentary rocks that reach maximum altitudes of about 7,300 feet and rise about 1,000 to 1,200 feet above the valleys on the east but nearly 2,000 feet above the floor of Portneuf Valley on the west. The plateaulike character noted by Peale is with little doubt due to the preservation of the Elk Valley and Dry Fork erosion surfaces, which are apparently present. These older erosion surfaces are now submaturely dissected by canyons of the Blackfoot cycle that range from a few hundred to about 1,000 feet in depth. A number of permanent streams drain on the west and south into Portneuf River and on the east and north into Corral Creek and Blackfoot River.

The Chesterfield Range bears some timber and is utilized as a range for stock. Ranches are scattered here and there at favorable places. Phosphate beds occur on the east and west flanks and elsewhere in the range. Those on the west flank, in T. 5 S., R. 38 E., are in the Fort Hall Indian Reservation and have already been described.[54] Those on the east flank are described in part in Chapter VII.

SODA SPRINGS HILLS

The group of rocky hills here called the Soda Springs Hills, constitutes the southern member of the group to which Peale gave this name. It lies southeast of the Chesterfield Range and extends from Tenmile Pass at the southern border of the Portneuf and Henry quadrangles to the bend of Bear River west of Soda Springs, a distance of about 10 miles. These hills have not yet been mapped topographically or studied in detail geologically. Their northern tip is included in the adjoining corners of the southern parts of the Portneuf and Henry quadrangles.

WILLOW CREEK LAVA FIELD

General features.—The Willow Creek lava field is bounded by the Blackfoot Mountains and Wilson and Pelican Ridges on the west and the Willow Creek Basin ridges on the east and extends southeastward into the Cranes Flat quadrangle as far as the middle of sec. 6, T. 5 S., R. 42 E. It takes its name from Willow Creek, one of the larger tributaries of Snake River in this region. The lava field also occupies a considerable portion of the valley of Meadow Creek, and the two streams are separated by a low divide in the basalt, successive flows of which have produced the lava field.

The Willow Creek lava field, which occupies valleys along the boundary between the Northern Rocky Mountain and the Basin and Range provinces, illustrates the interfingering of the Snake River plain with the mountains which border that plain on the south and southeast and represents an extension of that plain. The basalt in Homer and Outlet Valleys represents similar interfingering on a smaller scale.

The lava field, though more or less covered with soil and dotted here and there with groves of aspen, affords numerous exposures of basalt, especially along the canyon walls of Willow Creek and its tributaries. The surface is in general that of a youthfully dissected lava plain that has an altitude of nearly 6,600 feet. The basalt is apparently horizontal for the most part, but it is sufficiently undulatory to produce faint ridges that have a northwestward trend. The streams are mostly dry or intermittent, but Willow Creek and a few of its larger tributaries, such as Cranes Creek and Long Valley, maintain permanent flows of water. The upper courses of many of the streams are hardly more than drainage lines on the surface, but the parts of their courses that lie in canyons are flat-bottomed, relatively narrow, and walled with vertical cliffs of basalt. The cliffs in many places are as much as 50 feet and locally more than 100 feet high. The highest cliff, about 200 feet high, forms the southwest face of the pronounced ridge in sec. 24, T. 3 S., R. 40 E. Its form and position are suggestive of local faulting.

The lava field merges on the northwest with Sheep Mountain and southward it connects with the Blackfoot lava field through the gap northwest of Wilson Ridge. Probably, too, it is continuous beneath cover with the basalt in Meadow Creek Valley, which itself is an extension of the Blackfoot lava field. In favorable places, where the soil cover is sufficient, homesteads have been taken up, chiefly for dry farming.

Cranes Flat.—Cranes Flat is a broad alluviated area that has a youthful and partly marshy surface. It is with little doubt underlain by basalt and is part of the Willow Creek lava field. It is drained by Cranes Creek, the largest affluent of Willow Creek within this district. There was only one ranch in the flat in 1916, and the area was used in part as a range for cattle. Its altitude is about 6,500 feet.

[53] Peale, A. C., op. cit., p. 596.

[54] Mansfield, G. R., The geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, 1920.

BLACKFOOT LAVA FIELD

General features.—The Blackfoot lava field affords another example of the interfingering of the Snake River lava plain with its bordering mountains. The name is here given to the broad basalt-covered area that extends from Wilson Ridge and the south end of the Blackfoot Mountains to a point on Bear River about 5 miles southeast of Soda Springs. It includes much of the Henry quadrangle and the area called by Peale[55] Soda Springs Valley. On the north it has received an inflow of basalt from the Willow Creek lava field through the gap between Wilson Ridge and the Blackfoot Mountains. On the northeast it has received similar inflows from the valleys of Meadow Creek and the Little Blackfoot. The smaller areas of basalt in Enoch, Upper, and Wooley Valleys in the Lanes Creek quadrangle may be connected beneath the alluvium with that of the Blackfoot lava field, but of this relation there is no direct evidence. The basalt has overflowed northwestward through the valley of Blackfoot River and westward through Tenmile Pass to Portneuf Valley. It probably also escaped southwestward through the gap occupied by Bear River west of Soda Springs, though the connection of the basalt at the gap with the main body to the east is concealed by Quaternary deposits.

The youthful surface of the lava field in the Henry quadrangle is in general about 6,000 to 6,300 feet above sea level, but the area southeast of the reservoir is somewhat higher and its maximum altitude is 6,683 feet. Although the surface is covered in many places with wind-blown soil, volcanic ash, alluvium, or spring deposits the basalt is exposed over large areas in dark somber ledges that reveal its characteristic columnar structure. (See pl. 18, *A*.) There are many cliffs, which can probably be variously explained, and numerous fissures and sinks. Crag Lake, in secs. 1 and 12, T. 7 S., R. 41 E., receives its name from the fine basaltic cliff that forms its eastern wall. (See pl. 57, *A*.) Good examples of fissures are found in prolongation of the southward arms of the Blackfoot River Reservoir and elsewhere. Sinks of different sizes are scattered here and there over the surface, in some places in linear arrangement as if denoting the course of a partly collapsed tunnel in the lava. Here and there also the basalt yields a hollow sound to the tread that is suggestive of cavities beneath.

Three youthful rhyolitic cones rise above the basaltic plain south of the reservoir and are well-known landmarks. The largest of these cones has long been known as China Hat, China Cap, or The Cap. It rises nearly 1,000 feet above the surrounding plain. The other two cones are here named Middle and North Cones for reference. Between Middle Cone and North Cone are two small crater lakes. Some of these features are illustrated and further described in Chapters IV and V.

[55] Peale, A. C., op. cit.

A number of cones composed of scoriaceous basalt and lapilli are scattered here and there over the field and on certain islands in the reservoir. These appear to have no local names but several of them are named below for reference. These and other volcanic features are more fully described in Chapter IV.

Crater Mountain.—Crater Mountain, in sec. 14, T. 5 S., R. 41 E., is the upper, more scoriaceous part of a large lava cone.

Little Crater.—Little Crater, which stands mostly in sec. 34, T. 6 S., R. 41 E., though it extends into the adjoining township, is the finest example of a cinder cone in the region here described. Its shallow crater forms nearly a perfect circle.

Broken Crater.—Broken Crater, in sec. 9 and vicinity, T. 7 S., R. 41 E., is one of the largest of these cones. It is little dissected but has apparently been breached on the south by explosion.

Water supply.—Water on the surface of the Blackfoot lava field is relatively scarce. Most of the smaller streams are dry for long periods. On the east side, however, Blackfoot River, which is the main supply of the Blackfoot River Reservoir, Little Blackfoot River, and Meadow Creek are permanent streams of considerable volume. Woodall Spring and other springs along the base of the Aspen Range, in T. 7 S., R. 42 E., have produced large marshy areas but furnish little water that is available for irrigation. Farther south along the base of the Aspen Range in T. 8 S., R. 42 E., several springs, the largest of which is Formation Spring, supply small amounts of water for irrigation. Along the western side of the field Corral Creek and its tributaries form a permanent stream tributary to the Blackfoot, but its water had been little utilized at the time of the writer's visit (1916). Tenmile Creek which drains through the pass of the same name, has a small though permanent flow for its course above the pass. Farther south, along the east base of the Soda Springs Hills, Soda Creek is a relatively short permanent stream, whose waters supplied chiefly by springs are tributary to Bear River.

In T. 8 S., Rs. 41 and 42 E., an area known as Fivemile Meadows, perhaps 3 or 4 square miles in extent, which was formerly farmed, became flooded and to a large extent unfit for agriculture when the Blackfoot River Reservoir was filled in August, 1914, to the level shown on the maps of the Henry and Cranes Flat quadrangles. The waters of Soda Creek were augmented, as were also the waters in Crag Lake and the crater lakes south of the reservoir. These features and their causes are more fully described in Chapter VII.

To reduce the effects of this flooding the waters of the reservoir have been lowered 10 feet or more below the level indicated on the maps, so that the outlines of the reservoir, though generally maintained, are now considerably modified in detail. For example, in secs. 12 and 13, T. 6 S., R. 41 E., a large island, which is shown on the geologic map (pl. 3) has emerged. The island in sec. 35, T. 5 S., R. 41 E., and a considerable strip to the southeast, shown on the map as water, has been added to the land area to the east. Similarly the large island shown in sec. 5, T. 6 S., R. 42 E., is now a peninsula joined to land at the west and the water area north of it has been greatly reduced. The reservoir can not be remapped, because it is now used to regulate the flow of Blackfoot River and its outline may vary considerably during any given year. The change in water level of Crag Lake as a result of the lowering of the surface of the reservoir is clearly shown in Plate 57, *A*.

The larger soil-covered areas of the Blackfoot lava field were being rapidly taken up by dry farmers in 1916. Water for domestic use was hauled from the reservoir or obtained from wells sunk in the basalt to depths of 200 feet or more.

Meadow Creek extension.—The valley of Meadow Creek is in part a fault trough or graben, the geologic features of which are discussed on pages 162 and 163. Its sides are relatively steep, and its broad and youthful surface merges with that of the Willow Creek lava field. Its altitude, however, is somewhat lower—about 6,250 feet. Though it is largely an alluviated area there is little doubt that the basalt in its southeastern part is continuous beneath the alluvium with that of the Willow Creek field to the north. Flows of basalt whose cliffed fronts are 100 feet high occupy the southeastern part of the valley, and in secs. 18, 19, and 30, T. 5 S., R. 43 E., tongues of basalt descend to the valley from Grays Range.

The obstruction of Meadow Creek by basalt has produced the marshy and partly alluviated area in secs. 34 and 35, T. 5 S., R. 42 E., called Pelican Slough, above which the course of the creek is unusually sinuous.

There are two or three scattering ranches, but the valley is utilized mainly for grazing.

PORTNEUF MOUNTAINS

The Portneuf Mountains are shown in part in Plate 15 and in the maps of the Portneuf and Paradise Valley quadrangles. They lie in Bingham and Bannock Counties, Idaho, between Portneuf River and Marsh Creek on the west and the upper Portneuf and Bear Rivers on the east. Portneuf River cuts a gorge through them midway of their length.[56] The southern limit is the northern end of Cache Valley, and the northern limit is Ross Fork.[57] In this paper the name is extended northward to include the region between Ross Fork and Blackfoot River.[58] There is no reason geologically or even geographically for cutting them off at Ross Fork.

The mountains have not been studied in detail, though parts have been described in connection with the Fort Hall Indian Reservation. They are high enough in places to preserve parts of the Gannett erosion surface, and the later erosion surfaces are undoubtedly represented. In the higher parts they bear some good timber, but they are principally utilized for grazing. Mineral prospects have been opened in them here and there, and some ore has actually been shipped,[59] but the outlook for any substantial mineral development, aside from that of the phosphate deposits in the northern part, is poor.

CLIMATE

Climatologic data for 17 stations within or near the region described in this report are given in publications of the United States Weather Bureau.[60] At some of these stations records have been kept continuously for periods as great as 10 or 20 years. At others the records have been discontinued after longer or shorter intervals. At still others the records have been kept for so short a time that they have as yet little value in climatologic studies. There is also considerable difference in the degree of completeness of the records at the several stations.

In order to show the variation of climatic conditions in different parts of the region some of the more significant records of all these stations are given in tables below. In these tables the records summarized in the first publication, cited above, which include data for the year 1914, have been corrected to the close of the year 1920 by interpolation of data from the other volumes cited. From these later volumes also the data for the newer stations have been compiled. The location of the stations is shown in Figure 9.

Table 3 gives the names, locations, and altitudes of the several stations, together with the lengths and limiting dates of their records. Table 4 gives the monthly and annual mean precipitation at each station in inches and hundredths. Table 5 gives the average number of rainy days (days with 0.01 inch or more of precipitation) at each station for each month and for the year. Table 6 shows the average snowfall (unmelted) in inches. Tables 7, 8, and 9, give respectively the highest, lowest, and mean temperatures recorded for each station for each month and for the year. Table 10 shows the prevailing direction of the wind, and Table 11 gives data regarding frost and shows the length of the growing season at each station and for the region.

[56] MS. on file with U. S. Geographic Board; Hayden's definition cited by Gannett.

[57] Peale, A. C., op. cit., p. 567; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., atlas, pl. 2, 1883.

[58] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pl. 3, 1920.

[59] Idem, p. 116.

[60] Summary of climatology of the United States by sections; U. S. Dept. Agr. Weather Bureau Bull. W, secs. 22 and 23, 1912; idem, 2d ed., vol. 1, secs. 22 and 23, 1926; Climatological data of the United States by sections, vols. 1-6, 1914-1919, inclusive.

In all these tables in which monthly records are given a parallel column shows the number of years for which the record is available at the given station. This column is used for computing the annual means.

In the regional summary, which is included in most of the tables, the averages are weighted according to the lengths of the records at the respective stations.

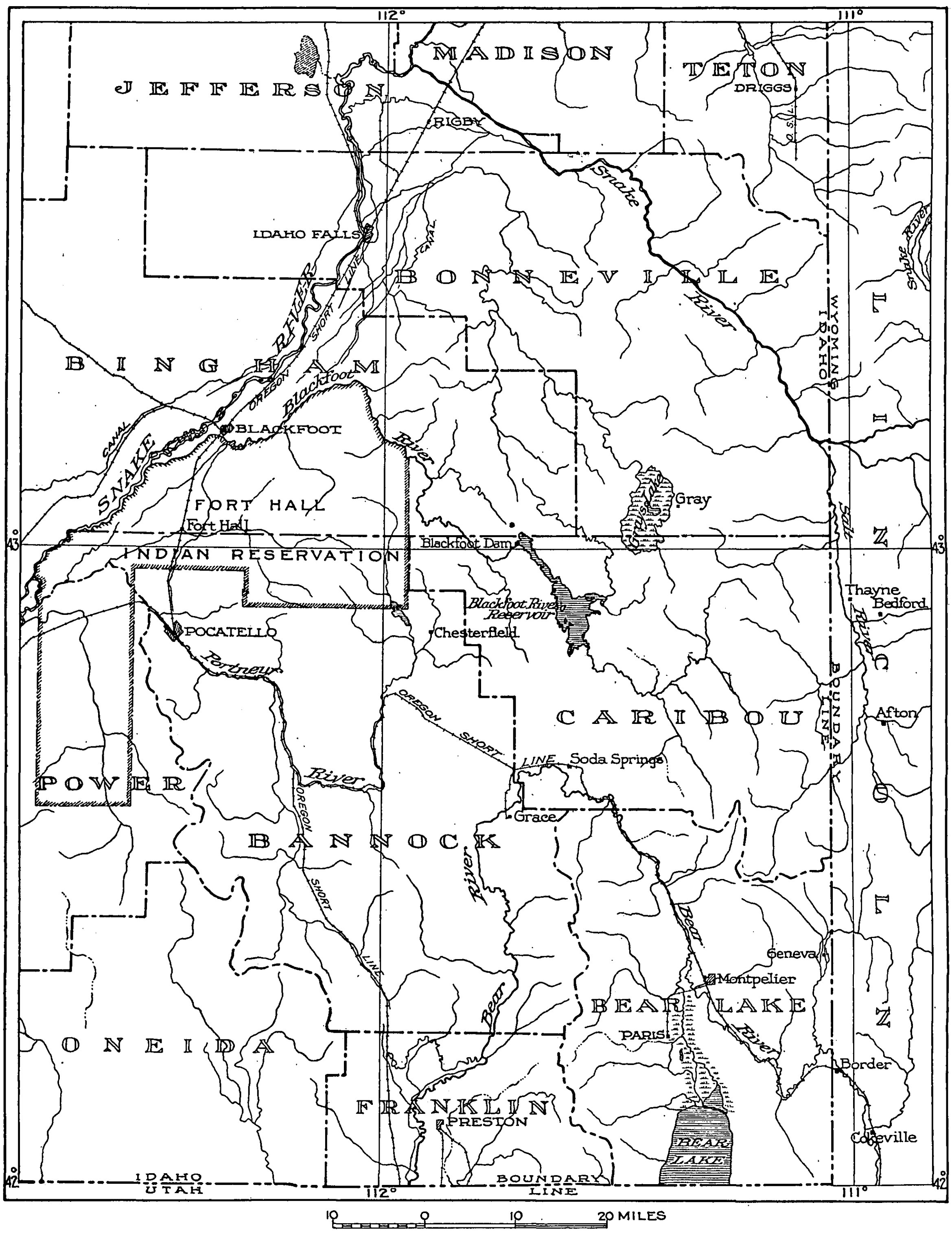


FIGURE 9.—Map showing the location of climatologic stations in southeastern Idaho and western Wyoming

TABLE 3.—*Climatologic stations of the region*

Station	Location	Altitude (feet)	Length of record	
			Years	Dates
Afton	Lincoln County, Wyo., on Swift Creek at the east side of Star Valley (6 miles wide) and at the west base of the Salt River Range. Afton quadrangle.	6,200	18	[a] 1903–1920
Bedford	Lincoln County, Wyo., near Strawberry Creek in Lower Star Valley a mile and a half from the west base of the Salt River Range. Afton quadrangle.	6,200	22	[b] 1899–1920
Blackfoot	Bingham County, Idaho, at the junction of Snake and Blackfoot Rivers in the Snake River Plain.	4,503	25	[a] 1896–1920
Blackfoot dam	Caribou County, Idaho, near the north end of Blackfoot River Reservoir on Blackfoot lava field. Low mountains rise at distances of 1½ to 3 miles. Cranes Flat quadrangle.	6,150 (6,129 U. S. G. S. B. M. at dam.)	12	[c] 1909–1919
Border	Lincoln County, Wyo., on State line in valley of Bear River about ¼ mile from north slope of Bear River Plateau and about ½ mile from the river. Montpelier quadrangle.	6,073 (U. S. G. S. B. M. at border.)	19	1902–1920
Chesterfield	Bannock County, Idaho, on Twentyfourmile Creek, at the northeastern side of Portneuf Valley (4 miles or more wide) and at the west base of the Chesterfield Range. Portneuf quadrangle.	5,454 (U. S. G. S. B. M.)	27	[a] 1894–1920
Cokeville	Lincoln County, Wyo., in the valley of Bear River near the rocky gap by which Smith Fork enters the valley.	6,204	12	1909–1920
Fort Hall	Bingham County, Idaho, on Ross Fork of Portneuf River and on the Gibson terrace east of Snake River in the Fort Hall Indian Reservation.	4,500	6	1915–1920
Geneva	Bear Lake County, Idaho, in the northern part of Thomas Fork Valley. Mountains rise on either side at distances of 1 to 1½ miles. Montpelier quadrangle.	6,171 (U. S. G. S. B. M.)	13	[d] 1908–1920
Grace	Bannock County, Idaho, in the northern part of Gentile Valley, near the west base of the Bear River Range.	5,400	14	[e] 1907–1920
Grays Lake	Bonneville County, Idaho, on the east side of Grays Lake and at the west base of the Caribou Range.	6,300	3	[a] 1917–
Idaho Falls	Bonneville County, Idaho, on Snake River, about 3 miles west of the foothills of the Caribou Range on the Snake River lava plain.	4,742	29	[f] 1880–1920
Montpelier	Bear Lake County, Idaho, at the mouth of Montpelier Canyon on the east side of Bear Lake Valley, there about 5 miles wide, and at the west base of the Preuss Range, Montpelier quadrangle.	5,943 (U. S. G. S. B. M. 5,963.)	7	1914–1920
Paris	Bear Lake County, Idaho, on the west side of Bear Lake Valley, there about 9 miles wide, and immediately east of the foothills of the Bear River Range, Montpelier quadrangle.	5,946 (U. S. G. S. B. M. 5,966.)	22	[a] 1893–1914
Pocatello	Bannock County, Idaho, in the lower part of the canyon of Portneuf River with high hills to northeast and southwest and canyon extending from southeast to northwest.	4,483	22	[a] 1899–1920
Pocatello Nursery.	Bannock County, Idaho, detailed location not stated.	5,396	11	[d] 1906–1917
Thayne	Lincoln County, Wyo., in Lower Star Valley about 4 miles west of the Salt River Range and 1 mile east of the Caribou Range. Freedom and Afton quadrangles.	5,900	8	1899–1906

[a] Some months missing.
[b] A few months missing.
[c] Some years missing.
[d] Records very incomplete.
[e] Records incomplete.
[f] Many months missing.

TABLE 4.—*Precipitation at 16 stations in Wyoming and Idaho: Monthly and annual means (in inches and hundredths)*

Station	Average length of available record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	15.1	1.44	1.48	1.65	1.49	2.23	1.25	1.20	1.01	1.51	1.97	0.73	1.10	17.06
Bedford	20.2	2.01	1.69	1.61	1.53	2.32	1.53	.91	1.09	1.09	1.76	1.15	1.43	18.18
Blackfoot	23.7	.97	.82	.95	.87	1.47	.87	.77	.65	.82	1.14	.80	.85	10.98
Blackfoot Dam	11.0	1.67	1.57	1.23	1.25	1.84	1.79	1.13	.94	1.53	1.65	1.38	1.28	17.26
Border	19.0	1.33	1.37	1.20	1.06	1.43	1.16	.54	.82	1.20	1.24	.80	.72	12.87
Chesterfield	24.7	1.31	1.00	1.33	1.03	1.86	1.28	.86	1.03	.83	1.07	.99	1.15	13.74
Cokeville	11.0	1.03	1.08	.98	1.33	1.18	.96	.88	.68	1.42	1.30	.79	.67	12.80
Fort Hall	6.0	.45	.77	1.08	.95	1.53	.38	.50	.54	1.06	1.29	.67	.59	9.81
Geneva	12.0	1.83	1.47	1.38	1.08	1.10	.77	.93	.53	1.15	1.09	1.54	.95	13.82
Grace	12.9	1.35	.95	1.20	.99	1.64	1.20	.90	.89	.99	1.34	1.14	1.04	13.63
Grays Lake	2.1	1.58	1.38	1.52	.97	2.88	.49	1.21	.51	1.85	1.13	1.22	1.12	15.86
Idaho Falls	25.3	1.54	1.13	1.48	1.03	1.65	1.30	.64	.72	.96	1.18	.90	1.16	13.69
Montpelier	6.3	.81	1.80	1.14	1.55	1.46	.76	.59	.59	1.34	1.55	.88	.79	13.26
Paris	21.7	1.56	1.23	1.30	1.16	1.14	.87	.69	.85	.94	1.04	1.10	.88	12.76
Pocatello	21.5	1.39	1.29	1.57	1.40	1.67	1.13	.66	.73	.88	1.22	.92	1.02	13.88
Thayne	6.8	1.70	1.54	1.74	1.27	2.63	1.06	.86	.88	.77	1.29	1.07	1.14	15.95
Region	14.9	1.41	1.24	1.34	1.18	1.68	1.13	.80	.82	1.06	1.30	.98	1.02	13.96

TABLE 5.—*Average number of days with 0.01 inch or more of precipitation at 16 stations in Wyoming and Idaho*

Station	Average length of available record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	15.0	8	8	10	8	9	7	6	5	6	8	6	9	90
Bedford	20.0	10	9	10	9	10	7	5	6	6	8	7	9	96
Blackfoot	25.0	6	5	5	5	6	4	3	3	4	5	4	5	55
Blackfoot Dam	4.8	8	9	6	5	8	3	5	2	5	4	5	6	66
Border	19.0	7	7	8	6	7	5	2	4	4	6	4	6	66
Chesterfield	25.0	7	6	7	6	8	6	4	4	4	5	5	6	68
Cokeville	10.0	7	8	7	7	8	5	6	3	6	7	5	6	75
Fort Hall	4.9	7	8	8	7	8	4	6	4	6	5	6	7	76
Geneva	1.9	6	8	7	4	7	6	4	4	6	4	5	5	66
Grace	13.0	7	6	7	5	7	6	5	5	6	8	6	8	76
Grays Lake	1.7	5	6	4	3	----	3	3	4	7	----	4	6	----
Idaho Falls	16.0	10	7	9	7	9	7	4	4	5	6	7	8	83
Montpelier	4.8	10	10	8	8	9	3	4	2	6	7	7	6	80
Paris	13.0	9	7	8	6	7	5	3	4	4	5	6	8	72
Pocatello	21.0	11	10	11	9	10	7	5	5	5	7	8	5	93
Thayne	7.0	12	12	14	10	12	7	8	5	5	8	10	10	113
Region	12.6	8.1	7.9	8.1	6.6	8.3	5.3	4.6	4.0	5.3	6.2	5.9	6.9	77

TABLE 6.—*Average monthly and annual snowfall (inches) at 16 stations in Wyoming and Idaho*

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	14.0	17.1	16.3	12.9	8.6	2.8	0.2	0	0	1.5	4.7	5.9	11.5	81.5
Bedford	21.0	20.4	18.4	14.8	8.1	2.2	0.2	Trace.	0	1.0	5.3	8.6	16.3	95.3
Blackfoot	25.0	7.6	6.6	4.1	1.1	0.2	Trace.	0	0	Trace.	1.9	3.1	6.0	30.6
Blackfoot Dam	4.5	15.8	19.5	13.5	2.0	2.5	Trace.	0	0	0.1	4.9	8.6	14.2	81.1
Border	10.0	15.2	15.5	11.9	6.4	1.5	Trace.	Trace.	0	1.0	2.4	4.6	4.5	63.0
Chesterfield	25.0	12.3	10.6	9.0	2.8	1.1	0.1	0	0	0.9	1.2	3.8	11.0	52.8
Cokeville	10.0	12.9	13.6	10.6	6.9	2.4	0.4	0	0	1.6	5.3	6.7	7.8	68.2
Fort Hall	5.0	4.3	8.3	6.4	0.8	0.2	Trace.	0	0	0	0.6	2.0	5.5	28.1
Geneva	1.9	19.5	15.0	6.5	2.5	7.0	2.5	0	0	0	0.5	10.5	12.0	76.0
Grace	13.0	8.5	6.5	5.3	1.8	0.3	Trace.	0	0	0.1	1.3	3.1	8.7	35.6
Grays Lake	2.8	20.5	22.0	17.0	4.0	1.8	Trace.	0	0	0	----	8.8	14.2	87.8
Idaho Falls	23.0	10.7	6.7	8.3	1.5	0.8	Trace.	0	0	0.1	2.0	4.3	9.6	44.0
Montpelier	4.7	17.0	24.4	4.0	5.0	1.9	1.6	0	0	Trace.	4.1	9.1	6.8	73.9
Paris	15.0	16.3	12.6	11.7	2.9	1.6	0	0	0	1.1	4.5	7.3	9.4	67.4
Pocatello	21.0	9.2	9.1	8.3	4.0	1.0	Trace.	0	0	0.1	1.7	3.4	8.2	45.0
Thayne	7.0	15.0	12.3	10.4	4.5	3.4	Trace.	0	0	1.5	2.6	5.5	10.3	65.5
Region	12.7	13.9	13.6	9.7	3.9	1.9	0.3	0	0	0.6	2.9	5.9	9.7	62.4

TABLE 7.—*Highest temperature, monthly and annual (°F.) at 15 stations in Wyoming and Idaho*

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	14.0	70	55	69	81	86	96	93	94	90	82	76	59	96
Bedford	18.0	49	58	59	76	93	93	97	93	88	82	66	51	97
Blackfoot	25.0	54	64	79	85	95	108	103	101	92	88	68	58	108
Blackfoot Dam	4.7	50	47	57	80	78	94	96	94	89	78	64	55	96
Border	19.0	48	50	67	79	88	94	96	96	89	84	67	58	96
Chesterfield	25.0	56	53	69	83	90	96	99	99	96	87	72	59	99
Cokeville	11.0	53	63	64	79	90	96	96	95	89	75	64	51	96
Fort Hall	5.0	57	52	69	81	94	100	98	100	91	83	70	58	100
Grace	13.0	68	59	70	84	95	100	103	102	98	90	69	63	103
Grays Lake	2.3	48	44	62	62	77	94	103	90	88	75	66	54	103
Idaho Falls	16.0	51	57	74	86	95	98	99	97	91	85	70	58	99
Montpelier	4.9	52	51	61	76	92	98	100	100	89	79	67	53	100
Paris	15.0	61	63	64	79	88	97	97	97	92	87	78	59	97
Pocatello	21.0	57	56	70	84	94	97	102	99	92	86	69	57	102
Thayne	7.0	47	55	56	74	81	92	96	91	87	78	65	48	96
Region:														
Highest	----	70	64	79	86	95	108	103	102	98	90	78	63	108
Mean	13.4	54.7	55.1	66	79.3	89.1	96.9	98.5	96.5	90.7	82.6	68.7	56.1	99.2

TABLE 8.—*Lowest temperature, monthly and annual (°F.) at 15 stations in Wyoming and Idaho*

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	14.0	−47	−41	−23	−5	4	22	18	16	15	−2	−26	−44	−47
Bedford	18.0	−34	−46	−27	−6	13	20	24	16	16	3	−26	−34	−46
Blackfoot	25.0	−30	−32	−24	11	19	20	30	23	18	4	−28	−26	−32
Blackfoot Dam	4.9	−35	−38	−27	−7	13	22	31	28	17	−4	−25	−42	−42
Border	19.0	−37	−51	−36	−1	12	21	27	20	13	−18	−29	−36	−51
Chesterfield	25.0	−38	−48	−31	−5	4	19	18	11	8	−1	−26	−33	−48
Cokeville	11.0	−38	−44	−38	−6	8	18	26	21	13	−12	−20	−33	−44
Fort Hall	4.9	−26	−13	8	13	17	27	34	33	24	4	−12	−28	−28
Grace	13.0	−22	−22	−14	6	21	19	32	26	20	10	−7	−23	−23
Grays Lake	2.3	−42	−21	−31	−3	12	25	25	29	25	−8	−8	−40	−42
Idaho Falls	16.0	−33	−32	−26	11	20	24	32	22	19	1	−26	−23	−33
Montpelier	5.0	−32	−24	−25	0	13	23	24	30	17	0	−20	−26	−32
Paris	15.0	−33	−35	−23	0	15	15	21	24	15	3	−13	−19	−35
Pocatello	21.0	−19	−20	−12	17	24	29	38	28	21	13	−3	−16	−20
Thayne	7.0	−26	−47	−23	2	11	21	24	19	13	7	−1	−30	−47
Region:														
Lowest	----	−47	−51	−38	−7	4	15	18	11	8	−18	−29	−44	−51
Mean	13.4	−32.8	−34.3	−23.5	1.8	13.7	21.7	26.9	23.1	16.9	0	−18.0	−30.2	−38

TABLE 9.—*Mean temperatures, monthly and annual (°F.) at 15 stations in Wyoming and Idaho*

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	15.0	16.4	18.8	27.2	37.6	46.8	55.6	61.0	59.7	52.4	43.4	32.4	17.9	39.1
Bedford	20.0	17.4	19.3	27.6	37.2	46.0	53.2	59.8	58.6	50.8	40.3	29.9	17.6	38.1
Blackfoot	25.0	22.1	26.0	35.4	44.4	52.8	61.6	68.0	66.2	56.8	45.1	34.2	23.4	44.6
Blackfoot Dam	4.7	14.4	18.1	25.3	37.7	46.7	56.6	62.9	58.2	51.2	41.4	27.5	16.9	37.8
Border	19.0	13.0	15.0	25.2	38.4	47.2	55.8	63.3	60.9	51.6	40.8	28.6	14.2	37.8
Chesterfield	25.0	18.8	21.0	28.6	40.8	48.6	56.0	62.1	60.2	51.2	41.2	31.0	20.2	40.0
Cokeville	11.0	15.6	18.8	27.4	37.7	46.4	54.9	61.1	58.2	49.8	37.6	27.0	14.9	37.4
Fort Hall	4.8	20.2	29.4	39.1	45.6	51.2	61.7	69.6	66.9	58.6	45.7	33.3	25.3	45.4
Grace	13.0	23.2	26.4	34.1	42.8	51.6	60.4	68.6	66.2	57.6	46.4	34.0	24.1	44.6
Grays Lake	1.4	14.0	19.0	24.9	34.3	42.3	55.0	61.7	58.9	52.9	39.4	31.8	30.7	38.7
Idaho Falls	16.0	21.0	25.6	35.4	45.1	52.4	60.4	68.1	65.8	56.8	45.7	34.2	23.0	44.5
Montpelier	4.8	16.3	21.0	28.0	41.2	47.9	59.1	66.0	63.7	54.8	42.3	31.4	22.6	41.4
Paris	15.0	19.7	19.7	27.4	39.6	49.2	55.8	63.5	62.9	55.0	44.0	33.1	21.0	40.9
Pocatello	21.0	26.5	29.4	37.9	46.2	53.5	62.6	70.9	69.3	59.8	48.4	38.0	27.3	47.5
Thayne	7.0	18.6	18.8	28.0	37.7	47.5	54.4	59.0	58.7	50.1	40.6	31.0	17.4	38.4
Region	13.5	18.5	21.7	30.1	40.4	48.7	57.5	64.4	62.3	54.0	44.1	31.8	21.1	41.1

TABLE 10.—*Prevailing direction of wind at 15 stations in Wyoming and Idaho*

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Afton	6.0	n	w	s	s	s	s	s	s	s	s	s	s	s
Bedford	20.0	w	w	w	w	w	w	w	w	w	w	w	w	w
Blackfoot	25.0	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw
Blackfoot Dam	4.9	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw
Border	16.0	w	w	w	w	w	w	w	w	w	w	w	w	w
Chesterfield	25.0	sw	sw	sw	w	w	w	w	w	w	sw	sw	sw	w
Cokeville	10.0	w	w	w	w	w	w	w	w	w	w	w	w	w
Fort Hall	4.3	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw
Grace	13.0	s	n	s	n	n	s	s	s	s	s	n	n	s
Grays Lake	1.6	sw	sw	sw	sw	----	sw	sw	sw	----	----	sw	sw	sw
Idaho Falls	16.0	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw
Montpelier	2.1	n	s	n	n	w	nw	s	n	nw	n	n	n	n
Paris	15.0	nw	nw	w	w	w	w	w	nw	nw	nw	w	w	w
Pocatello	21.0	se	se	se	se	se	se	se	se	se	se	se	se	se
Thayne	7.0	se	se	se	se	sw	w	w	sw	w	w	se	se	se
Region	12.5	sw	sw	sw	sw	w	w	w	sw	w	sw	sw	sw	sw

TABLE 11.—*Data regarding frost at 17 stations in Wyoming and Idaho*

Stations	Length of record (years)	Average date of last killing frost in spring	Average date of first killing frost in autumn	Latest date of killing frost in spring	Earliest date of killing frost in autumn	Length of growing season; average number of days between last and first killing frosts
Afton	13	July 7	Aug. 23	July 31	Aug. 1	46
Bedford	21	June 30	Aug. 26	July 31	Aug. 11	56
Blackfoot	25	May 21	Sept. 15	June 25	Aug. 22	116
Blackfoot Dam	12	June 16	Aug. 4	July 28	Aug. 4	48
Border	19	June 28	Aug. 24	July 22	Aug. 1	56
Chesterfield	23	June 16	Aug. 21	July 30	Aug. 1	65
Cokeville	11	June 21	Sept. 3	July 19	Aug. 18	73
Fort Hall	4	May 27	Sept. 26	June 13	Sept. 10	121
Geneva	10	July 3	Sept. 3	July 19	Aug. 18	61
Grace	14	May 25	Sept. 14	July 19	Aug. 19	111
Grays Lake	1	---------	---------	June 30	Sept. 14	75
Idaho Falls	24	May 20	Sept. 16	July 7	Aug. 25	118
Montpelier	3	June 7	Sept. 6	June 30	Aug. 22	90
Paris	13	June 14	Sept. 3	June 28	Aug. 9	80
Pocatello	22	May 1	Oct. 7	June 1	Sept. 8	158
Pocatello Nursery	3	June 19	Sept. 26	June 26	Sept. 10	98
Thayne	6	July 8	Aug. 31	July 30	Aug. 18	53
Region	13.2	June 9	Sept. 4	(a)	(a)	87

a Freezing temperature every month.

The climate of the region is semiarid, for the annual precipitation for the stations named ranges from 9.81 inches at Fort Hall to 18.18 inches at Bedford. The average for the region as determined by the given records is 13.96 inches. In the mountains the quantity is doubtless somewhat greater, but no stations have thus far been maintained actually in the mountains. Table 4 shows the distribution of the precipitation throughout the year.

The maximum mean monthly precipitation for the region, as shown in Figure 10, is 1.68 inches and occurs in May, but at Geneva and Paris the maximum occurs in January; at Montpelier in February; and at Cokeville it occurs in September. At some stations, such as Grays Lake and Montpelier, the length of the record is so short that the time of occurrence of the maximum may have been unduly affected by a few unusual storms. At other stations, such as Geneva and Paris, where the record is longer, local conditions probably affect the time of occurrence of the maximum, so that it is habitually earlier than that for the region. Secondary maxima occur in March (1.34 inches) and in October (1.30 inches).

The minimum precipitation for the year occurs in July and August, for which months the mean annual amounts are 0.80 and 0.82 inch. This precipitation occurs chiefly in the form of thunder showers. Secondary minima occur in November, for which the mean is 0.98 inch, in April, for which it is 1.18 inches, and in February, 1.24 inches. Thus precipitation throughout the year is well distributed but is marked by fairly systematic fluctuations.

Thayne has the largest number of rainy days (113, see Table 5), but Bedford, Blackfoot Dam, and Afton have more precipitation. The lowest recorded number of rainy days for the year in the region is 66, at Geneva, Blackfoot Dam, and Border. The records at Geneva and Blackfoot Dam, at least, are so short that they do not afford a satisfactory average. Probably observations for longer periods would show higher results, for the average for the region is 77 rainy days a year.

The snowfall for the region (Table 6) is fairly heavy, and the mean annual amount is 62.4 inches, or more than 5 feet, unmelted. The maximum monthly average is 13.9 inches, which is the amount that occurs in January. In February the snowfall is nearly as great (13.6 inches). Snowfall is recorded at most of the stations in all months except July and August, and at Bedford and Border a trace of snow is even recorded in July. The heaviest annual snowfall is reported at Bedford (95.3 inches) and at Afton (81.5 inches). Both these stations lie at the wind-ward base of the Salt River Range, which a few miles eastward reaches altitudes greater than 10,000 feet. The largest average amount recorded for any month at any station is 24.4 inches for February at Montpelier. The record for this station covers so short a period that it has doubtless been unduly affected by unusual storms. In the mountains the snowfall is without doubt heavier than at the stations which furnish the available records, a fact that is attested by the frequency of snowslides in the canyons, some of which have caused loss of life and property.

Southern Idaho lies outside the usual tracks of storms, so that both storms and cold waves are relatively infrequent and the temperature as a whole is equable. In southeastern Idaho, however, the valleys are higher than they are farther west and are bordered by fairly high mountains. Thus extremes of temperature are somewhat more marked in that region. Local topographic conditions exert some control upon the climate in different parts of the region.

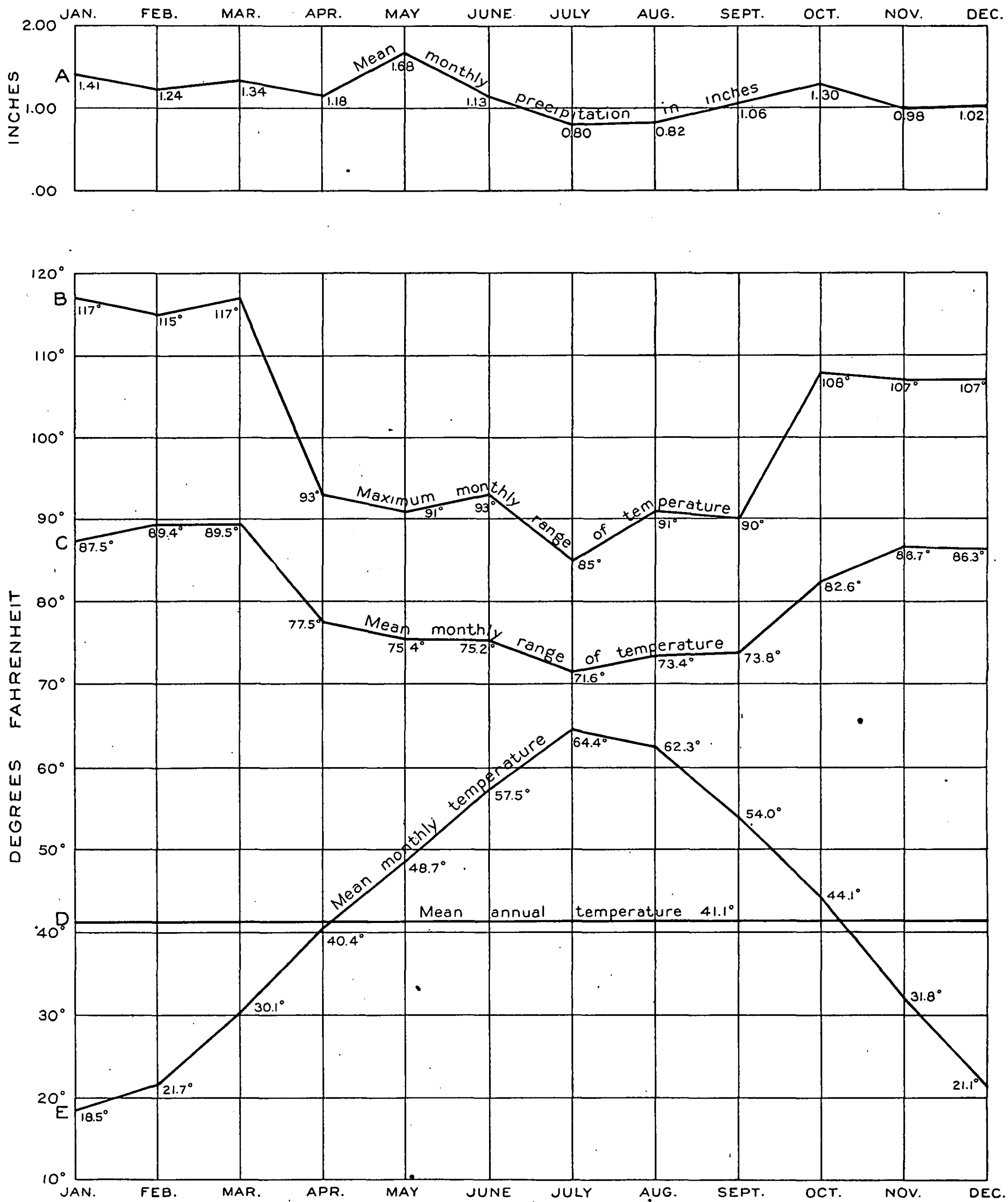


FIGURE 10.—Curves showing features of precipitation and temperature in southeastern Idaho and vicinity

Table 7 shows the highest recorded temperatures at each station for each month and for the period and also the mean of the highest temperatures and the highest temperature for each month and for the period in the region. Table 8 gives similar data for the lowest temperatures. July has the hottest days at all but two of the stations. The actual highest recorded temperature is 108°, which occurred at Blackfoot in June. The mean of the highest temperatures for July for the region is 98.5° and the corresponding mean for the region without regard to month is 99.2°. The lowest temperatures at a majority of the stations occur in February; the very lowest minimum is 51° below zero, recorded at Border. The mean of the minima for the same month is −34.3°. The mean of the minima for the region is −38°. Afton, Bedford, Chesterfield, Cokeville, Grays Lake, and Thayne all have recorded minima lower than −40°.

The difference between the highest recorded temperature and the lowest for a given month is the maximum range of temperature for that month. Similarly the difference between the mean of the highest temperatures and the mean of the lowest temperatures for a given month is the mean range of temperature for that month. Curves B and C, in Figure 10, show the maximum monthly and mean monthly ranges of temperature for the region. The maximum range is 117° in January, 115° in February and again 117° in March. It decreases abruptly to April (93°) and May (91°) and increases again to June (93°). The smallest range (85°) is in July. The curve rises to 91° in August and declines again in September, but in October it rises rapidly to 108° and then remains nearly uniform for the remainder of the year. The mean monthly range is also greater in the months from October to March, and the two maxima occur in March (89.5°) and in October (86.7°). From March (89.5°) to April (77.5°) the decrease is rather abrupt, like that of the maximum monthly mean. From April to September, however, the mean monthly range is nearly the same, but the range for July, which is also the minimum (71.6°), is a few degrees lower. There is a sharp increase in October, like that of the maximum monthly range.

A noteworthy feature is the mean of the lowest temperatures for the summer months. This figure bears witness to the coolness of the summer nights and shows the danger of frost incurred by growing crops on bottom lands, where cool air may stagnate.

The extreme temperatures noted above fortunately do not long persist, for the mean temperature of the warmest month for the region (July) is only 64.4° and that for the coldest month (January) is 18.5°. (See Table 9.) The stations recording the highest and lowest mean temperatures for individual months are Pocatello, 70.9° for July, and Border, 13° for January. The mean annual temperature for the region is 41.1°. The mean monthly temperature curve for the region (see curves D and E, fig. 10) is fairly uniform; it rises gradually from January (18.5°) to February (21.7°) and then more rapidly at a nearly even rate to July (64.4°). The fall from July to August (62.3°) is rather gentle, but from August to December (21.1°) it is more rapid and again nearly even.

Bear Lake probably exerts a modifying influence upon the temperature of the territory adjacent to it, but the arrangement and records of the stations do not make this influence clearly evident. The effects of difference in altitude upon the annual mean temperature are perhaps shown in a general way, for the stations that have the higher means have on the whole lower altitudes than those that have lower means. This effect, however, is overshadowed to some extent by local conditions. Thus Grace, which is 900 feet higher than Fort Hall, has nearly the same mean annual temperature. Possibly Pocatello, the station which has the highest mean annual temperature (47.5°), may owe its excess of temperature in part to the warming by compression of the cool air that descends from neighboring uplands into the relatively narrow valley of Portneuf River.

The prevailing winds (see Table 10) are southwesterly and ordinarily not of great velocity, except on the more exposed slopes and at higher altitudes. Local conditions again play a prominent part in the control of wind direction. Thus stations like Fort Hall, which permit a practically unrestricted sweep for the wind, have westerly winds the year round. Other stations, like Pocatello, which is situated in a more or less sheltered valley, have their wind direction modified by valleys. Thunderstorms occur frequently in July and August, but they often clear away over the broader valleys and yield little rain except in the higher hills. Conventional whirls that carry clouds of dust and light objects, such as bits of grass and sagebrush, occur in some of the broader and drier valleys.

In a general discussion of frost conditions throughout the United States Reed [61] presents a series of maps from which data that bear on southeastern Idaho may be gathered. He shows that the average date of the occurrence of the last killing frost in spring for the region discussed in this report, except the part that lies on the actual edge of the Snake River plain, is later than June 1. Similarly the date of the first killing frost in autumn, except for parts of Snake River, Portneuf, Blackfoot, Bear River, and Bear Lake valleys, is earlier than September 1. The number of times in 20 years in which the last killing frost in spring was 10 days or more later than the average was more than 5, and the number of times in a like period that the first killing frost in autumn was 10

[61] Reed, W. G., Frost and the growing season: U. S. Dept. Agr. Office of Farm Management, Atlas of American agriculture, pt. 2, Climate, 1918.

days or more earlier than the average was also more than 5. The dates on which the chance of the last killing frost in spring and the first killing frost in autumn falls to 10 per cent occur respectively after June 1 and before September 1. The length of the growing season, except for stations on the edge of the Snake River plain, is shown to be less than 90 days and the number of times in 20 years when the season without killing frost was 15 days or more shorter than the average was more than 5.

The season of security from destructive frosts at the stations named, as compiled from the other reports previously cited, is shown in Table 11. At many stations (see also Table 8) freezing temperatures have been reported for every month in the year. In general, however, a growing season that ranges in length from 53 days (Thayne) to 158 days (Pocatello) and that averages 87 days for the region may be expected. The lowest figure is probably unduly small because of the brevity of the available record. The length of the growing season at a given station as compared with that at other stations is shown graphically in Figure 11. Altitude is probably a significant factor in the length of the growing season. The stations that have the longer growing seasons are in general lower than those where the season is shorter, but as in the distribution of mean temperatures local physiographic conditions play a prominent part. Pocatello Nursery, which is nearly 1,000 feet higher than Pocatello, has a much shorter growing season than that station. This difference is doubtless due in part to the greater altitude, but the higher station may also lack other physiographic advantages enjoyed by the lower. A comparison of Tables 9 and 11 shows the close correspondence of length of growing season and mean temperature at the respective stations. Thus Pocatello, Idaho Falls, Grace, Fort Hall, and Blackfoot, which have the longer growing seasons, have also the higher mean temperatures. For much of the region a growing season of more than 60 days may reasonably be expected, but the time may be extended if physiographic conditions warrant. Thus the bottom lands, as previously noted, are subject to frost and are therefore not adapted to any but the hardiest crops. They are largely devoted to the production of wild hay. On the other hand, along the sides of the valleys, on slightly higher ground or at the mouths of certain canyons, the air has better circulation. Cold air does not stagnate and different crops may be raised.

VEGETATION

The vegetation of the area under discussion may be divided into four groups, each denoting a pronounced difference in growing conditions. The border line between two successive types, however, is in many places not clearly defined, and there is a transition zone in which a mixture of both may occur. These general conditions may be further modified by the distribution of sunlight and shade at any given altitude. In the shaded areas, which are on the north and northeast slopes, the snow remains later in the spring, and usually in such areas a vigorous growth of different species of brush and trees is found. On the other hand, the growth on the sunnier west and southwest slopes consists of a number of species of short brush, grass, and weeds that produce by contrast a generally barren aspect.

The four groups of vegetation, as designated by the dominant member in each, are respectively the sagebrush, mountain brush, aspen, and conifer types. The sagebrush type, which is dominated by sagebrush (*Artemisia tridentata*), covers most of the untilled valley lands, the foothills, and the lower mountain slopes. The associated species include many grasses and weeds, the most useful of which are the bunch grasses—wheat bunch grass (*Agropyron spicatum*), curly bunch grass (*Festuca ovina*), and mountain bunch grass (*Festuca idahoensis*). In the valleys the continuity of the sagebrush and its associates may be broken by small meadows, the drier of which support the principal species of grass, but the wet meadows are covered with rushes, sedges, and grasses. The wet meadow lands furnish an inferior hay, but the grasses and weeds in the remainder of the area have a high forage value and these lands are extensively used for grazing.

The mountain brush type occurs on the slopes above the areas occupied by sagebrush and along the canyons. It consists of a number of species of brush the most abundant of which are buck brush (*Symphoricarpos*), service berry (*Amelanchier* species), sagebrush, choke cherry (*Prunus melanocarpa*), and mountain mahogany (*Cercocarpus parvifolius*). With the exception of the sagebrush, all of these species have a good forage value as browse and with the associated grasses and weeds they form a type that has a good grazing value. The aspen and conifer types are found at higher altitudes above the mountain brush where more moisture is received and temperatures are lower. These two types may occur either in pure stands or mixed growth where usually many species of brush are included. The growth of aspen (*Populus tremuloides*) varies from dense patches of small gnarled trees that resemble brush thickets to more open groves of trees ranging up to 12 and 14 inches in diameter. The conifer type is confined to the higher altitudes and is practically all included in the area covered by the Caribou or Cache National Forest. The mountain brush as well as the aspen and conifer areas also contain meadows having general characteristics similar to the meadows of the sagebrush areas.[62]

[62] The above discussion is kindly supplied by the conservation branch of the Geological Survey.

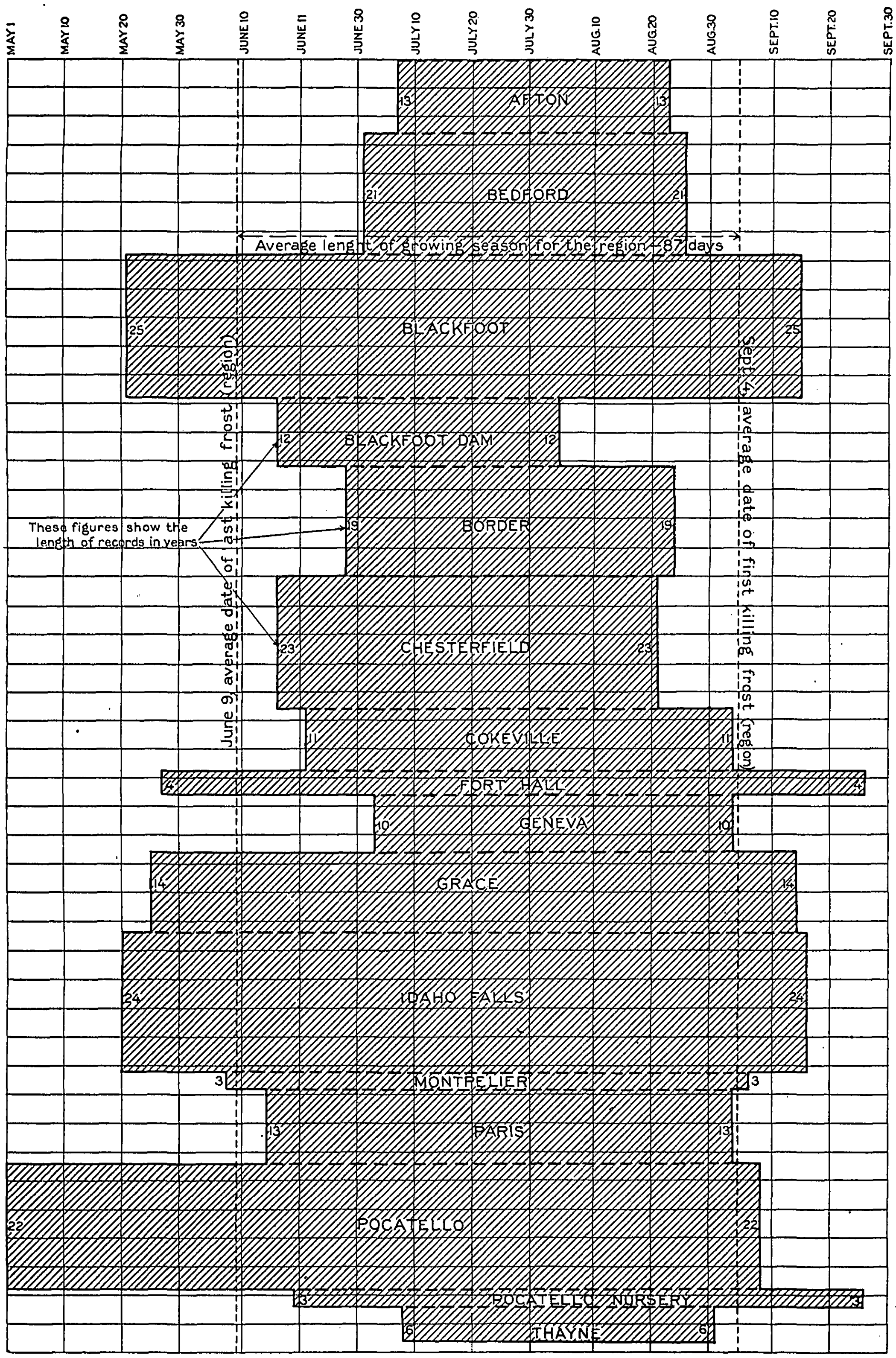


FIGURE 11.—Diagram showing the length of the growing season at 15 stations in southeastern Idaho and vicinity

The following account of the Caribou National Forest,[63] which is partly included in the region described in this report, gives a good idea of the character and distribution of the timber.

There are three principal forest types—the Douglas fir (*Pseudotsuga taxifolia*), the lodgepole pine (*Pinus contorta*), and the aspen (*Populus tremuloides*). Associated with these in lesser number are the Engelmann spruce (*Picea engelmanni*), the alpine fir (*Abies lasiocarpa*), and the limber pine (*Pinus flexilis*).

The Douglas fir is the most valuable timber tree and formerly surpassed all others in area and quantity. Many disastrous fires have reduced its area, so that it now occupies only about 30 per cent of the forested area. The lodgepole pine occupies about the same area, but when fires are prevented it will eventually give way to the Douglas fir. The aspen occupies about 40 per cent of the timbered area. The Engelmann spruce is a valuable forest tree and except for the small area which it occupies would rank next to the Douglas fir. It is found in mixture with the Douglas fir and lodgepole pine in moist places and along streams. The alpine fir and limber pine occur principally in the higher elevations, the alpine fir chiefly in the heads of gulches and canyons where, because of protection from the wind and better soil, it attains its best growth. The limber pine is practically confined to the higher ridges, and on account of poor soil and exposure has generally a scrubby growth. It is of little economic value.

The Douglas fir, lodgepole pine, aspen, and Engelmann spruce attain their best growth and are more evenly distributed between the altitudes of 6,000 and 8,000 feet. Of these the Douglas fir has a wide distribution above 8,000 feet and ranges as high as 10,000 feet, though it is less abundant at the higher altitudes. The alpine fir and limber pine occur at altitudes from 7,500 to 10,000 feet and are about as numerous at the higher altitudes as at the lower.

There is little mature timber on the forest. Most of it is the Douglas fir, which affords nearly all the saw timber, although some of the lodgepole pine is also used for this purpose.

ANIMAL LIFE

The drier slopes were once the haunt of numerous rabbits and other small game, but these animals have been largely killed off with the advance of settlement. The great abundance of rodents in dry meadows and on the gentler dry slopes is locally a menace to crops. Large game, though once abundant, is now relatively scarce. In the early days of the explorers and emigrants the broad open valleys were roamed by large herds of buffalo. Their places have since been taken by cattle and horses, and sheep now graze much of the mountainous area. A few bear, deer, and elk may be seen in the mountains, but they, too, are making way for advancing occupation of the country by man. Coyotes and a few wolves still menace the livestock here and there. Beaver, which once inhabited many streams of the region and were eagerly sought by the early trappers, have been legally protected from extermination for the past few years and may still be found in a few of the streams. Game birds, chiefly several species of the grouse family, occur in diminishing numbers on the sage-covered slopes and in the wooded areas. Ducks and other water birds frequent the larger streams and marshes. Song birds are numerous and of considerable variety. Fish, which were formerly abundant, are becoming relatively scarce, and the streams must be restocked if the supply of desirable food fish is to be maintained. The introduction some years ago of carp in Bear Lake has proved unfortunate, as they have increased in great numbers and menace the more desirable types. Insect life is abundant and varied, and though troublesome at certain times and places, is probably not more so here than in other parts of the Rocky Mountain region.

NATURAL RESOURCES

Aside from the timber and agricultural resources, to which some reference has already been made, the region has vast mineral wealth, chiefly in the form of phosphate rock, but it also has water, both for power and irrigation, building stone, limestone suitable for the manufacture of lime and cement, salt, road material, and other minor mineral resources, all of which are described in Chapter VII.

INDUSTRIES

The alluvial deposits in Bear Lake Valley, Star Valley, and the valleys of the larger streams at altitudes that range from 5,700 to 6,000 feet or more furnish considerable areas for irrigated fields that produce a variety of valuable crops, among which are wheat, oats, rye, alfalfa, hay, and potatoes. At favorable places, such as along the west wide of Bear Lake, small fruits are successfully raised and are of excellent quality. The bottom lands, which are too cold or wet for cultivation, yield large crops of wild hay that support large numbers of cattle. Dry farming, which was formerly practiced extensively, has experienced a set-back, and by 1925 many of these farms had been abandoned. In the lava-covered districts water is relatively scarce, and at certain localities, as in the region north of the Blackfoot River Reservoir, it must be hauled for domestic use or for stock or must be obtained by expensive drilling.

The mountains in places yield supplies of timber which is sawed into rough lumber by sawmills here and there. Dressed lumber is largely shipped in by rail. Through the grazing regulations of the United States Forest Service the mountains are also made available for the summer pasturage of large numbers of sheep and cattle.

[63] Bentz, G. G., Silvical report, Caribou National Forest, 1912 (MS. report on file with Forest Service, Washington, D. C.).

Phosphate rock is mined in Montpelier and Paris Canyons and at Conda where the most extensive operations in phosphate in the western States are now in progress. The phosphate beds and their economic development are described in Chapter VII.

Montpelier, in Bear Lake County, and Soda Springs, the county seat of Caribou County, are the principal shipping and distributing centers of the region. Cokeville, about 30 miles southeast of Montpelier in southwestern Wyoming, is a similar shipping and distributing center and maintains mail stage connections with Star Valley to the north. This service was formerly rendered by Montpelier. Each of these towns is on the railroad and is favorably situated to serve as a junction point for upcountry routes with the valley of Bear River. A relatively new town named Conda has been established by the Anaconda Copper Mining Co. near its mines about 9 miles northeast of Soda Springs.

TRANSPORTATION FACILITIES

The advantages for transcontinental travel afforded by the valleys of Bear and Portneuf Rivers were early recognized, and their utilization by the early explorers and emigrants and later by the railroad has been mentioned in the preceding chapter. The Oregon Short Line Railroad, a member of the Union Pacific System, follows these valleys and thus crosses the southwest corner of the region here described. A branch line has been constructed from Montpelier to Paris and a spur track from Paris to the phosphate mine in Paris Canyon. A similar branch line has been constructed from Soda Springs to the phosphate properties of the Anaconda Copper Mining Co. at Conda, in sec. 15, T. 8 S., R. 42 E., where a great mine is being developed. Similar track construction and development have been proposed for other phosphate properties, notably those in Georgetown Canyon, but at the end of 1926 no such extension had been undertaken.

The Oregon Short Line [64] has made two preliminary surveys from Idaho Falls, Idaho, up Snake River to Jackson, Wyo., the first in 1905 and the second in 1912. The proposed route lies along Snake River to the mouth of Salt River and thence up the transverse canyon of the Snake to Jacksons Hole. When this railroad is completed it will bring railway facilities within about 12 miles of the town of Freedom in Star Valley and will greatly alter economic conditions in eastern Idaho and northwestern Wyoming. At present most supplies for Star Valley are hauled from Montpelier or Cokeville, distances that are as much as 50 miles or more. Freighting over mountain roads is beset with many difficulties, especially in winter, and is expensive. With a railroad at the lower end of Star Valley or perhaps even extended up the valley much of this hauling will be eliminated and agricultural industry will be greatly benefited.

Aside from the scattered villages at favorable places the region is sparsely settled. Fair wagon or automobile roads traverse most of the larger valleys and are thus generally parallel with the trend of the mountain ranges. Transverse roads are relatively few and far between, so that distances by road between localities among the mountains are commonly considerably greater than their actual distances.

[64] Schultz, A. R., A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming: U. S. Geol. Survey Bull. 680, p. 60, 1918.

CHAPTER III.—STRATIGRAPHIC GEOLOGY

GENERAL FEATURES

The sedimentary rocks of southeastern Idaho furnish a remarkably full record of the geologic activities of the west-central portion of the Rocky Mountain region. Available measurements and estimates show that more than 46,000 feet of sediments, representing calcareous muds, silts, sands, and gravels, were deposited in this area. These sediments by consolidation formed the present stratified rocks. Consolidation was sufficiently progressive to permit the inclusion of hard fragments of earlier-formed rocks in some of the succeeding formations.

Geographic conditions varied from time to time during the deposition of the sediments, and these changes were reflected in the character and evolutionary progress of the organisms, the remains of which now constitute so significant a record, and in the lithologic character of the rocks. The marine sediments are abundantly fossiliferous at certain horizons, and though at many exposures fossils are few or absent it has been possible to determine the stratigraphic position of some of the beds with considerable accuracy. The nonmarine beds, which are fossiliferous only in places or in certain layers, furnish a far less satisfactory basis for the determination of their stratigraphic position and correlation.

The beds were originally deposited in layers that were horizontal or nearly so, but they have been warped, folded, and faulted so that they now stand in varying attitudes from horizontal to vertical. The truncation of the formations by erosion has exposed them to study at many places, but nowhere is the complete stratigraphic sequence shown. This sequence has been determined by combining data from different parts of the district and from other areas.

The early Paleozoic and most of the middle Paleozoic formations occur in the Bear River Range in the western part of the Montpelier quadrangle and in the southwestern part of the Slug Creek quadrangle. A few isolated areas of rocks assigned to the Devonian occur on the southwestern flank of the Aspen Range in the southwestern part of the Slug Creek quadrangle.

Later Paleozoic and Mesozoic rocks make up the bulk of the mountain ranges of the region, and as a rule the Paleozoic rocks give rise to higher and more rugged topography. Northwestward the ranges are embayed and interrupted by lava, which probably conceals many of these older strata.

Tertiary deposits overlap the southeastern part of the Montpelier quadrangle and occupy other areas of greater or less extent throughout the district. They cover some of the lower hills and occur in patches along the foothills of some of the higher ranges.

The Quaternary deposits, which, with the exception of the travertine, are unconsolidated, underlie portions at least of all the larger valleys and extend along many of the lower slopes. They are thus well distributed throughout the region.

The stratigraphy of this portion of southeastern Idaho is summarized in the accompanying columnar section (Table 12 and pl. 19).

The general distribution of the systems and formations is shown on the geologic maps (pls. 1–7 and 9, in pocket).

TABLE 12.—*General stratigraphic section of the sedimentary rocks of southeastern Idaho*

System	Series	Group and formation	Character	Thickness (feet)
Quaternary.	Recent.	Landslides.	Hummocky masses of boulders, soil, and other débris, chiefly of the Cretaceous formations; includes also a "talus glacier."	
		Alluvium.	Meadow land with fine soil, locally gravelly or marshy in valley bottoms; flood-plain deposits, locally stony.	
	Pleistocene.	Lake beds.	Deposits of former extension of Bear Lake.	
		Hill wash and older alluvium.	Débris cover of slopes that merges into talus or alluvial cones that contain poorly assorted material; also includes better-rounded gravels and finer materials, more or less dissected, that lie above present valley bottoms; some fine soil that is included here is perhaps wind blown.	
		Travertine.	White, gray, or buff, locally reddish porous rock in cones, terraces, basins, ledges, and low hills of Recent and Pleistocene ages; may possibly include some Pliocene.	
		Unconformity		

TABLE 12.—*General stratigraphic section of the sedimentary rocks of southeastern Idaho*—Continued

System	Series	Group and formation	Character	Thickness (feet)
Tertiary.	Pliocene(?).	Salt Lake formation.	Light-gray or buff conglomerates with white calcareous matrix; pebbles of local materials, angular, subangular, or rounded and of different sizes; calcareous grits, sandstones, marl, and clay, which weather to white soil; some beds carry rhyolitic or basaltic material.	0–1,000±
		—Unconformity—		
	Eocene.	Wasatch formation.	Red conglomerates and sandstones, boulders largely of Paleozoic quartzites and limestones of different sizes; beds of tan-colored limestone, locally of coarse pisolitic texture; white pisolitic limestone.	0–1,500±
		—Unconformity—		
Cretaceous.	Lower Cretaceous (?).	Wayan formation.	Upper unit composed of alternating sandstones and shales with some conglomeratic beds, but without significant limestones except Homer limestone member(?); thickness, 9,000 feet.	11,800±
			Lower unit in Tincup Canyon has eight members, including three of limestone, four of red beds, and one massive sandstone near the top, greenish gray, weathering yellow or reddish, and locally conglomeratic; thickness, 2,800 feet. Homer limestone member (Cranes Flat quadrangle) may correspond with No. 6 of Tincup section; consists of dark or light-gray limestone that weathers white and includes beds of gastropod limestone; thickness, 500 feet.	
		..Unconformity......		
Cretaceous (?).	Lower Cretaceous (?).	Gannett group. Tygee sandstone.	Gray to buff even-grained sandstone, without greenish or reddish tints of some higher sandstones; top not exposed.	100+
		Gannett group. Draney limestone.	Gray limestone similar to Peterson limestone but not so massively bedded near the top; compact; weathers dirty white; fresh-water gastropods.	175
		Gannett group. Bechler conglomerate.	Gray, reddish, and "salt and pepper" sandstones and interbedded conglomerates that in most places carry relatively small pebbles.	1, 725
		Gannett group. Peterson limestone.	Fine-grained slate-colored, grayish or white weathering limestone; contains massive beds that form prominent ridges; fresh-water gastropods.	205
		Gannett group. Ephraim conglomerate.	Red conglomerates with minor amounts of sandstone and bands of purplish limestone; includes near base band of greenish-gray conglomerate that contains pebbles of chert.	1, 025
		..Unconformity......		
Jurassic.	Upper Jurassic.	Stump sandstone.	Thin-bedded gray to greenish-gray fine-grained sandstones that weather into platy fragments; near base lies compact calcareous sandstone in massive beds, locally 6 feet thick; at base lies a bed of coarse-grained dense sandstone that carries Upper Jurassic fossils.	200–600
		Preuss sandstone.	Fine, even-grained sandstones, pale reddish-gray to deep dull red; mostly calcareous and more or less argillaceous, locally shaly, nonfossiliferous.	1, 300
		—Unconformity—		
		Twin Creek limestone.	Major part, thin-bedded grayish-white and bluish shaly limestone; weathers white and forms massive ledges but breaks into splintery fragments that veneer steep slopes; fossils sparse but indicate Upper Jurassic age.	3, 500±
	...........(?)...........			
	Jurassic.		Lower part massive brown porous-weathering sandy limestone that contains abundant poorly preserved fossils; includes also thin and cross-bedded limestones and a dense greenish siliceous band.	
		—Unconformity—		
		Nugget sandstone.	Generally well-bedded reddish to pinkish dense, fine-grained sandstones that weather brown and form rough ledges and coarse blocky talus piles; locally deeper red or yellowish beds; in places cross-bedded, lighter-colored in upper part; includes some shaly beds and in places limestone bands and red shale near top.	1, 350±

TABLE 12.—*General stratigraphic section of the sedimentary rocks of southeastern Idaho*—Continued

System	Series	Group and formation	Character	Thickness (feet)
Triassic (?).		Wood shale.	Thin-bedded brilliant red sandstones and red shales, locally gypsiferous; weather to bright-red soil.	150±
		Deadman limestone.	White, locally reddish or greenish limestone, massive, dense, cherty, locally nodular, nonfossiliferous; locally contains interbedded mottled limy shales; reddish color and shaly tendencies near base.	200±
		Higham grit.	Quartzitic grit, conglomerate with small quartzite pebbles, coarse quartzite or sandstone; white-weathering, pinkish; locally reddish, yellowish, and deeply ferruginous at base.	200±
		—Unconformity—		
Triassic.	Lower Triassic.	Timothy sandstone.	Yellowish to grayish, somewhat sugary sandstone, in beds 1 to 3 inches or more thick, generally uniform in character; locally weathers to a pinkish tinge, and some beds are reddish to purplish; local conglomeratic beds carry fragments of Thaynes (?) material.	250±
		—Unconformity—		
		Thaynes group. Portneuf limestone.	Siliceous, dense, massive olive-drab limestones; weather gray and are locally thin-bedded at top; silicified fossils, sparse but locally more numerous, project from weathered surface; thickness, 50–400 feet; red sandstones and shales, some greenish and chocolate-colored shales; thickness, 200–1,000 feet; lower massive limestone like that above; thickness, 200+feet.	2,600–3,100
		Thaynes group. Fort Hall formation.	Yellowish sandstones in lower part; calcareous platy olive-drab shales above and near top; massive gray to yellowish sandstones, weathering pinkish; large pectenoids with prominent rays distributed sparsely throughout and locally abundant.	
		Thaynes group. Ross Fork limestone.	Light-gray dense limestones; gray to slate-colored shales, yellow sandstones, and muddy limestones; locally massive limestones; the *Meekoceras* zone at base.	
		Woodside shale.	Olive-drab platy shales, alternating with thin beds of brownish-gray limestone that are locally purplish and highly fossiliferous; the shales are siliceous, calcareous, and hard; massive limestones near top carry abundant fossils and include *Terebratula* and *Myalina* zones.	1,000–2,000
		—Unconformity—		
Carboniferous.	Permian.	Phosphoria formation.	Rex chert member. In Montpelier district the Rex consists of massive cherts in lower 50–75 feet, above which lie massive gray limestones crowded with *Productus* and other fossils. Over most of the region the Rex consists of massive, dark chert ledges below and dark flinty or cherty shale above, or in places it consists entirely of flinty shale. Fossils scarce, except in limestone.	110–550
			Beds beneath Rex chert member consist of phosphatic shales, yellowish to brown phosphatic sandstones, dark-brown to black phosphatic shales, beds of brown or black fetid limestones, locally beds of chert, and one to three economically valuable beds of phosphate rock; fossiliferous.	75–180
		—Unconformity—		
	Pennsylvanian.	Wells formation.	Upper 75 feet or less consists of dense, very fine textured sandstone grading to siliceous limestone; contains white, massive, cliff-making beds; bluish chert bands 2 inches to 1 foot thick in upper part, darker and more nodular chert near bottom; silicified brachiopods.	2, 400
			Middle 1,700–1,800 feet contains sandy limestones and here and there thin beds of quartzite and sandstones; weather white, red, or yellow and form smooth slopes.	
			Lower 100–750 feet consists of sandy and cherty limestones and interbedded sandstones, limestones, dark gray to bluish gray, containing chert nodules, oval, and concentrically banded, 6–8 inches in diameter; fossiliferous.	
		—Unconformity—		

TABLE 12.—*General stratigraphic section of the sedimentary rocks of southeastern Idaho*—Continued

System	Series	Group and formation	Character	Thickness (feet)
Carboniferous.	Mississippian.	Brazer limestone.	Massive, gray, light to dark limestones that weather white to light gray. Chert nodules or streaks present at many localities. At Logan, Utah, a bed of phosphatic shale lies at the base. Locally a dark shale about 15 feet thick lies near the top. The limestones in places are arenaceous and interbedded with sandstones. The beds contain large cup corals and other fossils.	1, 130+
		—Unconformity—		
		Madison limestone.	Thin-bedded dark bluish-gray limestones that weather brown or gray; also massive beds of light-gray limestone; fossiliferous.	1, 000±
		—Unconformity—		
Devonian.	Upper Devonian.	Threeforks limestone.	Purplish cherty shales and sandy limestones, somewhat conglomeratic, that are purplish on fresh surfaces and weather to purplish drab; fossiliferous. Thickness in Portneuf quadrangle, Idaho, 180± feet.	180±
	Middle Devonian.	Jefferson limestone.	Dark, nearly black magnesian limestone, locally black limy sandstone. Limestone fractured, seamed with calcite. Fossiliferous. Remnants only. Thickness unknown. (In Portneuf quadrangle, Idaho, 935 feet).	935
		—Unconformity—		
Silurian.		Laketown dolomite.	Massive light-gray to whitish dolomite containing lenses of calcareous sandstone and locally a bed of purplish shale; fossiliferous. (In Portneuf quadrangle, Idaho, 485+ feet.)	0–1, 000±
Ordovician.	Upper Ordovician.	Fish Haven dolomite.	Dark-gray to bluish-black, locally cherty dolomite; includes some lighter-gray dolomitic beds and some shales; Richmond fossils.	500
		—Unconformity—		
	Lower Ordovician.	Swan Peak quartzite.	White quartzite, locally stained buff to red on weathered surfaces; beds 6 inches to 4 feet thick; peculiar stemlike structure on vertical joints; small fauna (Chazy ?).	500
		Garden City limestone.	Succession of thick and thin bedded gray limestone and beds of conglomerate or breccia composed of elongated fragments of limestone 2 to 3 inches long in matrix of same composition; forms large sinks; abundantly fossiliferous; Beekmantown fauna.	1, 250
		—Unconformity—		
Cambrian.	Upper Cambrian.	St. Charles limestone.	Bluish-gray to gray arenaceous limestones that contain some cherty and concretionary layers; forms numerous sinks.	950–1, 200
			Worm Creek quartzite member, 200± feet of white quartzite that weathers to rough ledges but is usually not a cliff maker; includes some reddish or brownish sandstone; fossiliferous.	
	Middle Cambrian.	Nounan limestone.	Lower part massive, whitish or light-gray, somewhat coarsely crystalline dolomitic limestone beds, about 18 inches thick, alternating with similar darker beds, then thinner, platy, blotchy limestones that are succeeded by more massive beds of bluish-gray limestone with which is included a greenish or reddish sandy limestone bed 10 feet thick; upper beds massive, locally cherty; fossils scarce.	1, 050
		Bloomington formation.	Bluish-gray limestones, somewhat thin-bedded but some massive layers; some beds carry small concretions and nodules of calcite; other beds are sandy or argillaceous; fairly well defined shale near top; fossiliferous.	1, 200
			Hodges shale member, 300 feet thick, papery olive-green shales and impure thin-bedded limestones.	
		Blacksmith limestone.	Cliff-making arenaceous limestones at base which mark off formation from the Ute; higher beds thinner, purer limestone that contain sandy bands on weathered surface; also beds of clear bluish-gray limestone, 1 to 2½ feet thick, that carry some oolitic bands, with branching calcitic forms; fossils scarce and poorly preserved.	750

TABLE 12.—*General stratigraphic section of the sedimentary rocks of southeastern Idaho*—Continued

System	Series	Group and formation	Character	Thickness (feet)
Cambrian.	Middle Cambrian.	Ute limestone.	Light-gray, greenish, or bluish-gray thin-bedded clayey limestones that include some oolitic beds and more massive light-gray beds; fossiliferous.	760
			Spence shale member; 30 feet of fine argillaceous papery shale that weathers readily; abundantly fossiliferous at type locality.	
		Langston limestone.	Massively bedded bluish-gray to light-gray limestone, somewhat coarsely crystalline; weathers buff or brownish and has a tendency to form rounded edges; locally porous, concretionary, sideritic streaks, fossiliferous.	250-600
	Lower Cambrian.	Brigham quartzite.	Vitreous quartzite or quartzitic sandstone, generally purplish or pinkish but also white, gray, deep red, or nearly black; some conglomeratic layers with pebbles of white to red or purple quartzite; near top locally lie beds of micaceous shale; beds generally massive and bedding well marked; base not exposed.	1, 000-1, 600±
Total maximum thickness of all formations				46, 000+

CAMBRIAN SYSTEM

GENERAL FEATURES

The oldest rocks recognized in the region are of Cambrian age and consist of quartzites, limestones, shales, and some sandstones. They have an aggregate thickness of about 7,000 feet and occupy a part of the east flank of the Bear River Range from the south boundary of the Montpelier quadrangle northward as far as Stauffer Creek.

Rocks that are still older have been described from other parts of this general section of the Rocky Mountains. For example, in the vicinity of Ogden and Salt Lake City, Utah, Blackwelder[1] has described a series of Algonkian quartzites from 1,000 to 12,000 feet in thickness in which there are minor alternations of slate and conglomerate. To the north also, in the Teton Mountains of Wyoming, gneisses and granites of Archean age underlie Cambrian sediments.

The Cambrian section of the Montpelier quadrangle is similar to that defined by Walcott[2] and studied by Richardson[3] in neighboring regions of Utah and Idaho. Walcott's sections are located in Blacksmith Fork, Utah, and in the Bear River Range 5 miles west of Liberty, Idaho. Richardson's section is in the Randolph quadrangle, Utah. The sections contain seven formations that will be described in ascending order as the Brigham quartzite, Langston limestone, Ute limestone, Blacksmith limestone, Bloomington formation, Nounan limestone, and St. Charles limestone.

[1] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, p. 520, 1910.

[2] Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 53, pp. 5-9, 190-200, 1908; Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 148-153, 1912.

[3] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 406-416, 1913.

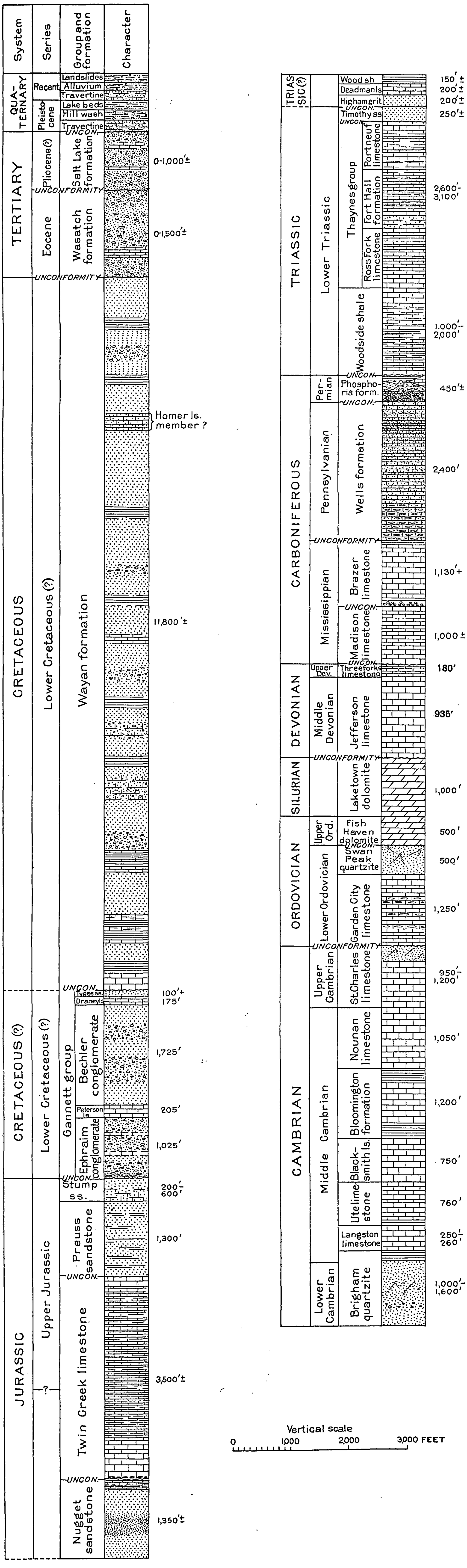
A good section of the Cambrian formations is displayed in St. Charles Canyon, part of which is shown in Plate 21, *C*. A representative group of fossils from the Cambrian formations selected by Edwin Kirk is shown in Plate 20.

BRIGHAM QUARTZITE

Name and definition.—The Brigham quartzite was named by Walcott from its occurrence in the west front of the Wasatch Range, northeast of Brigham, Box Elder County, Utah. The formation consists of massive, more or less vitreous quartzite or quartzitic sandstone, generally of purplish or reddish tinge, together with conglomeratic layers and some beds of hard, sandy, and more or less micaceous shale. According to Blackwelder[4] it rests in some places upon the eroded surface of Algonkian quartzite and slate and in other places upon older gneisses and schists that are generally referred to the Archean. In this region its base is not exposed.

Distribution and character.—The Brigham quartzite occurs in two separate areas near Fish Haven, in the southwestern part of the Montpelier quadrangle, where it is surrounded by Tertiary beds and in a belt that ranges in width from three-fourths of a mile to 2½ miles along the east flank of the Bear River Range from the vicinity of Fish Haven to Stauffer Canyon, about 28 miles north. It is more or less overlapped and in several places completely concealed by Tertiary deposits. On the west it is bounded by the Langston limestone, which lies above it in normal sequence, but on the east it is bounded by a fault or is so overlapped that its relations to other pre-Tertiary rocks are concealed.

[4] Blackwelder, Eliot, op. cit., p. 523.



Section continued at right

COLUMNAR SECTION FOR SOUTHEASTERN IDAHO

Figures for Devonian formations changed to agree with recent measurements in the Portneuf quadrangle

The formation is mainly a quartzite of prevailingly purplish or reddish tinge, but both texture and color are somewhat variable. The texture is locally sandy or even sugary rather than quartzitic, and there are numerous gritty and pebbly or conglomeratic layers, the pebbles in which are generally less than an inch in diameter and well rounded. The pebbles are composed chiefly of quartzite and are white to reddish. The pebble beds occur among beds of sandstone and do not appear to represent a basal conglomerate. The color ranges from light pink or nearly white to deep red or nearly black, and considerable oxide of iron is present. Some of the beds are greenish or grayish, but all tend to weather purplish red or reddish brown. Near the top in some localities beds of micaceous shale occur. The sandstone beds range from about 3 inches to 3 feet in thickness, and the bedding is generally well marked.

Thickness.—The thickness of the Brigham quartzite at the type locality is reported by Walcott to be 2,000+ feet and in Blacksmith Fork 1,250 feet. In the Montpelier quadrangle the quartzite is folded and the lower part faulted out or concealed. Its thickness is estimated to range from 1,000 to 1,600 feet.

Age and correlation.—Few fossils occur in the quartzite. Walcott reports annelid trails and trilobite tracks in the Blacksmith Fork section. Annelid borings and fucoids (?) have been collected at one locality in the Montpelier quadrangle.

Walcott considers that most of the Brigham quartzite is of Middle Cambrian age but that it also includes several hundred feet of Lower Cambrian beds. The boundary between the two sets of beds has not been recognized.

LANGSTON LIMESTONE

Name and definition.—The Langston limestone was named by Walcott from Langston Creek, Utah, but the type section is the canyon of Blacksmith Fork, Utah. The formation includes the limestone immediately above the Brigham quartzite and below the Spence shale member of the Ute limestone.

Distribution and character.—The Langston limestone is exposed above the Brigham quartzite in the vicinity of Fish Haven Canyon and again in a narrow uninterrupted band along the west side of the quartzite from a point 1½ miles north of Fish Haven Canyon to the west edge of the district, about 15 miles a little west of north.

As described by Walcott the rock is a massively bedded, bluish-gray limestone with many round concretions. In the Montpelier quadrangle the limestone is massively bedded, light gray, and somewhat coarsely crystalline. It weathers to a buff color and has a tendency to form rounded edges. In some places it is darker and has a bluish tint and yellow sideritic streaks. Generally it is not conspicuous as a ledge maker but at some places it forms well-marked dip slopes, as in St. Charles Canyon. The limestone is somewhat dolomitic, and locally, as in a ledge in Fish Haven Canyon, it weathers to a porous or vesicular texture.

Thickness.—The thickness of the Langston limestone ranges from 250 to about 600 feet.

Age.—The formation is not very fossiliferous in this area, but from the Blacksmith Fork locality Walcott lists *Obolus* (*Westonia*) *ella* (Hall and Whitfield), *Zacanthoides* sp., *Bathyuriscus productus* (Hall and Whitfield), *Neolenus*?, and *Ptychoparia*. From the vinicity of Malade, Idaho, where the limestone has a more compact facies, a more extended fauna has been obtained. The following list of typical Langston fossils is supplied by Edwin Kirk: *Micrometra* (*Iphidella*) *pannula* (White), *Zacanthoides* sp., and *Bathyuriscus productus* (Hall and Whitfield).

According to Walcott the Langston limestone is of early Middle Cambrian age.

UTE LIMESTONE

Name and subdivision.—The Ute limestone was named by Walcott from Ute Peak, Cache County, Utah. At the base of the formation lies a well-defined shale with an abundant fauna. This shale has been differentiated by him and named the Spence shale member, from Spence Gulch in unsurveyed sec. 11, T. 13 S., R. 42 E., about 5 miles west of Liberty, Idaho, its type locality. It has not been practicable to map this member separately.

Distribution and character.—The Ute limestone occurs in a small area along the fault in sec. 32, T. 13 S., R. 43 E., and is exposed in a narrow continuous band along the west side of the underlying Langston limestone. It extends about 15 miles a little west of north from a point about a mile and a half north of Fish Haven Canyon to the border of the region mapped.

As described by Walcott, the formation is composed of blue to bluish-gray thin-bedded fine-grained limestones and shales, together with some oolitic concretionary and intraformational conglomerate. In the Montpelier quadrangle the Ute limestone is composed generally of light-gray or greenish thin-bedded clayey limestones, which are succeeded by more massive light-gray limestones in beds 3 inches to more than a foot thick. A section measured on Mill Creek near Liberty gave a thickness of 761 feet.

The Spence shale member represents the lower 30 feet of the Ute formation and consists of a fine argillaceous papery shale that weathers readily and is well exposed in but few places. It generally forms depressions in the ridges and is in many places relatively free from tree growth, whereas the limestones on both sides of it bear trees. It is well exposed in Spence Gulch, a tributary of Mill Creek that heads in Danish Flats (Copenhagen Basin?) in the Preston quadrangle to the west.

PLATE 20

Typical Middle Cambrian fossils of the region

FIGURE 1. *Zacanthoides idahoensis* Walcott.
FIGURE 2. *Dolichometopus productus* (Hall and Whitfield).
FIGURES 3, and 4. *Neolenus inflatus* Walcott.

Typical Upper Cambrian fossils of the region

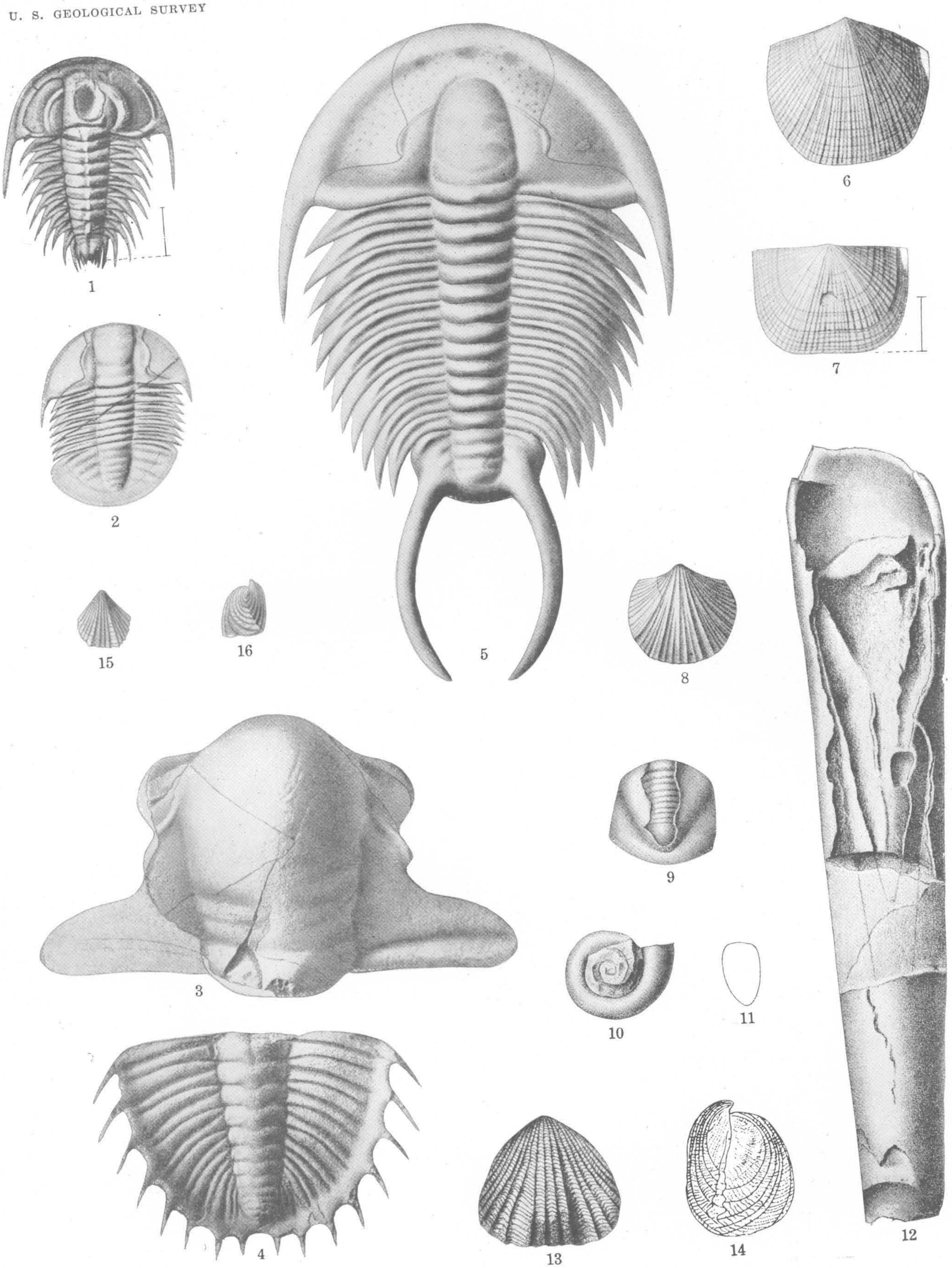
FIGURE 5. *Crepicephalus texanus* (Shumard).
FIGURES 6, 7. *Billingsella coloradoensis* (Shumard).

Lower Ordovician (Garden City limestone)

FIGURE 8. *Orthis (Dalmanella) hamburgensis* Walcott.
FIGURE 9. *Asaphus (?) curiosus* Billings.
FIGURES 10, 11. *Maclurea subannulata* Walcott.
FIGURE 12. *Endoceras proteiforme* Hall.

Upper Ordovician (Fish Haven limestone, Richmond fauna)

FIGURES 13, 14. *Rhynchotrema capax* (Conrad).
FIGURES 15, 16. *Rhynchotrema argenturbica* (White).



TYPICAL CAMBRIAN AND ORDOVICIAN FOSSILS

Above the Spence shale member the Ute formation for 200 feet consists of thin-bedded bluish-gray limestone, capped by about 25 feet of gray coarse-grained dolomite. Both the dolomite and the underlying limestone weather in places to brick-red. The remainder of the formation is composed mainly of thin-bedded bluish-gray limestone, which is banded with yellow sandy and sideritic streaks. Locally the limestone is in part oolitic and crowded with minute indistinct traces of fossils, possibly Bryozoa. The limestones of the upper part of the Ute formation locally weather into smooth slopes, without ledges and the top of the formation is marked by the cliffs made by the overlying Blacksmith limestone.

Age and correlation.—The following characteristic fauna is listed by Edwin Kirk from collections from the Montpelier and Randolph quadrangles:

Obolus (Westonia) ella (Hall and Whitfield).
Syntrophia cambria Walcott.
Micromitra (Paterina) superba (Walcott).
Olenoides quadriceps (Hall and Whitfield).
Alokistocare subcoronatum (Hall and Whitfield).
Zacanthoides idahoensis Walcott.

Walcott considers the age of the Spence shale member as early Middle Cambrian and that of the main body of the formation as Middle Cambrian. He correlates the Ute limestone as restricted by him with the lower portion of the Ute limestone of the Fortieth Parallel Survey.

BLACKSMITH LIMESTONE

Name.—The Blacksmith limestone was described by Walcott from Blacksmith Fork Canyon, Utah.

Distribution and character.—The Blacksmith limestone, which lies stratigraphically above the Ute limestone, occupies a narrow band that has similar distribution to that of the Ute.

The lithology is similar to that of the upper beds of the Ute, but the bedding is more massive and the boundary between the two formations is generally marked by low cliffs. In the Montpelier quadrangle the Blacksmith limestone consists of about 750 feet of beds that have cliff-making arenaceous limestones at the base, overlain by purer limestone in thinner beds, which are marked by yellow sandy bands on weathered surfaces. This limestone is in turn overlain by clear bluish-gray limestone in beds that range from 1 to 1½ feet in thickness, which include some oolitic bands and contain numerous branching calcitic forms.

Age.—Fossils are scarce in the Blacksmith limestone. Walcott reports annelid borings and fragments of a small trilobite (*Ptychoparia?*). The age of the formation, as determined by abundant fossil evidence in the immediately underlying and overlying formations, is Middle Cambrian.

BLOOMINGTON FORMATION

Name and subdivision.—The Bloomington formation was described by Walcott from the Bear River Range, Idaho. The type section is on Mill Creek, near Liberty, but the formation is named from Bloomington Canyon, which crosses the formation and causes good exposures of it. Richardson has differentiated the lower portion as the Hodges shale member, named from Hodges Creek, which crosses the shale and enters Bear Lake 1½ miles south of Garden City, Utah.

Distribution and character.—The Bloomington formation occurs in a belt about 14 miles long that extends a little west of north from Fish Haven Canyon to the border of the mapped area and immediately adjacent to the Blacksmith limestone, which it conformably overlies.

The Hodges shale member, about 300 feet thick, consists of papery olive-green shales and impure thin-bedded limestones and forms strike gulches or well-marked depressions in the ridges. In such depressions a low knob generally occurs, produced by the intercalated limestones.

Above the Hodges shale member the formation consists of a series of bluish-gray, more or less thin-bedded limestones that contain some massive layers. Some of the beds contain small concretions and nodules of calcite. Other beds are sandy or argillaceous, and there is a fairly well defined shale near the top.

Thickness.—The total thickness of the formation is about 1,200 feet.

Age.—The formation is abundantly fossiliferous. The following faunal list is supplied by Edwin Kirk from collections from the Montpelier and Randolph quadrangles:

Obolus (Westonia) wasatchensis Walcott.
Obolus mcconnelli pelias (Walcott).
Micromitra sculptilis (Meek).
Agraulos sp.
Doropyge sp.
Ptychoparia sp.

The Bloomington formation is assigned by Walcott to the Middle Cambrian.

NOUNAN LIMESTONE

Name.—The Nounan limestone was described by Walcott in connection with his studies of the Cambrian in the region of Blacksmith Fork, Utah, and west of Liberty, Idaho. The name is taken from the town of Nounan, which is near the type locality. Nounan Creek cuts across the formation.

Distribution and character.—The Nounan limestone forms a belt half a mile to a mile wide contiguous with the Bloomington formation on the east and extends about 15 miles a little west of north from the south boundary of the mapped area to the western edge. It is partly overlapped on the south by Tertiary deposits.

The boundary between the Bloomington formation and the Nounan limestone is marked by a change in lithology and the outcrop of massively bedded, whitish or light-gray, somewhat coarsely crystalline dolomitic limestone that sparkles on freshly fractured surfaces and occurs in beds about 18 inches thick. Alternating with these beds come dark-gray beds of similar character and thickness which have branching calcitic forms that are probably organic replacements. Upward in the section the lighter-colored beds prevail, followed by thin platy, bluish-gray limestones which have yellow blotches of limy and clayey material that weathers more easily than the parent rock. These beds are succeeded by more massive beds of alternating bluish-gray and gray limestones which contain a bed of thin platy, sandy limestone about 10 feet thick that weathers greenish or reddish. The upper part of the formation is composed of massive beds of limestone, portions of which contain streaks of impure chert. The thickness of the formation is about 1,050 feet.

Age.—The Nounan limestone has a relatively meager fauna. Walcott reports a few traces of fossils and large annelid borings. In the Montpelier quadrangle a single collection yielded *Ptychoparia* sp.

Walcott has assigned the Nounan limestone to the Middle Cambrian.

ST. CHARLES LIMESTONE

Name and subdivision.—The St. Charles limestone was described by Walcott from the Bear River Range, west of the town of St. Charles, in the southwest part of the Montpelier quadrangle. St. Charles Creek passes over the formation. The quartzite that forms the basal member of the formation has been differentiated by Richardson as the Worm Creek quartzite member, named from Worm Creek in the southwest part of the Montpelier quadrangle, where the quartzite is well exposed.

Distribution and character.—The St. Charles formation occupies a belt, half a mile to a mile or more wide, that extends northward about 13 miles from the south boundary of the region mapped and is contiguous with the Nounan limestone on the east, which it conformably overlies.

As described by Walcott, the formation consists of bluish-gray to gray arenaceous limestones, with some cherty and concretionary layers, which pass at the base into thin-bedded gray to brown sandstones.

Several sections have been measured, and these are given below.

TABLE 13.—*Section of the St. Charles limestone on Mill Creek, about 5 miles west of Liberty, Idaho*

	Feet
Limestone, gray, thin bedded	400
Limestone, bluish gray, thin bedded	50
Limestone, gray, thin bedded; weathers red	500
Worm Creek quartzite member:	
Quartzite, white	150
Quartzite, white, interbedded with cross-bedded brownish sandstone	100
	1,200

TABLE 14.—*Section of the St. Charles limestone on north side of Fish Haven Canyon, Idaho*

	Feet
Limestone, gray, crystalline, weathers dark gray to brownish gray; weathered surfaces are crowded with Bryozoa	300
Limestone, thick bedded	100
Limestone, gray with brown sandy layers and some chert	400
Worm Creek quartzite member:	
Quartzite, white, weathers into rough angular fragments; shows as ledges but does not stand out as cliffs; grades toward the base into sandstone, buff to red, and contains a minor amount of interbedded quartzite	200
	1,000

TABLE 15.—*Section of St. Charles limestone on north side of St. Charles Creek, Idaho*

	Feet
Limestone, gray, rather thin bedded, in part dense and barren except for silicified Bryozoa(?) on weathered surface, and in part more coarsely crystalline and crowded with trilobites	800
Worm Creek quartzite member:	
Sandstone, brown	75
Quartzite, white	75
	950

There is some variation in the lithology of the formation, and the thickness ranges from 950 to 1,200 feet. At the first two localities little lithologic change is noted at the upper boundary. At the last-named locality the overlying Ordovician section is marked by a 40-foot bed of limestone conglomerate.

Age.—The St. Charles formation yields a considerable fauna. The following list is supplied by Edwin Kirk from collections made in the Montpelier and Randolph quadrangles.

Billingsella coloradoensis (Shumard).
Lingulella desiderata Walcott.
Obolus (Westonia) iphis (Walcott).
Anomocare sp.
Ptychoparia sp.
Agnostus sp.

Walcott has assigned the St. Charles limestone to the Upper Cambrian.

ORDOVICIAN SYSTEM

The Ordovician system is represented by a series of gray limestones, quartzite, black cherty to gray magnesian limestone and dolomite, which have been divided by Richardson [5] into three formations—in ascending order the Garden City limestone, which contains a Beekmantown fauna; the Swan Peak quartzite, which contains a Chazy? fauna; and the Fish Haven dolomite, which is characterized by a Richmond fauna.

The rocks of these formations crop out extensively in the western part of the Montpelier quadrangle and an adjacent portion of the Slug Creek quadrangle.

[5] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci. 4th ser., vol. 36, pp. 406-416, 1913.

In the southwest corner of the district they occupy the axial region of a broadly open syncline and overlie with apparent conformity the Cambrian formations that form successive bands along the east flank of the fold. Unconformities, however, have been recognized by Richardson at the base of the lowest and highest Ordovician formations. The system is well exposed and has a general thickness of about 2,200 feet.

A good section of the Ordovician rocks is exposed in St. Charles Canyon, part of which is shown in Plate 21, *C*. A representative group of fossils from the Ordovician formations, selected by Edwin Kirk, is shown in Plate 20.

GARDEN CITY LIMESTONE

Name.—The Garden City limestone was named from Garden City Canyon, about 4 miles south of the Utah-Idaho State line.

Distribution and character.—The formation appears on both flanks of the syncline in the southwest corner of the district, and in a belt half a mile to a mile or more wide it extends northward about 14 miles from the south boundary of the region mapped. It lies immediately west of the St. Charles limestone and stratigraphically above it. Other lesser areas occur on the west side of Nounan Valley in T. 12 S., R. 43 E., about 4 miles northwest of Montpelier, and in Tps. 15 and 16 S., R. 43 E., in a narrow strip east of the fault which there constitutes the east boundary of the Cambrian belt.

The rocks form a succession of thick and thin bedded gray limestones about 1,250 feet thick. A characteristic feature is the presence throughout the formation of a conglomerate or breccia that consists of elongated fragments of limestone, the largest of which are 2 or 3 inches in length, embedded in a matrix of similar composition. Both the St. Charles limestone and the Garden City limestone produce large sinks.

Age and correlation.—An extensive fauna has been collected from the Garden City limestone in the Montpelier and Randolph quadrangles, from which the following list has been selected by Edwin Kirk:

Dalmanella pogonipensis Hall and Whitfield.
Dalmanella hamburgensis Walcott.
Syntrophia near S. calcifera Billings.
Strophomena? minor Walcott.
Polygrata rotuliformis Meek.
Polygrata trohiscus Meek.
Raphistoma? acutum Hall and Whitfield.
Maclurea subannulata Walcott.
Eccyliopterus sp.
Lophospira sp.
Hormotoma sp.
Bucanella nana Meek.
Endoceras sp.
Asaphus? near A. curiosus Billings.
Bathyurus sp.
Receptaculites sp.

The fauna of the Garden City limestone is of Beekmantown age and corresponds in part to that of certain portions of the Pogonip limestone of the Eureka district, Nev.

SWAN PEAK QUARTZITE

Name.—The Swan Peak quartzite was named from Swan Peak, in the Bear River Range, Utah, 1½ miles south of the Idaho boundary.

Distribution and character.—The formation occupies the extreme southwest corner of the Montpelier quadrangle and constitutes a portion of the axial region of the broadly open syncline in that locality. It also extends along the east flank of the fold in a narrow band near the west border of the region mapped as far north as Dry Canyon (Bloomington). An area of about 8 square miles north of Stauffer Canyon, which extends into the Slug Creek quadrangle, is underlain by the quartzite, and this rock also occurs at several places in the fault zone southward from Bloomington Canyon.

The Swan Peak quartzite is composed of about 500 feet of white quartzite, locally stained buff to red on weathered surfaces, in beds 6 inches to 4 feet thick. The weathered edges of quartzite from the upper portion are characterized by a peculiar vertically jointed or stemlike structure. In the area west of Fish Haven about 100 feet above the base the Swan Peak quartzite includes thin lenses of phosphate rock, which appears to be of fairly high grade as far as can be inferred from the qualitative tests made. The rock consists of bluish-black particles, which are in part fragments of trilobite and brachiopod shells and which are cemented by a translucent yellowish-brown material. The rock is jointed into rhomblike fragments and on the joint faces has a prominent laminated texture as if it were an aggregate of shell fragments. In this respect it is closely similar to rock collected from the lower part of the main phosphate bed in the Soda Springs district.[6] This Ordovician phosphate lacks the oolitic texture so characteristic of the rock of the extensive deposits of Permian age. However, its weathered surfaces have a white coating similar to that noted on weathered fragments from the Permian. The deposit has a maximum local thickness of only 3 inches and is not of commercial value but is interesting as indicating the deposition of phosphate in the West at a time that corresponds approximately with the formation of the economically valuable deposits of Tennessee.

Age and correlation.—Fossils are not abundant, but collections have been made in both the Montpelier and Randolph quadrangles, from which Edwin Kirk has furnished the following list:

Orthis near O. tricenaria Conrad.
Symphysurus? goldfussi Walcott.
Holosaphus? congeneris Walcott.
Leperditia sp.

[6] Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, p. 378, 1911.

The fauna of the Swan Peak quartzite is related to that which occurs in the lower part of the Simpson formation in Oklahoma and is tentatively referred to the Chazy by Ulrich and Kirk.

FISH HAVEN DOLOMITE

Name.—The Fish Haven dolomite was named from Fish Haven Creek, which crosses the formation in the southwest part of the Montpelier quadrangle.

Distribution and character.—The largest area underlain by the Fish Haven dolomite is that at the type locality, in Fish Haven Canyon, at the west border of the Montpelier quadrangle, where the rock occupies an axial position in the syncline. Northward it lies along the very border as far as Worm Creek. It also appears at several places in the fault zone southward from Dry Canyon (St. Charles).

The rock as described by Richardson is a fine-textured, medium-bedded, dark-gray to blue-black, locally cherty dolomite, about 500 feet thick. A sample from the head of Fish Haven Creek, which was analyzed by W. C. Wheeler, of the United States Geological Survey, contained 21.35 per cent of magnesia. In the Montpelier quadrangle the top of the formation is not exposed, but the base rests with apparent conformity on the white Swan Peak quartzite. It may be noted, however, that the fauna of the Fish Haven is of Richmond age, whereas that of the underlying Swan Peak is Chazy (?), so that a time interval, which is represented in the East by several well-recognized and distinct faunas, should intervene between the two formations, and these are in reality probably "disconformable."

The following stratigraphic sequence was noted in Fish Haven Canyon: The first 15 feet of the section consists of a bluish-black dolomite in beds 3 inches to 1 foot thick that contain *Streptelasma* sp. and crinoid fragments. The next 15 feet is composed of black cherty dolomite in beds 1 to 8 feet thick. This dolomite is overlain by about 30 feet of thin-bedded dark dolomite that carries chert in small irregular lenses. Beds near the bottom of this part of the section have yielded fossils identified by Kirk as *Halysites gracilis* (Hall), *Streptelasma* sp., *Colopoecia* cf. *C. canadensis* Billings, and crinoid fragments. Toward the top of this part large cup corals are abundant. These beds are succeeded by a 5-foot bed of rough-weathering cherty limestone (dolomite?) and this in turn by about 25 feet of lighter-colored limestone marked by dark lines and containing in places small calcite-lined cavities. A small gully next in the section shows reddish soil that contains fragments of limestone and may mark a shaly horizon. Next above is a light-gray spongy-weathering dolomite with cavities partly filled with sand composed of crystals of dolomite that represent poorly preserved fossil molds. The only fossil collected was identified as *Lophospira* sp. by Kirk. The bedding is indistinct, and dip readings were not obtainable. The next beds are irregularly mottled brown and gray dolomite from which *Hormotoma* was collected. Another gully here suggests the presence of a shaly horizon, and then a dark cherty dolomite, similar to that at the base comprises the rest of the section. This dolomite contains fossils identified by Kirk as *Streptelasma* sp., *Rhynchotrema capax* Conrad, *Columnaria* (*Paleophyllum*) *thorni* Hall, *Hormotoma* sp., and *Favosites* sp.

Age.—The age of the Fish Haven dolomite, as indicated by the fauna mentioned in the preceding paragraph, is Richmond.

SILURIAN SYSTEM

The Silurian system in the region mapped is represented by only two occurrences of small area, referred to the Laketown dolomite, described by Richardson [7] in the Randolph quadrangle, Utah.

LAKETOWN DOLOMITE

Name.—The Laketown dolomite was named from Laketown Canyon, 4 miles southeast of Laketown, Utah. It includes the light-colored calcareous and sandy beds that lie apparently conformably above the Fish Haven dolomite and immediately beneath another dolomitic series, which is correlated by Richardson with the Middle Devonian Jefferson limestone.

Distribution and character.—The formation has been found in the NW. ¼ sec. 36, T. 15 S., R. 42 E. (unsurveyed), on the border of the Montpelier quadrangle, and in the NE. ¼ sec. 27, T. 15 S., R. 43 E., and parts of adjoining sections exposed in a canyon about a mile and a half southwest of St. Charles.

As described by Richardson, the Laketown dolomite is a massive light-gray to whitish dolomite, which contains lenses of calcareous sandstone and which has a thickness of approximately 1,000 feet. An analysis of the rock in the laboratories of the Geological Survey shows 21.38 per cent MgO.

In the Montpelier quadrangle the same general characteristics have been noted. The principal exposure is in the canyon southwest of St. Charles, where the formation, only one contact of which is exposed, appears to be nearly 1,000 feet thick. On the west it is bounded by about 100 feet of shattered Fish Haven dolomite. Then comes a series of white, sandy, and coarsely crystalline dolomite of somewhat open texture, though more dense than that of the rock farther east. About 400 feet stratigraphically east of the west boundary lies a purple shale about 15 feet thick. East of this shale the beds are white, massive, and coarse textured and pass beneath Tertiary deposits. The whole group weathers into pinnacled and castellated forms that show rough surfaces. A section of the Laketown dolomite measured in the Portneuf quadrangle, Idaho, contained 485 feet of beds and the base was not exposed.

Age.—No fossils were collected at the second locality mentioned above, but at the first locality the collec-

[7] Richardson, G. B., op. cit., p. 410.

tions as identified by Kirk yielded *Pentamerus* sp., *Camarotoechia*? sp., *Halysites* sp., and *Cyathophyllum* sp. The following list of typical Laketown fossils is supplied by Kirk:

Pentamerus cf. P. oblongus Sowerby.
Conchidium cf. C. decussatus Whiteaves.
Halysites catenulatus (Linné).
Favosites cf. F. favosus (Goldfuss).

A similar fauna has been reported by Kindle [8] from Green Canyon, on the east side of Cache Valley, Utah. The formation is referred by Kirk to the Niagaran epoch of the Silurian period.

DEVONIAN SYSTEM

The Devonian system has been reported by Richardson [9] in the Randolph quadrangle and by Kindle [10] in the Bear River Range. It has also been found by the writer in the Fort Hall Indian Reservation and the Portneuf quadrangle, Idaho, and is thus well represented in neighboring districts. In the region included in this discussion the Devonian is exposed in only four small areas on the southwestern flank of the Aspen Range in the Slug Creek quadrangle and in the Bear River Range in the Montpelier quadrangle, located respectively in the NW. ¼ sec. 11, in the SE. ¼ sec. 3, in the NE. ¼ sec. 4, all of T. 10 S., R. 43 E., and in the SE. ¼ sec. 10, T. 15 S., R. 43 E.

In the occurrences without this district two formations have been differentiated, namely, the Jefferson limestone below and the Threeforks limestone above, names employed in Montana. In the Randolph quadrangle, Utah, Richardson assigns to these formations an aggregate thickness of about 1,400 feet. The Threeforks limestone has been recognized at only one place in the area covered by this report. In the Aspen Range localities only the Jefferson limestone has been recognized. In St. Charles Dry Canyon, in the Bear River Range, only the Threeforks limestone is present.

JEFFERSON LIMESTONE

The Jefferson limestone as here exposed is a dark, nearly black, magnesian limestone, in section 11 a black limy sandstone. The limestone is more or less fractured and seamed with calcite. A sample collected in Laketown Canyon by G. B. Richardson and analyzed in the laboratory of the United States Geological Survey contained 19.16 per cent MgO. The following fossils from the localities named have been identified by Kindle and Kirk:

Atrypa reticularis.
Productella close to P. subaculeata.
Favosites cf. F. limitaris (most abundant).
Diphyphyllum sp. undet.
Cystiphyllum sp. undet.

Favosites cf. *F. limitaris* is one of the characteristic species of the Jefferson limestone of Montana, and its presence in the fauna of the Aspen Range localities, together with the lithologic resemblance of the containing rock to that of the Montana occurrence, constitute the chief basis of the assignment of the Aspen Range rock to the Jefferson. Kirk assigns the fossils to the Middle Devonian.

The limestone here probably owes its position to faulting, for in sections 3 and 4 it occurs in fault relation with Pennsylvanian rocks. In section 11 the Devonian projects through Tertiary rocks that conceal the other pre-Tertiary formations. In the Portneuf quadrangle the Jefferson limestone is exposed along the southwest base of the Chesterfield Range. A measured section of this formation north of Monroe Canyon in that range was 935 feet thick.

THREEFORKS LIMESTONE

This formation had been recognized only in the complexly faulted area near the mouth of St. Charles Dry Canyon, in the Montpelier quadrangle, where it forms a thin wedge between the Fish Haven dolomite on the west and the Brazer limestone (upper Mississippian) on the east. The presence of the Threeforks limestone at this locality was not recognized in the field, but was determined by the fact that among the collections, chiefly of upper Mississippian material, taken from ledges within a few hundred feet of each other, some types proved to be characteristically of Threeforks age. The beds assignable to this formation probably include a purplish cherty shale at least 10 feet thick that has a steep westerly dip, exposed along a ditch, and on the west a series of sandy limestones, somewhat conglomeratic on the east side toward the shale. These beds are purplish on fresh surfaces and weather to a purplish drab. They become more sandy toward the west and show bedding planes. The Threeforks limestone has been recognized in the Monroe Canyon section of the Portneuf quadrangle, where it is 180 feet thick.

In the Randolph quadrangle to the south, according to Richardson,[11] the Threeforks limestone is a soft formation that lies between harder beds and is generally concealed by débris. Where exposed it consists of thin beds of impure reddish limestone. Its thickness is estimated at 200 feet. From a locality in the Crawford Mountains in the S. ½ sec. 29, T. 11 N., R. 8 E., the following fossils were identified by E. M. Kindle:

Productella coloradensis.
Camarotoechia cf. C. contracta.
Schizophoria striatula var. australis.
Spirifer notabilis.
Syringothyris cf. S. carteri.
Spirifer whitneyi var. animasensis.
Cleiothyridina sp. undet.

Kindle states that this fauna is of Upper Devonian age and includes elements both of the Ouray limestone and Threeforks shale fauna.

[8] Kindle, E. M., The fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Bull. Am. Paleontology, No. 20, p. 17, 1908.
[9] Richardson, G. B., op. cit., p. 411.
[10] Kindle, E. M., op. cit.

[11] Richardson, G. B., op. cit., pp. 411-412.

CARBONIFEROUS SYSTEM

The Carboniferous system is well represented in all the quadrangles included in the present discussion except the Freedom, in which it appears only in small areas in the southwest and northeast corners. The three series, Mississippian, Pennsylvanian, and Permian, are present, and consist chiefly of limestone and sandstones together with subordinate cherty and shaly members, including economically valuable beds of high-grade phosphate rock. The main occurrences are in the Preuss and Aspen Ranges and in the ridges in the western part of the Henry and Cranes Flat quadrangles. Other occurrences are in the Sublette Ridge, on the west side of the Bear Lake Plateau, and along the eastern foothills of the Bear River Range, in the southwestern part of the district. The aggregate exposed thickness of the system is nearly 5,000 feet.

MISSISSIPPIAN SERIES

The Mississippian series includes two formations—the Madison limestone below and the Brazer limestone above. Both formations are characterized by rather pure limestones, but there are lithologic as well as faunal differences. Both formations are greatly dislocated and are exposed only as a result of deformation and erosion.

MADISON LIMESTONE

Name.—The Madison limestone was named by Peale from the Madison Range, in south-central Montana, on the east and west flanks of which the formation is exposed.

Distribution and character.—The Madison limestone has been recognized at a number of rather widely separated localities in this region. In the Montpelier quadrangle there are four occurrences—in the fault block northeast of Montpelier, in the fault block near the mouth of Georgetown Canyon, and in two localities 2 to 3 miles southeast of Meade Peak. In the Slug Creek quadrangle a very striking occurrence is furnished by the rock that caps the ridge between the forks of Twin Creek 5 miles or more northeast of Georgetown, in T. 10 S., R. 44 E., where the Madison limestone forms the outlying portion of a great fault block that there overlies Jurassic limestone. (See pl. 38 *A* and *B*.) Two other areas, which are separated from each other by a band of Tertiary sediments, lie in the western and northwestern parts of the same township. In the northwest corner of the Lanes Creek quadrangle the Madison limestone forms part of a high ridge, and in the northeast corner of the Freedom quadrangle the formation in three neighboring areas constitutes several of the eastern foothills of the Caribou Range.

The base of the formation is not exposed. The Madison limestone consists of 1,000 feet or less of thin-bedded dark bluish-gray limestones that weather brown or gray and where not faulted pass upward with apparent conformity into the massive beds of the overlying Brazer limestone, but the evidence presented on page 183 indicates that the two formations are probably unconformable. There are also included more massive beds of light-gray limestone. Although the beds of the Madison are usually relatively thin they form massive ledges and cliffs owing to their topographically resistant character. Plate 21, *B*, shows the northern tip of the Madison fault block northeast of Montpelier, which is here cut by the youthful gorge known as Joes Gap.

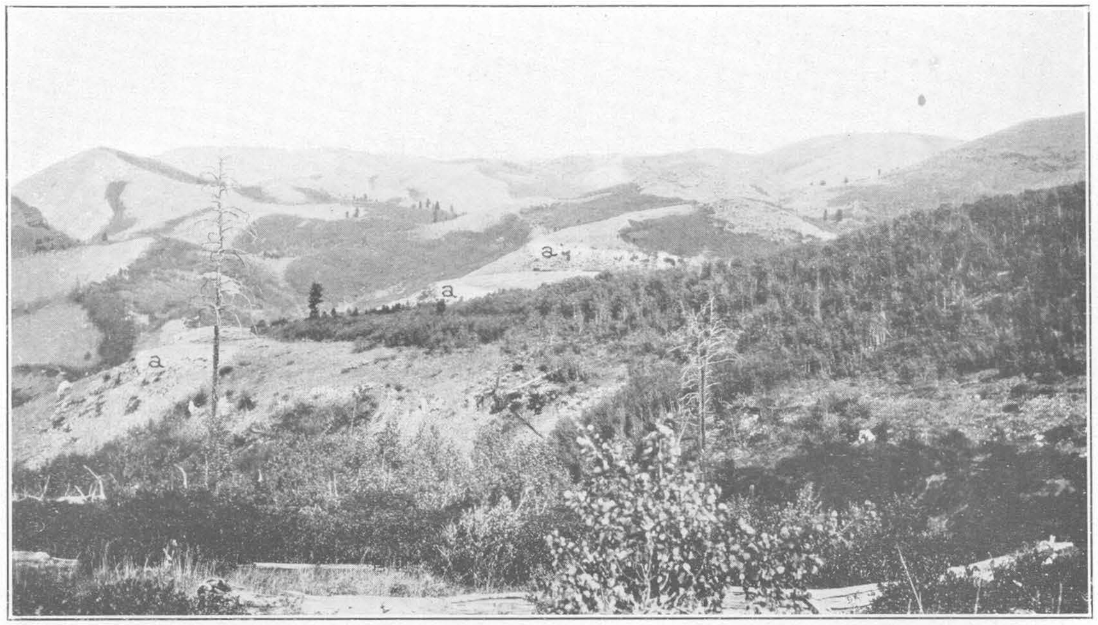
Age and correlation.—Fossils are numerous in the Madison limestone. The occurrence of small cup corals in association with high and low coiled gastropods and spiriferoid brachiopods forms a convenient means of distinguishing the Madison in the field from the Brazer limestone, which in general has thicker beds and large cup corals 3 to 8 inches or more long. Some of the typical Madison fossils of the region are shown in Plate 22. These were selected by G. H. Girty, who has also furnished the following note upon the fauna:

> Though fossils are abundant in the Madison limestone of this region, they are rarely well preserved and most of those studied were either fragmentary, exfoliated, or coarsely silicified. For this reason the specimens figured on Plate 22 came in large part from other areas. It seemed permissible thus to employ alien specimens, inasmuch as the plate was intended for use in identifying the formation rather than for evidence as to its geologic age and correlation. The poor preservation of the fossils has likewise affected the identification of individual specimens and also, though to a less degree, the identification of individual species. In the same way, though the age assigned to individual collections may later be revised, the age and correlation of the formation as a whole are beyond question. The evidence for this conclusion is contained in the subjoined list of species which, though rather lengthy, is by no means comprehensive. The new species included in this list are described on pages 411 to 414.

Leptopora typa.
Michelinia sp.
Syringopora sp.
Triplophyllum excavatum.
Meniscophyllum concinnum, MS.
Clisiophyllum teres.
Fenestella, several sp.
Pinnatopora sp.
Cystodictya sp.
Rhipidomella aff. R. pulchella.
Schizophoria compacta n. sp.
Leptaena analoga.
Schuchertella chemungensis.
Chonetes logani.
Chonetes loganensis.
Productella concentrica?
Productus ovatus.
Productus gallatinensis.
Productus parviformis.
Productus aff. P. sampsoni.
Productus aff. P. setiger.
Productus galeanus n. sp.
Pustula aff. P. punctata.
Pustula, several sp.
Camarotoechia metallica.
Rhynchotetra elongata.
Girtyella indianensis.
Dielasma occidentale.
Spirifer centronatus.
Spirifer aff. S. logani.
Spiriferina solidirostris.
Reticularia cooperensis.
Brachythyris chouteauensis.
Composita humilis.
Cliothyridina aff. C. fernglenensis.
Cliothyridina aff. C. incrassata.
Eumetria verneuiliana.
Nucula sp.
Paleoneilo sp.
Bellerophon mansfieldianus, n. sp.
Bucanopsis aff. B. perelegans.
Meekospira? sp.
Euomphalus luxus.
Euomphalus utahensis.
Straparollus ophirensis.
Platyceras, several sp.
Phillipsia peroccidens.
Ostracoda indet.

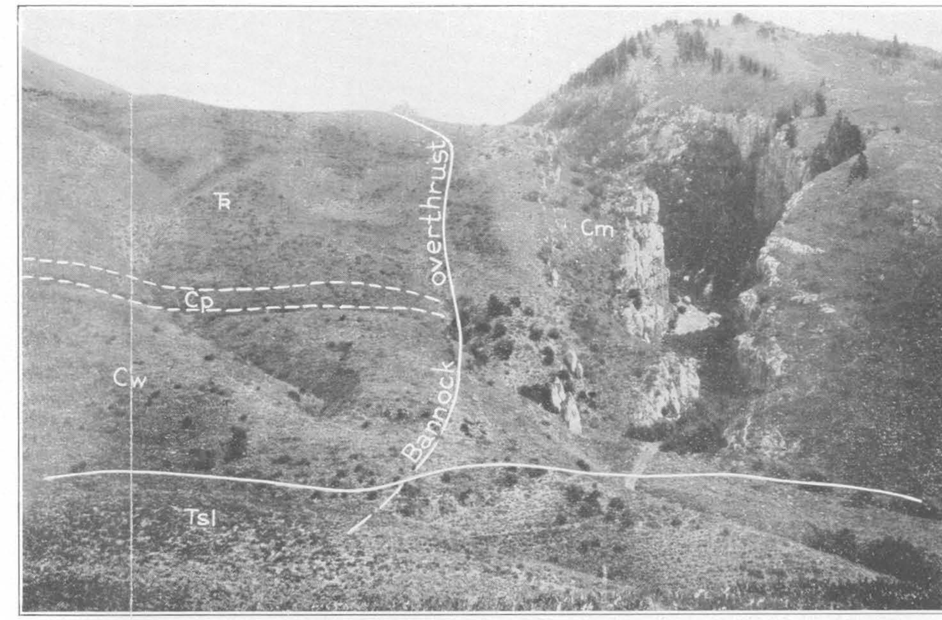
Mansfield, 17.

Mansfield 128.



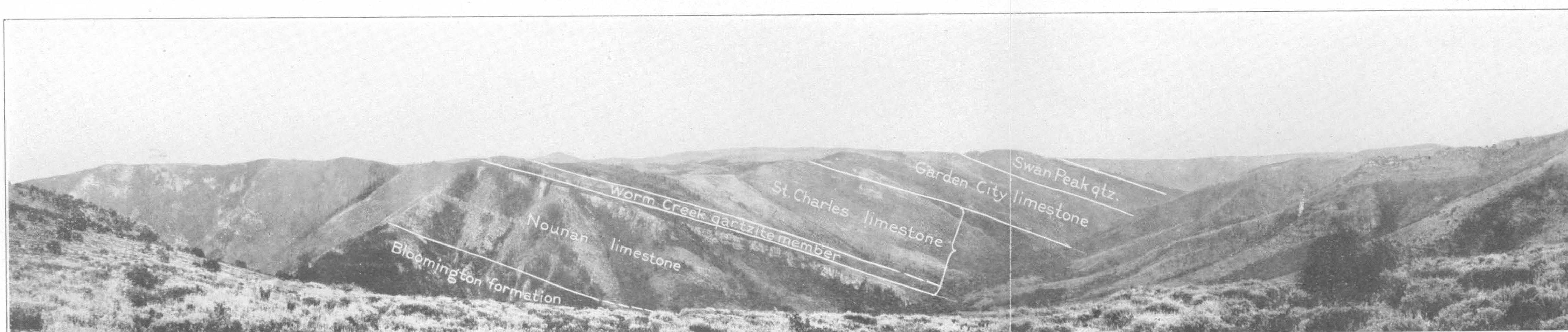
A. VIEW IN ASPEN RANGE NORTHWARD ACROSS SOUTH SULPHUR CANYON, T. 9 S., R. 43 E., SLUG CREEK QUADRANGLE

The Gannett and younger erosion surfaces are cut by canyons of the Blackfoot cycle. a, Ledges at top of Wells formation



B. LEDGES OF MADISON LIMESTONE OF BANNOCK OVERTHRUST BLOCK EXPOSED AT JOES GAP, NEAR MONTPELIER, MONTPELIER QUADRANGLE

Cm, Madison limestone; Cw, Wells formation; Cp, Phosphoria formation; Ѣ, Triassic formations; Tsl, Salt Lake formation



C. VIEW OF SOUTH SIDE OF ST. CHARLES CANYON AND OF THE BEAR RIVER RANGE FROM A POINT IN SEC. 18, T. 15 S., R. 43 E., MONTPELIER QUADRANGLE

Snowdrift peneplain (?) in extreme background

Mansfield 100 – 104.

The foregoing list has been selected with the view of showing the variety and general character of the Madison fauna of this area, and it includes the rare as well as the common, the nondescript as well as the characteristic. In one sense, however, the Madison, like most Carboniferous faunas, contains but few species that are really characteristic of it. To be characteristic in a practical way a species should occur everywhere within the formation and nowhere outside of it, and it should be readily distinguishable from related forms. Obviously if a species were rarely found its use in identifying a formation would be but small, or if it were so like some kindred shell as to be recognizable only by the cognoscenti, and not even by them unless the preservation was exceptionally good, the purpose would be equally ill served. In either case the value of such species in the identification of individual outcrops would be greatly impaired, that of the one kind because they could but rarely be identified, that of the other because they could be rarely found at all; yet in determining the age of the formation as a whole and likewise its correlation they would in any comprehensive set of collections prove of first importance.

In the sense just implied the Madison fauna contains few if any species that are strictly characteristic. Several, however, are characteristic in some degree. In the Carboniferous of North America, at least, *Leptaena analoga* seems to be restricted to the basal beds, not occurring probably above the Burlington limestone. *L. analoga*, however, has rather generally been held to be the same species as *L. rhomboidalis*, which has a long range through the lower and middle Paleozoic beds. On the other hand, *L. rhomboidalis* seems to occur very rarely in the Devonian faunas of the West, and any residual uncertainty on this score is generally dispelled by the associated faunas. In somewhat similar case is *Rhynchotetra elongata*. There is no Devonian species of the same region for which this Carboniferous shell is likely to be mistaken, not even *Camarotoechia endlichi*, and the Carboniferous species that resemble it are all of about the same geologic age. On the other hand, *L. analoga* and still more *Rhynchotetra elongata* are very rare in the Madison, so that these species, though they are highly distinctive of the Madison fauna as a whole, are of little use in identifying individual outcrops. Much more useful for this purpose is *Chonetes logani*, which, though less conspicuous, is much more commonly found. The associated *Chonetes* (*C. loganensis*) appears to range into Brazer limestone, but no species of the *logani* type, with its coarse, sometimes obscure ribs and coarse strong crenulations, is at present known in the Brazer, or indeed in any rocks of corresponding age in the east, though certain Devonian species are allied to it. Still another type that might be mentioned in this category is the one identified as *Schuchertella chemungensis*, which is common but not easily recognized. Species of very similar appearance occur in the Brazer and also in the Wells formation included under the genera *Orthotetes* or *Derbya*. Superficially there is no certain way of distinguishing these genera, but the pedicle valve of *Derbya* and *Orthotetes* is provided on the inside with a perpendicular plate extending longitudinally and dividing the interior into two equal parts. No corresponding structure is developed in *Schuchertella*. Brachial valves of these genera, however, are practically indistinguishable, and even pedicle valves are sometimes hard to distinguish because of difficulty in ascertaining the facts. The presence or absence of a septum is sometimes shown by exfoliated or broken specimens, but if necessary the fact can be ascertained by filing a notch across the shell a little anterior to the beak. So far as known septate shells like those of *Orthotetes* do not occur in the Madison, and on the other hand, nonseptate shells like those of *Schuchertella* are rare in the Brazer. The Brazer does contain in small numbers a nonseptate form which is provisionally referred under the genus *Streptorhynchus* and which is distinguished from the Madison species, though not always very sharply, by the greater height and more irregular growth of the pedicle valve. On the other hand, the Madison form differs so little from one which is common in the Upper Devonian that it is here cited under the same species, *Schuchertella chemungensis*. Much more might be said along these lines, especially in setting off the Madison against the Devonian faunas, for the two faunas seem to be sharply distinguished in the West and the features characteristic of the Madison are many. The very rarity of the Devonian and the very sharpness of the distinctions, however, blunt the point of any such discussion. It is much more pertinent to consider the relationship between the Madison and Brazer faunas. On this head mention has already been made of *Leptaena analoga*, *Schuchertella chemungensis*, *Chonetes logani*, and *Rhynchotetra elongata*. To these might be added the coral *Leptopora typa*, which is of rare occurrence and of not always obvious relationship, and also other forms which would be valuable if found at all, or if, when found, they could be definitely identified.

With a change from the specific to the general, the Madison horizon is somewhat distinguished by the very abundance of its fossils. Corals are especially numerous, chiefly Syringoporas and small cup corals. They are even more abundant in the Brazer, but in contrast the cup corals of the Madison are mostly small, those of the Brazer mostly of extraordinary size, and compound corals of the *Lithostrotion* type, which abound in the Brazer, are here unknown. They occur sparingly in the Madison of other regions, however, and their absence from our collections is probably accidental. Though corals are numerous, the main part of the Madison fauna consists of brachiopods, and the great bulk of the brachiopods are referable to the same genera that occur in the Brazer and even in the Wells. The species also are in many instances similar, and their recognition rests upon the perfection of the specimens as well as upon the knowledge of the observer, even though the distinction is generally very real. The abundance of *Chonetes* is somewhat characteristic of the Madison, as it is of many other early Mississippian faunas, and one species of this type, as already mentioned, does not occur in the Brazer. Spirifers likewise are in some collections very abundant, the common form being identified as *S. centronatus*. Spirifers of similar type occur in the Brazer (*Spirifer* aff. *S. pellensis*) and also in the Wells (*S. opimus* var. *occidentalis*), but *S. centronatus* can usually be recognized by its transverse shape and rather numerous fine costae.

Gastropods, and especially pelecypods, play but a small part in the Madison fauna. At some localities, to be sure, gastropods are fairly abundant, though most of them are poorly preserved and unidentifiable. Shells of the *Euomphalus* and *Straparollus* type are, however, more or less characteristic of the Madison fauna. Species which are similar but which can be adequately distinguished with suitable material occur at higher horizons. In the Madison, however, these shells are apt to be abundant and large; in the Brazer they are apt to be rare and small, especially those coiled into a high spire.

As has already been said, individually but few of the Madison species are strictly characteristic. In combination, however, they form a fauna that is really distinctive, but it is distinguished by its assemblage rather than by individual species, by the consensus of all rather than by the preponderance of one. The Madison fauna is also characterized by what it does not contain as well as by what it does contain, for it lacks many of the forms that occur in the Brazer. This evidence is much more to be considered in its application to the whole fauna than to the fauna taken piecemeal, as it appears in single collecions, and it is liable to modification as new facts of range and distribution are established.

PLATE 22

Schizophoria compacta Girty, n. sp. (p. 411)

FIGURES 1, 2, 3. Three views of a specimen preserved as an internal mold in chert. It is one of several cotypes. Boone limestone, Webb City, Mo.

FIGURES 4, 5. Exterior and interior of a silicified specimen referred to the same species. Madison limestone, Slug Creek quadrangle, Idaho (station 1667).

Leptaena analoga

FIGURES 6, 7, 8. Three views of a perfect specimen. Lake Valley limestone, Lake Valley, N. Mex.

Schuchertella chemungensis

FIGURES 9, 10. Two views of a finely striated pedicle valve. Madison limestone, Yellowstone National Park.

FIGURE 11. Brachial valve of the same general character. After Hall and Whitfield. Madison limestone, Ogden Canyon, Utah.

Chonetes loganensis

FIGURES 12, 13. Exterior of a brachial valve, natural size and enlarged. Madison limestone, Slug Creek quadrangle, Idaho (station 7618).

FIGURES 14, 15. Exteriors of two pedicle valves. Madison limestone, Slug Creek quadrangle, Idaho (station 7618).

Chonetes logani

FIGURES 16, 17, 18. Three views of a pedicle valve referred to this species. After Girty. Madison limestone, Yellowstone National Park.

Productus gallatinensis

FIGURES 19, 20, 21. Three views of a pedicle valve. Madison limestone, Montpelier quadrangle, Idaho (station 7419).

Productus parviformis

FIGURES 22, 23, 24. Three views of a pedicle valve. After Girty. Madison limestone, Yellowstone National Park.

FIGURES 25 and 26. Two views of a brachial valve referred to the same species. Madison limestone, T. 8 S., R. 41 E., Idaho (station 7622).

Productus galeanus Girty, n. sp. (p. 412)

FIGURES 27, 28, 29, 30. Four views of a pedicle valve. Figure 28 is enlarged to 1½ diameters. Madison limestone, Montpelier quadrangle, Idaho (station 7419).

FIGURES 31, 32. Two views of a brachial valve. Madison limestone, Montpelier quadrangle, Idaho (station 7419).

Rhynchotetra elongata

FIGURES 33, 34. Two views of a pedicle valve. Madison limestone, Afton quadrangle, Wyo. (station 1437).

Spiriferina solidirostris

FIGURE 35. Exterior of a pedicle valve. After Girty. Madison limestone, Yellowstone National Park.

Spirifer centronatus

FIGURE 36. Exterior of a brachial valve. After Hall and Whitfield. Madison limestone, Dry Canyon, Utah.

FIGURE 37. Exterior of a pedicle valve. After White. Madison limestone, Mountain Spring, Nev.

Composita humilis

FIGURES 38, 39. Views of two specimens. Madison limestone, Henry quadrangle, Idaho (station 7661).

Bellerophon mansfieldianus Girty, n. sp. (p. 413)

FIGURE 40. View of two silicified specimens cemented together by chert. Madison limestone, Slug Creek quadrangle, Idaho (station 1441).

FIGURE 41. Side view of the specimen on the left. Madison limestone, Slug Creek quadrangle, Idaho (station 1441).

Euomphalus luxus

FIGURES 42, 43. Two views of a small specimen. After Hall and Whitfield. Madison limestone, Dry Canyon, Utah.

Euomphalus utahensis

FIGURE 44. Upper side of one of the type specimens. After Hall and Whitfield. Madison limestone, Dry Canyon, Utah.

Straparollus ophirensis

FIGURES 45, 46. Two views of the type specimen. After Hall and Whitfield. Madison limestone, Dry Canyon, Utah.

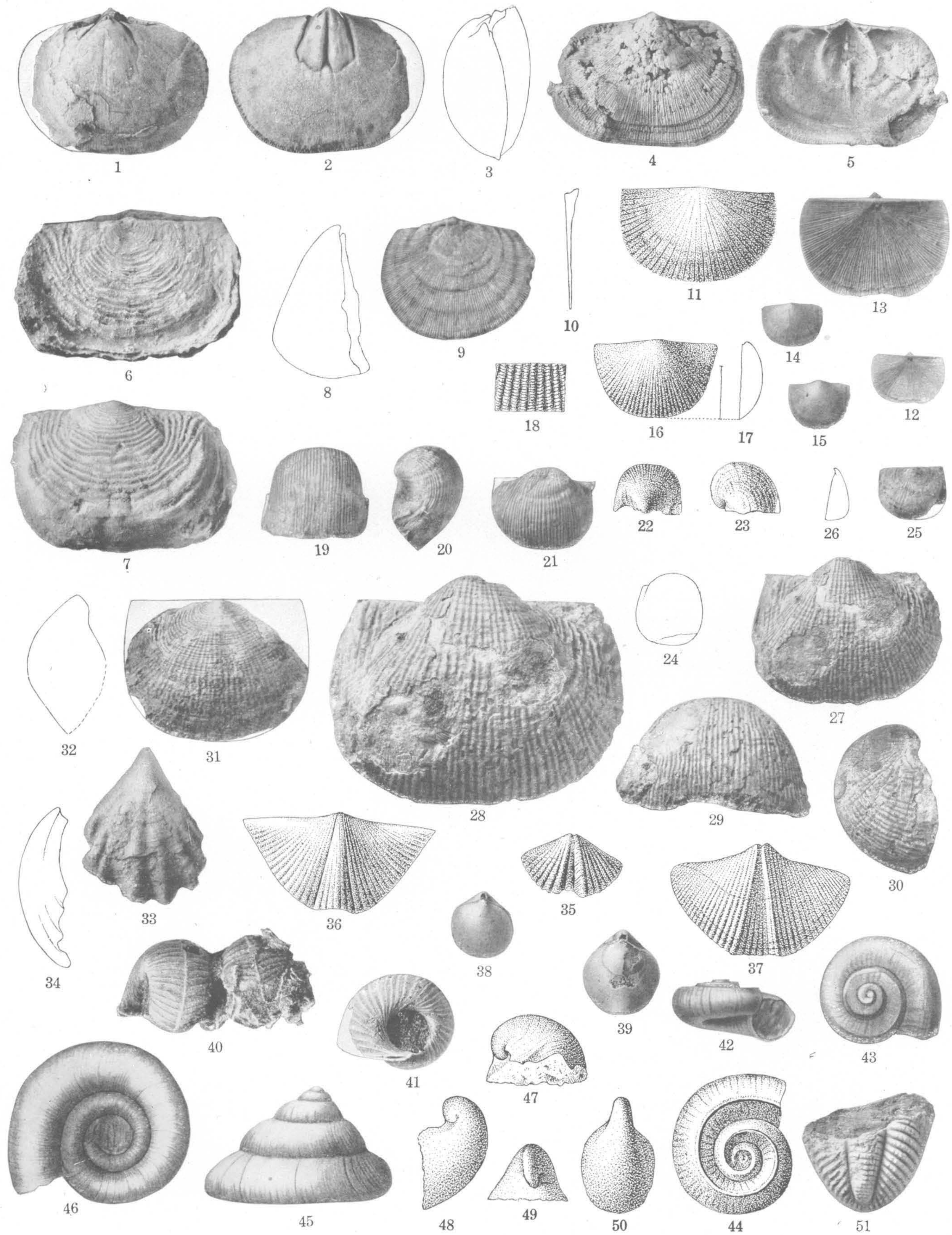
Platyceras sp.

FIGURE 47. View of an unidentified specimen. After Girty.

FIGURES 48, 49, 50. Three views of a specimen possibly belonging to a different species, ×2. After Girty. Madison limestone, Yellowstone National Park.

Phillipsia peroccidens

FIGURE 51. A fragmentary pygidium referred to this species. Madison limestone, Slug Creek quadrangle, Idaho (station 80b).



TYPICAL FOSSILS OF THE MADISON LIMESTONE

BRAZER LIMESTONE

Name.—The Brazer limestone was named by Richardson [13] from Brazer Canyon, in the Crawford Mountains, Randolph quadrangle, Utah.

Distribution.—The Brazer limestone is exposed in each of the quadrangles mapped except the Freedom. In the Montpelier quadrangle it occurs in four localities—in the Preuss Range (Meade Peak and adjacent ridges, pls. 34 and 46, *B*), at Montpelier and along the Bear River Plateau north of Hot Springs, and at the mouths of St. Charles and Dry Canyons, on the west side of Bear Lake Valley.

In the Slug Creek quadrangle this formation occupies considerable areas in Tps. 9 and 10 S., Rs. 43 and 44 E. It forms much of the high ridge between the forks of Twin Creek and follows the canyon of the Left Fork across the divide into the head of Slug Creek. It makes the crest of the Aspen Range, where the range is crossed by the line between Bannock and Bear Lake Counties, in the southwest corner of T. 9 S., R. 44 E., and is exposed at several places along the southwest flank of the range. Fine ledges are displayed in Fossil Canyon, Swan Lake Gulch, and Sulphur Canyon.

In the Crow Creek quadrangle the Brazer limestone follows the west flank of Dry Ridge near the west boundary for about 5 miles and forms the crest of the anticlinal Snowdrift Mountain for a somewhat greater distance. It also forms a broad strip along the west side of the valley of Crow Creek, in the northeast corner of T. 10 S., R. 45 E.

In the Henry quadrangle exposures of the Brazer are confined to a few small areas in the southwestern and northeastern parts of the quadrangle.

The Lanes Creek quadrangle contains notable exposures of the formation in the high ridge in the northwestern part of the quadrangle and on the southwest flank of the ridge northeast of Wooley Valley. Also a number of smaller exposures are connected with local anticlines in the southwestern part of T. 7 S., R. 44 E.

The Cranes Flat quadrangle contains conspicuous exposures of the Brazer in Wilson Ridge, in the southern part of the quadrangle, besides lesser areas in the southeast corner and on the west border near the center of T. 4. S., R. 40 E.

Character.—The Brazer limestone rests with apparent conformity on the Madison limestone, but evidence set forth on page 183 shows that it is probably unconformable on that formation. The rocks are massive, gray, light to dark, and weather white to light gray. Locally a dark shale, about 15 feet thick, is developed near the top. In the Ogden district, Utah, Blackwelder [14] has reported a Mississippian phosphate bed, and near Logan, Utah, Finch [15] has found such a bed in dark shales at the base of the Brazer limestone. In some prospects south of Joes Gap, in the Montpelier district (see p. 267), a bed 3 or 4 feet thick, composed of dark-brown phosphatic limy shale and limestone with a very little oolitic material, may lie at this horizon. Nodules of chert that have concentric and irregular forms and streaks of chert are present at many localities. Locally the limestones are arenaceous and are interbedded with sandstones. At many places, however, the beds are composed of relatively pure limestone adapted for industrial use. The limestones are at some places specked with siderite and seamed with calcite and at certain horizons are abundantly fossiliferous, but considerable portions of the formation are barren or only sparingly fossiliferous. The fauna includes large cup corals with many fine septa, *Syringopora, Lithostrotion, Martinia,* and *Productus brazerianus.* The Martinias are found in a bed near the top of the formation. The limestones are resistant to weathering and conspicuous as cliff makers, and produce a rugged country.

Plate 35, *A*, shows how the Brazer limestone forms the backbone of a rough ridge, the summit of which is called Limerock Mountain, in the southern part of the Cranes Flat quadrangle.

The following section was measured on the north side of Wells Canyon, in T. 10 S., R. 45 E., in the Crow Creek quadrangle:

TABLE 16.—*Section of exposed part of Brazer limestone on north side of Wells Canyon, T. 10 S., R. 45 E., Boise meridian, Idaho*

	Feet
Limestone, earthy; contains chert in irregular concretions and streaks parallel to bedding	20
Limestone, light gray to whitish, thin bedded; fossil collection 101	46
Sandstone, white, calcareous; bears large zaphrentoids	14
Limestone, dark gray, crinoidal, includes a *Martinia* zone; about	100
Shale and reddish quartzite fragments; about	30
Quartzite, whitish; outcrops small and scattered; bears small zaphrentoids	270
Concealed	200
Limestones, gray, in 1-foot to 3-foot beds; fossil collections	450
Base of Brazer limestone not exposed.	
	1, 130

Age.—The upper Mississippian age of the Brazer limestone rests on abundant fossil evidence, as indicated in the following discussion kindly contributed by G. H. Girty. (See also pls. 23, 24, and 25.)

A large number of collections were taken from the Brazer. Some of the collections show characters that suggest a classification into distinct faunal groups. Most, however, by combining the characters of several, appear no more related to one group than to another, or, by lacking individual character, show no close relation to any. Some of the differences in the Brazer faunas undoubtedly bear a relation to geologic time; others appear to be local or accidental.

[13] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 406-416, 1913.

[14] Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, p. 539, 1910.

[15] Finch, E. H., manuscript report.

PLATE 23

Productus brazerianus

FIGURES 1, 2. A large brachial valve (preserved as an external mold) and a small pedicle valve. After Girty. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 112).

Productus aff. P. keokuk

FIGURES 3, 4, 5. Three views of a specimen retaining both valves. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

FIGURE 6. Impression of a brachial valve. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

Productus richardsi Girty, n. sp. (p. 414).

FIGURES 7, 8. Two views of a brachial valve preserved as an external mold. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

FIGURES 9, 10. Two views of a more coarsely ribbed brachial valve, similarly preserved. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 44).

FIGURES 11, 12, 13. Three views of a pedicle valve. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

FIGURES 14, 15, 16. Three views of another pedicle valve. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

FIGURES 17, 18, 19. Three views of a finely ribbed pedicle valve. Brazer limestone, Cranes Flat quadrangle, Idaho (station 3034a).

Diaphragmus elegans

FIGURES 20, 21, 22, 23. Four views of a somewhat damaged specimen that retains both valves. Figure 21 shows part of the brachial valve surrounded by the broad diaphragm; the other figures show the line of cleavage where the diaphragm meets the pedicle valve, here close to the margin. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

FIGURES 24, 25, 26, 27. Four figures of another specimen similarly preserved. Figure 24, unlike Figure 21, shows the brachial valve and diaphragm as preserved with the marginal parts instead of with the dome of the pedicle valve. In this specimen the pedicle valve is developed much farther beyond the diaphragm than in the other. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

Composita sulcata

FIGURES 28, 29, 30. Three views of a specimen from which much of the thick shell has been exfoliated. Brazer limestone, Slug Creek quadrangle, Idaho (station 828).

FIGURES 31, 32, 33. Three views of another specimen. Brazer limestone, Slug Creek quadrangle, Idaho (station 828).

Pugnoides parvulus Girty, n. sp. (p. 414).

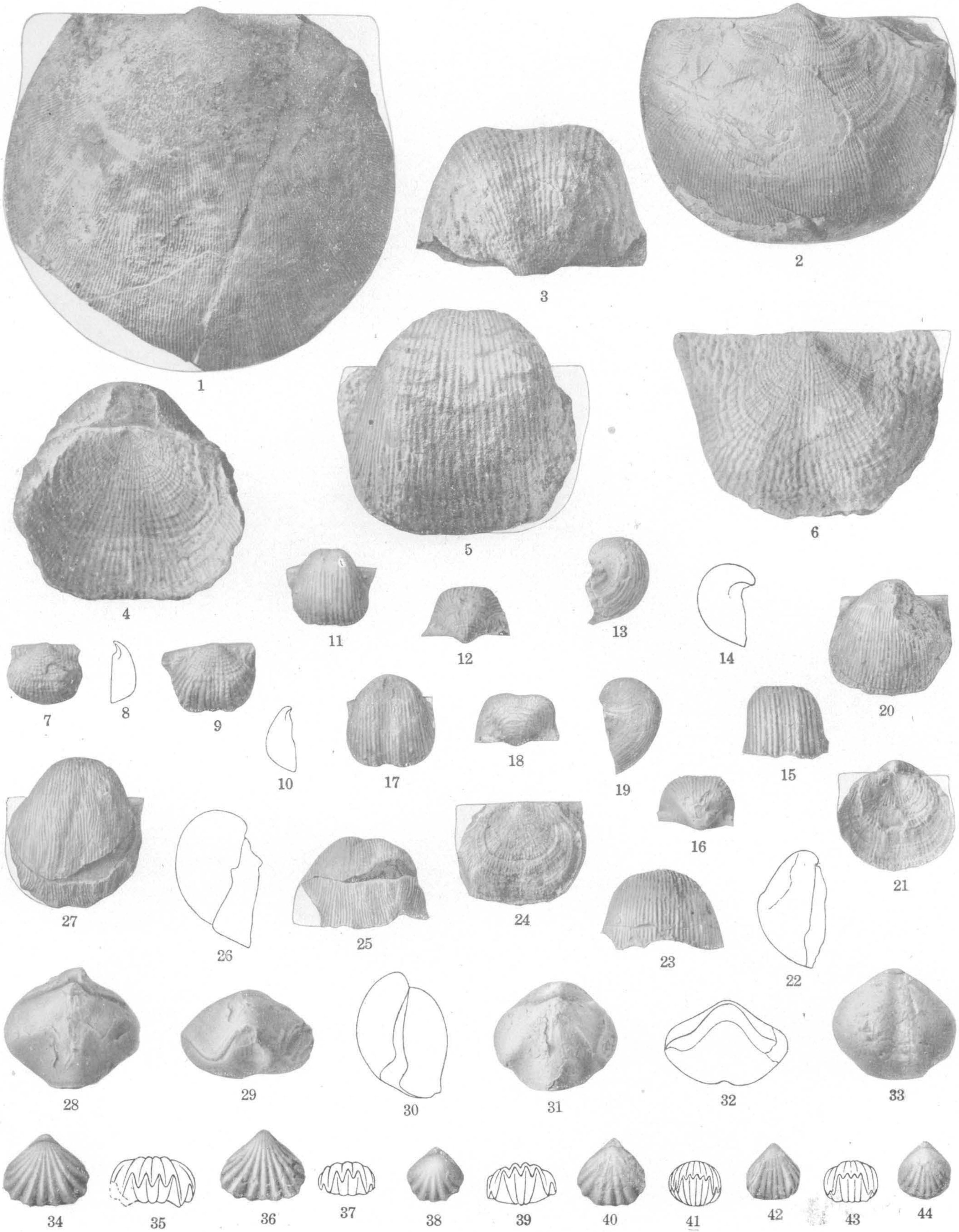
FIGURES 34, 35, 36. Three views of a specimen that has exceptionally strong and numerous plications, of which four occur on the fold and four others, which are distinct, on the lateral slopes, ×2. Brazer limestone, Henry quadrangle, Idaho (station 3023).

FIGURES 37, 38. Two views of a specimen that has three plications on the fold and three on each lateral slope, the last one faint, ×2. Brazer limestone, Henry quadrangle, Idaho (station 3023).

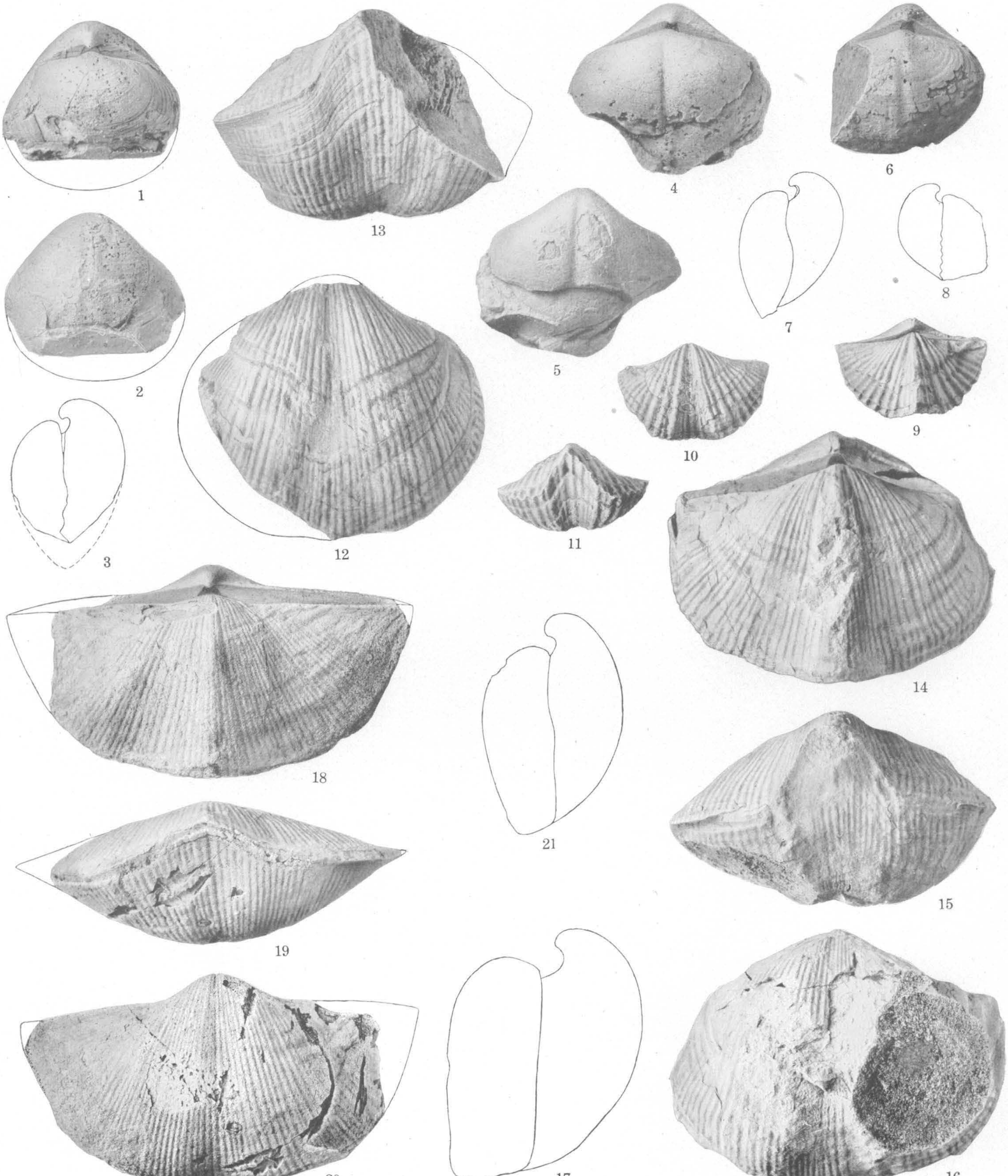
FIGURES 39, 40. Two views of a specimen that has four plications on the fold and three on the lateral slopes, two distinct and one faint, ×2. Brazer limestone, Henry quadrangle, Idaho (station 3023).

FIGURES 41, 42. Two views of a globular specimen that has five plications on the fold and three on each lateral slope, ×2. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

FIGURES 43, 44. Two views of a globular specimen that has four plications on the fold and three on each lateral slope, the last one on each side scarcely more than a denticle in the margin, ×2. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).



TYPICAL FOSSILS OF THE BRAZER LIMESTONE



TYPICAL FOSSILS OF THE BRAZER LIMESTONE

PLATE 24

Martinia lata Girty, n. sp. (p. 417)

FIGURES 1, 2, 3. Three views of a specimen that is broken across the front. The brachial valve is slightly displaced. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (stations 108 and 108a).

FIGURES 4, 5. Two views of another specimen which has a conspicuous sinus in both valves. Here also the brachial valve is displaced. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (stations 108 and 108a).

FIGURES 6, 7. Two views of a specimen complete at the anterior end but broken at one side. The valves are considerably displaced, causing the specimen to appear unsymmetrical. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (stations 108 and 108a).

Spirifer aff. S. pellensis

FIGURES 8, 9, 10, 11. Four views of an exfoliated specimen. Brazer limestone, T. 8 S., R. 41 E., Idaho (station 7623).

Spirifer brazerianus Girty, n. sp. (p. 416)

FIGURES 12, 13. Two views of an imperfect specimen. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

FIGURES 14, 15, 16, 17. Four views of a fairly complete specimen. Malformation on one side renders the specimen very unsymmetrical. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).

Spirifer haydenianus Girty, n. sp. (p. 416)

FIGURES 18, 19, 20, 21. Four figures of the type specimen. This *Spirifer* is not only much more extended transversely than *S. brazerianus* but also less convex and less strongly flexed into a fold and sinus. Brazer limestone, Slug Creek quadrangle, Idaho (station 7609).

PLATE 25

Pleurotomaria aspeniana Girty, n. sp. (p. 427)

FIGURES 1, 2, 3. Three views of a characteristic specimen. In Figure 3 faint growth lines are shown sweeping backward to the slit band above, ×3. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).
FIGURES 4, 5, 6, 7. Four views of a rather large specimen ×3. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Pleurotomaria brazeriana Girty, n. sp. (p. 428)

FIGURES 8, 9. Two views of a broken specimen ×3. Brazer limestone, Henry quadrangle, Idaho (station 3023).
FIGURES 10, 11. Two views of a smaller specimen ×3. Brazer limestone, Henry quadrangle, Idaho (station 3023).
FIGURE 12. A broken specimen with sharply expressed sculpture ×3. Brazer limestone Henry quadrangle, Idaho (station 3023).

Pleurotomaria pealeana Girty, n. sp. (p. 429)

FIGURES 13, 14, 15, 16. Four views of what is probably a young specimen ×3. Brazer limestone, Slug Creek quadrangle, Idaho (station 7607a).
FIGURES 17, 18. Two views of a large specimen apparently belonging to the same species ×2. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Worthenia? sp.

FIGURES 19, 20. Two views of a specimen whose sculpture is not sharply defined ×3. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Pleurotomaria dinglensis Girty, n. sp. (p. 428)

FIGURES 21, 22, 23, 24. Four views of the typical specimen ×5. Brazer limestone, Montpelier quadrangle, Idaho (station 1446).

Phanerotrema brazerianum Girty, n. sp. (p. 430)

FIGURES 25, 26, 27. Three views of the typical specimen ×5. Brazer limestone, Montpelier quadrangle, Idaho (station 1446).

Phymatifer? tricarinatus Girty, n. sp. (p. 431)

FIGURES 28, 29, 30. Three views of the typical specimen ×3. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Bulimorpha elegans Girty, n. sp. (p. 432)

FIGURES 31, 32. Two views of the typical specimen. Natural size. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Capulus striatulus Girty, n. sp. (p. 430)

FIGURES 33, 34, 35. Three views of a characteristic specimen ×2. Brazer limestone, Henry quadrangle, Idaho (station 3023).
FIGURES 36, 37, 38. Three views of a specimen which, if not broken at the posterior margin, is more inclined ×2. Brazer limestone, Henry quadrangle, Idaho (station 3023).

Capulus striatulus Girty, var. gracilis Girty, n. var. (p. 431)

FIGURES 39, 40, 41. Three views of the typical specimen ×4. Brazer limestone, Henry quadrangle, Idaho (station 3023).

Leptodesma occidentale Girty, n. sp. (p. 418)

FIGURES 42, 43, 44. Three left valves of slightly different character ×3. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).

Edmondia brazeriana Girty, n. sp. (p. 418)

FIGURE 45. The typical specimen ×4. Brazer limestone, Montpelier quadrangle, Idaho (station 1446).

Schizodus semistriatus Girty, n. sp. (p. 418)

FIGURES 46, 47, 48, 49. Two right valves, natural size and enlarged to 3 diameters. Brazer limestone, Montpelier quadrangle, Idaho (station 1446).

Sphenotus meekanus Girty, n. sp. (p. 426)

FIGURE 50. The typical specimen ×4. Brazer limestone, Henry quadrangle, Idaho (station 3023).

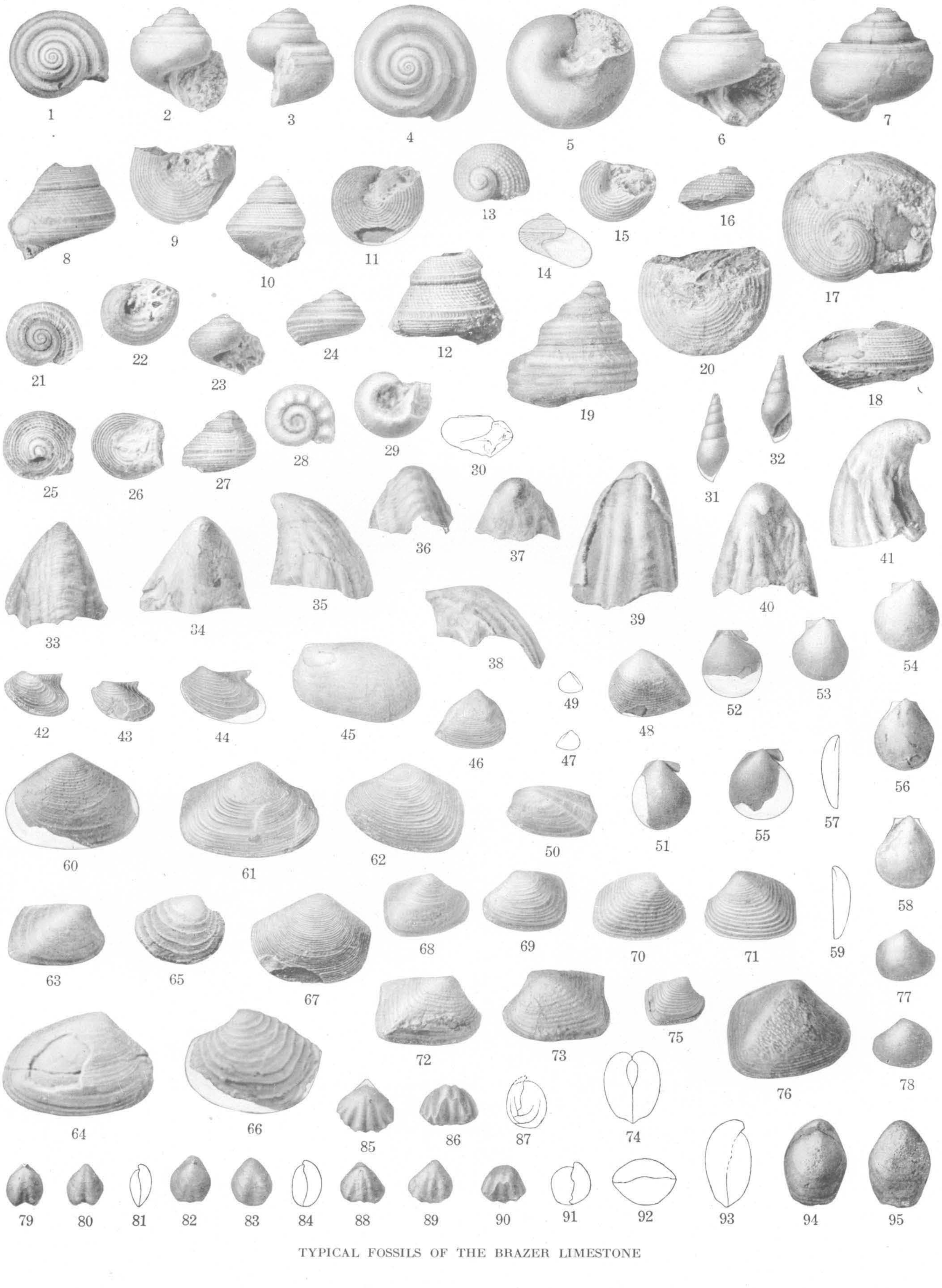
Streblopteria simpliciformis Girty, n. sp. (p. 419)

FIGURES 51, 52. Two right valves ×2. Brazer limestone, Montpelier quadrangle, Idaho (station 1446).
FIGURES 53, 54, 55. Two left valves and one right valve ×2. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Streblopteria simpliciformis Girty, var. marginata Girty, n. var. (p. 420)

FIGURES 56, 57, 58, 59. Two left valves. The inflected margins are not as conspicuous in the side views as they are in the specimens themselves, ×2. Brazer limestone, Henry quadrangle, Idaho (station 3023).

[Description continued on p. 67]



TYPICAL FOSSILS OF THE BRAZER LIMESTONE

Cypricardella dubia Girty, n. sp. (p. 422)

FIGURE 60. The typical specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Cypricardella occidentalis Girty, n. sp. (p. 423)

FIGURE 61. The typical specimen ×4. Brazer limestone, Henry quadrangle, Idaho (station 3023).

Cypricardella occidentalis Girty, var. lacus-cygni Girty, n. var. (p. 424)

FIGURE 62. The typical specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).

Cypricardella varicosa Girty, n. sp. (p. 426)

FIGURE 63. The typical specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).

Cypricardella sublevis Girty, n. sp. (p. 424)

FIGURE 64. The typical specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).

Cypricardella sectoralis Girty, n. sp. (p. 424)

FIGURE 65. A right valve ×4. Brazer limestone, Henry quadrangle, Idaho (station 3023).
FIGURE 66. A left valve ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Cypricardella tenuilineata Girty, n. sp. (p. 425)

FIGURE 67. The typical specimen ×4. Brazer limestone, Henry quadrangle, Idaho (station 3023).

Cypricardella brazeriana Girty, n. sp. (p. 422)

FIGURES 68, 69, 70, 71. Views of two specimens retaining both valves. The original of Figures 70 and 71 may be regarded as the type specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).

Cypricardella gibbosa Girty, n. sp. (p. 423)

FIGURES 72, 73, 74. Three views of a large specimen retaining both valves ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).
FIGURE 75. A small but characteristic specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).

Cypricardella subquadrata Girty, n. sp. (p. 425)

FIGURE 76. The typical specimen ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7606a).
FIGURES 77, 78. A small specimen which retains both valves but which is doubtfully referred to this species ×4. Brazer limestone, Slug Creek quadrangle, Idaho (station 7607a).

Girtyella turgida

FIGURES 79, 80, 81. Three views of a somewhat compressed specimen. Natural size. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).
FIGURES 82, 83, 84. Three views of gibbous specimen. Natural size. Brazer limestone, Slug Creek quadrangle, Idaho (station 975).

Camarophoria explanata

FIGURES 85, 86, 87. Three views of a large strongly plicated specimen. Natural size. Brazer limestone, Crow Creek quadrangle, Idaho-Wyo. (station 101).
FIGURES 88, 89, 90, 91. Four views of a specimen which is nearly perfect but which is unsymmetrical, possibly through compression. Natural size. Brazer limestone, Slug Creek quadrangle, Idaho (station 7411).

Cranaena occidentalis Girty, n. sp. (p. 415)

FIGURES 92, 93, 94, 95. Four views of the typical specimen. The valves have become somewhat skewed, which has caused the specimen to appear slightly unsymmetrical and has somewhat enhanced the pentagonal shape of the outline. Natural size. Brazer limestone, Portneuf quadrangle, Idaho (station 5925).

Taken as a whole, the Brazer fauna is peculiarly rich in corals, which consequently form one of its characteristic features. Most striking among these are colonies of the *Lithostrotion* type, some of which have a massive, others a bushy mode of growth. Scarcely less common, though decidedly less characteristic, are masses of *Syringopora.* Cup corals also are very abundant, and some of them are exceptionally large. They have been referred in part to *Cyathophyllum* (*C. multilamella*), in part to *Campophyllum,* and many of the smaller forms are referable to *Triplophyllum.* Other genera, such as *Amplexus, Lophophyllum, Cystelasma,* and *Clisiophyllum,* have likewise been recognized in a more or less provisional manner. No group of Carboniferous fossils that is as abundant and as significant as the corals has received so little attention and is in so chaotic a condition, and what has just been said of the corals of the Brazer is merely an attempt to convey some general idea of their character and abundance; but little close study has been applied to them. The Lithostrotions are largely confined to this formation. *Lithostrotion*-like forms have been noted in a few collections from the Madison and also in a few collections from the Wells, but either the generic reference or the stratigraphic reference is in most cases tinctured with doubt. The large cup corals also are found chiefly in the Brazer, but the small zaphrentoids of the *Triplophyllum* type and the Syringoporas range practically throughout the Madison, the Brazer, and the Wells. Those that belong to the different periods are to be distinguished, if at all, only by careful and laborious study. Some of the Brazer collections contain corals alone; some contain corals with a varying quota of other forms; very few are entirely without them.

Some of the Brazer collections are characterized by the extreme abundance of a single species, almost to the exclusion of other types. *Productus brazerianus,* which is itself a rather striking form, if for no other reason than because of its large size, sometimes occurs in this way, forming the main constituent of certain beds of limestone. At other localities *Martinia lata* is found with scarcely more rock than is necessary to hold the shells together, thus creating a sort of paradox, inasmuch as specimens are so numerous that perfect ones are hardly to be obtained. A much smaller *Martinia* is in places equally abundant; whether these are young shells of *M. lata* or a distinct species has not been satisfactorily determined. In some collections *Martinia lata* and *Productus brazerianus* occur together, and in others (though by no means in such great numbers) they form part of a varied fauna, so that it is only where the faunal phase is highly specialized that the collection falls naturally into one group rather than into another.

As has just been said, for the most part only collections of marked peculiarity are amenable to decisive classification, and in many instances, no doubt, the peculiarities are due more to the accidents of collecting than to some property of the horizon or of the place. Large corals, whether colonies of *Lithostrotion* or individuals of the smaller but nevertheless conspicuous cyathophylloids, would, in a collection hastily made, be the first fossils to be taken, or possibly the only ones, where without question a larger, more varied, and perhaps more diagnostic fauna might have been recovered. On the other hand, the small, inconspicuous shells of the so-called Spergen fauna of the Brazer limestone, to which consideration will shortly be given, might be overlooked if the rock were not closely examined.

Some of the Brazer faunas doubtless owe their character to accident or at least to causes obscure and, so far as can be judged, of minor significance. Other facies, however, are related to stratigraphic occurrence. Thus, near the top of the Brazer we found at some localities a varied fauna which has a Chester facies and is comparable in many respects to the typical Chester faunas of the Mississippi Valley. Apparently holding a stratigraphic position below this Chester fauna, we found in places another interesting and rather well-defined fauna which consists for the most part of small pelecypods and gastropods, and is comparable to the Spergen and Ste. Genevieve faunas of the Mississippian section. This fauna is probably to be regarded as older than the foregoing on faunal as well as on stratigraphic evidence. These aspects of the Brazer fauna deserve detailed consideration.

The Chester fauna in its most typical aspect was found at the top of the Brazer, though in only a few places. Other collections, less well marked faunally or less well located stratigraphically, contain some of the more characteristic species, but they also contain some that are alien. As illustrating the Chester fauna, therefore, it has seemed best to list one large and characteristic collection rather than to compile a list from a number of collections in which there were possibly included species from other faunas and other horizons. Two collections made on different occasions but at the same locality have, then, furnished the following species:

A characteristic fauna from beds near the top of the Brazer limestone collected in the Crow Creek quadrangle, sec. 10, T. 10 S., R. 45 E. (Station 101, p. 63.)

Campophyllum, n. sp.	Edmondia sp.
Anisotrypa? sp.	Sphenotus sp.
Stenopora aff. S. ramosa.	Parallelodon sp.
Anomalopora fibrosa, n. gen. and n. sp.	Cypricardinia indianensis.
Rhombopora sp.	Schizodus sp.
Productus ovatus.	Myalina elongata.
Productus richardsi.	Pseudomonotis? sp.
Productus aff. P. inflatus.	Conocardium sp.
Productus aff. P. keokuk.	Sulcatipinna ludlowi.
Productus sp.	Deltopecten? aff. D. batesvillensis.
Pustula aff. P. genevievensis.	Deltopecten? aff. D. tahlequahensis.
Pustula? sp.	Aviculipecten aff. A. jenneyi.
Diaphragmus elegans.	Pleurotomaria? sp.
Camarophoria explanata.	Euomphalus sp.
Dielasma sp.	Meekospira aff. M. minuta.
Spirifer brazerianus.	Orthoceras sp.
Spirifer aff. S. pellensis.	Griffithides mucronatus.
Brachythyris? sp.	Poretus? sp.
Spiriferina aff. S. salemensis.	
Composita trinuclea.	

To this list the following species may be added as coming from the same horizon—or at least so it is thought—but from scattered localities. In this connection it may be well to note, though the same caution applies generally, that the collections were made at various times and by various collectors, not all of them equally careful or well versed, and that some features which appear anomalous may be due to a failure to discriminate between different horizons in the field or sometimes to mixing in the laboratory.

Lithostrotion sp.	Pustula aff. P. vittata.
Pentremites aff. P. conoideus var. perlongus.	Dielasma aff. D. formosum.
Schellwienella, n. sp.	Cliothyridina sublamellosa.
Chonetes loganensis.	Eumetria verneuiliana.
Productus inflatus.	Hustedia sp.
Productus aff. P. parvus.	Phanerotrema brazerianum.
	Bembexia sp.

Although this highest fauna of the Brazer is not a typical Chester fauna, inasmuch as it lacks some of the commonest forms of the typical Chester and contains others not found there at all, it is, without much question, of Chester age. This is indicated by its general facies and especially by such species as *Diaphragmus elegans* and *Camarophoria explanata,* which are fairly abundant. Of the types that are almost omnipresent in the typical Chester faunas but are absent in this one *Archi-*

medes and *Pentremites* are undoubtedly most worthy of note, but *Archimedes* and *Pentremites*, in their abundance at least seem to be regional types and largely restricted to the eastern half of the continent. *Archimedes* does occur in the West, and even abundantly, but only a few such occurrences are known, while *Pentremites*, though not unrecorded, is or appears to be in our western faunas among the rarest of Mississippian types. Other though less diagnostic species will also come to mind as being absent from the Brazer fauna listed above, but the absence of such types is in line with what we know of the Chester faunas of the West, even though it is at variance with what we know of the Chester faunas of the East. On the other hand, *Spirifer brazerianus, Spirifer haydenianus, Productus richardsi,* and some others are distinctly alien to the faunas of the typical Chester. Indeed, *S. brazerianus* and *S. haydenianus* represent types of *Spirifer* that in the Mississippi Valley have not been found above the Keokuk, and they lend the Brazer fauna a singular character. They are probably to be regarded as varieties of *Spirifer striatus*, just as *Productus brazerianus* is probably to be regarded as a variety of *P. giganteus*, thus allying the Brazer faunas with that of the Mountain limestone of Asia, of continental Europe, and of England, or at least suggesting that the Brazer had a composite or intermediate facies between that fauna and our own typical Mississippian. Certain aspects of this highest fauna of the Brazer carry a suggestion of early Chester if not of slightly pre-Chester age. As of this character one might cite *Productus* aff. *P. keokuk*, *Pustula* aff. *P. genevievensis*, *Spiriferina* aff. *S. salemensis*, *Composita trinuclea*, and some others. More complete collections and more detailed study are needed before the upper Brazer fauna can be correlated definitely with any minor subdivision of the typical Mississippian section.

The fauna of the Brazer, which is on the whole more interesting than any other, is the one which has been the longest known. In 1873 Meek[16] published a notice of a fauna from the divide between Ross Fork and Lincoln Valley, Mont., which presented a remarkable resemblance to the Spergen fauna of Indiana and which is probably the same fauna that I am about to consider, though a wide stretch of country lies between them.

Meek's list, with his annotations,[17] I quote as follows:

1. Zaphrentis stansburyi Hall (?).
2. Cyathophyllum subcaespitosum Meek.
3. Lophophyllum or Cyathaxonia. Perhaps more than one small species.
4. Syringopora.
5. Platycrinus. Body only of a very small globose species.
6. Pentremites bradleyi Meek.
7. Pentremites godoni Defrance (?).
8. Pentremites conoideus Hall.
9. Pentremites subconoideus Meek.
10. Melonites. A single very thick, hexagonal, interambulacral plate, with outer surface a little convex and granular.
12. Hemipronites. Very small or only about one-half inch in diameter, with a high triangular area.
13. Productus. About half an inch in diameter, very gibbous; beak narrow, stongly incurved; surface smooth, or apparently so.
14. Productus. Like P. biserialis Hall.
15. Productus semireticulatus Martin (species). Large and well developed.
16. Productus longispinus Sowerby. Of usual size.
17. Rhynchonella macra Hall (?).
18. Rhynchonella mutata Hall (?).
19. Athyris. Small and like A. hirsuta Hall.
20. Retzia verneuiliana Hall.
21. Spirifer. Very small; like a miniature S. opimus Hall.
22. Spiriferina. Like S. spinosa (Spirifera spinosà Hall) but smaller and apparently without spine bases.
23. Terebratula turgida Hall.
24. Nucula shumardii Hall.
25. Macrodon (?).
26. Cypricardina indianensis (Cypricardella indianensis Hall).
27. Cypricardella plicata Hall (?).
28. Cypricardella subelliptica Hall (?).
29. Nuculana nasuta (Nucula nasuta Hall?).
30. Conocardium meekianum Hall (?).
31. Platyceras. One or more small species.
32. Euomphalus spurgenensis Hall.
33. Naticopsis. Like Naticopsis carleyi (Natica carleyi Hall).
34. Bellerophon. Two small smooth species.
35. Holopea. Fragments of very small species.
36. Pleurotomaria. Very small.
37. Cythere. Very near C. carbonaria Hall.
38. Spirorbis annulatus Hall.
39. Phillipsia. Fragments of small species.

Faunas more or less closely resembling that listed by Meek are represented among my collections by nine lots, but as they differ somewhat among themselves and may not have come from the same horizon, it has seemed best to list one representative collection and offer comments merely on the others.

A varied fauna which has a Spergen facies, collected from the Brazer limestone in the NE. ¼ sec. 14, T. 5 S., R. 41 E., 6¾ miles northwest of Henry (station 3023)

Cladochonus sp.
Paleacis cuneiformis.
Triplophyllum aff. T. cassedayi.
Cystelasma aff. C. tabulatum.
Lithostrotion? sp.
Echinocrinus, 2 sp.
Pentremites sp.
Mesoblastus, n. sp.
Fistulipora sp.
Stenopora sp.
Batostomella sp.
Dichotrypa sp.
Anomalopora fibrosa n. gen. and n. sp.
Fenestella, several sp.
Hemitrypa sp.
Polypora sp.
Cystodictya lineata.
Cystodictya pustulosa.
Streblotrypa sp.
Crania sp.
Streptorhynchus sp.
Productus brazerianus, n. sp.?
Productus ovatus.
Productus aff. P. parvus.
Productus aff. P. setiger.
Pustula biseriata.
Pustula indianensis.
Pustula, n. sp.
Camarotoechia grosvenori.
Camarotoechia sp.
Pugnoides parvulus, n. sp.
Girtyella turgida.
Dielasma formosum.
Dielasma, n. sp.
Dielasma? sp.
Spirifer pellensis.
Spirifer aff. S. rostellatus
Brachythyris sp.
Spiriferina aff. S. salemensis.
Spiriferina transversa.
Spiriferina transversa var.
Spiriferina sp.
Reticularia setigera.
Composita trinuclea.
Composita sp.
Cliothyridina hirsuta.
Eumetria verneuiliana.
Nucula randolphensis?
Nucula illinoisensis?
Nucula shumardiana?
Leda, n. sp.
Yoldia levistriata?
Yoldia sp.
Parallelodon aff. P. obsoletus.
Parallelodon aff. P. carbonarius.
Parallelodon micronema.
Leptodesma occidentale, n. sp.
Conocardium pratteninum.
Conocardium aff. C. carinatum.
Conocardium, 3 sp.
Schizodus semistriatus, n. sp.
Streblopteria simpliciformis, n. sp.
Streblopteria simpliciformis var. marginata, n. var.
Deltopecten aff. D. monroensis.
Myalina aff. M. swallowi.
Myalina elongata.
Sphenotus plicatus.
Sphenotus Meekianus, n. sp.
Sphenotus monroensis.
Sphenotus, 2 sp.
Sphenotus?, n. sp.
Cypricardinia indianensis.
Cypricardinia indianensis var.

[16] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1872, p. 433, 1873.
[17] Idem, p. 470.

Cypricardinia?, n. sp.
Cypricardella sectoralis, n. sp.
Cypricardella brazeriana, n. sp.
Cypricardella tenuilineata, n. sp.
Cypricardella occidentalis, n. sp.
Cypricardella gibbosa, n. sp.
Cypricardella sp.
Levidentalium venustum.
Dentalium??, n. sp.
Gryphochiton parvus.
Bellerophon sublevis.
Bellerophon sp.
Bucanopsis textilis.
Euphemus randolphensis.
Pleurotomaria henryensis.
Pleurotomaria brazeriana.
Pleurotomaria brazeriana var.
Pleurotomaria bradleyi.
Pleurotomaria bradleyi var.
Pleurotomaria aff. P. piasaensis.
Pleurotomaria aff. P. giffordi.
Pleurotomaria, 3 sp.
Euconospira, 2 sp.
Euconospira? sp.
Goniospira?, n. sp.
Murchisonia aff. M. archimedes.
Murchisonia aff. M. missouriensis.
Murchisonia aff. M. nebraskensis.
Straparollus planispira.
Straparollus subumbilicatus?
Straparollus quadrivolvis.
Euomphalus spergenensis?
Euomphalus similis, var. planus.
Cyclonema aff. C. globosum.
Cyclonema, 2 sp.
Anomphalus rotuliformis.
Naticopsis wortheni.
Naticopsis carleyana.
Sphaerodoma aff. S. hallana.
Sphaerodoma stinesvillensis var.
Sphaerodoma aff. S. fusiformis.
Sphaerodoma? melanoides.
Pseudomelania? sp.
Bulimorpha elegans, n. sp.
Aclisina aff. A. quadricarinata.
Aclisina?? sp.
Holopella, 4 sp.
Holopea proutana.
Holopea aff. H. oligospira.
Capulus striatulus, n. sp.
Capulus sp.
Platyceras aff. P. acutirostre.
Platyceras aff. P. latum.
Orthoceras? sp.
Coelonautilus, 2 sp.
Coelonautilus? sp.
Griffithides, 2 sp.
Paraparchites carbonarius.
Paraparchites carbonarius var.
Paraparchites nicklesi.
Paraparchites, n. sp.
Bairdia attenuata.
Bairdia aff. B. cestriensis.
Bairdia, n. sp.
Bairdia sp.
Glyptopleura inopinata, var.

The foregoing list comprises approximately 150 species, but to give it entire seemed worth while in order to convey more adequately the variety and richness of this interesting fauna as it is represented in a single collection. To be sure, species have been more liberally dispensed here than if the work had been of the description order. There the tendency is to include doubtful forms with those definitely recognized, so as to avoid burdening the literature; here no such consideration exists. Long as it is, this list might be considerably augmented by species collected at other localities but supposed to belong in the same fauna. Only those of special interest, however, will be cited; they are listed below:

Interesting species not found at station 3023, but contained in other collections from the Brazer limestone, supposed to represent about the same horizon

Endothyra baileyi
Lithostrotion harmodites?
Pentremites bradleyi.
Pentremites conoideus.
Spirorbis annulatus.
Spirorbis nodulosus.
Chonetes loganensis.
Edmondia brazeriana, n. sp.
Leda curta?
Aviculipecten talboti.
Aviculipecten squamula.
Sphenotus, n. sp. aff. S. obliquus.
Cypricardella sublevis, n. sp.
Cypricardella dubia, n. sp.
Cypricardella varicosa, n. sp.
Cypricardella subquadrata, n. sp.
Gryphochiton, n. sp.
Pleurotomaria aspeniana, n. sp.
Pleurotomaria pealeana, n. sp.
Pleurotomaria dinglensis, n. sp.
Pleurotomaria tayloriana.
Pleurotomaria, n. sp. aff. P. conula.
Pleurotomaria aff. P. arkansana.
Pleurotomaria, 2 n. sp.
Phanerotrema brazerianum.
Solenospira aff. S. turritella?
Solenospira aff. S. attenuata.
Euomphalus spergenensis var. planorbiformis.
Euomphalus planispira.
Cyclonema aff. C. leavenworthanum.
Naticopsis splendens.
Sphaerodoma stinesvillensis.
Sphaerodoma littonana?
Bulimorpha aff. B. chrysalis.
Bulimorpha bulimiformis?
Bulimorpha aff. B. elongata.
Macrocheilina canaliculata.
Aclisina aff. A. swallowiana.
Holopea, n. sp. aff. H. proutana.
Zygopleura, 2 sp.
Platyceras, n. sp.

Small pelecypods and gastropods resembling those of the Spergen are found at several horizons in the Carboniferous. In the East, faunas thus suggesting the Spergen occur in the Chester, also in the Pottsville, and perhaps even in the higher Pennsylvanian, if close regard for detail is not demanded. Many of the pelecypods and gastropods of the higher horizons merely resemble Spergen species but are not identical with them, and in any good collection, and especially in any series of collections, they are associated with forms that indicate their true horizon. Indeed, the Madison fauna, which precedes the Brazer in this region, is not without a goodly representation of small gastropods and pelecypods, most of which belong to Brazer genera and many of which closely resemble Brazer species. These types have been recovered from the Madison in only a relatively few collections where the shells have been silicified, but I suspect that they are more common than is apparent. Where I have seen them these small fossils show great diversity, though their preservation is such that they can be neither identified nor described. For this reason they are not cited in the list of Madison fossils, that list in fact being intended as an exposition of only the more characteristic species, a description that does not fit these rare and little known forms. Taken together they make up a facies so like that of the Brazer, nice distinctions being out of the question, that, if the more diagnostic or at least more closely identifiable species happen to be lacking, there is actually some doubt as to where such collections belong. It may well be questioned whether these misnamed "recurrences" of a Spergen fauna do not bespeak environmental conditions that were continuous through all geologic time but not continuous at the same place. In attempting to correlate the so-called Spergen fauna of the Brazer limestone this question is not to be evaded.

The so-called Spergen fauna from the Brazer contains a number of new species, and these in the present state of our knowledge have little or no significance in correlation. It also contains many species that are not known in the true Spergen fauna, some of which appear to belong to later faunas, and others, though not definitely new or definitely identifiable with later species, are at least definitely alien to the Spergen fauna as we know it to-day. As conspicuous types that occur in the Brazer and not in the Spergen may be mentioned *Mesoblastus*, *Parallelodon*, *Schizodus*, *Streblopteria*, *Deltopecten*, *Myalina*, and *Euphemus*, although these genera may be represented in the Brazer by new species or by forms that appear to be identical with post-Spergen species. Representatives of all these genera are known in both older and younger rocks than the Spergen, and undoubtedly representatives of them lived in Spergen time as well, though they have not yet been found or if found, have not been recognized as of that age. It would be useless to speculate as to what the Spergen species of *Euphemus* and other genera will be like when they are brought to light, but the consideration just advanced should make us wary in giving weight to evidence of this sort. The fact that those genera are known in the Brazer but not in the Spergen does not necessarily point to the conclusion that this Brazer fauna is not of Spergen age.

Even if we take the more solid ground, caution rather greater than ordinary must be used in interpreting these facts as we know them, for though it be granted that some of the identifications of the Brazer forms will be revised, the Brazer fauna appears to contain some species that are known in the Spergen and not in the later faunas and other species that are known in the later faunas and not in the Spergen. The explanation of the anomaly is to be found, I believe, largely in the imperfect state of our knowledge, for the "recurrent Spergen faunas" have as yet received no detailed study, and the Spergen fauna itself is known from only a small area and will undoubtedly prove far more rich in genera and species than it now appears to be. Another consideration that is far from negligible is the great distance that lies between the Brazer fauna and many of those with which it has just been compared. The geographic factor would almost certainly assert itself strongly even between faunas that were contemporaneous.

In view of all the facts just recited, taken together with the stratigraphic position of this fauna in the Brazer below a very different fauna which shows marked Chester affinities, the fauna from station 3023 may tentatively be regarded as essentially of Spergen age. Furthermore, the other Spergenlike faunas of the Brazer, though they present individual features, are probably to be regarded as of the same horizon with each other and with this one. Furthermore, though on less substantial grounds, this fauna from Idaho may probably be regarded as of essentially the same age as the one from Montana reported by Meek, which would thus correlate with the Spergen limestone just as Meek believed that it did. These conclusions appear to be the most conservative as a result of the more or less conflicting facts. They may be regarded, so to speak, as in a state of unstable equilibrium, and quite open to revision as our knowledge augments.

The more or less nondescript faunas of the Brazer characterized by *Martinia lata* or by *Productus brazerianus* or by the Lithostrotions have not been considered in their correlative aspects. I have used *Diaphragmus elegans*, *Camarophoria explanata*, and *Spirifer brazerianus*, and occasionally, where these were wanting, other forms or groups of forms for identifying the Chester horizon of the Brazer. In that fauna, distinguished in the manner described, nothing has been found that could be definitely identified with either *Productus brazerianus* or *Martinia lata* (though the small Martinias mentioned above are found associated with *Diaphragmus*); and the Lithostrotions, too, are essentially foreign to it. These types either do not occur at all in that Chester fauna or appear in it sparingly as collected by the Geological Survey, and in a condition that forbids definite recognition. On the other hand, *M. lata* occurs freely with *Productus brazerianus*. *P. brazerianus* is accompanied in many collections by *Lithostrotion*, and it is more or less closely linked with the Spergen fauna. In the East and Middle East *Lithostrotion*, as is well known, is especially characteristic of the St. Louis limestone, though it ranges also into the base of the Ste. Genevieve. *Martinia* is there largely, if not entirely, restricted to Chester horizons, and *Productus brazerianus* has no representative at all unless it be *Productus ovatus* var. *latus* in the Moorefield fauna, which I regard as probably pre-Chester in age. The zonal distribution in the Brazer of *Productus brazerianus*, of *Martinia lata*, of the Lithostrotions, and of the Spergen fauna can not be stated at this time, and I am inclined to doubt that any zones in the Brazer are definitely characterized in that way. On the countrary, I am inclined to believe that below the Chester horizon there is a considerable thickness of rocks in the Brazer in which these faunas appear more or less indiscriminately and which represents possibly other periods of time, but especially in its faunal aspects the Spergen and St. Louis.

There remains to be mentioned one more aspect of the Brazer fauna—an aspect which is of especial interest but one which in our collections is very meagerly represented. It is a facies that seems to be widely flung over the North American Continent, for it ranges from Alaska to Alabama, and that, so far as the facts are known, makes its appearance always in the upper Mississippian, though probably not always at the same horizon. Like the so-called Spergen fauna of the Brazer it most likely represents the response to special conditions that may have occurred simultaneously in several of the areas where it is known, but hardly in all. I refer to the fauna characterized by *Leiorhynchus carboniferum* and *Productella hirsutiformis* but associated with various other forms, some assembled here, some there. In the present instance *Leiorhynchus carboniferum* is in our collection (lot 5944) associated with a productoid that is probably *Diaphragmus elegans*, though it can not be definitely so identified. In another collection (lot 7489) the same species occurs associated with a large smooth productoid that is probably *Productella hirsutiformis*. Not in the region that we are considering, but near Mackay, *Productella hirsutiformis* is found in the Brazer associated with a rather varied fauna, which, especially in its *Productella*-like forms, recalls the fauna of the Moorefield shale, though it lacks *Leiorhynchus carboniferum* and other noteworthy Moorefield species.

PENNSYLVANIAN SERIES

The Pennsylvanian rocks of the district all belong to the Wells formation. Like the Mississippian formations the Wells is brought to the surface by deformation and erosion. It assumes great topographic prominence in the Preuss and Aspen Ranges and is exposed in lesser areas in other parts of the region.

WELLS FORMATION

Name.—The Wells formation was named from Wells Canyon, T. 10 S., R. 45 E., in the Crow Creek quadrangle, where the type section given below was measured.[18]

Distribution.—The Wells formation is exposed in each of the quadrangles mapped. In the Montpelier quadrangle it occupies an area of about 2 square miles north of Crow Creek, along the north boundary. It also occupies small areas a mile west of Meade Peak and in Georgetown (South) Canyon. It occurs on the west flank of the Sublette Ridge, and on the west side of Bear Lake Plateau north of Hot Springs it forms a narrow band east of the Brazer limestone. Also west of Bear Lake valley there are local exposures along the east side of the fault in the vicinity of Paris and southward to St. Charles.

In the Slug Creek quadrangle the Wells formation makes a broad zigzag, more or less interrupted by faults and minor folds, around the tips of three large synclines that project southward into the quadrangle. Thus it constitutes portions of the flanks and crest of the Aspen Range, strips along the east side of Trail Creek, Slug Creek, and Dry Valleys, a northward-pointing triangle between Johnson and Slug Creeks, a southward-pointing triangle between Slug Creek and upper Dry Valley, and part of a broad

[18] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, pp. 681-707, 1912.

loop around the syncline that is cut almost axially by Georgetown Canyon. There are also lesser areas which contain the minor folds and faults, as in the north-central part of T. 9 S., R. 43 E.

In the Crow Creek quadrangle the Wells formation together with the Brazer limestone forms three long anticlinal folds that extend northward with a curving trend nearly through the west half of the quadrangle.

The Henry quadrangle contains four scattering small areas in its west half and four larger areas in its east half. These last form high northwestward-trending ridges in Tps. 7, 6, and 5 S., R. 42 E.

The Lanes Creek quadrangle is marked by three broad anticlinal belts of the Wells that extend in a northwesterly direction partly across the quadrangle and are associated with the larger folds of the region. There are also several smaller areas that are associated with minor folds or faults or that represent continuations of larger structural features from the Slug Creek quadrangle.

The Freedom quadrangle contains only a single small anticlinal area of Wells in the southwest corner.

The Cranes Flat quadrangle has several smaller areas of Wells in the southeast corner and along the southwest border. The main occurrence is in Wilson Ridge in the southern part of the quadrangle. Here the Wells formation flanks the Brazer limestone north and south.

Character.—The Wells formation has three variable but fairly distinct parts—a lower sandy and cherty limestone facies, a middle sandy facies, and an upper siliceous limestone. The general topographic appearance of the Wells is shown in Plate 40, *C.* Table 17 gives the result of the detailed measurement of the formation at its type locality.

TABLE 17.—*Section of Wells formation, north side of Wells Canyon, T. 10 S., R. 45 E., Boise meridian, Idaho*

	Feet
Facies 1:	
Limestone, light brownish gray, sandy; contains *Squamularia* or *Composita*, possibly *Productus*, and crinoid stems	5
Chert, bluish gray	1
Limestone, light brownish gray, sandy	44
Facies 2:	
Concealed	172
Sandstone, gray, calcareous, fine grained; in loose blocks and thin beds of quartzite or chert	150
Concealed	50
Sandstone, whitish, soft; in loose blocks; weathers like limestone; includes small quartz-lined geodes; is poorly exposed and is partly represented by sandy soil and small fragments	350
Limestone, light bluish gray, earthy; has considerable dark chert	330
Sandstone, yellowish to red, in large blocks weathered rounded	100
Sandstone, whitish, rather soft	150
Quartzite, white, weathers pink to red, in large loose slabs, laminated and cross-bedded	200
Limestone, in part clear, in part cherty	200
Facies 3:	
Limestone, dark gray; has large chert concretions; fossil collection No. 45	200
Limestone, sandy, alternating with quartzite and clearer limestone	400
Sandstone, whitish, fine grained, one bed	2
Sandstone, red in part, nearly quartzite, cross-bedded	100
Limestone, sandy, with quartz-lined geodes, one bed	3
Sandstone, white to reddish, soft; bears abundant *Schizophoria*; also represented by fossil collections Nos. 28 and 32 for near-by locality	35
Sandstone, one bed	2
Sandstone, thin bedded; fossil collection 101c	6
	2, 400

The lower part of the section has a maximum observed thickness of about 750 feet. In another locality only 2 miles distant the same interval was represented by only 100 feet of beds. Sandy and cherty limestones with their interbedded sandstones make up this portion of the formation. The limestones are dark gray to bluish gray, and the chert is largely in the form of nodules, some of which are oval and concentrically banded and attain a length of 6 or 8 inches. There are also bands and irregular streaks of chert. In the sandy limestone the sand in many places forms thin beds or laminae that project slightly from the weathered surfaces and locally display cross-bedding. In some places intercalated limestone beds have become silicified, as shown in Plate 26. This part of the formation is topographically resistant and forms cliffs. The cherty limestones carry a fauna which, according to G. H. Girty, is probably similar to that of the Morgan formation of Utah, although it is not identical with that fauna. According to Blackwelder,[19] the Morgan formation of Utah is composed of red sandstone, shale, and thin intercalated limestones. This formation is thus distinct lithologically from the cherty limestones of the Wells.

The middle part of the formation comprises 1,700 to 1,800 feet of sandy limestones, in places containing thin beds of quartzite and sandstones. These rocks weather white, red, or yellow and attain a somewhat sugary texture and form smooth slopes with few projecting ledges but commonly strewn with rounded weathered fragments. (See pl. 40, *C.*) Locally this part becomes quartzitic and is then comparable with the Weber quartzite of Utah. No fossils have yet been found in it.

The upper limestone ranges from 75 feet to a few inches in thickness or it may be absent. It consists of a dense calcareous, very fine textured sandstone that grades in places to a siliceous limestone. The rock weathers into white massive beds that are topographically conspicuous as cliff makers, as shown in Plate 21, *A.* Bluish-white chert occurs in it in bands

[19] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America, vol. 21, p. 529, 1910.

Mansfield, 60.

WELLS FORMATION, SEC. 5, T. 10 S., R. 44 E., SLUG CREEK QUADRANGLE

Showing characteristic interbedding of sandstone and cherty limestone (largely silicified)

2 inches to 1 foot thick and locally in nodules. Toward the base the chert becomes more nodular and darker. Silicified fragments of brachiopods, most of them a species of *Squamularia*, project in little crescents from the weathered surfaces of the limestone. This limestone is sparingly fossiliferous, and at Swan Lake Gulch, in T. 9 S., R. 43 E., about 12 miles northwest of Georgetown, Girty reports a small fauna.[20]

The upper limestone is useful as a marker for the phosphate beds, which lie in close proximity above it (see pls. 21, *A*, 40, *C*, and 48, *A*), and has locally been called the "underlying limestone" because of this association.

Relations to other formations.—The variable thickness of the lower part of the formation without recognized corresponding variability of thickness in the overlying sandy part suggests disconformity or unconformity with the Brazer limestone. This suggestion is further supported by the fact that beds of the upper Brazer, which are present in some localities, are absent in others. The local absence of the upper member of the Wells, where phosphatic shales lie directly upon the more siliceous rocks of the formation, which in these places are composed of a breccia of chert and quartzite, also suggests unconformity but one that does not mark any great stratigraphic break.

Age and correlation.—Collections of fossils have been made in many parts of the region mapped and from different horizons, as explained in the preceding paragraphs. The typical fossils, illustrated in Plate 27 have been selected by Girty,[21] who contributes the accompanying lists and comments, as follows:

The fauna of the Wells formation lacks both variety and interest. This statement scarcely appears to be borne out by the appended faunal list, but the list includes many rare species as well as the few that are common, and is the summary of well-nigh 100 collections. Of the major zoological groups, only two are at all abundant in the formation, the Bryozoa and the Brachiopoda. *Foraminifera* have been noted in but two or three collections and *Fusulina* in but one. Though other forms may have been overlooked owing to their small size, not so the Fusulinas, which are so characteristic of our Pennsylvanian rocks and in many places so abundant. If *Syringopora* be excepted, corals are decidedly rare, thus marking a sharp contrast to the preceding Brazer fauna. *Lithostrotion* especially does not appear in the list of Wells fossils. Corals of this type have in fact been found in one or two collections, but some uncertainty exists whether the fossils are *Lithostrotion* or the formation is Wells.

Among the Bryozoa fenestelloids are abundant in a few collections, but the types that recur most persistently are the cylindrical stems of arborescent forms. These branches show a wide range in size, which is their only obvious distinction, as many of them can not be identified even generically without the aid of thin sections. They appear to be referable to *Stenopora*, *Batostomella*, *Leioclema*, *Rhombopora*, *Rhabdomeson*, and possibly other genera.

The brachiopods are largely confined to a few types, which reappear over and over again. These forms comprise two or three species of *Productus* (sensu lato), two species of *Spirifer*, and a *Composita*, though *Composita* is far from occupying the prominent place here that it does in many Pennsylvanian faunas. The pelecypods, gastropods, and other groups are so rare as scarcely to deserve mention except for this fact alone.

Several aspects of the Wells fauna are of interest in respect to their stratigraphic position. In the basal part of the formation we found at a number of localities, often in a matrix of light-gray sandy limestone, abundant shells of *Schizophoria texana* and *Spirifer opimus* var. *occidentalis*. Though neither species is confined to this horizon the *Schizophoria* especially is most numerous there. At the opposite extreme, at the top of the formation, are beds that are almost barren of fossils save for fragmentary and waterworn valves of *Squamularia*. These shells have been cited as *S. perplexa*, but their specific relations, or even their generic relations, are not, in the specimens seen, strictly determinable. Indeed, a close identification of the Wells fossils is more than ordinarily difficult, for they have suffered from compression and other mishaps of fossilization to a greater degree than the older fossils that come from the Madison and Brazer.

That the Wells formation is of Pennsylvanian age will scarcely be questioned. The position that it occupies in the Pennsylvanian and the range of Pennsylvanian time that it represents admit of more doubt. Certain features in the fauna are suggestive of Pottsville age; certain other features are suggestive of post-Pottsville Pennsylvanian. The forms conveying these suggestions do not, however, occur together, and both periods may be represented. In the collections that may be Pottsville neither is the preservation favorable to a close identification of the species nor the assemblage so extensive and characteristic as to be conclusive. The faunas neither depart from the one form so far that they might not be some regional phase of the later Pennsylvanian nor approach the other so closely that in our present knowledge they are definitely Pottsville. Nor has it been possible to test the matter by determining that the collections most strongly suggestive of Pottsville regularly occur below the collections most strongly suggestive of a later Pennsylvanian age, owing to the paucity of sections in the Wells that have a considerable extent and contain a number of fossiliferous horizons and to the uncertainty of correlating definite horizons in separated sections. In my own judgment the probabilities are that the Wells covers both Pottsville and post-Pottsville Pennsylvanian, but that in so far as it is represented in the paleontologic collections, it does not cover a considerable part of the later Pennsylvanian. The following list gives a fairly complete survey of the fauna of the Wells formation. The new species contained in this list are described on pages 432 to 434.

Fusulina secalica.
Fusulinella sp.
Textularia sp.
Cribrostomum sp.
Lophophyllum profundum?
Campophyllum sp.
Syringopora sp.
Stenopora gracilis
Stenopora wellsiana, n. sp.
Stenopora idahoensis, n. sp.
Stenopora carbonaria var.
Batostomella sp.
Leioclema sp.
Fenestella, several sp.
Polypora, several sp.
Septopora sp.
Rhombopora lepidodendroides
Rhabdomeson sp.
Cystodictya sp.
Lingula sp.
Lingulidiscina sp.
Schizophoria texana.
Orthotetes aff. O. kaskaskiensis.
Orthotetes mutabilis
Chonetes complanatus
Chonetes mesalobus var. impressus.
Productus coloradoensis.
Productus aff. P. semistriatus.
Productus cora.
Productus pertenuis.

[20] Girty, G. H., Fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 436, p. 6, 1910.

[21] See also Girty, G. H., quoted in Jour. Geology, vol. 20, p. 693, 1912.

PLATE 27

Schizophoria texana Girty, n. sp. (p. 432)

FIGURES 1, 2, 3. Three views of a specimen which is one of several cotypes. Marble Falls limestone, San Saba quadrangle, Texas (station 2417).

FIGURES 4, 5, 6, 7, 8. Five views of a rather small specimen, also one of the cotypes. Marble Falls limestone, San Saba quadrangle, Texas (station 2607).

Orthotetes mutabilis Girty, n. sp. (p. 433)

FIGURES 9, 10, 11. Three views of a low and very unsymmetrical pedicle valve. Wells formation, Slug Creek quadrangle, Idaho (station 7608).

FIGURE 12. An imperfect brachial valve. Wells formation, Slug Creek quadrangle, Idaho (station 7608).

FIGURES 13, 14, 15. Three views of a very high, distorted pedicle valve. Wells formation, Slug Creek quadrangle, Idaho (station 7608).

Chonetes mesolobus var. inflexus Girty, n. var. (p. 433)

FIGURE 16. View of a pedicle valve. Wells formation, Slug Creek quadrangle, Idaho (station 7608).

Productus coloradoensis

FIGURE 17. Pedicle valve seen from above. After Girty. Weber (?) formation, Leadville district, Colo.

Productus cora

FIGURE 18. A somewhat crushed pedicle valve. After Girty. Hermosa formation, Durango quadrangle, Colo.

Pustula nebraskensis

FIGURE 19. An exfoliated pedicle valve. After Girty. This figure does not show the real characters of the species, but it shows how most specimens actually look. Hermosa formation, Durango quadrangle, Colo.

Marginifera splendens

FIGURES 20, 21, 22, 23. Four views of a specimen which is in some respects intermediate between *M. splendens* and the related *M. wabashensis*. Wells formation, Slug Creek quadrangle, Idaho (station 1466).

Spirifer cameratus

FIGURES 24, 25, 26, 27. Four views of a typical specimen. *S. cameratus* has often been misinterpreted; many citations belong under *S. triplicatus*. Putnam Hill limestone member of Allegheny formation, near Zanesville, Ohio.

Spirifer opimus var. occidentalis Girty, n. var. (p. 433)

FIGURES 28, 29. Two views of a crushed specimen that retains both valves. Wells formation, Crow Creek quadrangle, Idaho-Wyo. (station 32.)

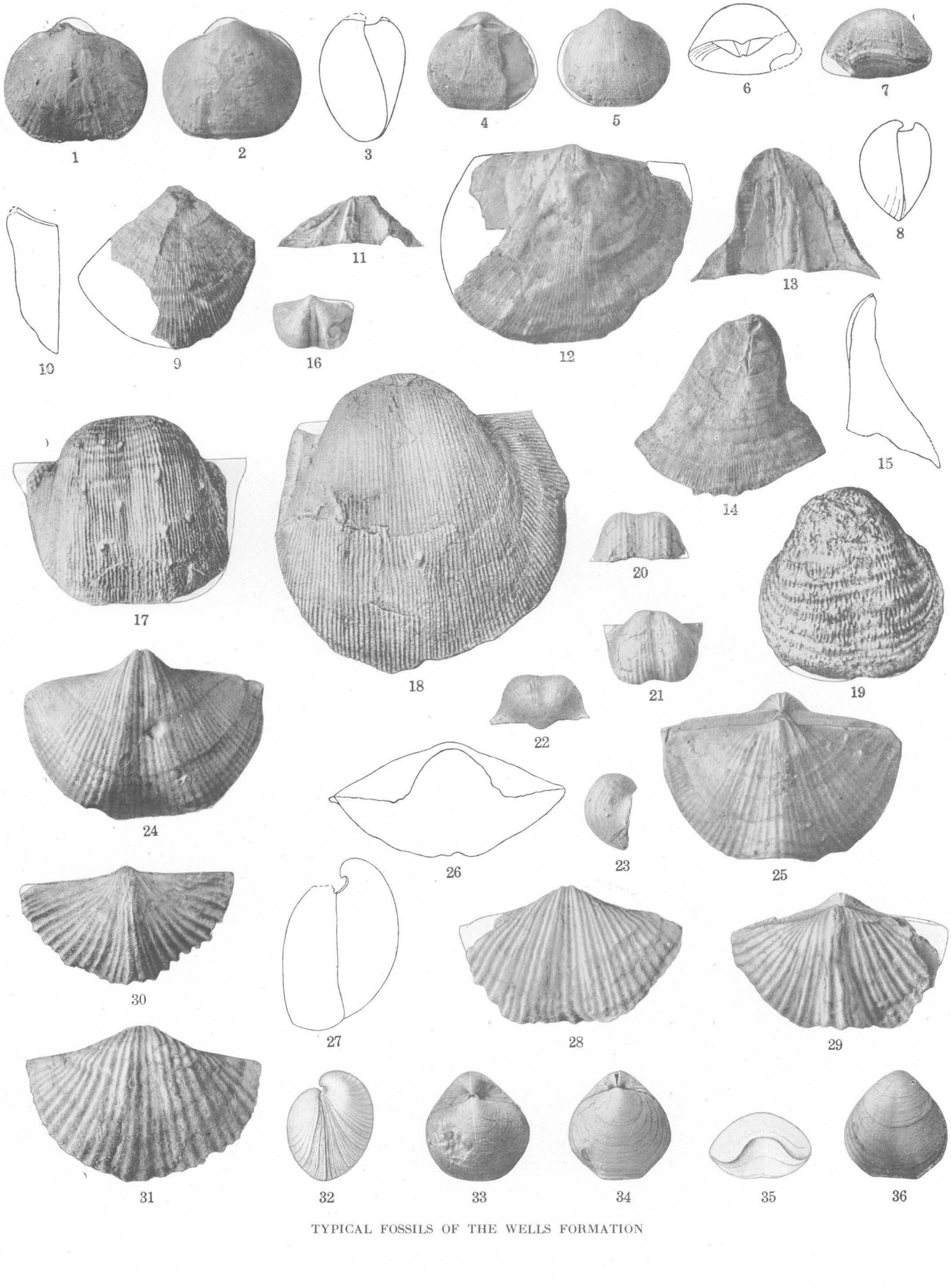
FIGURES 30, 31. Figures of two isolated valves, a brachial valve and a pedicle valve. Wells formation, Crow Creek quadrangle Idaho-Wyo. (station 32).

Squamularia perplexa

FIGURES 32, 33. Two views of a large specimen. After Girty. Wewoka formation, Coalgate quadrangle, Okla.

Composita subtilita

FIGURES 34, 35, 36. Three views of a rather small specimen. After Girty. On a cursory glance this specimen closely resembles that shown by Figures 32 and 33, but it is vitally different. *C. subtilita*, as commonly identified, comprises a great variety of forms, a number of which are found in the Wells formation. Wewoka formation, Coalgate quadrangle, Okla.



TYPICAL FOSSILS OF THE WELLS FORMATION

Pustula nebraskensis var.	Squamularia perplexa?
Pustula semipunctata.	Composita subtilita.
Pustula aff. P. humboldti.	Cliothyridina orbicularis.
Avonia sp.	Hustedia aff. H. multiscostata
Marginifera splendens.	Allerisma sp.
Marginifera muricata.	Nucula sp.
Rhynchopora illinoisensis.	Myalina aff. M. kansasensis.
Dielasma sp.	Aviculipecten sp.
Spirifer opimus var. occidentalis.	Dentalium sp.
	Bellerophon sp.
Spirifer cameratus.	Pleurotomaria sp.
Spirifer wellsianus.	Euconospira, n. sp.
Spiriferina aff. S. spinosa.	Platyceras sp.

In the Idaho field the stratigraphic interval occupied by the Wells formation is probably the same as that represented by the Morgan formation, Weber quartzite, and the lower division of the Park City formation of Utah.

PERMIAN SERIES

The Permian beds in this area constitute a single formation, the Phosphoria, which, though not of great thickness, maintains a high degree of uniformity of character over wide areas. The rocks are exposed in narrow bands along the flanks of the larger and simpler folds or in more complex crumplings in the smaller folds or along the borders of faulted areas. The Phosphoria formation is of great economic and scientific interest because it contains the valuable and extensive deposits of high-grade phosphate rock that constitute the chief mineral resource of the region.

PHOSPHORIA FORMATION

Name and subdivision.—The Phosphoria formation[22] was named from Phosphoria Gulch, a small stream that joins Georgetown Canyon at a distance of 2½ miles N. 16° W. of Meade Peak, in which the formation is typically exposed. The name was given to about 450 feet of limestone, massive cherts, shales, and phosphate rock that comprise the upper two members of the Park City formation as heretofore mapped in Idaho and Utah,[23] namely the "overlying chert" or "upper *Productus* limestone" and the phosphatic shales.

The formation contains two distinct lithologic units, upper and lower. The upper unit, which consists of massive limestones and cherts, is called the Rex chert member, from Rex Peak in the Crawford Mountains, Rich County, Utah, where the chert forms an anticlinal capping. The lower unit comprises the phosphatic shales, with which are included beds of limestone and of fetid limestone.

Distribution.—The Phosphoria formation occurs in each of the quadrangles mapped. In the Montpelier quadrangle it comes to the surface in a narrow band north of Crow Creek near the north boundary and on opposite sides of a faulted syncline in Georgetown (South) Canyon. About 3 miles east of Montpelier the formation appears along the sides of a complex and faulted anticline. On the west flank of Bear Lake Plateau the formation extends about 4½ miles northward from the vicinity of Hot Springs, east of the Wells formation. The Sublette Ridge contains two sets of exposures, one extending southward 3½ miles from a point half a mile north of Raymond Canyon, along the east side of an anticline, and the other capping the northern extension of the same anticline, 1½ miles north. On the west side of Bear Lake Valley the Phosphoria formation is exposed in a strip 1½ to 2½ miles west of Bloomington and Paris, just east of the Bannock overthrust. Other less notable occurrences are 2 miles southeast of Bennington, 1 mile west of Meade Peak, and 1 mile north of Sharon.

In the four quadrangles to the north of the Montpelier quadrangle the Phosphoria formation serves well to outline the form of many of the folds, both great and small, and to mark the position of faults. For example, the west half of the Crow Creek quadrangle is occupied by a great curving, bifurcated syncline that overlaps the southeast and northeast corners of the Slug Creek quadrangle and passes northwestward into the Lanes Creek, Freedom, Henry, and Cranes Flat quadrangles. The bifurcation is produced by a sharp anticline, the axis of which is depressed in the region of the southeast corner of the Lanes Creek quadrangle but emerges again farther to the northwest. These folds give rise to a series of subparallel or diverging bands of the Phosphoria formation, symmetrically disposed toward younger and older rocks. Similarly, to the west of this great syncline a series of folds gives rise to other symmetrically disposed bands of the Phosphoria, which appear in the southwestern part of the Lanes Creek quadrangle and in the northern half of the Slug Creek.

Many subordinate folds modify the outlines of the great folds, as in the tip of the anticline north of Sage Valley, in the Crow Creek quadrangle, or in the south tip of the big syncline in Georgetown Canyon, in the Slug Creek quadrangle, where the effect of erosion is accentuated by the presence of a small anticline. The subordinate folds give rise to more or less local occurrences of the Phosphoria formation, many of which are found in both the Slug Creek and Lanes Creek quadrangles. The single occurrence of the Phosphoria in the southwestern part of the Freedom quadrangle is apparently due to the local upwarping and faulting of the depressed axis of the anticline mentioned above.

The effect of erosion on beds of different degrees of inclination is well illustrated by the outcrop of the Phosphoria formation. Where the beds are nearly horizontal the headward erosion of canyons causes deep recessions of the line of outcrop, as in Wells

[22] Richards, R. W., and Mansfield, G. R., The Bannock overthrust: Jour. Geology, vol. 20, pp. 684–689, 1912.

[23] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, pp. 434–458, 1907. Gale, H. S., and Richards, R. W., Phosphate deposits in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 430, pp. 457–535, 1910.

Canyon, in the Crow Creek quadrangle, or in the south tip of the big syncline north of Swan Lake Gulch, in the Slug Creek quadrangle. Where beds are nearly vertical the deep incision of the canyons causes little change in the lines of outcrop of the formations that are cut, as shown by the position of the bands of the Phosphoria on the flanks of Snowdrift Mountain, in the Crow Creek quadrangle.

The symmetry of arrangement of the bands of the Phosphoria produced by the folds is marred or even partly obliterated by faults that are especially numerous in the Slug Creek and Lanes Creek quadrangles. In some places the fault produces simply an offset of greater or less distance in the line of outcrop. In other places it causes the complete disappearance of the formation. Many faults occur at the horizon of the phosphatic shales, which, because of their relative weakness, have furnished a convenient zone of adjustment for the stresses and strains developed by the folding of the more massive beds above and below. As a result of faults and subordinate folds the distribution of the Phosphoria formation in the Slug Creek quadrangle is quite irregular.

In the Henry quadrangle the chief occurrences of the Phosphoria are in the southeast corner of the quadrangle, in Tps. 7 and 8 S., R. 42 E., which represents the continuation of the west limb of the big syncline of the northwestern part of the Slug Creek quadrangle, and east of Henry, in T. 6 S., R. 42 E., where the big bifurcated syncline to the southeast is continued into the quadrangle. Minor occurrences of the Phosphoria are exhibited in sec. 29, T. 5 S., R. 42 E., along a fault that flanks the south side of an anticlinal fold that corresponds in position with the long anticline of the Lanes Creek and Crow Creek quadrangles; in the region of the southwest corner of sec. 20, T. 5 S., R. 41 E.; in secs. 12 and 13, T. 6 S., R. 40 E.; and in sec. 30, T. 6 S., R. 41 E.

In the Cranes Flat quadrangle the formation is exposed in secs. 20 and 27, T. 4 S., R. 41 E., along the north flank of the anticline that continues northwestward from the Henry quadrangle; in secs. 32 and 33 of the same township on the south flank of the same anticline; and in secs. 34 and 35, T. 4 S., R. 40 E., extending into sec. 2 of the adjoining township.

Phosphatic shale member.—The lower part, or the phosphatic shale member, of the Phosphoria formation consists of 75 to 180 feet of yellowish to brown phosphatic sandstones, dark-brown to black phosphatic shales, beds of brown or black fetid limestone, and one to three economically valuable beds of phosphate rock.

The phosphate rock is characterized by gray, brown, or black color, fine to coarse oolitic texture, and a strong fetid odor when freshly broken. Weathered fragments or pieces of float have a characteristic bluish-white bloom and commonly white reticulate markings. The thickest and richest bed of phosphate rock is generally at or near the base and ranges in thickness from 4 to 7 feet or even more over large areas. The other valuable beds are thinner and occur near the top and the middle respectively of the shale interval. Details regarding the phosphate rock itself are given on pages 208 to 213 and in Plates 63 to 70. (See also pp. 361 to 367.)

In the Montpelier district and some of the adjoining regions to the north the main phosphate bed is overlain by a bed of dark, fetid, and highly fossiliferous limestone 2 to 3 feet thick, known as the "cap lime." Numerous rounded or oval nodules of dark fetid limestone that range in diameter from a few inches to several feet also occur in the beds. These nodules are very dense, compact, and fine grained and yield a low percentage of phosphoric acid. In the regions farther north the "cap lime" is less well developed or absent and the nodules are smaller and much less numerous. The main phosphate bed with the "cap lime" is shown in Plate 52, *B*.

The phosphate rock itself is practically nonfossiliferous, so far as observed, although a few discinoids and bone fragments have been found and locally one of the beds contains many shell fragments close to its base. The beds that accompany the phosphate rock, notably the "cap lime," have, however, yielded a rich fauna that has been described by Girty,[24] who has selected the following list as characteristic of the phosphatic shales:

Lingula carbonaria (?).
Lingulidiscina missouriensis.
Chonetes ostiolatus.
Productus geniculatus.
Productus eucharis.
Productus montpelierensis.
Productus phosphaticus.
Pugnax weeksi.
Pugnax osagensis var. occidentalis.
Ambocoelia arcuata.
Leda obesa.
Plagioglypta canna.
Omphalotrochus ferrieri.
Omphalotrochus conoideus.
Hollina emaciata var. occidentalis.

The stratigraphic details of the phosphatic shales are well illustrated in the following section. (Table 18.) A number of other detailed sections are given on pages 222 to 290, in connection with the discussion of the phosphate deposits.

[24] See also Girty, G. H., Fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 436, 1910.

TABLE 18.—*Section of lower or phosphatic member of Phosphoria formation in SE. ¼ sec. 7, T. 10 S., R. 45 E. of the Boise meridian, Idaho, 1911*

[Land lines theoretical]

Field No. of sample		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	Per cent	Ft.	in.
	Shale, dark brown, weathers light brown, not fetid			1	10
M 20-1	Phosphate rock, gray, coarsely oolitic, with large pebbles, fossils, or oolites near base; the largest 2 inches in diameter	36.3	79.3	1	
	Shale, brown, finely oolitic				5
M 20-2	Phosphate rock, gray, coarsely oolitic pebbles or oolites, the largest being 1 inch in diameter	36.7	80.1		8½
	Shale, brown, weathers gray, in part finely oolitic				2½
	Clay, yellow, weathered sandy, largest concretions one-fourth inch in diameter; grades into the shale above				8
M 20-3	Phosphate rock, brown, medium oolitic; weathers gray	35.3	77.1		5
	Shale, dark brown, phosphatic				2
M 20-4	Phosphatic rock, dark brown, weathers gray, medium oolitic, single bed	29.4	64.2		5
	Shale, brown, sandy; contains concretions, the largest 1 inch in diameter				5
M 20-5	Phosphate rock, gray, coarsely oolitic	35.9	78.4	1	2
	Shale, dark brown to black, finely oolitic				3
M 20-6	Phosphate rock, coarsely oolitic	35.9	78.4		4
	Shale, brown, sandy				1
	Phosphate rock, medium oolitic				1½
	Shale, brown, weathers gray with bluish tinge; finely oolitic				5
	Phosphate rock, black, soft, medium oolitic				2
	Shale, brown, calcareous				4
	Phosphate rock, black, medium oolitic, soft				1
	Shale, brown, oolitic in thin streaks				2
M 20-7	Phosphate rock, gray, coarse to finely oolitic	33.2	72.5		11
	Phosphatic rock, brown, finely oolitic, shaly				3
	Phosphate rock, brown, medium oolitic				4
	Shale, brown; one-fourth inch streak of oolitic rock near base				6
M 20-8	Phosphate rock, dark brown, coarse to finely oolitic, shaly in places	33.2	72.5		9
M 20-9	Phosphate rock, gray, coarsely oolitic; includes half an inch of shale near base	37.0	80.8	1	1
	Limestone, drab, impure				5
	Phosphate rock, medium to finely oolitic				3
	Shale, brown, weathers gray				9
	Phosphate rock, dark gray, coarsely oolitic, soft				2
	Shale, brown				3
M 20-10	Phosphate rock, dark gray, coarsely oolitic, with several shaly partings less than one-eighth inch thick	30.0	65.5		10
	Limestone, lenticular				10
M 20-11	Phosphatic rock, dark brown, medium to finely oolitic	26.1	57.0	9	8
	Shale, black, in part finely oolitic			3	
	Shale, brown, partly weathered to clay			1	8
	Shale, black, phosphatic, in part finely oolitic			6	6
	Shale, brown; contains concretions, the largest 2 inches in diameter				10
	Shale, rusty brown to yellow; contains a few concretions, the largest 1 inch in diameter			1	8
	Shale, dark brown, with thin pebbly or concretionary bed at top, phosphatic in places			16	6
	Pebbly or concretionary bed; contains concretions, the largest 2 inches in diameter				4
	Shale, brown			1	2
	Shale, black to dark brown				9
	Pebbly or concretionary layer, phosphatic				3
	Shale, black, slightly oolitic				7
	Shale; contains pebbles or concretions, the largest 2 inches in diameter				6
	Shale, brown; weathers to ocherous soil			3	4
	Pebbly or concretionary bed				4
	Shale, brown; weathers to ocherous soil			2	3
	Pebbly or concretionary bed, phosphatic?			1	
	Shale, brown, phosphatic			2	6
	Shale, black, thin bedded				6
	Clay, ocherous				10
	Shale, brown			1	
	Shale, black to light brown, slightly phosphatic			11	
	Limestone, broken and intermixed with shale			6	
	Shale, broken and weathered, only slightly phosphatic			21	
	Shale, black, phosphatic, finely oolitic		[a] 40 ±	5	6
	Shale, brown; weathers yellow, concretionary			1	
	Limestone, purplish drab, lenticular				8
	Shales, dark, broken, and weathered			15	
	Phosphate rock, broken, weathered drab			3	
	Soil, black, fetid			9	
	Shale, black, phosphatic, finely oolitic			5	6
	Limestone, dark, fetid				6
	Shale, brown, somewhat phosphatic, contorted			15	
	Limestone, dark gray, dense ("cap lime" fossils)			3	
	Phosphate rock, dark brown, medium oolitic, soft, broken, apparently high grade (corresponds to bed 144-S of section to south, Table 66, p. 274), not sampled		[a] 70 ±	7	
	Shale, brown, contorted, soft			1	
	Limestone, white; weathers buff, sandy, not measured.				
				175	2½

[a] Estimated.

Rex chert member.—The Rex chert member is the conspicuous part of the Phosphoria formation, and because of its superior hardness stands out in strong cliffs and ledges. The phosphatic shales, on the other hand, are topographically weak and are commonly eroded into gullies and depressions. These topographic features are well shown in Raymond Canyon in the Sublette Ridge (pl. 54), where the Rex forms a veritable wall, and west of Dry Ridge in the northeastern part of T. 8 S., R. 44 E., Slug Creek quadrangle (pl. 29, *A*). (See also pl. 50, *A*.)

In the Montpelier district the Rex chert member is composed of massive chert in the lower 50 to 75 feet, above which are massive beds of gray limestone which are so crowded with fossils, especially *Productus*, that the name "upper *Productus* limestone" has been locally applied. Farther north the limestone facies gives way to chert, and this also may appear in two facies—a massively bedded chert, which is topographically conspicuous, or a flinty or cherty shale. Where both cherty facies are present the shaly type occupies the top of the section and is locally difficult to distinguish from the overlying Woodside shale, although this distinction is usually easy. Elsewhere the shaly facies may occupy the entire Rex chert interval or the major part of it. The color of the chert is prevailingly dark gray or black, but in places purplish, flesh tints, or even whitish colors have been observed.

In the region north of Montpelier, however, the cherty facies gives way locally in the lower part to a coarsely granular gray limestone which is crowded with large crinoid stems and other fossils and which contains minor thin intercalated beds of bluish-black chert, as in Wood Canyon, in T. 8 S., R. 42 E. A similar occurrence was noted in the south fork of Deer Creek, in T. 10 S., R. 45 E., where G. H. Girty obtained the following fauna:

Amphiporella laminaria.
Productus nevadensis.
Productus eucharis.
Productus multistriatus?
Camarophoria, n. sp.

A number of other species frequently found in the limestone at this horizon are reported by Mr. Girty, among which the most characteristic are:

Productus multistriatus.
Productus subhorridus.
Spirifer aff. S. cameratus.
Spiriferina pulchra.
Composita subtilita var.

The cherty facies of the Rex chert member is generally nonfossiliferous, but locally it contains sponge spicules, discinoids, and casts of crinoid stems. Microscopically the chert consists of cryptocrystalline quartz with tiny scattered fragments of the same mineral.

This member also contains locally a thin bed of rock phosphate, which in most places is less than 6 inches thick.

The Rex chert member shows a considerable range in thickness, so that the width of its outcrop as mapped is not wholly dependent on the inclination of its beds. It ranges from a minimum thickness of about 110 feet in T. 15 S., R. 44 E., to a maximun of about 550 feet in T. 9 S., R. 45 E. A complete section measured in T. 10 S., R. 44 E., is given in Table 19.

TABLE 19.—*Complete section of Rex chert member in sec. 12, T. 10 S., R. 44 E. of Boise meridian*

	Feet
Shale, black, cherty; weathers red	80
Chert, brown to purple, in heavily iron-stained ledges	60
Limestone, gray, banded, with ashy gray to black chert	100
	240

Age and correlation.—The Phosphoria formation, as previously stated, is the equivalent of the upper two members of the Park City formation, as described in earlier reports on parts of the district. The Park City formation was at first referred by Boutwell to the Pennsylvanian, but in his later work [25] he referred it as a whole doubtfully to the Permian. The lower part, which at Park City contains the well-known ore deposits, is now referred by G. H. Girty on faunal evidence to the Pennsylvanian, whereas the upper part, which corresponds to the Phosphoria formation, is regarded as Permian. Fossils from the phosphatic shales and from the Rex chert member are listed under the descriptions of those members, and a typical group of fossils from the formation, selected by Mr. Girty, is illustrated in Plate 28.

In earlier papers [26] the Phosphoria formation has been correlated with the upper part of the Embar formation in Wyoming and with the phosphatic beds above the massive quartzite of the Quadrant formation, as mapped in early reports on parts of southwestern Montana.

The following subsequent note on the fauna of the Phosphoria formation and its correlation has been furnished by George H. Girty.

Of the two members which go to make up the Phosphoria formation the fauna of the lower member alone has been carefully studied. Figures and descriptions of the species that occur in the phosphatic shales are given in the Geological Survey's Bulletin 436, and the illustrations given on Plate 28, together with the list of characteristic species given on page 76, are taken from that source. The fauna of the Phosphoria as it was described in 1910, even that of the phosphatic shales, was incomplete in several respects. Subsequent collections, though numerous and valuable, have added a few new forms though scarcely as many as one would expect, for the fauna proves to be rich in specimens but somewhat poor in species. Furthermore one subordinate member of the Phosphoria was

[25] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 51, 1912.

[26] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, p. 687, 1912; Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, p. 23, 1914.

not included in the original discussion, and it also is the source of a few additional species.

Most of the specimens in Bulletin 436 came from a bed of limestone locally known as the "cap lime," whose position was above the main phosphate bed at Montpelier and in the region round about. The omitted fauna is that which occurs in a thin black limestone whose position is just below the phosphatic shale in the same region. In the introductory discussion in Bulletin 436 the Park City formation, to which the phosphate beds were formerly assigned, was described as consisting of two limestones with the phosphatic shale between. Of these, the two upper members subsequently became known as the Phosphoria formation. When I received the original collections from the black limestone, to which reference has just been made, they were said to have come from the lowest member of the Park City formation, which in local parlance was known as "under lime" or the "lower *Productus* limestone," and were supposed to be characteristic of the entire fauna of that member. For this reason they were not included in the report on the phosphatic shales but were reserved for an independent report when adequate material was obtained from the lowest member of the Park City formation. It subsequently developed, however, that the black limestone, from which these collections came, was but a thin film locally spread upon the massive light-colored deposits of the "under lime" and that it was allied faunally as well as lithologically to the phosphatic shales above. Thus the evidence that at first seemed to bind the "under lime" on to the Phosphoria formation now seemed to bind only a local and insignificant part of it, and the conspicuous change in fauna at the top of the cream-colored sandy limestone together with certain features of the fauna itself, meager as that fauna is, led to a classification of the "under lime" as Pennsylvanian and thus to a disruption of the Park City formation.

The fauna of the thin black limestone now recognized as forming part of the Phosphoria formation, is related to that of the phosphatic shales, yet presents a few notable features. The subjoined list represents almost the complete fauna shown by several collections, which are essentially repetitions one of the other.

Lingulidiscina sp.
Chonetes ostiolatus.
Productus phosphaticus.
Pustula aff. P. porrecta.
Rhynchopora taylori.
Spirifer aff. S. triplicatus.
Composita subtilita.

Of these species *Chonetes ostiolatus* and *Productus phosphaticus* occur also in the phosphatic shale. The original specimens of *Rhynchopora taylori*, though supposed to have come from that horizon, I am now satisfied came from this one, so that *R. taylori*, together with *Pustula* aff. *P. porrecta*, *Spirifer* aff. *S. triplicatus*, and *Composita subtilita* are peculiar to the lower fauna. It would be hard to name any two types of brachiopods that occur more unfailingly in Pennsylvanian and Permian collections than Compositas of the *subtilita* group, and Spirifers of the *cameratus* or *triplicatus* group; the absence of these types from the phosphatic shales has therefore been an outstanding peculiarity. Furthermore two of the common and characteristic types found in the phosphatic shales do not occur in this lower limestone, namely either species of *Omphalotrochus* and *Pugnax* (or *Pugnoides*) *weeksi*. These two faunas, therefore, though related, present some remarkable differences.

Like the little faunule just discussed, the entire fauna of the upper member of the Phosphoria formation is not represented upon the plate of Phosphoria fossils, and in fact this fauna is not very well represented in the region immediately under discussion. It can be definitely identified, however, as the fauna which by reason of the striking character and abundance of a single species may be called the *Spiriferina pulchra* fauna. It has been described piecemeal by Meek and others, and contains, besides *Spiriferina pulchra*, such characteristic species as *Spirifer pseudocameratus*, *Productus multistriatus*, *Productus longus*, *Pustula subhorrida*, and *Pustula nevadensis*. Where well developed this fauna has considerable variety and is somewhat conspicuous for its bryozoan content, especially ramose forms, both large and small. Even this brief sketch shows that the fauna of the upper member of the Phosphoria formation, that is the *Spiriferina pulchra* fauna, differs strikingly from the fauna of the phosphatic shales, the peculiar character of which, one must believe, is due to the peculiar environmental conditions that rendered possible the accumulation of the phosphatic material that makes the formation economically important.

When the Phosphoria fauna was described in 1910, and the fact will bear repetition that only the fauna of the phosphatic shales had been carefully studied or indeed carefully collected, it was tentatively assigned to the "upper Carboniferous" or Pennsylvanian on the strength of a few parallels that could be drawn with the Gschelian fauna as described by Tschernyschew, the Gschel-stufe in the Russian section occupying a position immediately below the Artinskian or basal member of the Russian Permian. For the same reason the highest Paleozoic beds of Alaska were likewise called Gschelian or youngest Pennsylvanian. In Bulletin 436, however, no comparison was made between the "Gschelian" faunas of Alaska and of Idaho. With our present perspective such a comparison is possible and it discloses a very appreciable relationship, which, however, can be properly evaluated only when more is known of the extensive region within the Canadian borders that separates the latest Paleozoic beds of Idaho and Wyomong from those of southeastern Alaska. It is my own expectation that eventually these rocks will be traced through the cordilleran region and shown to have been at one time essentially contemporaneous and continuous. The differences between the faunas are at present as impressive as the resemblances, but they are probably less significant. Indeed in view of the extensive tract of territory that lies between, it is suprising that resemblances should be so numerous. On this head it may be stated that the Alaskan fauna contains a very large, smooth *Chonetes*, which may prove to be identical with *C. ostiolatus*. It contains a *Productus* (which I have usually cited as *Productus* aff. *P. mammatus*) that may prove to be identical with *P. geniculatus*. It contains a *Productus* (which I have usually cited as *Productus* aff. *P. aagardi* and which like Toula's original species, should probably be included under the genus *Marginifera*) that is probably identical with *Productus eucharis*. It contains another very spinose *Productus* (*Pustula* aff. *P. humboldti*) that may prove identical with *Productus montpelierensis*. It contains a *Rhynchopora* (*Rhynchopora* aff. *R. nikitini*) that may prove to be identical with *R. taylori*; and it contains a pentameroid in great profusion (*Camarophora* aff. *C. margaritovi*) that may prove to be identical with a very rare species found in the Rex chert and limestone. A few other parallel or identical species might be named under *Spirifer* and *Marginifera*, and still others will surely come to light. On the other hand, I recall nothing in the Alaskan faunas comparable to the two outstanding types of the phosphatic shale of the Phosphoria formation, *Omphalotrochus ferrieri* and *O. conoideus*, and *Pugnoides weeksi* and *P. nobilis* (*P. weeksi* var. *nobilis*), nor yet any of the common species of the *Spiriferina pulchra* fauna, such as *Productus multistriatus*, *Pustula subhorrida*, or *Spiriferina pulchra* itself.

Thanks to a knowledge of the Russian faunas, which he owed more to contacts with Russian geologists and to observations on Russian collections than to the incomplete and scattered literature, Doctor Holtedahl, who examined all the Alaskan material that I then had, gave me his opinion that the Alaskan fauna was really Artinskian (basal Permian) instead of Gschelian (highest Pennsylvanian) as I thought it to be, and it has been

PLATE 28

[The figures on this plate are reproduced from U. S. Geological Survey Bulletin 436]

Pugnoides weeksi

FIGURES 1, 2, 3. Three views of a narrow specimen with obscure plications. Phosphoria formation, Montpelier, Idaho.
FIGURES 4, 5, 6. Three views of a specimen of the broad type; Figure 4 shows the thick shell exfoliated over the umbonal region. Phosphoria formation, Montpelier, Idaho.
FIGURES 7, 8. Two views of a specimen with strong plications of which three instead of two occur on the fold. Phosphoria formation, Montpelier, Idaho.

Pugnoides osagensis var. occidentalis

FIGURES 9, 10, 11. Three views of a specimen which have three plications on the fold; some specimens have only two. Phosphoria formation, Montpelier, Idaho.

Pustula montpelierensis

FIGURES 12, 13. Two views of the typical specimen. Phosphoria formation, Montpelier, Idaho.

Productus geniculatus

FIGURES 14, 15, 16. Three views of a pedicle valve. Phosphoria formation, Montpelier, Idaho.

Lingula carbonaria var. exporrecta

FIGURE 17. A brachial valve. Phosphoria formation, Thomas Fork, Wyo.

Lingula carbonaria?

FIGURES 18, 19. Views of two specimens supposed to be a brachial and a pedicle valve respectively. Phosphoria formation, Thomas Fork, Wyo.

Chonetes ostiolatus

FIGURE 20. A large pedicle valve. Phosphoria formation, Montpelier, Idaho.

Chonetes ostiolatus var. impressus

FIGURES 21, 22. Two views of a pedicle valve, natural size and enlarged to 3 diameters. Phosphoria formation, Cokeville, Wyo.

Marginifera? eucharis

FIGURES 23, 24, 25. Three views of a specimen retaining both valves. Figure 24 represents part of the brachial valve, and Figure 25 is an enlargement to two diameters. Note the wrinkled and lamellose character of the brachial valve. *Productus eucharis* may be identical with *Productus aagardi* Toula, which probably is a *Marginifera.* Phosphoria formation, Montpelier, Idaho.

Ambocoelia arcuata

FIGURES 26, 27. Two views of the typical specimen. Phosphoria formation, Montpelier, Idaho.

Grammysia? carbonaria

FIGURES 28, 29. Views of two imperfect right valves. Phosphoria formation, Montpelier, Idaho.

Yoldia mcchesneyana

FIGURES 30, 31, 32. Views of three different specimens, two left valves and one right. Figures 31 and 32 are enlarged to 3 diameters. Phosphoria formation, Montpelier, Idaho.

Schizodus ferrieri

FIGURES 33, 34. Views of a right and a left valve. Phosphoria formation, Montpelier, Idaho.

Leda obesa

FIGURE 35. A left valve deformed by pressure. Phosphoria formation, Swan Lakes, Idaho.

Aviculipecten montpelierensis

FIGURES 36, 37. Views of a left valve and of a right valve ×2. Phosphoria formation, Montpelier, Idaho.

Nucula montpelierensis

FIGURES 38, 39, 40, 41. Four views of the typical specimen, three of them enlarged to 3 diameters. Phosphoria formation, Montpelier, Idaho.

Omphalotrochus conoideus

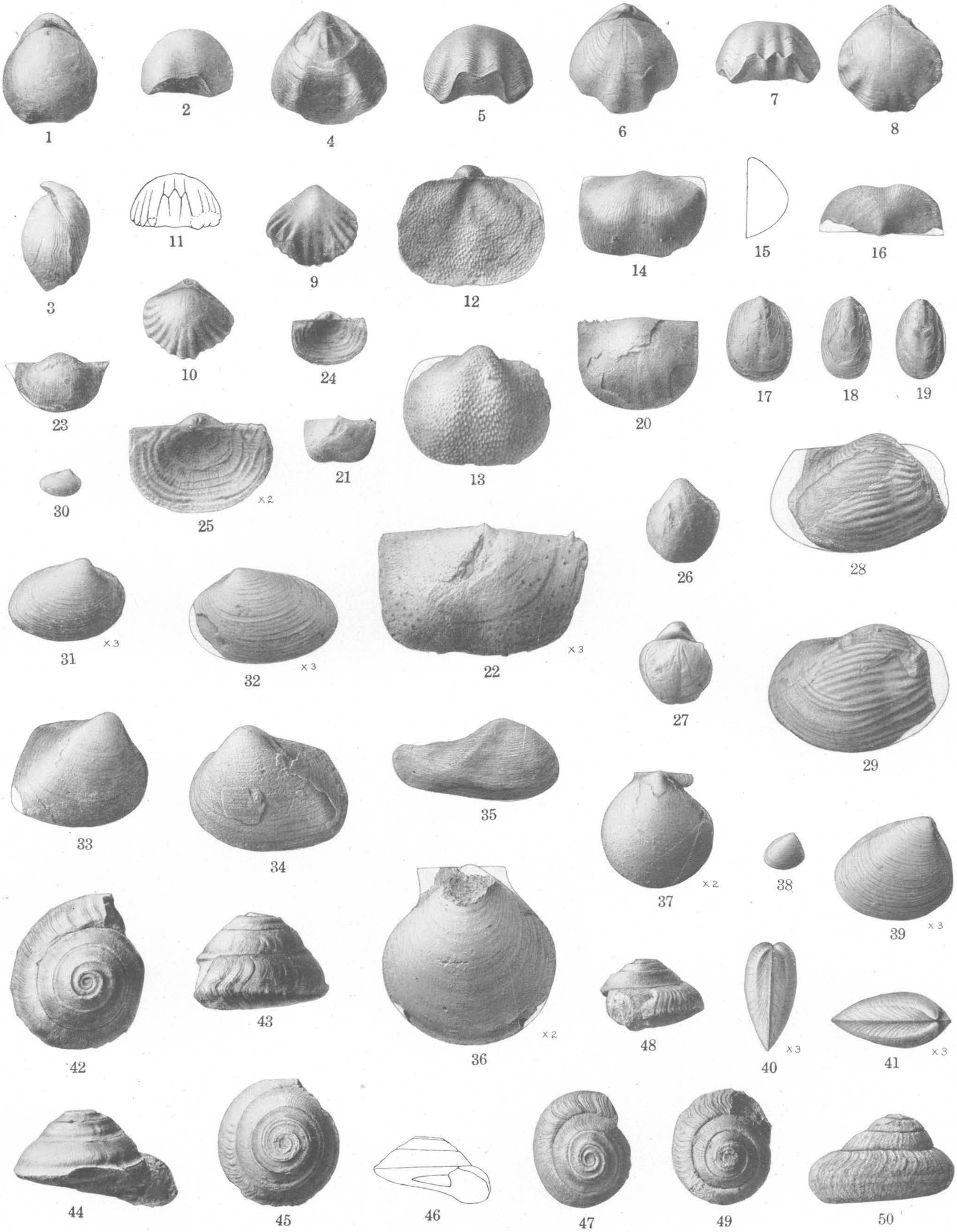
FIGURES 42, 43, 44. Three views of a large specimen. Phosphoria formation, Montpelier, Idaho.
FIGURE 45. Upper side of another specimen. Phosphoria formation, Montpelier, Idaho.

Omphalotrochus ferrieri

FIGURES 46, 47. Two views of one specimen. Phosphoria formation, Montpelier, Idaho.
FIGURES 48, 49. Two views of another specimen. Phosphoria formation, Montpelier, Idaho.

Omphalotrochus ferrieri var.

FIGURE 50. A specimen with rounded volutions. Phosphoria formation, Montpelier, Idaho.



TYPICAL FOSSILS OF THE PHOSPHORIA FORMATION so regarded on that authority ever since. At present one dare do no more than forecast the probable outcome of the evidence bearing upon the relation of the Phosphoria fauna to the Permian fauna of Alaska, but if the relation proves as close as I incline to believe, the Permian age, which was subsequently assigned to the Phosphoria on independent grounds, will be corroborated from this source. The formation has for several years in fact been regarded as Permian, partly on stratigraphic evidence that needed to be checked up before being fully accepted and partly on paleontologic evidence that was not concrete and conclusive but consisted of an apparent gradual transition of the Phosphoria fauna, especially the *Spiriferina pulchra* phase, into other faunas generally regarded as Permian.

Later interpretations of the Embar have been given by Blackwelder and Condit,[27] to which reference is made elsewhere. (See pp. 372 and 373.)

The term Quadrant has been restricted to the quartzite beneath the phosphatic beds, which corresponds to the typical quartzite of the Yellowstone National Park.

TRIASSIC SYSTEM

OCCURRENCE AND SUBDIVISION

The Triassic system is well developed in this region and is exposed over large areas, particularly in the Montpelier quadrangle and the four quadrangles to the north. In the Henry and Cranes Flat quadrangles it is well represented but occupies smaller areas.

Three subdivisions, which aggregate 5,350 feet in maximum thickness, are distinguished and assigned to the Woodside shale, Thaynes group, and Timothy sandstone of the lower Triassic series. In addition three other formations of uncertain age—the Higham grit, Deadman limestone, and Wood shale—whose combined thickness is 550 feet, are considered provisionally Triassic. The Thaynes group consists of three formations,[28] in descending order the Portneuf limestone, Fort Hall formation, and Ross Fork limestone, but it is here mapped as a single unit, for it is not practicable to differentiate the subdivisions in this district.

The Nugget sandstone, which overlies the Wood shale and was formerly considered Triassic or Jurassic, is now referred to the Jurassic.

REVIEW OF NOMENCLATURE

General discussion.—The names applied to Triassic formations in southeastern Idaho have undergone many changes during the progress of geologic studies in the region. It is desirable therefore to review briefly these changes in order that the application of the names used in this report may be more clearly understood. (See Table 20.)

Hayden surveys.—The region here described was included in the work of the Hayden surveys. Although both Triassic and Jurassic rocks were recognized, it was not possible to differentiate clearly the one system from the other; hence both were included in the so-called "Jura-Trias." Three subdivisions that were recognized consist of, (1) a lower series of arenaceous limestones characterized by the occurrence of the fossil ammonite *Meekoceras* and called the "*Meekoceras* beds"; (2) the red beds, a series of red sandstones and shales classed with (1) as Triassic; and (3) a series of limestones, shales, and sandstones that carries Jurassic fossils. The last series was subdivided into two formations. The doubt as to the nomenclature was caused by the apparent intermingling of Triassic and Jurassic faunas.[29] This broad grouping is still applicable in a general way to the district.

Park City district, Utah.—In his original studies of the Park City mining district Boutwell described the Woodside shale and Thaynes formation. The faunal content of the Thaynes was found to agree with that of the "Permo-Carboniferous beds" of the Fortieth Parallel Survey, and the Woodside, almost nonfossiliferous but lithologically related to the Thaynes, was grouped with that formation rather than with the underlying Park City formation, which was correlated with the "Upper Coal Measures limestone" of the Fortieth Parallel Survey. To the red beds above the Thaynes Boutwell gave the name Ankareh shale.[30] In later work [31] he correlated the Woodside and Thaynes with the *Meekoceras* zone of southern Idaho (the Lower Triassic of Hyatt and Smith[32]) and restricted the name Ankareh shale to red beds between the Thaynes formation and a light-colored sandstone, which he had formerly included in his term Ankareh but to which he now gave the name Nugget sandstone using Veatch's name for similar beds in southwestern Wyoming. Boutwell's Ankareh and Nugget, which he correlated with King's Triassic, doubtless correspond in the main with Peale's "red beds," for in the Park City district, as in the region of Peale's studies, the red-bed formations are overlain by beds that contain marine Jurassic fossils. Thus the stratigraphic limits of the Triassic system in the Park City district and in southeastern Idaho appear to be essentially the same.

The Woodside in the Park City district is chiefly a red shale without fossils and about 1,180 feet thick. The *Meekoceras* fauna does not appear to be present in the Thaynes there, the boundary between the two formations being indicated by the change from the

[27] Blackwelder, Eliot, Reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 476, 477, 1911. Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, p. 263, 1916; Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U. S. Geol. Survey Prof. Paper 120, pp. 111-113 and pl. 10, 1918.

[28] Mansfield, G. R., The geography, geology, and mineral resources of the Fort Hall Indian Reservation: U. S. Geol. Survey Bull. 713, 1920.

[29] Peale, A. C., Report of the Green River division. U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 621-629, 1879.

[30] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, pp. 434-458, 1907.

[31] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 42-59, 1912.

[32] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: U. S. Geol. Survey Prof. Paper 40, pp. 17-19, 1905.

TABLE 20.—*Tentative correlation of stratigraphic units of different authors in reports on areas in northeastern Utah, southeastern Idaho, and southwestern Wyoming*

Boutwell Park City district, Utah[a]	Veatch Southwestern Wyoming[b]		Gale and Richards Southeastern Idaho[c]		Boutwell Park City district, Utah[d]	Mansfield Fort Hall Indian Reservation, Idaho[e]		Mansfield Cranes Flat, Henry, Lanes Creek, Freedom, Slug Creek, Crow Creek, and Montpelier quadrangles in southeastern Idaho[f]			Schultz Rock Springs uplift, southwestern Wyoming[g]	Age[f]
[Absent.]	Twin Creek formation, 3,500–3,800 feet.		Twin Creek limestone.		Twin Creek limestone to northwest.	Twin Creek limestone, 2,500 feet.		Twin Creek limestone, 3,500±feet.			Twin Creek limestone, 140 feet.	Jurassic.
Ankareh shale (red shales with interbedded coarse gray sandstones), 1,500 feet.	Nugget formation, 1,900 feet.	Yellow thin-bedded sandstones and shales, weathering dark brown, 1,300 feet.	Nugget sandstone, 1,900 feet.	Massive white sandstone.	Nugget sandstone (white sandstone with intercalated red shales), 500 feet.	Nugget sandstone, 2,400 feet.	Main sandstone member, 1,500 feet.	Nugget sandstone (red and light-colored sandstones), 1,350±feet.			Nugget sandstone, 1,000 feet.	
		Red-bed member (bright red sandstones and shales), 600 feet.		Massive red sandstones and sandy shales.	Ankareh shale (red shales with interbedded coarse gray sandstones), 1,150+feet.		Wood shale member, 250 feet.	Wood shale (red), 150±feet.			Ankareh shale, 300 feet.	Triassic(?).
							Deadman limestone member, 150+feet.	Deadman limestone, 200±feet.				
							Higham grit member, 500+feet.	Higham grit, 200± feet.				
	[Unconformity.[h]]					Ankareh sandstone, 800 feet.		Timothy sandstone (yellowish), 250±feet.				
Thaynes limestone (calcareous strata with sandstones and shales), 1,190 feet.	[Absent?]		Ankareh shale (maroon, reddish, and chocolate-colored, some greenish beds), 670 feet.		Thaynes formation (limestones with sandstones and shales; "mid red" shale separates more calcareous upper part from more arenaceous lower part), 1,190 feet.	Thaynes group, 3,650 feet.	Portneuf limestone, 1,500±feet.	Thaynes group, 2,600 to 3,100 feet.	Portneuf limestone.	Limestone.	Thaynes(?) formation, 0–200 feet.	Lower Triassic.
										Red sandstones and shales, 200–1,000 feet.		
	Thaynes formation, 2,400–2,600 feet.									Limestone.		
			Thaynes limestone, 2,000 feet.				Fort Hall formation, 800± feet.		Fort Hall formation.			
							Ross Fork limestone, 1,350± feet.		Ross Fork limestone.			
Woodside shale, 1,180 feet.	Woodside formation, 500 feet.		Woodside shale, 1,000–1,200 feet.		Woodside shale (red shale), 1,180 feet.	Woodside shale, 900 feet.		Woodside shale, 1,000–2,000 feet.			Woodside shale, 300 feet.	

[a] Jour. Geology, vol. 15, pp. 434–458, 1907.
[b] U. S. Geol. Survey Prof. Paper 56, 1907.
[c] U. S. Geol. Survey Bull. 430, 1910.
[d] U. S. Geol. Survey Prof. Paper 77, 1912.
[e] Washington Acad. Sci. Jour., vol. 6, pp. 31–42, 1916.
[f] This paper.
[g] U. S. Geol. Survey Bull. 702, 1920.
[h] Veatch in his report did not mention an unconformity between the Nugget and Thaynes formations, but Mr. A. R. Schultz, who has studied the rocks at the Nugget type locality, believes that an unconformity occurs at the base of the Nugget there, and that the Wood shale will be found to constitute the upper part of Veatch's "red-bed member" of the Nugget. A brief inspection of the type locality by the writer, all that conditions at the time permitted, proved insufficient to determine the relationships. Nothing corresponding to the Higham grit was recognized, but the Timothy sandstone, Wood shale, and possibly the Deadman limestone appeared to be present, together with a purplish lava at about the horizon of the Deadman limestone. No definite data regarding unconformity were obtained.

shaly, nonfossilferous beds below to the sandy, calcareous, and fossilferous beds above. The Thaynes formation is 1,190 feet thick. The Ankareh is also distinguished from the Thaynes on lithologic grounds by the change from the calcareous beds below to the siliceous beds above. The Ankareh is composed mainly of red shales that in places are sandy through considerable thicknesses. It includes a number of well-marked beds of coarse gray sandstone 20 to 55 feet thick, and at the base lies a coarse, massive sandstone that immediately overlies a thin limestone. A few fossiliferous grayish-blue limestones are intercalated in the formation, apparently about 200 feet or more above the base. The thickness of the formation is 1,150 feet, and the top is defined by the massive white sandstone of the overlying Nugget, which is 500 feet thick and includes reddish shale intercalated with the sandstone.

Southwestern Wyoming.—In his report on southwestern Wyoming Veatch distinguished the Woodside and Thaynes formations and correlated them with the "Permo-Carboniferous." The red beds above the Thaynes were all grouped by him in a single formation, the Nugget formation, which he describes as overlain by the marine Jurassic Twin Creek formation.[33] Veatch's Nugget consists of a lower brightly colored red-bed member, 600 feet thick, correlated by Boutwell with his Ankareh,[34] and an upper member, 1,300 feet thick, composed of thin-bedded light-colored sandstones, light yellow on fresh fractures but weathering dark brown, which form rugged topography that exhibits characteristic dark-brown talus slopes.

It now appears that the Thaynes and Woodside of southwestern Wyoming, like the formations of the same names in the Park City district, should be considered Triassic, and that the stratigraphic limits of the Triassic system in southwestern Wyoming are essentially the same as in southeastern Idaho. The Nugget sandstone, however, is found to correspond with the Nugget as described below for southeastern Idaho by Mansfield rather than with the Nugget of Boutwell in the Park City district.

Earlier work in southeastern Idaho.—The interpretations of Boutwell and Veatch were carried northward in southeastern Idaho by Gale and Richards,[35] and later by Richards and Mansfield,[36] with such adaptations as were required by the somewhat changed stratigraphic conditions. The Woodside shale was found to be thicker, more calcareous, locally meriting the designation limestone, not red but olive drab or yellow, and to have abundant fossils. The Thaynes formation also was thicker, and sufficiently calcareous to be called a limestone. In addition to the "Permo-Carboniferous" faunas found in Wyoming and the Park City district numerous ammonites were found, and the *Meekoceras* zone, or lowest ammonite horizon, was selected to mark the base of the formation. The term Ankareh shale was applied to a series of maroon, chocolate-colored, and reddish shales that include some sandy and limy beds which lie above the massive limestones of the upper Thaynes and includes at its top another massive limestone. The Nugget sandstone was marked by the occurrence in some parts of the area studied of beds of pure white and conglomeratic sandstone near the base. The formation included beds of red sandy shales, and in some areas there was an upper division of several hundred feet of white sandstone. The thickness assigned to the Ankareh was 670 feet and to the Nugget 1,900 feet. The effect of this adaption of Park City terms was the downward extension of Boutwell's term Nugget and the restriction of his term Ankareh.

Fort Hall Indian Reservation.—In 1913 the writer and G. H. Girty made a joint study of the Triassic formations of the Fort Hall Indian Reservation, 15 to 30 miles west of the northern part of the region described in this paper. (See fig. 1.) The Woodside shale was found to be somewhat thinner than in the Montpelier district, 900 feet, but the Thaynes much thicker, about 3,650 feet. The Thaynes proved to be a group divisible into three formations, each having a distinctive fauna. These formations have been described and named,[37] but only the uppermost, the Portneuf limestone, need be mentioned here. Previous usage in southeastern Idaho was followed here in assigning the beds between the massive Portneuf limestone and the conglomerate supposed to mark the base of the Nugget to the Ankareh, but these comprised 800 feet of sugary yellow sandstones, without significant shales. From their stratigraphic position, however, they were called "Ankareh sandstone." The basal conglomerate of the Nugget as then interpreted was about 500 feet thick and was succeeded above by well-defined limestone and shale members below the main sandstone. The aggregate thickness was apparently as much as 2,400 feet. These four members were also differentiated and named.

Recent work in southeastern Idaho and Wyoming.—In 1914–1916 the interpretations used in the Fort Hall Indian Reservation were carried eastward into the Cranes Flat, Lanes Creek, and Freedom quadrangles

[33] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 50–56, 1907.

[34] Boutwell, J. M., op. cit., p. 59.

[35] Gale, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: U. S. Geol. Survey Bull. 430, pp. 112–121, 1910. Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457–535, 1910.

[36] Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve; U. S. Geol. Survey Bull. 470 pp. 371–439, 1911; Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 1914.

[37] Mansfield, G. R., Subdivisions of the Thaynes limestone and Nugget sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci. Jour., vol. 6, No. 2, pp. 31–42, 1916.

and southward into the Montpelier quadrangle. In the Lanes Creek and Freedom quadrangles the Portneuf limestone of the Thaynes group was divisible into two massive limestone members separated by a well-defined red-bed member. The "Ankareh sandstone" of the Fort Hall Indian Reservation and the four members of the Nugget above mentioned were all present and readily recognizable. The limestone member above the basal conglomerate of the Nugget, however, was locally reddish and showed shaly tendencies in its lower part.

In the Montpelier quadrangle east and northeast of Montpelier the subdivisions of the region to the north are still recognizable. The uppermost member of the Portneuf limestone, however, has dwindled in thickness from about 400 feet in the Freedom quadrangle to about 50 feet in the Home Canyon section near Montpelier, but the red-bed member has increased in thickness from about 200 feet in the Freedom quadrangle to 1,000 feet or more in Home Canyon. Here the apparent increase is in part due to folding. These red beds and the overlying limestone, which belong in the Thaynes as traced southward, were included in the Ankareh shale as traced northward in the earlier mapping.

The "Ankareh sandstone" of the Fort Hall Indian Reservation as traced southward decreases in thickness, and in the Home Canyon section east of Montpelier it is only about 100 feet thick, though farther south it appears to be somewhat thicker. This sandstone was perhaps originally included by Gale and Richards with the overlying conglomeratic bed in the Nugget and not considered a part of the Ankareh shale. In their description of the Ankareh shale [38] they state that a massive limestone marks the top of the formation, but in their description of the Nugget they refer to the conglomeratic bed as "near the base." This sandstone was, however, considered a part of the Ankareh in a section measured in 1912 by Mr. Richards and the present writer in a branch of Indian Creek, east of Bear Lake.

The four subdivisions of the Nugget as previously described are present in the Home Canyon section, but the conglomeratic member is represented by a dense purplish quartzite, and the shaly tendency of the lower part of the limestone member above mentioned has there developed, so that the limestone appears in the midst of shale rather than below the shale member.

In 1920 the writer made a brief inspection of the Nugget section in the vicinity of the type locality at Nugget Station, Wyo. The main body of the formation hitherto correlated with Boutwell's Nugget in the Park City district was found to correspond with the writer's "main sandstone member" in the Fort Hall Indian Reservation, and the "red-bed member" of the Nugget of Wyoming was found to correspond with the three underlying members of the Nugget as described for the Fort Hall Reservation.

Present classification.—The attempts to carry the Triassic terminology of Boutwell and Veatch into southeastern Idaho showed the necessity for a revision or redefinition of Triassic formation names. The terms Woodside, Thaynes, and Nugget are well established in the literature of the general region and apply to rocks that are characteristically developed and readily recognized, though they show considerable variation from their character at their type localities. These names are therefore retained respectively as the Woodside shale, the Thaynes group, and the Nugget sandstone.

The conglomeratic, calcareous, and shaly members in the lower part of the Nugget as described in the Fort Hall Indian Reservation are now designated formations, with the names Higham grit, Deadman limestone, and Wood shale, respectively, and the name Nugget sandstone has been restricted to the "main sandstone member" of the author's earlier report, which has the characteristic lithology and position of the upper division of Veatch's Nugget, which is the conspicuous sandstone at Nugget Station, Wyo., the type locality of the formation.

The term Ankareh shale can not be retained in southeastern Idaho without confusion and is therefore dropped from the classification of that area. The name Timothy sandstone has been introduced for the sandstone that lies between the top of the Thaynes formation and the Higham grit, which in an earlier report was designated "Ankareh sandstone."

The preceding discussion is summarized in Figures 24 and 25 (pp. 190 and 191.) It has been published elsewhere [39] in abbreviated form.

RELATION OF TRIASSIC TO PERMIAN

The relations of the Triassic to the Permian in this region are not definitely known. As first described in the Park City district the Woodside, Thaynes, and Ankareh were all assigned to the Permian. Later studies have demonstrated the Triassic age of the Thaynes group and have pointed strongly to the base of the Woodside as the probable base of the Triassic system. The marked lithologic and faunal change at that horizon makes this interpretation easy to express cartographically.

The field relations suggest conformity between the two systems, for the boundary between the Woodside and Phosphoria is marked by great regularity wherever it is shown and the attitudes of the two formations correspond quite closely. There is, too, no conglomeratic development at the base of the Woodside or evidence of erosion in the Phosphoria preceding the deposition of the Woodside, unless the somewhat vari-

[38] Gale, H. S., and Richards, R. W., op. cit., p. 480.

[39] Mansfield, G. R., Triassic and Jurassic formations in southeastern Idaho and neighboring regions: Am. Jour. Sci., 4th ser., vol. 50, pp. 53–64, 1920.

able thickness of the Phosphoria is so considered. Nevertheless, the striking faunal and lithologic differences above noted point to very different conditions of deposition for the two formations and indicate a stratigraphic break (unconformity) of some magnitude.

In this connection it is interesting to note that in the Fort Hall Indian Reservation [40] a Paleozoic fauna was found by Girty in beds that lithologically resemble the Woodside and above the usual cherty shales of the Rex. This fauna consisted chiefly of the brachiopod *Ambocoelia* in abundance, together with pelecypods that suggest Paleozoic characteristics but have not been definitely identified. Although this fauna has not been recognized outside the Fort Hall Indian Reservation, it indicates the possibility that the real change from Permian to Triassic may in some places come somewhat above the base of the Woodside as mapped.

Since the above was written Mr. Girty has given further consideration to the problem, reexamined the fauna, and changed his views regarding these beds. In a memorandum on the subject to the writer he says:

In the first place, as I recall the circumstances, fossils were not plentiful at this locality, which is No. 2930 in the Survey register, and the collection was made from loose pieces that were lying upon a little bench made by some more resistant ledges. Care was taken to reject material that might have come down from above, and obviously none could have come up from below. In spite of this care one piece of limestone apparently did come from a source higher in the section, and in the faunal list I have omitted three species that were found in it. The following list then represents what we originally believed and what I now believe to be essentially a single horizon that lies just above the Rex chert:

Lingula sp.	Myalina aff. M. aviculoides.
Discina sp.	Pleorophorus sp.
Ambocoelia, n. sp.	Pleorophorus sp.
Aviculipecten sp.	Myophoria sp.
Aviculipecten sp.	Myophoria? sp.
Aviculipecten sp.	Myophoria? sp.
Aviculipecten sp.	Bellerophon sp.

The salient and perplexing thing about this fauna is that it appears to have contradictory affinities, which point to Carboniferous age on one hand and to Triassic age on the other.

The *Lingula* and the discinoid are neutral, but the *Ambocoelia* is strongly Carboniferous in the trend of its evidence. This form is extremely abundant, and I have been at great pains to determine its generic position, which seems almost certainly to be with *Ambocoelia*. Now *Ambocoelia* is not only unknown elsewhere in the Triassic of the West, but it is unknown elsewhere in the Triassic of the world. Therefore it would appear to be a weighty factor in the evidence pointing to the Carboniferous age of this horizon, and I was especially impressed by it in my earlier interpretation. On the other hand, this *Ambocoelia* is not the species that is common in the Phosphoria formation. The pectinoids, the *Myalina*, and the *Pleurophorus* are more or less neutral, for the same genera, so far as the genera can be determined at all, occur in Idaho in both the Carboniferous and the Triassic. This is essentially true also of *Bellerophon*, which, though commonly restricted to the Paleozoic, is known also to occur in the Triassic of Europe, and I have found it at one locality in the Triassic of Idaho also. One of the pelecypods, however, actually appears to belong to the Triassic genus *Myophoria* rather than to the similar Paleozoic genus *Schizodus*.

I have confined myself to listing these forms merely as genera and to discussing them as such, for the fossils themselves are so poorly preserved that they could not be identified positively even if they did not belong to species that were undescribed, as are so many of those in the Lower Triassic faunas. Even the generic references can not be insisted upon, because the real generic characters are not shown. The shape and general expression sometimes afford an adequate clue to generic position, and consequently the assignment of some specimens is fairly trustworthy.

When I first reported on the age of this fauna I called it Permian because of the *Ambocoelia* and to a less degree because of the *Bellerophon*. Upon reconsideration, after the lapse of a number of years in which I have given the Triassic faunas of this region considerable though desultory study, I am disposed to reverse my original judgment and determine the geologic age as Triassic. All the really Paleozoic types so common in the Phosphoria have disappeared in this higher fauna, and we find an almost complete faunal change between the two except for the *Ambocoelia* and a few other forms as mentioned above. Indeed, the fauna of this *Ambocoelia* zone now has to me a decidedly Triassic aspect, for without contradicting what I have just said relative to the fossils not being strictly identifiable, a number of the forms are at least very similar to forms that occur in the Lower Triassic of this region. The suggestion carried by this fact is supported by the stratigraphic position of the fauna, as above the Rex, and by the lithologic character of the rocks, which is much more nearly like the Triassic than the Phosphoria.

In brief, it is my present judgment that *Ambocoelia* would better be regarded as having transgressed the boundary between Paleozoic and Mesozoic as *Myalina*, *Bellerophon*, *Spiriferina*, and a number of other genera are known to have done, and that this fauna and its horizon would better be assigned to the Triassic. In reaching this conclusion I have been influenced considerably by other lines of evidence than the paleontologic. As the paleontologic evidence is conflicting, I could hardly object if facts in your possession caused you to adhere to my earlier determination and to reject my later one.

LOWER TRIASSIC FORMATIONS

GENERAL FEATURES

The formations assigned to the Lower Triassic include 3,850 to 5,350 feet of shales, calcareous beds, and sandstones grouped in three formations, of which the Woodside shale and Thaynes group are fossiliferous at certain horizons. The age determination, as pointed out in the discussion of the Thaynes, is based upon ammonite zones which occur 1,000 to 2,250 feet above the top of the Paleozoic formations. The fossils of the overlying 3,300 feet of the sediments are less distinctive, and the faunal relations of some of them, notably certain brachiopods of the Portneuf limestone, have not been fully studied. It is therefore possible, though perhaps not probable, that some of these beds may be of later age than Lower Triassic.

[40] Mansfield, G. R., The geography, geology, and mineral resources of the Fort Hall Indian Reservation: U. S. Geol. Survey Bull. 713, p. 41, 1920.

WOODSIDE SHALE

Name and definition.—The Woodside shale was named by Boutwell[41] from a gulch of that name in the Park City mining district of Utah. In southeastern Idaho this name is given to 1,000 feet or more of platy and calcareous shales with some limestones that lie, probably unconformably, on the Rex chert member of the Phosphoria formation and that pass upward conformably to the overlying Thaynes group.

The base of the Woodside shale is in general sharply defined because of the marked lithologic differences of the formations involved. Even where the Rex chert is represented by the flinty shale facies the distinction is usually easy. The upper limit is not so easily distinguished, for the lithology of the Woodside and the overlying Thaynes is in many respects similar, and the boundary has been somewhat arbitrarily placed at the layer immediately below the *Meekoceras* zone, which marks the entry of ammonites. This division seems appropriate, however, because of the remarkable persistence of the *Meekoceras* zone over large areas and because of additional faunal and minor lithologic differences.

Distribution.—The Woodside shale is exposed in each of the quadrangles mapped except the Cranes Flat. In the Montpelier quadrangle it forms a belt 1½ miles wide along the west side of Bear Lake Valley, between Mill Creek and Bloomington Creek and east of the great Paleozoic fault block. In Montpelier Canyon the formation flanks the Paleozoic anticline, 3 miles east of Montpelier. In the upper part of Georgetown (South) Canyon and along Crow Creek in the north part of the quadrangle, in the Sublette Ridge, and along the west side of Bear Lake Plateau from the vicinity of Hot Springs northward the formation is exposed in small areas or narrow belts in connection with various folds.

In the quadrangles north of the Montpelier the Woodside shale is exposed, chiefly in connection with the three major synclines of the region, though minor areas occur in connection with smaller folds or with faults.

In the Slug Creek quadrangle extensive exposures occur in the Aspen Range north of Swan Lake Gulch and subordinate exposures just south of the same canyon. Other large areas occur in the ridge between Slug Creek and Dry Valley, the crest of Dry Ridge, the west side of upper Slug Creek Valley, and in Georgetown Canyon.

In the Crow Creek quadrangle the Woodside shale is confined to the west half. The chief exposures are included in the great bifurcated syncline that stretches nearly through the quadrangle from south to north. Minor areas occur along Crow Creek from the south boundary to lower Sage Valley.

In the Freedom quadrangle exposures occur along the west side of Star Valley near the east border of the quadrangle and in Diamond Creek and Webster Canyon in the southwest part.

In the Lanes Creek quadrangle the Woodside shale forms bands of considerable extent and generally of northwest trend, associated with different folds and fairly well distributed throughout the district. These bands continue with some interruption into the east half of the Henry quadrangle. In the last-named area there are also exposures in the northwest part east of Corral Creek and near Blackfoot River.

Character.—As described by Boutwell the Woodside shale in the type district is largely composed of a fine-grained dark-red shale, with subordinate occurrences of buff, brown, and greenish-gray shales with ripple marks, mud cracks, and raindrop impressions throughout the formation. In the mapped portion of southeastern Idaho the red colors are practically wanting, except in a small area west of Bloomington in the Montpelier quadrangle. The ripple marks, mud cracks, and raindrop impressions are also absent, and the formation as a whole is characterized by olive-drab platy shales, with alternating thin beds of brownish-gray limestones that have locally a faint purplish tint. The shales are siliceous and calcareous, so that they are hard and ring under the hammer. They weather into rusty brown, yellowish, or even black fragments that on breaking show the characteristic olive-drab color, and they commonly contain dendrites. The limestones on weathering preserve the purplish-gray or brownish-gray color and assume a sort of velvety surface.

Topographically the Woodside shale is represented by rounded and smooth slopes that are well covered with vegetation. (See pls. 21, *A*, and 29, *B*.) The upper limestones with thick layers, however, form massive ledges, and where cut by streams make imposing gateways, particularly in parts of the Crow Creek quadrangle.

Several sections of the Woodside shale which give local details of stratigraphy have been measured as follows:

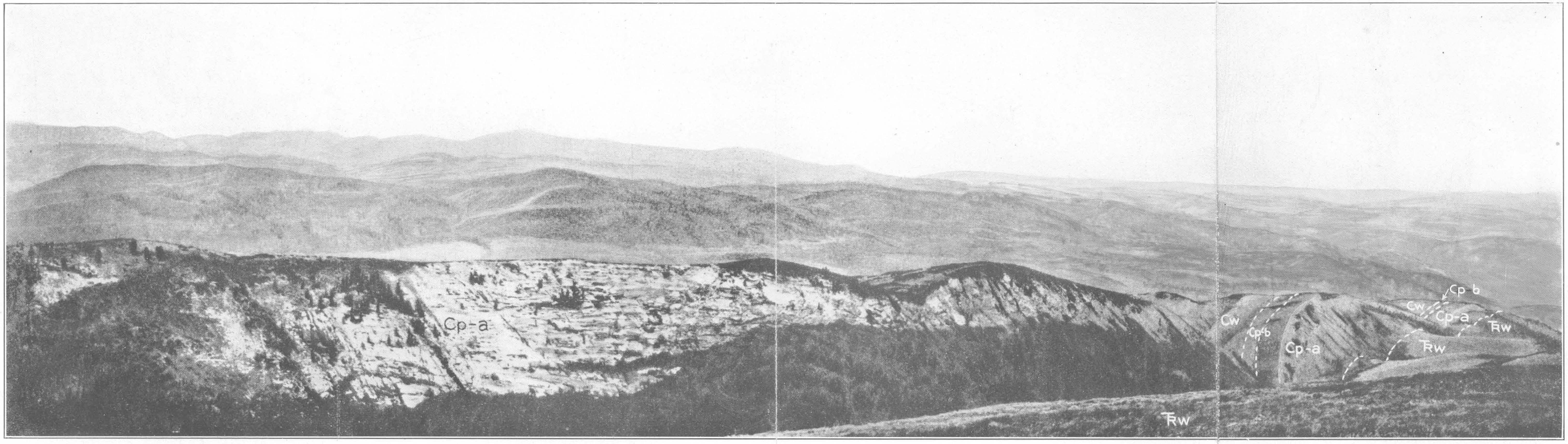
TABLE 21.—*Part of stadia measurements of Triassic section in Raymond Canyon, Sublette Ridge, Wyo.*[42]

	Feet
Woodside shale (upper limit not defined; probably should include some higher beds), largely concealed by talus of limestone from harder ledges, but includes some thin-bedded limestone and beds of shale (not well exposed)	600

[41] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, p. 446, 1907.

[42] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull 430, p. 471, 1910.

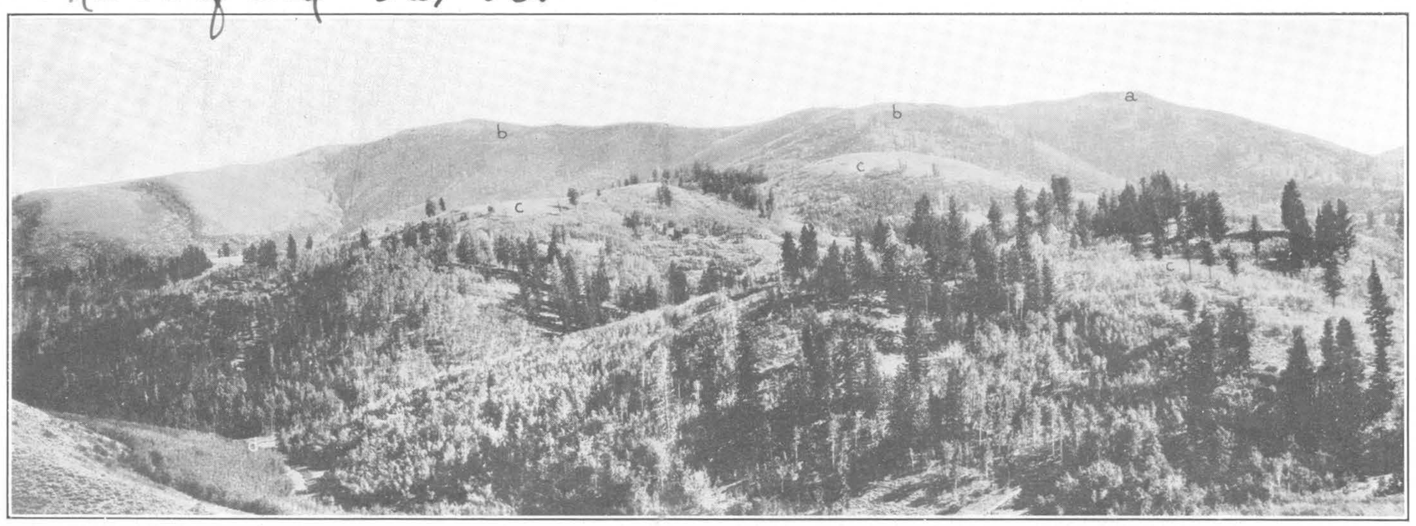
No neg.



A. RIDGE EXTENDING FROM SEC. 14 THROUGH SEC. 3, T. 8 S., R. 44 E., SLUG CREEK QUADRANGLE

Showing dip slope of Rex chert member (Cp-a); Cp-b, phosphate shales of Phosphoria formation; Cw, Wells formation; T̶Rw, Woodside shale

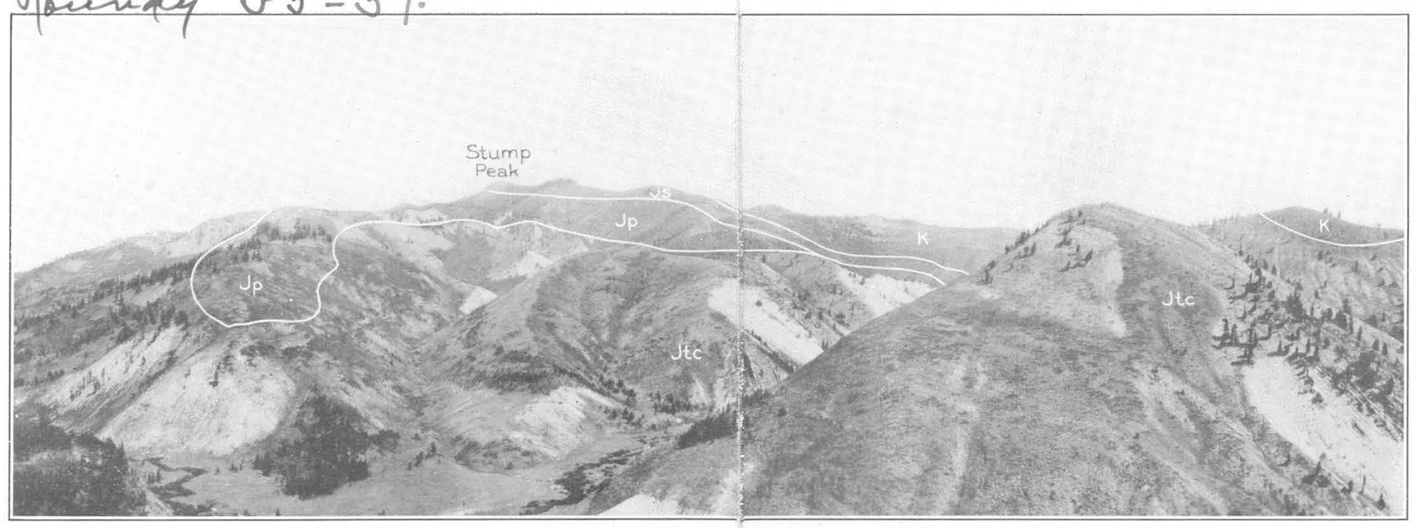
Mansfield 32, 33.



B. VIEW SOUTHEASTWARD IN THE ASPEN RANGE FROM THE HEAD OF MIDDLE SULPHUR CANYON, T. 9 S., R. 43 E., SLUG CREEK QUADRANGLE

a, Gannett erosion surface (?); b, Elk Valley cycle; c, Dry Fork cycle; d, Blackfoot cycle

Roundy 55-57.



C. VIEW NORTH FROM HILL SOUTH OF THE JUNCTION OF STUMP CREEK AND NORTH FORK, T. 6 S., R. 45 E. (UNSURVEYED), FREEDOM QUADRANGLE

Jtc, Twin Creek limestone; Jp, Preuss sandstone; Js, Stump sandstone; K, Cretaceous

TABLE 22.—*Part of stratigraphic section of Triassic formations in Montpelier Canyon, Idaho*[43]

[By C. L. Breger, 1909]

	Feet
Thaynes group. (See beds 8–16, p. 89.)	
Woodside shale:	
7. Limestone, like 8 but somewhat darker, containing *Myalina* in abundance	55
6. Sandstone, gray, shaly below	87
5. Shale and thinly laminated sandstone, gray and red, the whole forming a red-bed member that furnishes a persistent horizon marker	198
4. Sandstone, light colored, shaly below, quarried for building stone at top; contains large *Myalina*	200
3. Limestone, gray, blue, thin bedded; contains a couple of massive bands, the whole forming a conspicuous horizon marker; fossils at base, small lamellibranchs, including a small, smooth pectinoid	48
2. Shales, gray; thin-bedded limestone in seams and bands, pale coco brown in color	235
1. Interval, covered, like 2; thickness roughly estimated, possibly more than 150 feet	150
Productus-bearing or cherty limestone at top of Park City formation.	
	973

Beds 1 and 2 contain chiefly *Lingula*, with some obscure lamellibranchs.

TABLE 23.—*Stratigraphic section of Woodside shale eastward from a point near center of west side of sec. 18, T. 6 S., R. 41 E., Henry quadrangle, Idaho*

[By P. V. Roundy, 1916. Measurements normal to bedding. The letters and numerals A to G[1] correspond with Mr. Roundy's original notation]

	Feet
Thaynes group (*Meekoceras* zone).	
Woodside shale:	
G[1]. Limestone, massive beds, similar to G and E with a tendency to weather brownish gray; darker sandstone bands. Strike, N. 5° E.; dip, 22°–45° E	275
G. Limestone, massive beds and thin platy sandstone; shale in small amounts. Strike, N. 20° W.; dip, 21° E	100
E. Limestone and sandstone similar to D; more massive and with greater amount of limestone; limestone in upper part more shaly. Strike, N. 20° W.; average dip, 27° E	400
D. Limestone and sandstone, shaly, similar to B–B[3]	190
C. Sandstone, purplish to brownish gray; dense, weathering locally with films of black oxide of iron. Strike, N. 15° W.; dip, 24° E	75
B[3]. Limestone and sandstone, pieces exposed on surface with local ledges. Strike, N. 10° W.; dip, 27° E	150
B[2]. Shale, calcareous and greenish with beds of sandstone and limestone similar to those of B[1]. At 75 feet more yellowish-weathering sandstone appears, and here and there beds of limestone 10 inches thick. Top 75 feet not well exposed. Strike, N. 9° E.; dip, 22° E	250
B[1]. Sandstone, calcareous, and shale, greenish yellow, dendritic, weathering brown. Numerous bands of limestone 3 to 10 inches thick with beds 1 to 4 inches thick occur at irregular intervals. More shaly near top. Strike, N. 20° E.; dip, 23° E	150
Woodside shale—Continued.	
B. Limestone band, dense, purplish gray, weathering brownish; contains some calcite and fragments of *Lingula*. Strike, N. 10° E.; dip, 23° E	2
A[2]. Covered; shaly sandstone float and dark-gray soil with a little float of dark-gray impure limestone	290
A. Covered; shaly sandstone float, probably considerable shale present. Strike and dip measured from neighboring exposures. Strike, N. 10° E.; dip, 25° E. Rex chert boundary on west part of saddle	155
	2,037

[43] Gale, H. S., and Richards, R. W., op. cit., p. 473, 1910.

Thickness.—The Woodside shale differs somewhat in thickness in different places. In the southern part of the region it is 1,000 feet thick or perhaps less, but in the northern part it is considerably thicker, approximately 2,000 feet.

Age.—The shales of the Woodside are sparingly fossiliferous, and the forms contained are poorly preserved. Linguloid brachiopods and pelecypods, chiefly of the genus *Myalina*, are found in a few places. The limestones at some horizons are highly fossiliferous. This is especially true of the upper part of the formation, where the limestones are in greater abundance, more massive, and in places are crowded with pelecypod shells, chiefly species of *Myalina*. A *Myalina* zone and a zone of brachiopods, chiefly species of *Terebratula*, occur just below the top of the formation and serve as convenient guides.

As stated on page 84, the age of the Woodside shale has sometimes been questioned. Its lithologic and faunal similarity to the Thaynes, however, have caused it to be grouped with that formation as Lower Triassic rather than with the Paleozoic beds. (See pp. 93 and 94.) Thus its base is provisionally regarded as the base of the Triassic in this region.

THAYNES GROUP

Name and definition.—The Thaynes formation was named by Boutwell[44] from a canyon of that name in the Park City mining district of Utah. In the Fort Hall Indian Reservation[45] the Thaynes deposits constitute a group, which is subdivided into three formations, but, on account of certain variations in lithology, it has not been practicable to differentiate these subdivisions on the maps of the quadrangles here represented. In this district the name is applied to 2,600–3,100 feet or more of calcareous shales and limestones that pass, with apparent conformity, at the base into the upper limestones of the Woodside shale, and are overlain, also with apparent conformity

[44] Boutwell, J. M., op. cit., p. 55.

[45] Mansfield, G. R., Subdivisions of the Thaynes limestone and Nugget sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci. Jour., vol. 6, pp. 31–42, 1916.

by the Timothy sandstone. As noted later, however, there is reason for supposing at least local unconformity at this upper horizon. The base of the Thaynes is in the *Meekoceras* zone. Where this zone is not well exposed the *Terebratula* and *Myalina* zones of the upper Woodside serve as convenient guides for the approximate boundary. The top of the Thaynes is generally represented by massive beds of dense siliceous and cherty limestone which carry silicified shells that project from the weathered surfaces.

Distribution.—The Thaynes group is exposed in each of the quadrangles mapped. It occurs at intervals along the west side of Bear Lake Valley north of Bloomington and east of Nounan Valley. In the Preuss Range and Bear Lake Plateau the Thaynes occupies a prominent area that extends as a broad band, somewhat interrupted by folding and faulting, nearly across the Montpelier quadrangle from south to north. In the Sublette Ridge the Thaynes is upturned along the west flank for the greater part of its length and locally forms conspicuous exposures.

The Thaynes group occurs on both sides of Bear River in the southwest corner of the Slug Creek quadrangle and forms the axial portion of the syncline in the northwest corner. Similarly it forms the central part of the syncline between Slug Creek and Dry Valley and appears in the syncline in Georgetown Canyon.

The outcrops of the Thaynes in the Crow Creek quadrangle are associated chiefly with the synclines in the western and northwestern districts, though a considerable band lies east of Sage Valley and smaller areas occur in Crow Creek.

In the Freedom quadrangle the Thaynes group covers an extensive area in the southwest part. It is exposed in an eroded anticline in Boulder Creek and appears in two parallel bands west of Star Valley near the east boundary.

The Lanes Creek quadrangle includes large areas of the Thaynes, especially in the rugged hills of the central portion between Lanes Creek and Enoch Valley. Other notable exposures occur north of Browns Canyon, west of Diamond Creek, between Dry Valley and Slug Creek, and in the southwest corner of the quadrangle.

In the Henry quadrangle the chief occurrences of the Thaynes are in the hills northeast and west of the Blackfoot River Reservoir. Other exposures are found in the extreme northwest corner and along the southeast border.

The Thaynes areas of the Cranes Flat quadrangle are relatively small and lie in the southwest corner and along the west flank of the hills east of Cranes Flat.

Character.—The lithology of the Thaynes is similar to that of the Woodside in many respects, but some differences should be noted. The more shaly parts of the group have in general the same olive-drab color and weathering features that are noted in the beds of the Woodside, but locally, as near Paris, in the Montpelier quadrangle, they are lighter colored and more sandy. Elsewhere for almost 200 feet above the base, the rocks are more clayey and have a well-defined grayish color that differs from the yellowish and greenish tints of the Woodside. This feature is helpful as an indicator where the *Meekoceras* zone is not well developed. The middle portion of the Thaynes contains at many places thin, platy beds of sandy and calcareous shale, in which the individual plates are large and smooth and might almost be used for roofing material.

The limestones are more prominent in the Thaynes than in the Woodside. They form ledges that in many places are conspicuous and make rougher slopes than those developed on the Woodside. The limestones contain much clay and sand and turn dark on weathering, so that they then resemble dark-brownish sandstones except along fresh fractures.

In some places massively bedded yellowish and reddish weathering sandstones, sparingly fossiliferous, occur in the upper middle portion. These beds resemble lithologically certain beds of the Wayan formation (Cretaceous) on the one hand and of the Wells formation (Pennsylvanian) on the other, so that in the absence of fossils particular attention must be paid to stratigraphic association.

The tripartite arrangement of the upper Thaynes (Portneuf limestone) with its included red-bed member has already been mentioned. It should be added that the limestone above these red beds, though sparingly fossiliferous, is lithologically and faunally like the Portneuf limestone of the Fort Hall Indian Reservation, [46] and is thus clearly upper Thaynes. In the mapping of the Montpelier quadrangle, however, which was largely completed before the above relationships were determined, these red beds, with the overlying limestone, which is there very thin, and the Timothy sandstone, were included in the "Ankareh shale." The map has been revised to some extent. The term "Ankareh" has been dropped from the nomenclature of this area, and the name Timothy sandstone inserted. North of Montpelier Canyon the region has been remapped and corrected. It has not been practicable to remap the region south of Montpelier Canyon. The Timothy sandstone, as there represented, simply replaces the Ankareh shale and thus includes a narrow strip of the upper Thaynes.

The red-beds member of the Portneuf is well exposed in the hills between Webster Canyon and Horse Creek in the southern part of the Freedom quadrangle and in the hills of Thaynes that lie west of Lanes Creek. It also appears in Home Canyon and in the hill south of Montpelier Canyon, in secs. 29 and 32, T. 12 S., R. 45 E.

[46] Mansfield, G. R., op. cit., pp. 38–40.

Some of the topographic and structural features of the Thaynes are shown in Plate 36, *A*, which represents the locality where the stratigraphic sections given in Tables 23 and 24 were measured.

Stratigraphic sections of the Thaynes have been measured at four localities: In secs. 17 and 18, T. 6 S., R. 41 E., Henry quadrangle; in Montpelier Canyon, just east of Montpelier; in a small tributary of Indian Creek in T. 15 S., R. 45 E.; and in Raymond Canyon in the Sublette Ridge. These sections are given in Tables 24 to 27.

TABLE 24.—*Stratigraphic section of Thaynes group eastward from SE. ¼ NE. ¼ sec. 18, T. 6 S., R. 41 E., Henry quadrangle, Idaho*

[By P. V. Roundy, 1916. Measurements normal to dip]

		Feet
S.	Limestone, light yellowish gray, much fractured, in part a breccia with many small fragments of chert. Strike, N. 9° W.; dip, 50° W	220
R¹.	Sandstone, calcareous (top of hill), partly covered (east of crest)	170
R.	Sandstone, fine grained, fairly pure, and reddish or buff	80
Q.	Sandstone, calcareous, yellowish gray, and thin-bedded(?) sandy limestone	100
P.	Limestone, dark gray but weathers lighter, coarsely crystaline, beds 4 to 14 inches thick, fossiliferous; large aviculipectens in limy sandstone; the heavy ledges of pure limestone confined to lower part. Strike, N. 10° W.; dip, 71° W	190
N.	Sandstone, yellowish and reddish to purplish gray, fine textured	170
M.	Sandstone, calcareous, locally a limestone; weathers gray and yellow; nodular; on fresh fracture shows dense hard and gray masses in somewhat less compact streaky matrix that stands out on weathered surface. Strike, N. 15° W.; dip, 72° W	200
L.	Sandstone, calcareous, yellowish gray to olive drab. Strike, N. 14° W.; dip changes from 88° to 60° W	315
K.	Mostly covered; greenish-yellow and brownish-yellow sandstone float	165
J.	Covered; float of limestone mingled with rusty-yellow sandstone. Strike and dip assumed to agree with those of division H	250
I.	Covered; float of rusty-yellow sandstone. Strike and dip assumed to agree with those of division H	1, 250
H.	*Meekoceras* zone; scarcity of fossils (only 5 specimens of *Meekoceras* seen); heavy bluish-gray limestone but weathers reddish. Strike, N. 7° W.; dip, 60° E	20±
G–A.	Woodside shale. (See p. 87.)	
		3, 130

TABLE 25.—*Stratigraphic section of Thaynes group in Montpelier Canyon, Idaho* [47]

[By C. L. Breger, 1909]

	Feet
Mississippian: 17. Limestone, massive, brecciated, and cherty (overthrust).	
Thaynes group:	
16. Shale, gray, thin; like division 14; limestone lenses as much as 4 feet thick; in many places crowded with terebratuloids	210
15. Limestone, brownish, thick bedded; contains terebratuloids	40
14. Shales, gray to olive colored, thin, contain scattered limestone lenses as much as 15 feet thick; rayed pectinoids abundant locally; terebratuloids and *Pugnoides triassicus*, n. sp., abundant in some of the limestones	656
13. Sandy limestones and calcareous thick-bedded sandstones; upper portion produces brown-weathering talus slopes	574
12. Limestones that form a conspicuous horizon marker as far south as the Woodruff area in Utah; basal 10 to 15 feet crowned with terebratuloids; rayed pectinoids and *Pugnax utah* Marcou? also occur at the base as well as higher up in the division	[48] 85
11. Interval, covered; includes some thin gray shales	83
10. Sandstones, locally calcareous; form brown-weathering talus slopes; contain *Bakewellia?*; some bands or lenses of purer limestone as much as 15 feet thick are in places loaded with terebratuloids and some *Pugnax utah* Marcou?	216
9. Interval, mostly covered; includes some gray shales	379
8. Limestone, light colored, resistant; the *Meekoceras* zone of Peale, White, Hyatt and Smith, and others; a well-defined horizon marker from Hot Springs northward; exposed	39
7–1. Woodside shale. (See p. 87.)	
	2, 282

TABLE 26.—*Part of stratigraphic section in tributary of Indian Creek in sec. 18, T. 15 S., R. 45 E., 2 miles southeast of Hot Springs, Bear Lake County, Idaho.*

	Ft.	in.
Higham grit (?): Sandstone, white and pink, gritty	200±	
Timothy sandstone (?):		
Sandstone, calcareous, fossiliferous (?); weathers brown and white to drab; fragments of coal and also fragments of shale	100	
Sandstone, red, friable	8	
Shale, red	20	
Sandstone, greenish gray, calcareous	8	
Shale, red and brown, broken	30	
Thaynes group (?):		
Limestone, gray	30	
Shale, red and greenish gray	60	
Sandstone, red	50	
Sandstone, white		4
Shale, red, thin bedded, alternating with red sandstones	6	6
Sandstone, red and friable, with interbedded red shale	210	
Sandstone	8	
Interval, slope covered with vegetation, fragments of red sandstone, and other material	249	
Limestone, massive (lower member of Portneuf limestone?).		
	780±	

[47] Gale, H. S., and Richards, R. W., op. cit., pp. 472–473.

[48] Figure inadvertently omitted in publication cited.

TABLE 27.—*Stadia measurement of the Raymond Canyon section, Sublette Mountains, Wyo.* [49]

	Feet
Twin Creek limestone: Limestone, white, weathered, splintery, fractured, shaly, and massive (not measured).	
Nugget sandstone:	
Sandstone and quartzite, very massive, dark red and brown; forms heavy talus slopes	1, 700
Sandstone, massive and sandy shale; at top a heavy ledge of conglomeratic white quartzite	200
	1, 900
Ankareh shale: Mostly shaly beds, dark-red and maroon shales, and some massive sandstone (not well exposed)	700
Thaynes formation:	
Limestone ledges, very massive, muddy and rusty weathered surface; form steep, rocky canyon walls	1, 300
Interval, bounded by massive limestone ledges at top and bottom; covered by brown weathered limestone talus and contains some massive limestone beds	800
	2, 100

The Thaynes deposits show considerable variation in thickness and lithologic character from northwest to southeast. In the Fort Hall Indian Reservation they comprise a group about 3,650 feet thick and the upper formation or Portneuf limestone is about 1,500 feet thick.[50] In that region the separation of this limestone into upper and lower members with intervening red beds was not recognized, though certain red beds there interpreted as Nugget in the light of more recent studies farther east may prove to be Thaynes. The tripartite arrangement of the upper Thaynes (Portneuf limestone) is well developed in the Lanes Creek and Freedom quadrangles. The changes in thickness southward from these localities have been mentioned in the discussion of the Triassic system.

In the Indian Creek section (Table 26), which was measured in 1912 before the tripartite character of the Portneuf limestone was known, the beds between the gritty sandstone at the top and the massive limestone at the bottom were considered Ankareh, and indeed the section was selected and measured as an Ankareh section. It now appears probable that the gray limestone there shown, which is 30 feet thick, and the red beds beneath correspond, respectively, to the topmost limestone of the Portneuf and the underlying red-bed member of that formation. The rest of the section upward to the gritty sandstone corresponds fairly well with the Timothy sandstone and will be referred to again in the discussion of that formation.

The Raymond Canyon section (Table 27) was measured in 1909 and revisited in 1912 but not since the more detailed knowledge of the Thaynes was gained. It now seems probable that the Ankareh of that section may correspond with the red-bed member of the Portneuf limestone, and that most of the lower division of the Nugget there described may correspond with the Timothy sandstone. No limestone which could represent the upper member of the Portneuf is mentioned in association with the red beds, as in the sections previously discussed, and it may be that it has disappeared by wedging out, by gradation into red beds, or by erosion, or it may be covered.

In the Montpelier Canyon section (Table 25) the red beds have been removed or are concealed by the overthrust block of Mississippian limestone, but these beds are well exposed farther east as noted above. The section in T. 6 S., R. 41 E., shown in Table 24, is also incomplete because of folding. The brecciated cherty limestone at the top may represent part of the massive limestone that normally occurs beneath the red beds.

If the red beds of the Raymond Canyon and Indian Creek sections are assigned to the Thaynes as above suggested the thickness of the Thaynes appears to range from about 2,600 to 3,100 feet.

Age and correlation.—Many of the horizons of the Thaynes are occupied by fossiliferous beds. The *Meekoceras* zone at the base of the formation consists of whitish to gray limestone 10 to 25 feet thick, which is crowded with ammonites, whose chambered shells are conspicuous on the weathered surfaces of the rock. Characteristic ammonites of this horizon are *Meekoceras gracilitatis*, *M. aplanatum*, *M. mushbachianum*, *Aspidites*, *Ophiceras*, *Flemingites*, *Ussuria*, *Pseudosageoceras*, and *Nannites*.[51] Two other notable horizons characterized by ammonites have been recognized by Smith in the Thaynes in Paris Canyon, Montpelier quadrangle. These horizons are known as the *Tirolites* and the *Columbites* zones. The *Tirolites* zone consists of gray calcareous shales about 250 feet above the *Meekoceras* zone and contains *Tirolites* aff. *T. cassianus* Quenstedt, *T.* aff. *T. smiriagini* Mojsisovics, *T.* aff. *T. haueri* Mojsisovics, *Dalamatites* cf. *D. morlaccus* Kittl, *Dinarites*, n. sp., *Pseudomonotis idahoensis* Meek, and other forms. About 25 feet higher lies a thin bed of brownish bituminous limestone in which occurs the *Columbites* fauna, which includes *Columbites parisianus*, several other species of the same genus, *Xenaspis*, *Xenocliscus*, *Celtites*, *Pseudoharpoceras*, *Ophiceras*, and some survivors of the two preceding horizons.[52]

In addition to the horizons marked by ammonites there are noteworthy horizons marked by brachiopods (*Pugnax*, *Spiriferina*), pelecypods, and other forms. A group of typical Thaynes fossils selected by G. H. Girty is illustrated in Plate 30. He has also supplied some comments on the Lower Triassic faunas (see pp. 93 and 94) and described some new species. (See pp. 434 to 446.)

[49] Gale, H. S., and Richards, R. W., op. cit., p. 471.
[50] Mansfield, G. R., op. cit., p. 39.
[51] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: U. S. Geol. Survey Prof. Paper 40, pp. 17-19, 1905.
[52] Smith, J. P., Distribution of Lower Triassic faunas: Jour. Geology, vol. 20, pp. 13-20, 1912.

The Thaynes of the Park City district does not contain ammonites and was at first assigned to the "Permo-Carboniferous," as noted in the discussion of the Triassic system. It was later found to be faunally related to Peale's "*Meekoceras* beds" of southeastern Idaho, which had been referred by C. A. White [53] to the Triassic. Further studies of the cephalopod genera by Hyatt and Smith [54] showed that the fauna of Idaho is intimately related to the Lower Triassic faunas of India and eastern Siberia and that it contains species which may even be identical with those from Asia. The Thaynes is therefore assigned to the Lower Triassic.

TIMOTHY SANDSTONE

Name and definition.—The Timothy sandstone was named from Timothy Creek, which rises in the southwestern part of the Freedom quadrangle, flows northwestward, and cuts across the sandstone. It is bounded below by the generally massive but locally thin-bedded uppermost limestone of the Thaynes group and above by the Higham grit.

Distribution.—The Timothy sandstone is exposed in four of the seven quadrangles mapped—the Montpelier, Freedom, Lanes Creek, and Cranes Flat quadrangles. It may also include some of the beds mapped as Nugget south of the lower end of Sage Valley, in the Crow Creek quadrangle.

In the Montpelier quadrangle the sandstone forms narrow bands which are associated with the folds that extend northward through the central part of the quadrangle and with the anticline that forms the west flank of the Sublette Ridge near the east boundary. In the Bear Lake Plateau there are four parallel bands. As mapped, these may include certain beds here assigned to the Thaynes.

In the Freedom quadrangle a small exposure occurs in association with Higham grit on the north side of Spring Creek in the southern part and a narrow band follows the zigzag outcrop of the grit around the tips of anticlinal and synclinal folds in the southwestern part. A similar band, roughly circular as projected on the map, is exposed in the canyon of Boulder Creek.

The sandstone forms several sets of exposures between Old Williamsburg and the vicinity of the Middle Dairy, in the northeastern part of the Lanes Creek quadrangle, where the continuity of the formation is interrupted by faults It follows the grit band in the vicinity of Browns Canyon and outlines the core of a faulted syncline in the central part of the quadrangle. Two small faulted bands lie east of this syncline on the slope toward Lanes Creek.

The Cranes Flat quadrangle contains minor areas of the sandstone along the foothills east of Cranes Flat, near the center.

Character.—The Timothy sandstone is typically a somewhat sugary, yellowish to grayish rock in beds 1 to 3 inches thick or locally more massive. It is generally uniform in character and in some places weathers with a pinkish tinge. Locally beds assigned to this formation are reddish or purplish. It is usually less resistent to weathering than the limestone below or the grit above and hence occupies depressions or relatively smooth slopes, on which exposures are few and poor.

In the Fort Hall Indian Reservation the Timothy sandstone, at first called "Ankareh sandstone," [55] is about 800 feet thick. Eastward the formation becomes thinner, and in the Lanes Creek and Freedom quadrangles the Timothy is about 250 feet thick, though apparently it retains the same lithologic characteristics.

In Home Canyon, about 6 miles east of Montpelier, the Timothy sandstone consists of cross-bedded and coarse-textured sandstones that have conglomeratic layers, in which the fragments are small pieces of limestone like that of the Thaynes. Several of these layers are 2 to 3 feet thick and are interbedded with sugary sandstones. At this place the whole formation is not more than 100 feet thick. This phase has not been observed elsewhere.

In the Indian Creek and Raymond Canyon sections (Tables 26 and 27, pp. 89 and 90) the Timothy sandstone, which includes part of the beds formerly mapped as Ankareh and Nugget, appears to have in its lower portion 50 feet or more of reddish or varicolored beds with shales and sandstones, and the formation is probably less than 200 feet thick. The limits here assigned to the sandstone at these two places must be regarded as tentative until opportunity is afforded for revision of the mapping of that part of the region in the light of the latest interpretations.

Although the relationship of the Thaynes and Timothy sandstone is that of apparent conformity, the occurrence of the conglomeratic beds with fragments of limestone like that of the Thaynes in the Home Canyon section indicates that at least locally there was erosion of Triassic limestones while the deposition of the sandstone was in progress. The southeastward thinning of the upper limestone (Portneuf) of the Thaynes previously noted may perhaps be in part due to erosion, in which event the boundary between the two formations would mark an unconformity of considerable note.

Age and correlation.—In the Indian Creek section beds assigned to the Timothy sandstone contain fragments of coal and of shale. Carbonized remains of unidentifiable plants with which are associated copper-

[53] White, C. A., Triassic fossils of southeastern Idaho: Contributions to invertebrate paleontology, No. 5; U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pp. 105-118, 1880.

[54] Hyatt, Alpheus, and Smith, J. P., op. cit., pp. 18-19.

[55] Mansfield, G. R., op. cit., p. 40.

PLATE 30

Pugnoides triassicus Girty, n. sp. (p. 434)

FIGURES 1, 2. Two views of a broad specimen with three plications on the fold. Thaynes group (?), Montpelier quadrangle Idaho (station 7631).

FIGURES 3, 4. Two views of a narrow specimen with two plications on the fold. There are several other cotypes. Thaynes group (?), Montpelier quadrangle, Idaho (station 7631).

Terebratula semisimplex

FIGURES 5, 6, 7. Three views of the typical specimen ×1½. After White. Thaynes group, southeastern Idaho.

Terebratula thaynesiana Girty, n. sp. (p. 435)

FIGURES 8, 9, 10, 11. Four views of one of the cotypes. Thaynes group, Montpelier quadrangle, Idaho (station 7406).

Spiriferina roundyi Girty, n. sp. (p. 436)

FIGURES 12, 13. Two views of a pedicle valve. Thaynes group, Cranes Flat quadrangle, Idaho (station 7813a).

FIGURE 14. A small brachial valve. Thaynes group, Cranes Flat quadrangle, Idaho (station 7813a).

FIGURES 15, 16. Two views of a specimen retaining both valves. There are several other cotypes. Thaynes group, Cranes Flat quadrangle, Idaho (station 7813a).

Spiriferina mansfieldi Girty, n. sp. (p. 436)

FIGURES 17, 18, 19. Three views of one of the cotypes. Ross Fork limestone, Portneuf quadrangle, Idaho (station 7879).

Monotis superstricta var. parksi Girty, n. var. (p. 441)

FIGURES 20, 21. Two views of the typical specimen, one an enlargement ×2. Thaynes group, Crow Creek quadrangle, Idaho-Wyo. (station 7877).

Aviculipecten disjunctus Girty, n. sp. (p. 437)

FIGURES 22, 23, 24. Views of three different specimens all of which, from their shape, appear to be left valves. Thaynes limestone, Cokeville quadrangle (provisional name), Wyo. (7306 i).

Monotis idahoensis

FIGURE 25. A specimen thus identified by White but apparently not the type specimen, which has not been figured. After White. Thaynes group, southeastern Idaho.

Monotis alta

FIGURE 26. The typical specimen. After White. Thaynes group, southeastern Idaho.

Monotis thaynesiana

FIGURES 27, 28. A rather large specimen identified as of this species. One view shows the specimen in outline natural size; the other is ×2. Thaynes group, Crow Creek quadrangle, Idaho-Wyo. (station 7878).

Monotis bregeri Girty, n. sp. (p. 439)

FIGURE 29. A broad specimen, one of several cotypes ×1½.

Monotis bregeri var. laticostata Girty, n. var. (p. 440)

FIGURES 30, 31. One of the cotypes natural size; the other is ×1½. Thaynes group, Montpelier quadrangle, Idaho (station 7485).

Myalina platynotus

FIGURES 32, 33. Two specimens from Utah. Thaynes limestone, Park City district, Utah (station 3180a).

Myalina postcarbonica Girty, n. sp. (p. 442)

FIGURES 34, 35. Views of a left and a right valve ×2. There are several other cotypes. Woodside shale, Montpelier quadrangle, Idaho (station 7380).

Pleuromya haydeniana Girty, n. sp. (p. 443)

FIGURE 36. The typical specimen. Thaynes limestone, Cokeville quadrangle (provisional name), Wyo. (station 7306 i).

Monotis pealei

FIGURE 37. The typical specimen. After White. Thaynes group, southeastern Idaho.

Pleurophorus similis Girty, n. sp. (p. 446)

FIGURES 38, 39. Two of the cotypes ×2. In both specimens the umbonal ridge is rounded and the postumbonal slope lacks visible plications. Woodside shale, Montpelier quadrangle, Idaho (station 7380).

Pleurophorus bregeri Girty, n. sp. (p. 445)

FIGURES 40, 41. Two of the cotypes ×2. Woodside shale, Montpelier quadrangle, Idaho (station 7382).

Pleurophorus rotundus Girty, n. sp. (p. 446)

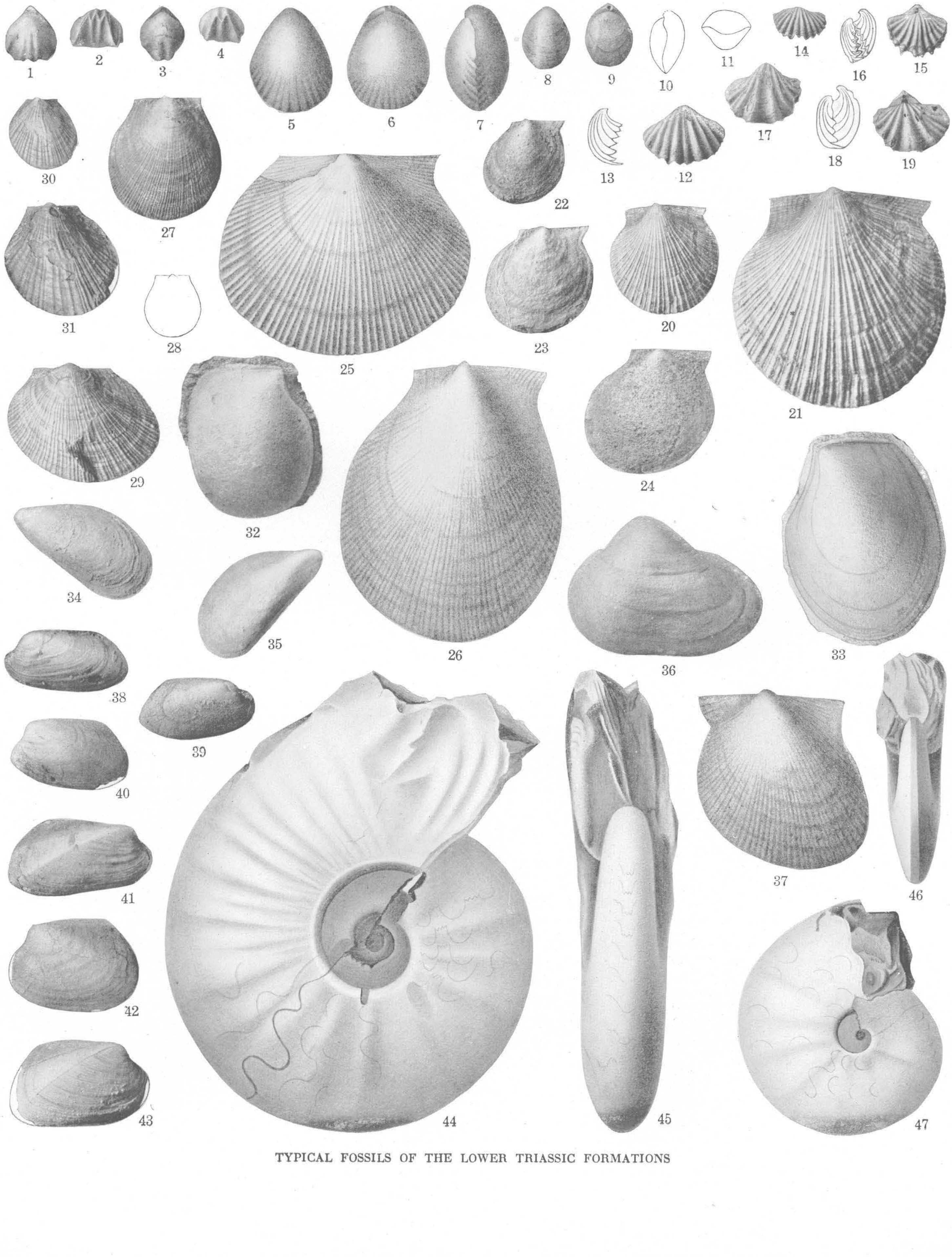
FIGURES 42, 43. Two of the cotypes ×2. Woodside shale, Montpelier quadrangle, Idaho (station 7380).

Meekoceras mushbachianum

FIGURES 44, 45. Two views of the typical specimen. After White. Thaynes group, southeastern Idaho.

Meekoceras gracilitatis

FIGURES 46, 47. Two views of the typical specimen. After White. This species together with the preceding one are only two units in a very extensive and varied ammonite fauna characteristic of the Thaynes. Thaynes group, southeastern Idaho.



TYPICAL FOSSILS OF THE LOWER TRIASSIC FORMATIONS bearing minerals occur in some places along the formation as mapped between Bear River and Montpelier Canyon. The copper deposits have been described by Gale [56] and are reviewed on pages 345 to 347. No other fossils have been found in the formation.

The Timothy sandstone represents an unidentified part, possibly the base, of the Ankareh shale, as defined by Boutwell [57] in the Park City mining district, and the upper part of the Ankareh shale, as described in the previous reports on southeastern Idaho [58]. It lies with at least local unconformity above the beds that contain a well-recognized Lower Triassic fauna, but is itself practically unfossiliferous and is overlain by other unfossiliferous formations, of which the Nugget sandstone, the uppermost, is referred to the Jurassic. The Timothy sandstone is now regarded as Lower Triassic, but it may prove to be of later age.

LOWER TRIASSIC FAUNAS

By G. H. Girty

The Lower Triassic rocks of Idaho are uncommonly rich in fossil shells, both in number and in variety. Of these fossils only one group, the ammonites, have received any but the most casual notice. The ammonitic types, which are especially characteristic of the Thaynes rocks, are far too numerous to be shown on the available space for illustrations. Aside from the ammonites the types at present known are on the contrary far too few to afford an adequate conception of the other aspects of the fauna. Accordingly, a few new species have been described (see pp. 434 to 446), but these were selected rather because they are interesting and are represented by specimens of quality than because they are more characteristic than the rest either of this fauna or of the region which forms the subject of this report. The plate of illustrations then affords scarcely a glimpse of the Lower Triassic faunas of Idaho.

Aside from the ammonites, which are usually very abundant where they occur at all, this Lower Triassic fauna is preeminetly one of pelecypods, and amongst these bivalves no group occurs in such numbers and in such variety as the pectinoid shells. From the term just employed it will be understood that the shells mentioned have the general appearance of *Pecten* or *Aviculipecten*, and in fact the species that have been described are cited mostly under the latter genus. Some of the species do almost certainly belong under one genus or the other, although their hinge structure is practically unknown, but most specimens have the superficial characters of left valves only, and at the same time their abundance is such as reasonably to destroy the hypothesis that no right valves occur among them. It is therefore necessary to conclude that most of these forms are essentially equivalve and consequently that they can not belong to the Pectinidae at all.

The other pelecypod shells are like the pectinoids in that very few are preserved so as to show the hinge structure. Consequently an assured generic assignment is even less possible with these forms than with the others, for pectinoid genera can be distinguished more satisfactorily than the genera of many other pelecypods on external characters only.

The third great molluscan group, the Gastropoda, is in comparison but poorly represented. The only forms that are at all abundant are naticoid shells, especially a small species that may be identical with *Natica lelia*. These occur especially in the Woodside shale associated with more elongated forms, of which some suggest *Holopea*, others *Loxonema*, and which are rather characteristic of that formation.

Brachiopods are by no means rare at certain localities but are chiefly represented by *Lingula*, *Spiriferina*, and a few rhynchonelloid and terebratuloid types, the latter being by far the most numerous and most varied. Even the kindred group of Bryozoa has been recognized at one or two localities, a slender-stemmed ramose type generically related to *Lioclema*. Corals are unknown and pentacrinoid columnals are much less abundant than in the Triassic rocks of other areas.

These Lower Triassic formations of this region are undoubtedly distinguishable by their faunas, although, as these faunas are as yet largely undescribed and in fact, except in a superficial way, unstudied, it is not possible to name the species that are found in one and not in the other. As already mentioned, the Thaynes is distinguished by its ammonites. These shells, if they occur in the Woodside at all, are extremely rare. Most of the brachiopods, except *Lingula* and small terebratuloids that occur at the top of the Woodside, are Thaynes species. On the other hand, the small gastropods already mentioned are more or less distinctive of the Woodside as are also the Lingulas and the small pelecypods here described under *Pleurophorus* and *Myalina*.

Inasmuch as the Triassic age of these formations is largely determined by their ammonitic fauna, and as the ammonites are largely if not wholly restricted to the Thaynes, the question may be raised, and possibly has been raised, whether the underlying rocks known as the Woodside shale may not really belong in the Permian. On this head the evidence that the Woodside is Triassic is very strong, whereas the evi-

[56] Gale, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: U. S. Geol. Survey Bull. 430, pp. 112–121, 1910.

[57] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, pp. 434–458, 1907.

[58] Gale, H. S., op. cit. Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457–535, 1910. Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470 pp. 371–439, 1911; Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 1914. Mansfield, G. R., and Roundy, P. V., Revision of the Beckwith and Bear River formations of southeastern Idaho: U. S. Geol. Survey Prof. Paper 98, pp. 75–84, 1916.

dence that it is Permian is very weak. Stratigraphically the Woodside gradates into the Thaynes above but is sharply distinguished from the Paleozoic Phosphoria below. Paleontologically the same is equally if not more decisively true. All the characteristic Carboniferous brachiopods, such as *Productus*, *Chonetes*, *Spirifer*, *Composita*, *Derbya*, to mention only a few, are extinguished with the Phosphoria never to reappear in the rocks of this continent. Such recurring brachiopods as *Pugnoides*, *Spiriferina*, and the terebratuloids recur rather in the Thaynes than in the Woodside. The terebratuloids moreover, though this is not true of the other brachiopods, are of a rather characteristic Mesozoic type, inasmuch as they show a reversed fold and sinus (the sinus being in the brachial valve instead of in the pedicle valve), inasmuch as they lack dental plates, and inasmuch as many of the species are freely plicated. Certain pelecypod genera, like *Myalina* and *Pleurophorus*, apparently survived from the Carboniferous but *Myalina* at least continued through the Woodside into the Thaynes. As for the weight of this evidence, not only is the survival of some pelecypod genera from the late Paleozoic into the early Mesozoic reasonably to be expected, but the generic references themselves are mostly uncertain, for the references in the last resort depend upon internal characters, which for most of the forms are known imperfectly if at all. Thus these faunas show a profound transformation with very little survival in passing from the Phosphoria formation to the Woodside.

The conditions of study which make it impossible to state specifically the characters by which the Thaynes and Woodside faunas are distinguished from one another also make it impossible to state specifically the characters in which they are related, but that the two faunas resemble each other broadly will not be questioned by anyone who tries to recognize the formations on paleontologic characters alone, and they are bound together, it is believed, by many types held in common.

When it is recalled that in the Phosphoria we already have a formation and a fauna of Permian age and that the Woodside in its faunal and stratigraphic relations is sharply distinct from the Permian Phosphoria, and at the same time in fauna and stratigraphy closely allied to the Triassic Thaynes, it is convincingly apparent that the natural grouping of these faunas places the Woodside with the Thaynes, that if the Woodside is Permian though later Permian than the Phosphoria, the Thaynes is likewise Permian, and if the Thaynes is Triassic so is the Woodside.

TRIASSIC (?) FORMATIONS

GENERAL FEATURES

The great thickness of the formations assigned to the Lower Triassic, 5,350 feet, the unconformity at the base of the Timothy sandstone, and the marked unconformity at the base of the Higham grit suggest that the Higham grit and the overlying Deadman limestone and Wood shale may be of later age than Triassic. No fossils, however, have yet been found in any of these formations, so they are provisionally retained in the Triassic. The general characteristics of these formations and of the overlying Nugget sandstone are shown in Table 28.

TABLE 28.—*Stratigraphic section of the Nugget sandstone and underlying Triassic (?) formations in tributary of Stump Creek in the NW. ¼ sec. 19, T. 6 S., R. 45 E. (unsurveyed), Freedom quadrangle, Idaho-Wyo.*

[By E. L. Jones, jr.]

	Feet
Twin Creek limestone (base concealed).	
Nugget sandstone:	
Massive gray sandstones	412
Massive red sandstones	480
Massive gray sandstones containing reddish bands	65
	957
Wood shale: Thin-bedded red sandstone and red shales with green spots	130
Deadman limestone:	
Purple and green limestone with some interbedded mottled limy shales	55
Massive cherty and somewhat vesicular limestone	78
Concealed	55
	188
Higham grit: Grit and coarse quartzitic sandstone, base not exposed	85
	1,360

DISTRIBUTION.

The mapping of the Montpelier and Slug Creek quadrangles had been practically completed before the Higham grit, Deadman limestone, and Wood shale had been differentiated. These formations have been recognized in the Preuss Range north of Montpelier Canyon, in the Montpelier quadrangle, but it has not been practicable to map them separately from the Nugget sandstone, with which they have hitherto been grouped. They have not been recognized in the Slug Creek and Henry quadrangles. In the Crow Creek quadrangle they are not present unless perhaps in a small area mainly south of the mouth of Sage Creek. Here red shale, limestone, and sandstone are present, resembling, respectively, the Wood shale, Deadman limestone, and Timothy sandstone. The structural relationships appear to be complex, and possibly small fault blocks of these formations should be represented on the map. Similar rocks, however, occur in the upper part of the Nugget sandstone, and until more detailed data are available the doubtful rocks are referred to that formation.

In the Lanes Creek and Freedom quadrangles the Higham grit, Deadman limestone, and Wood shale are well exposed and easily traced. These formations occupy a syncline in the crest of one of the ridges of the Preuss Range in the central part of the Lanes Creek quadrangle, and at the base of the southeastern slope of the same ridge the grit is exposed. East of Lanes Creek in the northeastern part of the Preuss Range is a broad syncline, occupied by these formations together with the Nugget sandstone and Twin Creek limestone. This syncline extends southeastward into the Freedom quadrangle and is there bifurcated by a large unsymmetrical anticline. Fine exposures are afforded by the canyons of Browns, Timothy, Horse, and Boulder Creeks, which drain portions of this broad region of folded rocks. Complexly faulted areas that include the grit, limestone, and shale, together with the Nugget sandstone, lie in the northeastern part of T. 6 S., R. 44 E., and in the southwestern part of T. 5 S., R. 44 E., in the Lanes Creek quadrangle.

In the Cranes Flat quadrangle the Higham grit, Deadman limestone, and Wood shale occupy narrow strips along the western slope of the ridge east of Cranes Flat.

HIGHAM GRIT

The Higham grit was named from Higham Peak, in the northeastern part of the Fort Hall Indian Reservation,[59] the highest summit of a prominent ridge composed of that rock. The formation is a coarse white to pinkish gritty or conglomeratic sandstone, locally quartzitic, with subangular fragments or pebbles of quartzite. No other rock type has been observed as a constituent. The material appears to have been derived from early Paleozoic or older quartzites. The grit is distinct lithologically from the other rocks of the region and is prominent topographically. It forms strike ridges that are marked by rough craggy ledges in many places, as, for example, the fine dip slope into Browns Canyon. The lower 10 to 20 feet at some localities, notably in the north fork of Boulder Creek, is fine grained, purplish or yellowish, and more or less ferruginous. In Home Canyon, near Montpelier, the Higham grit is represented by a purplish quartzite that corresponds in texture to some of the finer beds of the grit elsewhere.

The formation appears to lie conformably on the Timothy sandstone, but several features suggest that the base of the grit probably represents a stratigraphic break of considerable size. These features are the abrupt and striking change in lithology from preceding formations, the strongly ferruginous character of the basal beds, and the southward thinning of the underlying Timothy sandstone. The striking diminution in the thickness of the Timothy eastward and southeastward from the Fort Hall Indian Reservation may be entirely a lithologic change, but it is at least suggestive of transgression by the overlying grit. This subject is further discussed in Chapter VIII, which deals with the broader geologic problems of the region (pp. 373 and 374). The Higham grit is apparently nonfossiliferous, much fractured, and locally slickensided with high polish. Its thickness, as exposed in the Freedom quadrangle, is about 200 feet. In the Fort Hall Indian Reservation it is much thicker, about 500 feet.

DEADMAN LIMESTONE

The Deadman limestone was named from a creek in the northeastern part of the Fort Hall Indian Reservation. The limestone is a peculiar rock of variable character and of white, pinkish, or greenish color. In places it is dense and of almost lithographic quality. Elsewhere it is cherty and has an irregular streaky and nodular character and roughly weathered surface. At still other places it is somewhat oolitic, and the calcareous concentrically banded oolites inclose grains or fragments of dense limestone or chert. The bedding is generally indistinct. Where the rock is greenish and cherty it has locally been prospected, presumably for copper. As a whole the rock is resistant to weathering and prominent topographically; in favorable places it forms fine ledges. So far as observed it is nonfossiliferous.

In the Freedom and Lanes Creek quadrangles the Deadman limestone follows directly above the Higham grit, as in the Fort Hall Indian Reservation. In the Boulder Creek district of the Freedom quadrangle and in the Cranes Flat quadrangle the lower limestones tend to be more shaly and to have reddish or purplish tints. In the Home Canyon district of the Montpelier quadrangle this tendency is more pronounced, and the limestone, which there is only about 50 feet thick, appears to lie in the midst of the red shale. The limestone has not been recognized farther southeast.

In the Freedom quadrangle the formation as measured in Table 28, is 188 feet thick. At the head of Horse Creek, however, the limestone appears to be somewhat thicker, perhaps because of folding. In the Fort Hall Indian Reservation to the west the Deadman limestone is about 150 feet thick.

WOOD SHALE

The Wood shale was named from a creek in the northeastern part of the Fort Hall Indian Reservation and lies just above the Deadman limestone. It is composed of bright-red shales and sandstones that weather to a red soil and occupy depressions or smooth slopes with few exposures, except where cut by streams. Locally there are small lenticular deposits of gypsum, usually represented by rows of white fragments of gypsum that lie on the surface. No fossils have been found in the shale. In the Home Canyon region of the Montpelier quadrangle the formation is well developed. The increasingly shaly character of the lower beds of the Deadman limestone at this locality, as noted above, may indicate the complete wedging out of the limestone farther east and south and the merging of the shale below

[59] Mansfield, G. R., Subdivisions of the Thaynes limestone and Nugget sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci. Jour., vol. 6, No. 2, pp. 31-42, 1916.

with the overlying Wood shale. In the Cranes Flat quadrangle the Wood shale seems to be cut out by faulting, except in the SE. ¼ sec. 2, T. 4 S., R. 41 E., where it is exposed for about half a mile. The thickness of the Wood shale, as shown in Table 28, is about 130 feet. About 2 miles southeast of the locality where the measurement was made the shale is partly cut out by a fault which may extend northwestward to the line of the section and thus reduce its apparent thickness. In the head of Horse Creek the Wood shale, though not measured, appears to be considerably thicker, perhaps because of folding. In the Fort Hall Indian Reservation it is 200 to 250 feet thick.

JURASSIC SYSTEM

GENERAL FEATURES

The Jurassic system is well represented in many parts of southeastern Idaho, where it includes four formations, named, in ascending order, the Nugget sandstone, formerly considered Triassic or Jurassic, the Twin Creek limestone, the Preuss sandstone, and the Stump sandstone. The Nugget sandstone in this region is apparently conformable with the Wood shale below, but it is thought to be unconformable with the Twin Creek above, and Schultz[60] believes that, in southwestern Wyoming at least, the Nugget sandstone will prove to be unconformable on beds that correspond to the Wood shale. The Twin Creek limestone is overlain unconformably by the Preuss sandstone, and another unconformity separates the Stump sandstone from the overlying Cretaceous (?) formations. The total thickness of the rocks here assigned to the system is about 6,700 feet.

NUGGET SANDSTONE

Name.—The Nugget sandstone was named by Veatch[61] from Nugget station on the Oregon Short Line Railroad in southwestern Wyoming, but in this report the name is applied to only the upper part of the beds to which Veatch applied the name, as explained on page 84. Veatch's lower "red bed member" is correlated with the Triassic (?) formations (Wood shale, Deadman limestone, and Higham grit).

Distribution.—Some features of the distribution of the Nugget formation have been mentioned in the discussion of the Triassic (?) formations. In the Preuss Range a series of folds causes a zigzag in the outcrop of the sandstone northeast of Montpelier and a second exposure in an anticlinal axis east of Georgetown. In T. 11 S., R. 45 E., the Nugget emerges along the edge of the great fault block produced by the Bannock overthrust and is continued northward into the Crow Creek quadrangle. Southward along the Preuss Range the Nugget sandstone forms the west flank of a large syncline occupied by the Twin Creek limestone. This belt is continued southward into the Bear Lake Plateau and joins in another zigzag due to the erosion of adjacent folds. Here the rocks are partly concealed by Eocene strata. Small patches emerge here and there from cover. The crest of the Sublette Ridge is composed of the Nugget sandstone, which there forms the east flank and north end of a sharply folded anticline.

In the Slug Creek quadrangle the only outcrops occur in the Left Fork of Twin Creek, in the southern part of T. 10 S., R. 44 E., where the Nugget forms the core of an anticline that has been uncovered by the erosion of a great fault block. In the Crow Creek quadrangle exposures occur along the west flank of the Gannett Hills east of Sage and Tygee Valleys, adjacent to a fault. A prominent band of the Nugget sandstone, partly concealed by later deposits, lies along the east flank of the Caribou Range between Auburn and Miller Creek in the Freedom quadrangle.

Character.—The Nugget sandstone gives rise to ledgy, rugged, brushy, picturesque hills and high ridges with rounded slopes that are covered in many places with angular pinkish or grayish blocks that weather brown or black and impede travel. The rocks consist chiefly of massive reddish sandstone locally deeply colored and in places much cross-bedded. The stratification is commonly well developed and here and there produces slabby blocks. The texture is generally fine and uniform; the grains are subangular and the matrix siliceous. At some places the rock is sufficiently silicified to be called a quartzite. The formation includes beds of sandy shale, which are generally obscured by talus of the more massive strata. Locally the upper part of the formation is composed of several hundred feet of white or yellowish sandstone. The absence of these upper white beds in other localities may be due to unconformity or possibly the white condition represents a local phase of the more prevalent dark-red rock.

In Dunns Canyon, in sec. 10, T. 11 S., R. 44 E., and also in sec. 10, T. 11 S., R. 45 E., the upper part of the formation is marked by deep-red sandy and shaly beds and two or more massive beds of gray limestone. In the last-named locality, also, pieces of gypsum lie on the surface.

These occurrences recall to a certain extent the Deadman limestone and Wood shale, but the limestone and red shale are thinner and more extensively interbedded. Their position is only a few feet below the base of the Twin Creek, and they appear to be in normal order. Somewhat similar red beds occur in a small detached area in the Left Fork of Twin Creek in the Slug Creek quadrangle. The occurrence of similar beds near the mouth of Sage Creek, in the Crow Creek quadrangle, has already been mentioned in another connection. These occurrences may be due simply to local development, but as they are separated from each other by distances of 4 to 8 or more miles

[60] Schultz, A. R., personal communication.

[61] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming; U. S Geol. Survey Prof. Paper 56, p. 56, 1907.

it seems more probable that these beds were once widely distributed. Their present local preservation would be explained by unconformity. The local distribution of the upper, light-colored beds lends support to this view, as does also the character of the lower beds of the overlying Twin Creek limestone, though no actual erosional unconformity has been observed.

Thickness.—The thickness of the formation is somewhat variable. In the section given in Table 28 it is 957 feet. In the Raymond Canyon section, in Table 27, it is stated as 1,900 feet, but probably the lower 200 feet may be assignable to lower formations. In the Fort Hall Indian Reservation it is estimated as at least 1,500 feet thick.

Age and correlation.—Imprints of rain drops have locally been found on some layers of the Nugget, and in the Fort Hall Indian Reservation a few markings that resemble footprints or casts of footprints were found. These markings proved to be unidentifiable, however, and may have been of inorganic origin. No fossils have been found, but the Nugget sandstone is considered equivalent to the White Cliff and Vermilion Cliff sandstones as mapped by Gale [62] in northwestern Colorado and northeastern Utah, from the upper part of which he collected Jurassic fossils. Although the base of the formation is apparently conformable upon the Wood shale, relations elsewhere suggest that an unconformity may be found at this horizon. Two unconformities, one of which is probably extensive, occur, as previously noted, in rocks that lie between the Nugget and the fossiliferous rocks of the Thaynes group. For these reasons the Nugget sandstone is referred to the Jurassic.

TWIN CREEK LIMESTONE

Name.—The name Twin Creek limestone was applied by Veatch [63] to 3,500 feet or more of marine beds that are well exposed along the creek of that name between Sage and Fossil, two towns on the Oregon Short Line Railroad in southwestern Wyoming, about 20 miles southeast of the region described in this report.

Distribution.—The Twin Creek limestone is exposed in each of the quadrangles mapped except the Henry. In the Montpelier quadrangle it forms a belt 5 miles or more wide where it passes beneath the fault block of Paleozoic and early Mesozoic rocks at the north. Southward it continues as a band 3 miles or more wide along the east side of the Preuss Range. In the Bear Lake Plateau it crops out in several bands or discontinuous areas, where it lies in synclines and is more or less covered by Eocene beds. At the head of Thomas Fork Valley a large area is exposed by the erosion of the anticline which farther south forms the Sublette Ridge. The boundaries of the formation have zigzag outlines caused by the relations of the formation to eroded and pitching folds.

In the Slug Creek quadrangle the Twin Creek limestone is confined to the region of the canyons of Twin Creek and its left Fork in the southeastern part, where it is exposed by the erosion of the great Paleozoic thrust block which there forms the rugged portion of the Preuss Range.

On the east side of Crow Creek and northward on the east side of Tygee Creek the limestone forms a somewhat interrupted band along the western margin of the Gannett Hills. A large area also lies along the east boundary of the Crow Creek quadrangle, where the limestone forms high hills with steep slopes and extends into adjoining territory.

In the Freedom quadrangle the Twin Creek limestone forms an interrupted belt on the east slope of the Caribou Range between Auburn and Freedom and a large area of varying width along Stump Creek, in the boundary region of the Preuss and Caribou Ranges. Farther west the limestone forms high rugged hills in a synclinal area that overlaps the border of the Lanes Creek quadrangle. It also occurs in small areas near Old Williamsburg.

The Twin Creek exposures in the Cranes Flat quadrangle are confined to the eastern part of T. 4 S., R. 42 E., and the northeastern part of T. 4 S., R. 41 E., where the limestone occurs in several detached areas and forms broad, low hills that have smooth slopes and low rocky ridges.

Character.—The basal beds are locally somewhat pebbly with mud balls and consist of massive brown porous-weathering sandy limestone together with thin and cross-bedded limestone. The brown sandy beds carry abundant poorly preserved pelecypod remains, chiefly species of oyster. At many localities, perhaps 30 feet above the base, occurs a dense, nearly structureless, fine-textured green rock, which forms a bed about 5 feet thick that is widely distributed. Its bluish-green color and unusual porcelain-like appearance have caused it to be fruitlessly prospected for copper in a number of places. This bed is an old volcanic ash in which the fragments of volcanic glass may still be distinguished under the microscope. It has, however, been largely silicified and there has been a little infiltration of calcium carbonate. Locally near the base there is also a red-bed horizon. Higher beds are massive, gray, somewhat sparingly fossiliferous, and contain ferruginous concretions that range in size from tiny grains to masses a quarter of an inch in diameter. The main body of the formation is composed of grayish-white and bluish shaly limestones that form steep slopes, which are covered by a veneer of chippy and splintery weathered pieces. Locally ripple marks have been observed. In places the close jointing of the shales makes difficult the determination of the bedding.

[62] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 51, 52, 1910.
[63] Veatch, A. C., op. cit., pp. 56–57.

An interesting occurrence of phosphate rock is reported from this formation near Cokeville, Wyo., by Gale and Richards.[64] No other occurrence of this character has yet been observed.

The shaly character of much of the formation produces smooth rounded hills, many of them relatively high, that break with abrupt, bare slopes to the adjoining valleys. On such slopes massive ledges with steep dips appear in many places. The soil weathered from the formation does not produce abundant vegetation, so that the light color of regions underlain by the limestone is noticeable for great distances and gives the appearance of a dreary desert. These characteristics are shown in Plate 29, *C.*, in which the two overlying formations are also shown and in Plate 36, *C*, where the Twin Creek is shown emerging from beneath the southern end of the great Paleozoic thrust block in the northern part of the Montpelier quadrangle.

Intense folding, favored by the presence of shales, has produced unfavorable conditions for the measurement of the formation in this region. The broad extent of the exposures and the generally steep dips indicate that a considerable thickness of strata is represented. At the type locality Veatch reports a thickness of 3,500 to 3,800 feet. In southeastern Idaho the thickness of the Twin Creek limestone appears to be comparable with that at the type locality.

The unconformity between the Twin Creek limestone and underlying Nugget sandstone has already been referred to.

Age.—Although the Twin Creek limestone is fossiliferous in certain localities there are many places where fossils are absent or scarce, and the collections made do not show very many types. The most common fossils are species of *Ostrea* (oyster) and *Pentacrinus*. The following species have been identified by T. W. Stanton from collections at the localities named:

T. 11 S., R. 44 E.:
- Sec. 24 (unsurveyed):
  - Pentacrinus asteriscus Meek and Hayden.
  - Gryphaea planoconvexa Whitfield?
  - Tancredia? sp.
- Sec. 25 (unsurveyed):
  - Serpula sp.
  - Ostrea strigilecula White.
  - Pecten sp.
  - Camptonectes sp.
  - Pleuromya sp.
  - Camptonectes pertenuistriatus Hall and Whitfield?
  - Lima sp.
- Sec. 26 (unsurveyed):
  - Pinna sp.
  - Pleuromya? sp.
- Sec. 28:
  - Pentacrinus asteriscus Meek and Hayden?
- Sec. 34 (unsurveyed):
  - Lima occidentalis Hall and Whitfield?

[64] Gale, H. S., and Richards, R. W., op. cit., p. 508.

T. 10 S., R. 45 E.:
- Sec. 23:
  - Pentacrinus sp.
  - Ostrea strigilecula White.

T. 8 S., R. 46 E.:
- Sec. 15:
  - Pentacrinus sp.
  - Gryphaea? sp.
- Sec. 34:
  - Ostrea strigilecula White.

T. 7 S., R. 45 E.:
- Sec. 1 (unsurveyed):
  - Gryphaea calceola var. nebrascensis Meek and Hayden.
  - Camptonectes sp.
  - Perisphinctes? sp.

A selection by T. W. Stanton of representative Twin Creek types is illustrated in Plate 31.

From the fossils listed above and others collected in the region of the type locality the age of the upper part of the formation has been determined as Upper Jurassic. Possibly the lower part may include Middle Jurassic rocks.

PREUSS SANDSTONE

Name.—The Preuss sandstone[65] was named from Preuss Creek, about 12 miles northeast of Montpelier, in the vicinity of which the sandstone is well exposed.

Distribution.—The Preuss sandstone does not appear in the Henry quadrangle, and in the Lanes Creek quadrangle only one small area in the northeastern part has been found. In the Montpelier quadrangle the formation has considerable extent in the Preuss Range and Gannett Hills in the northeastern part, where it is involved in broad synclinal and anticlinal folds.

In the Crow Creek quadrangle broad belts and areas of the sandstone associated with relatively open folds occur in the Gannett Hills southeast of Crow Creek, and a narrow band extends northward east of Tygee Creek into the Freedom quadrangle. A somewhat wider belt continues north of Crow Creek, along the east flank of the Gannett Hills, into the Freedom quadrangle. The two bands last mentioned continue northwestward into the Caribou Range, where several other strips appear, associated with numerous minor folds that are interrupted by faults. Three of the bands are relatively continuous through the quadrangle, one on each flank and one near the middle of the Caribou Range.

In the Cranes Flat quadrangle the Preuss sandstone occurs in a number of disconnected areas of different sizes and shapes arranged in a line that extends from the southeast corner northwestward nearly two-thirds of the distance across the quadrangle. The irregularities of distribution are due to minor folds and numerous faults.

[65] Mansfield, G. R., and Roundy, P. V., Revision of the Beckwith and Bear River formations of southeastern Idaho: U. S. Geol. Survey Prof. Paper 98, p. 81, 1916.

In the Slug Creek quadrangle an area of varicolored rocks lies in T. 10 S., R. 44 E., just west of the great fault block in Georgetown Canyon and was formerly mapped as Beckwith. The name Beckwith has been discontinued in the region here described, and these beds are now mapped as Preuss sandstone. Although generally red they have some lithologic resemblance to parts of the Twin Creek limestone, and they were for a time referred to that formation. Similar beds with similar associations occur in sec. 23, T. 10 S., R. 45 E., in the Crow Creek quadrangle, near salt springs which probably originate in the Preuss sandstone. Both sets of beds are accordingly now referred to the Preuss.

Character.—The formation consists of very fine, even-grained sandstones that range in color from pale reddish-gray to deep dull red. The sandstone is generally calcareous and more or less argillaceous and becomes very shaly in some places. Locally flakes of reddish clay curved at the edges and half an inch or more in diameter have been noted in the sandstone. The beds are generally less than 6 inches thick, weather to a dull-red soil, and make the slopes of subordinate ridges. A boring made since the completion of the field work in this region indicates the presence of salt beds that should probably be assigned to the lower part of the Preuss sandstone. These beds are not naturally exposed, but prior to the boring a salt bed had been encountered at the old salt works opposite Lowe's ranch on Crow Creek and salt springs had been recognized at places in Crow, Tygee, and Stump Creeks. A graphic measurement at the head of Thomas Fork Valley gives a thickness of 1,300 feet A part of the formation is included in the stratigraphic section in Table 29.

The unconformity at the base of the Preuss appears to be of the nature of an overlap rather than of angular unconformity. The fineness of texture and generally even bedding suggest marine rather than fluviatile conditions. The absence of mud cracks and impressions of rain drops points in the same direction. On the other hand, the red color and the lack of fossils, together with the curved flakes of clay, suggest nonmarine deposition. The formation grades upward into the marine Stump sandstone.

Age and correlation.—The Preuss sandstone is apparently nonfossiliferous, but it lies between two formations that contain Upper Jurassic fossils. Its stratigraphic position is therefore clear. It represents the lowermost portion of the Beckwith formation as hitherto described in southeastern Idaho [66] and perhaps a corresponding portion of the Beckwith of southeastern Wyoming.[67]

[66] Breger, C. L., Salt resources of the Idaho-Wyoming border, with notes on the geology: U. S. Geol. Survey Bull. 430, p. 562, 1910.

[67] Veatch, A. C., op. cit., pp. 57-59.

STUMP SANDSTONE

Name.—The Stump sandstone [68] was named from Stump Peak, at the head of Stump Creek, near the center of T. 6 S., R. 45 E. Boise meridian (unsurveyed), in the Freedom quadrangle, where the sandstone forms the crest of a prominent ridge, of which Stump Peak is the culminating point. (See pls. 29, *C*, and 32, *A*.)

Distribution.—The Stump sandstone occupies a faulted synclinorium that extends northward from the northeastern part of the Montpelier quadrangle through the Crow Creek and Freedom quadrangles and into the Cranes Flat quadrangle. In the Montpelier quadrangle the sandstone forms a faulted loop about 6 miles long around the south end of Red Mountain in the Gannett Hills and a narrow band 6 miles long farther east in the Gannett Hills near the border of the quadrangle. It also occurs in two small patches in the same region.

In the Crow Creek quadrangle the sandstone forms two synclinal loops 5 and 6 miles long, respectively, on either side of Elk Valley in the southern part. The eastern loop forms a broad Y-shaped connection with a faulted band that extends northward through the quadrangle along the west flank of a large syncline. Near the east border another band extends with some interruptions along the east flank of the same sycline northward into the Freedom quadrangle. A broad synclinal patch of the sandstone lies north of Elk Valley, in Tps. 9 and 10 S., R. 46 E.

In the Freedom quadrangle the Stump sandstone occurs in numerous narrow bands associated with large and small folds and with faults. The distribution of the formation may best be seen by reference to the detailed map of that quadrangle (pl. 5).

In the Cranes Flat quadrangle the Stump sandstone forms broad exposures and high ridges in the southern part of the Little Valley Hills in the southeastern part of the quadrangle. Other occurrences lie in the southeast extension of Sheep Mountain north of Cranes Flat.

Character.—The Stump sandstone consists mainly of thin-bedded gray to greenish-gray fine-grained sandstones which weather into platy fragments about an inch thick. Near the base lie some beds of compact calcareous sandstone, locally as much as 6 feet thick. The grains are very fine and chiefly of colorless quartz. The rock tends to break with a conchoidal fracture and to ring under the hammer. Fresh surfaces have a steel-gray color, but weathered surfaces are velvety brown. Instead of ledges these beds commonly form lines of irregularly weathered blocks that at first glance resemble trap rock. At the base is a bed of grit, or coarse-grained sandstone, which contains marine fossils of Jurassic age. The component grains are colorless

[68] Mansfield, G. R., and Roundy, P. V., op. cit.

PLATE 31

FIGURES 1, 2. *Pholadomya kingii* Meek.

3. *Pseudomonotis* (*Eumicrotis*) *curta* (Hall).

4, 5. *Astarte packardi* White.

6, 7. *Gryphaea calceola* var. *nebrascensis* Meek and Hayden.

8, 9. *Ostrea strigilecula* White.

10, 11. *Pentacrinus whitei* Clark.

12, 13. *Cucullaea haguei* Meek.

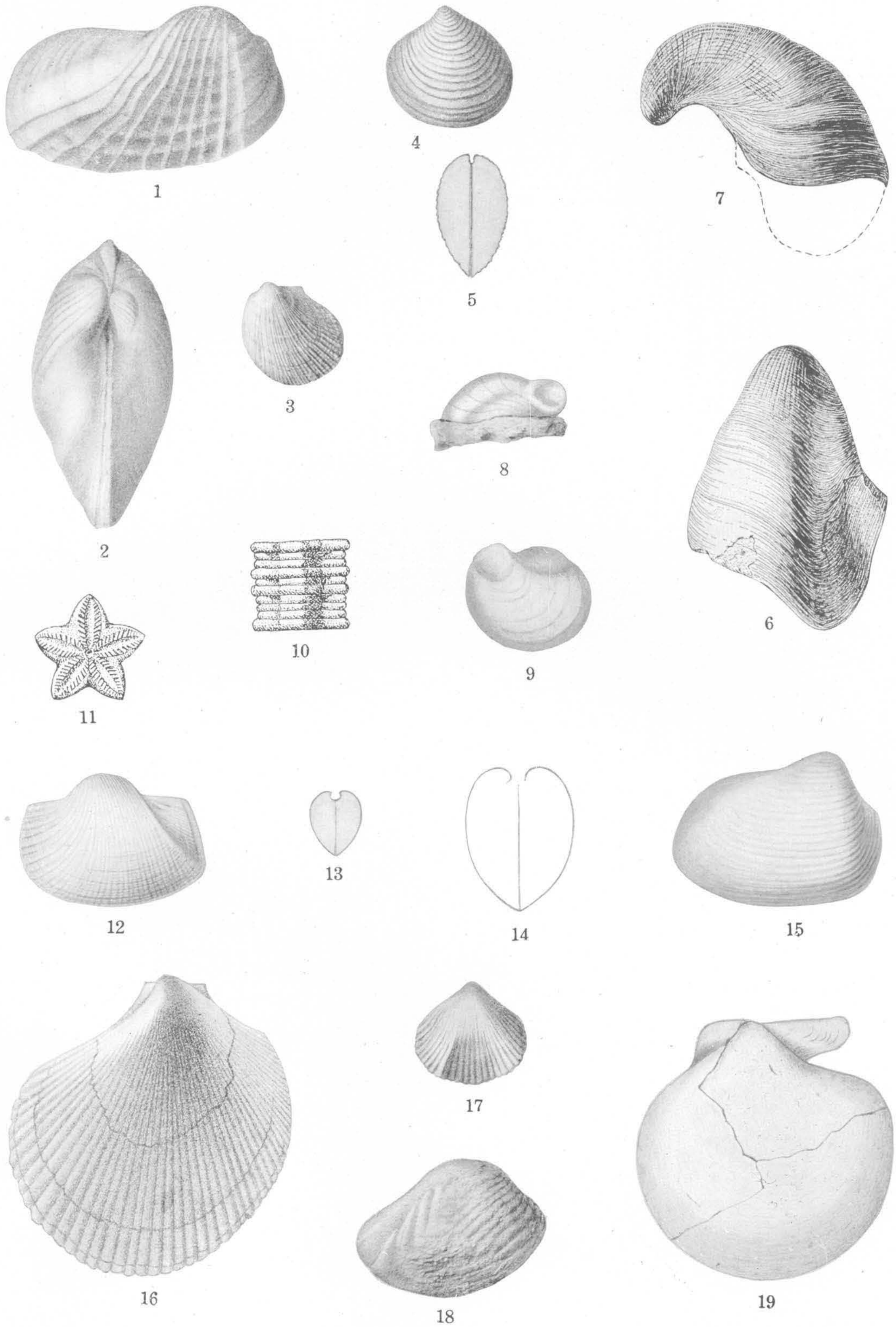
14, 15. *Pleuromya subcompressa* Meek.

16. *Lima occidentalis* Hall and Whitfield.

17. *Rhynchonella myrina* Hall and Whitfield.

18. *Trigonia quadrangularis* Hall and Whitfield.

19. *Camptonectes stygius* White.



CHARACTERISTIC FOSSILS FROM THE TWIN CREEK LIMESTONE quartz, with some greenish chloritic material, and the cement is calcareous and grayish. The fresh rock has a slight pinkish cast, and weathered surfaces are decidedly pinkish. This bed is practically the only bed in the entire formation from which fossils were obtained and the collections at several localities gave practically the same fauna.

The Stump sandstone is usually resistant to weathering and forms conspicuous ridges (pl. 32, *A*), but south of the Halfway House, on the southern edge of the Crow Creek quadrangle, it forms a valley. The rock there has probably been weakened by fracturing or other structural disturbance.

The essential features of this formation are present throughout the region mapped. The thickness ranges from 200 to 600 feet. A stratigraphic section of the sandstone is given in Table 29.

Age and correlation.—The grit or coarse-grained sandstone at the base of the formation has yielded fossils at several localities. The forms, which were identified by T. W. Stanton, are *Ostrea strigilecula* White?, *Rhynchonella?* sp., *Camptonectes?* sp., and *Pentacrinus* sp.

A collection from the foothills about 1½ miles northwest of Freedom, which is assigned tentatively to the same or nearly the same horizon, included *Astarte* sp., *Trigonia* sp., and *Belemnites* sp. Interesting collections from the southern part of T. 4 S., R. 42 E., Cranes Flat quadrangle, included the following fauna:

Lot No. 9748. SE. ¼ sec. 28, T. 4 S., R. 42 E., 9¼ miles north and 1½ miles west from Henry, Idaho, near base of Stump sandstone:
- Corals, two or more genera; not yet studied.
- Pentacrinus sp., sections of stems.
- Cidaris? sp., spines and fragments of tests.
- Ostrea strigilecula White?
- Gryphaea calceola var. nebrascensis Meek and Hayden?

Lot No. 9749. NE. ¼ sec. 33, T. 4 S., R. 42 E., 9 miles north and 1½ miles west from Henry, Idaho, near base of Stump sandstone:
- Thamnastraea? sp.
- Pentacrinus? sp.
- Ostrea strigilecula White.
- Camptonectes bellistriatus Meek.
- Lima? sp.
- Mytilus whitei Whitfield.
- Tancredia? sp.

According to Mr. Stanton, these forms might all be considered as Twin Creek, though the corals are a new element. They are, however, separated from that formation by an unconformity and more than 1,000 feet of unfossiliferous sandstones.

Like the Preuss sandstone the Stump represents a lower part of the Beckwith formation as hitherto described in southeastern Idaho and perhaps a corresponding part of the Beckwith of southwestern Wyoming. It is the "lower gray band" of Breger's section of the Beckwith.[69] On faunal evidence the Stump sandstone is assigned to the Upper Jurassic.

[69] Breger, C. L., op. cit.

CRETACEOUS (?) FORMATIONS

Above the marine Jurassic sandstones lies a series of conglomerates, fresh-water limestones, and sandstones that contain a fresh-water fauna which, according to Stanton, is of later aspect than Jurassic and has affinities with the faunas of the Kootenai and Bear River formations. The fossils thus far collected are not distinctive, but the beds, which have been designated as the Gannett group [70] and subdivided into five formations, are assigned tentatively to the Lower Cretaceous (?).

GANNETT GROUP

NAME AND GENERAL FEATURES

The Gannett group was named from the Gannett Hills, which lie in Bannock County, Idaho, and Lincoln County, Wyo., in the eastern part of the region described in this report, between Thomas Fork Canyon, in the northeastern part of the Montpelier quadrangle, and Stump Canyon, in the southeastern part of the Freedom quadrangle, where all the formations of this group are well exposed.

The group includes five distinct formations—the Ephraim conglomerate at the base, Peterson limestone, Bechler conglomerate, Draney limestone, and Tygee sandstone—and has a maximum thickness of over 3,200 feet. It rests, with apparent conformity, upon the Stump sandstone and follows the outcrop of that formation with a high degree of uniformity for long distances. Nevertheless the sudden appearance of massive conglomerates accompanied by fresh-water limestone and the local absence of certain red beds near the contact of the two formations probably indicate a stratigraphic break of considerable size.

The group occurs in much the same areas as the Preuss and Stump sandstones but is confined more closely to the central portion of the synclinorium.

A stratigraphic section of the Gannett group and some of the underlying formations is given in Table 29. Detailed descriptions of the formations follow.

TABLE 29.—*Stratigraphic section of the Gannett group with some underlying beds in secs. 3 and 2, T. 8 S., R. 46 E., east of Miller ranch, Freedom quadrangle, Idaho*

[By P. V. Roundy]

	Feet
Gannett group, Cretaceous (?):	
Tygee sandstone: Sandstone, gray to buff, somewhat resembling No. 7 of the Wayan (p. 106) but not greenish; not exposed in this section but appears above upper limestone in Crow Creek quadrangle 6 miles or more to the south where about 100 feet of beds is exposed.	
Draney limestone—	
V. Limestone, white, much like the Peterson limestone; dip uncertain; near top of hill a prominent gastropod layer; top of bed not determined	125
Covered; light soil, float composed of light limestone	50
	175

[70] Mansfield, G. R., and Roundy, P. V., op. cit., pp. 75-84.

Gannett group, Cretaceous (?)—Continued.

Bechler conglomerate—	Feet
Covered	150
Sandstone, salt and pepper color	4
Covered; soil reddish; float scarce; a few pebbles as from conglomerate	60
U. Conglomerate, reddish gray, heavy bedded and cross-bedded; some finer conglomerate, a maker of subordinate ridges. Average strike, N. 6° W.; dip, 23° E	100
Covered	60
T. Sandstone, gray, fine grained, beds 4 inches to 2 feet. If obtainable in good quantity would make good building stone (?); in most places masked by the débris of the conglomerate above	8
Covered; soil reddish; float is from conglomerate and sandstone above	60
S. Sandstone, gray, fine grained, with purplish patches. Dip uncertain but assumed for purposes of measurement as 30° E	25
Covered; soil a light reddish gray; abundant float; small pieces of limestone, gray to purplish pieces of fine-grained sandstone, chert pebbles, and some pieces of red sandstone. This division is probably like the overlying division (S)	95
Covered; mostly conglomerate pebbles	200
R. Conglomerate and sandstone like division Q; conglomerate predominates	60
Covered; soil red, float mainly that of a conglomerate and sandstone	225
Q. Sandstone and conglomerate; the sandstone is of pepper and salt color, coarse to medium grained, and forms a small, very subordinate ridge in the saddle; the sandstone changes along the strike to a medium-coarse conglomerate. There are some slickensides, the grooves in which correspond to the dip and are probably due to the synclinal folding (slipping along bedding planes). Where measured the lower 45 feet is composed of sandstone overlain by conglomerate; 100 feet north there is not over 20 feet of sandstone. This division makes ridges south and north	75
P. Conglomerate, medium, calcareous cement weathering red; aspect of weathered ledge is red. Strike, N. 12° W.; dip, 45° E. Ledge shows only in few favorable positions; bedding massive; one bed 2 feet 11 inches thick	30
Covered; reddish soil; float small; varied pebbles	70
O. Sandstone, pepper and salt color, coarse; beds appear to be 1 to 2 feet thick; soil not red but quite gray	40
N. Mostly covered; float composed of pepper and salt sandstone like M	115
Covered; soil red; probably this interval and covered interval between K and M both correspond to J; the float is composed of scattered pieces of red sandstone	60

Gannett group, Cretaceous (?)—Continued.

Bechler conglomerate—Continued.	Feet
M. Sandstone, coarse; pepper and salt color like that of L and K; weathers roundish, so that strike and dip are uncertain. Ledges strike N. 10° W.; for purposes of measurement dip assumed to be 45°, to correspond with dips above; soil reddish	18
L. Covered; soil reddish; float mainly scattered pieces of red sandstone	65
K. Sandstone, coarse, pepper and salt color; like I without the hard, fine-grained sandstone at base. Dip 50° ± E	45
Covered; probably like J	40
J. Sandstone, reddish, rather dull and grayish, seems to weather easily	50
I. Sandstone, coarse, pepper and salt color, with a small amount of fine-grained sandstone near base, thin bedded, beds 8 to 10 inches thick. Strike, north; dip, 55° E	70
	1, 725

Peterson limestone—	Feet
H. Limestone, fine-grained, weathers white; is slate color to light gray inside. Strike, north. Dip, 66° E. Considerable calcite in upper part in the form of veins. Most veins are 1/8 inch or less thick; one is 1/2 inch. Upper part is the more massive; average bed 1 1/2 feet thick; thickest bed 2 feet 10 inches. This limestone is the prominent ridge maker of this region; forms white soil	205

Ephraim conglomerate—	Feet
G. Sandstone, coarse, conglomeratic, grayish to reddish, massive, like division F. Upper 20 feet is mixed float from "lower white limestone" above and coarse reddish sandstone of division G	145
Covered; soil reddish; float composed of small varied pebbles and reddish sandstone	95
F. Sandstone, coarse, conglomeratic, grayish to reddish, heavy bedded; upper 10 feet somewhat purplish and slightly calcareous. Coarse sandstone predominates with conglomerate in scattered bands, pebbles in conglomerate, 1/8 to 1/4 inch in diameter; thickest bed, 3 1/2 feet thick. Strike, N. 7° W.; dip, 66° E	355
Covered; soil reddish, float composed of different kinds of pebbles less than 1 inch in diameter	65
E. Covered; soil varies from gray to red, mainly reddish gray; float not very abundant but mainly grayish limestone boulders, all containing chert in irregular ornamental forms	75
D. Limestone band forming roughly rounded fine-grained dense boulders 1 to 14 inches in diameter, close together, color on fresh fracture dull gray to purplish gray; weathered surface white to purplish gray but white predominates; no ledges exposed in this region, but this band is rather constant; soil a dull gray	25

	Feet
Gannett group, Cretaceous (?)—Continued.	
Ephraim conglomerate—Continued.	
Covered; soil grayish red, float composed of dull pale-red sandstone with gray limy patches and small gray limestone pebbles. This area and the overlying covered area form a saddle between low peaks	45
Covered; soil dark and rather clayey, float small angular pieces of indurated sandstone with purplish and grayish colors	90
C. Sandstone and conglomerate, gray, indurated; contains black, gray, and yellowish chert pebbles; this band is rather constant in this region on both sides of the syncline, but it is not present everywhere in the Crow Creek quadrangle; a few beds 2 to 3 feet thick stand out prominently and the rest of the band is composed of scattered exposures of beds and float of small angular pieces; a bed of this conglomerate east of Peterson's ranch measures 7 feet thick	130
	1, 025
Total, Gannett group	3, 130
Jurassic:	
Stump sandstone—	
B. Sandstone, at base steel-gray fine-grained calcareous sandstone, which weathers somewhat like trap; hard, rings under the hammer; is not exposed here as ledges though commonly does form ledges, abundant on surface and lies just below the crest; generally this band forms the crest; above lies a thin-bedded greenish-gray to gray sandstone mainly with greenish cast in this region; the thickest bed observed is 2 feet 8 inches thick; this bed upon the more weathered portions appears to be composed of distinct beds 1 to 3 inches thick; some cross-bedding, float not as angular as red sandstone below and usually roughly platy, few pieces as much as 2 inches thick, generally ¼ to ¾ inch; dip of middle portion, 68° E.; soil grayish; this band makes a series of low subordinate peaks and ridges, elsewhere prominent peaks and ridges, and is much thicker to the south; lower contact not clearly shown, as débris from overlying bed overlaps this bed. This zone in Crow Creek quadrangle and other places contains a reddish-gray grit that carries scattered oyster shells	430
Preuss sandstone—	
A. Sandstone, dull red, fine, even grained, somewhat calcareous, also somewhat shaly, thin bedded; not a ridge maker occupies slopes that have dull-red soil which contains angular pieces of stone ½ to 8 inches across; small pieces about same thickness as breadth, larger pieces 1 to 4 inches thick; few ledges exposed, but better ledges occur in southeastern corner of Crow Creek quadrangle	360
Jurassic—Continued.	
Preuss sandstone—Continued.	
Base of formation concealed by Salt Lake formation, which contains well-rounded, assorted pebbles of red and gray sandstone, limestone, quartzite, and chert	
	3, 920

EPHRAIM CONGLOMERATE

Name.—The Ephraim conglomerate, the basal formation of the Gannett group, was named from Ephraim Valley, in sec. 36, T. 10 S., R. 45 E., Crow Creek quadrangle, which lies in the formation.

Distribution.—The Ephraim conglomerate does not appear in the Henry or Slug Creek quadrangles. In the Montpelier and Crow Creek quadrangles, however, it forms large synclinal areas, the easternmost of which continues northward into the Freedom quadrangle. There the formation is more complexly folded and faulted and is particularly well developed in the central portion of the quadrangle. (See map, pl. 5.) Two bands continue northward through the quadrangle and a third passes into the Lanes Creek quadrangle, where it becomes separated into distinct areas.

In the Cranes Flat quadrangle the formation occupies considerable areas in the southeastern part and northeast of Cranes Flat.

Character.—The rock is a red conglomerate that contains minor amounts of sandstone and some thin bands of gray to purplish limestone, some of which is nodular. It is about 1,000 feet thick at the type locality, but differs much in thickness and character, becoming in some regions practically all conglomerate, the pebbles in which range in size from less than 1 inch to nearly a foot in diameter. The pebbles represent a wide variety of materials, including quartzite, limestone, and chert, probably derived from Carboniferous or early Paleozoic formations, the Woodside and Thaynes formations, and perhaps even from the Nugget sandstone. The pebbles are mostly smooth and subangular and some are even well rounded. A few of the larger pieces are angular. Perhaps 100 feet above the base there is an olive-yellow band, 25 feet or more thick, in which the pebbles are almost exclusively composed of dark chert, rounded or subangular, and are generally an inch or less in diameter. The Ephraim conglomerate makes rough, ledgy hills and ridges. Locally it gives rise to landslides, as along the ridge northwest of Stump Peak. It forms most of the mass known as Red Mountain, in the northeastern part of the Montpelier quadrangle, where it is well exposed. (See pl. 32, *C*.)

Correlation and age.—The Ephraim conglomerate is equivalent to the upper middle part of the Beckwith formation of southeastern Idaho as described by Breger[71] and perhaps to part of the lower division of the Beckwith formation of southwestern Wyoming as described by Veatch.[72] No fossils have been found in it, but the occurrence of the conglomerate above marine Upper Jurassic beds and below strata with fossils of later aspect than Jurassic favors at least its tentative reference to the Lower Cretaceous.

PETERSON LIMESTONE

Name.—The Peterson limestone was named from Peterson's ranch, along Tygee Creek, in sec. 34, T. 7 S., R. 46 E., Freedom quadrangle, east of which the formation is well exposed.

Distribution.—The limestone forms the top of a local ridge east of Hardmans Hollow, in the northeast part of the Crow Creek quadrangle, and a band on each side of the syncline east of Tygee Creek in the same region. These bands are continued northward into the Freedom quadrangle and are cut by the canyon of Stump Creek, where the limestone and its synclinal structure are well shown. North of this canyon the synclinal structure becomes complex and there are many faults. As a result numerous bands of the Peterson limestone occur in the south end of the Caribou Range, the distribution of which may best be seen by reference to the map (pl. 5). The limestone extends northward into unmapped areas but does not appear in the other quadrangles described in this report.

Character.—The Peterson limestone is about 200 feet thick, massively bedded near the top, and very persistent throughout the region studied, in which it forms prominent ridges that can be followed by the eye for miles from some of the higher summits. (See pl. 32, *B*.) It is locally difficult to distinguish from certain limestone beds of the Wayan formation.

Age and correlation.—The following fossils from this limestone have been identified by T. W. Stanton: *Unio* sp., *Planorbis* (*Gyraulus*) sp. related to *P. praecursoris* White, *Viviparus* sp., *Goniobasis?* sp., and two distinct species of *Physa*. Fossils of similar types occur in the Kootenai, Bear River, and later formations. The fresh-water gastropods are not distinctive, and similar forms of *Planorbis* are found in both the Morrison and Bear River formations. but no species of *Physa* have been reported from beds older than the Bear River.

The Peterson limestone is the "upper gray band" of the Beckwith formation, as described by Breger.[73] Its age is regarded as probably Lower Cretaceous.

BECHLER CONGLOMERATE

Name.—The Bechler conglomerate is named from Bechler Creek, which enters Stump Creek from the north about a quarter of a mile north of the mouth of Boulder Creek, in T. 6 S., R. 45 E. Boise meridian (unsurveyed), in Caribou County. Bechler Creek is named in honor of G. R. Bechler, topographer of the Teton division of the Hayden Survey, who did the first topographic mapping in the region that adjoins the Freedom quadrangle on the north.

Distribution.—The Bechler conglomerate lies above the Peterson limestone in the syncline in the northeastern part of the Crow Creek quadrangle. Its chief exposures are in the complexly folded and faulted part of the Caribou Range in the Freedom quadrangle. (See map, pl. 5.) It extends northward into unmapped adjacent regions but does not appear in the other quadrangles described in this report.

Character.—The formation is composed of about 1,700 feet of gray, reddish, and salt and pepper sandstones that contain interbedded conglomerates. The salt and pepper color predominates, and there is probably more than twice as much conglomerate as sandstone. The proportion of sandstone, however, is greater than in the Ephraim conglomerate. The pebbles in the conglomerate are small, and few have a diameter of more than 1 inch. They are generally smooth and subangular. Some are rounded. Like the Ephraim conglomerate the Bechler forms rough ledgy slopes or ridges.

Correlation and age.—The Bechler conglomerate lies above the Beckwith beds described by Breger[74] and probably corresponds to some part of the Beckwith of southwestern Wyoming,[75] but no definite correlation is now practicable. The age of the formation is regarded as probably Lower Cretaceous.

DRANEY LIMESTONE

Name.—The Draney limestone is named from the Draney ranch, on Tygee Creek, in sec. 10, T. 8 S., R. 46 E. Boise meridian. The limestone occurs on the top of the ridge about a mile and a quarter east of the ranch.

Distribution.—The formation occurs in two separate areas in the northeastern part of the Crow Creek quadrangle, on a linear hill about 2 miles east of the old salt works in Tygee Valley, and in the core of the syncline along the State line, extending northward into the Freedom quadrangle. The only other occurrence is a synclinal loop about 3 miles long, east of Bechler Creek, near the center of the Freedom quadrangle.

Character.—The Draney limestone is about 200 feet thick and is fairly massive, the individual beds reaching a maximum thickness of 1½ feet. The rock is much like that of the Peterson limestone but is not so massively bedded near the top. It is compact and gray but weathers to a dirty white.

If it was not for its stratigraphic position this formation might readily be mistaken for the Peterson limestone or one of the limestones of the Wayan

[71] Breger, C. L., The salt resources of the Idaho-Wyoming border: U. S. Geol. Survey Bull. 430, pp. 562–563, 1910.

[72] Veatch, A. C., op. cit., pp. 57–58.

[73] Breger, C. L., op. cit., pp. 562–563.

[74] Breger, C. L., op. cit.

[75] Veatch, A. C., op. cit., pp. 57–58.

formation. It forms low ledges and is not so conspicuous a ridge maker as the Peterson limestone.

Age and correlation.—The following fossils from this limestone have been identified by T. W. Stanton: *Unio* sp. related to *U. vetustus* Meek, *Viviparus?* sp., and *Goniobasis?* sp., a simple smooth form resembling *G.? increbescens* Stanton or *Amnicola? cretacea* Stanton. Like the Bechler conglomerate the Draney limestone lies stratigraphically higher than beds hitherto called Beckwith in southeastern Idaho. It may correspond with some part of the Beckwith of southwestern Wyoming, but definite correlation is now impracticable.

TYGEE SANDSTONE

Name.—The Tygee sandstone is named from Tygee Creek, east of which, in T. 8 S., R. 46 E., the formation is well exposed together with the Draney limestone on the top of the ridge along the Idaho-Wyoming boundary.

Distribution.—The Tygee sandstone has been found only with the Draney limestone in the syncline of the northeastern part of the Crow Creek quadrangle, where it includes the uppermost beds, and in a similar relationship east of Bechler Creek. In this locality the boundary between the Tygee and the overlying Wayan formation is not distinct and there is some lithologic similarity between the beds of the two formations. Possibly the Wayan formation should here be extended farther southeast.

Character.—The Tygee sandstone is gray to buff, even grained, and without the greenish or reddish tinges of some of the higher sandstones. The top is not exposed, and in much of the region this sandstone and part or all of the limestone below it has been eroded before the deposition of the Wayan formation. At the type locality about 100 feet of this sandstone is exposed.

Correlation and age.—The Tygee sandstone resembles the Bechler conglomerate in that no definite correlation is feasible. For reasons previously stated the formation is assigned to the Lower Cretaceous (?).

CRETACEOUS SYSTEM

Unconformably upon the Gannett group lies a series of sandstones, shales, carbonaceous shales, limestones, and conglomerates that has an apparent thickness of about 11,800 feet. The fossils thus far found in these beds are relatively few and yield little decisive information regarding their age, but the position of the beds above a relatively thick series of formations of post-Jurassic aspect leaves little doubt that the unconformable higher series is Cretaceous. On the other hand, the affinities between the fossils of the beds and those of the Kootenai and Bear River formations show that part of the beds at least is in all probability Lower Cretaceous. However, some of the beds may not unlikely prove to be of Upper Cretaceous age. The examination of regions to the north and east may yield information sufficient to show definite relationships between these beds and some whose stratigraphic position is established. In the meantime the beds are assigned to the Lower Cretaceous (?). They are all included in the Wayan formation.[76]

WAYAN FORMATION

Name and subdivision.—The Wayan formation derives its name from Wayan post office, Bannock County, Idaho, in the northern part of the Lanes Creek quadrangle. The mountains to the east of Wayan are underlain by the formation. Since the topographic map was made the location of the Wayan post office has been changed. In July, 1916, its location was on Landers Cutoff, in the SE. ¼ SE. ¼ sec. 10, T. 5 S., R. 43 E.

In the Cranes Flat quadrangle the Homer limestone member has been differentiated and mapped. It is named from Homer Creek in the northern part of the quadrangle. The limestone is well developed in the hills northeast of this creek and in secs. 16 to 25, T. 2 S., R. 41 E. A large tributary of Homer Creek has excavated its valley in the limestone.

Distribution.—The Wayan formation is exposed in a faulted area in sec. 14, T. 8 S., R. 46 E., just west of the State line in the Lanes Creek quadrangle and in patches in the SW. ¼ sec. 5, T. 32 N., R. 119 W., about a mile southwest of Auburn, Wyo., and in sec. 14, T. 8 S., R. 46 E., on the State line east of Tygee Valley. Northwestward from the lower canyon of Stump Creek the formation is extensively developed in the Caribou Range in the Freedom quadrangle and in the northeastern part of the Lanes Creek quadrangle. It enters the southeastern part of the Cranes Flat quadrangle and extends northwestward through it, constituting most of the sedimentary area of the northeastern half. It forms most of the portion of the Caribou Range that is included in the region here described.

Character.—In the Freedom and Lanes Creek quadrangles the Wayan formation appears to be broadly divisible into two units, the upper composed chiefly of alternating sandstones and shales together with some conglomeratic beds but without significant limestones, except possibly the Homer limestone member, the position of which is not clear, and the lower of approximately eight subdivisions, including several thick beds of limestone.

The lower unit in the section exposed in Tincup Canyon includes four sets of red beds, three of limestone and shale, and one of yellow sandstone. These beds in ascending order may be briefly described as follows:

1. Beneath the limestone of the dome that forms a fine arch about a mile west of the mouth of South

[76] Mansfield, G. R., and Roundy, P. V., op. cit.

Fork of Tincup Creek there is a suggestion of reddish soil that may represent red beds not otherwise exposed.

2. Gray limestones, weathering whitish, and dark shales. The topmost 20 feet consists of rather massively bedded limestone; shale and limestone are interbedded below, and the proportion of shale gradually increases toward the base.

3. Red beds, which consist largely of red-weathering soft gray sandstone but include also some gray and red shaly beds and some calcareous beds. These rocks generally form slopes and soil of a light-red color, a brighter color than that of No. 5.

4. Bands of gray limestone in dark shales. Some of the limestone beds are relatively massive, 1½ feet or more thick, and project from the weaker shales.

5. Red beds and purplish to reddish-gray sandstone, massive near the top but in thinner beds and associated with shale below; the whole mass weathers to a red soil and forms fairly smooth slopes.

6. Dark-gray to black shale with massive buff limestone near the top and thinner beds of limestone below. (See pl. 40, *B*.)

7. Greenish-gray sandstones and grit; weathers yellow and reddish and generally forms marked ridges and rough talus slopes of large blocks. The sandstone becomes conglomeratic in places.

8. Red to purplish sandstone that contains some shaly and some calcareous beds.

Landslides are numerous in the region occupied by the lower member, apparently induced by the character of the shaly members, particularly No. 6. Some of these landslides are indicated on the map (pl. 5).

Some of the subdivisions listed above may be recognized north and south of Tincup Canyon, but their structure is complex, they appear to differ in lithology and thickness, and they are in places not well expressed topographically. For these reasons it is not yet practicable to map them separately. Their combined thickness is estimated at about 2,800 feet.

The upper unit of the formation, if there is no reduplication by folding and faulting, comprises some 9,000 feet of westward-dipping beds that lie along the upper course of Tincup River above the canyon. These beds are chiefly red and gray sandstones, together with intervening shales and some calcareous beds. The sandstones form a series of low ridges and points, but the shales are mainly weathered into soil-covered areas. Toward the top yellowish and brownish sandstones appear, and the uppermost strata recognized are shown only by fragments of dark-gray siliceous sandstone and pieces of dark-brown or black silicified wood that has weathered white.

Associated with the sandstones of the lower part of the upper member are calcareous conglomerates and grits of generally grayish or pepper-and-salt appearance. The darker fragments against the white calcareous matrix produce a curious patchy appearance. Some of the white patches are due to white calcareous or siliceous fragments; others to areas of the matrix without foreign particles, and still others to rounded, concentrically banded, calcareous coatings on some of the larger fragments. The fragments themselves are chiefly angular or subangular, though some are rounded, and consist of dark and varicolored chert, with quartzite. The sizes of the fragments range from one-sixteenth of an inch to 2 inches or more. Some of them are fractured and veined with calcite. The fragmental material thus far recognized appears to be of Paleozoic origin. This type of conglomerate has not been found in any other formation, though it resembles to a certain degree some of the Pliocene (?) conglomerates of the region. It is well shown at places on the divide between Tincup River and Lanes Creek in the Lanes Creek quadrangle and in the ridge west of Little Valley in the northwestern part of T. 4 S., R. 42 E., in the Cranes Flat quadrangle.

In the SW. ¼ sec. 20, T. 5 S., R. 44 E., where the road crosses the northwest slope of the hill (altitude 6,839 feet) in the Lanes Creek quadrangle, a small ledge of indurated rhyolitic or latitic tuff is exposed. The rock has a greenish-drab color and waxy texture and on broken surface shows flakes of biotite. Included with this rock are dark-reddish to flesh-colored bands of somewhat coarser texture that contain considerable feldspathic material, which is kaolinized on the weathered surface. Opaline silica has been deposited in some of the cracks. In thin section, as determined by E. S. Larsen, jr., there are seen angular fragments of fresh plagioclase and quartz, biotite, and pieces of the walls of broken bubbles in a fine feebly polarizing groundmass. The stratigraphic position of the tuff in the Wayan formation is not definitely known, but it appears to lie in the lower or middle portion of the upper member.

In the Freedom and Lanes Creek quadrangles the upper unit apparently represents the east limb of a broad syncline, the axial region of which is occupied by the layer that contains silicified wood. The syncline is broken on the west by a fault. The northward continuation of the beds and the structural relations suggest that higher beds may appear in that direction.

Cranes Flat quadrangle.—In the absence of studies in the intervening regions, it is not possible to state definitely how the Wayan beds of the Cranes Flat quadrangle are related to those of the Freedom and Lanes Creek quadrangles.

In the central and southeastern parts of the Cranes Flat quadrangle the occurrence of the peculiar patchy conglomerate that corresponds with beds of the upper division of the Tincup River section has already been noted. In the NE. ¼ sec. 25, T. 3 S., R. 41 E., near the section corner fragments of rock regarded by Mr. Larsen as rhyolitic or latitic tuff cemented by opaline silica were found. This tuff is apparently identical in lithology and appearance with the tuff described from T. 5 S., R. 44 E., in the Lanes Creek quadrangle, and strongly suggests the same stratigraphic horizon. The tuff is here included in small folds and is therefore twice repeated within a distance of about 900 feet. The same general horizon is perhaps indicated by an indurated dark fine-textured sandstone with flesh-colored bands that lies in the NE. ¼ sec. 31, T. 3 S., R. 42 E., and strikes directly toward the first-named locality. This dark sandstone contains much relatively fresh and angular feldspathic material. No bed that corresponds to that which bears the silicified wood has been found.

Homer limestone member.—This limestone occurs in the northeastern part of the Cranes Flat quadrangle and extends into adjacent regions north and east. An interrupted area that ranges from 2 miles to about half a mile in width extends northwestward from the northwest corner of T. 3 S., R. 42 E., to the north boundary of the region mapped. Northeast of Grays Lake Outlet a broad Y-shaped area extends from secs. 16 and 15 to sec. 26, in T. 2 S., R. 42 E.

The stratigraphic position of the Homer limestone member is not definitely known. Although the limestone and the adjacent beds bear some lithologic resemblance to members 5 to 7 of the lower division of the Tincup Canyon section, the stratigraphic order of the beds is not the same and there are differences in the lithology of the limestones at the two places. Moreover the synclinorial structure of the limestone makes it lie above the beds just described as probably belonging in the upper division of the Wayan, unless a fault is postulated along the west side of the limestone area between Sugarloaf Mountain and Homer Creek. From available evidence such a fault may exist but is not necessarily present.

Ordinarily the surface underlain by the limestone is strewn with white pieces of the rock, which by their arrangement on the slopes suggest the attitude of the beds. Locally, as on the slope northeast of Sugarloaf Mountain, the limestone forms massive ledges. At this locality some of the upper beds are dull gray, coarsely crystalline, and crowded with poorly preserved pelecypods and shells of tiny gastropods one-eighth of an inch or less in diameter. Collections from these beds have yielded the following fauna, as identified by T. W. Stanton:

Lot No. 9750. SW. ¼ sec. 23, T. 2 S., R. 41 E., Cranes Flat quadrangle:
- Unio sp. cf. U. douglassi Stanton.
- Unio sp.; short, stout form.
- Goniobasis sp. cf. G. increbescens Stanton.

Lot No. 9752. SE. ¼ sec. 26, T. 2 S., R. 41 E., Cranes Flat quadrangle:
- Goniobasis? pealei Stanton?
- Goniobasis? increbescens Stanton.

Lot No. 9753. SW. ¼ sec. 30, T. 2 S., R. 42 E., Cranes Flat quadrangle:
- Unio? sp.
- Goniobasis? sp.

According to Mr. Stanton, "these fossils strongly indicate the horizon of the so-called Dakota of Yellowstone National Park, which is now classified as Kootenai."

Other beds associated with these are dark, compact limestones that weather light gray. The dark shales associated with the limestone have been observed at only one locality, the sag between the two hills in the western part of sec. 22, T. 2 S., R. 42 E.

The limestone appears to have been structurally weaker than the inclosing sandstones and to have yielded readily to deforming influences. It is folded, faulted, and intruded by andesite and, with the exception of the phosphatic shale in T. 5 S., R. 40 E., is the only formation with which that rock has thus far been found in contact in this region.

A graphic measurement in the NW. ¼ sec. 26, T. 2 S., R. 41 E., shows a thickness of about 500 feet.

On the east flank of Sheep Mountain and on the top of the ridge farther southeast there is a narrow, irregular, and discontinous band of limestone that may prove to be assignable to the Homer limestone. The massive fossiliferous beds of the Homer are missing here but their absence may be due to faulting. Probably however, this irregular limestone band, together with the somewhat variegated sandy, shaly, and calcareous beds to the west, have greater lithologic resemblance to members of the lower division of the Wayan formation, possibly Nos. 3 and 4 of the Tincup Canyon section, than to the Homer limestone and its accompanying strata.

Age and correlation.—The fossils collected from the Wayan formation have come almost entirely from the limestone bands. The following forms have been identified by T. W. Stanton: *Unio*? sp., *Rhytophorus*? sp., *Viviparus*? sp., *Limnaea*?, opercula of gastropods, and fragments of fresh-water shells. A dense greenish-gray sandstone at one locality has yielded the following fossils, identified by Mr. Stanton:

Lot No. 9751. NE. ¼ NE. ¼ sec. 28, T. 2 S., R. 41 E., Cranes Flat quadrangle:
- Unio, imperfect specimen representing three or more species.
- Sphaerium? sp.
- Viviparus? or Campeloma? sp.
- Goniobasis? sp.; striated form.
- Goniobasis sp.; smooth form.

In Tincup Canyon an unidentifiable fragment of bone has also been found. The fossils from the Homer limestone member are listed above.

In the region described in this paper no identifiable plant remains have been found in the Wayan formation, though indeterminable fragments of stems and bark have been found here and there in some of the sandstone.

In the Fall Creek Basin farther north plant remains have been obtained from beds that may be of Wayan or perhaps of Bear River age. The locality is probably the same as that from which St. John,[77] in 1877, collected leaves determined by Lesquereux as "*Aralia.*" Lesquereux recognized the affinities of these fossils with forms in the Dakota "group," but for other reasons the formation in which it occurred was referred at that time to the Laramie. The writer's collections from the locality were identified by F. H. Knowlton as follows:

Lot 7328, SE. ¼ sec. 32, T. 1 N., R. 42 E., Fall Creek basin, Idaho. This material embraces some stems and fragments of bark and a large number of fragments of dicotyledonous leaves. These leaves are so poorly preserved that none of them can be identified with certainty. Three types of leaves are present: A narrow willow-like leaf 7 or 8 centimeters long and 2 centimeters wide, a large deeply lobed *Aralia*-like leaf, and a fragment of a large wholly unknown leaf. On the basis of present knowledge this material can not possibly be as old as the Kootenai. The Kootenai has a flora of about 100 species made up of ferns, conifers, and cycads, but not a known scrap of a dicotyledon.

The few invertebrate fossils found in both the Wayan formation and the Gannett group are poorly preserved fresh-water forms belonging to *Unio* and to small uncharacteristic gastropods referred to several genera. There are therefore marked faunal similarities between the Gannett group and the Wayan formation, and certain beds in both, particularly the limestones, are also lithologically similar. These likenesses in some places make difficult the distinction between the formations where the similar beds of each occur in proximity, and thus the unconformity between them, usually distinct, is locally hard to detect, though it may represent a stratigraphic interval of 1,000 to 3,000 feet or even more.

On the maps of the Hayden Survey the rocks of the Wayan formation are in greater part referred to the Laramie, though some of the beds are mapped as "Juratrias." In later work in this general region these strata have been referred in part to the Beckwith formation and in part to the Bear River formation. It has been found,[78] however, that neither of these references is satisfactory. The paleontologic situation is summarized in the following quotation from Mr. Stanton's report on the fossils from the Wayan formation:

The collections from this district fail to show any characteristic species of the Bear River formation, and if the Bear River is recognized there it must be on some other basis than paleontologic correlation. This fact is also true of the Beckwith formation, for the reason that in its type area the Beckwith has yielded so few fossils that it can not be said to have a characteristic fauna.

Regarding the plant remains Mr. Knowlton says:

I have compared this material as well as could be done under the circumstances with a number of plant-bearing formations. For instance, Campbell and Stanton collected fossils from a locality in the Glacial National Park in 1911, in beds thought possibly to belong to the Kootenai. This lot also contains dicotyledons, and for this reason I excluded it from the Kootenai. I have compared the Idaho material with this Glacier Park lot and do not find anything in common.

If there is any relation between this Idaho lot and the Bear River formation it can not be settled by the plants, for only one plant is known from the Bear River formation.

I have compared the Idaho lot with the flora of Dawson's so-called Intermediate Series as well as with his Mill Creek series and can find no identical forms. I have also compared it with the flora of the Frontier formation, as well as with the Dakota flora, and with like result.

Recently dicotyledons have been reported from the type section of the Morrison formation at Morrison, Colo., but none of them appear to be the same as this Idaho lot.

If these Idaho specimens were well enough preserved to permit identification it might be possible to fix their stratigraphic position, but as it is I do not know what the position is, except that on the basis of present understanding it is younger than Kootenai.

The relations of the above-mentioned leaf-bearing beds to the Wayan formation of this region are not definitely known, for intervening areas have not been studied. They may represent a horizon stratigraphically higher than any of those exposed in the quadrangles under consideration.

Definite correlation of the Wayan formation is impossible at present. The reasons for the tentative assignment to the Lower Cretaceous have already been presented.

TERTIARY SYSTEM

GENERAL FEATURES

The Tertiary system is represented in this region by patches of sediments that differ greatly in size, thickness, character, and degree of consolidation and that lie unconformably upon rocks of the older systems. Two series of these beds have been differentiated, the earlier of which is with little doubt largely Eocene. The later series presents conflicting paleontologic evidence. The available fossils are few and poorly preserved, chiefly gastropods. Some of them suggest Eocene age and others Pliocene. Possibly Oligocene beds may be included in one of the divisions. The later series of beds has long been tentatively considered Pliocene, and it appears unwise to change this reference until more satisfactory evidence is available. The correlation of the different Tertiary patches thus rests mainly upon lithologic and structural data. The distinction between Eocene and Pliocene (?) in this region is locally difficult where limestones of the two groups are in contact or proximity. Thus the Pliocene (?) as mapped may include beds that will prove to be Eocene. The present mapping has the advantage of showing boundaries that in general may be readily recognized by lithologic differences in the field. The combined thickness of the two Tertiary formations is probably more than 2,500 feet.

[77] St. John, Orestes, Report of the geological field work of the Teton division: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 366, 1879.

[78] Mansfield, G. R., and Roundy, P. V., op. cit.

EOCENE SERIES

The beds assigned to the Eocene series consist of conglomerates, soft sandstones, and fresh-water limestones. They are referred to the Wasatch formation. The unconformity at their base is very pronounced.

WASATCH FORMATION

Name and subdivision.—The Wasatch formation was named by Hayden[79] in 1869, from Wasatch station on the Union Pacific Railroad in Summit County, Utah.

The Wasatch deposits[80] in neighboring regions of southwestern Wyoming have been subdivided by Veatch into three formations: The Almy formation at the base, which consists of reddish-yellow sandstones and conglomerates, in some places of deep-red color; the Fowkes formation, white or light-colored rhyolitic ash with some calcareous beds; and the Knight formation, which consists of reddish-yellow sandy clays and irregular sandstone beds, closely resembling the Almy formation lithologically but separated from the Almy and the Fowkes by an unconformity.

G. B. Richardson[81] and later P. V. Roundy and the writer have examined parts of the field described by Veatch. They have come to the view that the Fowkes formation may in reality be a lens and that the postulate of unconformity between the Knight and Almy formations, which closely resemble each other lithologically, may not be compulsory. More extended study of the Tertiary formations of the general region of southwestern Wyoming and northern Utah will be necessary before a definite opinion on the matter can be rendered.

In the region considered in this paper the Fowkes formation has not been definitely recognized, although at one locality rhyolitic débris has been found in beds here assigned to the Pliocene (?). It is also impracticable to distinguish the Almy and Knight formations. The Eocene rocks are therefore mapped and described under the name Wasatch formation.

Distribution.—The Wasatch deposits of this region are exposed only in the Montpelier and Slug Creek quadrangles. In the Montpelier quadrangle these beds occur chiefly in the Bear Lake Plateau, where they underlie much of the country, but they also occur as erosional remnants of greater or less size and widely separated.

In the Preuss Range, about 9 miles east of Montpelier, such a remnant occupies an area of nearly a square mile. On the west side of Bear Lake Valley several patches occur along the foothills from the vicinity of Glencoe to a point about 1½ miles south of Lanark. The largest of these patches, between Dry Canyon (St. Charles) and the ridges north of Bloomington Canyon, has an area of approximately 6 square miles.

In the Slug Creek quadrangle an irregular area in the northeastern part of T. 10 S., R. 43 E., occupies about 2½ square miles. In the southeastern part of the same township a larger and more irregularly shaped area extends eastward into T. 10 S., R. 44 E. In addition there are in the same region several very small patches.

The irregularities of shape, size, and distribution of these patches of Wasatch beds all indicate that the sediments now found are but erosional remnants of a formerly much more extensive deposit.

Character.—The Wasatch formation of southeastern Idaho, so far as examined, consists mainly of coarse red conglomerate with pebbles or boulders that range from less than an inch to 3 feet or more in diameter, largely subangular, though some are well worn and rounded, chiefly of Paleozoic quartzites and limestones, including many of Cambrian and Ordovician age. In the southeastern part of T. 10 S., R. 43 E., boulders of basalt were noted with the conglomerate. The grouping of the boulders suggests a small extrusion of lava. As no actual ledge of basalt was observed these boulders may have formed part of the conglomerate, though their relatively fresh condition would make this seem unlikely. In the same locality a dense tan-colored limestone with included brecciated pisolites of dark-gray, concentrically banded, crystalline limestone, half to three-fourths of an inch in diameter, is associated with the conglomerate. There are also beds of nonpisolitic limestone of similar color and appearance. In the western half of section 24 a prominent white limestone band 50 feet or more wide strikes N. 32° E. and dips 32° S. Parts of this band are massive and dense, but other parts have linear drusy cavities, so that the band as a whole represents a vein rather than a bed. In the Montpelier quadrangle coarse red sandstones, locally concretionary, and minor amounts of reddish or purplish shales and limestone lenses or beds are associated with the conglomerates. In the vicinity of Glencoe, in the southwestern part of the quadrangle, isolated exposures of white pisolitic limestone, which are included in the area mapped as Pliocene (?), may represent areas of Wasatch limestone, too small to map separately, from which the white Pliocene (?) beds have been eroded.

The exposed thickness of the Wasatch probably does not exceed 1,500 feet, but the beds have been greatly eroded and may have been much thicker.

Age.—No fossils of determinative value have been recovered from the Wasatch beds in the region described in this report, but these appear to be continuous, in part at least, with the (Knight or the Almy) formation of southwestern Wyoming as mapped by Veatch, where the Knight beds have yielded both

[79] Hayden, F. V., U. S. Geol. Survey Terr. Third Ann. Rept., p. 90, 1869.

[80] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 88, 1907.

[81] Personal communication.

animal and plant remains, among them the first vertebrate bones obtained from the Wasatch, consisting of species of *Coryphodon*, described by Cope as *Bathmodon*.[82]

PLIOCENE (?) SERIES

Unconformably upon the Wasatch deposits in the southwestern part of the Montpelier quadrangle and elsewhere unconformably upon other pre-Tertiary sedimentary rocks lies a group of generally light-colored grayish or yellowish conglomerates with associated marly, gritty, or sandy beds of similar tints that produce white or light-colored soils. Few fossils have been found in these beds, and these furnish no very satisfactory data for age determination. The beds are tentatively regarded as of Pliocene age and are all included in the Salt Lake formation.

SALT LAKE FORMATION

Name.—In 1869 the name Salt Lake group was introduced by Hayden,[83] in the following words:

> In the valley of Weber River, from Morgan City to Devil's Gate, there is a thickness of 1,000 to 1,200 feet of sands, sandstones, and marls of a light color for the most part, which I regard as of upper Tertiary age. These newer beds must have not only occupied this expansion of the Weber Valley but also all of Salt Lake Valley, for remnants of it are seen all along the margins of the mountains inclosing Salt Lake Valley. * * * I found this series of beds so widely extended and so largely developed in Weber Valley and Salt Lake Valley that I regard it as worthy of a distinct name and in consequence have called it the Salt Lake group.

This term was introduced by Peale [84] into the region here discussed and has been employed in a quotational sense (the Salt Lake group of Hayden and Peale) in later publications on the region as the designation of the Pliocene(?) rocks. In the above citation the name appears to be used in a strictly geographic sense with neither a definite implication of lacustrine origin of the beds nor implication of connection with Great Salt Lake. It is true, however, that members of the Hayden surveys did regard these beds as lacustrine in origin, for Peale,[85] in referring to similar beds in Marsh Valley, to the west, states:

> I believe they were deposited in the same lake that occupied this valley, Cache Valley, Salt Lake Valley, and the valley of the upper Portneuf, and Bear Lake Valley.

The long usage of the name in this region and the fact that it was directly applied by Peale to the beds under consideration make its retention desirable. It has been shown by Gilbert,[86] however, that these deposits long antedate the origin of the present Great Salt Lake, and it is now believed that the beds, though probably partly lacustrine, are largely of fluviatile origin.

The modification of Hayden's term to Salt Lake formation appears to meet the need of an appropriate geographic name and at the same time to avoid doubtful implications. The word formation is also applicable because of the varied character of the constituent beds.

Distribution.—The Salt Lake formation is exposed in each of the quadrangles mapped except the Cranes Flat. It commonly forms foothill slopes along some of the larger valleys, as on the western side of Bear Lake Valley in the Montpelier quadrangle from the vicinity of Glencoe northward, and in places it rises high on the flanks of the mountains, as in the vicinity of Georgetown Canyon, where its altitude in places is greater than 7,300 feet. In other places the formation covers large areas of moderately high hills, as southeast of Montpelier or north of Ovid, where it occupies more than a township, has a vertical range of more than 1,000 feet, and rises to an altitude of 7,156 feet. Smaller patches occur in some of the higher hills, as along the west flank of Red Mountain, where the Pliocene(?) deposits reach an elevation of about 7,850 feet, and in the northwest part of T. 13 S., R. 46 E.

Large areas of the Salt Lake formation occur in the southwestern part of the Slug Creek quadrangle and smaller areas or patches along the west flank of the Aspen Range and in the valleys of Slug Creek and Johnson Creek. The formation is also well developed north of Crow Creek in the quadrangle of that name and extends into Sage Valley, Tygee Valley, and along the west flank of Star Valley.

The hills along the western border of the Henry quadrangle are largely covered with the conglomerates of the Salt Lake formation and the south end of the hills west of the Blackfoot River Reservoir is in large measure similarly constituted.

In the Lanes Creek quadrangle there are only a few small patches in the southwestern and northeastern parts, but in the Freedom quadrangle extensive deposits occur in the valleys of Tygee and Stump Creeks and along the west side of Star Valley, especially in the vicinity of Thayne.

Character.—As most commonly encountered, the Salt Lake formation consists of light-gray or buff conglomerates, in which the matrix is white, relatively soft, loose textured, and calcareous. The pebbles are generally of local materials and rather angular, though many are subangular or even rounded. There is great variation in size, for some of the boulders are 4 or 5 feet in diameter but many of the fragments are less than an inch in diameter. The grayish or light color of the conglomerate and the local nature and angularity of the pebbles serve in general to distinguish these conglomerates from those of the Wasatch formation, which are usually reddish, consist of better-rounded

[82] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 89-96, 1907.

[83] Hayden, F. V., U. S. Geol. Survey Terr., vol. 3, p. 92 (p. 192 in combined First, Second, and Third Ann. Repts.), 1869.

[84] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 588 and 640, 1879.

[85] Peale, A. C., op. cit., p. 567.

[86] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 214, 1890.

materials, and are largely composed of older Paleozoic rocks. It is, however, locally difficult to make the distinction. Hills covered with conglomerate of the Salt Lake formation are strewn with countless pebbles and boulders of sandstone, quartzite, limestone, and chert. Ledges are few and poorly exposed. At some places, as in the lower part of Georgetown Canyon, heavy ledges of the conglomerate are exposed with a jumble of local materials of different sizes and shapes. The bedding in some places is fairly distinct, but there is little marked difference in the coarseness of the materials.

In addition to the conglomerates there are beds of white marls, calcareous clays, sandstones, and grits, which furnish a white soil and underlie considerable areas, particularly north of Ovid and a mile or more north of Georgetown. At the last-named locality some of the white calcareous beds contain much rhyolitic material in the form of glassy fragments of the walls of bubbles and resemble parts of the Fowkes formation of Veatch in the Eocene of southwestern Wyoming. Beds of this type however, are common in sediments of supposed Pliocene age in the Fort Hall Indian Reservation. In a small gulch about half a mile southwest of Bern a tunnel cuts into nearly horizontal white Pliocene(?) beds. The lower 4 feet of the exposure is composed of grayish-white sandstone. Above this sandstone lies 18 inches to 2 feet of white dense marl which hardens in drying and is so fine that it does not form grit when crushed between the teeth.

The marl was at first mistaken for a calcareous clay. A sample analyzed by the Bureau of Standards at the request of the Geological Survey gave the following results:

Silica	17. 70
Alumina	3. 96
Iron oxide	1. 61
Lime	21. 95
Magnesia	16. 76
Loss on ignition	38. 15
	100. 13

The small percentage of alumina indicates that the substance is not a clay. The relatively large percentage of loss on ignition probably represents in large part carbon dioxide, which if combined with the lime and magnesia would produce a marl.

In the southwestern part of the Montpelier quadrangle, near Glencoe, white, calcareous beds, more or less overspread with bouldery débris from local sources, are referred to the Pliocene (?). With these beds are associated white pisolitic marls. As noted above, these pisolitic rocks are tentatively regarded as inliers of the Wasatch formation. Locally travertine is associated with the Pliocene (?) beds and is difficult to distinguish from the marly limestones of that series.

The thickness of the formation ranges from a few inches at places that border exposures of older terranes to more than 1,000 feet where old valleys filled with these beds have been reexcavated, as in Georgetown Canyon. Great erosion has occured since these sediments were deposited, so that without doubt the maximum thickness was formerly much greater.

Hayden [87] in 1871 noted the occurence of a bed of impure coal in beds that probably belong to the formation. Peale [88] regards this coal as of Quaternary age. The exposure occurs at the water's edge on Bear River about 3 miles above Soda Springs and is visible only at low water in the autumn. The coal is included in a bed of "black slaty clay" underneath superficial drift. The "slate" above the coal is crowded with *Planorbis* and other fossils.

The formation is in many places nearly horizontal, but at other places it is inclined at angles that range from a few degrees to nearly vertical.

Age and correlation.—Some fossils have been collected from the Salt Lake formation, but these are chiefly poorly preserved fresh-water mollusks, which are not of determinative value. From clayey layers among conglomerate bands on the south side of Montpelier Creek the following forms, collected by C. L. Breger, were identified by W. H. Dall:

Pisidium sp., common.
Valvata sp., common.
Planorbis (round whorls, low spires), rare.
Lymnaea sp., rare.
Ostracodes, abundant.

In collections from T. 10 S., R. 42 E., a short distance west of the Slug Creek quadrangle, W. H. Dall has identified imperfect impressions of *Planorbis* and *Sphaerium* and from the west side of Bear River Valley in the same quadrangle a minute *Planorbis*, perhaps undescribed.

A collection from the forks of Miller Creek, in the NW. ¼ sec. 34, T. 5 S., R. 46 E., in the Freedom quadrangle, yielded the following fossils, which were identified by Dall and thought by him to indicate Eocene age:

Pisidium saginatum White.
Planorbis, resembling P. aequalis White.
Lymnaea, of the type of L. similis Meek.

On the other hand, in collections from Pliocene (?) beds in the Fort Hall Indian Reservation, he has identified the following forms:

Succinea? or Lymnaea? internal casts, not otherwise identifiable.
Oreohelix (one or possibly two species), internal casts not identifiable further.
Bifidaria, internal cast, not identifiable further.

These forms he is inclined to regard as Pliocene (?).

Most of the fossils thus far found are of long-ranging types, but some, such as *Oreohelix* from the Fort

[87] Hayden, F. V., U. S. Geol. Survey Terr. Fifth Ann. Rept., 1871, p. 154, 1872.
[88] Peale, A. C., U. S. Geol. Survey Terr. Eleventh Ann. Rep., p. 589, 1879.

Hall Indian Reservation, suggest later rather than earlier age, whereas others, as noted above, suggest Eocene age. These light-colored beds occur at sufficiently close intervals in the region described in this report and westward toward the Fort Hall Indian Reservation to make it reasonably certain that they belong together, and they have been so mapped. Their stratigraphic position at some localities, as along the west side of Bear Lake Valley, indicates that they are of later age than the Wasatch formation.

In the Yellowstone National Park the "Canyon" conglomerate, which according to recent field work by W. C. Alden may prove to be younger than the main body of the rhyolite, has yielded vertebrate remains that were identified by Prof. O. C. Marsh as belonging to the skeleton of a fossil horse of Pliocene time.[89] Rhyolites occur westward along the northern parts of the ranges from the Yellowstone National Park to the region here described and to the Fort Hall Indian Reservation. The rhyolite is probably not absolutely continuous, but the occurences are so numerous and the character of the rock so similar that there seems little reasonable doubt that the rhyolites in this region and in the Yellowstone National Park are essentially of the same geologic age.

In the region of the seven quadrangles here described the relations of rhyolite to the Salt Lake formation are not clearly shown, though the occurrence of volcanic ash in that formation near Georgetown has been mentioned. In the Fort Hall Indian Reservation, however, the rhyolite and the Salt Lake formation are interbedded here and there and are associated with beds of volcanic ash. Thus, if the rhyolite of the Fort Hall Indian Reservation and of the intervening regions is considered as contemporaneous with that of the Yellowstone National Park, the Salt Lake formation may be of Pliocene age. It was so recognized by Hayden and Peale.[90]

QUATERNARY SYSTEM

The rocks of the Quaternary system consist for the most part of unconsolidated gravels, sands, and clays, which occupy the larger valley bottoms, and of coarse or finer débris, less well stratified, which has accumulated here and there along the lower slopes above the valley bottoms.

Glacial deposits are absent from the immediate region, though they are present in St. Charles Canyon, about 2 miles west of the Montpelier quadrangle and other evidence of glaciation has been noted in the Bear River range without this district.

Deposits of travertine are also included. These deposits are well consolidated and locally difficult to distinguish from Tertiary limestones. The Quaternary deposits are all unconformable upon older rocks and are subdivided for mapping and discussion into four groups—travertine, hill wash, alluvium, and landslides—though each group is somewhat more inclusive than is directly implied by its title.

TRAVERTINE

General features.—The rocks thus designated consist in the main of calcareous sinter, which is the principal substance deposited by the former and present mineralized springs of the district. Certain springs of the region, however, are chalybeate or iron-bearing and others sulphurous or saline. The chalybeate springs have deposited travertine that is more or less discolored by oxide of iron and the sulphurous springs small amounts of finely divided sulphur. Larger deposits of sulphur occur in T. 9 S., R. 42 E., just west of the Slug Creek quadrangle. The saline springs do not have mappable surface deposits. It has not been practicable to map separately the chalybeate or sulphurous spring deposits. Where these deposits are represented they are included with the travertine.

Distribution.—The travertine occurs in large or small patches in the broader valleys, on the lower slopes of some of the hills, and in some of the canyons. Locally, also, it occurs as a dense coating beneath soil on basalt and appears as float with basaltic débris. It has not been observed in the Lanes Creek and Crow Creek quadrangles, except in the creek bed near the mouth of Sage Valley, but large areas are found in the Slug Creek, Henry, and Cranes Flat quadrangles. The Montpelier and Freedom quadrangles have smaller deposits. In each occurrence the travertine appears to be intimately associated with noteworthy faults. Many of these deposits, including some of the larger ones, are associated with active springs. Other deposits mark the site of extinct springs.

In the Montpelier quadrangle a deposit that covers an area of nearly half a square mile occurs in the upper course of Crow Creek, in sec. 3, T. 11 S., R. 45 E. Another area nearly as large is found in secs. 25 and 36, T. 11 S., R. 43 E. Here the travertine has formed fine terraces.

In the Slug Creek quadrangle the travertine makes prominent ledges along the road from Georgetown to Soda Springs in secs. 26 to 28, T. 10 S., R. 43 E., and near the center of that township it forms two prominent hills southwest of the road. Fine ledges of travertine also occur in sec. 15. The most extensive area, which occupies about 5 square miles, expands southwestward from the mouth of Swan Lake Gulch toward Bear River and overspreads adjacent portions of three townships. The Swan Lakes occupy large basins in the travertine. A fine group of extinct basins and terraces lies to the west, along the base of the foothills, and ledges are exposed in the creek valleys.

[89] U. S. Geol. Survey Geol. Atlas, Yellowstone National Park folio (No. 30), 1896.

[90] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 640, 1879.

The most striking assemblage of basins and terraces in the general region is that of Formation Spring, in secs. 27, 28, 33, and 34, T. 8 S., R. 42 E., about 2½ miles west of the region described in this paper. Several small patches of travertine occur along the fault at the west base of the Aspen Range.

In the Henry quadrangle a deposit of this rock occupies an area of nearly 5 square miles in the south-central part of T. 7 S., R. 42 E., bordering the north tip of the Aspen Range. Another accumulation about 1½ square miles in extent lies just west of Henry, in T. 6 S., R. 42 E. Smaller deposits occur in sec. 1, T. 6 S., R. 41 E., and in secs. 12 and 13, T. 6 S., R. 40 E.

In the Cranes Flat quadrangle a travertine area about 1½ square miles in extent lies north of the Blackfoot River Reservoir in secs. 31 and 32, T. 4 S., R. 41 E. Other smaller areas lie west of the north end of the reservoir in secs. 1 and 2, T. 5 S., R. 40 E., and secs. 35 and 36, T. 4 S., R. 40 E. A group of interesting cones stands near Blackfoot River in sec. 15, T. 5 S., R. 40 E., just west of the region mapped.

The Freedom quadrangle contains a number of rather small areas of travertine. Pretty sinter terraces occur in the head of Spring Creek in the southern part. Travertine that extends into the mapped area is also associated with the active hot springs about 3 miles north of Auburn and just east of the quadrangle. West of Thayne and northward along the east foothills of the Caribou Range deposits of travertine form prominent ledges.

Character.—The travertine is generally a white, gray, or buff porous rock, locally deeply ferruginous, that forms rounded, ledgy hills, mounds, or cones that mark the sites of springs that have probably been long extinct. Elsewhere it forms more or less extensive areas of basins and terraces, as shown on Plate 60, *A*, and cones with apertures, where the springs are still active or only recently extinct (pl. 60, *B*). The texture in some places is coarse, open, or even cavernous; in other places it is dense, fine, and banded. Locally casts of stems of grasses and gastropod shells occur in the deposits. The rock forms successive layers that give a concentric, shelly structure to cones or that form inclined beds in some of the larger mounds or ledges. The more massive and dense ledges resemble some of the Tertiary limestones and are locally difficult to distinguish from them. In some places where the depositing waters filtered through gravels and consolidated them, as in upper Crow Creek, in the Montpelier quadrangle, the resulting conglomerate resembles some of the Pliocene(?) conglomerates.

Age.—Travertine deposition probably began at the time of the crustal disturbance that marked the close of the Tertiary period and has continued with varying intensity until the present. Thus the deposits probably span the entire Quaternary period. At present, however, deposition is on a much less extensive scale than formerly.

HILL WASH AND OLDER ALLUVIUM

General features.—The lower slopes of many of the hills are covered with fragments of rock and soil that conceal the underlying formations. This material is in many places poorly assorted or without definite arrangement. Elsewhere it merges with fluviatile deposits and forms alluvial fans or cones that may have considerable areal extent, as in the northwestern part of the Montpelier quadrangle, where fans at the mouths of neighboring canyons have merged to form a broad sheet of waste 1 to 3 miles wide and 12 miles or more long. The upper limit of the deposits as mapped is the general line that marks the actual outcrop of the older, underlying formations or the line where the débris of these rocks is sufficiently characteristic and abundant to indicate the strong probability of their occurrence beneath. The line is of necessity somewhat generalized. The lower limit, also somewhat generalized, is the line of demarkation of these deposits from those of the valley bottoms, which are generally finer and better sorted.

Distribution.—Hill-wash deposits occur in each of the quadrangles mapped. They range in extent from small patches to areas of several square miles. They lie along the sides of the longer valleys and even overspread much of the valley floors at some places.

In the Montpelier quadrangle, besides the deposit already mentioned, there is a large accumulation along the west flank of the Sublette Ridge and a number of widely separated smaller patches.

In the Slug Creek quadrangle the largest area lies in T. 10 S., R. 42 E. It covers more than 8 square miles and extends southwestward from the base of the Aspen Range nearly to Bear River. Dry Valley, in the northeastern part, has extensive deposits, including a fine alluvial fan near the north boundary of the quadrangle. Lesser deposits lie along parts of the valley sides of Slug Creek and Trail Creek. Similar deposits flank parts of the larger valleys in the Crow Creek quadrangle, the most noteworthy of which are in the valley of upper Crow Creek, Elk Valley, and the valley of Tygee Creek.

In the Henry quadrangle the largest areas are in the valley of Corral Creek, in the western part, and of Meadow Creek in the northeastern part. Each of these areas includes several square miles, and there are besides numerous smaller strips or patches.

The Lanes Creek quadrangle has the most widely distributed deposits of hill wash with strips, patches, or larger areas in all the large valleys. The deposits of Enoch, Wooley, and Rasmussen Valleys and of upper Lanes Creek valley are especially noteworthy. The Freedom quadrangle has accumulations of hill wash in the lower valleys of Stump and Tygee Creeks, at different places along the west side of Star Valley and at other widely separated places.

In the Cranes Flat quadrangle extensive areas are underlain by hill wash in Meadow Creek and Little Valleys in the southeastern part and in Long Valley and the valleys of Homer Creek and of Grays Lake Outlet in the northern part. Other lesser areas lie along the southwestern border of the quadrangle and along the southwest base of the ridge between Meadow Creek and the Blackfoot River Reservoir.

Character.—Some characteristics of the hill wash have been mentioned in the general discussion. It should be noted further that the materials are generally local or from near-by sources. They differ in texture from boulders to fine soil and are generally not well rounded. The deposit has been submaturely or even maturely dissected by stream erosion, so that the present surface is uneven and has low-lying spurs and interfingering depressions. The low-lying spurs and higher slopes of the deposits are generally sage-covered. The depressions are in many places grass-covered and where large enough to be separately indicated are mapped with the alluvium, as shown in Wooley Valley (T. 7 S., R. 43 E., Lanes Creek quadrangle), Homer Creek valley (T. 3 S., R. 41 E., Cranes Flat quadrangle), and elsewhere.

Some of the finer materials or soils mapped with the hill wash have a hummocky surface, as in Corral Creek valley, Henry quadrangle, and probably represent accumulations of wind-blown dust. The general characteristics of the hill wash indicate that it is a product of climatic conditions more arid than those of to-day.

No fossils have been recovered from these deposits. The thickness is variable and the maximum not known, but in the vicinity of Bennington and Georgetown, in the Montpelier quadrangle, it seems clear that the thickness exceeds 100 feet. The maximum may indeed be much greater.

Age.—The hill wash locally overlaps the Salt Lake formation, but it has suffered submature or mature erosion and is in its turn overlapped by the alluvium. As stated above, it is the product of arid climatic conditions. It will presently be shown that its deposition was succeeded by more humid conditions than those even of to-day. The climatic oscillations of the Quaternary period in southeastern Idaho have probably differed in degree rather than in character from those of the Bonneville Basin, near Great Salt Lake, as described by Gilbert. The epoch of deposition of the hill wash is here regarded as corresponding with Gilbert's pre-Bonneville epoch.[91]

ALLUVIUM AND LAKE BEDS

General features.—In the broader valley bottoms and along the courses of many of the larger streams occur narrow bands or broader areas of grassy meadow land that have fingerlike or foliate extensions up tributary streams. The materials that underlie these areas are generally well sorted and fine textured or locally gravelly. Along some of the more rapid streams there are stony flood-plain deposits, as in Blackfoot Canyon just west of the region mapped. Special mention should be made of the smooth meadow-like surface of the deposits and of the marshy character of parts of the larger areas, as in the upper valley of Blackfoot River, the head of Grays Lake, and Cranes Flat.

Included in the mapping with the alluvium are the deposits of the former extension of Bear Lake. These deposits now form gravel terraces and beaches that stand 30 feet or less above the present level of the lake. In many localities the old lake-floor deposits are not clearly distinguishable from those of the modern flood plain of Bear River, and it has not been practicable to map them separately.

Distribution of alluvium.—Considerable areas of alluvium are found in each of the quadrangles. In the Montpelier quadrangle the deposits are chiefly grouped in Bear Lake, Thomas Fork, and Nounan Valleys and along Bear River. The last two named deposits extend into the Slug Creek quadrangle, where Dry Valley and the valleys of Slug Creek and Trail Creek also contain much alluvium. Crow Creek, Sage, Elk, and Star Valleys, and the valley of upper Diamond Creek contain the larger accumulations of alluvium in the Crow Creek quadrangle.

In the Henry and Cranes Flat quadrangles the more extensive deposits lie in Corral Creek, Cranes Flat, Meadow Creek, Pelican Slough, and the outlet of John Grays Lake. The south end of that lake with its alluvial border extends into the northern part of the Lanes Creek quadrangle. Enoch Valley and the upper and lower valleys of Blackfoot River contain broad alluvial meadows. In the Freedom quadrangle alluvial deposits occur in the valleys of Stump and Tygee Creeks and in Star Valley.

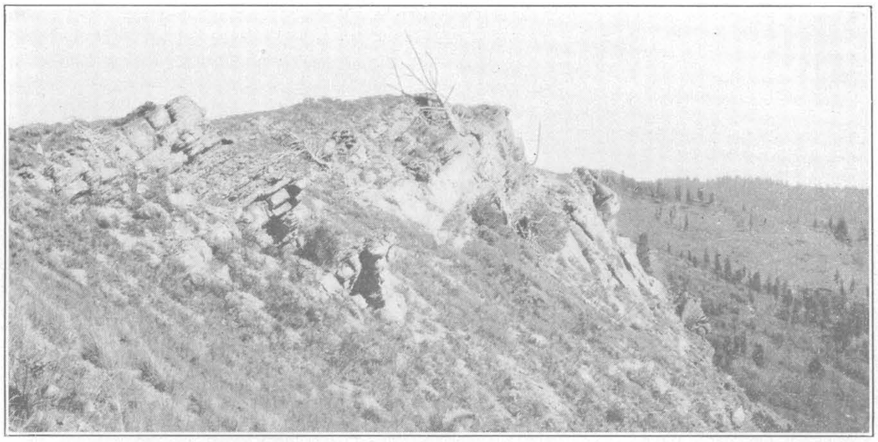
Lake beds.—The lake beds of the earlier stages of Bear Lake furnish the principal gravel banks of the region, as, for example, cuts about half a mile south of Dingle, at Liberty, and east of Bloomington. South of Dingle the lake gravels show pebble beds that have an aggregate thickness of 4½ feet, composed of pebbles of chert, limestone, sandstones, and quartzite 1 to 8 inches in diameter and subangular to rounded. These are overlain by about 3 feet of sand.

In a ditch cut in the lake beds half a mile east of Bern the following section was obtained:

	Feet
Sand, cross-bedded with streaks of clay 2 to 3 inches thick (shells)	10
Clay	6
Sand	1
	17

[91] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 221, 1890.

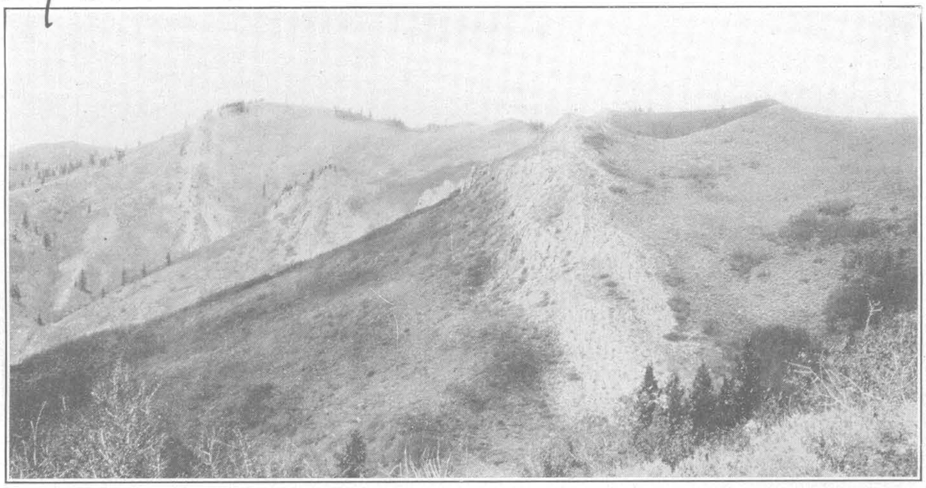
Roundy 59.



A. VIEW NORTHWEST ALONG THE RIDGE SOUTH OF THE HEAD OF LANES CREEK, IN THE NORTHWESTERN PART OF THE FREEDOM QUADRANGLE

Characteristic exposure of Stump sandstone

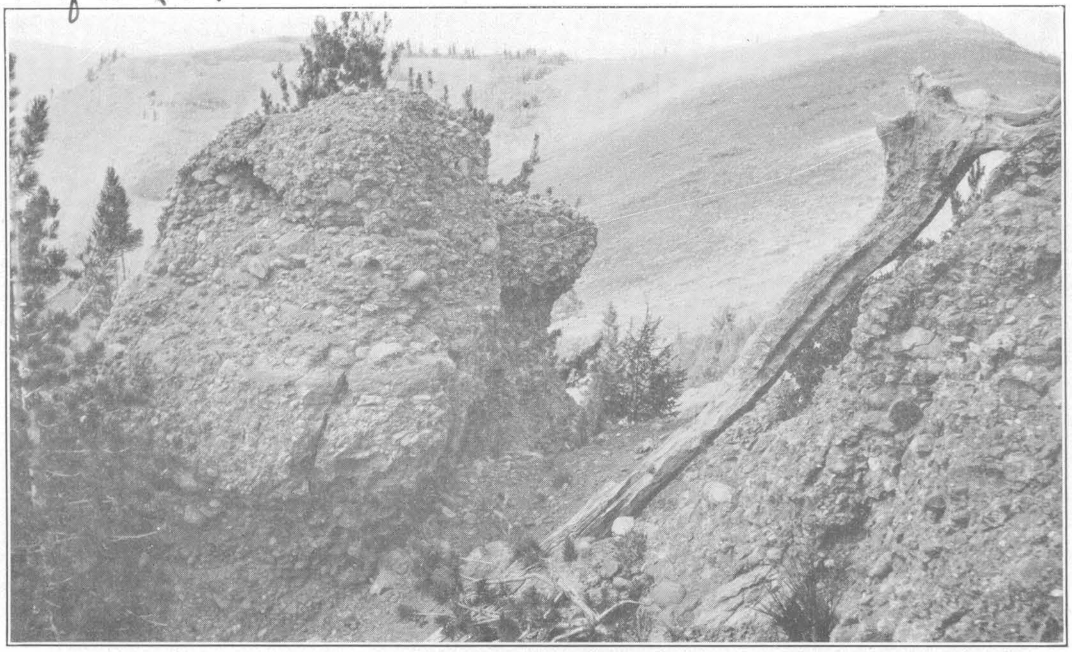
Roundy 58.



B. VIEW NORTH ALONG THE WEST FLANK OF THE CARIBOU RANGE, IN THE EAST-CENTRAL PART OF THE FREEDOM QUADRANGLE

Characteristic exposure of Peterson limestone

Mansfield. 72.

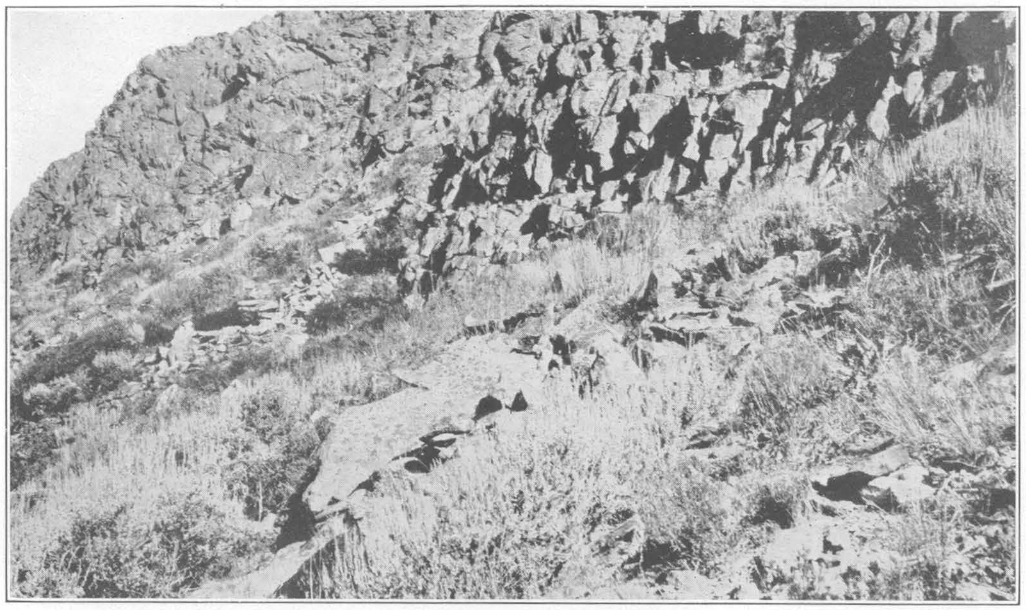


C. VIEW NORTH NEAR THE SUMMIT OF RED MOUNTAIN, IN THE NORTHEASTERN PART OF THE MONTPELIER QUADRANGLE

Characteristic exposure of Ephraim conglomerate

Mansfield 324.

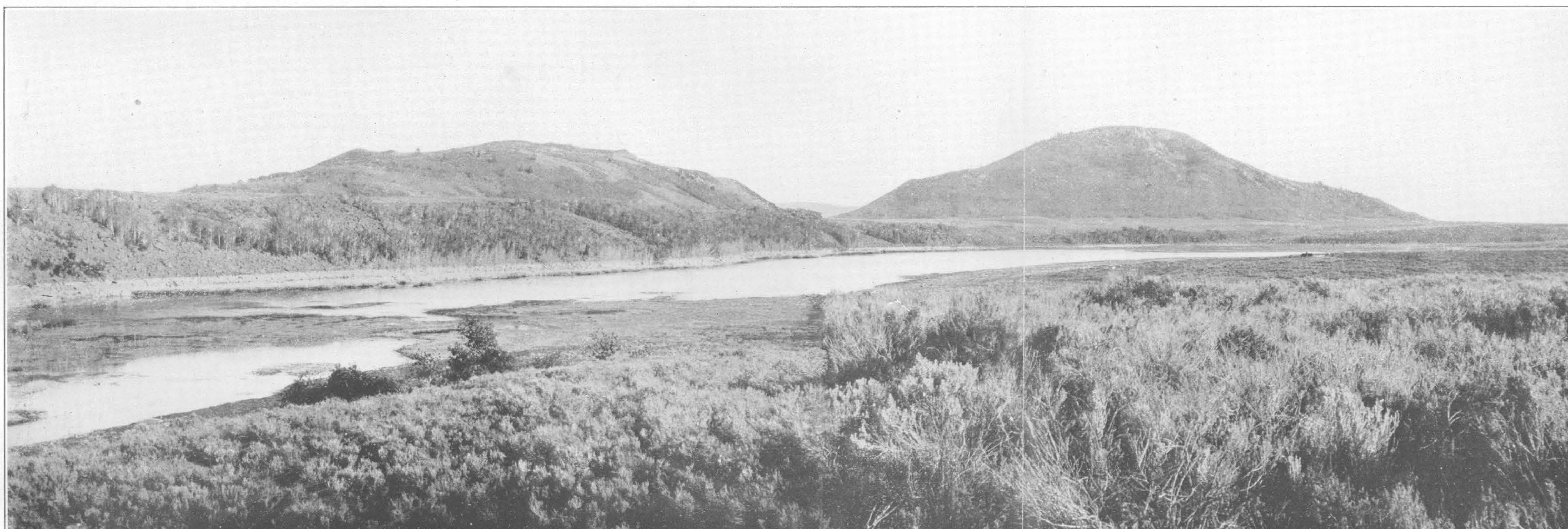
Mansfield 121.



A. CLIFF OF HORNBLENDE ANDESITE PORPHYRY ON THE SOUTHWEST SIDE OF SUGAR-LOAF MOUNTAIN, T. 2 S., R. 41 E., CRANES FLAT QUADRANGLE

B. LEDGE OF RHYOLITE ON THE NORTH SLOPE OF MIDDLE CONE, NW. ¼ SE. ¼ SEC. 7, T. 7 S., R. 42 E., HENRY QUADRANGLE

Showing inclusions of basalt

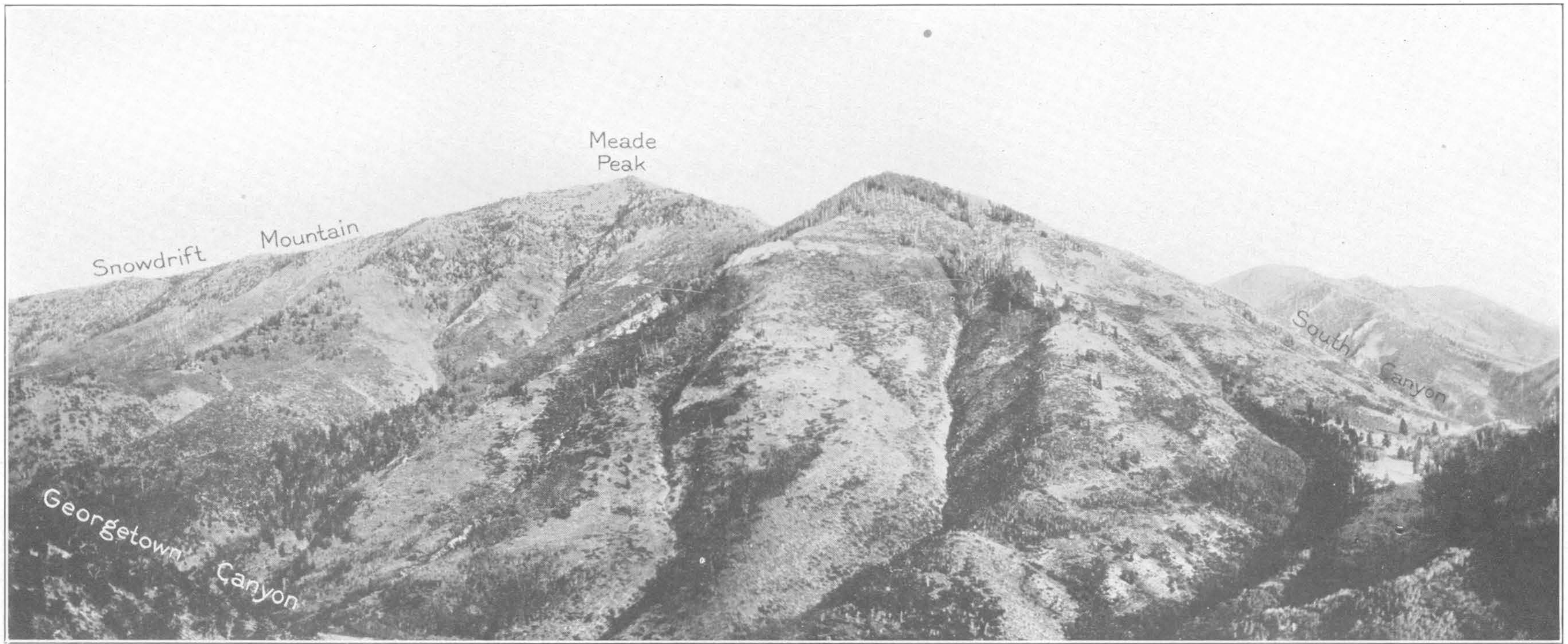


C. CHINA HAT (RIGHT), MIDDLE CONE, AND CRAG LAKE, FROM A POINT 2½ MILES NORTH OF CHINA HAT, HENRY QUADRANGLE

Note higher water marks in Crag Lake

Mansfield 288–291.

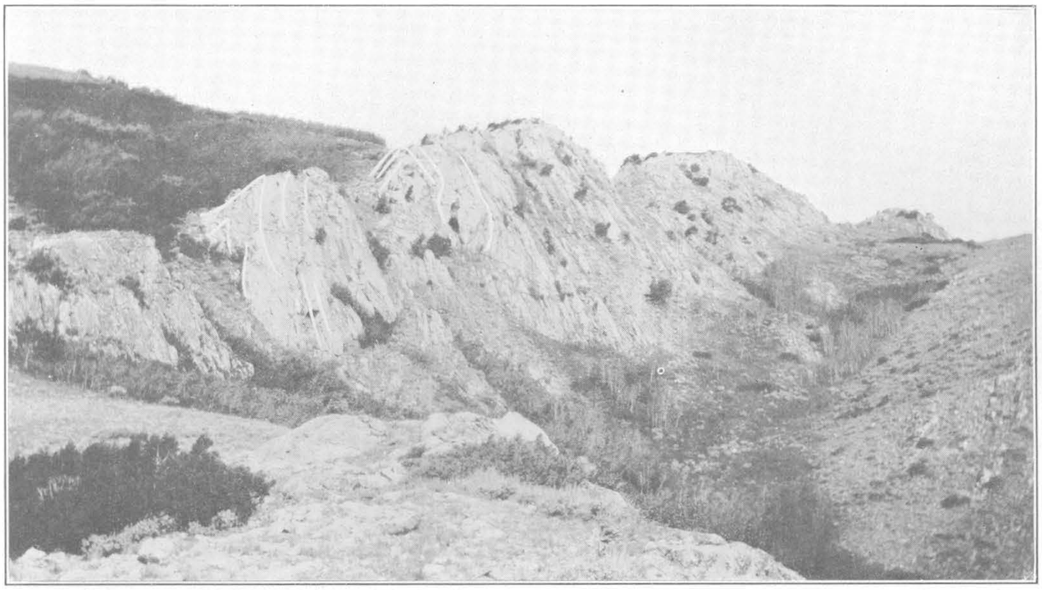
Gale 473-A and B.



SNOWDRIFT MOUNTAIN, MEADE PEAK, AND VICINITY FROM THE NORTHWEST

View across Georgetown Canyon, Crow Creek, Slug Creek, and Montpelier quadrangles

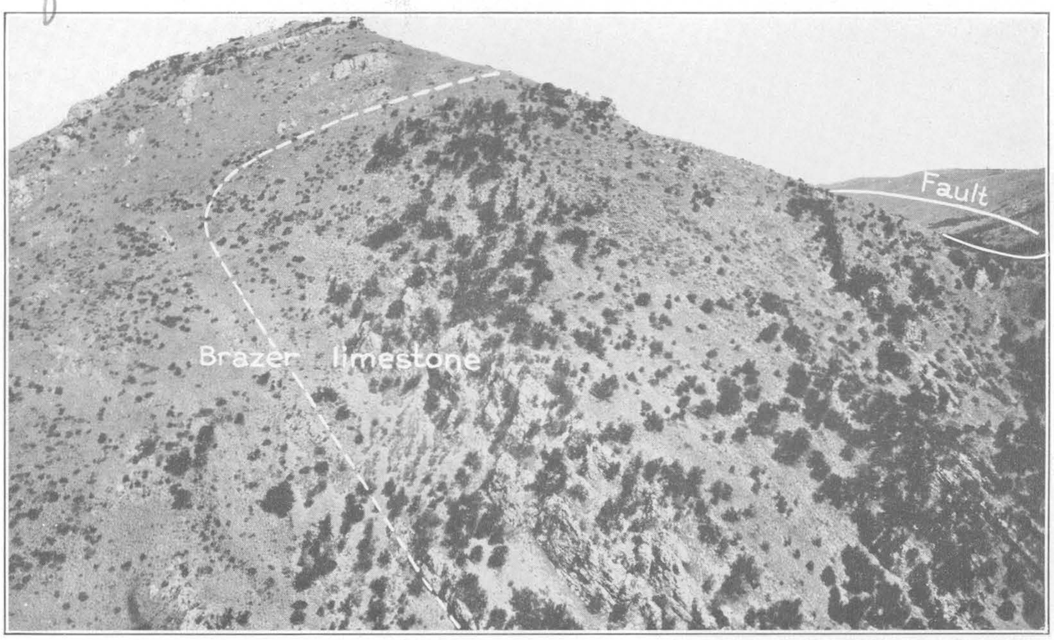
Mansfield 315.



A. LIMEROCK MOUNTAIN, CRANES FLAT QUADRANGLE

An anticlinal fold in Brazer limestone (part of the Snowdrift anticline), from the NE. ¼ sec. 12, T. 5 S., R. 41 E.

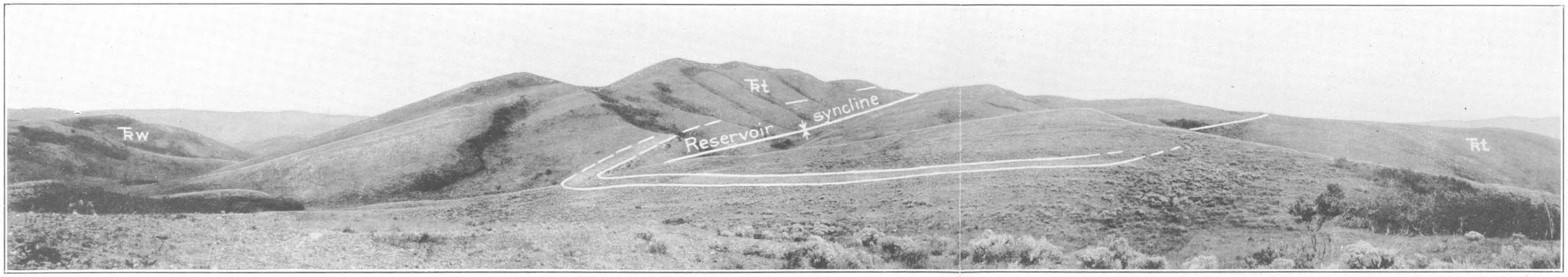
Mansfield, 12.



B. OVERTURNED FOLD AT THE MOUTH OF MIDDLE SULPHUR CANYON, NORTH SIDE, T. 9 S., R. 43 E., SLUG CREEK QUADRANGLE

Note hanging valley of Dry Fork age at extreme right

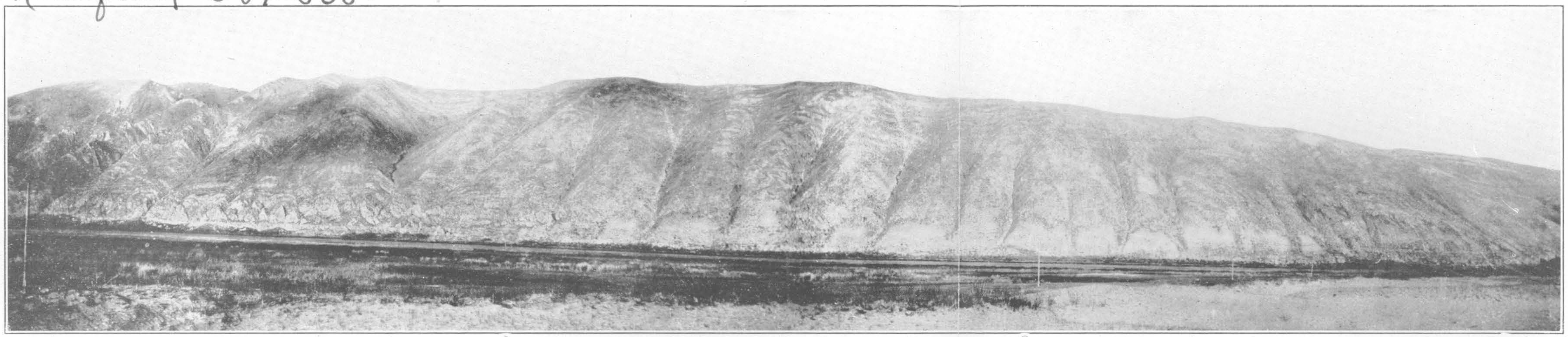
Boundy 71-74.



A. RESERVOIR MOUNTAIN, HENRY QUADRANGLE

View north and northwest from the NW. ¼ sec. 20, T. 6 S., R. 41 E. T̶R̶w, Woodside shale; T̶R̶t, Thaynes group

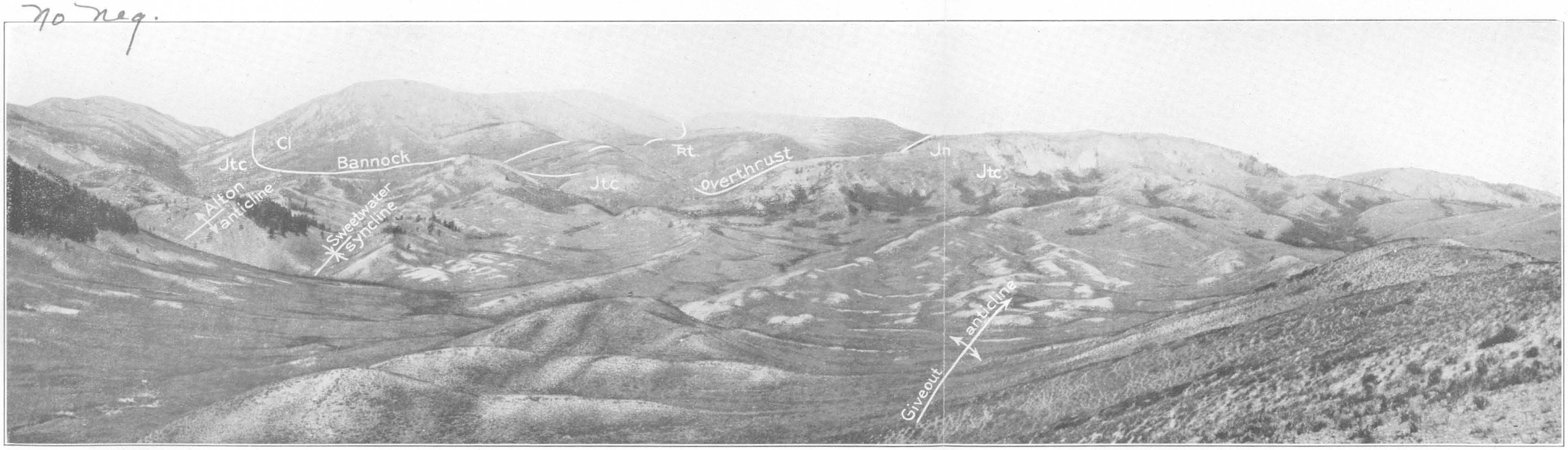
Mansfield 534-535.



B. SCARP OF THE BEAR LAKE FAULT, EAST SIDE OF BEAR LAKE VALLEY, MONTPELIER QUADRANGLE

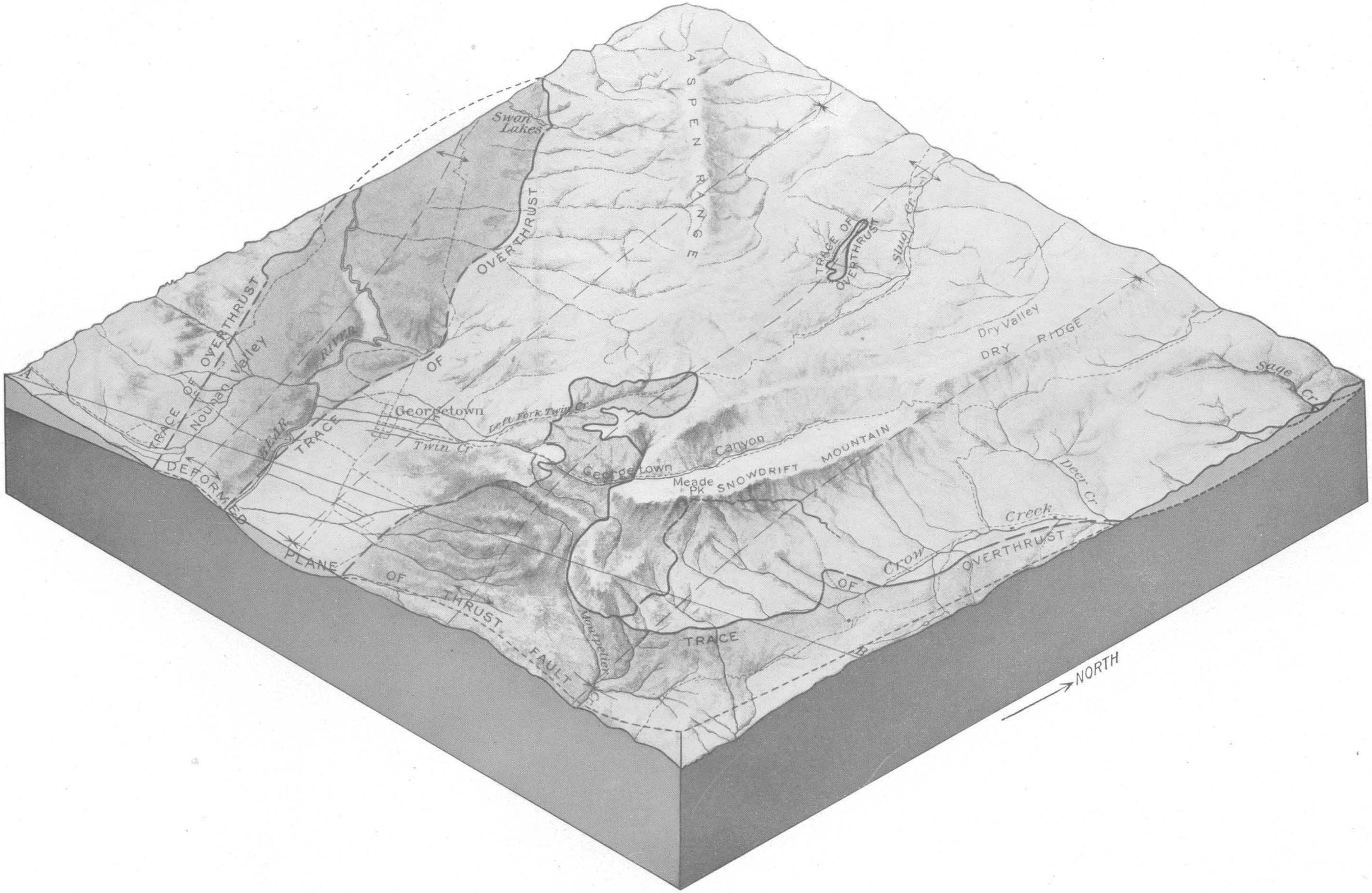
Note faceted slopes. The top of the escarpment marks the western edge of the Bear Lake Plateau

No neg.



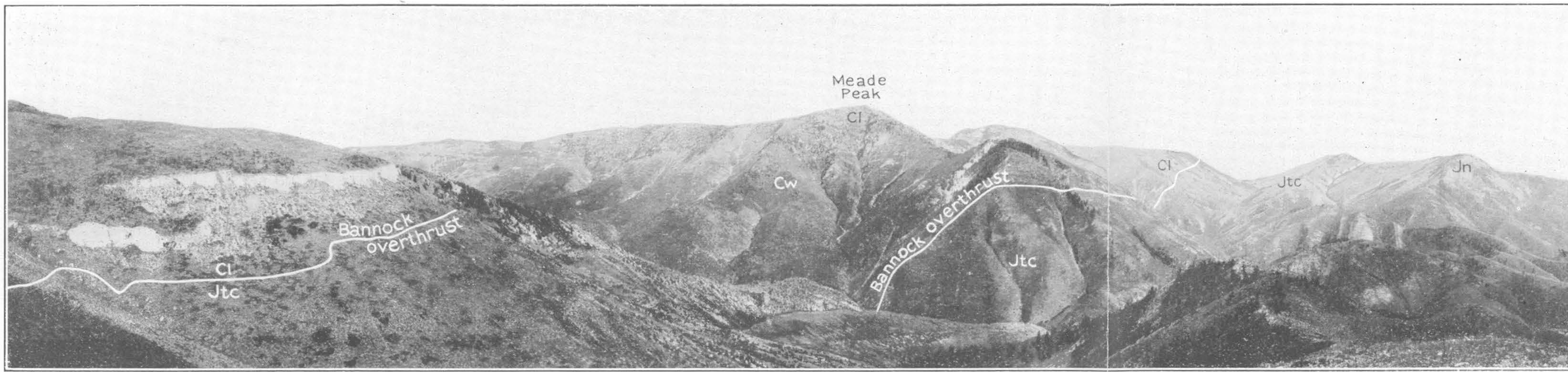
C. PANORAMA FROM POINT NEAR THE SOUTHEAST CORNER OF AREA SHOWN IN PLATE 37

Looking northwest. Shows southern tip of uneroded part of the overthrust block and position of subordinate branch fault. Cl, Carboniferous formations; T̶R̶t, Thaynes group; Jn, Nugget sandstone; Jtc, Twin Creek limestone. Syncline and anticlines of lower fault block in foreground



STEREOGRAM OF TPS. 9–11 S., RS. 43–45 E., PART OF REGION TRAVERSED BY BANNOCK OVERTHRUST

Movement was in general from west to east. Note deformation of thrust plane. *A–B*, Approximate position of line of section W–W′ shown in Plate 12



A. PANORAMA FROM SOUTHWARD-POINTING SPUR ON HILL NORTH OF GEORGETOWN CANYON

Looking northeast to south. Cl, Mississippian limestone; Cw, Wells formation; Jn, Nugget sandstone; Jtc, Twin Creek limestone

B. GEORGETOWN CANYON WHERE CROSSED BY THE BANNOCK OVERTHRUST, SLUG CREEK AND MONTPELIER QUADRANGLES

View northwest across South and Georgetown Canyons. Cl, Carboniferous limestone; Jtc, Twin Creek limestone; Jp, Preuss sandstone

A tooth and large fragments of bone of a fossil elephant were recovered from this cut reported by O. P. Hay as *Elephas columbi*. Shells from the same locality were identified by W. H. Dall as follows:

Polygyra sp., fragment.	Fluminicola nuttalliana Lea.
Unio cf. U. gibbosus Barnes; fragment.	Planorbis parvus Say.
Sphaerium sulcatum Lamarck.	Lymnaea desidiosa Say.
Sphaerium sp. indet.	Lymnaea palustris Müller; fragment.
Pisidium variable Prême.	Lymnaea sp.; young.
Valvata utahensis Call.	Lymnaea sp.; fragment.
Amnicola longinqua Gould.	Ancylus vivularis Say.
Amnicola sp.; young.	

Mr. Dall comments that some of the species listed above were described from Lake Bonneville, Utah, in Call's report on the Pleistocene shells of the lake margin, whereas others are Recent.

Shells were also collected from the spit that separates Bear Lake from Mud Lake and Dingle Swamp. Of these *Sphaerium sulcatum* Lamarck, *Carinifex newberryi* Lea, *Lymnaea apicena* Lea, and *Lymnaea emarginata* Say are reported by Mr. Dall as Recent, whereas *Amnicola longinqua* Gould and *Lymnaea bonnevillensis* Call are reported as Pleistocene.

The lake beds that represent earlier expansions of Bear Lake may, with little doubt, be referred to the Lake Bonneville epoch, or the epoch in which Lake Bonneville and other Pleistocene lakes of the Great Basin existed, as suggested by the fossils and the somewhat analogous prelacustrine and lacustrine development of Bear Lake Valley. This epoch has been correlated by Gilbert with the glacial epoch.[92] The glaciation of the western mountains appears so recent that at least the last glaciation of that region is thought not to have preceded the Wisconsin glacial stage of the interior.[93] The lake beds are separated by more or less well-defined terraces from the younger alluvial deposits, which may then be considered of Recent age.

LANDSLIDES

General features.—Two other types of débris accumulations have been differentiated, both of which are due to the action of gravity without the direct transporting agency of water. The first of these is the so-called "talus glacier." [94] This type is not strictly a landslide, but is grouped for convenience with the landslides for mapping and discussion. A "talus glacier" is the product of several processes, including (1) the passage of talus over snowbanks at the bases of cliffs; (2) the sliding, creeping, and slumping of bodies of talus, perhaps cemented by ice; and (3) incipient glacial motion. The second type is the true landslip or slide. There are many of these in certain parts of the region, and some of them have been mapped.

Distribution and character.—Only one "talus glacier" has been observed, and this is in the southwest fork of Fish Haven Canyon, in T. 16 S., R. 43 E., in the Montpelier quadrangle. There a mass of locally derived bouldery débris lies at the base of cliffs developed in the Swan Peak quartzite. The débris bears evidence of sorting and transportation through the agency of snow.

In a valley head in the northeast corner of the same quadrangle, in T. 11 S., R. 46 E., there are three distinct, parallel, moraine-like ridges which consist mainly of large subangular boulders of conglomerate and sandstone that have been derived from the Ephraim conglomerate and adjacent formations. The lowermost ridge is about 300 feet long, 25 feet high, and extends across the canyon; behind it lies a small swamp. This accumulation is apparently the result of successive landslips in the conglomerate. Small landslides were observed in the Nugget sandstone and Triassic (?) formations in a branch of Home Canyon, in secs. 29 and 20, T. 12 S., R. 45 E.

Numerous other landslides occur in the Caribou Range in the Freedom quadrangle. These landslides were not mapped in the field, but it has seemed advisable to show from data available in the office the approximate location of some of the more striking slides. Along the east side of the ridge about 1 mile northwest of Stump Peak here is a fine slide of considerable extent which is apparently composed in part at least of the Ephraim conglomerate. At the time of the writer's visit in 1915 the scarred surface from which the slide broke away appeared still fresh and was a brilliant red. The hummocky confused débris below was in part composed of the red conglomerate. Within a mile to the east of this slide there are several others in the Wayan formation that expose dark shales. The slope that descends eastward to the canyon of the South Fork of Tincup River is marked by numerous slides in the Wayan formation, some of which are of considerable extent. These slides are somewhat older than those near Stump Peak, for the scars have been softened and are more or less overgrown. Two of these slides have been indicated on the map. The larger one includes several ponds. Along Tincup Canyon there are several well-marked slides, some of which were still so fresh in 1915 as to leave steep cliff-like scars in which beds of the Wayan formation are exposed. Two of these are shown. The débris that has accumulated in all these slides consists of large and small fragments of the more massive sandstone, limestone, or conglomerate beds, mingled with shales.

On the upper slopes of China Hat in T. 7 S., Rs. 41 and 42 E., there are several flowlike areas of broken blocks of rhyolite that are probably to be interpreted as landslides, although no definite scars were recognized near the point of origin in the mass from which the débris broke away.

Age.—All the landslides observed belong to the Recent epoch. The formation of slides appears to be still in progress.

[92] Gilbert, G. K., op. cit., p. 315.

[93] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, pp. 471-472, New York, 1906.

[94] Chamberlin, T. C., and Salisbury, R. D., op. cit., p. 474.

Chapter IV. IGNEOUS ROCKS

GENERAL FEATURES

Igneous rocks do not occur in the Crow Creek and Freedom quadrangles. In the Montpelier quadrangle they are represented only by the ash bed of Jurassic age described on page 97 and in the Slug Creek quadrangle their occurrence is limited to a few small areas. They occupy, however, more than half of the Henry and Cranes Flat quadrangles and include considerable areas in the Lanes Creek quadrangle. Thus they increase in relative abundance northwestward toward Snake River. They represent chiefly, perhaps, marginal members or inflows of the great body of extrusive rocks that constitutes the so-called Snake River lava plains, but they have obviously come from local vents or fissures.

Although there is considerable variation in the physical condition and appearance of the igneous rocks they may all be referred to three groups—hornblende andesite porphyry, rhyolite, and olivine basalt. Specimens and thin sections of these rocks have been studied by E. S. Larsen, jr., and the late J. F. Hunter, to whom the writer is indebted for the petrographic descriptions given below.

HORNBLENDE ANDESITE PORPHYRY

Distribution.—In the region considered in this paper the hornblende andesite porphyry has been found only in the northeastern part of the Cranes Flat quadrangle, in secs. 26, 25, 36, and 35, T. 2 S., R. 41 E.; sec. 1, T. 3 S., R. 41 E.; sec. 6, T. 3 S., R. 42 E.; and secs. 31, 21, and 22, T. 2 S., R. 42 E.

Rocks of this type, however, are rather widely disbuted in the general region. They are known in the Portneuf quadrangle and Fort Hall Indian Reservation to the west and probably occur in regions to the north. Caribou Mountain, in T. 4 S., R. 44 E., owes its altitude (9,854 feet) to the occurrence and relative resistance to weathering of intrusive igneous rocks described by St. John [1] as gray hornblendic trachyte. The same name is applied by him to the rock at his Station XVII, now called Sugarloaf Mountain, which he regards as mineralogically identical [2] and which is here grouped with the hornblende andesite porphyry.

Mode of occurrence.—Most of the occurrences in the mapped area are dikes and perhaps some steeply inclined sills that differ in length from a few hundred feet to nearly a mile and in width from 4 feet to 20 feet or more. Sugarloaf Mountain is capped by a sill or incipient laccolith that appears to conform with the folding of the inclosing strata and has a maximum thickness of approximately 100 feet. In the Cranes Flat quadrangle the andesite is found only in association with the Homer limestone member of the Wayan formation. The rock is generally deeply weathered and at many places has disintegrated to a yellowish or greenish-yellow gravel. The sill at Sugarloaf and some of the dikes furnish massive ledges, but at many localities there is no ledge, and the position of the dike is indicated by yellow gravel and scattered pieces of weathered andesite, some of which crumble between the fingers. The sill at Sugarloaf is composed in part of relatively fresh rock, which has resisted weathering and produced the sharply featured hill that bears the name. Two or three of the dikes in sec. 36, T. 2 S., R. 41 E., are also prominent topographically. Plate 33, *A*, shows the andesite as exposed on the southwest slope of Sugarloaf Mountain.

Character.—The hornblende andesite porphyry as here exposed is a gray crystalline rock that weathers pinkish, yellowish, or greenish and is mottled with light or dark spots, which represent phenocrysts of feldspar, hornblende, or biotite. The following petrographic descriptions of several specimens are slightly modified from descriptions kindly given by Mr. Larsen.

M. 97–16; sec. 22, T. 2 S., R. 42 E. Macroscopically this specimen is a light-gray rock that shows plagioclase phenocrysts, the largest of them 1 centimeter across, prominent but smaller hornblende prisms, and a little biotite in a groundmass that has the appearance of a microgranular rock. The study of the thin section shows that the rock contains large phenocrysts of andesine and pale-green, zoned hornblende. There are a few crystals of apatite and smaller crystals of plagioclase, biotite, and iron ore in a fine groundmass that is chiefly plagioclase but that probably includes some orthoclase and quartz.

M. 98–16; sec. 22, T. 2 S., R. 42 E. The specimen was taken from a dike in the vicinity of that from which M. 97–16 came. This rock is similar except that macroscopically the hornblende is somewhat less conspicuous and there are fairly numerous biotite crystals 0.25 centimeter or more in diameter. In thin section the rock shows fewer orthoclase phenocrysts and the hornblende exhibits partial alteration to a reddish-brown product.

M. 110–16; sec. 25, T. 2 S., R. 41 E. Summit of Sugarloaf Mountain. In general appearance this rock differs from the preceding types in having no large feldspar or biotite crystals. Phenocrysts of hornblende 0.5 to 1 centimeter or more in length and locally in cruciform arrangement are conspicuous against a uniform finely crystalline gray groundmass. In thin section the rock shows little if any biotite and the groundmass is coarser than in the preceding types and contains considerable quartz and orthoclase. It might be called a hornblende-quartz latite porphyry but is not very different from M. 97–16.

M. 114–16; sec. 1, T. 3 S., R. 41 E. This rock is a dark-gray porphyry that weathers greenish or reddish and contains weathered phenocrysts and casts of hornblende and plagioclase crystals. The groundmass is fine textured and shows tiny phenocrysts of feldspar. In thin section this rock is not very different from the preceding type.

[1] St. John, Orestes, Report of the geological field work of the Teton division: U. S Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 396, 397, 1879.

[2] Idem, p. 356.

Sill at Sugarloaf.—The most noteworthy occurrence of the hornblende andesite porphyry (here almost a latite, in specimen M. 110–16) is the sill at Sugarloaf Mountain. This rock was at first considered a dike that contained limestone inclusions which formed patches along the ridge. The little knoll west of the crest and the northeastward projecting point east of the crest are occupied by andesite similar to that at the summit of the mountain but deeply weathered into rounded bouldery fragments and reddish-yellow gravel. This rock was thought to represent an earlier intrusion than the relatively fresh rock of the summit, which forms sharp angular fragments.

More extended examination northward along the ridge, however, showed fresh rock, like that of the summit, grading into the more deeply weathered variety with no line of demarkation. The andesite also passes horizontally beneath limestone and parallel to its bedding at a place where the limestone forms good ledges. On the east and west slopes of the ridge the contact of the andesite is steep and apparently conforms with the bedding. The crest at the summit is composed of horizontally and vertically jointed andesite that suggests horizontal position and forms a steep westward-facing cliff. (See pl. 33, *A*.) Thus it appears that the andesite probably represents a single intrusion in the form of a sill, curved and thickened where it forms the summit of the mountain. St. John describes it as wedge-shaped (see p. 126), but in cross sections it is probably shaped more like an unsymmetrical crescent. The limestone patches, which at one locality have a faintly synclinal structure, thus represent remnants of an overlying limestone bed. The facts that the andesite shows no shearing and that the minerals in thin section show no strain indicate that the rock was not folded after its intrusion but that it either followed structure lines already established or itself participated in the deformation of the associated strata.

Relative age.—The relations of the hornblende andesite porphyry to the sedimentary rocks have already been mentioned. In this region this porphyry has been found in contact with only two formations. In the Cranes Flat quadrangle it is associated with the Homer limestone member of the Wayan formation, and in T. 5 S., R. 40 E., it is intruded into the phosphatic shales of the Phosphoria formation. Its deeply weathered condition shows that it is probably older than the other igneous types, none of which shows so much alteration. Differences in weathering, however, are dependent upon so many variable factors that they may prove deceptive as guides to the relative ages of igneous rocks. Hence not too much confidence should be placed in this type of evidence. In the Fort Hall Indian Reservation andesitic tuffs of somewhat different composition from the andesites here described are locally overlain by rhyolite. The andesites of this region show some differences in age, for in sec. 22, T. 2 S., R. 42 E., the dikes that bear biotite in noteworthy amounts appear to cut the more hornblendic dikes, though contacts are not well defined because of weathering. The extensively weathered condition of both sets suggests that the difference in age is not great and that in all probability the andesites of this district all belong to a single epoch of igneous activity.

RHYOLITE

Distribution.—The rhyolites of the district studied are confined to the Henry and Cranes Flat quadrangles and to parts of the Portneuf quadrangle. In the Henry quadrangle the exposures include only the three large hills in the northwestern part of T. 7 S., R. 42 E., the largest of which is known as China Hat, and two islands in the Blackfoot River Reservoir, in the northeastern part of T. 6 S., R. 41 E.

In the Cranes Flat quadrangle the rhyolite occupies three areas in the southwestern part of T. 4 S., R. 42 E., the largest of which includes an area of nearly 2 square miles. In the northwestern part of the quadrangle, on and near the north boundary, occur two other areas of mappable size, the larger in secs. 13 and 14, T. 2 S., R. 40 E., which occupies nearly half a square mile in the quadrangle and extends northward. Two minor occurrences are noteworthy, one near the center of T. 4 S., R. 42 E., about 100 feet vertically below the crest, on the steep east-facing slope of the high ridge. Here many weathered fragments of fine-textured rhyolitic rock occur in the Preuss sandstone near its contact with the Stump sandstone, as if remnants of a dike. The other locality is in the mouth of the small valley that heads against Meadow Creek Mountain, in the NW. ¼ sec. 34, T. 4 S., R. 41 E. Here fragments of a brown-weathering, white rhyolitic rock from an unknown source were found in the dry stream bed. The occurrences in the Portneuf quadrangle are shown on the map accompanying the description of T. 5 S., R. 40 E. (pl. 43).

Mode of occurrence.—The rhyolite occurs in the form of cones, flows, and dikes(?). There are also beds of rhyolitic ash.

The cones are the three prominent hills called respectively China Hat and Middle and North Cones, which stand south of the Blackfoot River Reservoir in T. 7 S., Rs. 41 and 42 E., and the islands in secs. 11 and 14, T. 6 S., R. 41 E., in the Henry quadrangle. The cones are built of pumiceous, glassy, and perlitic rhyolite, locally like obsidian, not generally distinguishable as separate flows. The greater weathering of some parts of the lava and the relative freshness of other parts, though the rocks concerned are essentially of the same character, indicate that the cones represent a succession of eruptions rather than the products of single volcanic outbursts. China Hat, the largest cone (see pl. 33, *C*), has a relatively fresh steep marginal part, which incloses a more weathered and more gently sloping higher part. Several rock slides that resemble flows, two of which have been mapped, occur in the older part. They are composed of rough blocks of rock in which the flow structure may readily be distinguished.

The cones have no well-defined craters, but the upper parts of Middle and North Cones are relatively flat or gently sloping and are surmounted by numerous conical knobs or monticules, suggestive of minor eruptions. These knobs consist of broken masses of lava, in which flow structures are well developed, but they show no clear radial arrangement. The grouping of these knobs locally produces depressions suggestive of faint craters of which the knobs would form parts of the rims. At least four such depressions were noted in North Cone, in sec. 8, T. 7 S., R. 42 E. Middle Cone, which shows characteristics similar to those just noted, is shown in Plate 33, *C*.

The most prominent flows are the larger occurrences in the Cranes Flat quadrangle. The rhyolite is of the same general character as the rock that makes the cones, but at these localities the lava has been poured out on the flanks of existing hills in the sedimentary rocks and has not heaped up sufficiently to form cones. The group of hills in secs. 19 and 30 (undesignated), T. 4 S., R. 42 E., may represent a broad, flat dome or cone of rhyolite partly dissected.

The fragments of rhyolite previously noted near the contact of the Preuss and Stump sandstones in the central part of T. 4 S., R. 42 E., probably represent a small weathered dike of rhyolite. The float fragments in sec. 34, T. 4 S., R. 41 E., may indicate the presence of an unrecognized small dike in Meadow Creek Mountain. No other dikes of rhyolite have been found.

The bed of volcanic ash noted in the Twin Creek limestone in the Montpelier quadrangle is apparently rhyolitic. A bed of indurated rhyolitic or latitic ash occurs in the Wayan formation at several localities. A bed of rhyolitic ash also occurs in a locality in sec. 1, T. 11 S., R. 43 E., Slug Creek quadrangle, associated with Pliocene (?) deposits. Whether this bed has any relation to the rhyolites of the China Hat and Cranes Flat region farther north is not known. It may perhaps antedate these eruptions. A cut in the bank of Blackfoot River east of China Hat in 1912 exposed the section shown in Table 30.

TABLE 30.—*Section of west bank of Blackfoot River in NE. ¼ sec. 16, T. 7 S., R. 42 E., Idaho*

	Ft.	in.
1. Soil at top of section about	2	
2. Volcanic ash, white, horizontal beds, fine-textured	13	
3. Volcanic ash, dark, with fragments of basalt as much as 3 inches in diameter	1	6
4. Volcanic ash, white, like bed No. 2, to water level	13	6
	30	

The section exposed in a well dug by Pat Griffin in the NW. ¼ sec. 18, T. 7 S., R. 42 E., is shown in Table 31.

TABLE 31.—*Section in Pat Griffin's well, in the NW. ¼ sec. 18, T. 7 S., R. 42 E., Idaho*

[Measured in June, 1916]

	Feet
Soil, drab, clayey; about	25
White sand, rhyolitic	3
Basaltic débris, dark, ferruginous; about	15
Basalt, bottom of well; no water.	
	43

Considerable rhyolitic débris is mingled with basaltic and some sedimentary material in the vicinity of North Cone, in sec. 8, T. 7 S., R. 42 E. Rhyolitic débris may also constitute the white material exposed by the lowering of the waters since 1914 on the south side of the long point in secs. 34 and 27, T. 5 S., R. 41 E. (not visited). It has not been practicable to map these ash beds, but probably they are concealed at many places in the general area mapped as basalt in the region west and south of the Blackfoot River Reservoir.

Character.—The acidic lavas, as described by Mr. Larsen, show little variation and probably represent closely related flows. The chief differences are textural.

They are nearly white to pale quaker-drab, pink, gray, or even dark, rather porous fluidal rhyolites, which include a few crystals of quartz and orthoclase and a little plagioclase. They carry also a very little biotite, which is partly altered, zircon, apatite, and iron ore. In some specimens the groundmass is a perlitic or streaked glass, in others it is composed of beautiful coarse spherulites. These spherulites are commonly made up of concentric layers with gas cavities between some of the layers. Spherulites of a fibrous, very weakly birefracting zeolite with an index of refraction of about 1.485 are abundant in these cavities (R. 69–16; sec. 29, T. 4 S., R. 42 E.). In some specimens the spherulites are embedded in glass. In others (R. 36–16; NE. ¼ sec. 14, T. 6 S., R. 41 E.) the spherulites are made up of very coarse fibers, and these appear to grade into rude phenocrysts of micrographic intergrowths of quartz and orthoclase. The spherulitic varieties disintegrate rather readily into gravel. Tridymite, or a mineral that resembles it under the microscope, is abundant in some of the rocks.

One specimen, M. 337c–12, described by Mr. Hunter, deserves special mention. It represents an acid inclusion in basalt that is exposed on the northwest side of the pond, in the SE. ¼ sec. 7, T. 7 S., R. 42 E. This rock is light in color, rather dense and aphanitic, save for a few minute phenocrysts. When studied microscopically it is found to be hypocrystalline, porphyritic, and perpatic. The phenocrysts are as a rule euhedral and the largest of them are a millimeter across. In order of decreasing abundance, they consist of orthoclase, plagioclase (of the approximate composition of albite), quartz, augite, and biotite. The groundmass is composed chiefly of glass, feldspar, quartz, augite, biotite, and magnetite. The amount of augite in the rock is noteworthy.

Thickness.—The thickness of the rhyolite has not been determined. Owing to the local character of the occurrences the thickness probably differs considerably from place to place. In section 30 (undesignated), T. 4 S., R. 42 E., canyons have been excavated more than 200 feet without cutting through it. The mass of the rhyolite in the three cones south of the Blackfoot River Reservoir is doubtless considerably greater than now appears, for their lower parts are concealed by basalt to an unknown depth, and by ash deposits and soil.

Relative age.—The rhyolitic hills south of the Blackfoot River Reservoir are surrounded by basalt, which is thus younger than much of the rhyolite. Similar evidence is furnished by basalt that contains inclusions of rhyolite at locality M. 337c–12 noted above. On the other hand, a ledge of rhyolite about 500 feet south of the center of the same section on the north slope of Middle Cone contains inclusions of basalt as much as 6 to 8 inches in length and 2 to 4 inches in width and thickness. (See pl. 33, *B*.) Thus some of the rhyolite is younger than some of the basalt. Similar evidence is borne by the occurrence in the section given in Table 31 of rhyolitic ash above the basalt. The basalt débris between rhyolitic ash beds in the Blackfoot River section (see Table 30) may indicate that a minor basaltic eruption took place between two rhyolitic eruptions. But it may indicate only the washing in from local sources, possibly to the east, of a thin bed of basaltic material during the general epoch of the rhyolitic eruptions. The difference in the character of the two sections, which are only about 2½ miles apart, shows that local conditions varied considerably within short distances. This subject will be further discussed under the heading, "Epochs of igneous activity." (See pp. 123 to 125.)

OLIVINE BASALT

Distribution.—The olivine basalt is the most widely distributed of the igneous rocks of the region. In the Slug Creek quadrangle a basaltic patch that occupies about 1½ square miles lies in the upper valley of Slug Creek on the line between Tps. 9 and 10 S., R. 44 E. In the SW. ¼ sec. 11 (unsurveyed), T. 10 S., R. 44 E., a group of basaltic boulders suggests a small flow or possibly a dike. Basaltic boulders in the midst of Eocene conglomerate in sec. 24, T. 10 S., R. 43 E., as already noted, probably represent a small extrusion.

The Lanes Creek quadrangle contains a number of separated areas of basalt that have been poured out from local sources. Some of these basaltic masses, such as those of Enoch Valley and the Little Blackfoot, Lanes Creek, and the Upper Valley may be connected under cover, but this condition can not safely be assumed. The Little Blackfoot mass does connect with the larger masses to the west. The larger bodies of basalt within the quadrangle are those of Lanes and Chippy Creeks and the area in the northwestern part which extends westward into the Henry quadrangle.

The Henry quadrangle is underlain in large part by basalt, which like a somber sea embays or separates mountainous sedimentary masses near the east and west borders of the quadrangle and surrounds the three rhyolite hills south of the Blackfoot River Reservoir. The basalt is partially overspread in some places by hill wash and alluvium and elsewhere by soil and deposits of basaltic and rhyolitic ash. Locally these deposits are 40 feet or more thick, as shown in Tables 30 and 31. They are particularly thick in districts south and west of the reservoir. The outcrops of the basalt, however, are so numerous and so well distributed as to leave no reasonable doubt of the continuity of the rock mass. Hence that district is all mapped as basalt. In Corral Creek and Meadow Creek, on the other hand, the concealed areas are so continuous and extensive that it appears advisable to map the surface deposits, though in all probability the basalt passes beneath them. The islands in secs. 23 and 24, T. 6 S., R. 41 E., are composed of basalt and a new island in sec. 13, produced by lowering the level of the reservoir since the topographic map was completed, in 1914, is also composed of basalt.

More than half of the Cranes Flat quadrangle is underlain by basalt, which is distributed in much the same way as in the Henry quadrangle. Wilson Ridge projects like a promontory into the basaltic area that extends from the Blackfoot River Reservoir and from Meadow Creek northwestward through the quadrangle. Connection is made eastward from the head of Meadow Creek with the basaltic area that occupies the hills north of Little Valley and descends to the plain of Grays Lake outlet. Thus the basalt forms two great areas nearly separated by the high sedimentary ridge that extends northwestward through the center of the quadrangle.

Mode of occurrence.—The basalt occurs in four general forms—flows, cones or craters, dikes, and ash beds.

The great body of the basaltic rocks of the region occurs in the form of flows. With a few minor exceptions it has not been practicable to map individual flows, but in any considerable exposed section of the basalt it is usually apparent that more than one flow is represented.

Two wells drilled by A. G. Kugler, 2 or 3 miles southeast of Soda Springs, show basalt flows and intervening sedimentary deposits, as indicated in Tables 32 and 33.

TABLE 32.—*Section of well in NE. ¼ NW. ¼ sec. 22, T. 9 S., R. 42 E.*

	Feet
Alluvium, light-colored soil, and sand and gravel	45
Basalt	17
Alluvium, light colored	48
Basalt	65
	175

TABLE 33.—*Section of well in sec. 20, T. 9 S., R. 42 E.*

	Feet
Basalt	110
Shale, carbonaceous	4
Clay, white (travertine?)	10
Basalt	4
Sand, yellow	16
	144

In several wells drilled in the Blackfoot lava field layers of red cinders were encountered between layers of basalt.

In most places, however, nothing intervenes between the flows; their distinction is made on textural differences, which in turn have induced differences in weathering. Thus cliffs of massive basalt 10 to 20 feet high are locally separated by thin, platy basalt more or less concealed by blocky talus. The middle parts of a flow are coarser textured, the lower and upper parts fine textured, and the upper parts more vesicular. The basalt has the characteristic columnar jointing, and the individual columns at many places are cross-jointed in such manner as to produce here and there on weathering the appearance of ball and socket arrangement. Some of these structural features of the basalt are shown in Plates 14, *C;* 18, *B;* 57, *A;* and 61, *B*. The number of flows recognized in any one vertical section is generally not more than two or three, but the margins of flows form low cliffs on the broad basaltic areas, so that from favorable points of view the flows resemble dark waves like those which are formed on a smaller scale by successive sheets of water poured upon a surface and then frozen.

The basalt flows in the main occupy broad valley areas, as in the region of Chippy and Lanes Creeks in the Lanes Creek quadrangle and the region of Grays Lake Outlet, Cranes Flat, and the Blackfoot River Reservoir. Locally, as east and north of the reservoir in T. 6 S., R. 42 E., and T. 4 S., R. 40 E., these accumulations form relatively high lands that have undulating surfaces or faint or well-defined ridges. Prominent ridges occur in the southwestern part of T. 3 S., R. 42 E., and west of Cranes Flat. Flows of basalt form the large cones that are described below. In the Little Valley Hills in T. 4 S., R. 42 E., the basalt has formed large masses on the top of the high ridge composed of sedimentary rocks which traverses the Cranes Flat quadrangle. The lava descends to the valley on each side but more largely to the east. In the northwestern part of the Lanes Creek quadrangle the basalt has burst forth at altitudes of 7,250 feet or more from the west flank of the great limestone ridge of that region. Another high-level occurrence is found in the northern tip of the Aspen Range in the Henry quadrangle. There the summit (altitude, 7,250 feet) in the NW ¼ sec. 35, T. 7 S., R. 42 E., is capped by basalt. Small flows have broken out at various places and at different elevations. Two of these flows may be mentioned—one a tiny flow in the SW ¼ sec. 7, T. 7 S., R. 42 E., on the northwest flank of Middle Cone, in the Henry quadrangle, and the other in the SW ¼ sec. 36, T. 4 S., R. 41 E., on the north slope of Limerock Mountain, in the Cranes Flat quadrangle.

The topographic aspects of the basalt are discussed on pages 35 to 37.

Here and there over the dark lava fields rise cones that range in area from a few acres to perhaps 10 or 12 square miles. To some extent they are composed of flows or accompanied by them, but their more conspicuous features are cinder cones made up of basaltic fragments generally deep red and ranging in size from buckshot to masses several feet in diameter. Some of the fragments are dense and have a ropy appearance and well-marked flow structure, others are highly vesicular, and still others have the characteristic "bread-crust" structure of volcanic bombs. Generally a crater is present, but locally it has been breached, in some cones by explosion and in others by erosion. In many of the cones no definite structure was observed, but in others the mass is composed largely of reddish, frothy, or scoriaceous lava, more or less broken into great blocks that exhibit a well-marked flow structure, which dips away from the vent or crater at angles locally as high as 30° or more. An apparent exception to the last statement occurs in sec. 16, T. 6 S., R. 41 E., Henry quadrangle. Here beds of scoriaceous lava on three sides dip toward a crateriform depression and are concealed on the fourth side. On the east side of this depression the westward-dipping beds are terminated as if by an explosive breach, and the inclined beds form the west rim of a crater that has largely been blown away. The north and west sides are less clearly developed, but are probably to be explained in a similar way, so that the depression above described is in all probability merely an unfilled area between neighboring breached craters. The most symmetrical cone and the one with the most complete crater is located in the SE. ¼ sec. 34, T. 6 S., R. 41 E., in the Henry quadrangle and is called Little Crater. It rises about 200 feet above its base, which is approximately 1,200 feet in diameter and has a crater about 200 feet across and 20 feet or more deep. The cone rises above a broad arched flow that has a general northward trend and is surrounded by lava. The eruption of the cone appears to have preceded the outflow of at least part of the lava, for no ejecta were seen on the lava beyond the limits of the cone, such as might have been expected if the uppermost layers had assumed their place before its eruption. A small flow has issued from its northeast base.

A group of two similar cinder cones occupies an area of nearly half a square mile in the SE. ¼ sec. 9, T. 7 S., R. 41 E., and adjacent territory. The large crater on the east called Broken Crater has been breached on the south side, probably by an explosion, and a flow descends northward from the region between the two craters. The group is surrounded by basalt, except that on a low point on the northeast side red scoriaceous material like that of the cones extends for perhaps 300 yards from the base. Other cones or groups of cones occur in this vicinity and also in the vicinity of China Hat. The island in sec. 24, T. 6 S., R. 41 E., forms part of a similar cone. The group in sec. 16 of the same township has already been described. It is accompanied by a flow and forms an eastward projection from Reservoir Mountain. A similar crater with lava flow in the SE. ¼ sec. 21, T. 5 S., R. 42 E., occupies a low shoulder of Pelican Ridge.

The cones thus far described consist chiefly of volcanic ejecta and do not themselves appear to be the source of much lava but rather to represent places where explosive activity was localized, possibly along concealed fissures. Some of them may be only large sputter cones.

There are, however, two large lava cones, each surmounted by one or more cinder cones with craters. One of these cones called Crater Mountain has developed about the vent represented by the largest cone of the district, in sec. 14, T. 5 S., R. 41 E. This cone is composed of reddish and bluish black frothy lava. It is about 3,000 feet in diameter at the base and rises more than 300 feet. The sides are relatively steep. The crater is about 1,700 feet in diameter and has a maximum depth of about 150 feet. The rim is uneven and is marked by hills composed of scoria or bodies of denser lava 50 to 100 feet high. From beneath this surmounting cone the lava slopes away on all sides but particularly to the south, west, and north. Eastward it abuts against a high limestone ridge and makes its way through the neighboring gap for nearly a mile. The whole accumulation covers an area of nearly 10 square miles, and its summit rises about 900 feet above the surface of the reservoir.

The other large cone forms much of the mass known as Sheep Mountain in the northwestern part of the Cranes Flat quadrangle. The summit of the mountain is part of a low cinder cone, about 1,800 by 1,000 feet at the base, breached on the south and located on the eastern part of the rim of an earlier, larger, shallow crater with flat floor, nearly half a mile in diameter. A small knob about 1,300 feet northwest of the summit represents part of the rim of another crater that is smaller and breached on the north. The lava slopes away steeply to the north and more gently to the northwest, west, and south. The nature of the long ridge about a mile south of the summit of Sheep Mountain suggests that lava may have flowed from a fissure in that locality as well as from the vent that is indicated by the craters at the summit. The lava cone can not be delimited with any precision, but it appears to include most of the area from the summit to the canyon of Cranes Creek and northward along the quadrangle boundary to the lower part of Long Valley, which lies between flows that are apparently derived from Sheep Mountain and from hills to the north. The area thus outlined is approximately 12 square miles.

The scoriaceous and cindery cones are differentiated on the maps as basic vents, but the lava is mostly included with the basalt.

In the southern part of sec. 3, T. 8 S., R. 42 E., in the Henry quadrangle, a basic dike lies along a fault that separates the Woodside and Wells formations. The rock is a dark lava, vesicular in places and not thoroughly crystalline, a typical basalt like that which constitutes the flows elsewhere. The dike enters the quadrangle from the south and has a total length of nearly a mile. In a knoll in the SW. ¼ NE. ¼ sec. 10 the dike is apparently inclined eastward about 30°, but its course along the side hill suggests instead a rather steep westerly dip.

In T. 6 S., R. 41 E., in the Henry quadrangle, a bifurcating basaltic dike extends southward into sec. 21 from the cones that occupy the east half of sec. 16. The dike cuts steeply dipping beds of the Thaynes group but has produced no noteworthy alterations in them.

A bed of basaltic ash mingled with some sedimentary material occurs in the basaltic hills of secs. 10 and 3, T. 7 S., R. 42 E., in the Henry quadrangle. A bed that is probably the same appears in the SW. ¼ sec. 33, T. 6 S., R. 42 E., and continues northward into sec. 28. The connection between the two parts is concealed by soil. The ash is a brownish-gray rather friable rock with basaltic lapilli, yellow-weathered pumiceous fragments, and small rounded and angular pebbles of quartzite and chert in a somewhat earthy matrix, rudely bedded. A few of the quartzite pebbles are as much as 5 inches in diameter, but most of them do not exceed 1 or 2 inches. The bed is apparently horizontal or nearly so and is poorly exposed. Its thickness probably does not exceed 10 to 20 feet.

In the Blackfoot River section (see Table 30) a basaltic ash bed 18 inches thick is exposed, and Griffins well (see Table 31) contains 10 feet of basaltic material. The well is close to a small cinder cone and probably penetrates the outer edge of the basal part of it.

Character.—The cinder cones, though widely scattered, show a close correspondence in the general character of their component rocks.

These rocks are dark red-brown to dark gray. Most of them are highly scoriaceous and show few phenocrysts in the hand specimen. The microscope shows that the phenocrysts, which are chiefly olivine and feldspar together with a little augite and magnetite, compose from a very small proportion to about half the rock. The groundmass is very fine and partly glassy to distinctly crystalline and is made up chiefly of augite, feldspar, olivine, and magnetite, together with some apatite and hematite. A few erratic phenocrysts of resorbed quartz are present in specimens M 50–16, from the SE. ¼ SW. ¼ sec. 21, T. 5 S., R. 42 E., and R. 2–16, from the NE. ¼ SE. ¼ sec. 24, T. 7 S., R. 41 E., both in the Henry quadrangle. The rocks are rather fresh, except that the olivine is in part altered to iddingsite and secondary analcite is present in the vesicles of some of the specimens.

R. 22–16, from the NW. ¼ SW. ¼ sec. 7, T. 7 S., R. 42 E., is a specimen of olivine basalt not very different from some of the basalts above mentioned.

Specimens have been collected from the basalt flows in many parts of the district, and some of these specimens are described below. The first three enumerated come from the Lanes Creek quadrangle.

Specimens M. 214–12, from the SE. ¼ NE. ¼ sec. 9, T. 7 S., R. 44 E., and R. 258–12, from the SE. ¼ SW. ¼ sec. 32, T. 6 S., R. 44 E., were described by J. F. Hunter. These rocks are aphanitic and vesicular basalts. In section they are hypocrystalline, subophitic, and somewhat porphyritic, showing a few scattered phenocrysts of plagioclase, olivine, and augite. These phenocrysts are but little larger than the individuals of the groundmass. The groundmass is made up chiefly of laths of plagioclase, irregular grains of augite, olivine, magnetite, and a small amount of glass. The plagioclase has the approximate composition of labradorite.

Specimen M. 263–12, from the SW. ¼ sec. 21, T. 6 S., R. 43 E., was described by J. F. Hunter. This rock is very vesicular, dark, and aphanitic. With the aid of the microscope it is found to be nearly holocrystalline and ophitic, with a slightly porphyritic tendency. Euhedral phenocrysts of labradorite and olivine occur in a groundmass composed of laths of plagioclase in a matrix of augite, olivine, and magnetite. The rock is similar to M. 214–12 and R. 258–12, but is coarser and contains more olivine.

The other specimens are from the Cranes Flat and Henry quadrangles and are described by Mr. Larsen.

Specimens M. 33–16, from the NE. ¼ sec. 25, T. 4 S., R. 40 E., and R. 95–16, from the SE. ¼ sec. 13, T. 2 S., R. 40 E., are much alike. They are gray rocks with some small vesicles and have the appearance of rather coarse diabases. Crystals of feldspar, olivine, and augite are visible with a pocket lens. The microscope shows that the rocks are diabasic in texture and that they are made up of calcic labradorite laths, olivine crystals, interstitial augite, and a little groundmass, apatite, and iron ore. The groundmass is a glass filled with skeleton crystals. A small amount of analcite is in the vesicles. The olivine is partly altered to iddingsite.

Specimens M. 80–16, from sec. 3 (undesignated), T. 4 S., R. 42 E.; R. 8–16, from SE. ¼ sec. 16, T. 7 S., R. 41 E.; and R. 54–16, from SW. ¼ sec. 36, T. 4 S., R. 41 E., are very similar, but they are porphyritic in texture and have a rather fine-textured groundmass.

Specimen R. 85–16, from SW. ¼ sec. 13, T. 2 S., R. 41 E. is a fine, even-grained basalt.

Specimen M. 525 D–10, from NE. ¼ sec. 10, T. 8 S., R. 42 E., is very fine textured but is otherwise similar. It represents the large basaltic dike.

All the basalts of the region apparently contain olivine and may be classed as olivine basalts. There are, however, many differences in color and texture, particularly between the basalts that compose the cones and those that constitute the flows. An interesting feature is the presence of phenocrysts of resorbed quartz at locality M. 50–16, described above, and the occurrence at the same locality of scattering phenocrysts of feldspar as much as three-fourths inch in length and one-fourth inch in width and thickness.

It is worthy of note that specimen R. 22–16, which represents a basic inclusion in the rhyolite at the north base of the middle cone in the Henry quadrangle, and specimen M. 525–10, from the dike in the southeastern part of that quadrangle, are both olivine basalts similar to the other basalts of the region.

All the basalts are relatively fresh. Mechanical disintegration through the agency of frost and changes of temperature has occurred locally and has given rise to rough blocky talus slopes at the base of cliffs along some of the canyons, as shown in Plates 14, *C*, and 61, *B*. The steep fronts of some of the flows are formed of rough blocks, which have doubtless been disintegrated to some extent by the same agencies. A typical lava wall, the origin of which is discussed on page 168, is shown in Plate 57, *A*.

Chemical disintegration has produced little effect. The red color of the scoria is probably in part at least original. The alteration of some of the olivine to iddingsite and the development of analcite in vesicles, as described above, together with the formation of white calcareous coatings in favorable places and the local development of brown-weathered surfaces, are the principal chemical alterations to be noted. The soils above the basalt are not residual, so far as observed, but represent finely divided particles of drab clayey material so arranged as to suggest wind-blown dust. Locally the basalt is overlain by rhyolitic ash, hill wash, or alluvium.

Thickness.—The thickness of the basalt doubtless differs considerably from place to place, especially where it was outpoured over higher ground, from which it would tend to run off. In the broad valleys, however, greater uniformity in thickness and greater thickness may be expected. The lowest altitude thus far observed is in a well in the NW. ¼ NE. ¼ sec. 30, T. 7 S., R. 42 E., in the Henry quadrangle. Beneath about

12 feet of soil in this well basalt, including two layers of red ashes, was penetrated for 279 feet without reaching the bottom of the lava. The altitude of the surface of the ground at the mouth of the well is about 6,215 feet and that of the Blackfoot River Reservoir in 1914 was 6,111 feet. The basalt therefore descends more than 175 feet below the level of the reservoir. On the other hand, basaltic hills east and southeast of the reservoir, in which the basalt appears to lie practically horizontal, reach a maximum altitude of 6,609 feet, about 500 feet above that level. The thickness of the lava in these hills is unknown, or whether the lava overlies the extension of the lava exposed in the well cited, but clearly the lavas in the well and in the hills may represent a continuous series of flows, in which event the basalt in that part of the region may prove to be more than 700 feet thick. Probably, however, the basaltic flows in the hills east of the reservoir constitute an older group than those in which the wells cited are bored.

The basalt on the north side of Grays Lake Outlet in sec. 14, T. 2 S., R. 41 E., in the Cranes Flat quadrangle, has an exposed thickness of about 250 feet. In sec. 3, T. 3 S., R. 42 E., it does not appear to be more than about 100 feet thick, but the cliff may there represent a truncated wedge of the basalt and not its true thickness. In other canyons, such as those of Blackfoot River and Willow and Cranes Creeks, the exposed thickness of the basalt does not much exceed 100 feet. In sec. 24, T. 3 S., R. 40 E., however, a basalt section more than 200 feet thick is exposed.

Relative age.—In the discussion of the relative age of the rhyolite it was pointed out that the basalt is younger than much of the rhyolite but that some of the rhyolite is younger than some of the basalt. The evidence there stated need not be repeated here.

CONTACT METAMORPHISM

With perhaps one exception neither the rhyolites nor the basalts appear to have produced any noteworthy metamorphic effects upon the sediments with which they came in contact. The exception is in favor of the rhyolite. About 700 feet south of the summit of the hill (altitude 6,627 feet) in the SE. ¼ sec. 7, T. 3 S., R. 42 E., in the Cranes Flat quadrangle, there is a zone about 100 feet wide of somewhat indurated fragments of limestone and sandstone of the Wayan formation together with a few pieces of white, much-altered igneous rock that contain casts of crystals. About 100 feet east of the summit of the same hill a similar zone of indurated fragments occurs together with pieces of a light-gray pumiceous material that breaks easily in the fingers but does not form a ledge. At the very summit lies a white sandstone that contains irregular silicified streaks and masses as if infiltered by thermal solutions bearing silica. These phenomena are attributed to contact metamorphism of the sediments by rhyolite, but the igneous rocks which produced them may perhaps represent a highly altered and decomposed facies of the hornblende andesite porphyry, which occurs in the hills about 1½ miles northwest in similar relationship with limestone but is there much less altered.

The andesitic sill at Sugarloaf Mountain, in sec. 25, T. 2 S., R. 41 E., and the dikes in sec. 22, T. 2 S., R. 42 E., have produced a certain degree of metamorphism in the beds of Homer limestone with which they have come in contact. The main effect has been the induration or crystallization of the limestone for a distance of a few feet from the igneous rock. There has been some interpenetration of the limestone with silica. On a subordinate peak about 800 feet west of the center of section 22 the gray-weathering dark limestone contains dark spherical masses of chert about one-eighth inch in diameter that give the rock a peculiar spotted appearance. A similar spotted effect has been produced in some of the limestone on Sugarloaf Mountain, where a slight local copper stain has led to fruitless prospecting. These chert masses are probably replacements of small gastropods such as have been noted in similar limestone in the Ammon quadrangle, farther northwest.

In the NW. ¼ sec. 9, T. 6 S., R. 43 E., in the Lanes Creek quadrangle, there is a metalliferous prospect, a caved tunnel, in the sandy limestone of the Wells formation. Metalliferous and other minerals have been developed here, replacing some of the rock. Samples have been examined by Mr. Larsen. The following minerals have been recognized: Hematite in tabular crystals and beautiful rosettes, some of which are as much as half an inch in diameter; yellowish-green garnet in masses and in small individual crystals; calcite in veins, linings of cavities, and scattered individual crystals; quartz in small prisms in cavities; chalcopyrite in small scattered masses; a green copper mineral, which according to E. V. Shannon, is brochantite; iron oxide; a black opaque mineral; and a secondary iron mineral, black in mass but red brown in powder. The mineralization is purely local and points to the proximity of igneous rock, but none is exposed.

EPOCHS OF IGNEOUS ACTIVITY

The geologic record, as here interpreted, shows at least six epochs of igneous activity, which may readily be distinguished. The possibility of three other epochs is also recognized, though these may prove to be identical with some of the six first mentioned.

1. The rhyolitic ash that now forms the indurated bed noted in the Twin Creek limestone represents the earliest extrusive epoch known in this region. The thickness of the bed is about 5 feet. It doubtless represents only a single eruption or at least a brief period of volcanic activity.

2. The indurated ash bed in the Wayan formation marks another similar volcanic outburst of considerably later date.

3. Next in age is probably the hornblende andesite porphyry. The structural relations and character of the rock at Sugar Loaf Mountain show that a considerable amount of erosion has been necessary to produce the present exposures. This prolonged erosion would mean greater age for the andesite than for the other igneous rocks, which were outpoured on the surface and have not been greatly eroded. The andesitic tuffs of the Fort Hall Indian Reservation [3] farther west are much altered and eroded and represent the earliest igneous rocks recognized there.

4(?). The inclusion of basaltic fragments in rhyolite, noted above, may indicate the occurrence of olivine basalts in the region before the first outflows of rhyolite. The relative freshness, however, of both the basalt and the including rhyolite, at the locality named and the practical identity in mineralogic character of the basaltic inclusions with the broad basaltic flows of the region suggest that the inclusions are parts of the main flows and that the inclosing rhyolite belongs with the later rhyolitic extrusions.

5. Much of the rhyolite that forms the cones and perhaps the greater part of the flows was extruded during the next epoch. Probably several eruptions occurred at greater or less intervals; for the masses of rhyolite now exposed are considerable. China Hat alone, the largest of the cones, measures at the level of the surrounding country approximately 7,000 by 5,000 feet in area and rises about 1,000 feet above that level. It has a content above ground of roughly one-eighth of a cubic mile, besides a concealed mass of unknown dimensions. The mass as a whole is doubtless the product of many flows.

6. Basalt surrounds the rhyolite cones and floods much of the lower ground in the northwestern part of the district besides covering some of the higher hills. Some of the basalt, as noted above, includes fragments of rhyolite. Many successive flows were required to make up the great mass of the basalt, and some of them have been recognized. There is little difference in the relative freshness of the flows thus far observed, and no eroded surfaces between them have been noted, so that it is improbable that any great time interval elapsed between successive flows. The accumulation, however, of such great masses may be presumed to have required considerable time. Although the basaltic eruptions were probably in greater part of the quiet type, the numerous cinder cones and the fineness of basaltic ash beds at the localities previously mentioned indicate that some of the eruptions were explosive. These eruptions were distributed to some extent throughout the epoch, as shown by the ash beds in the well in sec. 30, T. 7 S., R. 42 E., and the bed east of the Blackfoot River Reservoir. Some of them occurred later on at the close of the epoch, as shown by the section in Griffin's well in sec. 18, T. 7 S., R. 42 E. (See Table 31.)

7. A second rhyolitic epoch gave rise probably to the lavas that include fragments of basalt, and supplied rhyolitic ash that here and there overlies the basalt. The presence of the ash beds indicates that the eruptions were in part of the explosive type.

8 (?). The little basaltic flow in the NW. ¼ SW. ¼ sec. 7, T. 7 S., R. 42 E., on the northwest slope of Middle Cone suggests a possible basaltic episode later than the second rhyolitic epoch. The basalt that contains inclusions of rhyolite in the southeast quarter of the same section tends to support such a view. Additional evidence is furnished by the presence of a basaltic ash bed between beds of rhyolitic ash in a cut bank of Blackfoot River in sec. 16, T. 7 S., R. 42 E. (See Table 30.) In the northwestern part of the Portneuf quadrangle also, in secs. 10–12, 13–15, and 24, T. 5 S., R. 39 E., basaltic flows overlie the rhyolite at a number of places. At one locality in the NE. ¼ sec. 14 rhyolite with gentle easterly dip is apparently both underlain and overlain by basalt, thus suggesting two basaltic outflows and an intervening rhyolitic flow. On the other hand, the basaltic ash bed has not been found elsewhere in the quadrangles here considered and may indicate only wash of basaltic material from other beds. The basaltic flows and the basalt with rhyolitic inclusions might be explained by a single basaltic epoch (6). In the localities cited in the Portneuf quadrangle the basalt generally overlies rhyolite and the rhyolite appears here and there as an uncovered patch. The shape of the rhyolite exposure and the mode of occurrence of the rhyolite at the locality cited in sec. 14, however, are not so easily explained as the result of one basaltic extrusion. If the rhyolite at this locality is correlated with that which may be called the main rhyolitic epoch (5) the basaltic flows would correspond, respectively, to the earlier and later basaltic epochs (4 and 6), which appears to be the most reasonable view. If the rhyolite is correlated with the second rhyolitic epoch (7), then the accompanying basaltic flows would fall, respectively, in epochs 6 and 8.

9 (?). The most recent extrusive activity appears to have been rhyolitic. It is represented by deposits of rhyolitic ash, perhaps the higher bed of the Blackfoot River section above mentioned, and by the explosion craters now occupied by ponds in the eastern half of sec. 7, T. 7 S., R. 42 E., between Middle and North Cones. Mounds of débris, including both rhyolitic and basaltic fragments, mostly fine textured, and some sedimentary material, partly surround these craters. The rhyolitic material is finer and more abundant. Doubtless the explosions burst through some sedimentary rocks and basalt on their way to

[3] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, 1920.

the surface. Basalt is now exposed on the northwest side of the southern crater. The craters, the exposed basalt, and accompanying mounds of débris are so fresh that they might easily have been formed within historic time. The only trees within the craters, however, are aspens that are so small as to throw no light on the age of the explosions. All these features may perhaps be referable to the second rhyolitic epoch above decsribed (7), in which event that epoch would be the latest, if the first of the two correlations suggested above for the rhyolite in sec. 14, T. 7 S., R. 42 E., is accepted. If the second correlation is employed the upper basalt at that locality would represent epoch 8 and would be the latest eruption of the region.

In the Fort Hall Indian Reservation [4] andesitic tuffs are overlain by rhyolite. Rhyolite in places contains basic inclusions and elsewhere is overlain by basalt. Basalt is cut by acid intrusions and both rhyolite and basalt are overspread in places by latitic ash. Thus there is a close correspondence between the igneous records of the Fort Hall Indian Reservation and those of the region described in this paper, but thus far no nepheline-bearing rocks have been found in the last-named region.[4]

SOURCES OF RHYOLITIC ASH

The actual source of the ash beds in the Twin Creek limestone and the Wayan formation must probably remain a matter of speculation. On the assumption that the prevailing winds of Jurassic and Lower Cretaceous (?) time had similar courses to those of to-day the material must have come from westerly sources. According to Lindgren,[5] great batholithic intrusions occurred in the coast region in Lower Cretaceous time.

Ransome [6] favors early Cretaceous age for certain granitic rocks of the Goldfield, Nevada, district and cites several authors to show that the age of the principal granitic intrusions of the Nevada ranges is contemporaneous. The effusive rocks of that region appear to be of later age than early Cretaceous. The great Idaho granitic batholith also is believed to be of late Cretaceous or Eocene age.[7] In British Columbia, according to Dawson,[8] some of the Lower Cretaceous sediments contain much volcanic material, but that region is relatively remote from southeastern Idaho. The foregoing citations show that igneous activity occurred in a number of regions at considerable distances to the southwest, west, and northwest during Lower Cretaceous time, but with the exception of British Columbia it seems to have been attended by comparatively little effusion. However, a single great outburst, the records of which may have been removed by erosion or concealed by later deposition, would very likely suffice to produce the beds under consideration. If such were the cause, the source of the deposit was probably less remote than British Columbia.

The ash bed mapped with the Salt Lake formation in the NW. ¼ sec. 1, T. 11 S., R. 43 E., in the Slug Creek quadrangle, may perhaps have been derived from the rhyolitic cones in T. 7 S., R. 42 E., 16 or 18 miles to the northwest. It will later be shown that there are reasons for considering the cones Pliocene. If the reference of the Salt Lake formation to the Pliocene (?) should be confirmed, the cones mentioned would thus form a suitable source for these beds. However, no intervening occurrences of similar ash between the cones and this locality have been recognized. On the other hand, their resemblance to beds of the Fowkes formation of southwestern Wyoming (Eocene) has been mentioned in the discussion of the Salt Lake formation. According to Veatch,[9] the volcanic ash in the Fowkes formation may have been derived from a buried source south of the Crawford Mountains, in the Randolph quadrangle. No occurrences of similar ash have been recognized between the localities enumerated by Veatch and the locality in T. 11 S., R. 43 E.

The other beds of rhyolitic ash previously described occur in general proximity to the rhyolitic cones south of the Blackfoot River Reservoir and the craters in the E. ½ sec. 7, T. 7 S., R. 42 E. These craters may with little doubt be regarded as the source of much of this ash. Possibly some ash may also have accompanied the later flows or have come from the crateriform depressions that appear in these cones.

ORIGIN OF THE IGNEOUS ROCKS

Many petrologists hold the view that successive outpourings of igneous rock in a given region are the result of the differentiation of a great underlying magma which, under favorable conditions, gave rise at times to intrusions or effusions of rocks that have different chemical and mineral composition. The general subject of magmatic differentiation is of broad scope, and the literature upon it is extensive. Mention can be made here of only certain aspects of the subject that bear directly on the discussion of the igneous rocks of this district. For further details the reader is referred to the works of Iddings,[10] Daly,[11] and Harker,[12] and of the numerous authors cited by them.

[4] Mansfield, G. R., The geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 60, 1920. See also Mansfield, G. R., and Larsen, E. S., Nepheline basalt in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci. Jour., vol. 5, pp. 463-468, 1915.

[5] Lindgren, Waldemar, The igneous geology of the Cordilleras and its problems: Yale University, Silliman Foundation, 1913, Problems of American geology, pp. 234-286, p. 258, New Haven, 1915. Cites references.

[6] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, p. 35, 1909.

[7] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 42, 1913; An old erosion surface in Idaho; its age and value as a datum plane: Jour. Geology, vol. 20, pp. 139-147, 1912.

[8] Dawson, G. M., On earlier Cretaceous rocks of the northwestern part of the Dominion of Canada: Am. Jour. Sci., 3d ser., vol. 38, pp. 120-127, 1889.

[9] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 91, 1907.

[10] Iddings, J. P., Igneous rocks, 2 vols., New York, 1909.

[11] Daly, R. A., Igneous rocks and their origin, New York, 1914.

[12] Harker, Alfred, The natural history of igneous rocks, London, 1909.

The simplest view of magmatic differentiation as applied to the igneous rocks of this district is that these rocks were formed from an original magma of intermediate composition, from which came first the hornblende andesite porphyry and then by continued differentiation the series of rhyolites and basalts. This conception would accord with the principle stated by Iddings [13]

that in any period of volcanic activity the earliest eruptions are of rocks having an average or intermediate composition, and that subsequent eruptions are of magmas with more and more diverse compositions, the last eruptions producing the most diverse kinds.

Lindgren,[14] in summarizing the extrusive activity of the Cordilleras, presents a different view of the problem, as shown by the following paragraphs, which the present writer has taken the liberty of transposing. Lindgren divides the extrusives of the Cordilleras into two groups, one of which

embraces the volcanoes of the Sierra Nevada, the Cascades, innumerable vents in Nevada, the Yellowstone Park region, and the San Juan country in southwestern Colorado. All these yield predominant andesite with considerable rhyolite and minor masses of basalt, and it seems fair to advance the hypothesis that they are caused by explosive action from the magmas of older granodioritic or quartz monzonitic batholiths, which have had time to differentiate in their upper gas-charged "cupolas," or from satellitic intrusions of such batholiths. Wherever we find local intrusions in such volcanoes they appear to be of magma of intermediate composition.

The other group includes

the Columbia River lavas, many fields in Nevada, and those of central and eastern Arizona. These eruptions go over into the type of latest Pliocene and of Quaternary age, in which only basalts were poured out. It seems probable that these eruptions are not connected with the granodioritic magmas but are of more deep-seated origin.

In the region described in this paper the hornblende andesite porphyry is apparently the oldest of the igneous rocks in place and thus represents the first products of the magmatic intrusion of the region, perhaps before any significant differentiation had taken place, if the simpler view implied by the citation from Iddings is assumed, or it may represent a differentiation product from a granodiotitic magma, such as those postulated by Lindgren. No effusion appears to have occurred in this immediate region, but in the Fort Hall Indian Reservation considerable areas of andesitic tuff show that there were actual volcanic outbursts not far away.

The rhyolites and basalts may represent the products of further differentiation of a magma of intermediate composition or a granodioritic magma, but the basalts, according to Lindgren's view, more probably came from a different and more deeply seated magmatic source. The region has thus been underlain by at least one great body of rock magma or possibly by an earlier and a later magma at different depths. From these the igneous rocks of the areas here described have been derived. It is possible that further intrusions or effusions may develop from the same source or sources, although present evidence points to the dying away of volcanism.

MODES OF ERUPTION

INTRUSION

In the Cranes Flat quadrangle the hornblende andesite porphyry was intruded in dikes or in sheets that conform more or less closely with the bedding of the inclosing sedimentary rocks. These sheets do not occur along recognized fault lines but seem rather to have been guided by the weak, shaly character of the Homer limestone member of the Wayan formation, with which the andesite is exclusively associated in this quadrangle. In the Portneuf quadrangle it occurs in shaly beds of the Phosphoria formation.

One of the sheets which became locally thickened, gave rise to the andesitic mass that now forms much of Sugarloaf Mountain. (See pp. 117 and 134.) St. John[15] regards the intrusion of the andesite as the cause of the upheaval of the mountain (his station XVII). He says:

Although the deposits in the immediate southwest slope of station XVII are somewhat obscure, and withal so altered by metamorphic action as to render their examination difficult yet their more favorable exposure in the opposite hillside to the west affords satisfactory data for the determination of the relations of the sedimentaries to the volcanic phenomena with which they are here associated. The igneous mass protruding in the crest of the ridge seems to have been forced up nearly in a vertical direction, carrying the sedimentary beds up with it instead of fracturing them at once, so that at the extremities of the upthrust they were not rent apart. But at the point of greatest tension they were partly fractured, the igneous matter following the crevice thus produced, as a wedge-shaped mass, which subsequent erosion has bared, and thus revealed the origin of the little anticlinal fold, of which it forms as well the nucleus.

The intrusion at Sugarloaf Mountain has been described for convenience as a sill, because it follows in general the bedding of the inclosing sediments. Its sides, however, are not parallel. The upper surface bulges at the top of the mountain, so that St. John described the intrusive body as wedge-shaped. In reality it should probably be considered as having an unsymmetrical crescentic form and may represent an incipient laccolith. Harker[16] uses the term "phacolite" for an intrusive body that occurs along the crest or trough of a fold so that it takes advantage of the tendency of folded strata to be spread apart in those regions and is compressed in the middle limbs of the folds. The phacolite would according to his view not tend to arch the inclosing strata, as does the laccolith, and it would have a convexo-concave cross section rather than plano-convex, such as the laccolith may be presumed to have.

[13] Iddings, J. P., op. cit., vol. 1, p. 257.
[14] Lindgren, Waldemar, op. cit., p. 285.
[15] St. John, Orestes, op. cit., p. 356.
[16] Harker, Alfred, The natural history of igneous rocks, pp. 77-78, London, 1909.

The distinction seems artificial, for the hydrostatic pressure of the injected rock magma would doubtless, when acting in conjunction with forces of upheaval producing the folds, accentuate the effects of those forces and actually arch the strata. The distinction would thus apparently represent not a difference in kind but in place of intrusion, the laccolith occurring in regions of horizontal strata and the phacolite in folded strata. In Sugarloaf Mountain a certain amount of arching of the overlying strata is suggested by the separated blocks of limestone that lie on the andesite along the crest of the mountain.

Intrusions of basalt in the form of dikes have been mentioned in a previous paragraph.

INTRUSION AND UPLIFT

The part that igneous intrusion may play in uplift is emphasized by Lindgren,[17] who says in reference to the Cordilleras:

> Everywhere intrusions correspond to uplifts, and the evidence, it seems to me, is entirely favorable to simultaneous uplift and intrusion.

After summarizing evidence afforded by various batholiths and laccoliths, the same author continues:

> Laccoliths are simply offshoots of batholiths and, under the same hydrostatic pressure, strong enough to lift up thousands of feet of superincumbent strata. Can we doubt that uplift was one of the consequences of batholithic intrusion? Is it not also probable that large areas of elevation in the Cordilleras are underlain by concealed batholiths?

Upon such a conception it may be supposed that the general region described in this paper is underlain by a batholith, from which have come at least the different andesitic intrusions and perhaps by differentiation the rhyolites and basalts as well.

EXTRUSION OF RHYOLITE

The earlier extrusions of rhyolite that constitute probably the greater bulk of the rhyolitic masses show fairly definite relations to fracture or fault lines in many of their occurrences. The alinement of the cones and craters in the northwestern part of T. 7 S., R. 42 E., Henry quadrangle, can scarcely be accidental. It doubtless marks a fissure, or more probably the intersection of a northeastward-trending fissure with a set of northwestward-trending fissures. The rhyolitic islands in the Blackfoot River Reservoir lie in close proximity to a concealed fault that probably passes beneath the reservoir and connects the transverse faults that offset the Woodside shale and Thaynes group in T. 6 S., Rs. 41 and 42 E. The islands may mark the intersection of this fault with a northerly or northwesterly fissure, which perhaps continues northward from one of the cones. The flows in T. 4 S., R. 42 E., in the Cranes Flat quadrangle, are less obviously connected with faults, but in the discussion of the structure of this region in Chapter V (p. 136) a reason will be stated for supposing the presence of a fault beneath the two larger areas at least. One or more concealed faults also probably pass near the rhyolitic area in secs. 13 and 14, T. 2 S., R. 40 E., but the relationship of these faults to the rhyolite can not be determined without studies of the district farther north.

The later extrusions of rhyolite, so far as distinguished, were localized in general along the lines of previous rhyolitic activity.

EXTRUSION OF BASALT

The Snake River lavas, with which those of this region are closely associated, were long considered as the product of eruptions from great fissures. Lindgren,[18] however, believes that these

> basalts were erupted from a great number of inconspicuous craters, both in the plains and in the adjoining mountains. Their fluidity was remarkable, continuous flows of 50 miles or more being noted. One flow for instance, followed the South Fork of Boise River for that distance down to its mouth.

Russell,[19] too, after quoting Geikie's vivid description of the Snake River Plains, says:

> Although the idea that the lava reached the surface as immense fissure eruptions has perhaps gained general acceptance, my observations failed to sustain it, on the contrary, led me to conclude that many local eruptions from distinct vents are accountable for the origin of the extrusive sheets of once molten rock.

Bradley [20] and Peale [21] regarded the craters near Soda Springs as the sources of the lavas of this region. Russell [22] also shared this view. Some of the craters named are doubtless those of the Henry and Cranes Flat quadrangles. The present study of the region has led to the view that these craters have played on the whole a relatively subordinate part and that fissure eruptions were probably more extensive.

The craters at first sight seem scattered and without definite arrangement, but in the Henry quadrangle, about 2 miles northwest of the line of rhyolite cones, there are four basaltic cones, two with double craters, that lie approximately in a line parallel with that of the rhyolitic cones and only 7 miles long, and, beyond, a shorter parallel line that is marked by two additional craters. Too much confidence should not be placed in this apparent arrangement, but it is at least suggestive.

The two basaltic cones described above (p. 121)—Sheep Mountain in the Cranes Flat quadrangle and Crater Mountain in sec. 14, T. 5 S., R. 41 E., in the Henry quadrangle—represent single vents or closely

[17] Lindgren, Waldemar, op. cit., pp. 282-284.

[18] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Boise folio (No. 45), 1898.

[19] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 63, 1902.

[20] Bradley, F. H., Report of the Snake River division: U. S. Geol. Survey Terr., Sixth Ann. Rept., p. 204, 1873.

[21] Peale, A. C., Report of the Green River division: U. S. Geol. Survey Terr., Eleventh Ann. Rept., pp. 643-644, 1879.

[22] Op. cit., p. 65.

grouped vents from which extensive outpourings of basalt took place. The flows from Sheep Mountain descended chiefly into Willow Creek drainage, where they were probably joined by basalt from other sources or were interbedded with it. The lavas from Crater Mountain contribute to the flows that now occupy the Blackfoot Valley and are cut by the Blackfoot Canyon. (See pls. 14, *C;* 18, *B;* and 61, *B.*) Here also the flows were probably in part derived from other sources. The numerous other cones scattered here and there in the Henry and Cranes Flat quadrangles mark vents from which with little doubt considerable quantities of lava were extruded. They do not, however, form great basaltic piles, such as those first mentioned, but instead their scoriaceous and cindery masses rise like islands from a generally level basaltic plain, as if partly buried by lava. They probably represent explosive vents that are located at favorable places along faults or fissures, possibly at fault intersections. They may, however, have been independent eruptive centers.

A significant fact in this connection is the large number of faults that occur in the neighboring areas of sedimentary rocks and extend forward directly under the lava or pass toward it under cover of hill wash or alluvium. The general map (pl. 1) and the map of the Lanes Creek quadrangle (pl. 4) show a number of these faults. The suggestion is very strong that the cracking of the earth's crust in that region into blocks by these faults and the down-settling of the blocks were the main causes for the outburst of the lava, which welled up along many of the cracks, overflowed the surface of the country, and occupied much of the lower ground.

The valley of Chippy Creek, in the Lanes Creek quadrangle, is traversed by a number of faults which probably gave rise to the basaltic flows that occupy the valley and extend southward into Lanes Creek. There are no other obvious sources for that lava. The basaltic hills east of the Blackfoot River Reservoir and north of Little Valley and the basaltic ridges west of Cranes Flat probably represent similar outpourings from fissures or faults. North of Little Valley the basalt surmounts a sedimentary ridge. East of the reservoir and in the Willow Creek lava field the basaltic hills may owe their ridgelike appearance to the viscosity of the lava and to buried topography. Bradley [23] thus explained some lava ridges observed by him in the Snake River Plains. Russell,[24] however, rejected this explanation and showed that along the Snake River Canyon near Shoshone Falls, where characteristic domes and cracked ridges are cut through, they are hollow arches above flat lava sheets or else folds that die out gradually below. He explained these features as the effect of forces generated by slow-moving lava beneath upon a still yielding crust above. In the hills east of the reservoir and the ridges of the Willow Creek lava field the lavas are nearly horizontal but are locally gently arched. The cause of the arching is not evident. Lava ridges might be expected to form over fissures in the later stages of an eruption and may mark the sites of such fissures. The lava from fissure eruptions is here supposed to have augmented the flows from the large cones described above and perhaps even to have supplied the greater part of the lava that now occupies the valleys of Willow Creek and Blackfoot River. The lava in Outlet Valley has doubtless been partly derived from the Little Valley Hills, but it was probably also supplied by fissures elsewhere, now concealed beneath the lava.

Localities where basalt has been extruded along fault lines in the Cranes Flat quadrangle are cited on page 135. Small independent flows have occurred along fault lines in secs. 34 and 35, T. 7 S., R. 42 E., on the south side of Enoch Valley, and also possibly at the head of Slug Creek. Other flows from local vents, not obviously connected with faults, occur on the north slope of Limerock Mountain and elsewhere.

SUCCESSION OF IGNEOUS ROCKS

The succession of igneous rocks has been studied by many geologists at many localities with somewhat discordant results, which have been well summarized by Lindgren [25] as follows:

> Richthofen's conclusion, announced at an early date, was that the eruptions in Nevada began with andesite, which later was followed by trachyte, rhyolite, and basalt in the order given. Since that time our knowledge has increased greatly and the subject has been studied by Iddings, Cross, Spurr, Ransome, Ball, and others. Iddings believes that the eruptions begin in general by intermediate rocks, changing later to rhyolite and basalt. Spurr, on the other hand, arrives at the conclusion that in a broad way the eruptions in the Great Basin began by rhyolite, followed by andesite, later rhyolite, later andesite, and finally basalt. Ransome doubts the general applicability of Spurr's succession.
>
> In many districts where apparently a complete cycle is preserved, rhyolite was certainly the first erupted lava. However, comparing the data available, it does not seem possible to formulate a law which will hold in all cases. At many places in Arizona and the Great Basin, rhyolites have for instance been repeated from three to five times, alternating with basalts and andesites, and as stated before the andesites are entirely absent in some districts. Almost all recorded successions agree, however, in one point, namely, that the eruptions close with outpourings of basalt.

With the exception of the two earlier ash falls, the succession in this region, as outlined in a previous paragraph, probably began with an intermediate type, andesite, as in the successions of Richthofen and Iddings, and was followed by alternations of rhyolite and basalt, including at least two and possibly three

[23] Bradley, F. H., op. cit.

[24] Russell, I. C., op. cit., p. 97.

[25] Lindgren, Waldemar, The igneous geology of the Cordilleras and its problems, Yale University, Silliman foundation, 1913, pp. 273-274, New Haven, 1915.

outbursts of rhyolite and possibly two of basalt. The general conclusion of Lindgren that eruptions close with outpourings of basalt does not seem to be sustained in this district. Here rhyolitic ash overlies basalt locally, and the craters between the cones in sec. 7, T. 7 S., R. 42 E., are bordered by piles of mingled débris, chiefly rhyolitic. A similar condition was noted in the Fort Hall Indian Reservation, where a dark volcanic sand composed of latitic lapilli overlies basalt. Possibly in each of these regions some flow of basalt later than these acidic eruptions may exist beyond the district affected by the rhyolite, but no such flow has thus far been distinguished.

CAUSES OF IGNEOUS ACTIVITY

One of the greater and much discussed problems in geology, which may receive only brief mention here, relates to the causes of igneous activity. The ultimate cause is speculative, and opinions about it rest upon assumed conceptions regarding the constitution and condition of the earth's interior. General agreement, however, seems to have been reached upon the idea of interdependence of igneous activity and crustal deformation and the dependence of these phenomena upon common causes. As stated by Daly,[26]

> The location and alinement of mountain ranges, the location and alinement of geosynclinals, the final development of igneous batholiths and satellitic injections, all are interdependent and related to special zones of powerful abyssal injection from the substratum.

RELATIONS OF IGNEOUS ROCKS TO SEDIMENTARY ROCKS

The beds of rhyolitic or latitic ash in the Montpelier, Lanes Creek, and Cranes Flat quadrangles are not well exposed, but they appear to be interbedded with the Twin Creek limestone and the Wayan formation and to share in their deformation. Similarly the rhyolitic ash in sec. 1, T. 11 S., R. 43 E., in the Slug Creek quadrangle, is interbedded with strata of the Salt Lake formation and shares in its deformation.

The relations of the hornblende andesite porphyry to the accompanying sediments at Sugarloaf Mountain and vicinity have been discussed in a previous paragraph. The folding of the strata is not noticeably greater in Sugarloaf Mountain than in many other parts of the field where igneous rocks are not exposed. Thus it would seem that the part played by the intrusion of the porphyry in the upheaval of the mountain was relatively insignificant, but the intrusion of the supposed concealed batholith from which the igneous rock was derived may have been a notable factor in the general deformation of the region. It seems probable that the injection of the porphyry was concomitant with the folding of the sedimentary beds, but, if later, it followed existing structural features.

[26] Daly, R. A., op. cit., p. 193.

The rhyolite in the Cranes Flat quadrangle overlies inclined beds that range in age from Carboniferous to Lower Cretaceous (?). In the adjacent Portneuf quadrangle, in T. 5 S., Rs. 39 and 40 E., it overlies the Salt Lake formation. The basalt bears a similar relationship to the pre-Quaternary strata, and in the Henry quadrangle occupies depressions excavated in the Salt Lake formation. Both the rhyolite and basalt are overspread locally by the earlier Quaternary deposits.

AGE OF IGNEOUS ROCKS

The age of the ash beds in the Twin Creek limestone, in the Wayan formation and in sec. 1, T. 11 S., R. 43 E., has already been shown. The age of the hornblende andesite porphyry may be judged only by its structural relations and present state of preservation. Some inference may also be drawn from the relationships of similar rocks in neighboring regions. In Chapter V it is shown that the major structural disturbance of the region probably occurred at the close of the Cretaceous or the beginning of the Tertiary and that another notable deformative epoch occurred in the later part of the Pliocene. Of intervening diastrophic movements there is no clear record, but there may have been some such activity. If the andesitic intrusion accompanied folding, it may have occurred as early as the first epoch named. The deeply weathered condition of the rock and the probable amount of erosion of the region since the intrusion favor such a reference. The same evidence would be less favorable to the idea of late Pliocene age. Much of the volcanic activity that gave rise to the great volcanic accumulations of the Columbia River region and the Yellowstone Park occurred in Miocene time.[27] In Lemhi County, Idaho, Tertiary lavas dating from Oligocene or early Miocene to about the end of the Pliocene are reported by Umpleby.[28] In the Fort Hall Indian Reservation [29] andesitic tuffs are overlain by or interbedded with white and yellow conglomerates that are here correlated with the Salt Lake formation. On the assumption that the andesites of the general region are approximately contemporaneous it would appear that they are not later than early Pliocene and may be as old as early Eocene.

In the discussion of the age of the Salt Lake formation, comparison was made with the Yellowstone Park section, and the possible Pliocene age of that formation and of its accompanying rhyolite was indicated. In the Fort Hall Indian Reservation rhyolite is intercalated with or overlies sediments that should be correlated with the Salt Lake formation, and basalt overlies similar sediments and locally also overlies rhyolite. Likewise the basalt is overlapped by early

[27] U. S. Geol. Survey Geol. Atlas, Ellensburg folio (No. 86), Mount Stuart folio (No. 106), and Yellowstone National Park folio (No. 30).

[28] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho; U. S. Geol. Survey Bull. 528, p. 48, 1913.

[29] Mansfield, G. R., op. cit., p. 60.

Quaternary deposits, which are themselves in places overlain by latitic ash. Thus in that region the ages of the rhyolite and basalt range apparently from Pliocene into early Quaternary. The similarity of the igneous succession in the Fort Hall Indian Reservation with that of the region described in this paper has been pointed out in a previous paragraph. Hence it appears that the igneous activities in the two regions, which are neighboring parts of the same general region, were essentially contemporaneous.

The rhyolitic ash in the Henry quadrangle, though it forms the soil at a number of places, does not so clearly overlie the early Quaternary deposits as does the latitic ash of the Fort Hall Indian Reservation. However, the recent appearance of the craters in the eastern part of sec. 7, T. 7 S., R. 42 E., and of their accompanying débris, suggests that their age is probably not greater than that of the latitic ash. The age here assigned to the rhyolite and basalt accords with that of the basalt of the general region as described by Peale [30] and Russell. [31] If the age of the Salt Lake formation should prove to be earlier than Pliocene, a possibility intimated in the description of that formation, the age of the basalts and later rhyolites would not be affected, for they overlie topography that has been developed in part by the erosion of the Salt Lake formation.

[30] Peale, A. C., Report of the Green River division: U. S. Geol. Survey Terr. Eleventh Ann. Rept., pp. 643-644, 1879.

[31] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 61, 105, 1902.

Chapter V. STRUCTURAL GEOLOGY

GENERAL FEATURES

The structure of the ancient sedimentary beds that constitute the greater body of the rocks of the region has much scientific interest through the light that it sheds on the geologic history of the Rocky Mountains. It has economic significance as well through its relations to the phosphate deposits and the other mineral resources of the region.

The present chapter presents first the broader structural features as outlined on the general map (pl. 1) and then local details as shown on the large-scale maps, (pls. 2–7 and 9) and on the structure section sheets (pls. 11 and 12 in pocket). The treatment is intended to be purely descriptive, setting forth the facts and the logical inferences derived from them but leaving the discussion of the broader problems involved to another chapter.

Some aspects of the structure of the igneous rocks have already been mentioned in the chapter on igneous geology. Further details will be added after the discussion of the structure of the sedimentary beds.

STRUCTURAL TRENDS

The most conspicuous features of the general map, as seen at first glance, are the long, somewhat curved, and looped bands that mark the structural trends of the rock formations. These trends are no less impressive in the actual country represented by the map, where ridges and valleys in large measure follow the strike of the rocks, a conspicuous example of which is Snowdrift Mountain in the southwestern part of the Crow Creek quadrangle. (See pl. 7.) The different formations make lines that trend northerly or even northeasterly in the southern part of the region but bend sharply to the northwest in the western part of the Crow Creek quadrangle and continue northwesterly in general throughout the rest of the country mapped. The curvature of the trend lines is relatively gentle near the eastern margin but stronger near the central part of the region.

CAUSES OF TREND

The causes of trend lie in the disturbances which the beds have undergone since their deposition as sediments. It may be presumed that the original sediments which form the present beds were largely deposited in horizontal or nearly horizontal layers. Horizontal beds have no trend. Their outcrop follows the intricate pattern of the stream valleys and may be highly irregular, but it can ordinarily have no dominant direction, for the stream valleys by which these rocks are exposed may develop in one direction as easily as in another unless guiding fractures or variations in composition are present.

Disturbed beds are tilted at different angles. The layers of hard and soft rock thus exposed exert a directive influence upon erosional development with a resulting linear outcrop of the respective formations and linear topography. Great variety of trend is possible with different structure, but the differences in topographic and cartographic expression of such structure and of horizontal beds are characteristic. These differences are well shown in the Bear Lake Plateau, where sharply folded Triassic and Jurassic beds pass beneath nearly horizontal or gently flexed Wasatch deposits.

The disturbance of rocks is due to stresses that reside in the earth's crust and are themselves due to interacting causes, the operation of which is not well understood but which include the action of gravity upon great masses of unequal density, probably accompanied by deep-seated rock flow, unequal distribution of temperatures within the earth, unequal rigidity and differences in chemical composition of portions of the earth's crust and unequal erosion of the earth's surface. In any given locality and during any given period of time these stresses have generally a dominant direction, though local causes may change that direction at different places. Stress may exist in the earth's crust without the development of visible structure in the rocks. The degree to which rocks yield to stress depends upon the rigidity and general competence of the rocks to transmit pressures and bear loads. Accumulating stresses find relief in distortion or rupture, which is commonly expressed by the folding and faulting of the rocks.

CURVING TRENDS

Curving trends show differential yielding to stress, if the stress is considered essentially uniform for a given area, or unequally developed stresses in different parts of the area. In either event they serve to show the direction in which the stress is effective, for compressive stresses would tend to make the curvature convex in the direction toward which the thrust acts. Tensional stresses might produce convexity of curvature in a similar direction to that of compressive stress, but in that event the source of the tension with reference to a given area would be opposite in direction to that of compression. In the area described in this paper the stresses that have produced the structural trends have been largely compressive, as will be more fully shown below, and the convexity of curvature is in general northeast. The greatest convexity of trend marks the line of maximum yielding to stress. This line trends approximately east-northeast, which means that the direction of compressive stress was approximately from west-southwest to east-northeast.

LOOPED TRENDS

Loops in the trend of a given formation indicate folds in the rocks and mark the places where the given formations cross the crest lines or axes of the folds and are truncated by erosion. Numerous folds are represented on the general map, and these are hardly less conspicuous than the general trends above noted. The loops pointing in opposite directions represent zigzag or overlapping folds comparable to those of the Appalachian Mountains, so well described by Hayes, Willis, Keith, Campbell, and others.

DISCONTINUOUS TRENDS

Discontinuity of some of the trend lines is very noticeable and may be due to several causes. The formation represented by the trend line may pass beneath cover of later deposits or of lava. It may terminate against an unconformity or a fault. If there is an unconformity, the formation may disappear altogether or continue intermittently along the line of unconformity. Where there is a fault, if the formation reappears, it is generally off line (offset), both because of actual displacement along the fault and because of unequal erosion on opposite sides of the fault line. If a fold is cut by a transverse fault the higher standing block is more actively eroded than the lower. Erosion cuts down the beds along the dip. If the structure is anticlinal the effect of erosion on the relatively upraised block will be to broaden the distance between the outcrops of a given formation on opposite sides of the fold. If the structure is synclinal the reverse is true. All these features are present in the region and are described more fully below.

TYPES OF STRUCTURE

The region is traversed by many folds and faults. Some of the folds exceed 50 miles in length, and the most noteworthy fault, the Bannock overthrust, is believed to have a length of more than 270 miles. The more prominent folds are synclinoria with relatively narrower intervening anticlines or anticlinoria, generally unsymmetrical and inclined or even overturned eastward or northeastward. The crests of the folds for long distances are nearly horizontal or slightly undulatory, and the pitch is gentle. This arrangement gives rise to long overlapping folds, like those of the southern Appalachians, rather than to shorter zigzag ranges, such as those of eastern Pennsylvania. The Idaho folds, however, are less regular than those of parts of the Appalachian region, such as the Pawpaw-Hancock area.[1] A noteworthy feature is the great bifurcated or "swallowtail" syncline that occupies the west half of the Crow Creek quadrangle and some of the adjacent area.

The folds of southeastern Idaho also have certain alpine characteristics. An inverted fan fold has been definitely recognized in the vicinity of Sugarloaf Mountain in the Cranes Flat quadrangle. (See structure section A–A′, pl. 11.) Broken fan folds also occur in Sulphur Canyon, in the Slug Creek quadrangle, and in Pelican Ridge, in the Henry quadrangle. (See structure sections P–P′, pl. 12, and G–G′, pl. 11.) Snowdrift Mountain, in the Crow Creek quadrangle, is probably also an eroded fan fold, as is indicated in structure sections S″–S‴ and T′–T″ (pl. 12).

The principal faults of the region are reverse and are doubtless chiefly associated with the Bannock overthrust, which is described below. With one striking exception the reverse faults conform to the general trend of the folds. The exception is the transverse Blackfoot thrust fault that cuts Dry Ridge, in the southern part of the Lanes Creek quadrangle, and is discussed later. Normal faults are numerous and of great prominence. Possibly some of the faults now regarded as reverse may prove to be normal. Both strike faults and dip faults are present, but the strike faults are on the whole more numerous and impressive. One of the interesting structural types of the region is the faulted graben of Meadow Creek valley, in adjoining parts of the Cranes Flat, Henry, and Lanes Creek quadrangles. (See structure sections E–E′, G–G′, and H–H′, pl. 11.)

PRINCIPAL FOLDS

CARIBOU SYNCLINORIUM

General features.—The northeastern half of the Cranes Flat quadrangle is occupied by the Caribou Range, which is there composed chiefly of Cretaceous formations that are included in a great synclinorium that extends southeastward from the border of the Snake River lava plains into western Wyoming, a distance of more than 85 miles. The greatest breadth of the synclinorium is approximately 18 miles. Its greatest depth within the region here described is in the Williamburg syncline, in the northeastern part of the Lanes Creek quadrangle, where about 15,000 feet of Cretaceous sediments are included in the synclinorium. (See structure sections H–H′ and I–I′, pl. 11.) Possibly minor folding, unrecognized because of the lithologic similarities of many of the rocks, has increased the apparent thickness of the deposits, but in any event a great body of Cretaceous beds thousands of feet thick is present. In the Williamsburg syncline and farther northwest only the Wayan formation is exposed in the mapped area. In the southeastern part of the synclinorium members of the Gannett group play a notable part in its structure. The southwestern boundary of the synclinorium throughout much of its length is the fault zone of the Bannock overthrust

[1] Stose, G. W., and Swartz, C. K., U. S. Geol. Survey Geol. Atlas, Pawpaw-Hancock folio (No. 179), 1912.

which brings rocks that range in age from Carboniferous to Jurassic into contact with the Cretaceous. Part of the synclinorium has been covered with basalt.

Sugarloaf district.—The northern and northeastern parts of the Cranes Flat quadrangle may be called the Sugarloaf district from Sugarloaf Mountain, a prominent topographic feature. This district is part of the region studied by St. John in 1877 in a reconnaissance that included considerable territory in southeastern Idaho and western Wyoming.

The ridges between Grays Lake Outlet and Willow Creek were grouped by St. John[2] under the name Willow Creek Basin. Ridges or Willow Creek Ridge. His four stations on these ridges consist of XIV, at the summit of Sheep Mountain; XV, at the summit of the basaltic hill in the SE. ¼ sec. 13, T. 2 S., R. 40 E.; XVI, 1½ miles north-northeast of XV, probably near the center of sec. 7, T. 2 S., R. 41 E.; and XVII, at Sugarloaf Mountain. He made stratigraphic and structure sections through Stations XV and XVI and Stations XIV and XVII.

an igneous intrusion. He also shows the valley east of Sheep Mountain as occupied rather fully by basalt. (Fig. 13.)

The occurrence of the basalt at Sheep Mountain, as indicated in St. John's section, is very striking. The lava appears to have flowed from the indistinct craters at the top down all sides except to the east and southeast. Southwesterly dipping rocks occupy the eastern slopes of the mountain, though farther south there are some rocks that have easterly dips. The valley of Homer Creek (called West Gray's Creek by St. John) is in part occupied by basalt, but sandstone ledges of the Wayan formation emerge here and there from cover. A prominent fault, described below, cuts the east face of Sheep Mountain. The structure of the region near Sugarloaf Mountain is not so simple as figured by St. John. Detailed mapping in that vicinity has shown the presence of a number of small folds that are represented in the structure section drawn along the line A–A′ (pls. 2 and 11).

Section A–A′ is approximately parallel to and 5 miles southeast of St. John's section through his

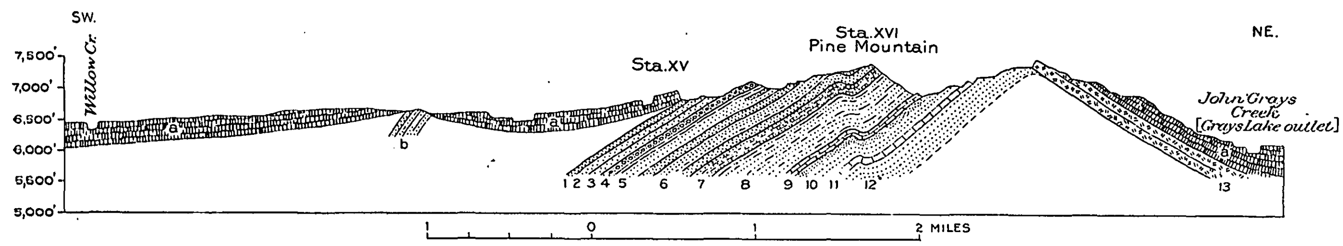


FIGURE 12.—Geologic structure section through St. John's Stations XV and XVI. *a*, Basalt; *b*, Laramie (?) gray sandstone; 1-12, Laramie beds; 13, trachyte. (After St. John)

In the section through Stations XV and XVI, which is reproduced in Figure 12, he shows a southwesterly dipping set of strata, chiefly sandstones, which he assigns to the Laramie, and which is overlapped on the southwest by basalt. The ledge in the NE. ¼ sec. 26, T. 2 S., R. 40 E., appears in the structure section. The beds have some undulations but maintain their general southwesterly dip. On the northeast they are overlapped first by northeastward-dipping "trachyte" and this in turn by basalt. The section probably gives an accurate picture of the structure of part of the region north of Long Valley. Along the quadrangle line, however, in sec. 17, T. 2 S., R. 41 E., a syncline in the Homer limestone, which may be partly concealed farther northwest, shows that overturned folds are present in the region. These overturned folds have been recognized at a number of places farther southeast.

In his section through Stations XIV and XVII St. John shows the same southwesterly dipping series of strata, overlapped on the west by the basalt at Sheep Mountain (Station XIV) and arched into a prominent anticline at Sugarloaf Mountain (Station XVII) by

[2] St. John, Orestes, Report of the geological field work of the Teton division U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 351-360, 1879.

Stations XV and XVI, and it forms an angle of perhaps 30° with his section through Stations XIV and XVII. The structure at the southwest end of the section is concealed beneath the older alluvium of the valley of Homer Creek. The first exposures northeastward consist of low-lying ledges of southwesterly dipping sandstones of the Wayan formation. These ledges are succeeded by more cover of alluvium with some basalt. The outlying hills northeast of the creek are occupied by the same series of southwesterly dipping sandstones, though some variations in dip are noted. Northeast of the sandstones lie beds of limestone which obviously have synclinorial structure and which also dip southwestward. Thus the sandstones and limestones are overturned toward the northeast in this part of the section.

The structure west of the limestone has not been worked out in detail. Some evidence, which is not, however, conclusive, indicates that a fault may lie just southwest of the limestone area. The variable dips above mentioned suggest the occurence of an anticlinal fold southwest of the limestone, comparable with folds farther northeast. Such a fold is tentatively represented in the section. Other folds southwest of the line of the section have apparently kept the limestone for the most part above the level of the present surface of erosion, but on a low knob about 1¼ miles east of Sheep Mountain there is a small area of fractured white limestone and some fragments of gypsum accompanied on the east by red soil. This occurence may represent the bottom of a pinched syncline of limestone of which the upper portions have been eroded, or it may have been preserved along a fault not otherwise recognized.

The limestone synclinorium near Sugarloaf Mountain is cut by several sheets of hornblende andesite. The structure at Sugarloaf Mountain and St. John's interpretation of it are discussed in the chapter on igneous geology. Evidence is there given to show that the andesite (trachyte of St. John) forms a thickened sill or incipient laccolith, which has been largely eroded and unroofed. This condition accounts for the steep southwest face of the andesite beneath the summit (see pl. 33, *A*), whereas to the northwest the andesite arches over both flanks of the mountain.

Northeast of Sugarloaf Mountain the dips are northeasterly, and, as the limestone in this locality is synclinal, there appears again to be overturning but this time toward the southwest. Thus the structure of the limestone area as above outlined appears to be not only a synclinorium but an inverted-fan fold. The intrusion at Sugarloaf Mountain seems to be a minor accompaniment of the folding rather than a cause of the disturbance. These conclusions regarding the structure at Sugarloaf Mountain are at variance with those of St. John, as may be seen by a comparison of the two structure sections. (See fig. 13 and section A–A′, pl. 11.)

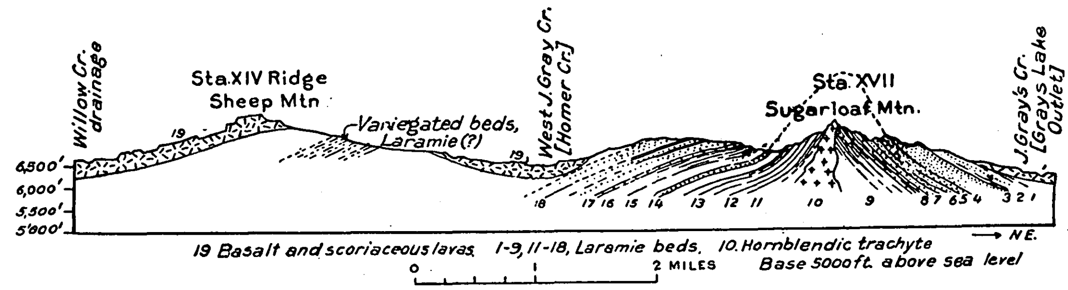


FIGURE 13.—Geologic structure section through St. John's Stations XIV and XVII. (After St. John)

Northeast of Sugarloaf Mountain the sandstones dip northeasterly in the main, but at one ledge the beds dip northeasterly at one place and southwesterly at another, as if on the crest of a southwesterly inclined fold. The structure beneath Outlet Valley is largely concealed, but from exposures at the borders of the valley and at a point to the northwest along the strike of the general axis of the valley the structure appears synclinal and is so represented.

On the southwest flank of the Caribou Range along the northeast side of Outlet Valley anticlinal and synclinal axes, respectively, appear in the sandstones. Northeast of these axes lies a southeasterly pitching syncline of the Homer limestone, which, southeast of the line of the structure section, is shot with dikes of andesite. This syncline is inclined northeastward. Near the top of the hill at the end of the structure section an anticlinal axis in the sandstone is succeeded on the northeast by a syncline that causes the limestone to catch at a few points on the ridge. Farther southeast this syncline joins the pitching syncline just described. The two synclines with the intervening anticline form a rudely Y-shaped area of limestone.

Cranes Flat district.—The district east of Cranes Flat includes the southeastern extension of Sheep Mountain and the northern part of the Little Valley Hills. The exposed part of the Caribou synclinorium in this district is relatively narrow, and the structure along its southwestern border is complex and shows faults and broken folds. Structure sections B–B′ and C–C′ (pls. 2 and 11) are tentative interpretations of this structure.

The older formations at the southwest end of structure section B–B′ are concealed by alluvium and probably also by basalt, which may be presumed to lie beneath the alluvium. Exposures farther southeast seem to show that the Nugget sandstone, with the fault at its eastern boundary, underlies the eastern border of Cranes Flat at that place. The fault is interpreted as normal and as having a displacement of not more than 200 feet. As exposed farther southeast it causes lower beds of the Nugget sandstone to rest against the Deadman limestone. The Wood shale is absent. The first exposures along the base of the hill are of Higham grit. This bed is succeeded on the northeast by purple and red Nugget sandstone, without the Deadman limestone and Wood shale that should intervene. A thrust fault with southwesterly dip is here inferred and the Higham grit is supposed to be shoved forward from the southwest upon higher beds. The Nugget sandstone apparently dips southwestward. The thrust fault may represent a broken subordinate anticline. The displacement is probably not great, perhaps only a few hundred feet.

East of the area of Nugget sandstone lie two narrow masses of Higham grit, separated by faults from the Nugget sandstone on the southwest, and the Portneuf limestone of the Thaynes group on the northeast. The western fault is considered to be normal and to have a downthrow to the northeast. The eastern fault, which presumably causes the greater dislocation, is considered a thrust, for it seems to change its angle of inclination and to have an irregular course along the hillside. About a mile to the northwest of the line of the section this fault runs into basalt, which, from its position on the slope, appears to have welled out along the line and would thus suggest a deep fracture, perhaps accentuated by the junction of this thrust fault with the fault which in the area to the south lies farther west. The displacement produced by this fault may be as much as 2,000 or 3,000 feet, for beds presumably of lower Nugget age are brought into proximity with limestones and red beds of Portneuf age. The structure of both the Nugget sandstone and the Portneuf limestone is apparently synclinal. These two sets of beds may have been involved in an inverted fan fold, which was broken by the thrusting. The Portneuf beds give way abruptly on the northeast to Nugget sandstone, which southeast of the line of the section forms a conspicuous and sharply featured hill. This sandstone in turn is succeeded on the northeast by southwesterly dipping beds of Portneuf limestone. The area of Nugget sandstone just mentioned is interpreted as representing a small block of the sandstone let down by normal faults into the midst of the Portneuf limestone.

The Portneuf area is bounded on the northeast by a narrow band of Stump sandstone, which is succeeded on the northeast by a strip of the lower Ephraim conglomerate. Much of the Ephraim conglomerate, as known farther southeast, and the other members of the Gannet group are missing and probably also some of the beds of the Wayan formation. Thus a thrust fault of considerable magnitude, the stratigraphic throw of which perhaps exceeds 5,000 feet, probably separates the conglomerate from the Wayan formation to the east.

Northeast of the conglomerate lie sandstones and a limestone band of variable width, which are believed on lithologic grounds to correspond with members of the lower division of the Wayan formation as exposed in the Freedom and Lanes Creek quadrangles (see p. 106), though they may correspond with the Homer limestone member. The fractured condition of the limestone and its irregular development probably indicate faulting, and a thrust fault is accordingly drawn between it and the other portions of the Wayan to the east. The throw of this fault is unknown, but may amount to several thousand feet.

The thrust faults indicated in the structure section B–B′ and discussed above are believed to be associated with the great thrust zone known as the Bannock overthrust, which is described on page 150. The smaller normal faults are probably the result of the fracturing of the upper thrust block and the jostling of the resulting smaller fault blocks along the main planes of thrusting.

Northeast of the eastern branch of the supposed Bannock overthrust the Wayan formation is thrown into a series of folds, the axes of which presumably cross the line of the structure section. The lines A–A′ and B–B′, though offset, practically give a continuous geologic structure section across the northwestern part of the Caribou synclinorium, as exposed in the region described in this report.

About 2 miles northwest of the line of section B–B′ (pl. 2) the sedimentary formations other than the Wayan pass beneath the basalt of Sheep Mountain. Small patches of Portneuf limestone, Stump sandstone, and Ephraim conglomerate occur at the margin of the basalt. These beds are separated by a basaltic tongue from their southeastward representatives and are out of line with them. A normal cross fault, with downthrow on the southeast, is postulated to account for the observed offset. Lava appears to have issued along this fault, as suggested by the manner in which basalt embays the sediments along the fault line. The fault probably also offset the Nugget sandstone, as suggested by the sharp angular encroachment of the basalt on the sandstone. The intersection of this fault with the thrust fault to the southeast presumably supplied the means by which the basalt found its way to the surface along the thrust fault, as above described.

The structure described along the line B–B′ continues with some modification into the northern part of the Little Valley Hills. Several of the faults already described combine southward, and a branch fault cuts the exposed formations in such manner as to cause a reversal in the order of their occurrence along the west base of the hills. The resulting changes are shown in the structure section drawn along the line C–C′ (pl. 11).

The older formations, at the southwest end of the section, are concealed by basalt in Cranes Flat. At the base of the slope issues a spring, which may mark the position of a fault not otherwise suggested, and a ledge of Portneuf limestone that dips northeastward is exposed. Farther up the slope the Portneuf limestone dips southwestward, at first steeply and then more gently. Then follow the Timothy sandstone, Triassic (?) formations, and Nugget sandstone in ascending order, but the Wood shale is only partly represented and is absent a short distance northwest and southeast of the line of the section. Hence a fault is indicated. The formations named dip northeasterly near the fault, and on the sidehill to the south the dip of these beds steepens. All beds are overturned, except at the base of the slope and in the Nugget east of the fault. The structure thus appears to indicate the northeast flank of a faulted anticlinorium, the axial plane of which is inclined northeastward. No dips were measured in the area of Nugget sandstone east of the fault, but from the dip in the Twin Creek area, about three-fourths of a mile south of the line of the section and of the Nugget in section 36 to the north it seems probable that the dip is southwestward and that the sandstone forms part of a broken syncline.

A small patch of Higham grit and associated Timothy sandstone occurs in the eastern part of the Nugget sandstone area. This patch may represent part of a small rock slice, otherwise eroded, which now lies upon the Nugget sandstone as suggested in the structure section, or it may represent part of the underlying fault block which has been exposed by the erosion of part of the overlying block. The last alternative is hardly probable because of the proximity of the Wayan formation.

East of the Nugget area lies the upper division of the Wayan formation. The dips near the fault are generally southwesterly, but they differ greatly in short distances. These differences may be in part due to faults, but folding has also occurred. The southwesterly dips near the fault indicate that such folds would be inclined toward the northeast.

Upon the assumption that as much as 5,000 feet of the Wayan formation is present, which would include only about 2,000 feet of the upper division, the stratigraphic interval represented by the fault would be somewhat more than 13,000 feet. Upon the assumption of the postulated structure as shown in the section along the line C–C′ (pl. 11), without allowing for further folding in the lower fault block, the displacement along the fault plane would be about 3 miles. This amount would represent a minimum figure for the displacement. The actual amount might be much greater.

Little Valley district.—As in the Cranes Flat district, only the southwest border region of the Caribou synclinorium is exposed in the Little Valley district, which includes the southern part of the Little Valley Hills, called Gray's Lake Ridge by St. John.[3] The geologic structure is complex, as shown by the structure section along the line E–E′. At the west base of the hills lie southwesterly dipping Carboniferous limestones and sandstones as shown by St. John, who draws a normal fault with northeastward downthrow between them and the rocks to the northeast, which he assigns to the "Jura-Trias" and shows as having southwesterly dips. (See fig. 14.)

Detailed studies of the region have shown that the composition and structure of the Little Valley Hills is much more complex than was supposed by St. John. The attitude of the Carboniferous rocks suggests that they form the west limb of a broken anticline. The fault east of the Carboniferous, which is largely concealed by igneous rock and Quaternary deposits, may be normal, but the irregularity of the boundary between the Wells formation and the Ephraim conglomerate in the region of sec. 3, T. 5 S., R. 42 E., suggests that it is more probably an overthrust. The thickness of the missing beds which should intervene between the Brazer limestone and the Ephraim conglomerate amounts to about 14,000 feet and indicates that the fault represents one of the major displacements of the region. This fault is regarded as perhaps the main branch of the Bannock overthrust.

Northeast of the fault just mentioned and just off the line of the section to the northwest lies a small area of Twin Creek limestone. This area appears to be isolated from other Twin Creek areas and is doubtless in fault relation with the adjacent Ephraim conglomerate. Possibly it may be connected beneath the rhyolite with larger areas of Twin Creek to the north in some such manner as is suggested on the map. Along the line of the section the conglomerate succeeds the Carboniferous beds with a dip that is supposed to be southwesterly but changes to easterly near the contact with the Stump sandstone, which thus appears to be overturned southwestward at that place. The northeast border of the Stump sandstone area is interpreted as a thrust fault of small displacement, probably the continuation of the fault in the valley to the northwest. Southeastward the discordant dips along the Stump and Ephraim contact and the occurrence of rhyolite a mile and a half distant suggest the continuation of the fault in that direction. It may connect with the main overthrust, as tentatively shown on the map.

The Ephraim conglomerate and Stump sandstone that next appear along the line E–E′ have gentle southwesterly dips and form the southwest limb of an anticline, the axis of which shows in the hills to the northwest and southeast but in the line of the section is cut out by a thrust fault, which is believed to be another branch of the Bannock overthrust and which brings the Preuss sandstone over beds of the upper division of the Wayan formation. The beds cut out by the fault probably represent a thickness of 6,500 feet or more.

The Wayan formation east of the last named fault has generally southwesterly dips, but these are somewhat variable, and they may indicate minor folds inclined northeastward. About three-quarters of a mile northeast of the last-named fault there is another fault, interpreted as normal with downthrow to the northeast, which brings in Stump and Preuss sandstone and which is believed to represent a part of the upper fault block of the previously described thrust fault. The Stump and Preuss have anticlinal structure, and a narrow strip of Ephraim conglomerate extends along the east limb. The Ephraim in turn gives way northeastward to Wayan débris and basalt, so that another normal fault with downthrow to the southwest is postulated to account for the relations of the Ephraim and Wayan. The structure of the eastern part of the down-faulted area is obscure because of vegetation and lack of outcrops. The relations above

[3] St. John, Orestes, op. cit., p. 357.

outlined are based on the arrangement of the débris of the respective formations. The supposed normal fault near the end of the line E–E′ (pl. 11) is favorably situated to produce the westward-facing scarp that borders the basalt in that region. If produced northwestward it falls in line with prominent scarps in the basaltic hills north of Little Valley and in the upper valley of Homer Creek. There seems a probability that this fault may have produced the scarps noted.

The fault at the southwest border of the down-faulted area, near the northeast end of the line E–E′ may be of earlier date, for its topographic effects are apparently obliterated in the line of the section. It should be noted, however, that it occurs in relatively weak sedimentary rocks, which would be eroded much more readily than the hard basalt. It is probably cut off on the north by the normal fault above described.

Along the general crest of the Little Valley Hills about 2 miles northwest of the line E–E′ is a complexly folded and faulted area that involves the Jurassic formations and the Ephraim conglomerate. Closely appressed folds, which apparently originate as cross folds athwart the general structural trend of the region, have been broken by several faults. Considerable portions of the faulted folds are concealed by a large area of rhyolite. Hypothetical connections of faults beneath the rhyolite are suggested by dotted lines on the map.

Tincup River district.—In the northeast corner of the Lanes Creek quadrangle Tincup River turns from a southeasterly to a northeasterly course and then flows through the northwestern part of the Freedom quadrangle. The river in its upper course lies somewhat east of the main axis of the Caribou synclinorium, represented by the Williamsburg syncline and parallel with it. After the river turns eastward it crosses the eastern part of the synclinorium and produces a series of fine exposures of the Cretaceous beds, chiefly of the lower division of the Wayan formation.

The structural details of the Williamsburg syncline have not been worked out. The general relations of the syncline are shown in structure sections H–H′ and I–I′ (pls. 4 and 11). To judge from the structure of the shallower portions of the Caribou synclinorium, as indicated in structure sections J–J′, K″–K‴, and L–L″ (pls. 5 and 11), the structure of the Williamsburg syncline is probably much more complex than represented, and the syncline itself is perhaps not so deep. Sections I–I′ and J–J′ give practically a complete section across the synclinorium.

East of the Williamsburg syncline lies a broad anticlinorium marked by a number of subordinate folds. The most conspicuous of these folds is Bear Canyon anticline, in the axial region of which, in Bear Canyon near the center of section J–J′ (pl. 11), occurs a fine exposure of limestone. This fold is bounded on the east by a small fault that is exposed in Tincup Canyon and here produced to the line of the structure section. The limestone lies near the base of the recognized Wayan. Farther east the structure is generally synclinal and the higher beds include most of the lower division of the Wayan. Still farther east occur two normal faults that bring in yellowish sandstones on the east against red beds that are supposedly higher on the west. East of the yellow sandstones lie limestones and shales that are stratigraphically lower and sharply folded. These two faults continue southeastward along the east side of the South Fork of Tincup River. The area of folded limestone is well exposed in Tincup Canyon. (See pl. 40, *B*.)

East of the Wayan limestones and shales occurs a steeply dipping series of beds of the Preuss and Stump sandstones, which form the east flank of a broken anticline, inclined gently northeastward. This anticline is bordered on the east by a syncline that includes members of the Gannett group and is probably broken by the strike fault that farther southeast causes the repetition of the Stump and Preuss sandstones.

The Bechler conglomerate of the Gannett group is in contact on the east with limestones, conglomerates, and sandstones that are assigned to the Wayan formation. The limestone resembles lithologically the limestones of the Gannett group but appears to belong to a series to the east which with little doubt is Wayan. The contact of the Bechler with the limestone is apparently a fault, and the limestone wedges out against it about half a mile southeast of the canyon. The fault is interpreted as normal and as having a downthrow to the northeast. The dips in the Wayan east of the fault are steep but become more gentle to the northeast. The structure is synclinal.

South Caribou district.—The portion of the Caribou Range south of Tincup River in the Freedom quadrangle may conveniently be described as the South Caribou district. It has a very complex structure, which is shown in part in structure sections K″–K‴ and L–L″ (pl. 11).

The westernmost notable fold is the Bechler Creek syncline, which in the line of section K″–K‴ is occupied by beds of the Wayan formation whose variable dips appear to indicate small undulating folds. These beds overlie unconformably a syncline in the Gannett group, the structure of which is projected to the line of section K″–K‴. The southern part of the syncline has synclinorial structure and is broken by faults, as shown in section L–L″. A branch fault from the Bannock overthrust enters the Bechler Creek syncline and may interrupt its continuity.

The eastern margin of the syncline is marked by a fault, which farther to the southeast cuts across several members of the Gannett group and accompanying Jurassic beds and is believed to be normal. Just west of the place where the normal fault cuts the line of section K″–K‴ a limestone bed of the Wayan formation makes a fine dip slope on the southwest flank of the hill. The eastward extension of the hill is formed in part by the Peterson limestone of the Gannett group, which the Wayan limestone bed closely resembles. About 2 miles southeast, in the area mapped as Ephraim conglomerate, there are small exposures of similar limestone which have somewhat different stratigraphic relations and are assigned with clastic beds to the conglomerate.

East of the normal fault lies the South Fork synclinorium, which is occupied by members of the lower division of the Wayan formation and is broken by normal faults in the vicinity of the South Fork of Tincup River. About a mile southeast of the line of section L–L″ (pl. 11) the Wayan formation is faulted out, but the main axis of the synclinorium is continued southward by the Spring Creek syncline. The eastern part of the synclinorium along the line K″–K‴ includes a belt composed of several limestone bands that may represent distinct beds or perhaps repetitions of the same bed by close folding. They were at first included in the Gannett group, but upon revision in the field were assigned on lithologic grounds to the Wayan. Close folding, in at least parts of this belt, is shown by the exposure on the north side of Tincup Canyon. (See pl. 40, *B*.) The limestone bands are locally cut out by the east boundary of the synclinorium, which is a normal (?) fault that has a strong southwesterly hade. Farther to the south this fault is cut by a normal fault which has a downthrow to the west. This normal fault forms the boundary of the synclinorium at the line of section L–L″.

The Deer Creek anticlinorium, which lies east of the South Fork synclinorium, is composed of members of the Gannett group, in which the Preuss and Stump sandstones are closely folded and broken by normal faults. In the line of section K″–K‴ the east flank of the anticlinorium is overlapped by beds that contain a limestone band, which were at first regarded as a portion of the Gannett group faulted against the other members to the west. Upon revision in the field these beds were assigned to the Wayan formation and considered unconformable with the Bechler conglomerate. In the line of section L–L″ a broad cross fold, hardly more than slight upwarping, makes a faint angle with the line of the section. Two synclinal areas of Wayan that probably were once connected are now separated, as a result of erosion along this cross fold, and the canoe-shaped and cigar-shaped folds of the Gannett beds are exposed. The unconformity of the Wayan formation upon the Gannett group is well displayed where the Gannett beds emerge from the Wayan cover.

These synclinal areas may together be called the Smith Creek syncline. The pitch is southeastward and gentle, so that the southern member of the syncline expands in that direction. It is, however, partly overridden by the Jurassic thrust block of the Auburn fault and passes beneath Tertiary and Quaternary beds west of Auburn. The Smith Creek syncline is probably a synclinorium, but the details of its structure have not been worked out.

The Miller Creek syncline, which lies east of the Deer Creek anticlinorium, is bounded by a normal fault on the west where it is crossed by section K″–K‴ and probably has synclinorial structure, though the details have not been worked out because of the lithologic similarity of the beds involved. Near the eastern margin it is broken by another normal fault. Both these faults have relatively small throw. Near the eastern edge a limestone band of the Wayan lies with supposed unconformity against Bechler conglomerate and farther north against Peterson limestone, where, because of lithologic similarity, it is difficult to distinguish the two formations. Gannett formations and Stump sandstone form the eastern margin of the syncline, which is overlapped by Jurassic beds that compose the thrust block of the Auburn fault.

Along the line L–L′ the Miller Creek syncline suffers a slight constriction because of the cross axis that separates the two portions of the Smith Creek syncline. The eastern boundary of the syncline is formed by an anticline composed of Ephraim conglomerate. The anticline in turn is bordered by a narrow synclinal strip of Wayan beds that are connected on the north with the Miller Creek syncline.

The Auburn fault forms the east boundary of the Caribou synclinorium in the Freedom quadrangle.

Spring Creek syncline.—The Spring Creek syncline is the southeastward extension of the South Fork synclinorium, which itself is probably the main axis of the greater Caribou synclinorium. The syncline extends from the area near the central part of the Freedom quadrangle southeastward across Stump Canyon, where it is well exposed, into the Gannett Hills and along Spring Creek nearly through the Crow Creek quadrangle, a distance of about 25 miles. About 2 miles north of the ranger station in Stump Valley the syncline is offset by a fault that probably has resulted from a minor cross fold similar to that which deformed the Smith Creek syncline. Southward from this fault it continues without further offset, but it undergoes different modifications that are due chiefly to its relation to the fault zone of the Bannock overthrust, which forms its western boundary for much of its length. It is represented in three of the geologic structure sections—N–N′, O′–O″, and S″–S‴ (pls. 5, 7, 11, and 12).

Where the Spring Creek syncline is crossed by the line of section N–N′, near the south border of the

Freedom quadrangle, it forms a symmetrical upright fold about 2½ miles wide, composed of formations of the Gannett group, the highest of which is the Draney limestone.

About 2½ miles farther south, at the line O′–O″ (pl. 12), the syncline is compressed along the west border as a result of the conditions that produced the Bannock overthrust. The uppermost beds are limestones that upon careful field examination were referred to the Draney. This interpretation requires a fault to separate the Draney limestone from the surrounding Ephraim conglomerate. Considerable lithologic resemblances, however, exist between the Draney and Peterson limestones. Should this area prove to be Peterson limestone faults would be required only at its southern and northeastern boundaries. At the south it is faulted against Jurassic beds and at the northeast against sandstones of the Wayan formation.

Along the State line in the region of the structure section this syncline is broken by a fault which is interpreted as normal and as having a downthrow to the east. The vertical displacement is nearly 2,000 feet. About 1½ miles south of the line of the structure section a cross fault with downthrow to the north cuts out beds higher than the Peterson limestone.

The section S″–S‴ crosses the Spring Creek syncline nearly 7 miles south of the line of section O′–O″ (pl. 12). Here the syncline is more open and undulatory, and the highest formation is the Ephraim conglomerate. The normal fault continues southward and causes a small displacement. The syncline narrows gradually southward and passes beyond the area here described.

HEMMERT ANTICLINE

The easternmost fold in the region described in this report is the Hemmert anticline, which extends northward from Auburn Hot Springs across Hemmert Canyon to the mouth of Smith Canyon, a distance of about 6 miles. The maximum width of the anticline is about 1 mile. The Rex chert is exposed near the Hot Springs, but farther north the beds are all Triassic. The chert is faulted against the Woodside shale. The occurrence of a chert band in the sag south of Hemmert Canyon suggests that this fault may continue with small throw throughout the axial region of the fold. Deposits of travertine occur at the hot springs at the south and at the mouth of Smith Canyon to the north. The anticline is bounded on the west by a normal fault with downthrow to the west that brings Nugget sandstone into contact with the Thaynes group. The anticline and its relations to the structures farther west are shown in structure section L′–L″ (pl. 11).

BOULDER CREEK ANTICLINE

The Boulder Creek anticline, which is well exposed in Boulder Creek, lies just west of the Bannock overthrust zone, which serves as the general boundary between the Caribou synclinorium on the east and the folded older rocks to the west and southwest. The Boulder Creek anticline has a curved course southeastward from the head of Browns Canyon, in the Lanes Creek and Freedom quadrangles, to Smoky Canyon, in the Crow Creek quadrangle, and thence southward and southwestward to the head of Crow Creek, in the Montpelier quadrangle, a distance of about 32 miles. It is relatively narrow, generally not more than 2 miles wide. The oldest rocks exposed by it are Brazer limestone near the south end, and the youngest rocks are Nugget sandstone near the north end. The pitch is gentle, averaging about 260 feet to the mile, or about 5 per cent toward the north. The anticline is shown in structure sections K″–K‴, L–L′, N–N′ (pl. 11), and O′–O″, S″–S‴, and T′–T″ (pl. 12).

The Boulder Creek anticline is generally unsymmetrical or inclined eastward, but as exposed in Webster Canyon along the line N–N′ (pl. 11), it is a low, broad arch. The eastern limb is broken by a fault practically throughout its course. At the line of section T′–T″ the anticline is overturned eastward. A cross fold gently arches the axis of the anticline from the vicinity of Alleman's ranch to the mouth of Deer Creek, permitting the exposure of the Brazer limestone.

Northward from Crow Creek the Boulder Creek anticline is flanked by the Phosphoria formation or by higher beds underlain by phosphate. At Smoky Canyon the phosphate beds cross the axis of the anticline. Northward from that canyon they overspread the anticline at gradually increasing depth. Noteworthy exposures of postphosphate formations reveal the anticlinical structure in Webster Canyon, Horse Canyon, and Boulder Canyon.

WEBSTER SYNCLINE

The main axis of the Webster syncline extends from the vicinity of secs. 13 and 14, T. 6 S., R. 44 E., Lanes Creek quadrangle, in a curving course southeastward and southward nearly through the Crow Creek quadrangle, a distance of about 27 miles. The fold is named from the Webster Range, in which it lies.

On the south the syncline is cut off by a fault, a branch of the Bannock overthrust. At the north a branch axis projects northwestward in T. 6 S., R. 44 E., toward the Lanes Butte syncline, with which the branch axis was probably once continuous. One or more faults now intervene between the two parts of the original fold, which are also separated by the broad alluvial deposits of Upper Valley and Lanes Creek. The Little Gray anticline intervenes between the Lanes Butte syncline and the Webster syncline. These folds will be described separately.

The Webster syncline differs in width and character in different parts of its course. At the south end, where it is cut off by the fault, it is barely a mile wide. Northward it narrows and is nearly cut through by

Wells Canyon in the region where the cross axis that deforms the Boulder Creek anticline affects this fold also. The south flank of the cross fold and two minor cross folds are shown in structure section V–V′ (pls. 7 and 12). From Deer Creek northward it expands and reaches a maximum width of about 3½ miles in the region of Bacon Creek, where it bifurcates northwestward, as previously stated. The east branch turns northward and approaches the axis of the Boulder Creek anticline.

The lowest beds exposed are the phosphatic shales of the Phosphoria formation and the highest are Twin Creek limestone. From the constriction at Wells Canyon to the region north of Bacon Creek the pitch is estimated at 350 feet to the mile, or about 6⅔ per cent, toward the north. The syncline is of great economic importance because of the great body of valuable phosphate rock contained in it. The northward pitch of the syncline makes these deposits lie progressively deeper in that direction, so that a short distance north of the line N–N′ they lie at depths greater than 5,000 feet. Along the margins of the syncline they extend a somewhat greater distance before reaching that depth. The Bannock overthrust, which is believed to pass beneath the syncline, may cut out the phosphate beds in the deeper portions.

The attitude of the syncline changes along its course. At the south, where it is crossed by the lines T′–T″ and S″–S‴ (pl. 12), the axial plane is inclined eastward. Farther north, at the lines O′–O″, N–N′ (pl. 12), and L–L′ (pl. 11), the syncline is relatively upright and is divided into two subordinate shallow synclines with an intervening low anticline that brings the *Meekoceras* zone to the surface west of the head of Smoky Canyon. At the line K″–K‴, which crosses both branches of the syncline, both folds are unsymmetrical and are inclined westward.

LITTLE GRAY ANTICLINE

The Little Gray anticline has a recognized length of about 18 miles from the southwest slope of the Little Valley Hills in the Cranes Flat quadrangle southeastward along Little Gray Ridge and into Upper Valley, where it produces the bifurcation of the Lanes Butte and Webster synclines. It may continue southward as the low anticline recognizable as a subordinate feature in the Webster syncline. Its width ranges from 1 to 2 miles.

The anticline is interrupted by faults and by minor folds. In the Little Valley Hills it is bounded on the west flank by the Chubb Springs normal fault and is broken on the east flank by a great thrust fault, as shown in structure section E–E′ (pl. 11). In Little Gray Ridge the fold is offset by two normal faults and broken between them along the axis by a supposed normal fault. At the southeast tip of Little Gray Ridge it is broken by normal faults at the west border and by thrust faults in the axis, as suggested in structure section H–H′ (pl. 11). At the head of Gravel Creek the Little Gray anticline is crossed by a subordinate synclinal axis and is relatively broad and flat, as shown in structure section I–I′ (pl. 11). In Lanes Valley it is joined by other subordinate axes, and in the same locality it is interrupted by one or more faults.

The lowest beds exposed by it are of the Madison limestone in Little Gray Ridge; the highest are of the Nugget sandstone in sec. 27, T. 6 S., R. 44 E. The pitch is southeastward and is estimated to average about 500 feet to the mile, or about 9 per cent.

LANES BUTTE SYNCLINE

The Lanes Butte syncline, which is named from its most prominent topographic feature, has a continuous exposed length of about 9 miles from the lava-covered area in the northwest part of the Lanes Creek quadrangle southeastward to Upper Valley, where it becomes the west branch of the Webster syncline, as shown in structure section K″–K‴ (pl. 11). It continues northwestward beneath the basalt an unknown distance, but exposures of Woodside shale and of the Thaynes group northeast of Pelican Ridge indicate its occurrence at least as far northwest as the pass between Pelican Ridge and Limerock Mountain 8 miles farther in that direction. It is represented beneath the basalt in structure section E–E′.

The northwest extension of the syncline is bounded by the Chubb Springs and Limerock normal faults and constitutes the Meadow Creek graben, described below. A thrust fault in secs. 3 and 4, T. 6 S., R. 43 E., crosses the syncline and causes beds of the Woodside and lower Thaynes to override middle and upper Thaynes, as shown in structure section H–H′ (pl. 11). An interesting detail of the contact between the Thaynes and the Woodside may be noted in the ravines in the NE. ¼ sec. 3, T. 6 S., R. 43 E. Here the *Meekoceras* zone, which marks the normal boundary between the two formations, emerges from the margin of the Thaynes thrust block. The boundary faults die out southeastward, and the syncline broadens to a maximum width of about 3 miles at a point about 1 mile southeast of the line of structure section I–I′. The Triassic (?) formations there form an irregular canoe-shaped mass, which is faulted along the southeast side.

The syncline is presumably underlain by valuable deposits of bedded phosphate rock, but in a strip a mile or more wide along much of the axial region these deposits lie at depths greater than 5,000 feet, the maximum depth regarded as workable under existing regulations of the Geological Survey. Moreover, the Bannock overthrust, which is believed to pass beneath the syncline, may cut out some of the phosphate.

SNOWDRIFT ANTICLINE

The Snowdrift anticline is one of the most persistent structural features of the region and may be traced in the area mapped for about 55 miles in a curving course first southeasterly and finally southwesterly. It takes its name from Snowdrift Mountain, near the south end, its highest and most conspicuous part. (See pl. 34.) Although the anticline is interrupted here and there by basalt or alluvium, there is little reason to doubt its essential continuity from the ridge of Carboniferous rocks, where it enters the region in sec. 13, T. 4 S., R. 40 E., in the Cranes Flat quadrangle, to the point where it terminates against the Bannock overthrust southwest of Meade Peak, in the Montpelier quadrangle. Besides the ridges named it includes Wilson, Pelican, and Rasmussen Ridges. The anticline is offset by cross faults in the eastern part of T. 4 S., R. 40 E., at each end of Pelican Ridge and in Upper Valley. It is also affected here and there by broad, low cross folds that cause downwarpings or upwarpings of its axis, but on the whole the axis remains nearly horizontal for considerable distances. All the ridges named consist chiefly of Carboniferous rocks. The anticline is relatively narrow, generally less than 1½ miles wide.

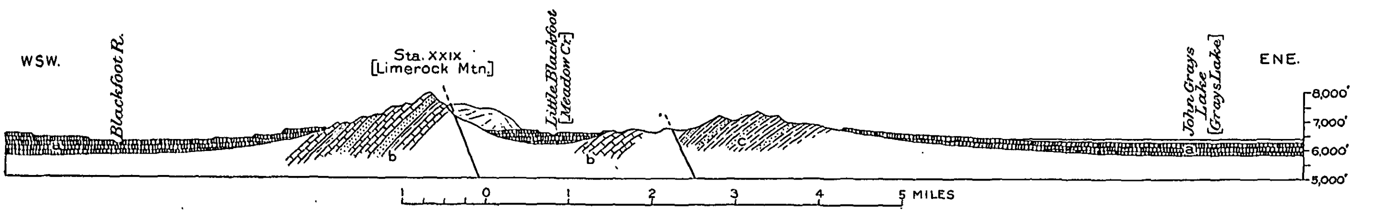


FIGURE 14.—Geologic structure section through Limerock Mountain, St. John's Station XXIX. *a*, Basalt; *b*, Carboniferous; *c*, Jura-Trias. (After St. John)

St. John [4] used Limerock Mountain as one of his stations (XXIX) and measured and figured a section across the ridge a short distance south of that point northeastward to Grays Lake. The structure section is described as drawn at right angles to the trend of the ridge and thus should correspond quite closely in direction with the structure section of the present report drawn along the line E–E′ (pl. 11). St. John's section is reproduced (fig. 14) for comparison. He shows the ridge as a monocline of Carboniferous rocks, down-faulted on the northeast. More detailed study of the ridge has shown that its structure is in reality anticlinal, and the crest of the mountain ridge is formed of massively bedded Brazer limestone. The anticlinal structure is clearly and admirably shown at Limerock Mountain (see pl. 35, *A*) but may have been mistaken by St. John for a minor fold. Farther northwest along the ridge the contacts of the Brazer with the Wells are believed to be faults, for beds of the lower Wells are missing. At Limerock Mountain these faults may be present but are not so clearly recognizable. Concealed faults described later occur along the base of the ridge on each side. These structures are believed to continue northwestward beneath the lava to the neighboring Carboniferous ridge and to be offset in the eastern part of T. 4 S., R. 40 E., by a concealed fault with upthrow to the northwest, which raises the anticline sufficiently to bring to the surface broad masses of Brazer limestone.

Pelican Ridge continues southeastward the general structure of the ridges just described. As shown in structure section G–G′ (pls. 3 and 11), the ridge is sharply anticlinal and has normal faults and downthrow on each flank. The throw of these faults is not known, but it is estimated at 3,000 to 4,000 feet. The Brazer limestone does not reach the surface along the main ridge, but it does appear in a small isolated exposure in the basalt in the NE. ¼ sec. 14, T. 5 S., R. 41 E.

Divergent dips on the northeast flank of the ridge indicate the presence of at least two subordinate folds, a syncline and an anticline, for the easternmost exposures of the Wells are of beds stratigraphically high in the formation.

On the southwest flank of Pelican Ridge, in the line of the structure section, the uppermost beds of the Wells are overturned southwestward and with the Phosphoria formation apparently dip northeastward into the ridge. The phosphate rock here is badly mashed and is probably closely folded, as suggested in the structure section. This structure suggests the possibility of fan folding, as in the region of Sugarloaf Mountain in the Cranes Flat quadrangle. If a fan structure ever existed here, however, the larger part of it lay above the level of present erosion and has been worn away.

Rasmussen Ridge is shown in structure sections H–H′, I–I′, and K′–K″ (pls. 4 and 11). The Limerock fault on the northeast flank dies out within a mile or more of the line of section H–H′, but the Enoch Valley fault on the southwest probably continues through Rasmussen and Upper Valleys. At the line of section I–I′, (pl. 11) only the Enoch Valley fault cuts the anticline. Here the fault lies within the Wells formation, but to the southeast it cuts out the Phosphoria for about 2 miles along the east side of Rasmussen Valley. The drag folds shown in the structure section on either side of the anticline are introduced to account for the unusual width of the Woodside belts. The existence of such folds along the east flank at least is proved by the exposure of the small anticline of Rex chert in the NE. ¼ sec. 26,

[4] St. John, Orestes, op. cit., pp. 358–359 and pl. 16 B.

T. 6 S., R. 43 E., about 1½ miles southeast of the line of the section. It may be, however, that the Woodside is really thicker than represented. At the time this mapping was completed the thick sections of Woodside west of Reservoir Mountain and east of the Blackfoot Reservoir were not known.

Southeast of the line K′–K″ the higher formations may close around the Wells, as suggested by dotted lines on the map (pl. 4), or the Carboniferous beds may continue beneath the alluvial cover through Upper Valley to the exposures in the southwest corner of the Freedom quadrangle. The transverse Blackfoot fault, which produces such noteworthy effects in Dry Ridge to the west, crosses the anticline, and it seems probable that the down-thrown block, on the north at least, has been sufficiently depressed to permit the erosion of the valley in beds higher than the Carboniferous formations.

A faint upwarping of the axis of the anticline brings Carboniferous beds to the surface on the east side of Upper Valley, where they are broken by faults, as shown in structure section L–L′ (pls. 5 and 11). Southward the axis is again depressed and the anticline is overlapped by Woodside shale. This depression is caused by a broad, shallow transverse syncline that produces the maximum expansion of the Webster syncline to the east and corresponding effects in the folds to the west. Near the Ranger station in Diamond Valley the Carboniferous beds emerge again and continue southward throughout the remaining course of the anticline. At the line of section O′–O″ the anticline is surmounted by a minor anticline that causes a relatively sharp northward projection of the line of outcrop of the Phosphoria formation. The generally broad and low form of the main anticline at this point may be contrasted with its form farther northwest and south and is probably due to the proximity of the transverse syncline mentioned above.

At the lines of sections S″–S‴ and T′–T″ (pl. 12) the anticline is narrower and the flanks steeper. The forms of the synclines on either hand are such as to suggest that the anticline was originally a fan fold and is now so eroded that, as in Pelican Ridge, only the lower compressed portion of the fold remains. The Brazer limestone and the lower, more massive beds of the Wells formation constitute the axial region of the anticline in this part of the region and produce the ridge called Snowdrift Mountain, which culminates in Meade Peak.

GEORGETOWN SYNCLINE

The Georgetown syncline, which is named from Georgetown Canyon in the southeast corner of the Slug Creek quadrangle, where it was first recognized, has an exposed length of approximately 40 miles. It extends from the basalt-covered area northwest of Pelican Ridge in the Henry quadrangle southeastward and finally southwestward until cut off by a branch of the Bannock overthrust in the Georgetown Canyon district. Like the Snowdrift anticline it is offset by transverse faults and modified by longitudinal faults and folds and by transverse folds.

There is little doubt that the main structure continues northwestward beneath the basalt beyond the limits of the area mapped. St. John [5] describes and figures a fault between Carboniferous rocks at his Station XI and "Jurassic" rocks to the southwest. Station XI was located probably on the continuation of the Snowdrift anticline a short distance west of the Cranes Flat quadrangle. The so-called Jurassic rocks contain fossils now recognized as belonging to the Thaynes group. The structure is therefore generally similar to that at Pelican Ridge and Limerock Mountain and is probably the northwestward continuation of it. Several faults project from the area of sedimentary rocks to the southeast into the basalt-covered area, so that the concealed part of the syncline may be much broken. Part of this supposed structure is represented in structure section E–E′.

The structure of that part of the syncline west of Pelican Ridge is shown in the section along the line G–G′ (pl. 11). Here the fold is overturned toward the southwest and is broken by faults. The eastern boundary of the syncline is the northwestern continuation of the Enoch Valley fault, which is described below.

The siliceous limestones of the upper Thaynes along the crest of the Triassic ridge are succeeded on the east by yellow sandstones probably of the lower Thaynes. There does not seem to be room enough for the beds that should intervene. Hence the normal fault with downthrow to the southwest is postulated. Farther northwest the *Meekoceras* zone is cut out in all but a few places. Thus the boundary between the Thaynes and the Woodside on the east is doubtless a fault. The trace of the fault plane indicates a moderate easterly dip. The Woodside shale along the outlying hills to the southwest is apparently about 2,000 feet thick as in Reservoir Mountain. The attitude of the Woodside and the position of the *Meekoceras* zone indicate that the Phosphoria formation would rise to the base of the basalt and alluvium beneath the reservoir unless an unsuspected fault intervenes.

The structure of the syncline in Enoch and Rasmussen Valleys is synclinorial, as shown in the sections along the lines H–H′, I–I′, and K′–K″ (pl. 11). A thrust fault along the western flank divides the synclinorium into two synclinoria. The structure of the western fold is marked by rather closely appressed minor folds, inclined northeastward. The eastern fold or main synclinorium is relatively more open and more nearly upright.

South of Rasmussen Valley the syncline is offset by the Blackfoot fault, which is described below. Where

[5] St. John, Orestes, op. cit., pp. 345–346.

the beds are crossed by the line of section M–M′ (pl. 11), the structure is synclinorial and the fold as a whole is inclined eastward. The arrangement of the subordinate folds, as shown in the structure section, is determined by the available dips and by the fact that except in one small area nearly a mile and a half northwest of the line of the section the syncline is not deep enough to include the upper Thaynes. The east flank of the synclinorium is supposed to be broken in some such manner as indicated in the structure section by normal and reverse faults in Upper Valley. Part of the east limb of the synclinorium is shown in structure section L–L′.

The Georgetown syncline has a maximum breadth of about 2 miles at a place about 2½ miles north of the line of section O–O″ (pl. 12). It is there crossed by the same broad, shallow syncline that depresses the axes of the Snowdrift anticline and the Webster syncline. At the line O–O″ the syncline has an apparently more simple and open structure than at places illustrated by structure sections farther north or south, perhaps owing to the influence of the transverse syncline.

At the line S″–S‴ (pl. 12) the syncline is less than a mile wide and is overturned eastward. At the line T–T″ it is about 2 miles wide and has a synclinorial structure inclined eastward and faulted. A subordinate anticline at the south end divides the fold into two synclines, which, together with the anticline, produce a zigzag line of outcrop in the Phosphoria formation.

Throughout much of the course of the syncline beds of the Thaynes group are exposed. From the south end of the syncline to the point of maximum width, a distance of about 18 miles, the pitch averages about 200 feet to the mile, or somewhat less than 4 per cent. Northward the fold is more nearly horizontal.

The Georgetown syncline has great economic importance because of the great body of high-grade bedded phosphate rock that it contains. With the exception of a strip about half a mile wide in the deeper part of the syncline west of Pelican Ridge, the phosphate lies at a depth less than 5,000 feet, the limit of depth of beds considered workable under present regulations of the Geological Survey. Possibly, however, some of the phosphate may be cut out by the Bannock o er hrust, which is believed to pass beneath the syncline.

DRY VALLEY AND WOOLEY VALLEY ANTICLINES

The main part of the Dry Valley anticline extends in a curving course 20 miles southeastward from the Narrows of Blackfoot River until it is cut off by one of the faults in the Georgetown district. For much of its course its axis lies in Dry Valley. At the Narrows it is cut by the transverse Blackfoot fault. Northward from this fault two anticlines that were probably branches of the original fold continue the structure for 1½ and 11 miles respectively.

The longer of these branches is the Wooley Valley anticline, which extends southeastward from the vicinity of Henry and is probably offset by a fault in the southeast corner of T. 6 S., R. 42 E. For about 4 miles southeast of Henry only the east flank of the anticline is exposed, as shown in structure section H–H′ (pl. 11). Farther south it is cut obliquely by a thrust fault at the head of Enoch Valley. Here the anticline is nearly 2 miles wide, strongly inclined eastward, and faulted on the east flank. The Brazer limestone is exposed in the axial region as indicated in structure section I–I′. At the south end the anticline is more compressed and a number of subordinate folds are developed.

The shorter branch, which is really the continuation of the main Dry Valley anticline, is inclined eastward and cut off on the west by a fault that is thought to be a branch of the Bannock overthrust. This fold occupies part of the down-thrown block of the Blackfoot thrust fault and is less than half a mile wide.

The Dry Valley anticline itself occupies the upper block of the Blackfoot thrust fault, and its outcrop has been greatly widened by erosion down the dip. At the fault it is about 3½ miles wide, but where crossed by the line of section M–M′ it is somewhat narrower. The anticline is here really a broad anticlinorium that is developed chiefly in the Wells formation. Numerous minor folds of Brazer limestone are exposed near the line of the section and northward. The pronounced westerly dips at many of these Brazer exposures indicate that they are not mere undulations of the top of the Brazer but probably represent sharp folds of the drag-fold type, as indicated in the structure section.

At the line O–O′ (pl. 12) the anticline becomes lower and less compressed, probably because of the influence of the same transverse syncline that affects the folds to the east, which have already been described. The relative narrowing of the exposure of the Wells in this vicinity is probably due to the same cause. The east side of Dry Valley here occupies the west flank of the anticline, the axis of which lies nearly midway up the west slope of Dry Ridge, and the axial plane is inclined slightly eastward. The subordinate fold shown on the west flank of the anticline in Dry Valley is apparently required by the projected position of the phosphatic shales and the undue width of the belt of Woodside shale. East of the crest of the anticline a minor thrust fault locally cuts out the phosphatic shales.

Farther south the anticline becomes more compressed and more strongly inclined eastward, as shown in structure section S′–S‴. The form of the Georgetown syncline on the east and of the folds still farther east suggests that the Dry Valley anticline, like the Snowdrift anticline, may be the eroded base of a former fan fold.

South of the line S′–S‴ (pl. 12) the area of Brazer limestone in the axial region of the fold becomes wider probably because of the same transverse anticline that causes the pronounced constriction in the Webster syncline. Southward the Dry Valley anticline becomes narrower as the Georgetown and Webster synclines become wider, probably because of another transverse syncline.

At the line of section T–T′ (pl. 12) the anticline is broken by several faults, probably closely related to the Bannock overthrust, which comes to the surface about 1½ miles west of the point where the structure section crosses the anticline.

The Dry Valley anticline throughout its course exposes Carboniferous rocks. With the exception of the gentle undulations produced by the transverse warpings the axis is nearly horizontal.

SCHMID SYNCLINE

The Schmid syncline, which is named from Schmid Ridge, extends from the Blackfoot fault in Wooley Valley southeastward and then southwestward to the Bannock overthrust in the Georgetown Canyon district, a distance of about 20 miles. For the first 14 miles it contains a canoe-shaped body of rocks which belong to the Phosphoria, Woodside, and Thaynes formations and which have great economic value because the extensive high-grade phosphate deposits contained in them are readily accessible and lie at a maximum depth of little more than 3,000 feet. The breadth of this part of the syncline ranges from less than a mile, where it is crossed by structure section K′–K″ (pl. 11) to about 2½ miles in secs. 32 to 34, T. 8 S., R. 44 E. The expansion in width is doubtless due to the same transverse syncline that has depressed the folds to the east in the vicinity of structure section O–O′ (pl. 12), as previously noted. At that line the Schmid syncline is relatively broad and undulatory but somewhat unsymmetrical and inclined westward. Farther north, as shown in structure section M–M′ (pl. 11), it is more closely folded and contains more pronounced subordinate folds. The pitch of the canoe-shaped body is steeper from the south toward the maximum depression than from the north toward the same point. The northerly pitch of the southern part is estimated at 500 feet to the mile and the southerly pitch of the northern part at 300 feet to the mile. The west margin of the syncline is locally broken by thrust faults.

North of the Blackfoot fault the synclinal structure probably continues beneath the alluvium and basalt of Wooley Valley, though offset and perhaps otherwise modified by the fault. The broken syncline at the head of Wooley Valley (see structure section I–I′, pl. 11) may thus represent the northward continuation of the Schmid syncline.

South of the phosphate-bearing portion of the syncline the fold continues for 6 miles and becomes more complex. The minor anticline shown in structure section O–O′ (pl. 12) becomes more pronounced southward and causes the bifurcation of the syncline into two synclines, as shown in structure section S′–S″ (pl. 12). The bottoms of these synclines are probably in part cut out by the plane of the Bannock overthrust, which is thought to come to the surface in secs. 21 and 28, T. 9 S., R. 44 E. Along Slug Creek the western syncline is broken by a normal fault with down throw on the west, so that a broad, shallow, phosphate-bearing syncline is preserved west of the fault. This syncline, which may be called the Dairy syncline from the old dairy in upper Slug Valley, is interrupted by the up-arching of the plane of the Bannock overthrust and contains minor folds and faults.

Farther south, at the line T–T′ (pl. 12), the development of the anticline which separates the two synclines is still more pronounced and causes the exposure of the Brazer limestone. The east syncline, which is the southward continuation of the main Schmid syncline, is relatively narrow, inclined eastward, and broken by faults along the east side. The west syncline is broader and is broken on the west by a fault that is believed to be a branch of the Bannock overthrust, which brings Madison limestone into contact with the Wells formation.

ASPEN RANGE ANTICLINE

The Aspen Range anticline, which forms much of the more rugged portion of the Aspen Range, is best developed in the southeastern part of T. 9 S., R. 43 E., and adjacent territory, where it brings to the surface a broad area of Brazer limestone and farther south of Madison limestone. At the line of structure section S′–S″ (pl. 12) the anticline has the form of a broad, low anticlinorium about 2 miles wide. For about 5 miles southward and perhaps an equal distance northward the form of the anticlinorium remains fairly unbroken. Toward the south, however, it becomes more compressed and is involved in a fault block that is probably part of the Bannock overthrust zone. Its structure at the south is therefore less distinctive, as shown in structure section T–T′ (pl. 12).

Northward from the line S′–S″ the anticline includes mainly rocks of the Wells formation, though a minor transverse faulted syncline brings in beds of the Phosphoria formation in the northeast corner of T. 9 S., R. 43 E. Northward from this area the anticline broadens somewhat, contains numerous minor folds, some of which are deep enough to hold beds of the Phosphoria formation, and is broken by a number of normal faults. The broader part of the fold with its accompanying faults is shown in structure section O–O′ (pl. 12).

North of the line O–O′ the fold becomes narrower and sharper. At the line M–M′ (pl. 11) it is only about a mile wide. The axis appears to lie west of the normal fault beneath the alluvium, for the little knoll of Rex chert in the NW. ¼ sec. 35, T. 7 S., R. 43 E., has an easterly dip. At the line K′–K″ the fold is less pronounced but apparently similar conditions obtain. North of the Blackfoot fault the anticline is doubtless offset like the structural features farther east. Probably it is represented by the faulted anticlinorium west of Wooley Valley, as shown in structure section I–I′.

The total length of the Aspen Range anticline is about 23 miles. It passes beneath cover at both ends. The rocks exposed by it are practically all Carboniferous. The pitch of the fold is northward and gentle and probably does not exceed 200 feet to the mile, or about 4 per cent.

SLUG CREEK SYNCLINE

The Slug Creek syncline extends about 9 miles southeastward from the Blackfoot fault and for much of its course lies along the valley of Slug Creek. Its maximum width is not much more than a mile, but it is economically important because of the high-grade phosphate deposits that it contains. These deposits are relatively accessible and are probably nowhere deeper than 2,000 feet below the surface. The structure is really synclinorial, and the fold is bounded on either side by faulted anticlines. The Slug Creek syncline appears to originate as a shallow subordinate fold in the Aspen Range anticline a little south of the line O–O′ (pl. 12). Northward it grows wider and deeper and reaches a maximum depth somewhere near the line M–M′. Farther north, as at the line K′–K″ (pl. 11) it is somewhat wider. Here it seems to merge with the Trail Creek syncline, from which it is separated by only a subordinate anticline. North of the Blackfoot fault both synclines are concealed by alluvium and basalt.

TRAIL CREEK SYNCLINE

The Trail Creek syncline extends about 13 miles southeastward from the basaltic canyon of Blackfoot River, in secs. 14 and 15, T. 7 S., R. 42 E., up the valley of Trail Creek and into the rugged portions of the Aspen Range. The Trail Creek syncline is really a synclinorium of fairly uniform breadth but widest at the north, where its width is about 3 miles. Its borders are faulted, modified by subordinate folds, and locally made irregular by erosion. Along its west limb a thrust fault cuts out lower Thaynes and upper Woodside beds for much of its length. On the east it is separated from the Slug Creek syncline by a broken anticline that appears to originate at the south as a minor fold of the Aspen Range anticline. The boundary anticline is probably most pronounced about 1½ miles north of the line O–O′ (pl. 12) and is well developed at the line M–M′ (pl. 11). Northward it becomes less conspicuous and at the line K′–K″ (pl. 11) is hardly more than a subordinate fold in the general synclinorium that there includes both the Trail Creek and Slug Creek synclines.

Near the south end a transverse anticline arches up the Phosphoria and Wells formations at the head of Johnson Creek, thus making readily accessible phosphate deposits of the axial region of the syncline. A shallow, broken syncline that contains beds of the Phosphoria formation projects southward for nearly 2 miles beyond the main body of the Phosphate-bearing portions of the syncline. The structural features at the south end of the syncline are shown in structure section S–S″ (pl. 12).

The Trail Creek syncline is important economically because it contains a great body of readily accessible phosphate beds that probably lie nowhere at greater depth than 3,500 feet. The pitch of the syncline is northward and for the 10 miles north of Johnson Creek probably does not exceed 350 feet to the mile, or 6⅔ per cent. The central and northern parts are interpenetrated by broad alluvial valleys that are occupied by Trail Creek and other branches of Blackfoot River.

FOLDS WEST OF TRAIL CREEK SYNCLINE

Several smaller folds, both anticlines and phosphate-bearing synclines, lie between the Trail Creek syncline and the broad, basalt-covered valley to the west. These folds are more or less broken by faults. The anticline which forms the west boundary of the Trail Creek syncline also forms the northwest tip of the Aspen Range and is shown in structure section K–K′ (pl. 11).

The general northwestward pitch of these folds indicates that the basalt-covered area is probably largely underlain by post-Phosphoria formations. The older rocks along the west base of the Aspen Range are of the Woodside shale. Exposures are poor and the attitude of the rocks is not clear. Doubtless the structure is in part synclinal.

Between Swan Lake Gulch and Dry Canyon, in T. 9 S., R. 43 E., a phosphate-bearing syncline with northwesterly trend is faulted along the northeast side. (See pl. 6.) At the southeast it contains minor folds.

On the north side of Middle Sulphur Canyon, in the same township, the area west of the Trail Creek syncline is occupied by a broken fan fold in the Wells formation (see structure section P–P′, pls. 6 and 12) and by a broken and eastward-inclined anticline that may have proclivities toward fan structure and is composed of Brazer limestone. This fold is shown in part in Plate 35, *B*.

At Threemile Hill, in secs. 20 and 29, T. 8 S., R. 42 E. (see pl. 44), the general structure is a synclinorium (?) in the Portneuf limestone of the Thaynes group. The upper limestone member of the Portneuf is partly eroded away, exposing the red-bed member on the southeast and northwest flanks of the hill.

RESERVOIR SYNCLINE

The Reservoir syncline, which occupies the main axis of Reservoir Mountain in the Henry quadrangle, has an exposed length of about 7 miles. It is believed, however, that the fold continues northward and northwestward beneath the basalt. It is perhaps offset by a concealed tranverse fault, but the fold probably joins the syncline north of Blackfoot River and has an extended course beyond the region described in this report.

The syncline north of the Blackfoot, as shown in structure section D–D′ (pls. 2 and 11), is relatively deep and narrow, less than 2 miles wide. Northwestward it joins a group of folds in the Woodside and Thaynes beds that may prove to be parts of a great synclinorium. It is broken along the east side by a fault, probably normal, that brings Phosphoria beds against middle Thaynes.

The main mass of Reservoir Mountain is composed of the Thaynes group in an unsymmetrical synclinorium that is inclined eastward. A somewhat lower ridge on the west is composed of Woodside shale that forms an anticline which is also overturned toward the east. Outlying knolls farther west are occupied by the Wells and Phosphoria formations, which form an anticline, apparently downfaulted on the west. The presence and course of the fault is suggested by the extensive deposits of travertine and the line of spring cones in secs. 12 and 13, T. 6 S., R. 40 E. This fault and other structural features farther east are offset eastward by a cross fault that is more fully described below. The thickness of the Woodside shale in the subordinate ridge along the west side of the mountain is somewhat greater than elsewhere and may be due in part to the manner of its folding. The Thaynes of the main ridge is overturned on the west flank and does not include the entire thickness of the formation. The highest beds appear to be the siliceous limestones of the lower Portneuf. The general structure of the mountain as above interpreted is shown in the structure section drawn along the line F–F′. (See pls. 3, 11, and 36, *A*.)

The southern part of the Reservoir Mountain is cut by a cross fault that offsets the boundaries between the Rex and Woodside and between the Woodside and Thaynes, so that south of the fault they have been shifted eastward more than half a mile.

The Reservoir syncline is relatively deep. The eastern half, from a line drawn about a quarter of a mile west of the crest of the mountain and extending perhaps half its length, contains phosphate beds that lie at greater depth than 5,000 feet—too deep to be considered workable under the present regulations of the Geological Survey.

The northeastern outliers of Reservoir Mountain include a faulted anticline that brings the Wells and Phosphoria formations to the surface.

GIRAFFE CREEK SYNCLINE

The Giraffe Creek syncline extends from Crow Creek, near Lowe's ranch, southeastward across the northeast corner of the Montpelier quadrangle, a distance of about 12 miles in the region described in this paper and passes some distance beyond. Giraffe Creek lies along part of its southwest border. The maximum width of the syncline is about 2 miles. Structure section T′–T′′ (pl. 12), which crosses it in the widest part, shows the fold to be a shallow, undulatory syncline, slightly unsymmetrical and deeper near its eastern margin. The pitch is gentle toward the southeast. The fold is probably canoe-shaped, but the southern tip lies outside the region here described.

The highest beds included in it are of the Ephraim conglomerate. The syncline is closely related to the Spring Creek syncline, from which it is separated by only a narrow anticline of Jurassic beds. It is thus closely related also to the Caribou synclinorium. The phosphate beds of the Phosphoria formation lie beneath the Giraffe Creek syncline but at depths too great to be considered workable under present regulations of the Geological Survey. It contains no other known deposits of value and is thus of no economic significance.

SUBLETTE ANTICLINE

The Sublette anticline, which is named after the prominent ridge on the east border of the Montpelier quadrangle extends 30 miles in a somewhat curved course southward from Crow Creek below the mouth of Sage Creek. In the northern part, as at the line T′–T′′ (pl. 12), it is a relatively broad, low arch that brings to the surface beds of the Preuss sandstone, well exposed on the borders of Elk Valley. Its maximum width is about 3 miles at the boundary of the Crow Creek and Montpelier quadrangles, where it contains a shallow minor syncline that includes lower beds of the Ephraim conglomerate, partly shown in section W–W′ (pl. 12).

Southward the fold grows narrower and steeper and brings older formations to the surface. At the line X–X′ (pl. 12) the anticline is unsymmetrical and inclined eastward. Beds of the Thaynes group are exposed on the west flank. About 1¼ miles south of that line the phosphatic shales of the Phosphoria formation are exposed along the west flank of the ridge for about 2 miles. Southward from a point about a mile north of Raymond Canyon the shales are again exposed for a distance of about 4 miles. The anticline passes beneath the alluvium of Bear River valley at the east border of the region here described but doubtless continues a considerable distance beyond. Sharply upturned strata exposed in Raymond Canyon are shown in Plate 54.

The axis of the anticline is probably somewhat undulatory, as indicated by the occurrence of the minor syncline above noted. The pitch is northward and is estimated to average about 500 feet to the mile north of Raymond Canyon, or about 9 per cent.

The Sublette anticline has great economic importance because for a distance of more than 15 miles along the east side of Thomas Fork valley it makes accessible valuable beds of phosphatic rock. The maximum depth of the phosphate along the anticline from Thomas Fork Canyon to Bear River probably does not exceed 3,000 feet.

RED MOUNTAIN SYNCLINE

The Red Mountain syncline, which is named from Red Mountain in the northeast part of the Montpelier quadrangle, has a probable extent of about 44 miles within the region here described, although it is largely concealed in the southern half of its course. It begins at Crow Creek, northeast of Book's ranch, and for the first 16 miles forms a canoe-shaped fold that ranges from less than half a mile wide at the north to about 2½ miles wide near Red Mountain, its broadest part. The highest beds contained in it are of the Ephraim conglomerate. As shown in structure sections T′–T′′ and W–W′ (pl. 12) the canoe-shaped portion of the fold is unsymmetrical and inclined eastward. Southward the syncline subdivides and itself becomes part of a broad synclinorium in which several of the folds are sufficiently distinct to be traceable for long distances and to receive separate names. In the Bear Lake Plateau the synclinorium is largely concealed by Tertiary beds that have themselves participated in later folding along the earlier established lines. The Red Mountain syncline continues along the east side of the synclinorium. It is crossed by several transverse axes that warp the fold slightly upward or downward and broaden or constrict its outline as at Red Mountain.

PREUSS ANTICLINE

The Preuss anticline originates as a minor fold of the Red Mountain syncline in the southern part of T. 11 S., R. 46 E., and takes its name from Preuss Creek, which it crosses. It is well shown in the hills west of Geneva and appears in the structure section along the line X–X′ (pl. 12), where it is in turn modified by minor folds. Southward it lies in large part beneath cover, but its presence in the Bear Lake Plateau is inferred because of the relationships of the exposures of Nugget sandstone and Twin Creek limestone in that district.

BOUNDARY SYNCLINE

The Boundary syncline also originates in the southern part of T. 11 S., R. 46 E., as a minor fold of the Red Mountain syncline. It causes a pronounced southward prolongation of the area of Preuss sandstone and appears at the line of structure section X–X′ (pl. 12) as a somewhat unsymmetrical fold modified by minor folds. Southward it passes beneath the west border of Thomas Fork Valley and enters the Bear Lake Plateau beneath the Tertiary cover, where it is supposed practically to coincide with the axial line of the syncline in the Boundary Ridge. Where it is crossed by the line of structure section Y–Y′ (pl. 12) it is inclined eastward.

The syncline at Boundary Ridge is developed in Tertiary rocks that overlie folded and extensively eroded Mesozoic rocks. It there represents a later epoch of folding than that which produced the folds previously described, but its position and direction were doubtless determined by the preexisting folds beneath. It is relatively broad and open but steeper on the east side and is thus inclined slightly westward.

GIVEOUT ANTICLINE

Northwest of Giveout, in sec. 35, T. 11 S., R. 45 E., a well-developed anticline, which is here called the Giveout anticline, appears in the Twin Creek limestone west of the road. (See pl. 36, *C*.) Northeastward this fold is believed to be broken by a thrust fault along its eastern limit, as indicated in the structure section along the line W–W′ (pl. 12). Southeast of Giveout the anticline may be recognized at a number of places. Near the line of structure section Y–Y′ it is inclined eastward and is represented by a wedge-shaped area of Nugget sandstone. Its further prolongation southward beneath cover is suggested by the occurrences of Nugget sandstone in Sweetwater, Horse, and Pegram Creeks. Its length, as above described, probably exceeds 35 miles.

SWEETWATER SYNCLINE

West of the Giveout anticline lies the Sweetwater syncline, which at the line of structure section W–W′ (pl. 12) is believed to be cut by the same fault that there affects the anticline. Farther south the syncline is relatively insignificant but may be recognized at a number of places. As shown in the structure sections X–X′ and Y–Y′ (pl. 12) it is rather narrow and sharp and is inclined eastward. Its width for most of its course is probably less than a mile, but its length as mapped is greater than 25 miles. Its name is derived from Sweetwater Creek, in the Bear Lake Plateau, which it crosses. Its course lies entirely in the Twin Creek limestone.

ALTON ANTICLINE

As projected to the line W–W′ (pl. 12) beneath the overlying block of the Bannock overthrust, and as suggested by stratigraphic conditions in areas east and west of this block, the Alton anticline at the north is a prominent fold that brings Nugget sandstone to the surface. Farther south it diminishes in size, and as shown at the lines X–X′ and Y–Y′ becomes relatively insignificant. It takes its name from the village of Alton, about a mile west of the fold.

PEGRAM SYNCLINE

The Pegram syncline is a subordinate fold that is developed chiefly in the Twin Creek limestone. It appears in all three of the structure sections W–W′, X–X′, and Y–Y′ (pl. 12) and is projected beneath the fault block to the line of section W–W′. Toward the north and toward the south it is apparently somewhat deeper than at the line of section X–X′, probably because of the transverse anticlinal axis that crosses the longitudinal folds near that line, and produces broad and gentle upwarping of the folds along its course, notably in the Sublette and Montpelier anticlines. The Pegram syncline, which takes its name from Pegram Creek at the south, probably continues in that direction beneath the Tertiary beds beyond the region mapped and thus exceeds 30 miles in length.

SHEEP CREEK ANTICLINE

The Sheep Creek anticline is best developed in the southern part of the Montpelier quadrangle along the lower course of Pegram Creek. Still farther south it is partly concealed by Tertiary beds and passes beyond the quadrangle. The valley of Bear River follows the axis of the anticline from the mouth of Pegram Creek to Sheep Creek valley, which also lies along the axis. At the line Y–Y′ (pl. 12) the anticline is one of the larger folds and has pronounced dips and a gentle eastward inclination. At the line X–X′ the fold, though still conspicuous, is much flattened, probably because of the transverse axis mentioned above. At the line W–W′, to which it has been projected, the fold is more sharply defined, probably because of the transverse synclinal axis that crosses the longitudinal folds a few miles south of the line W–W′. The length of the Sheep Creek anticline as traceable in the region here mapped is about 32 miles, but its breadth is generally less than 2 miles. Although it brings beds of the Thaynes group to the surface in the southern part of its course, the phosphate beds still remain too deep to have economic value. The axis pitches very gently northward for much of its length, probably not over 150 feet to the mile, less than 3 per cent.

HARER SYNCLINE

The Harer syncline lies along the west border of the upper block of the Bannock overthrust in Tps. 10 and 11 S., R. 44 E., and is there locally deep enough to contain beds of the Preuss sandstone. In T. 12 S., R. 45 E., it is offset by the fault that breaks the east limb of the neighboring Home Canyon anticline. Like the folds farther east it is less well developed at the line X–X′ (pl. 12), but is strongly developed a few miles both north and south of that line. Harer station, on the Oregon Short Line Railroad, is on its east flank, where the valley of Bear River crosses the fold. The axis, though slightly undulatory is very gently inclined toward the north, as indicated by the occurrences of Preuss sandstone. At the south the fold is partly covered by Tertiary strata in the Bear Lake Plateau. The axial plane is inclined eastward. The length of the syncline within the region here described is about 38 miles, and its breadth is generally less than 1 mile.

HOME CANYON ANTICLINE

The Home Canyon anticline is one of the most strongly pronounced folds in the southern part of the Preuss Range. In T. 12 S., R. 45 E., its axis lies in Home Canyon along the east side of which the anticline is broken by a thrust fault. South of Montpelier Canyon its west flank is broken by another thrust fault, as shown in the structure section along the line X–X′ (pl. 12). From Home Canyon to a point about 2 miles south of Bear River the Thaynes group is exposed by the erosion of the fold, and for a part of this distance the phosphate beds lie at depths of 2,500 to 5,000 feet and are thus considered in part available under present regulations of the Geological Survey. The axial plane of the fold is inclined eastward, as shown by the structure sections along the lines W–W′, X–X′ and Y–Y′. The axis is more strongly affected by cross folds than are the axes of the neighboring folds on the east. North of Bald Mountain a transverse syncline causes Twin Creek beds to overlap the axis. In Montpelier Canyon a broad upwarp brings the Thaynes group to the surface. The axis remains nearly horizontal as far south as Bear River, south of which it pitches very gently southward. In the Bear Lake Plateau the anticline is partly concealed by Tertiary beds. The length of the Home Canyon anticline is about 35 miles within the Montpelier quadrangle and its maximum breadth about 1½ miles.

BALD MOUNTAIN AND INDIAN CREEK SYNCLINES

Immediately west of the Home Canyon anticline are two synclines that may represent a single fold that was originally continuous. At present the Bald Mountain syncline is a canoe-shaped fold which has been broken by a thrust fault at its northern tip and which contains beds of the Twin Creek limestone. The syncline is about 9 miles long and has a maximum width of nearly 3 miles. At the south end the canoe is overlapped by the same thrust fault that encroaches on the Home Canyon anticline.

The Indian Creek syncline emerges from beneath the above-mentioned thrust fault about 3 miles northeast of Dingle station, on the Oregon Short Line Railroad. It continues southward across Indian Creek and passes beyond the region described in this paper. The portion of the fold represented is nearly 18 miles long and has a maximum width of about 1½ miles. The highest beds included within it are parts of the Twin Creek limestone, but patches of Tertiary strata overlie it here and there. The syncline pitches gently southward and is inclined eastward.

MONTPELIER ANTICLINE

In Montpelier Canyon, about 3 miles east of the town, occurs a complex anticline about 3 miles long from north to south but that has an eastward extension owing to a transverse upwarping. The anticline is accompanied by minor folds, some of which are too small to represent upon the areal map, and is greatly broken by faults that are perhaps associated with the Bannock overthrust. Some of these folds are shown in Figure 30 and Plates 50, *B*, and 52, *A*. The anticline is shown in part in the structure section along the line X–X′. Its economic relations are noteworthy because of the phosphate beds which it brings to the surface in a favorable location for mining. Further details of its structure are given in the discussion of the phosphate deposits of the Montpelier district (pp. 277 to 280).

HOT SPRINGS ANTICLINE

The Hot Springs anticline, which is perhaps continuous with the Montpelier anticline beneath the cover of Tertiary beds, forms a distinct area northeast of Bear Lake in which Carboniferous beds, including the Phosphoria formation, are brought to the surface, the lowest formation being the Brazer limestone. The exposed length of the anticline is about 8 miles and its maximum breadth about 2½ miles. The little settlement of Hot Springs is near the south end. The breadth of the Thaynes group on the east flank of the anticline is so great that a subordinate fold is thought to be present, as indicated in the structure section along the line Y–Y′ (pl. 12). The beds dip steeply westward, and the fold is inclined gently toward the east. On the west flank the anticline is truncated obliquely by the Bear Lake fault. The fold has economic significance because it makes accessible a large body of high-grade phosphate rock.

NOUNAN ANTICLINE (?)

East of Nounan Valley, in the northwest part of the Montpelier quadrangle, Triassic beds form hills and ridges. Where the beds are crossed by the line of structure section W–W′ (pl. 12) the beds are nearly horizontal. Farther north the beds have well-defined dips in a variety of directions. The area is bounded by faults, which are interpreted as forming a window of the Bannock overthrust. According to this view the plane of the Bannock overthrust is here arched and eroded so that the Triassic beds are exposed. The Triassic beds themselves are probably slightly arched in agreement with the fault plane. The structure east of Bear River is concealed for 3 miles along the line of the structure section and may be more complex than is shown in the structure section. West of Nounan Valley Ordovician and Cambrian beds in the upper block of the Bannock overthrust form two broad, low, anticlinal areas, separated by a broken syncline, as shown in the structure section.

PARIS SYNCLINE

Along the west side of Bear Lake Valley Triassic rocks form a syncline in the hills west of Paris. Its exposed length is nearly 9 miles and its maximum breath about 1½ miles. The syncline is unsymmetrical and is strongly inclined or even overturned eastward, as shown in structure sections along the lines X–X′ and Y–Y′ (pl. 12). It is overridden on the west by the upper block of the Bannock overthrust, and steep westerly dipping beds of the Phosphoria formation emerge here and there from beneath the margin of the fault block. The dips of the Triassic beds east are gentle or nearly horizontal. West of Paris beds of the lower Thaynes form a broad, canoe-shaped area. There the phosphate beds are probably not deeper than 1,500 to 2,000 feet. South of Liberty a somewhat thicker section of Thaynes strata forms the north end of the syncline, and in that district the phosphate may lie nearly 5,000 feet below the surface along the west border, but its depth would decrease eastward.

BEAR LAKE VALLEY

East of the Paris syncline the consolidated rocks are covered to an unknown depth by the alluvium of Bear Lake Valley. The structure of the rocks thus concealed is unknown, but certain inferences may be drawn from the known structures to the west. According to the physiographic interpretations given on page 30, Tertiary beds, including at least part of the Salt Lake formation and perhaps also some of the Wasatch beds, lie beneath the alluvium of Bear Lake Valley. The structure of the older formations beneath is hypothetical. In a previous report[6] a normal fault was postulated along the west side of the valley. Upon revision in the field this interpretation appears to be no longer necessary. An anticline would normally lie east of the Triassic syncline and might have broad and open form like that of the syncline. The Wells might have been raised high enough to be cut by the eroded surface on which the supposed Tertiary beds lie, but probably the massive limestone of the lower Wells and earlier Carboniferous formations were not raised high enough to intersect that surface. These rocks resist erosion

[6] Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 397–399, 1911.

more than the higher Wells and overlying Permian and Triassic beds. Hence the older rocks would not be completely removed by erosion and might retain some topographic expression unless they were too deeply buried. Probably several folds intervene between the anticline above discussed and the east side of the valley. They may be relatively open, like the folds to the west, or more closely appressed, like those farther east. They are probably inclined eastward like the folds both west and east of the valley.

A normal fault, here called the Bear Lake fault, is indicated along the east side of Bear Lake Valley by the scarplike valley wall, which cuts obliquely southward across successive geologic formations, and by the thermal springs along the base of the valley wall. (See pls. 17, *A*, and 36, *B*.) In the report above cited evidence was presented to show that this fault continued northward through the Montpelier quadrangle and along the west base of the Aspen Range. On the basis of further study, both in the field and in the office, it seems more probable that this fault is relatively local and that the features farther north that were formerly thought to be associated with it are rather to be assigned to the Bannock overthrust. Certainly the normal fault loses its topographic expression within 2 miles north of the line of structure section Y–Y′. The possible bearing of this fault on the structure of the region farther north is explained more fully in the discussion of the Bannock overthrust.

FISH HAVEN SYNCLINE

In the southwest corner of the Montpelier quadrangle the Cambrian and Ordovician formations lie in a syncline that is only partly included in the region described in this paper. At the edge of the quadrangle in the upper part of Fish Haven Canyon a small area of the Laketown dolomite is included in the syncline. The east flank of the syncline is remarkable for the fine section that it affords of the early Paleozoic formations. The east border of the syncline is formed by the complex fault zone of the Bannock overthrust, as shown in structure sections along the lines Z–Z′ and A″–A‴ (pl. 12).

PRINCIPAL FAULTS

BANNOCK OVERTHRUST

The most noteworthy fault, both in extent and in effect upon the structure and the topographic development of the region, is the Bannock overthrust, first described in 1912 [7] and named from Bannock County, Idaho, in which it is well exposed. Since that time there has been opportunity for revision of certain parts of the region included in the former study and for extension of field work in areas not previously examined in detail. The general conclusions set forth in the original description appear to be abundantly justified, but many additional details are available regarding the trace of the fault and its cartographic expression, and some modifications of interpretation seem advisable.

BLACKFOOT PEAK

The northernmost point where the Bannock overthrust may be recognized is probably in the vicinity of Blackfoot Peak, about 12 miles northwest of the region described in this report. St. John [8] describes this peak and shows Carboniferous beds on the eastern slope in contact with soft yellow, buff, and variegated beds that he correlates with those of the Sugarloaf region (his Station XVII), here grouped in the Wayan formation. He is in some doubt about the relationship of the two sets of sediments, but in his structure section (fig. 15) he separates them by a normal fault. Since the recognition of the prominence of thrust faulting in this part of the Rocky Mountain region it seems more probable that the fault at Blackfoot Peak is an overthrust, either closely related to or forming part of the Bannock overthrust, of which it is apparently a northwestward extension.[9] Not far beyond Blackfoot Peak the fault disappears beneath beds of the Salt Lake formation and volcanic rocks.

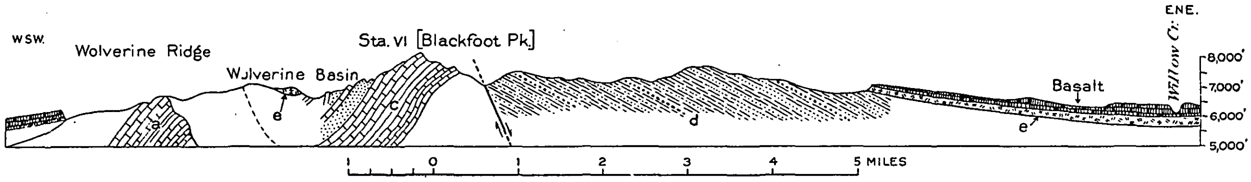


FIGURE 15.—Geologic structure section at Blackfoot Peak, St. John's Station VI. **a**, Lower Carboniferous limestone; **c**, upper Carboniferous deposits; **d**, variegated beds (Laramie?); **e**, porphyritic trachyte. (After St. John)

SHEEP MOUNTAIN AND LITTLE VALLEY HILLS

Within the region here described the Bannock overthrust first appears at the north as a fault zone composed of three members which emerge from beneath the basalt along the southeast flank of Sheep Mountain. The upper fault block is broken by a number of normal faults. The structural details are shown in the structure section along the line B–B′ (pls. 2 and 11). In the Little Valley Hills the fault zone is traversed by the lines of structure sections C–C′ and E–E′ (pl. 11), the details of which have

[7] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, pp. 681–707, 1912; Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, pp. 35–38, 1914.

[8] St. John, Orestes, Report of the geological field work of the Teton division: U. S. Geol. Survey Terr. Eleventh Ann. Rept., pp. 340, 341, 356, 1879.

[9] This statement has since been confirmed by field work.

been given on pages 134 to 137. The combined effect of the members of the fault zone in the localities just mentioned is to bring into the upper fault block, in a series of rock slices, beds that range in age from the Brazer limestone to the lower (?) division of the Wayan formation. The lower fault block appears to be composed chiefly of upper beds of the Wayan formation. The stratigraphic throw may range from a few thousand feet to 15,000 feet or more.

GRAYS LAKE

The beds in the area that immediately surrounds Grays Lake are concealed by alluvium and marshes. Little Gray Ridge, at the southwest, is composed of Carboniferous formations. Cretaceous formations lie to the southeast and northwest. East and northeast of the lake the formations have not been studied, but are presumably in large part Cretaceous. There is therefore little doubt that the Bannock fault zone passes beneath the lake and its accompanying alluvium and joins the fault complex in the valleys of Chippy and Lanes Creeks.

CHIPPY AND LANES CREEKS

In the upper courses of Chippy and Lanes Creeks the fault zone ranges from half a mile to nearly a mile and a half in width. Several rock slices of relatively small extent have been formed, which are illustrated in the structure sections along the lines H–H′ and I–I′. (See pls. 4 and 11.)

In the valley of Chippy Creek the space between the nearly vertical beds of the upper Thaynes and the gently dipping Woodside is probably insufficient to allow for the inclusion of the bulk of the Woodside and the lower and middle Thaynes without a break. The abrupt change in the dip favors the idea of a fault. It is therefore presumed that the fault which farther to the southeast separates the Wells and Phosphoria from the Nugget is continued under cover up the valley west of the Thaynes ledges. The stratigraphic throw of the fault as drawn would amount to about 2,000 feet.

Above the Thaynes to the northeast lie the Timothy sandstone and succeeding formations, including the lower part of the Nugget sandstone in normal order. The Nugget beds are faulted against Twin Creek limestone, which in turn is faulted against the Ephraim conglomerate on the northeast in such manner as to cut out part of the Twin Creek together with all of the Preuss and Stump sandstones and part of the conglomerate. The red conglomerates of the Ephraim rest in their turn against lighter-colored conglomerates that belong high in the upper division of the Wayan formation; thus another fault cuts out most of the Gannett group and all of the lower and much of the upper Wayan.

The four faults named are all considered as reverse faults and branches of the Bannock overthrust, and the easternmost branch produces the greatest displacement. Together they bring Lower Triassic or perhaps even Permian beds on the west into proximity with Cretaceous beds on the east. The displacement is distributed along all the faults, and it has not been practicable to determine the amount assignable to each. The total stratigraphic throw is estimated at about 20,000 feet.

A subordinate plexus of faults extends southeastward from the line of structure section I–I′ (pl. 11) toward the head of Browns Canyon and produces a shattering of the Nugget sandstone and some of the underlying formations into numerous irregular slices and blocks. These faults are probably in part normal and in part reverse.

STUMP CREEK

The easternmost branch of the Bannock fault zone in passing southeastward from Lanes Creek into Stump Creek subdivides into three branches, two of which combine to form the East Stump branch, and the other becomes the West Stump branch. This portion of the fault zone is illustrated in the structure sections along the lines K″–K‴ and L–L′. (See pls. 5 and 11.)

East Stump branch.—The East Stump branch has an irregular course along the west flank of the Caribou Range in the northwest part of the Freedom quadrangle. The attitude of the fault plane along the east side of the ridge crowned by Stump Peak is nearly vertical, but about 2 miles northwest of that peak it is variable. The fault plane dips first strongly northeast, then southwest, gently at first but steeper as it passes into the Lanes Creek quadrangle. The fault plane is thus flexed and locally overturned eastward. In the North Fork, about 2 miles southeast of Stump Peak, a branch fault of similar habit joins the East Stump branch and descends into the valley of Stump Creek. The fault branches below the mouth of Boulder Creek and separates the little knoll of Ephraim conglomerate from the Preuss sandstone on each side of the valley. Salt springs occur near this knoll and farther southeast. Probably these are associated with fault lines and the East Stump branch may continue down the valley, connecting with other faults in some such manner as indicated on the map. The East Stump may be continuous with the Hardman and East Crow Creek branches farther south, but these are given local names because of the intervening alluvial areas beneath which the fault connections are conjectural. The stratigraphic throw of the East Stump branch is seemingly greatest toward the northwest. In the line of section K″–K‴ (pl. 11) it is probably as much as 5,600 feet.

West Stump branch.—The West Stump branch lies from 1 to 2 miles southwest of the East Stump branch and forms the boundary between the Nugget sandstone and the Twin Creek limestone. Like the East

Stump branch it is nearly vertical for much of its course but is overturned toward the southwest at Boulder Creek and southeastward. The stratigraphic throw of this branch, where it is crossed by sections K''-K''' and L-L' is probably not greater than 1,000 feet. Northwestward the fault separates Nugget sandstone from Ephraim conglomerate and the displacement is greater. Southeastward the fault is believed to be continuous beneath cover with faults in the Crow Creek quadrangle. At Spring Creek, in the southern part of the Freedom quadrangle, the West Stump branch is probably offset by the faults that have caused the displacement of the Higham grit and Timothy sandstone.

CROW CREEK QUADRANGLE

In the northeastern part of the Crow Creek quadrangle the Bannock fault zone is complex and has a maximum breadth of about 3¼ miles. It includes as many as five branches and thus produces a number of subparallel rock slices that lie along the eastern margin of the great thrust block. Other faults that originate in the underlying block pass into or beneath the margin of the easternmost slice of the upper block. The fault zone in the Crow Creek quadrangle is crossed by the lines of structure sections O'-O'', S''-S''', and T'-T'' (pl. 12).

Hardman fault.—The easternmost fault ascribed to the Bannock fault zone in this district is the Hardman fault, which enters the Gannett Hills from Tygee Valley just south of the Draney Ranch and separates Jurassic formations from members of the Gannett group. It passes southward along Hardman's Hollow to Crow Creek, where it is supposed to subdivide and form the East Crow Creek and West Crow Creek branches of the Bannock fault.

East Crow Creek branch.—The Twin Creek-Preuss contact east of Crow Creek is considered a fault because it seems to truncate the structural features in the Preuss and Stump sandstones near the salt works opposite Lowe's ranch. The salt springs themselves are suggestive of faulting. At a locality 2 miles southwest of the line of section S''-S''' (pl. 12) the Twin Creek strikes directly into the Preuss. The structure of the Twin Creek under cover west of the fault at that line is assumed to be generally anticlinal to agree with the anticlinal structure of the Preuss and Stump sandstones southeast of the old salt works. In sec. 13, T. 10 S., R. 45 E., the fault turns abruptly to the southwest toward the West Crow Creek branch, which is there the main branch of the Bannock fault and is supposed to unite with it beneath cover. The connecting fault may be an independent fault, but if so it produces no effect on the contact between the Preuss and Stump to the east. At the southwest corner of the same section a fault emerges from cover and continues due south into the Montpelier quadrangle, where it dies out about 2 miles south of the north boundary. This fault may perhaps be regarded as the offset continuation of the East Crow Creek branch. West of this fault, in secs. 23 and 26, T. 10 S., R. 45 E., the Twin Creek area is broken by two branch faults, one of which lies along White Dugway Creek. A salt spring occurs at the junction of this fault with the east branch of the Bannock overthrust. The other branch fault extends northward from White Dugway Creek and separates reddish beds from the light-colored shaly limestone of the Twin Creek. The reddish beds were formerly mapped as Beckwith.[10] They are here included with the Preuss. The Hardman-East Crow Creek branch of the Bannock fault, though persistent for many miles, produces only a moderate stratigraphic displacement, probably less than 1,000 feet.

West Crow Creek branch.—The West Crow Creek branch is postulated beneath the alluvium between Lowe's ranch and Hardman's Hollow because of the fault at the mouth of the hollow and because of the repetition of upper Twin Creek limestone and Preuss sandstone on the north side of the valley 1 mile east of Lowe's ranch, though a subordinate syncline would perhaps account as well for the occurence of the Preuss at that place. Southwest of that ranch the supposed fault is joined by other branches and becomes, as stated, the main branch of the Bannock fault. It passes southward into the Meade Peak district. In sec. 26, T. 10 S., R. 45 E., below the junction with the Sage Valley Branch, the West Crow Creek fault brings beds of the middle Wells against lower to middle beds of the Twin Creek, so that the stratigraphic throw is between 8,000 and 9,000 feet.

East Tygee branch.—The East Tygee branch lies along the east side of Tygee Valley in the northeastern part of the Crow Creek quadrangle. Nugget sandstone is faulted against Twin Creek limestone in such manner as to cut out most of the Twin Creek. In sec. 27, T. 8 S., R. 46 E., the Twin Creek is cut out altogether along this fault. Northward the fault is supposed to join the West Tygee branch beneath cover and to continue into the West Stump branch. Southwestward the fault is traceable as far as Crow Creek, where it is presumed to join the West Crow Creek branch. The stratigraphic throw is probably 3,000 to 4,000 feet.

West Tygee branch.—The West Tygee branch is readily recognizable in the hills east of Sage Valley, where it separates beds of middle to upper Thaynes from beds of lower to middle Nugget sandstone. The stratigraphic throw probably does not exceed 1,000 feet. At the south the fault joins the West Crow Creek branch in about the NE. ¼ sec. 31, T. 9 S., R. 46 E. The northward continuation of the fault is concealed by Tertiary and Quaternary

[10] Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, p. 62, 1914.

formations. The Nugget sandstone, however, occurs here and there to the north in the midst of Tertiary beds, and in Tygee Valley salt springs in the SE. ¼ sec. 16, T. 8 S., R. 46 E., suggest the continuation of the fault through that district. Thus the West Tygee branch is supposed to join the East Tygee branch in the vicinity of the Draney ranch.

The branch fault near the old salt works in the SE. ¼ sec. 16, T. 8 S., R. 46 E., is drawn to provide for a small concealed slice of Preuss sandstone, the lower part of which is believed to contain the salt beds that supply the brine of the salt springs.

Sage Valley branch.—Along the west side of Sage Valley a thrust fault cuts out the phosphatic shale member of the Phosphoria formation in the east flank of the Boulder Creek anticline. This fault passes northward into the Woodside shale and beneath Tertiary beds. It probably joins the fault in the Thaynes group near the mouth of Webster Canyon, shown in the structure section along the line N–N′ (pl. 11). At this locality red beds which resemble some beds of the Nugget but which are here regarded as probably the red-bed member of the upper Thaynes (Portneuf) cross the canyon, dip steeply eastward, and are so broadly exposed as to suggest close folding. East of the red beds fossiliferous strata of the Portneuf limestone also dip steeply eastward and pass beneath cover. The fault which separates the lower Thaynes on the west from the red beds on the east is steep, and its hade has not been determined. It is regarded, however, as a thrust fault whose plane has been steepened or even somewhat overturned. Northward it is offset by the cross fault from the West Stump branch, with which it was probably formerly continuous. A second cross fault cuts through the travertine areas at the head of Spring Creek. A small wedge of Portneuf, Timothy, and Higham is caught in the junction of these cross faults. The eastward continuation of the wedge is concealed, but its position indicates a westward offset of these included formations about three-quarters of a mile from the line of their occurrence to the north. South of the wedge only Thaynes is exposed, and this in only a comparatively small area.

South of Sage Valley the fault cuts obliquely toward the axis of the Boulder Creek anticline and brings Brazer limestone into contact with Woodside shale about a mile north of Deer Creek. Here its stratigraphic throw is probably more than 3,000 feet. South of Deer Creek the Sage Valley branch runs nearly parallel beneath cover with the West Crow Creek branch and is separated from it presumably by only a narrow slice of Woodside shale. In secs. 14, 23, and 26, T. 10 S., R. 45 E., the fault turns back toward the east flank of the anticline and the throw diminishes. This branch joins the West Crow Creek branch in sec. 26.

MEADE PEAK DISTRICT

In passing from the upper part of Crow Creek Valley across the Preuss Range the plane of the Bannock overthrust forms a broad syncline, in which Meade Peak, near the south end of the Snowdrift anticline, is the most conspicuous topographic feature. The fault leaves Crow Creek and passes across Preuss Canyon into the head of Montpelier Canyon. Thence it goes northwestward along Dunn's Canyon and into Georgetown Canyon. The general features of the fault in this part of its course are shown in the structure sections along the lines U′–U′′, V–V′, and W–W′. (See pl. 12.)

From Crow Creek to Montpelier Creek the fault lies between the Thaynes and Nugget, and the throw is somewhat diminished. In sec. 20, T. 11 S., R. 45 E., a branch that brings Brazer limestone successively into contact with beds that range in age from Thaynes to Wells passes northward along the east side of Meade Peak and Snowdrift Mountain and then turns sharply east and cuts out the Phosphoria and Woodside formations at the south end of the Webster syncline, as shown in the section along the line V–V′. This branch fault for part of its course dips strongly eastward, as is clearly shown by the manner of its descent from the vicinity of Meade Peak into the head of Crow Creek and its attitude in crossing the ridges to the south. This easterly dip indicates the local overturning of the subordinate thrust plane. The branching of the Bannock overthrust and the courses of the two branches in the Meade Peak district are shown in the accompanying photograph and stereogram. (See pls. 36, *C*, and 37.) The Bannock overthrust in the head of Montpelier Canyon is particularly impressive, for the trail leads over beds of the Twin Creek limestone, and one may there look far up the mountain side to the massive ledges of Mississippian limestone that should, if in normal position, lie perhaps 10,000 feet underground.

Another fault, which is regarded as a branch of the Bannock overthrust, causes a rock slice that contains beds which range in age from Wells to Woodside to rest upon the Brazer limestone south of Meade Peak, as shown in the structure section along the line W–W′. This rock slice contains deposits of high-grade phosphate. The branch fault and rock slice are shown in part in Plate 46, *B*.

GEORGETOWN CANYON

The appearance of the Bannock overthrust in Georgetown Canyon and in the neighboring Left Fork of Twin Creek is strikingly prominent. (See pl. 38, *B*.) A low northwesterly anticlinal flexure of the fault plane, roughly parallel with the syncline in which Meade Peak lies, has permitted the erosion of the fault block and caused the exposure of beds of Twin Creek limestone between the Madison limestone ledges near the mouth of the canyon and those a mile north of the canyon. Similarly a transverse anticline in the Left Fork of Twin Creek has caused the exposure of Nugget and Twin Creek beds in the midst of Mississippian limestones. Ledges of Madison limestone occupy three of the summits between the two canyons and extend part way down the slopes between gullies that have been excavated in Twin Creek limestone. In Georgetown Canyon the gateway formed by the Brazer limestone where the Bannock overthrust crosses the canyon is impressive. Fine springs occur on the north side of the canyon just below the gateway. The course of the fault from the ridge north of Georgetown Canyon to the divide between Dunns and Montpelier Canyons is shown in Plates 36, *C*, and 38, *A*. Subordinate thrust faults, interpreted as branches of the Bannock overthrust, break the Carboniferous limestones into several rock slices, as shown in the structure sections along the lines T–T″ and U′–U″ (pl. 12).

SLUG CREEK

In the ridge west of Slug Creek, in T. 9 S., R. 44 E., an elongate area that is apparently surrounded by a fault boundary is interpreted as an anticlinal portion of the main thrust, or of a subordinate thrust, which has been unroofed by erosion so that the underlying block is exposed through a "window." The occurrence of similar anticlines more extensively eroded in the Georgetown Canyon district provides a favorable analogy. This window is illustrated in Plate 6 and is shown in the structure section along the line S′–S″ (pl. 12).

MONTPELIER DISTRICT

The thrust fault at Montpelier, which brings Brazer and Madison limestones into contact with beds of lower to middle Thaynes, is isolated by Tertiary and Quaternary formations, which conceal its extensions both to the north and south. Its effects are comparable to those produced by the great thrust in the Georgetown district, and there seems little reason to doubt the continuity of the two faults beneath cover. The occurrence of the anticlinal flexure in the plane of the Bannock overthrust, which causes the erosion of the fault block and the separation of the Carboniferous areas in lower Georgetown Canyon, may readily be succeeded on the west by a synclinal flexure. To this flexure may be assigned the outer Madison ledge at Georgetown Canyon and the Mississippian beds near Montpelier. The supposed structural relations of the Bannock overthrust at Montpelier are shown in the structure section along the line X–X′ (pl. 12). Plate 21, *B*, shows the northern tip of the fault block at Joes Gap, about 3½ miles north of Montpelier.

Beyond the Carboniferous ledges south of Montpelier there is no evidence of the continuation of the Bannock overthrust in that direction east of Bear Lake Valley. On the west side of the valley, however, it is well shown along the foothills at the east base of the Bear River Range.

WEST SIDE OF BEAR LAKE VALLEY

About a mile north of Sharon, in T. 12 S., R. 43 E., a group of ledges rises from the east bank of North Creek to the road. These ledges were considered in the field to be Rex chert, but if they are indeed Rex they represent an unusual facies of the chert. They more probably represent the cherty zone that locally marks the fault plane. They show the approximate position of the fault plane, which is elsewhere concealed in that vicinity.

West of Liberty the fault emerges from cover with the Brigham quartzite in contact with the Thaynes. The fault trace is inconspicuous on the hillsides and may be noted for much of its course only by the change in float or by the change in grade where stream valleys cross the hard quartzite into the weaker Triassic beds. The structural relations in the vicinity are shown in the structure section along the line X–X′ (pl. 12).

At Slight Canyon, in T. 13 S., R. 43 E., the Phosphoria and Wells formations emerge from beneath the upper fault block and continue as far south as Bloomington Canyon. The phosphatic shales are accessible and have been prospected and mined.

In Paris Canyon the fault zone is marked by a prominent ledge of siliceous breccia that crosses the canyon about three-quarters of a mile above the power house. This breccia occurs at intervals for nearly 3 miles north of Slight Canyon and was at first mistaken for Rex chert. The dip of the fault plane at this locality is about 23°.

At Bloomington Canyon (see structure section Y–Y′ (pl. 12) the eastern edge of the upper fault block is composed of Brigham quartzite. The westernmost formation of the lower block is the Wells. In the tributary canyon on the north side of Bloomington Canyon at the fault zone a white, dense quartzite, which resembles the Swan Peak quartzite, lies east of the sandstones of the Wells formation. A white, nearly pulverized quartzite also appears west of the phosphatic shales in prospects in the same gulch. This crushed rock contains larger fragments of undoubted Swan Peak quartzite and is locally stained along joints or fissures by red material that has infiltered from the neighboring Wasatch beds. The Bannock overthrust in Bloomington Canyon is thus accompanied by slices of Wells and Swan Peak rocks and probably also by smaller rock slices, one of which may include the phosphate exposed in the prospect holes.

Near the mouth of Worm Creek, about 2½ miles south of Bloomington Canyon, the fault branches apparently unite. A prominent outcrop of crushed Swan Peak quartzite, quarried for road metal, occurs just east of the Brigham quartzite. The Swan Peak here forms the northern tip of a rock slice that is better exposed farther south. On the south side of Worm Canyon about half a mile to the east occur low ledges of Brazer limestone and of the Wells formation in fault relationship. These are the northernmost ledges of recognized Brazer west of Bear Lake Valley. The stratigraphic throw of the Bannock overthrust near the mouth of Worm Creek is approximately 13,000 feet.

About a mile south of this locality, on a small southward-projecting point at the east edge of the hills, ledges of dark banded chert and accompanying nonfossiliferous gray limestone emerge from the cover of Wasatch conglomerate. The chert and limestone are probably assignable to the Rex. The phosphatic shales, if not faulted out, may occur beneath the Tertiary in the rock slice that extends southward from the exposures named to St. Charles Canyon. The silicified condition of the conglomerate at the top of the hill above the chert exposure suggests the action of thermal waters along a fault plane.

In the vicinity of St. Charles (see structure section Z–Z′, pl. 12) the fault zone is highly complex and includes probably no less than six faults, which divide the rocks into roughly parallel slices east of the belt of Brigham quartzite, the easternmost formation of the upper fault block. The trace of the west branch of the fault in this district and southward lies east of a series of topographic sags and laps up on the west side of the adjoining hills. The westernmost rock slice is composed of the Garden City limestone and Swan Peak quartzite, and the next slice of Fish Haven dolomite. The middle slice includes a small mass of Threeforks limestone which is the only occurrence of Threeforks limestone yet recognized in the entire area of the seven quadrangles considered in this paper, though the Jefferson limestone, also Devonian, occurs in the Slug Creek quadrangle. East of the Brazer limestone lies a slice of the Wells formation, which in turn is succeeded on the east by Fish Haven dolomite. The formations and the structure east of the dolomite are concealed by Tertiary beds and alluvium, but farther north scattered outcrops of Wells occur east of the fault zone. The synclinal structure east of the overthrust in the Bloomington and Paris district may therefore be continued southward beneath cover.

In the Fish Haven district the fault zone includes probably four faults by which an unsymmetrical syncline of Ordovician strata is sliced and thrust eastward upon Fish Haven dolomite. (See structure section A″–A‴, pl. 12.) Pliocene deposits possibly conceal Paleozoic or Mesozoic rocks farther east. These rocks are represented hypothetically in the section by the Wells formation because the Wells appears east of the fault zone between St. Charles and Bloomington. About 2 miles north of the line of the section the faulted syncline includes Laketown dolomite, which furnishes the largest exposure of Silurian rocks in the region mapped.

SOUTHWARD EXTENSION

The west branch of the Bannock overthrust, which crosses the south boundary of the Montpelier quadrangle, may be clearly traced about 6 miles southward into the Randolph quadrangle, where according to Richardson [11] it extends between the Brigham quartzite and Garden City limestone in the vicinity of Garden City, Utah. Farther south its course is concealed by the Wasatch formation. The other branches have not been identified in the Randolph quadrangle, though possibly they may be related to certain faults found by Richardson in the district south of Bear Lake. In Birch Creek, near the center of T. 9 N., R. 5 E., about 25 miles almost due south of the point where the fault disappears beneath cover, Richardson has mapped a fault between the Brigham quartzite and the Nugget sandstone that is comparable in magnitude to the Bannock overthrust, of which it is not improbably a continuation. The Birch Creek fault has been traced southward about 6 miles farther into Woodruff Creek, where it has been described by Gale and Richards [12] in connection with phosphatic shales of the Phosphoria formation. (Park City formation of report cited.)

BERN AND NOUNAN

In the northwest part of the Montpelier quadrangle (see structure section W–W′ pl. 12) a fault brings Brigham quartzite into contact with Swan Peak quartzite. The fault passes beneath the Tertiary beds south of Stauffer Creek and is believed to join the Bannock overthrust, though the place and manner of joining are conjectural. The Cambrian and Ordovician rocks, which form the upper thrust block, are thrown into several small folds. The Ordovician rock slice continues at least as far south as the hills a mile west of Bern, where an area of Garden City limestone has been uncovered by the erosion of Tertiary beds. The main branch of the Bannock overthrust passes through Nounan Valley, for Ordovician rocks lie on the west side and Triassic rocks on the east. At the line of structure section U–U′ the fault is exposed in the foothills west of the valley. The stratigraphic throw at that place is approximately 10,000 feet. The Triassic rocks thus form part of the lower fault block. They have locally variable dips but in general are nearly horizontal or faintly arched.

BEAR RIVER VALLEY

A fault along the east side of the Triassic area in the valley of Bear River is indicated by the travertine deposits at the mouth of Threemile Creek and by the

[11] Richardson, G. B., U. S. Geol. Survey, manuscript map of the Randolph quadrangle.

[12] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457–535, pp. 526–529, 1910.

well-recognized fault between the corresponding Triassic beds and Carboniferous rocks in the Slug Creek quadrangle to the north. The plane of the Bannock overthrust probably bends down beneath Bear River Valley and emerges again along the base of the foothills of the Preuss Range farther east. The undulatory character of the Bannock overthrust is clearly shown in the Left Fork of Twin Creek in the Slug Creek quadrangle and at the head of Montpelier Canyon, so that the undulation necessary to produce the arching and depression indicated in the structure section is entirely in keeping with the known character of the fault plane. Alternative interpretations are given on page 157. The erosion of the arched fault plane southeast of Nounan Valley is masked by the more recently deposited Tertiary beds, but possibly because of a transverse synclinal axis that has been recognized farther northeast, the arch of older rocks may not have been completely worn away. Hence the upper block is tentatively represented as overlapping the arch beneath the Tertiary beds west of Pescadero.

The thickness of the Quaternary beds beneath the valley of Bear River is not known, and nothing is known of the composition of the supposed downwarped thrust block in the valley where it is crossed by the line of structure section W–W′ (pl. 12). Near Montpelier, however, and north of Georgetown Canyon Carboniferous rocks are included in this portion of the thrust block. Therefore, in the region of the structure section Carboniferous or Triassic beds may be present beneath the hill wash, alluvium and probably the underlying Tertiary beds.

WEST FLANK OF PREUSS RANGE

The arch in the fault plane along the west flank of the Preuss Range is the southward continuation of the arch that is exposed in the Left Fork of Twin Creek. In that locality, as in the line of the structure section, the rocks exposed by the erosion of the upper block belong to the Nugget sandstone and the Twin Creek limestone. A small fault, which is apparently a thrust related to the great overthrust, offsets the Nugget-Twin Creek boundary near the base of the range. The synclinal structure of the Twin Creek in the vicinity of Maple Canyon suggests that the structure of the lower fault block beneath the east side of Bear River Valley is anticlinal, as shown in structure section W–W′ (pl. 12).

WEST FLANK OF ASPEN RANGE

The position of the fault trace along the west base of the Aspen Range is partly concealed, and its attitude elsewhere is obscure. In the concealed portion its position is suggested here and there by deposits of travertine. Near the line between Bear Lake and Bannock Counties the fault trace emerges from cover. From this point northwestward a yellowish breccia composed of fragments of Carboniferous and Triassic formations occurs along the slope above the Quaternary and Tertiary deposits and between the Carboniferous rocks and the outlying Woodside Hills. There are few definite ledges. The fragments are leached and porous and accompanied by several varieties of secondary calcareous deposits. This breccia marks the fault zone. In the southwest corner of sec. 19 (unsurveyed), T. 9 S., R. 43 E., the dip of the fault zone appears to be about 20° NE., but south of Diamond Gulch there are some suggestions of its steepening or even being overturned. In structure sections U–U′, T–T′, R–R′, and Q–Q′ (pl. 12) the dip of the fault plane has been curved and steepened to accord with this interpretation. The fault trace continues through T. 9 S., R. 42 E., into T. 8 S., R. 42 E., where it passes beneath travertine and basalt. (See pl. 1.)

SODA SPRINGS

The west limb of the arched and eroded fault plane is concealed north of Nounan Valley, but at Threemile Hill, about 3 miles north of Soda Springs, large fragments of Ordovician limestone and quartzite overlie red beds that probably belong to the Portneuf limestone of the Thaynes group. Some of the fragments are as much as 12 by 12 by 5 feet in dimensions. There is no good ledge, but these fragments were interpreted in the field as erosion remnants of the upper fault block. In more recent field work large fragments of Ordovician and other rocks have been observed in more or less isolated positions, where they seemed to have been left by the erosion of Tertiary conglomerates, of which they were formerly a part. The remnants at Threemile Hill are therefore not conclusive evidence of the former presence of the upper fault block. The Carboniferous and pre-Carboniferous areas northwest of Soda Springs have not been studied in detail, but their arrangement suggests faulting.

NORTHWESTWARD CONTINUATION

In the Portneuf quadrangle, which lies immediately west of the Henry quadrangle, the northeastern half is largely occupied by Carboniferous and post-Carboniferous rocks which show continuations of some of the structural features of the Henry quadrangle. The Fort Hall Indian Reservation, which adjoins the Portneuf quadrangle on the northwest, contains a noteworthy thrust fault which has been described as the Putnam overthrust.[13] There seems a likelihood that the two faults may be connected, and this expectation has been greatly strengthened by more recent field work in the Portneuf quadrangle.

The east trace of the eroded fault plane north of Formation Spring in T. 8 S., R. 42 E., is con-

[13] Mansfield, G. R., The geography, geology, and mineral resources of the Fort Hall Indian Reservation: U. S. Geol. Survey Bull. 713, pp. 62–65, 1920.

cealed by basalt. Numerous faults occur in the sedimentary areas north and northwest of the basalt, but as yet none of these faults has been identified with the overthrust.

ALTERNATIVE HYPOTHESES OF FAULTS IN BEAR RIVER VALLEY

Although the hypothesis of the arched and eroded fault plane in Bear River Valley as above outlined seems to afford an adequate explanation of the facts so far observed, two other hypotheses, which are in effect modifications of that already presented, deserve mention. The first is that of a normal fault along the east side of the valley; and the second is that of branch faults uniting in the vicinity of Bern in the northwest part of the Montpelier quadrangle. These hypotheses are illustrated in Figures 16 and 17.

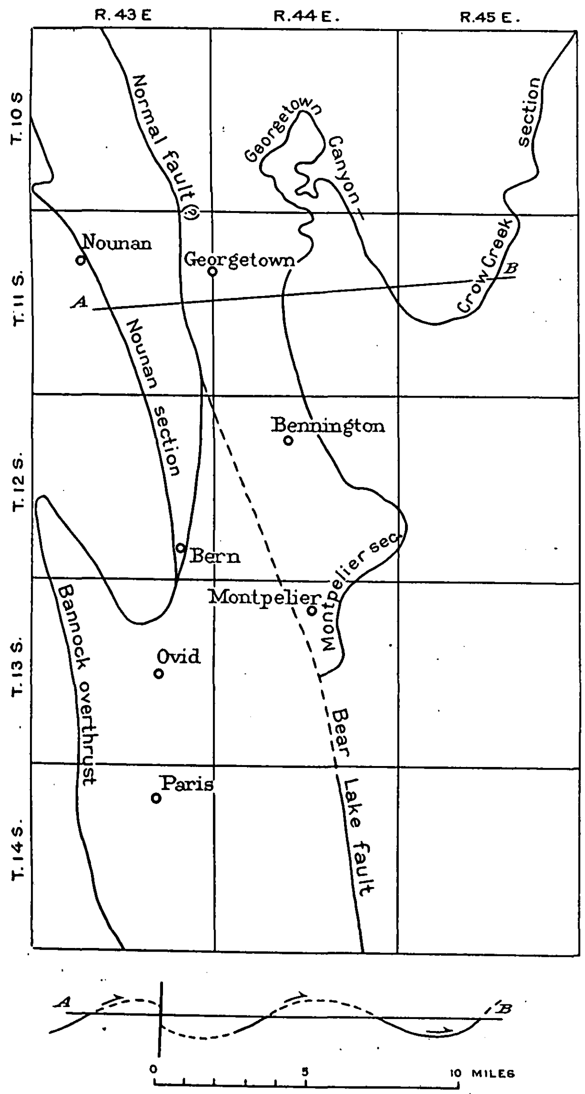


FIGURE 16.—Diagram to illustrate the hypothesis of normal faulting of the Bannock overthrust plane along the east side of Bear River and Bear Lake Valleys. *A-B*, Diagrammatic cross section

According to the first hypothesis the Bear Lake normal fault would be extended northwestward past Montpelier to the travertine deposits at the mouth of Threemile Creek, in T. 11 S., R. 43 E., and thence along the travertine deposits north of Georgetown to the west base of the Aspen Range. The fault in that district would then be considered to be normal and to have a steep westerly dip. Thence it would pass northwestward to Formation Spring and the area covered with basalt. The travertine deposits and sulphur springs along this line suggest a deep fracture and favor the hypothesis. This fault, if present, would break down the arched fault plane along the east side and produce other modifications of structure, as illustrated in Figure 16. On the other hand, a covered interval of more than 16 miles intervenes between the Bear Lake fault as mapped and the travertine at Threemile Creek. The fault at the west base of the Aspen Range is apparently older than the Bear Lake fault, for its physiographic expression, though produced in similar rocks and rock structure, is less fresh and less striking.

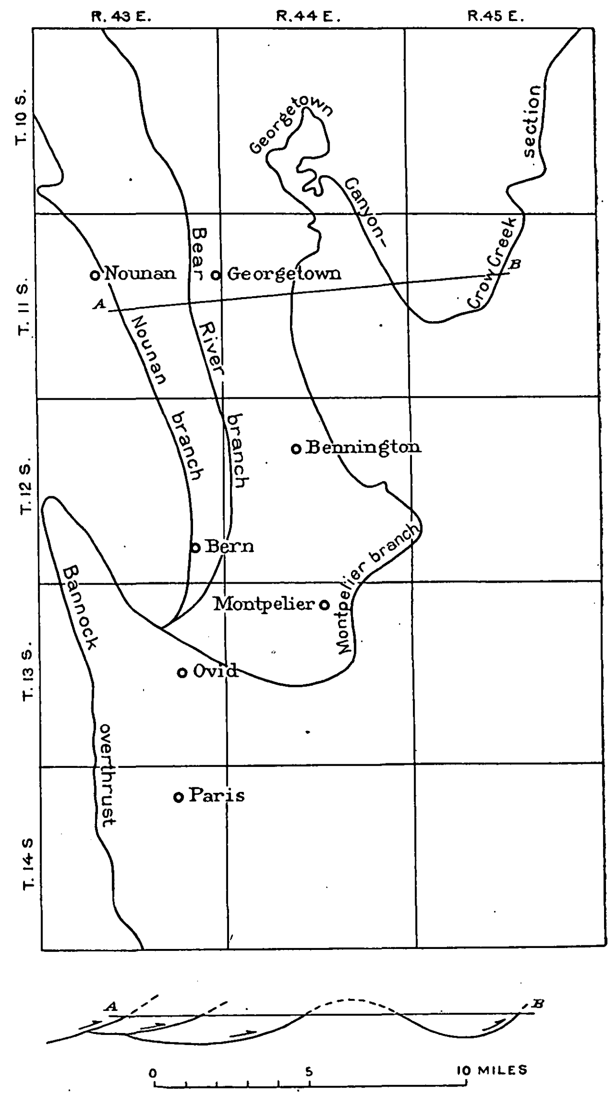


FIGURE 17.—Diagram to illustrate the hypothesis of branching faults in Bear Lake Valley. *A-B*, Diagrammatic cross section

Under the hypothesis of branching faults the faults in Nounan Valley and at Threemile Creek are considered to be branches that unite somewhere near Ovid, as suggested in Figure 17. The Montpelier fault would be a branch that might join the others near Bern or at some point farther south. This hypothesis would not require arching of the fault plane over Bear River Valley, but it would cause the valley to be underlain by rock slices composed of different formations. The Triassic slice east of Nounan would be underlain by a fault and might not contain phosphate deposits. In view of the obscure character of the fault trace along the west base of the Aspen Range no confirmation or denial of the hypothesis may yet be made.

Since the above paragraphs were written field work in the Portneuf and Paradise Valley quadrangles has

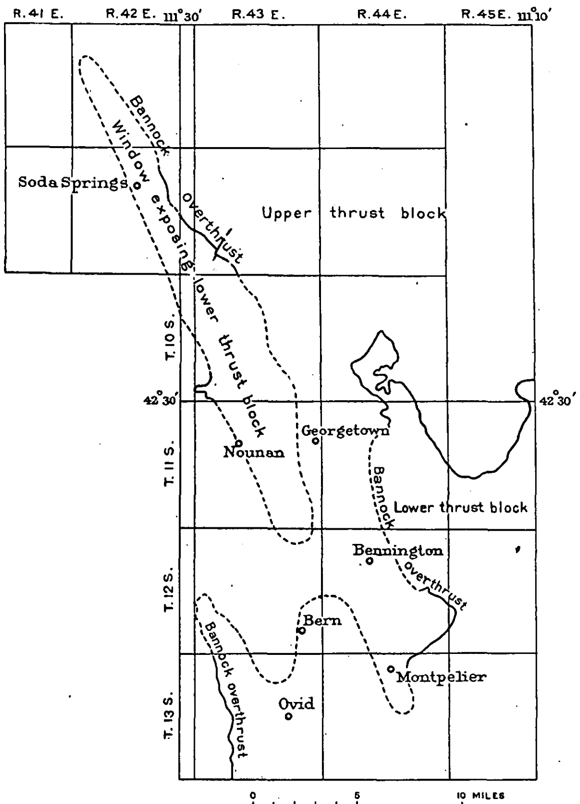


FIGURE 18.—Diagram to illustrate the hypothesis of a window in the fault plane in Bear River Valley

furnished definite evidence that the Chesterfield Range and Blackfoot Mountains are underlain, in part at least, by a thrust plane that corresponds in general character to that of the Bannock overthrust. This evidence supports the view that the exposures of Triassic beds in Bear River Valley are caused by the development of a window by erosion of the upper fault block. (See fig. 18.) This hypothesis is the most plausible, for the possible northward extension of the thrust fault on the east side of Bear River Valley has not been recognized although the structural features that cross its strike a few miles to the north have been examined.

DISPLACEMENT AND MAGNITUDE

Because of the intense folding experienced by the rocks of both the upper and lower blocks no accurate statement of the amount of vertical displacement can be made. Some idea of that displacement may, however, be gained for any district by the consideration of the thicknesses of the formations or parts of formations that are missing. Where the fault branches the stratigraphic throw is distributed among the different members, in some of which it may not exceed 1,000 feet. The cumulative stratigraphic throw of all branches in a given area may amount to 15,000 to 20,000 feet. The minimum stratigraphic throw for the entire fault zone is in the Stump Creek district of the Freedom quadrangle, where it may not exceed 1,000 feet. If the thicknesses assigned to the Wayan formation are not overestimated the maximum stratigraphic throw of the fault zone is probably in the northeastern part of the Lanes Creek quadrangle. At many places along the fault zone it is as much as 15,000 feet.

The structure section along the line W–W′ (pls. 9 and 12) illustrates one of the best exposures of the underlying block with a minimum amount of cover. A clue to the minimum horizontal displacement is suggested by the possibility that the Mississippian limestones of the western fold of the structure section may represent the source of the overthrust mass of these formations that lies about 12 miles to the east. On the basis of the supposed structure the source can not be nearer, for the Mississippian limestones do not rise to the level of the fault plane in any of the folds farther east in this district. Moreover, the size of the displaced Mississippian mass, if it is judged by its present area, suggests either that the fold in the structure section has not been made large enough or that the source was a more westerly fold or series of folds. Thus the horizontal displacement is probably not less than 12 miles.

Another measurement of the horizontal displacement may be expressed by a line drawn perpendicular to the general trend of the fault trace and extending from the westernmost point on the trace to the easternmost point on the east margin of the fault block. The length of such a line is about 35 miles. This measurement, however, neglects the recession produced by erosion along the east margin of the fault block.

The length of the fault trace with its major sinuosities, as shown in Figure 44, from the vicinity of Blackfoot Peak, Idaho, to Woodruff Creek, Utah, is approximately 270 miles. The direction of movement was from west-southwest to east-northeast.

DEFORMATION OF FAULT PLANE

Two phases of deformation of the fault plane have been recognized and described above—folding and overturning. The folding is clearly shown in the vicinity of Meade Peak and Georgetown Canyon; the overturning occurs at the head of Crow Creek in Boulder Canyon and northwest of Stump Peak. (See structure sections U–U′′, W–W′, L–L′, and K′′–K′′′, pls. 12, 36, *C*, and 37). The folding of the fault plane is doubtless to be ascribed to renewal of folding in the region along the earlier established lines. In this connection, however, the occurrence of the syncline in the fault plane beneath the massive limestone mass of the Snowdrift anticline may be more than a coincidence. It suggests a causal relationship between the load and the depression. In view, however, of the rigidity commonly ascribed to the earth's crust little significance may be attached to this possibility. The steepening or overturning of the fault planes in the various branches of the overthrust, which necessitates the curvature of these faults as represented in the structure sections, is doubtless due to the folding mentioned above.

POSSIBLE EASTWARD EXTENSION

The recognized deformation of the plane of the Bannock overthrust in the Slug Creek quadrangle and elsewhere raises the question whether the East Stump branch is actually the east front of the upper fault block. The attitude and relationships of the Star Valley and Auburn faults suggest the possibility that those faults may be eastward extensions of the Bannock overthrust. It is with this possibility in mind that the direction of movement on these faults is tentatively indicated in the structure section K′′–K′′′ (pl. 11 and fig. 45) as eastward rather than westward, which would supposedly be true if the faults were independent of the great overthrust.

OTHER THRUST FAULTS

STAR VALLEY OVERTHRUST

In the northeastern part of the Freedom quadrangle there are three isolated occurrences of Madison limestone. Near the mouth of Dale Creek the Madison lies in proximity to the Twin Creek limestone, and at the mouth of Miller Creek it is exposed within a few hundred feet of Nugget ledges and above them. The contacts are concealed, but faulting is suggested by the brecciated condition of the limestone and by the occurrence of travertine deposits. The separated areas of Madison limestone are regarded as parts of a thrust fault block in which the fault plane dips northeastward. The course of the fault as mapped is suggested by the arrangement of the travertine deposits. The stratigraphic throw is probably more than 10,000 feet, for the Madison limestone probably forms a thin cake over Nugget and Twin Creek formations. The fault may be called the Star Valley overthrust, because it laps against the west side of that valley. The nearest known outcrops of Madison limestone occur near the mouth of Strawberry Canyon, in secs. 27 and 28, T. 34 N., R. 118 W., in Wyoming, about 7 miles southeast of Freedom.

The absence of the Madison limestone east of the ledges first described is explained by the supposed continuation of the Freedom fault, which is thought to have caused the downthrow of the overthrust block on the west, which thus preserves the Madison ledges. On the upthrown side to the east, however, erosion has removed the Madison limestone and possibly the overlying formations and has excavated the valley in the weaker Twin Creek or Nugget beds. Both Nugget sandstone and Twin Creek limestone are exposed at the narrows of Salt River, about 3 miles south of Thayne, and unless unfavorable structure intervenes beneath the alluvium of Star Valley the general strike of the rocks would bring these formations northwestward into the vicinity of the Madison areas.

The structure just outlined is illustrated in structure section K′′–K′′′ (pl. 11). In view of the known arching and erosion of the plane of the Bannock overthrust at several places to the southwest it is an interesting speculation that the Star Valley and Bannock overthrust faults may once have been connected.

AUBURN FAULT

Along the east flank of the Caribou Range in the Freedom quadrangle the Twin Creek limestone, for a distance of about 14 miles, is brought against rocks that range in age from the Stump sandstone to the lower division of the Wayan formation by a fault that is interpreted as a thrust with an easterly dipping plane. Its position is marked by springs where it crosses the South Fork of Miller Creek. Its stratigraphic throw at the north is comparatively small, but farther south it increases and may be 7,000 feet or more. The fault is shown in structure sections K′′–K′′′ and L′–L′′ (pl. 11). It passes under cover about a mile west of the town of Auburn, from which it takes its name. It may be related to the Star Valley overthrust.

BOULDER CREEK FAULT

A subordinate fault, recognizable for about 4 miles, cuts out the Deadman limestone and Wood shale along the east flank of the Boulder Creek anticline, as shown in structure section L–L′ (pl. 11), and brings into contact the Higham grit and the Nugget sandstone. The fault is well shown in a tributary valley on the north side of Boulder Canyon. Its stratigraphic throw is probably less than 500 feet.

LANES CREEK FAULT

The Lanes Creek fault is postulated to connect three rather widely separated faults of supposedly similar habit. Its course is largely concealed beneath basalt and alluvium in the valleys of Lanes Creek and Diamond Creek. The first of the three faults is in sec. 4, T. 6 S., R. 44 E., in the Lanes Creek quadrangle. Here a hill composed of the Wells and Phosphoria formations lies in proximity to the Thaynes group on the east and to the Nugget sandstone on the north. In sections 20 and 29 of the same township the Thaynes group and Timothy sandstone lie in fault relation along the southeast base of Grays Range. Parts of both formations are missing. In the southwest corner of the Freedom quadrangle, east of Upper Valley, the Snowdrift anticline, which there brings Wells and Phosphoria formations to the surface, is broken by converging faults. The eastern fault at this place is probably a thrust, as shown in structure section L–L′ (pl. 11). The Lanes Creek fault as thus constituted is about 13 miles long. It is presumably offset in Upper Valley by the transverse Blackfoot fault. Its displacement at the south is comparatively slight, but farther north it increases, and near its junction with the Chippy Creek branch of the Bannock overthrust its stratigraphic throw is probably 2,000 feet or more. In sections 31 and 32 a thrust fault that is regarded as a branch of the Lanes Creek fault brings beds of the upper Wells against the Woodside formation.

HENRY FAULT

About a quarter of a mile north of Henry the Wells formation is faulted against Woodside shale. Westward the fault passes beneath cover north of the hills of Wells to the Reservoir, where it is probably cut by normal faults. Eastward the fault passes beneath basalt and then turns southeastward along the southwest sides of Enoch and Rasmussen valleys, where as previously stated it subdivides the Georgetown synclinorium. Its length is nearly 15 miles, but the stratigraphic throw is comparatively small, only a few hundred feet. For nearly two-thirds of its course it is concealed, but its general position, except at the northwest, is along the Thaynes and Woodside boundary, the *Meekoceras* zone and adjacent beds being cut out at most places. The fault is shown in structure sections H–H′, I–I′, and K′–K″ (pl. 11).

WOOLEY RIDGE FAULT

From sec. 25, T. 6 S., R. 42 E., to sec. 24, T. 7 S., R. 43 E., a thrust fault extends for about 8 miles along the northeast flank of Wooley Ridge. In the northern part it separates Brazer limestone from the Wells formation, which it transgresses diagonally. In sec. 32, T. 6 S., R. 43 E., it is joined by a branch that brings Wells into contact with concealed beds that are presumably Woodside. Southeastward from this place it lies generally along the boundary between the Wells and Phosphoria and locally cuts out parts of both formations. It has not been recognized south of the transverse Blackfoot fault. The fault is shown in structure sections H–H′, I–I′ and K′–K″ (pl. 11), where it is represented as a branch of the Bannock overthrust. The stratigraphic throw is greatest at about the line of structure section I–I′, where it may exceed 2,000 feet. From this point it diminishes rapidly in both directions.

BLACKFOOT FAULT

The Blackfoot fault, which is most conspicuously developed in the vicinity of the narrows of Blackfoot River (pl. 4), has a known length of about 13 miles in a general easterly direction. The relations of this fault at the north entrance to the narrows indicate that its dip is about 33° S. The variations in dips on the flanks of the big anticline in the upper thrust block, some of the strata in which are locally overturned, and the presence of minor folds make it difficult to determine the throw of the fault. The maximum observed effect of the fault is produced where it cuts the big Carboniferous anticline. Westward it apparently diminishes and passes under cover in Blackfoot Valley. It is probably offset beneath cover in Wooley Valley by the normal fault continued northward from Slug Valley. Eastward it crosses Upper Valley and dies out in the valley of Timothy Creek. The Blackfoot fault is shown in structure sections I–I′ and K′–K″, where it is represented as connecting with the Bannock overthrust.

The upper block affords an unusually fine example of the spreading of the outcrops of a formation, such as the Phosphoria, on the opposite limbs of a fold by the uplift or tilting and erosion of a fault block in which the fold is included. In the lower block to the north the corresponding outcrops are much nearer together. (See fig. 19.)

The Blackfoot fault is supposed to have originated in a transverse anticline, which was located near the line along which occurred the maximum yielding of the rocks to the compressive earth stresses of the region. The anticline broke, and the southeast limb, which became the upper fault block, swung northward about a pivot located in the vicinity of Timothy Creek in the Freedom quadrangle. The Timothy sandstone and overlying formations cross this creek without apparent displacement by the fault, but they make a pronounced turn which suggests the position of the unbroken axial portion of the anticline.

DRY RIDGE AND SLUG CREEK THRUSTS

Along the west flank of Dry Ridge in T. 8 S., Rs. 44 and 45 E., a thrust fault of small throw locally cuts out portions of the Phosphoria formation. This fault originates in a subordinate anticline on the east limb of the Dry Valley anticline, as shown in structure section O–O′ (pl. 12).

Similarly in sec. 24, T. 8 S., R. 43 E., near the township line, a thrust fault originates in a subordinate anticline on the west limb of the Schmid syncline, as shown in the same structure section. The fault apparently passes southward under cover beneath Slug Creek and into the hills beyond. In the west side of T. 9 S., R. 44 E., it cuts out part or all of the Phosphoria formation and locally brings the Wells formation into contact with the Woodside shale. Southward the fault joins the Bannock overthrust at the previously described "window." The length of the fault is nearly 7 miles, but its maximum stratigraphic throw probably does not exceed 600 feet.

ASPEN RANGE THRUSTS

A fault about 8 miles long but which has comparatively small stratigraphic throw extends from sec. 29 (unsurveyed), T. 8 S., R. 43 E., northwestward along the west limb of the Trail Creek syncline into sec. 14, T. 7 S., R. 42 E. It originates in a subordinate anticline and cuts out the *Meekoceras* zone and the adjacent beds, as shown in structure sections K–K′, M–M′, (pl. 11) and O–O′ (pl. 12).

dip and a course that is correspondingly more irregular. In South Sulphur Canyon the portion of the thrust block caught between these two faults is cut by a transverse thrust fault that has a northwesterly dip. The erosion of the canyon has cut away the Brazer and Wells rocks down the dip of the fault plane and has exposed beds of Rex chert and Woodside shale. Southwest of the normal fault the Brazer beds are preserved nearly to the mouth of Swan Lake Gulch, where the entire thrust block is cut and offset by a transverse normal fault that has a downthrow to the northwest. Southeast of this fault the thrust block is eroded away, except the portion caught between the longitudinal faults, and this is practically cut through at Swan Lake Gulch and Dry Canyon.

At Swan Lake Gulch the Brazer limestone is apparently conformable with the overlying Wells formation, but at the line of structure section R–R′ (pl. 12) the Wells is partly cut out by a thrust fault that dips northeasterly. Northwestward this fault probably passes beneath the fault that forms the eastern edge of the broken thrust block. Southeastward it is offset by the transverse normal fault described above.

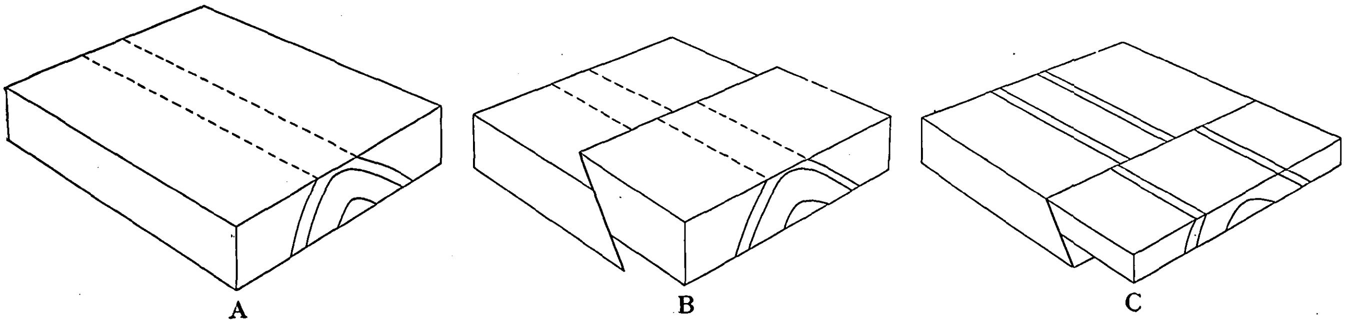


FIGURE 19.—Diagram to illustrate the increased distance between the linear outcrops of a folded formation produced by transverse thrust faulting and erosion. A, An anticline planed off by erosion; B, the same cut by a transverse thrust fault; C, the same after a second planation by erosion

From sec. 24, T. 8 S., R. 42 E., to sec. 17 (unsurveyed), T. 9 S., R. 43 E., a distance of about 7 miles, a thrust fault brings beds of middle to upper Wells against the upper Wells or Phosphoria. At the north it is cut off by a fault that is presumed to be normal. At the south it joins or is joined by a reversed fault that is described in the next paragraph. It marks the eastern edge of a broad and fractured thrust block which contains chiefly Carboniferous rocks but which at the north and south includes beds of the Woodside formation. The thrust fault that produced the block and some of the subsidiary faults that fracture it are regarded as branches of the Bannock overthrust, as shown in structure sections Q–Q′, R–R′, and S–S′ (pl. 12).

The broad thrust block is broken about midway by a longitudinal normal fault 10 miles or more long and a reverse fault of similar length that converge and apparently terminate in sec. 33, T. 9 S., R. 43 E. The normal fault, which is the western member of the pair, has a steep northeasterly dip, but the reverse fault at the east has a relatively gentle southwesterly

Between Wood Canyon and Middle Sulphur Canyon the fractured thrust block is cut by subordinate faults, both thrust and normal, in such manner that beds of the Phosphoria formation are preserved in a roughly boot-shaped area.

In the northern part of the thrust block (see pl. 1) there are several minor faults. The two principal longitudinal faults continue, and the eastern member of the pair is obliquely cut by the irregular normal fault, which cuts the eastern boundary fault of the block. In the southeastern part of the Henry quadrangle this normal fault is marked by a basaltic dike and by springs that have formed extensive deposits of travertine.

MONTPELIER AND HOME CANYON THRUSTS

In Montpelier Canyon east of the Carboniferous thrust block there are three thrust faults that deserve mention. One of these faults lies on the northern face of Waterloo hill and separates Wells and higher beds from the Thaynes. All the faults join northward and cut out parts of the Thaynes group. In sec. 16, T.

13 S., R. 45 E., one of the faults brings Nugget sandstone (?) against middle to upper Thaynes. The zone occupied by these faults is about 10 miles long.

In the ridge east of Home Canyon a thrust fault about 4 miles long brings upper Thaynes into contact with the lower Nugget and offsets the axis of the Harer syncline nearly half a mile.

HORST AND GRABEN STRUCTURE

MEADOW CREEK GRABEN

Perhaps the most striking effect of normal faulting in the region is the production of horst and graben structure in the northwestern part. The valley of Meadow Creek in the southern part of the Cranes Flat quadrangle is a fault trough or graben. This structure may be traced about 15 miles southeastward into T. 6 S., R. 43 E., in the Lanes Creek quadrangle, where it apparently dies out. The northward extension of the graben is concealed by basalt. The bounding ridges are composed of Carboniferous rocks and are conspicuous topographic features. (See pl. 39.)

Two transverse normal faults intersect the graben, one near the south boundary of the Cranes Flat quadrangle and the other in the northwest corner of the Lanes Creek quadrangle, and the portion between them is downfaulted. The bounding ridges in the downfaulted portion are farther apart than in the portions to the northwest or southeast. In the southeastern part of the graben beds of the Thaynes group are exposed, and in the widened, downfaulted portion both Woodside and Thaynes appear, though most of the area is underlain by basalt and Quaternary deposits. In the northwestern part basalt and Quaternary beds entirely conceal the older rocks. The structure of the rocks within the graben is probably synclinal, as shown in structure sections E–E′, G–G′, and H–H′ (pl. 11). It forms the continuation of the Lanes Butte syncline. The faults which have produced and intersected the graben are described below.

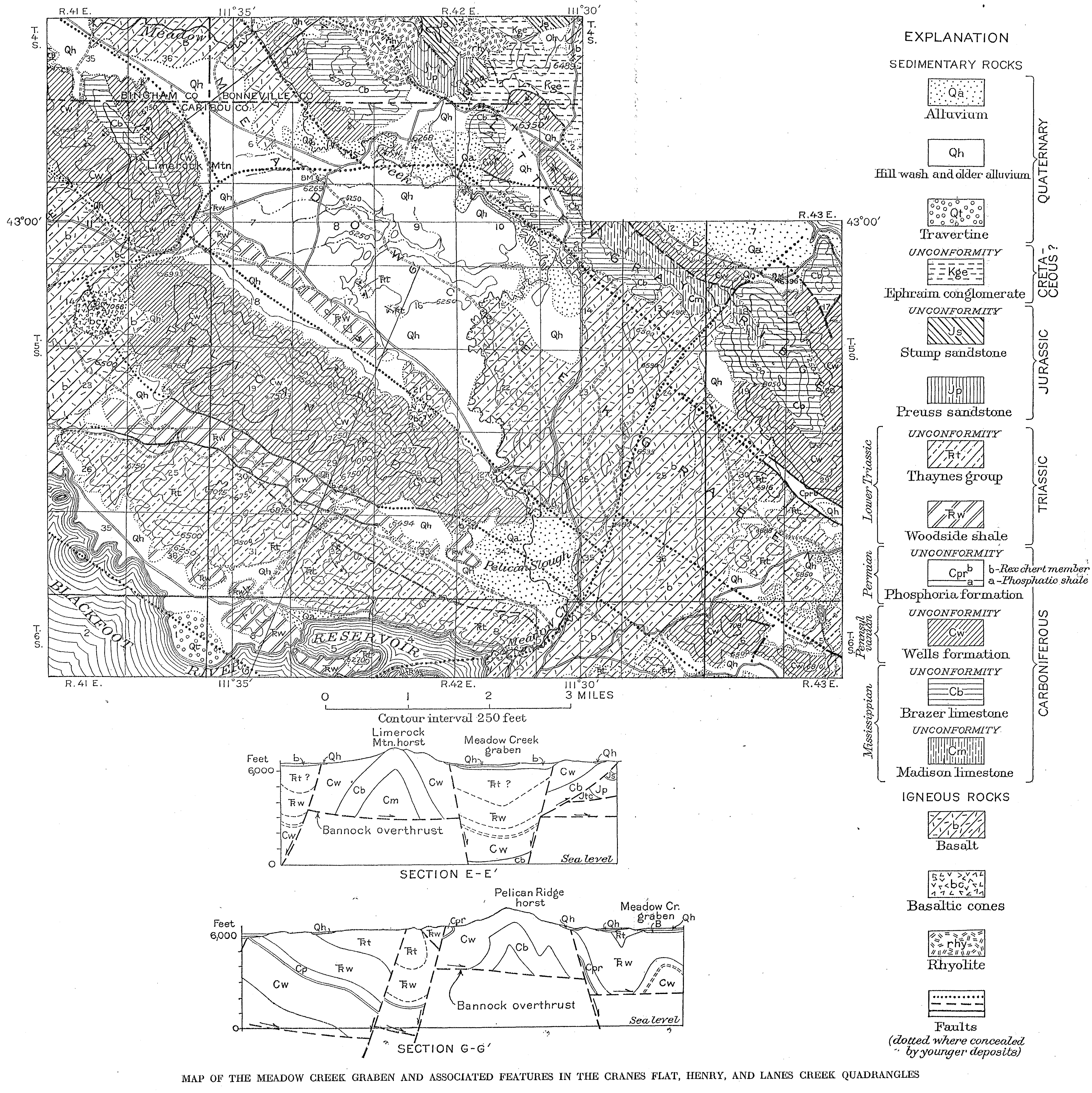
Chubb Springs fault.—The Chubb Springs fault, which lies along the northeast side, is concealed for much of its length, but in T. 5 S., R. 43 E., it is represented by two faults which are separated by a narrow strip of the Phosphoria formation and which together bring lower Thaynes into proximity with the Wells. (See structure section H–H′, pl. 11.) In the northeast corner of the Henry quadrangle the fault passes through Chubb Springs, at the west base of Little Gray Ridge, which is here rather steep. From this point northwestward it continues at the base of the Carboniferous ledges but is offset in the southeast corner of the Cranes Flat quadrangle. The steepening of the ridge slope, however, is probably largely due to the action of Meadow Creek. Beyond the Carboniferous ledges in the southwestern part of T. 4 S., R. 42 E., the fault doubtless continues beneath the lava, but its course is indeterminate. The stratigraphic throw of the fault is not known but is estimated at 3,000 to 4,000 feet.

Limerock fault.—The Limerock fault, which lies along the southwest border of the graben, takes its name from Limerock Mountain. The fault is believed to enter the region described in this report at the SE. ¼ sec. 34, T. 3 S., R. 40 E., to be offset in secs. 2 and 11, T 4 S., R. 40 E., and to pass southeastward beneath the basalt to the northeast base of Meadow Creek and Limerock Mountains. Thence it continues with the offsets noted to sec. 9, T. 6 S., R. 43 E., where it dies out. Its total length within the region described is about 22 miles.

At the base of Meadow Creek Mountain the phosphatic shales of the Phosphoria formation appear at a few places, but they are shattered and lie in an attitude different from that of the adjacent limestone to the southwest. At a prospect dug by the survey party in the SE. ¼ SE. ¼ sec. 20, T. 5 S., R. 41 E., the top of the Wells formation a few feet away has a northeasterly dip of 60°, whereas the broken phosphatic shales in the pit were nearly horizontal. In the SW. ¼ SW. ¼ sec. 21, near the prospect, the line of the Wells formation, and presumably the fault as well, is offset nearly 1,000 feet to the south with reference to the rocks at the west. Southeastward the fault is concealed nearly to the line of structure section H–H′ (pl. 11), where lower Thaynes is brought in contact with the Wells. Its presence east of Pelican Ridge is inferred from the absence of the Phosphoria formation and the scant representation of the upper beds of the Wells. The stratigraphic throw of this fault is not known but is estimated at 3,000 to 4,000 feet.

Little Gray fault.—The Little Gray fault which takes its name from Little Gray Ridge, is the transverse normal fault that passes between Limerock Mountain and Pelican Ridge and causes Limerock Mountain to stand nearly a mile northeast of the line of continuation of Pelican Ridge. The course of the fault in Meadow Creek Valley is not known, but the fault is presumed to connect with a fault on the east side of the valley that produces similar effects but in reverse order. It is cut by a fault about one-tenth of a mile east of the quadrangle boundary, beyond which point it has not been traced. West of the pass south of Limerock Mountain the fault is concealed by basalt, but it is presumed to continue at least several miles.

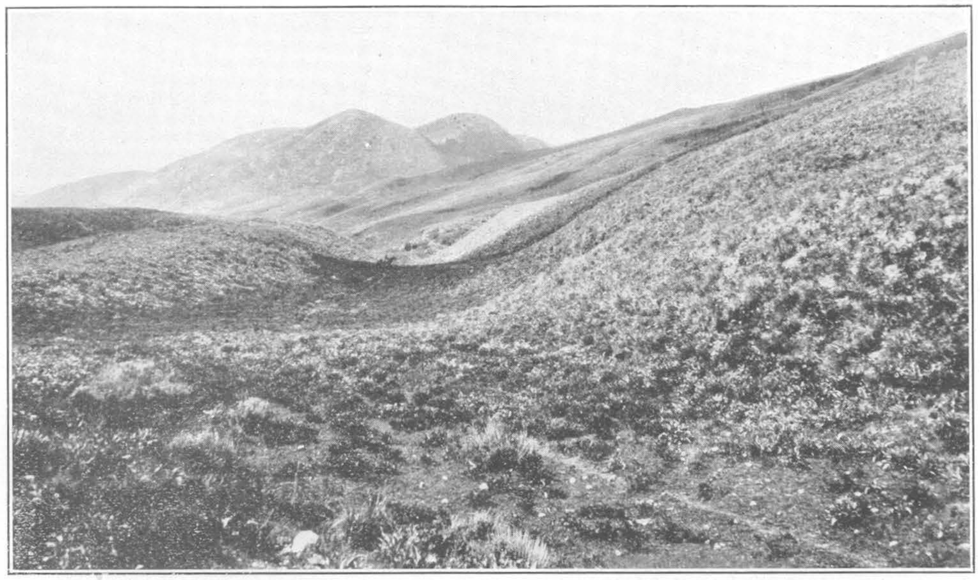
The downthrow of the Little Gray fault is to the south, for the distance between the Carboniferous ridges is greater in that direction. Neither the amount of the downthrow nor the hade of the fault plane is known, but some idea of the relative magnitude of the vertical displacement may be gained by considering the amount of offset of the lateral faults in relation to their dip, as illustrated in Figure 20. If only vertical movement is assumed in the downthrown block the traces of the longitudinal fault planes in



MAP OF THE MEADOW CREEK GRABEN AND ASSOCIATED FEATURES IN THE CRANES FLAT, HENRY, AND LANES CREEK QUADRANGLES

Richards, 227.

Mansfield 253.

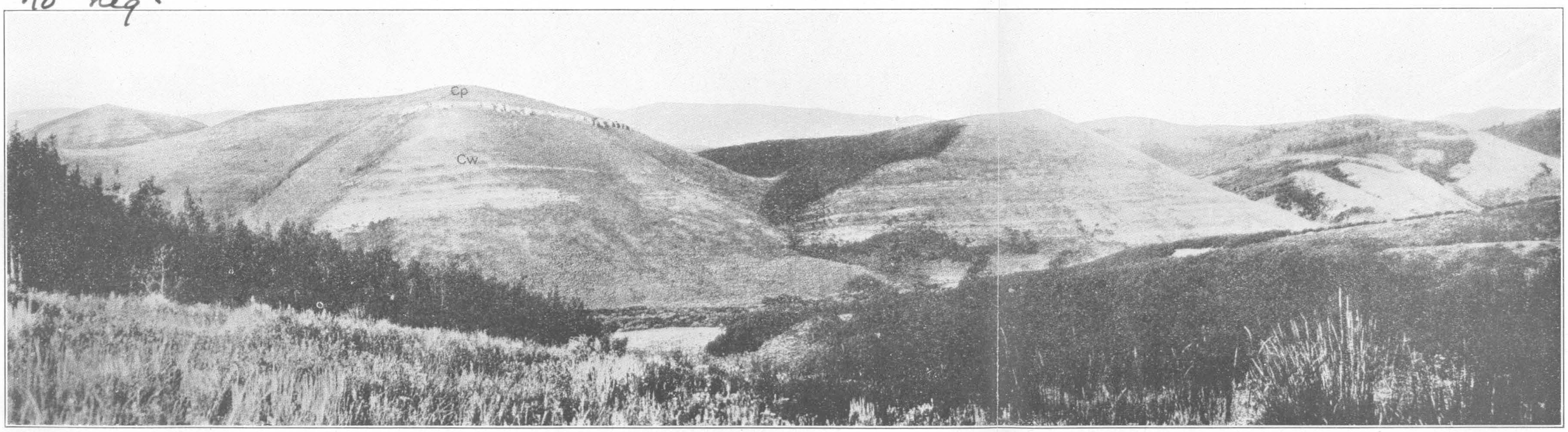


A. RECENT FAULT DEPRESSION IN SEC. 23, T. 12 S., R. 44 E., MONTPELIER QUADRANGLE

The horseman serves as scale

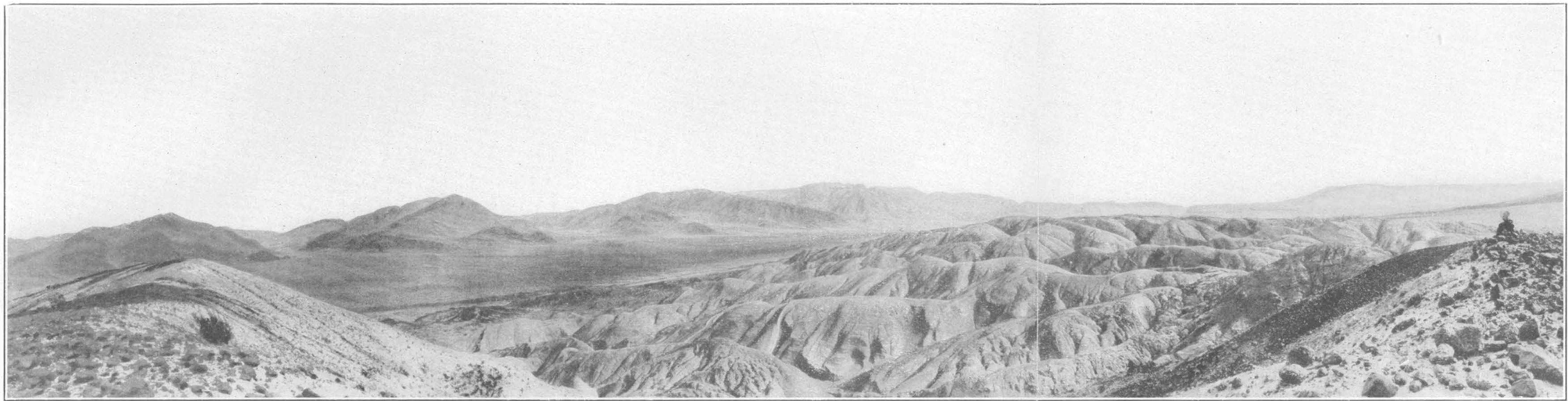
B. FOLDED SHALY AND LIMY STRATA OF THE LOWER DIVISION OF THE WAYAN FORMATION EXPOSED IN TINCUP CANYON, IN THE NE. ¼ SEC. 5, T. 15 S., R. 45 E. (UNSURVEYED), FREEDOM QUADRANGLE

No neg.



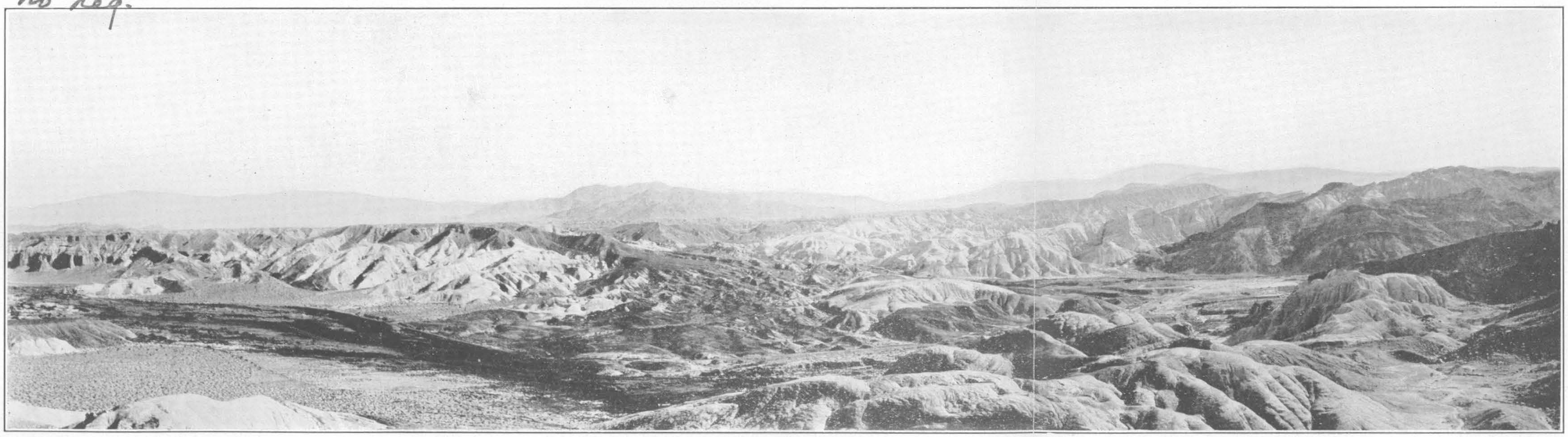
C. FAULT SCARP EAST OF SLUG CREEK, IN SEC. 16, T. 9 S., R. 44 E., SLUG CREEK QUADRANGLE

Showing succession from lower part of Wells formation (Cw) to upper part of Phosphoria formation (Cp). Note prospecting trench made by Geological Survey party near symbol Cp no neg.



A. VIEW SOUTHEASTWARD ALONG CREST OF CONFIDENCE HILLS, SHOWING GRAVEL FANS ALONG THE MOUNTAIN SLOPES ON THE EAST SIDE OF SOUTH DEATH VALLEY, CALIF.

no neg.



B. DISSECTED GRAVEL FAN NEAR ACME, ON AMARGOSA RIVER, SAN BERNARDINO AND INYO COUNTIES, CALIF.

Showing light-colored Tertiary clay exposed by erosion of the gravel both blocks, which dip toward each other and may here be regarded simply as formation boundaries, will tend to approach each other as erosion progresses but at a more rapid rate in the upthrown block because of its more favorable situation for erosive attack. When the upper block has worn down to the level of the lower block the erosion of the two blocks will go on at a fairly uniform rate unless great differences in the structural constitution of the two blocks have been disclosed by the erosion. The longitudinal fault traces in the upthrown block will be nearer together than in the downthrown block, and the offsets, measured at right angles to the direction of the faults, will be dependent upon the dips of the fault planes and the vertical displacement. If the offset is known and the dip of the fault plane is known or assumed, the vertical displacement under the assumed conditions may be readily computed. In the cross-faulted graben the offsets in the southeastern part of the Cranes Flat quadrangle average 3,000 feet. If the dips of the lateral faults are assumed as 60° the vertical displacement is 5,200 feet. If greater values were assumed for the dips of the lateral faults the resulting vertical distance would be greater.

Pelican fault.—The Pelican fault which is named from Pelican Slough, through which it passes, intersects the graben southeast of Pelican Ridge. Its generally east-northeasterly course is largely concealed by basalt, but it cuts across Little Gray Ridge and there offsets the Brazer and Madison boundary. Basalt has outflowed on the west flank of the ridge along part of the fault trace. The downthrow is to the northwest, and by employing similar assumptions to those used in the discussion of the Little Gray fault a general estimate of 3,500 feet may be made for the vertical displacement at this locality. Northeastward the fault passes beneath Grays Lake. Southwestward it passes north of Henry and offsets the Thaynes-Woodside boundary and presumably also the Henry and Slug Valley faults. Thence it continues beneath cover to Reservoir Mountain, where it offsets the Thaynes group and Woodside formation and the faults that lie east and west of the mountain. From the dip of the *Meekoceras* zone and the amount of offset it is estimated that the vertical displacement produced by the fault at Reservoir Mountain is approximately 2,600 feet. The known length of the fault within the region described in this report is about 18 miles.

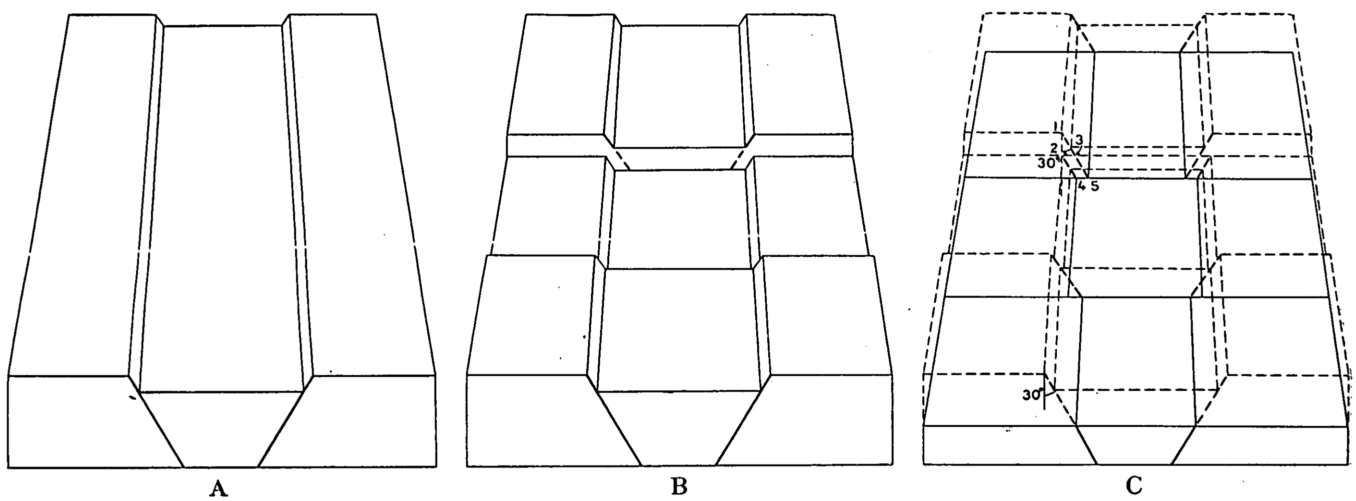


FIGURE 20.—Effects of transverse faulting and erosion upon a graben. A, Graben; B, same cut by two transverse normal faults; C, same planed off by erosion; 1-2, throw; 2-3, heave; 4-5, offset of boundary fault at level of peneplanation

MEADOW CREEK HORST

General features.—The name Meadow Creek horst may be given to the Carboniferous ridges, parts of the Snowdrift anticline, that lie along the southwest side of the Meadow Creek graben. To this horst are assigned the Wells and Brazer ledges that extend along the west side of the Cranes Flat quadrangle from sec. 34, T. 3 S., R. 40 E., to sec. 23, T. 4 S., R. 40 E., Wilson Ridge, the eastern half of Pelican Ridge, and Rasmussen Ridge. The northeast side of the horst is bounded by the Limerock fault, which has been already described, and the southwest side by the Enoch Valley fault, which is described below. The Meadow Creek horst is offset by an unnamed fault in T. 4 S., R. 40 E., and by the Little Gray and Pelican faults. Its structure is described above in the discussion of the Snowdrift anticline and is illustrated in structure sections E–E′, G–G′, H–H′ and I–I′ (pl. 11).

Enoch Valley fault.—The Enoch Valley fault is one of the most persistent normal faults of the region. From the point where it enters the Cranes Flat quadrangle, in sec. 22, T. 4 S., R. 40 E., to the southwest corner of the Freedom quadrangle it has a course of about 35 miles. It is named from Enoch Valley, along the northeast side of which it passes. As noted above in the discussion of the Georgetown syncline, St. John recognized this fault a short distance west of the Cranes

Flat quadrangle. Schultz and Richards [14] also recognized it there, and on their map they continued it southeastward and beyond the Blackfoot River Reservoir. It seems more probable that the fault should be connected beneath the basalt with the fault at the southwest base of Meadow Creek Mountain, where there is some evidence that post-Phosphoria beds are faulted against the Carboniferous. It is believed to be offset in secs. 24 and 25, T. 4 S., R. 40 E.

In secs. 30, 31, and 32, T. 4 S., R. 41 E., numerous large springs occur at the base of the steep slope, and there are extensive deposits of travertine. In the SE. ¼ sec. 32 and an adjacent part of section 33 phosphatic shales occur just above the hill-wash line, together with the cherty "underlying limestone" beds that mark the top of the Wells formation. Both these sets of beds are absent farther northwest and southeast, and the phosphatic shales at the localities named are thoroughly shattered. No evidence of the presence of the Rex chert member was found, though it may be concealed by the débris from the hillside or by basalt. About 2 miles south of the north boundary of the Henry quadrangle, a fault cuts out the Phosphoria at the southwest base of the corresponding Carboniferous ridge and brings in Woodside shale. Similar relations probably hold at the southwest base of Limerock and Meadow Creek Mountains, and the basalt-covered area to the southwest may be underlain by the Thaynes group and Woodside formation. This interpretation is shown at the southwest end of the structure section along the line E–E′ (pl. 11). The downthrow is not known, but is estimated to be perhaps 4,000 feet or more.

Southeastward the fault passes through the Lanes Creek quadrangle, where its throw is probably somewhat reduced. It cuts out the Phosphoria formation for more than 2 miles along the northeast side of Rasmussen Valley and is believed to offset the Blackfoot fault in Upper Valley, where its course is hypothetical. In addition to the structure sections named it is also shown in sections K′–K″, M–M′, and L–L′ (pl. 11).

BLACKFOOT RIVER RESERVOIR

Without doubt basalt underlies the Blackfoot River Reservoir as well as much of the adjacent land. With reference to the Meadow Creek horst and Reservoir Mountain the depression occupied in part by the reservoir is doubtless a modified graben. Between it and the horst lies an intermediate block of Triassic rocks downfaulted with respect to the horst but probably upfaulted with respect to the reservoir proper. The reservoir and the structure of its rocks are intimately associated with the more inclusive Blackfoot lava field, which is discussed below.

[14] Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267–284, 1913.

RESERVOIR HORST

Reservoir Mountain is with little doubt a horst, for it is apparently bounded on both the east and west sides by outward-hading normal faults. The physiographic relations of the mountain strongly support such a view, for Reservoir Mountain stands by itself, surrounded by relatively lower ground of small relief. Its eastern and western slopes are rather steep and locally abrupt, scored by many steep ravines. The general structure of the mountain is illustrated in structure section F–F′ (pl. 11) and described on page 146. Additional details are given here.

The northeastern outliers include a prominent hill composed of the Wells formation and the Phosphoria on the southwest flank. On the eastern side of this hill, in sec. 20, T. 5 S., R. 41 E., uppermost Wells occurs at the base of the slope and on lower knolls to the southeast, but middle or lower Wells lies immediately to the west. Thus a fault, presumably normal and with downthrow to the northeast, intervenes.

On the west flank of the hill the Woodside shale transgresses the Phosphoria and upper Wells and lies against middle Wells, thus indicating another fault. The downthrow here is to the west, and the general relations suggest that this fault is perhaps the same as the one that lies between the Thaynes and Phosphoria in the southwestern part of the Cranes Flat quadrangle, as shown in structure section D–D′ (pl. 11). Southward this fault appears to offset the Thaynes and Woodside boundary, though exposures at that place are poor, and it probably originates in a subordinate fold in the Thaynes group. A cross fault offsets the boundaries between the Thaynes and Woodside and between the Woodside and Rex and brings the Rex across the southeastern tip of the hill composed of the Wells formation above described. An oblique fault from the south offsets the boundary between the Thaynes and Woodside in the SW. ¼ sec. 29, T. 5 S., R. 41 E., and presumably extends northward beneath cover to the fault along the east base of the hill and possibly beyond.

The presence of basaltic craters at the east base of Reservoir Mountain indicates either a set of local vents or perhaps a deep fissure or fault. The relatively straight front and abrupt slope of the mountain suggest faulting. Therefore the fault in sec. 20, T. 5 S., R. 41 E., already described, presumably extends southward along the east base of the mountain with probable increase in throw in that direction.

The fault along the west side of the mountain is described on page 146. Both the eastern and western faults are offset by the Pelican fault, which is described above—the western fault nearly half a mile, as shown by the spring cones in the NW. ¼ and the fault breccia in the SW. ¼ sec. 19, T. 6 S., R. 41 E. The offset on the eastern fault, however, is inconspicuous. This relation may perhaps be explained by supposing the east fault to be more nearly vertical than the west fault. The relative straightness of the east front might also be explained by supposing the east fault to be younger than the cross fault. The general absence of hill wash along the east base of Reservoir Mountain suggests that the supposed east fault may be quite recent. On the other hand, the alluvial fans and hill wash that might be expected along the east front of the mountain may be concealed beneath more recent flows of basalt. If the cross fault is the continuation of the Pelican fault, as is here supposed, it offsets a number of other strike faults and is therefore younger than those faults. The strike fault east of Reservoir Mountain is classed with these other strike faults, for it produces similar physiographic effects.

The structure of the area west of Reservoir Mountain is concealed.

OTHER NORMAL FAULTS

STAR VALLEY DISTRICT

Two faults that are believed to be normal, the Hemmert and Freedom faults, lie near the west side of Star Valley, in the northeastern part of the Freedom quadrangle.

Hemmert fault.—The Hemmert fault, which lies along the axial region of the Hemmert anticline, has a length of about 6½ miles and probably joins the Freedom fault both at the north and south. For most of its course it lies within the Woodside shale and is not readily distinguishable, but toward the south end, in sec. 14, T. 33 N., R. 119 W., Wyoming, the Rex chert is apparently faulted against the Woodside, and in section 23, still farther south, travertine deposits and sulphur springs occur. A chert band in the sag south of Hemmert Canyon and travertine deposits in sec. 22, T. 34 N., R. 119 W., suggest the northward continuation of the fault. The features noted suggest that the fault is normal rather than reverse, but the stratigraphic throw is probably less than 500 feet. The fault is illustrated in structure section L′–L″ (pl. 11).

Freedom fault.—The Freedom fault lies nearly a mile west of the Hemmert fault and separates Nugget sandstone from middle Thaynes. Southward the fault passes beneath cover toward the travertine deposits and hot springs in sec. 14, T. 33 N., R. 119 W., where it probably unites with the Hemmert fault. North of Smith Canyon its course is concealed, but it probably joins the Hemmert fault in the travertine area in sec. 15, T. 34 N., R. 119 W., and produces the westward downthrow of the Madison limestone of the Star Valley overthrust block, as previously explained. As thus postulated the Freedom fault has a length greater than 13 miles. Its stratigraphic throw is estimated at about 2,500 feet. It is illustrated in structure sections K″–K‴ and L′–L″ (pl. 11).

FAULTS OF THE CARIBOU SYNCLINORIUM

The folds of the Caribou synclinorium are broken and locally offset by a number of faults that are interpreted as normal. Some of them have been sufficiently described for present purposes in the discussion of the members of the synclinorium. Others are described below. Their character and effects as here interpreted are illustrated in structure sections J–J′, K″–K‴ and L–L″ (pl. 11).

Faults of the Miller Creek syncline.—The Miller Creek syncline at the line of structure section K″–K‴ (pl. 11) is broken by two normal faults, the eastern one apparently of slight importance. The western fault, which originates about 2 miles south of the line of structure section K″–K‴, continues northwestward beyond the Freedom quadrangle and has an observed length of more than 6½ miles. At the line J–J′ it lies between the Bechler conglomerate of the Gannett group and limestones, conglomerates, and sandstones that are assigned to the Wayan formation. The limestone resembles lithologically the limestones of the Gannett group but appears to belong with the series to the east, which with little doubt is Wayan. The contact of the Bechler with the limestone is apparently a fault, and the limestone wedges out against it about half a mile southeast of Tincup Canyon. A limestone band that is probably the same group of beds lies in the Wayan area west of the fault between the lines J–J′ and K″–K‴ and is cut out by the fault at four places. The fault is nearly vertical and downthrow is toward the east. The stratigraphic throw is probably less than 1,000 feet.

The boundary between the Wayan and the Bechler from a point about half a mile south of the line K″–K‴ to a point within about 1½ miles of the line J–J′ was at first taken for a fault, but in view of the unconformable relations established between the Wayan and the Gannett group farther south, it was later considered an unconformity. The field evidence is inconclusive.

Schiess Creek fault.—In the ridge at the head of Schiess Creek a strike fault breaks the axial portion of an anticline which there exposes Jurassic beds and produces a small downthrow to the northeast. Beginning at a point about half a mile south of the line J–J′ (pl. 11), to which it has been projected, this fault has a general southeasterly course for nearly 16 miles to a point south of the mouth of Stump Canyon, where it passes beneath cover between Wayan and Preuss beds. It is shown in structure sections K″–K‴ and L′–L″ (pl. 11). In the northern half of its course the fault is offset at the head of the South Fork of Miller Creek by an oblique fault, which has a downthrow to the southwest and which passes into a strike fault at the northwest. In the south half of its course the fault is really due to the combination of several curved faults, which in part offset the folded formations and in part continue the strike. The downthrow is greater in the southern part, for the lower division of the Wayan formation is there brought in contact with the Preuss sandstone.

Tincup fault.—The boundary between the Preuss sandstone and the Wayan formation in Tincup Canyon is a fault that has a downthrow to the west. Its position at that place is marked by a 6-inch layer of brecciated limestone. West of the fault lie sandstones and shales of the Wayan formation, which are succeeded by sharply folded and faulted limestones that are beautifully exposed on a low point undercut by the river. (See pl. 40, *B*.) The limestone forms a dip slope on the ridge northwest of this exposure. The fault continues in that direction beyond the Freedom quadrangle. At the line J–J′ (pl. 11) the fault has a steep dip. About midway between the lines J–J′, and K″–K‴ the fault branches. The east branch, which has a steep dip, separates Ephraim conglomerate on the west from Preuss sandstone on the east. It is offset south of the line K″–K‴ by the same transverse fault that cuts the Schiess Creek fault. About a mile north of the line L′–L″ this branch subdivides and connects on the east with the Schiess Creek fault and on the west with the west branch of the Tincup fault, which has a more gentle dip and brings members of the lower division of the Wayan in contact with the Gannett group and locally with the Stump sandstone.

The Wayan beds along the Tincup fault for about 6½ miles south of the north boundary of the Freedom quadrangle include limestone bands that may represent separate beds or a single bed repeated by close folding. They locally resemble limestones of the Gannett group and may easily be mistaken for them, especially where the two sets of beds are in contact. The limestones of the Wayan, however, include locally some interbedded dark shales and are less massive. There are also minor faunal differences. The accompanying sandstones and shales are in most places readily distinguishable from the Gannett beds. South of the junction of its two branches the Tincup fault cuts across the south end of the South Fork synclinorium, breaks through Gannett and Jurassic beds, and disappears beneath cover in Stump Valley, where it is supposed to end at the Bannock fault.

The total length of the fault within the area described is about 12 miles. Its stratigraphic throw is locally 4,000 feet or more.

South Fork faults.—Two faults extend northwestward from a point near the center of the Freedom quadrangle along the east side of South Fork of Tincup River and beyond the quadrangle. The eastern fault brings the yellowish-weathering, greenish-gray sandstones near the top of the lower division of the Wayan against the shaly and calcareous beds that lie possibly 1,000 feet lower in the same formation. The fault locally cuts out some of the beds of limestone, and half a mile southeast of the line of structure section K″–K‴ is marked by a large spring and water hole. Southeastward this fault passes into the west branch of the Tincup fault.

The western fault lies between the yellowish-weathering sandstones just mentioned and red sandstones assigned to the next higher member of the group. The fault is suggested by the wedging out southeastward of the red beds and by springs and morasses in the canyon near the line of structure section K″–K‴. Southeastward the fault may join the eastern fault. Near the south end as mapped it receives a branch from the southwest. The stratigraphic throw at line K″–K‴ is apparently only a few hundred feet, but it probably increases northwestward. The length of both faults within the region mapped is about 6½ miles.

Head of South Fork.—Along the southwest flank of the upper canyon of South Fork a normal fault previously mentioned cuts across members of the Gannett group and separates these rocks from the Wayan beds of the South Fork synclinorium, as shown in structure section L–L′ (pl. 11). The fault has not been distinguished northwest of the line K″–K‴. Southeastward it ends against the southern extension of the Tincup fault. As mapped the fault is about 4½ miles long and has downthrow to the northeast. The stratigraphic throw may exceed 2,000 feet. Three normal faults in the Gannett beds to the south terminate against it and may be branches of it.

Spring Creek fault.—The Spring Creek fault is briefly described above in connection with the Spring Creek syncline. It is illustrated in structure sections O′–O″ and S″–S‴ (pl. 12). It has been traced for about 8 miles and is well exposed in ledges on the north side of Crow Creek about half a mile northeast of Hardmans Hollow.

SLUG VALLEY FAULT

As mapped the Slug Valley fault has a length of about 24 miles, though it is concealed for much of that distance. It takes its name from Slug Valley, in the lower part of which it lies on the eastern side. Its northern extension, in the Henry quadrangle, is postulated because of the travertine deposits in sec. 35, T. 5 S., R. 41 E., and in sec. 1, T. 6 S., R. 41 E., and on account of the warm spring in sec. 8, T. 6 S., R. 42 E. Its effects in this portion of its course are suggested in structure sections G–G′ and H–H′ (pl. 11).

At the head of Wooley Valley, in the Lanes Creek quadrangle, the proximity of Wells and Woodside ledges on opposite sides of the valley and the relative abruptness of the slopes on the northeast side suggest faulting. This view is not compulsory, for if the dips steepen and the Woodside turns sharply back under cover there is room for the intervening Phosphoria formation. Nevertheless, the presence of undoubted faulting farther to the southeast along the same structural zone lends support to the idea of the fault, which is accordingly mapped and represented in structure section I–I′.

In secs. 22 to 26, T. 7 S., R. 43 E., two faults of small throw in the Wells and Phosphoria formations are considered branches of this fault, as shown in structure section K′–K″. The supposed structural features along the fault in Lower Valley are indicated in structure section M–M′ (pl. 11). The anticline west of the fault is indicated by the occurrence of Rex chert in the little knoll just south of Blackfoot River. The fault is presumed to join the normal fault along the east wall of the valley, but it may proceed independently up the valley. The strike of the Phosphoria beds north of Lower Valley, if produced, would probably carry them far enough east to allow room for the Wells beneath cover east of the fault as drawn. A branch extending north along the east valley wall to a fracture zone in the Woodside in the NE. ¼ sec. 26 is postulated to account for the physiographic character of the ridge of Wells and for the offset of the Wells and Phosphoria formations north and south of the river.

Near the north boundary of the Slug Creek quadrangle the fault branches southward; one branch supposedly connects with a minor fault in the SE. ¼ sec. 36, T. 8 S., R. 43 E., and the other joins a fault between the Wells and Phosphoria formations, in sections 23 and 26 of the same township, and probably continues to meet the Johnson fault. These fault branches are shown in structure section O–O′ (pl. 12). The throw of the fault is apparently greatest near the boundary between the Lanes Creek and Slug Creek quadrangles, where it probably exceeds 2,000 feet.

JOHNSON FAULT

The Johnson fault, which has been briefly discussed above in the account of the Trail Creek syncline, originates in a subordinate fold that is related to the Aspen Range anticline in Dry Fork of Johnson Creek, in the northeast part of T. 9 S., R. 43 E., and has a nearly northerly course for about 10 miles. At the line O–O′ (pl. 12) it has two branches, which combine again northward. Along the east side of Trail Creek it separates lower Woodside or Rex from lower or middle Wells. Its maximum stratigraphic throw is thus about 2,400 feet. It apparently dies out in sec. 29, T. 7 S., R. 43 E. The fault appears in structure sections O–O′ (pl. 12), M–M′, and K′–K″ (pl. 11).

UPPER SLUG FAULT

A fault passes up the valley of Slug Creek beneath cover and separates lower Wells beds on the east from the concealed Woodside and lower formations. The occurrence of considerable float of Rex and upper Wells mingled with the Tertiary material of the ridge in secs. 22 and 27, T. 9 S., R. 44 E., may indicate that south of the line of structure section S′–S″ these formations underlie the Tertiary beds and represent the south end of the phosphate-bearing syncline west of the fault. The structural features along Slug Creek could be produced by either a normal or a reverse fault, and the fault was first interpreted as reverse.[15] It is here regarded as normal however, because of its relationship to the Salt Lake formation. These beds, which locally are steeply inclined, are apparently downfaulted by it. Thus the fault occurred after the deformation of the Pliocene (?) Salt Lake deposits and is more recent than the reverse faults, which at a number of places are covered by those beds. The maximum vertical displacement, which occurs near the line of the structure section, is estimated to be about 2,500 feet. A portion of the west face of the upthrown Wells block is shown in Plate 40, *C*.

BEAR LAKE FAULT

The Bear Lake fault has been described above in the discussion of Bear Lake Valley and is illustrated in structure section Y–Y′ (pl. 12). From the south line of sec. 14, T. 14 S., R. 44 E., to the south boundary of the Montpelier quadrangle it extends beneath cover at least 14 miles in the region described in this paper. It doubtless continues beneath the lake some distance into the Randolph quadrangle, but has not yet been identified at the south end of the lake. Its throw is indeterminate, but the maximum may exceed 2,000 feet. The possible northward extension of this fault is discussed on page 157. (See also p. 205.)

IGNEOUS AREAS

OUTLET VALLEY DISTRICT

In the northwestern part of T. 4 S., R. 42 E., the Little Valley Hills are crossed by basalt, the area of which becomes larger northeastward and includes a group of hills and ridges that have a general northwesterly trend. Beyond these hills lies Outlet Valley, which is largely overspread with basalt that is practically horizontal. The basalt composing the ridges is in many places inclined northeastward at perceptible angles, locally as high as 32°. Where the dips are pronounced the ridges have a gentle northeasterly slope and a steep or even scarplike southwesterly slope. In some of the hills, as in secs. 29 and 20, T. 3 S., R. 42 E., the basalt is horizontal or only gently inclined, but the west and southwest slopes are scarped.

The idea of retreating escarpments developed upon an inclined series of unequally dense flows can not be successfully applied to these basaltic hills because they are too short and discontinuous and because the retreat of escarpments in such resistant material is so slow that a considerable degree of weathering should take place in the basalt. This rock, on the contrary,

[15] Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposit northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, p. 43, 1914.

with local exceptions, is relatively fresh and has apparently not been greatly eroded, In general the arrangement and character of the scarps and slopes are such as to suggest a series of fault blocks, unevenly tilted northeastward. The faults probably do not represent great displacements. Direct evidence of faulting, in the form of breccias, striated surfaces, and mineral deposits, is largely absent. Iron-stained travertine, however, was observed in the gully in the NE. ¼ sec. 33, T. 3 S., R. 42 E. One of these faults is shown in structure section E–E′ (pl. 11). Its effects are traceable for 8 miles or more. Exposures to the southeast and northwest indicate that Outlet Valley is probably underlain in greater part by Cretaceous rocks.

WILLOW CREEK LAVA FIELD

The west central part of the Cranes Flat quadrangle is occupied by basalt that probably also underlies much of Cranes Flat and passes southward into Meadow Creek Valley and Blackfoot Valley. The lava field is marked by broad low ridges, the origin of which has been discussed in the chapter on "Igneous rocks" (p. 128). The basalt is horizontal or gently undulating. Local faulting is suggested by the escarpment in sec. 24, T. 3 S., R. 40 E. The structure beneath the basalt can not be determined without drilling. However, Triassic or Jurassic formations occur along the northeast border of Cranes Flat, whereas to the south phosphate beds occur at the north base of Meadow Creek Mountain. The presumption is therefore strong that the Phosphoria formation together with Triassic and some Jurassic formations, underlie at least part of the lava field and may lie beneath much of that covered area.

BLACKFOOT LAVA FIELD

Much of the area of the Henry quadrangle is occupied by basalt, which extends also into the adjoining quadrangles on each side. So far as this quadrangle is concerned the basalt is practically all associated with the Blackfoot drainage, and hence may appropriately be called the Blackfoot lava field. North of the quadrangle, however, it becomes contiguous with the Willow Creek lava field. Southward it spreads over into Bear River Valley and southwestward into the Portneuf drainage. Although it is so largely occupied by basalt, the lava field includes also several areas of rhyolite, which are relatively small but topographically conspicuous, including China Hat, Middle and North Cones, and two islands in the reservoir. Numerous basaltic cones are distributed over the field, which is in general fairly level and underlain by sheets of practically horizontal basalt that shows the characteristic columnar structure. Some of the structural features of the basalt have been mentioned in Chapter IV.

A glance at the general map shows that many faults pass beneath the basalt from the surrounding sedimentary areas. Some of them have been tentatively continued on the map. These faults, however, do not generally give surface evidence of their presence within the basaltic area. Some features of the igneous rocks themselves suggest fracturing or faulting. The alinement of the rhyolitic cones (pl. 3) south of the Blackfoot River Reservoir probably indicates the presence of a deep fissure. The basaltic cinder cones west of the rhyolitic group fall into line roughly parallel with that group and suggestive of parallel fractures. Three of the cinder cones, including Broken Crater and the cones to the north and southwest, are double. These craters arranged in pairs may indicate the existence of cross fractures intersecting the longitudinal fissures and thereby determining the position of the volcanic vents. Such an arrangement would reproduce on a small scale the mode of occurrence of the Galapagos and other islands described by Darwin[16] and the structure suggested for the great Hawaiian chain of volcanoes by Green.[17]

Another striking feature of the lava field that is probably closely related to its structure is the great number of linear cliffs in the basalt. These cliffs trend north or slightly northwest and are probably due to different causes. For example, the cliff in sec. 31, T. 7 S., R. 42 E., is about in line with a prominent fault in the sedimentary rocks to the southeast. To the northwest it extends toward a prominent basaltic, cinder cone and the rhyolitic cone known as China Hat. The basalt, however, is younger than the main body of rhyolite in the cone, so that if the basalt were faulted some evidence of the fault should be found on China Hat. No fault has been recognized there, and hence some other explanation than faulting is necessary unless the fault is assumed to be entirely local. The occurrence of a line of sinks just southwest of the cliff suggests the presence of underground passages that represent abandoned channels in the lava, the partial collapse of which may account for the relatively fresh cliff. A similar explanation may perhaps apply to the pronounced cliff along the east side of Crag Lake. (See pls. 3 and 57, *A*.) Other linear cliffs are doubtless the front edges of basaltic flows, such as the cliffs east of Pelican Slough in the northeast part of the quadrangle. (See pl. 3.) Still others have been developed by surface drainage along fractures of joint planes in the basalt, as in secs. 22 and 23, T. 7 S., R. 41 E.

The presence of actual fault scarps in the basalt is not clearly indicated, but the cliffs along the road from Soda Springs to Henry near the line between Tps. 6 and 7 S., R. 42 E., and in T. 8 S., R. 42 E., may be due to that cause.

Exposures of sedimentary rocks adjacent to the lava field suggest that the area beneath the basalt

[16] Darwin, Charles, Geological observations, p. 123, London, 1851.
[17] Green, W. L., Vestiges of the molten globe, pt. 2, pp. 144-155, Honolulu, 1887.

and northeast of a line extending from Threemile Hill, T. 8 S., R. 42 E., into the valley of Corral Creek, in T. 6 S., R. 40 E., is probably largely underlain by post-Phosphoria formations.

RECENT FAULTING

Along the west base of the Preuss Range between Montpelier and Bennington, in the Montpelier quadrangle, there is a line of depressions, in part drained but largely without drainage. The lack of outward drainage is caused in some places by small alluvial fans, but in other places there is no such obstruction. These depressions appear here and there as broad trenches 30 to 50 feet or more wide and 15 to 25 feet deep. (See pl. 40, *A*.) Toward the south they border the Madison limestone and conform fairly well with the strike of the formation. Farther north the line of depressions occurs in later beds, Tertiary conglomerate or Nugget sandstone. It locally separates the lower parts of valleys from their fans, which are here and there strikingly developed and have about the same grade as the valleys. The valleys themselves are in some places left hanging on the inner side of the depressions.

Near the mouth of Dunns Canyon a low scarp or terrace replaces the depression. The line has not been recognized north of that point nor south of the cemetery at Montpelier. It is not well developed north of Bennington Canyon, but south of that place it is fairly conspicuous. These phenomena are attributed to relatively recent normal faulting.

The material west of the fault shows no ledges. It consists mainly of fan wash or of weathered Tertiary conglomerate composed of local materials. The slopes to the west are graded where they are not modified by later drainage.

The relative freshness of the scarp of the Bear Lake fault and the hot springs along its base (see pls. 17, *A*, and 36, *B*) suggest that this fault may have been refreshed in relatively recent time.

UNCONFORMITIES

In the chapter on stratigraphic geology (pp. 48 to 115) evidence is cited for about 16 unconformities that range in age from pre-Ordovician to post-Tertiary. These unconformities represent geographic changes sufficient to be recorded by changes in character of deposits or of faunas or by angular discordance between successive formations. In general they suggest broad, gentle warpings of the lithosphere, which affected considerable areas but which did not produce orogenic disturbance. The unconformity at the base of the Wasatch formation (strikingly shown in the Bear Lake Plateau of the Montpelier quadrangle) does, however, record a great epoch of mountain building.

Two other unconformities are sufficiently striking to deserve comment. These are the unconformity between the Twin Creek limestone and the Preuss sandstone, which is well shown in the vicinity of the junction of Stump Creek and its North Fork in the Freedom quadrangle, and the unconformity between the Wayan formation and the Gannett group, which is shown farther up the valley of the North Fork but better shown in the Smith Creek syncline, about 4 miles to the east.

The gentler crustal disturbances, together with their accompanying records of sedimentation, nondeposition, or erosion, are reserved for discussion in the ensuing chapter on geologic history, as the present chapter is concerned primarily with the structure developed during the great mountain-building epochs.

EPOCHS OF MOUNTAIN BUILDING

Number and age.—At least five epochs of mountain building are probably represented in this region, consisting of the late or post-Jurassic Sierra Nevada movement, the Gannett-Wayan disturbance in the Lower Cretaceous, the post-Cretaceous Laramide revolution, the post-middle Miocene disturbance, and the late Pliocene or early Pleistocene deformation. Although all are described in the succeeding chapter on historical geology, two deserve mention here as the cause of the formation of most of the structural features described above. The earlier of these two epochs occurred after the deposition of the Wayan formation and before the deposition of the Wasatch. It probably corresponds with the interval between the Adaville and Evanston formations of Veatch,[18] or the epoch which, according to Ransome,[19]

> appears to have begun at the close of the recognized Laramie or possibly even earlier, and to have attained its maximum between the Fort Union, which, chiefly on the basis of its plant remains, is generally classed as basal Eocene, and the mammal-bearing lower Eocene Wasatch.

As stated in the discussion of the Wasatch formation (p. 109), there is reason to doubt the unconformity and corresponding deformation at the base of the Knight formation described by Veatch.[20]

The later epoch occurred after the deposition of the Salt Lake formation, which locally has steep dips and is thus thought to have occurred in late Pliocene or post-Pliocene time.

Compressional phases.—The earlier epoch was chiefly marked by tangential pressure, which caused the great overthrusts and folds that form the major structural features of the region. The intensity of the pressure is indicated by the eastward overturning of many of the folds and by the suggested fan structures pre-

[18] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 75, 1907.

[19] Ransome, F. L., The Tertiary orogeny of the North American Cordillera and its problems: Problems of American Geology, p. 322, New Haven, 1915.

[20] Veatch, A. C., op. cit.

viously described. Subordinate folds of the drag-fold type occur at a number of places, as, for example, in Montpelier Canyon about 2½ miles east of Montpelier (pl. 50, *B*); in Georgetown Canyon (pl. 48, *B*); and in T. 7 S., R. 44 E. (structure section M–M′). At the first-named locality beds of the "underlying limestone," uppermost Wells, are sharply folded and inclined. These beds, together with the phosphate shales, form incompetent beds between more massive beds of Rex chert above and of middle and lower Wells below. Similar conditions obtain in the second locality named. At the third locality the less competent strata are beds at the top of the Brazer limestone.

The Bannock overthrust was not among the earliest developed structural features of the region. It is thus unlike the great overthrusts near Philipsburg, Mont., which occurred in the same general epoch of deformation and which are described by Calkins.[21] Although its thrust surface is folded and even locally overturned, its folds do not accord closely with those of the related strata. The Bannock overthrust is regarded as a relatively late feature of the deformational epoch. It perhaps represents the climactic phase. The folding of the thrust surface may have occurred in the closing stages of the same epoch, but more probably it occurred in the later epoch, when folding was renewed to some extent along the previously established lines of deformation.

The thrust surface must originally have had a relatively low dip, else it could not have been brought within reach of erosion at so many places by later folding. The position of these folds of the thrust surface may have been determined by inequalities or warpings, initial dips developed during the thrust. The folds, however, show some relation to the structure in the underlying block. For example, the eroded anticline of the thrust surface in the Left Fork of Twin Creek in T. 10 S., R. 44 E., is underlain by an anticline in Jurassic formations.

The later deformative epoch was marked by less intensive folding, but there was broad uplift, which, in the Montpelier quadrangle, took in part the form of gentle tilting or upwarping toward the north, as shown by the patch of the Wasatch formation in the Preuss Range in the northwestern part of T. 13 S., R. 46 E., and its relations to the larger areas of the same formation in Bear Lake Plateau. To this epoch are assigned the folding of the Wasatch beds in the Boundary syncline and elsewhere, the folding of the Pliocene (?) beds, and the deformation of the plane of the Bannock overthrust.

Tensional phases.—The intense compression experienced by the region in the post-Cretaceous deformational epoch was doubtless succeeded by a condition of tension, during which the overdeformed mountain-built mass slowly returned to equilibrium. The numerous normal faults of the Caribou synclinorium may have been formed at this time. Normal faults that are locally concealed by the Salt Lake formation are also probably to be assigned to this interval of tension. Examples of these faults are the Hemmert and Freedom faults in the Freedom quadrangle, the fault along the west side of Reservoir Mountain in the Henry quadrangle, and the fault in the Dry Fork of Johnson Creek in T. 9 S., R. 43 E., in the Slug Creek quadrangle. Nothing more specific may be said of the age of these faults than that they are younger than the folds which they cut and older than the Salt Lake formation, Pliocene (?).

The broad uplift and renewed folding of the later deformational epoch was also succeeded by tensional phases, apparently more marked than those that followed the earlier epoch. The principal normal faults of the region probably belong here. Thus the horst and graben structure in the northwestern part of the region, the Slug Valley and Upper Slug faults, the normal faults of the Aspen Range, and the Bear Lake fault probably represent these tensional phases, though they may have been formed earlier. Some faults of earlier date may have experienced renewed movement in the later epoch. The relative recency of some of these faults or of their renewed movements is attested by the presence of thermal springs or of travertine deposits. Most of these faults are concealed in places by early Quaternary deposits, but their relation to Pliocene (?) beds is not generally evident. The Upper Slug fault, however, in T. 9 S., R. 44 E., is believed to have downfaulted beds of this age. Thus, if the Pliocene (?) age assigned to the Salt Lake formation is correct, the normal faulting that represents the tensional phases of the later deformative epoch appears to have followed closely after the uplift or perhaps to have accompanied its later stages and to have occurred in late Pliocene or earliest Quaternary time.

Igneous activity.—In the preceding chapter, on "Igneous rocks," the possibility of relationship of the geologic structure of the region to batholithic intrusion is briefly discussed. The andesite in the vicinity of Sugarloaf Mountain, in the Cranes Flat quadrangle, is the only igneous rock that could have been associated with the earlier deformative epoch in the region here described, and its connection with this epoch is not proved. Although it is with little doubt the oldest of the massive igneous rocks represented, its intrusion may have accompanied the revival of orogenic activity that marked the later epoch.

The rhyolite and basalt are associated with the tensional phases of the later epoch. The normal faulting and partial collapse of the region, especially toward the northwest, afforded opportunities for outpourings of lava from fissures and from local vents sufficient to

[21] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, pp. 146–151, 1913.

form the Outlet Valley, Willow Creek, and Blackfoot lava fields and the numerous local occurrences of rhyolite and basalt. Some of the extrusions encountered thrust planes, developed in the earlier deformative epoch, and followed them to the surface.

CONDITIONS OF DEFORMATION

Rocky Mountain geosyncline.—The entire region here described is part of a great geosyncline in which sediments were deposited with few interruptions of magnitude from early Cambrian to Upper Cretaceous times. This great structural feature has been called by different writers the Rocky Mountain trough, the Laramide trough, and the Laramide geosyncline. It extended from the Arctic Ocean southward through the Great Basin, and was in general an area of subsidence or a negative element [22] on which the sediments had accumulated in great thickness. On the west throughout much the same interval a relatively persistent land mass or positive element had separated the geosyncline from the Pacific Ocean, and on the east a less persistent barrier at times had separated it from interior seas. As Ransome [23] points out, the geosyncline is the only antecedent feature that has been recognized as having had probably a directive influence on the Laramide deformation. The tangential pressure, which produced the folds and overthrusts, was normal to the trend of this structure, and in the region described in this paper came from the west-southwest. Regarding the development of the Laramide system, which includes the mountains here described, Ransome [24] writes:

> Keeping fully in mind the speculative and tentative nature of the suggestion, we may suppose that in Cretaceous time the Cordilleran land mass was rising and was being eroded. In accordance with the general principles enunciated by Suess and Chamberlin, the rising mass probably had a tendency to spread laterally, particularly to the east, where sediments had previously accumulated to enormous thickness in the Laramide trough, derived doubtless from older land masses which occupied in part the position of the Cretaceous land. For a time, as Chamberlin has pointed out, the effect of this creep of the protuberant mass would be to favor sedimentation by pushing the sea shelf outward and partly downward. As uplift of the land mass and sedimentation of the adjoining area continued, resistance to lateral spread would diminish. Erosion, by cutting down the land, would tend to delay the final diastrophic event; but deposition, the complement of erosion, would tend to hasten it. Finally, if the forces causing the uplift of the land area were relaxed, by just so much as the underlying support of the protuberant arch was lessened would thrusting stresses accumulate along the borders of the land mass. Relief of these presumably would be accomplished by a thrusting forward of the land mass against the sediments to the east, the crumpling of these into folds, and their further deformation by thrust faulting. This diastrophic revolution, it is to be expected, would be followed by collapse and downsinking of the imperfectly supported Cretaceous continent and by normal faulting behind the overthrusts.

Initial dips.—Initial dips within the geosyncline would tend to localize the folds aud thrusts, and the character of the sediments would be to some extent a determining factor in the localization and character of the deformation. Thus, in the region here described it is significant that the formations exposed in the underlying block at the margin of the Bannock overthrust are generally Mesozoic beds that are relatively weak and incompetent as compared with the Paleozoic rocks that compose much of the upper block. These Mesozoic rocks occupied a deep trough of the geosyncline and were very thick.

Horizontal compression.—The vigor of the tangential pressure is indicated by the frequency of inclined or overturned structures. The original nearly horizontal attitude of the Bannock thrust plane has previously been noted. That attitude has been modified by subsequent compression and folding, but it indicates that the forces acted horizontally and were not the surface expression of obliquely emerging, deep-seated shear, such as was postulated by Willis [25] for the fault zone along the east side of the Sierra Nevada Mountains. Thus the locally steepened or overturned dips of the thrust plane represent deformation rather than rotation of the upper block.

Metamorphism.—The available evidence indicates only slight metamorphism of the rocks during deformation. Some of the more shaly beds, as, for example, the phosphatic shales of the Phosphoria formation, are sheared or shattered at many localities and thickened or thinned or even faulted out by differential movements between the more competent strata above and below. (See pl. 48, *B*.) Locally also beds of quartzite or other rocks are fractured, shattered, or even granulated in the fault zone of the Bannock overthrust. Examples are seen in the exposures of Swan Peak quartzite in Worm Canyon, 2 miles southwest of Bloomington, and of Fish Haven dolomite in the canyon 1½ miles southwest of St. Charles. These facts indicate that the deformation was accomplished in the zone of fracture. No evidence of flowage has been found. Several of the more sandy formations of the Paleozoic are more or less quartzitic. This condition was produced by cementation and was completed before deformation.

Hydrothermal action.—Deformation was accompanied at some places by hydrothermal action. Siliceous breccia has already been noted here and there along the Bannock overthrust. A somewhat similar breccia, possibly younger, occurs in sec. 19, T. 6 S., R. 41 E., at the west base of Reservoir Mountain. The fault rubble along the west base of the Aspen Range in T. 9 S., R. 43 E., shows evidence of hydro-

[22] Willis, Bailey, A theory of continental structure applied to North America: Geol. Soc. America Bull., vol. 18, pp. 389-412, 1917.

[23] Ransome, F. L., The Tertiary orogeny of the North American Cordillera and its problems: Problems of American Geology, p. 322, New Haven, 1915.

[24] Idem, pp. 307-308.

[25] Willis, Bailey, Structure of the Pacific Ranges, California: Geol. Soc. America Bull., vol. 30, No. 1, pp. 84-86, 1919.

thermal action in the form of leached and redeposited material. The travertine and associated spring deposits that occur appear in general to be more recent than the siliceous breccia and are probably associated chiefly with the tensional phases of the epoch of later deformation. Where they are found along the Bannock fault they may represent later movements along the earlier fault line or places where solutions ascending along normal faults have gained access to the thrust plane. Hydrothermal action is still in progress in certain parts of the region here described and in adjacent territory.

Favorable formations.—Many of the Paleozoic formations are massively bedded and would act as competent strata under deformation. A number of the formations, however, contain shaly members, such as the Spence shale member of the Ute limestone and the Hodges shale member of the Bloomington formation. Some of the limestones are thin-bedded, as, for example, the Ute limestone and certain beds of the Madison limestone. Such formations, if exposed to deformation in the zone of fracture, would furnish horizons in which thrust planes might originate. The Bannock overthrust zone is complex, and no one formation has yet been identified as the source of the thrust plane.

The Mesozoic formations are generally weaker and less well consolidated than are the Paleozoic rocks. As the Mesozoic rocks lay with favorable initial dip and in great thickness athwart the direction of maximum compression, they crumpled under the accumulating compressive stress and permitted the more or less folded Paleozoic rocks to override them. They thus generally form the basement over which the upper fault block moved and on which it now rests. Although it has been customary, in discussing overthrusts, to regard the lower block as passively overridden by the upper or thrust block, it is probable that both participate in the movement, the separated parts moving past each other, as suggested by Barrell.[26]

RELAXATION FROM DEFORMATION

The evidence of relaxation from the compression of the earlier deformative epoch is less well marked than is that of relaxation after the later epoch, doubtless in part because of the masking of earlier faults by later movement along the same lines. The evidence at hand is insufficient to distinguish clearly which faults were rejuvenated. On the other hand, the more abundant igneous activity that accompanied the late tensional epoch would seem to indicate that relaxation was more nearly complete in the later epoch.

[26] Barrell, Joseph, The upper Devonian delta of the Appalachian geosyncline: Am. Jour. Sci., 4th ser., vol. 37, p. 107, 1914.

Chapter VI. HISTORICAL GEOLOGY

SUMMARY OF RECORD

Historical geology is becoming more and more dependent upon its daughter science, paleogeography, certain principles of which are here set forth and utilized in the interpretation of the geologic history of southeastern Idaho. The record for this region, though imperfect, is unusually full, for the stratigraphic section includes more than 46,000 feet of sediments, a thickness greater than 8.7 miles.

PROTEROZOIC ERA

No rocks of pre-Cambrian age are exposed in southeastern Idaho, and inferences regarding the Proterozoic era must be drawn from the evidence of neighboring regions. The evidence thus obtained suggests that the region here described was land throughout much of that time, but that there was continental deposition, deformation, erosion, and even glaciation, as in later times, and that the great continental elements, including the Rocky Mountain geosyncline were already blocked out before the Paleozoic era began.

PALEOZOIC ERA

The Paleozoic record is dominantly marine and thus indicates the progressive subsidence of the Rocky Mountain geosyncline. The variations in character of the sediments, however, and the numerous stratigraphic breaks show that there were interruptions in subsidence and even reversals of movement and at times erosion. The diastrophic disturbances were gentle but were fairly well distributed throughout the era. A noteworthy feature is the general dominance of limestone deposition.

Early in the Cambrian the relatively low, perhaps peneplaned land of southeastern Idaho began to subside and to receive sandy sediments, at first probably nonmarine but later marine. The invasion of the sea may not have begun until the later part of Lower Cambrian or the early part of Middle Cambrian time. The sediments of the Middle Cambrian were chiefly calcareous, but with the opening of the Upper Cambrian the area of the sea became smaller and sands were for a time the predominant sediments again. This condition was succeeded by renewed deposition of limestone and even more extended invasion of the sea, the first great transcontinental marine inundation of Paleozoic time.

A brief erosion interval with little change in the attitude of the land separates the Upper Cambrian from the Ordovician, when limestone was again formed. A reversal of subsidence in the lower part of Middle Ordovician time brought first a change in sedimentation and then an erosion interval that lasted throughout much of Ordovician time. Toward the close of the period subsidence and deposition of limestone again took place.

The Silurian period in southeastern Idaho is represented by a single formation, the Laketown dolomite, the stratigraphic position of which is not well understood. In spite of apparent conformity with the underlying Ordovician Fish Haven dolomite a stratigraphic break of some magnitude may intervene. The Silurian sea was widespread in the west, but toward the close of the period it withdrew from the geosyncline and that entire region became land.

These conditions continued until Middle Devonian time, when the geosyncline was again occupied by the sea and limestone was again deposited without any marked discordance in attitude of the later with the earlier beds. From Middle through Upper Devonian time the geosyncline was extensively flooded. Gentle diastrophic movements during the period are indicated by changes in the lithologic character of the beds.

Mild diastrophic disturbances in southeastern Idaho are believed to have caused the unconformity between the Devonian and Carboniferous formations observed in the adjacent Portneuf quadrangle. There is evidence also of a stratigraphic break between the two formations of the Mississipian series, though here there is no conspicuous unconformity. Limestones form the main body of the rocks of this series, but shales and sandstones are also present, and indicate variations in conditions of deposition. Another diastrophic disturbance marked the interval between upper Mississippian and Pennsylvanian deposition. The beds formed in the later epoch were more sandy than those of the Mississippian epoch, and in both epochs subsidence of the geosyncline was intermittent or there were minor diastrophic oscillations. An unconformity separates the Permian from the Pennsylvanian beds. The Rocky Mountain geosyncline was cut off from the sea on the east, south, and much of the west but had northward and westward connections with the Pacific. Under special stratigraphic conditions not yet well understood, beds of phosphate rock that promise to be of great economic value were formed, and the overlying beds of the same period include beds of massive chert and of flinty shale. The history of the Permian in this region thus constitutes a series of interesting stratigraphic problems.

MESOZOIC ERA

The change from the Paleozoic to the Mesozoic in southeastern Idaho is marked by strong faunal contrasts rather than by any noteworthy discordance of strata. The Mesozoic is there distinguished by alterations on a great scale between marine and nonmarine conditions of deposition. The later part of the era witnessed the accumulation of enormous thicknesses of continental sediments.

Though the North American continent as a whole was a relatively broad land area in the Triassic period, part of the Rocky Mountain geosyncline was for a time occupied by an arm of the sea that was connected with the Pacific at the southwest. In the Lower Triassic open seas prevailed in southeastern Idaho, but farther east there were playa seas, lagoons, or estuaries that gave rise to red beds. The shore line of the sea advanced or retreated from time to time, causing some interfingering of marine and red-bed sediments. At least once during the epoch the sea withdrew sufficiently to permit erosion. After the deposition of the Lower Triassic formations there was widespread erosion followed by continental deposition, chiefly of the desert type, although a considerable area was occupied by a fairly persistent lake, which was probably without outlet and slightly saline. This lake was filled or perhaps drained before the close of the epoch. There were apparently no desiccation products from it.

No great change occurred at the opening of the Jurassic period, though there was probably widespread gentle warping, which depressed the geosyncline and elevated the adjoining positive elements. Desert sands accumulated during much of the Lower and Middle Jurassic epochs, but in the later part of Middle Jurassic or early in Upper Jurassic time the sea crept in from the north along the great Jurassic valley. Southeastern Idaho and southwestern Wyoming were occupied for a long time by a portion of this sea, and marine sediments with characteristic fossils were deposited there in great thickness. Then the sea withdrew, and its sediments were in places considerably eroded. Renewed subsidence was accompanied by the deposition of a thick series of red, mainly nonmarine sandy beds. Before the close of the epoch the sea again crept into the geosyncline, but its stay was relatively brief and its record, so far as fossils were concerned, was inconspicuous. The close of the Jurassic in southeastern Idaho is recorded in a marked change in type of sedimentation rather than in dislocation of strata. This change is attributed to the Sierra Nevada movement, which caused mountain building on a considerable scale in the Pacific coastal region.

The abrupt change in the character of sediments was the most noteworthy effect of this movement in southeastern Idaho. Lower Cretaceous time was occupied by the deposition of an enormously thick series of fluviatile beds together with some of lacustrine origin. Deposition was interrupted for a time by diastrophic movements and erosion but was resumed and continued till about the opening of the Upper Cretaceous. The conditions of deposition were probably analogous to those of the sub-Himalayan group of Tertiary deposits of India. There was no marked change of conditions between the close of the Lower and the beginning of the Upper Cretaceous. Transitional beds occur in neighboring territory, but these and marine Upper Cretaceous beds are absent from the immediate region here described. Upper Cretaceous time was a period of erosion. At its close came the great Laramide revolution, during which the complicated structural features of the region were produced. The great depth of the geosyncline, the character of its included sediments, and the position of its deeper portions with respect to the highest land of the time are thought to have had a directive influence upon the mountain-building forces.

The interval between the Cretaceous and Tertiary in southeastern Idaho was occupied by erosion, but in neighboring parts of southwestern Wyoming the coal-bearing Evanston formation was laid down at this time. The nature of this formation suggests that the reduction of the adjacent mountains of Idaho was well advanced by the beginning of the Eocene.

CENOZOIC ERA

The transition from the Mesozoic to the Cenozoic in the Northern Rocky Mountain province is ill defined and geologists are not agreed as to where the line between the deposits of the two eras should be drawn. The Cenozoic in southeastern Idaho was largely an era of erosion that was interrupted from time to time by diastrophic changes and by the deposition of continental sediments.

No beds of Fort Union age are present. The only Eocene deposits are those of the Wasatch formation, which show variations in conditions of deposition but are thought to correspond fairly well with the Wasatch group of southwestern Wyoming. Post-Wasatch time in southeastern Idaho was consumed in erosion, and the nature of the Green River and Bridger formations in Wyoming indicates that the Idaho mountains close at hand may have been reduced nearly to base-level. No crustal disturbances of note appear to have taken place at the close of the Eocene.

The Oligocene left no positive record.

The Miocene was an epoch of erosion. Although it was a time of great volcanic activity in many parts of the west no such activity is recorded in southeastern Idaho. Crustal disturbances in post-middle Miocene time are thought to have uplifted the old worn-down surface, remnants of which are here called the Snowdrift peneplain, and to have permitted in the later part of the epoch the development of broad and deep valleys.

The erosion of the Miocene may have continued into the Pliocene, but it eventually gave way to the aggradation that caused the deposition of the Salt Lake formation until the country perhaps resembled the waste-covered region around Amargosa Valley in southern California. Some climatic fluctuations during the period are suggested by the nature of the Salt Lake formation. Volcanic activity also occurred on a considerable scale. Further uplift came at the close of the period.

The Quaternary history of the region is largely one of erosion interrupted by intermittent uplift and modified by climatic change and volcanic outbursts, which have caused aggradation. The Gannett, Elk Valley, Dry Fork, and Blackfoot erosion cycles have produced the present topographic features. Late faulting has affected the basalt and even the slopes of hill wash and has revived some of the earlier faults. Recent erosion has accomplished little change since the Blackfoot cycle.

LENGTH OF RECORD AND PRESENT CONDITIONS

The length of time from the beginning of the Cambrian to the present, as estimated by Barrell, is between 550,000,000 and 700,000,000 years. In spite of the apparent tranquillity of the present it seems likely from the far-reaching studies of Barrell that southeastern Idaho in common with the rest of the world may be in the midst of a geologic revolution.

HISTORICAL GEOLOGY AND PALEOGEOGRAPHY

The historical geology of southeastern Idaho includes a summary of the geologic activities of the region from the earliest times to the present, in so far as the records may be deciphered from the evidence at hand. The latest page of the story is the geography of the region as it appears to-day. This page has already been discussed in an earlier chapter. The business of historical geology is to reconstruct and interpret in orderly sequence the geography of past epochs. It must therefore draw more and more largely upon its daughter science, paleogeography, which is concerned with the delineation of the ancient geography. A review of the rise of paleogeography is given by Schuchert[1] and need not be repeated here, but some of the more significant paleogeographic principles, on which the geologic history, as here interpreted, is based, are enumerated below.

PALEOGEOGRAPHIC PRINCIPLES

Of the many paleogeographic principles that bear upon the historical geology of any region the following 10 have been selected as a basis for the present study: The ocean basins and the continents have been relatively permanent features of the globe; the ocean basins are regarded as the sources of the major crustal disturbances; certain regions of the continents, called positive and negative elements, have been dominantly rising or sinking; geologic activities in any given region have shown a marked periodicity and rhythm; the ancient lands were relatively featureless and the epicontinental seas shallow; the present diversification of the lands is abnormal; the records of continental and marine deposition are complementary; faunas originate in different oceanic regions or realms; they change by evolution and migrate to other regions; the geologic record is very imperfect. These principles are discussed briefly in the order named.

PERMANENCE OF OCEAN BASINS AND CONTINENTS

The idea of the relative permanence of the ocean basins and of the continents has become practically a doctrine, but geologists are not united upon the degree of latitude permissible in its interpretation. For example, Willis[2] states that the ocean basins are permanent features of the earth's surface and that they have existed where they lie now with moderate changes of outline since the waters first gathered. The continents, he says, were never submerged to oceanic depths and consequently can not have been replaced by deep hollows, and no considerable part of the existing basins can ever have been occupied by land. The conclusion follows, according to his view, that the major oceanic drifts or currents have been constant from an early date in each of the great oceans, though this conclusion need not necessarily apply to the deep-seated circulation. He thinks with Chamberlin[3] that the present deep-seated circulation may be abnormal and that warm highly saline currents may have flowed poleward from the equator beneath cool and relatively less saline currents that flowed toward the Equator.

Schuchert,[4] on the other hand, maintains that, though the theory of the permanence of the ocean basins and continents is widely accepted, it does not follow that the continents and oceans have retained practically their present outlines since the beginning of the Cambrian. He points out that many geologists, especially those of Europe, hold that the continents may have been much changed in form and outline. His own studies have convinced him that during the Paleozoic era the continents not only were larger in area, but more especially that they were not then as now drawn out longitudinally.

Many facts of faunal and floral distribution are difficult to explain with so restricted an interpretation of the doctrine as that advocated by Willis. His view of the permanence of the oceanic drifts and currents seems particularly hazardous.

[1] Schuchert, Charles, Paleogeography of North America: Geol. Soc. America Bull., vol. 20, pp. 427-606, pls. 46-101, pp. 431-436, 1910.

[2] Willis, Bailey, Principles of paleogeography: Science, new ser., vol. 31, pp. 241-260 (pp. 243-245), Feb. 18, 1910.

[3] Chamberlin, T. C., On a possible reversal of deep-sea circulation and its influence on geologic climates: Jour. Geology, vol. 14, pp. 363-373, 1906.

[4] Schuchert, Charles, Correlation and chronology in geology on the basis of paleo geography: Geol. Soc. America Bull., vol. 27, pp. 491-514, 1916.

From the point of view of the student of the geologic history of southeastern Idaho, however, it seems certain that the Pacific Ocean was present during the entire period of which there is any available record, and that it profoundly influenced the geologic development of the region.

OCEAN BASINS THE SOURCES OF MAJOR CRUSTAL DISTURBANCES

The ocean basins, because they have greater extent and greater density than the continental masses, are regarded as the regions in which the greater deformative movements of the earth's crust originate. The bottoms of the oceans are believed to sink here or there, thus enlarging their capacity and causing the waters to withdraw to a greater or less extent from the lands. The continental masses between the oceanic beds are squeezed and suffer deformation that corresponds with the intensity of the oceanic disturbance. The squeezing of the continents may result in mountain-building, with accompanying severe and more or less localized deformation, or it may find relief in gentler warpings, which do not greatly affect the elevation of the surface. The effects of these movements are offset in some degree by continental creep and by increased sedimention, both of which tend to reduce the capacity of the ocean basins. All these features affect the position of the strand line, which is determined for any given time or place by the balance between the opposing tendencies. Where oceanic waters overspread the lower surfaces of the continental masses, shallow, epicontinental seas, such as the present Hudson Bay, are produced.

POSITIVE AND NEGATIVE ELEMENTS

The fact that the areas of some of the former epicontinental seas are now occupied by enormous thicknesses of sedimentary rocks that must from their very nature have been deposited in relatively shallow water, indicates that their bottoms subsided steadily or at intervals throughout the period of deposition. Portions of the continents that for long periods have been dominantly sinking and receiving sediments have been called by Willis [5] negative elements and those that have been dominantly elevated or subjected to erosion positive elements.

Southeastern Idaho lies in one of the largest and most persistent of the negative elements of North America, the so-called Rocky Mountain or Cordilleran geosyncline. This great epicontinental sea, called by Walcott [6] the Cordilleran sea, was dominated by Pacific waters, but at times it had connections northward with the Arctic and less frequently eastward or southeastward with waters of the Mississippi and Gulf regions. At times the sea withdrew completely, and the geosyncline was drained or even became locally the seat of continental deposition.

To the west, between the geosyncline and the Pacific Ocean, lay a relatively persistent land mass or positive element, which is designated by Willis the Pacific element and called by Schuchert [7] Cascadia. To the east, in the region that now comprises Wyoming, Colorado, and Arizona, a less persistent land area is recognized by Willis as the Rocky Mountain element. In spite of frequent submergence this region is shown by the sum of the unconformities among its strata to have been a recurrent land mass. From time to time these elements differed in size and in their relationship to one another.

PERIODICITY AND RHYTHM

Periodicity and rhythm are being recognized more and more as factors in paleogeography. As expressed by Ulrich,[8]

> All diastrophic movements and processes have ever been characterized by periods of activity alternating with periods of relative quiescence. Periodicity, then, is a fundamental factor of geologic history. Further, all diastrophic processes must be rhythmic in operation and recurrence, because they are occasioned by the necessarily rhythmic action of terrestrial forces.

The greater rhythms are expressed in periods of sedimentation or of orogenic or epeirogenic disturbance, which profoundly influence organic evolution and serve to mark the passage of geologic time. Lesser rhythms are recognized in such geologic activities as the movements of the strand lines within the geologic periods or the fluctuations of Pleistocene glaciation. Rhythms of still lower order are seen in the well-known Brückner 35-year climatic cycle,[9] in annual and seasonal variations of temperature and precipitation, and in the recurrence of stormy or pleasant weather with its respective effects upon local erosion or deposition.

LOW ANCIENT LANDS AND SHALLOW EPICONTINENTAL SEAS

The ancient lands were relatively featureless and the epicontinental seas shallow. Ancient sediments show, it is true, that locally and at recurrent times grades were steep and streams were swift, but over large areas the land was relatively flat and the grades gentle. Schuchert [10] points out that there are at least 10 "disconformities" for every known angular unconformity. Movements which permitted erosion on the one hand or deposition on the other must therefore have been on the whole so gentle as not to disturb noticeably the attitude of the beds. This argues for

[5] Willis, Bailey, A theory of continental structure applied to North America: Geol. Soc. America Bull., vol. 18, pp. 389–412, 1907.

[6] Walcott, C. D., Geologic time as indicated by the sedimentary rocks of North America: Am. Assoc. Adv. Sci. Proc., vol. 42, pp. 143, 144, 1894.

[7] Schuchert, Charles, Paleogeography of North America: Geol. Soc. America Bull., vol. 20, pp. 427–606 (p. 469), 1910.

[8] Ulrich, E. O., The Ordovician-Silurian boundary: Cong. géol. internat. Compt. rend. 12e sess., 1913, pp. 597–598, 1914. Also advance copy (pp. 5–6).

[9] Brückner, E., Klimaschwankungen seit 1700, nebst Bemerkungen über Klimaschwankungen der Diluvialzeit, Vienna, 1890. (Discussed by R. DeC. Ward, in his translation of Hann's Handbook of climatology, New York, Macmillan, 1903.)

[10] Schuchert, Charles, Correlation and chronology in geology on the basis of paleogeography: Geol. Soc. America Bull., vol. 27, p. 497, 1916.

low elevations and gentle grades. Epicontinental seas outspread upon such a surface must necessarily have been shallow. Barrell[11] calls attention to another phase of the argument:

Lime-depositing seas have formerly been regarded as the deepest, yet bottom-growing algae were at times abundant, as seen in the cryptozoon horizons. Sunlight must therefore have freely penetrated to the bottom. But more emphatic testimony is given by interformational conglomerates, which show during the deposition of the beds a vigorous stirring of the bottom by wave action. Still more positive in meaning are the mud cracks, which are abundant in certain horizons. These are not shore phenomena, since they occur at the same horizon over areas reaching thousands of square miles; neither are they of tidal origin, as shown by their breadth and the absence of tidal channels. With seasonal change of winds, or more probably with slight oscillations of level of longer periods, the water came and went.

ABNORMAL CONDITIONS OF THE PRESENT

The present great extent, relatively high elevation, and marked diversification of the lands is abnormal as compared with earlier periods. Barrell[12] states that there is nothing analogous to it since the pre-Cambrian. He thinks that the present rate of total denudation may be 10, 15, or even 20 times the mean for all of earth's history and that estimates of geologic time based on the present mean rate of denudation are entirely too low.

Ulrich,[13] who emphasizes the same idea, notes that

In the submergent stages to which our knowledge of the pre-Cenozoic periods is largely confined, the size of the continents, and especially the average relief of the lands, was generally much less than now. Therefore, while degradational agencies in the periodic highly emergent stages probably were active enough and occasionally perhaps comparable in vigor and results to those of the present time, those working on the relatively low lands prevailing in the intervening submergent phases must have been correspondingly inferior in both respects. * * * We know, for instance, that the character of the near-shore bottom of the Atlantic varies rapidly and greatly from place to place. Here we see a clean sand beach, near by a fine mud bottom, and not far away the shore is strewn with great boulders torn from a massive cliff. Similarly extreme, yet to-day very ordinary, variation of shore conditions seems to have been very rare, not to say impossible, in the Paleozoic epicontinental seas. Their shores were rarely or never precipitous, and the broad interior lands washed by these seas were often so low that the small clastic matter derived from them exerted a scarcely appreciable effect on the character of the deposits along hundreds, yes thousands, of miles of shore line.

CONTINENTAL AND MARINE DEPOSITION

The records of continental and of marine deposition for a given period are complementary. As noted by Ulrich,[14]

the one points to or centers in emergent stages of geologic history, the other in submergent stages. * * * The successive facies of the land flora thus must have attained their respective most typical developments in the intervals between those times when the successive marine faunal facies reached their respective high points. * * * Beginning with the Permian, and thence on to the present time, the terminal floras of each period are more readily distinguishable than is either one from the nearest flora of the preceding or the succeeding period, as the case may be. For instance, the early Jurassic flora is much more easily distinguishable from the late Jurassic facies than it is from the preceding late Triassic flora.

The seeming conflict of faunal and floral evidence in certain transitional formations, such as those that mark the closing stages of the Cretaceous or the beginning of the Tertiary, will not be satisfactorily disposed of until this principle is more clearly realized and applied. This conflict is illustrated by the recent discussions by Schuchert[15] and Cross and Knowlton[16] of a paper by Stanton[17] on the fauna of the Cannonball marine member of the Lance formation, in which Stanton, after a careful description and analysis of the fauna, chiefly invertebrates, concludes that the formation is Cretaceous. Schuchert agrees with Stanton, but Cross and Knowlton disagree and point to the necessity of reconciling both marine and nonmarine classes of evidence before a satisfactory conclusion may be reached

FAUNAL REALMS

A study of the Paleozoic faunas of North America shows that they were derived from three permanent oceanic realms. According to Schuchert,[18] these were, in the order of their persistence, the Gulf of Mexico mediterranean, which in reality is but the southern part of the northern Atlantic; the Pacific; and the Arctic. The faunas of the northern part of the north Atlantic were as a rule confined to the northeastern part of North America, though at times they spread into the interior basin. Pacific faunas at times spread completely across the continent to the foot of Appalachia. Arctic waters pulsated southward along the middle region of the continent far into the United States during the Ordovician and Silurian periods and less positively at other times. Faunas from the Gulf of Mexico frequently spread far throughout the Mississippi Valley and Appalachian area. They were at times also tinged with south European or South American forms.

[11] Barrell, Joseph, Rhythms and the measurement of geologic time: Geol. Soc. America Bull., vol. 28, p. 768, 1917.

[12] Idem, pp. 774, 775.

[13] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 318-319, 1911.

[14] Ulrich, E. O., Correlation by displacements of the strand line and the function and proper use of fossils in correlation: Geol. Soc. America Bull., vol. 27, p. 465, 1916.

[15] Schuchert, Charles, Are the Lance and Fort Union formations of Mesozoic time?: Science, new ser., vol. 53, pp. 45-47, Jan. 14, 1921.

[16] Cross, Whitman, and Knowlton, F. H., separate articles under the title, Are the Lance and Fort Union formations of Mesozoic time?: Science, new ser., vol. 53, pp. 304-308, Apr. 1, 1921.

[17] Stanton, T. W., The fauna of the Cannonball marine member of the Lance formation: U. S. Geol. Survey Prof. Paper 128, pp. 1-49, 9 pls., 1920.

[18] Schuchert, Charles, The delimitation of the geologic periods illustrated by the paleogeography of North America: Cong. geol. Internat. Compt. rend., 12e sess., p. 572, 1914 (advance copy, p. 18, 1913).

EVOLUTION AND MIGRATION OF FAUNAS

The development and withdrawal of epicontinental seas through the agencies of diastrophism and degradation have been thought to play an important part in the evolution and migration of faunas. With regard to migration there is no question but that the epicontinental seas afforded the means by which the faunas made their way from their respective centers to the places where they are now found. Chamberlin and Salisbury [19] emphasize the idea of expansional and restrictional evolution of faunas in connection with the advance or retreat of these seas. Ulrich,[20] however, holds that fossil species and genera must have become extinct during rather than before the intervals that separated the periodic invasions of the epicontinental seas. The final extinction of particular species or genera must as a rule have been accomplished in the oceanic basins. According to his view, there is no ground for the belief that the expansion of the waters in epicontinental basins made them areas of stimulated organic modification, because the deposits of such basins must then have been filled with such a wealth of intergrading mutations as to render the efforts of the systematic paleontologist positively futile.

IMPERFECTION OF THE RECORD

The earlier views on the subject are well summarized by Geikie,[21] when he says:

Apart from the fact that, even under the most favorable conditions, only a small proportion of the total flora and fauna of any period would be preserved in the fossil state, enormous gaps occur where, from nondeposit of strata, no record has been preserved at all. It is as if whole chapters and books were missing from an historical work. But even where the record may originally have been tolerably full, powerful dislocations have often thrown considerable portions of it out of sight. Sometimes extensive metamorphism has so affected the rocks that their original characters, including their organic contents, have been destroyed. Oftenest of all, denudation has come into play, and vast masses of strata have been entirely worn away, as is shown not only by the erosion of existing land surfaces, but by the abundant unconformabilities in the structure of the earth's crust.

Although other geologists in recent years have dwelt on this theme none have done so more effectively than Barrell, who, in a most illuminating essay,[22] calls attention to the universal presence and aggregate importance of minor breaks in the record, which he terms "diastems." These breaks at any given place are represented in other regions, commonly within the same formation, by a bed or a series of beds and are due to a variety of causes but largely to oscillations in the intensity of climatic factors. In an instructive diagram, which is reproduced in Figure 21, he shows a vertical columnar stratigraphic section with bedding planes and larger stratigraphic breaks ("disconformities"), accompanied by curves showing minor oscillations, chiefly due to climatic rhythms, superimposed upon the larger diastrophic oscillations that accompany a rise in base-level. At the top of the diagram a horizontal column shows the time interval represented by the vertical column. In the horizontal column the

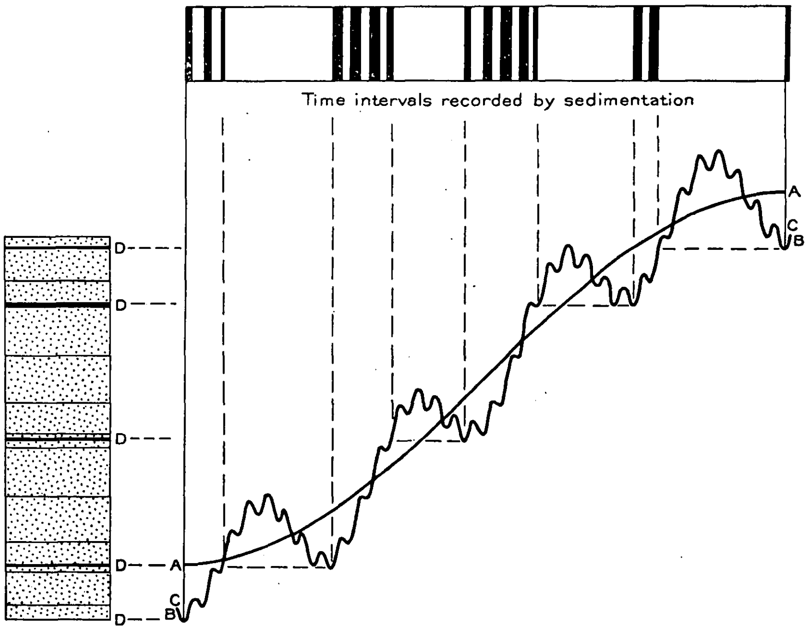


FIGURE 21.—Sedimentary record made by harmonic oscillations in base-level. (After Barrell.) A-A, Primary curve of rising base-level; B-B, diastrophic oscillations, giving "disconformities" (D-D); C-C, minor oscillations, exaggerated and simplified, due largely to climatic rhythms. Equation of curve C-C: $y=\sin x-0.25\cos 8x-0.05\cos 64x$

[19] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, 2d ed., p. 672, New York, 1905.

[20] Ulrich, E. O., Correlation by displacements of the strand line and the function and proper use of fossils in correlation: Geol. Soc. America Bull., vol. 27, p. 475, 1916.

[21] Geikie, Sir Archibald, Textbook of geology, 4th ed., vol. 2, p. 841, London Macmillan & Co., 1903.

[22] Barrell, Joseph, Rhythms and the measurements of geologic time: Geol. Soc. America Bull., vol. 28, pp. 794-798, pls. 43-46, 1917.

portion indicated by the heavy black lines corresponds with the parts of the record preserved by the sediments. If we apply the principles expressed in the diagram to the interpretation of any sequence of bedded rocks the time that has elapsed without leaving a visible record is shown to be astonishingly great.

In southeastern Idaho the maximum combined thickness of the sedimentary formations (see Table 12, p. 48) is greater than 46,000 feet, or more than 8.7 miles. As stated in the preceding chapter, 16 unconformities or major stratigraphic breaks have been recognized in the series. The deposition of so great a bulk of material, when these unconformities are taken into account, must have required a tremendously long time. When, however, it is realized that this great sedimentary record, full as it appears to be, is still further divided by minor breaks and is very fragmentary, and that in the light of Barrell's studies the time unrecorded may equal or even exceed that required for the deposition of the visible sedimentary rocks, the imagination staggers at the vastness of the time interval which the geologic history of the region embraces. Estimates of the length of the respective periods and of the entire interval are given on page 206.

PRE-CAMBRIAN TIME

Rocks of this age have not been recognized in southeastern Idaho, but some inferences regarding this era may be drawn from exposures in neighboring regions. The pre-Cambrian was in general a time of great continental emergence. Probably the surface of the North American continent had as great an area as now, or perhaps greater, but even at that remote age the development of the Rocky Mountain or Cordilleran geosyncline was well advanced. According to Walcott,[23] this geosyncline then extended from the head of the Gulf of California northward probably to the Arctic Ocean.

> In Arizona what is left of the Algonkian period of sedimentation is represented by nearly 12,000 feet * * * of sandstones, shales, and limestones of the Grand Canyon group. In Utah and Nevada sediments forming only sandstone and siliceous shale appear to have gathered, while in Montana there is a development of limestone 4,800 feet in thickness in addition to nearly 20,000 feet of siliceous and arenaceous beds.

These and the other Algonkian deposits of North America are regarded by Walcott as of nonmarine origin. Schuchert [24] is inclined to dissent from this view and considers that marine waters did for long periods of time invade North America during the Proterozoic era. In Utah [25]

> the pre-Cambrian rocks include some granite but consist mainly of schists, quartzites, and slates, all more or less metamorphosed. Locally, at least, as in Big and Little Cottonwood Canyons, tillite is an important and interesting member of the series. In general the lower members are the most highly altered * * *
>
> The boundary between the Cambrian and Algonkian rocks has been determined in but few places in the State. Blackwelder, Hintze, and others have located it from American Fork and the Cottonwoods northward to Brigham, and it seems highly probable that future studies may differentiate the great quartzite-slate-shale series at other localities.

The presence of great thicknesses of arenaceous sediments that carry but few fossil remains, the occurrence of algal limestones, and the presence of tillite point to diversity of climatic conditions during the Algonkian comparable to that of to-day. The metamorphosed character and disturbed attitude of the Algonkian sediments at many places point to continental revolutions similar to those of later periods. Finally, the unconformities that generally separate the Algonkian sediments from those of Paleozoic or later formations point to the protracted exposure of the disturbed and more or less metamorphosed Algonkian strata to erosion.

The part of the geosyncline occupied by southeastern Idaho doubtless formed a land area throughout much of pre-Cambrian time, though it probably was at certain times the seat of continental deposition. No evidence has been found of its occupation by the sea in pre-Cambrian times. It participated in the revolutions above mentioned, for in Big Cottonwood Canyon, south of Salt Lake City, Blackwelder [26] has recognized an angular unconformity between the algonkian and the overlying Brigham quartzite, of Cambrian age. The tillite mentioned indicates that at least locally and at certain times conditions in the general region were favorable for the development of glaciers. In the later part of the Algonkian and in early Cambrian time the geosyncline must have been subjected to erosion, which reduced it nearly to base-level. This condition is clearly shown in the Grand Canyon section, where the unconformity between the inclined Algonkian strata and the practically horizontal Cambrian beds is remarkably regular and is one of the most striking geologic features of the region. Similarly in southeastern Idaho apparently little warping was required in Cambrian time to permit the flooding of the geosyncline by marine waters. Pre-Cambrian time in southeastern Idaho, however, closed while the geosyncline still stood above sea level.

CAMBRIAN PERIOD

Lower and Middle Cambrian epochs.—The Brigham quartzite, which is the lowest formation of the Cambrian system in this region, is described by Walcott [27] as the overlapping shore deposit of Middle and Lower

[23] Walcott, C. D., Cambrian geology and paleontology, III: Smithsonian Misc. Coll., vol. 64, pp. 80, 81, 1914.

[24] Schuchert, Charles, in Pirsson, L. V., and Schuchert, Charles, Text book of geology, pt. 2, p. 570, 1915.

[25] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 77, 1920.

[26] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 520–522, 1910.

[27] Walcott, C. D., Nomenclature of some Cambrian Cordilleran formations: Smithsonian Misc. Coll., vol. 53, pp. 190–200, 1908.

Cambrian time, along what is now the Wasatch Range, derived from the Uinta region. The formation as a whole is practically nonfossiliferous, but in the sections west of Liberty, Idaho, and in Blacksmith Fork, Utah, described by Walcott, annelid trails and trilobite tracks were found in the upper part and in the corresponding part of the first-mentioned section he reports characteristic Middle Cambrian fossils. The thickness of the formation, which is 2,000 feet at the type locality near Brigham, Utah, together with the locally cross-bedded and conglomeratic character of the deposits indicate the long continuance of shallow water, if the beds are marine deposits, and the generally slow subsidence of the region during the deposition of the formation.

Barrell[28] has pointed out that thick deposits of coarse sediments are likely to be of nonmarine origin. In view of the preceding consideration of pre-Cambrian time it seems highly probable that much of the Brigham quartzite may be nonmarine and that the invasion of the Cambrian sea in this region may not have begun until the later part of Lower Cambrian time or the early part of the Middle Cambrian.

The source of the materials of the Brigham quartzite was undoubtedly the arenaceous and siliceous rocks of the pre-Cambrian, which occur to the south and southwest in Utah and in the Raft River region of northwestern Utah and southern Idaho. The Uinta Range of northeastern Utah is composed largely of quartzite that was formerly thought to be of pre-Cambrian age. If it were, in fact, of that age the Uinta region might be considered as a source of much of the material of the Brigham quartzite, and Walcott has so considered it. The "Uinta" quartzite, however, has thus far proved nonfossiliferous and has been assigned by different writers to different ages. These opinions have been reviewed by Gale,[29] who concludes that the quartzite may be largely Algonkian but that it may also include a considerable Cambrian section that corresponds to Walcott's Brigham formation of the Wasatch Mountains. More recently Butler and Loughlin,[30] from the study of numerous sections in various mining districts of Utah, have referred this quartzite, which they call by its earlier name, the "Weber" quartzite, to the Cambrian and have so designated it on their geologic map of Utah. With this uncertainty as to age the "Uinta" quartzite can not safely be regarded as a source of the materials of the Brigham quartzite.

The succeeding formations of the Middle Cambrian are chiefly limestones that are more or less fossiliferous, but two of the formations, the Ute limestone and the Bloomington formation, contain noteworthy shale members. Some beds are concretionary or oolitic, others are more or less clayey or argillaceous, and still others consist of more nearly pure limestones in thin or massive beds. The Ute limestone contains beds of interformational conglomerate. All the formations differ somewhat in thickness from place to place. These differences in constitution, arrangement, and thickness point to intermittent subsidence of the geosyncline or to minor oscillatory diastrophic movements of the region during the Middle Cambrian. None of the disturbances were sufficient to produce unconformities or "disconformities," but there are doubtless many "diastems" or minor breaks in the record.

The more calcareous beds probably mark the epochs when the bordering lands were lower, the grades gentler, and the wash of land-derived waste least, and the more clayey and more sandy beds represent epochs when the contributing lands stood somewhat higher and grades were steeper. The interformational conglomerates indicate epochs during the lower phases of the bordering lands, when the waters of the geosyncline were sufficiently shallow for the partly consolidated calcareous muds to be locally dislodged and agitated by wave action.

Throughout much of the time the waters teemed with marine life, as indicated by the abundant and somewhat varied faunas, which were largely derived from Pacific sources by way of Nevada and southern California, but Schuchert's paleogeographic map[31] also shows connection with Arctic waters. Some differences in temperature are suggested by the oolitic layers. The work of Vaughan[32] and Drew[33] in the region of Florida and the Bahama Islands shows that marine oolites are now being formed in warm tropical waters by precipitation of calcium carbonate largely through the agency of denitrifying bacteria, whereas in temperate waters these bacteria are less abundant and less active. (For further discussion of this topic see p. 363.) It seems probable that in Middle Cambrian times, as now, warmer temperature would favor the activities of such bacteria and the formation of oolites, whereas cooler temperature would be less favorable to these activities and would reduce or prevent the formation of oolites.

Upper Cambrian epoch.—The beginning of the Upper Cambrian was marked by a somewhat more pronounced diastrophic movement than the movements which had occurred during the preceding epochs. The conditions that produced the massive beds of the Nounan limestone gave way to those that favored the deposition of 200 feet or more of sand, which now constitutes the Worm Creek quartzite member of the

28 Barrell, Joseph, Some distinctions between marine and terrestrial conglomerates: Geol. Soc. America Bull., vol. 20, p. 620, 1910.

29 Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 47–48, 1910.

30 Butler, B. S., and Loughlin, G. F., op. cit. (Prof. Paper 111), p. 78.

31 Schuchert, Charles, in Pirsson, L. V., and Schuchert, Charles, Text book of geology, p. 597, 1915.

32 Vaughan, T. W., Preliminary remarks on the geology of the Bahamas, with special reference to the origin of the Bahaman and Floridian oolites: Carnegie Inst. Washington Pub. 182, pp. 47–54, 1914.

33 Drew, G. H., On the precipitation of calcium carbonate in the sea by marine bacteria and on the action of denitrifying bacteria in tropical and temperate seas: Carnegie Inst. Washington Pub. 182, pp. 9–45, 1914.

St. Charles formation. The volume of the epicontinental sea was thus diminished, and degradational activities on contributing lands increased sufficiently to supply large volumes of sandy waste. The grades, however, remained moderate, for no conglomeratic material was furnished. With the ensuing gradual subsidence of the geosyncline erosional activities diminished and with lower grades the limestone-making conditions were resumed and continued in southeastern Idaho probably till the close of the period, though, as in the Middle Cambrian, there were minor diastrophic fluctuations. The sources of the faunas remained the same, but the Cordilleran sea, according to Schuchert's maps,[34] overspread the geosyncline eastward across the continent to Appalachia, and thus registered the first great marine transcontinental inundation of Paleozoic time.

ORDOVICIAN PERIOD

The change from the Cambrian to the Ordovician in southeastern Idaho is not generally distinguished by any marked lithologic change, though at one locality a 40-foot bed of limestone conglomerate of the interformational type was observed. The variation in the thickness of the underlying St. Charles formation suggests an interval of erosion between the two formations. Richardson [35] also notes that in the Randolph quadrangle the Ordovician formations rest on beds at different horizons of the St. Charles in different parts of the quadrangle. Therefore, after the close of the Cambrian period the geosyncline in southeastern Idaho and adjacent parts of Utah was probably elevated and subjected to erosion sufficient to remove several hundred feet of Upper Cambrian beds. The sea then returned and resumed the deposition of limestone. Some clastic material was deposited as impurities in the limestone, but the quantity was not sufficient to produce separate beds of shale or of sandstone. The diastrophic activity at the close of the Cambrian was thus relatively slight, otherwise it would have given rise to coarser clastic beds.

In the Appalachian Valley and in the Ozark region of Missouri Ulrich[36] has distinguished a period, which he terms the "Ozarkian," between the well-recognized Cambrian and Ordovician beds. If Ulrich's views are substantiated the unconformity at the top of the Cambrian may represent a longer time interval than might otherwise be supposed.

The fauna of the Garden City limestone, which is of Beekmantown age, indicates that the formation belongs in the Lower Ordovician. Its most striking lithologic feature is the prevalence in it of interformational conglomerate, which indicates that throughout the epoch of its deposition the waters were shallow enough to permit the bottom muds to be locally dislodged and agitated by waves. The same evidence shows that the geosyncline must have subsided gradually while the limestone, 1,250 feet thick, was being deposited.

After the Garden City limestone was laid down crustal movements occurred that quickened erosion and supplied large volumes of sands to the geosyncline. This material was well sorted and cleaned before its deposition, which was doubtless effected by waves in shallow water. Fossils are not numerous, but the few forms preserved are of Chazy (?) age, as determined by Ulrich and Kirk. Locally organic matter was sufficiently abundant to produce lenses of phosphate rock as described on page 57. The crustal movements of the time could not have been intense or coarser sediments would have been furnished by the streams. These sands, which are now known as the Swan Peak quartzite, accumulated to a thickness probably greater than 500 feet, and their deposition was accompanied by further subsidence of the geosyncline.

A reversal of this movement caused the withdrawal of the sea and the beginning of an erosional epoch that was rather general in western North America and that, so far as southeastern Idaho was concerned, lasted throughout much of the Ordovician period. The crustal disturbance that produced this change was again gentle, for no noteworthy angular unconformity is observed between the Swan Peak quartzite and the overlying Fish Haven dolomite. Were it not for the absent faunas, which are represented in the eastern part of the United States, the length of the interval of erosion would scarcely be suspected.

When the sea at length returned as a result of the renewed gentle downwarping of the geosyncline the limestone making was resumed without the intervention of transitional deposits. The Fish Haven dolomite carries a Richmond fauna and is more strongly magnesian than the earlier limestones. The cherty masses contained in it are noteworthy and probably point to a higher percentage of siliceous organisms in its waters of deposition than in those of the earlier seas. Although the Richmond fauna is at present considered as of Upper Ordovician age it should be noted that Ulrich[37] regards it as the base of the Silurian. Schuchert's paleogeographic map[38] shows during this epoch the eastward connection of the Cordilleran sea through Wyoming and Colorado with the Mississippi Valley and Appalachian regions.

SILURIAN PERIOD

Although in eastern North America the close of the Ordovician was marked by an orogenic revolution of considerable proportions little record of such activ-

[34] Op. cit.

[35] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, p. 408, 1913.

[36] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 627-628, 1911.

[37] Ulrich, E. O., The Ordovician-Silurian boundary: Cong. geol. internat. Compt. rend. 12e sess., pp. 593-667, 1914 (advance copy, 50 pp., 1913).

[38] Schuchert, Charles, op. cit., p. 635.

ity is found in southeastern Idaho. There the only formation now credited to the Silurian is the Laketown dolomite. At the type locality of this formation Richardson [39] was unable to distinguish the boundary between it and the underlying Fish Haven dolomite because of the scarcity of fossils.

In the Montpelier quadrangle the principal mass of the Laketown dolomite lies in the fault zone of the Bannock overthrust southwest of St. Charles, so that the lithologic change at the boundary, which is more pronounced than in Laketown Canyon, is probably not typical of the formation as a whole. It would seem, therefore, that the limestone-making conditions were little interrupted by the change from one period to the other. It is true that the fossils of the Laketown are so sparse and so poorly preserved that the stratigraphic position of the formation within the system is not known. Hence, a considerable faunal break may be present, but in any event it is probably much less than that represented by the boundary between the Swan Peak quartzite and the Fish Haven dolomite.

The Silurian sea, according to Schuchert's map,[40] flooded the Cordilleran geosyncline from the Pacific at the southwest and from the Arctic and connected eastward along the Canadian boundary with the Appalachian geosyncline. He assigns this sea to the Louisville part of the Niagaran epoch. If the Laketown belongs here the break between it and the Fish Haven would correspond with the time represented in the East by the Clinton and Medina epochs plus whatever time may be needed to represent the orogenic disturbances that preceded the period there.

The question is raised whether in the light of Ulrich's studies the Fish Haven dolomite with its Richmond fauna may not after all be Silurian. In that event the faunal break which precedes it would include the Taconic revolution [41] of the East. The Fish Haven would represent the Medina epoch, at least in part, and the Laketown might be actually conformable, as indeed it appears to be. On the assumption of Louisville age for the Laketown a time interval of greater or less length would intervene between the Fish Haven and the Laketown, but this interval would then be considerably shorter than it would be on the assumption of Ordovician age for the Fish Haven.

Some variations in the constitution of the Laketown dolomite, such as sandy layers and the occurrence of one or more beds of shale, point to minor diastrophic oscillations during the general subsidence of the geosyncline. Toward the later part of the Silurian period the sea withdrew from the geosyncline, and indeed, as shown on Schuchert's paleogeographic maps,[42] all of the North American continent except some of the eastern portions became land.

[39] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, p. 410, 1913.

[40] Schuchert, Charles, op. cit., p. 671.

[41] Dana, J. D., Manual of geology, 4th ed., pp. 531-533, 1895. See also Pirsson, L. V., and Schuchert, Charles, Text-book of geology, pt. 2, p. 636, 1915.

DEVONIAN PERIOD

In Middle Devonian time the Cordilleran geosyncline was again occupied by the sea, and limestone making was resumed. The surface of deposition had been disturbed so little by the diastrophic and erosional changes of the later Silurian that the Jefferson limestone of the Devonian was deposited on the Laketown dolomite with apparent conformity, whereas in fact the stratigraphic hiatus between the two formations is comparable to that between the Fish Haven dolomite and the Swan Peak quartzite.

The geosyncline again subsided gradually until the Jefferson and Threeforks limestones, which have a combined thickness of 1,115 feet in the Portneuf quadrangle, had been deposited. Probably the subsidence was to some extent intermittent or even oscillatory, for some lithologic changes are noted. Thus thin-bedded strata occur near the base of the Jefferson at some places, though the formation as a whole is massively bedded. At other places sandy beds have been observed. The Threeforks, which overlies the Jefferson in apparent conformity, differs from it lithologically in being a relatively soft formation with thin beds of impure reddish limestone. In the light of Barrell's studies, already mentioned, these lithologic differences probably imply stratigraphic breaks of greater or less length, which from present data can not be evaluated.

Schuchert's maps [43] show that the inundation of the geosyncline began from the southwest in the early Devonian, but did not extend as far as southeastern Idaho until Middle Devonian time. The fossils thus far gathered from the Jefferson limestone in southeastern Idaho have been identified as of this epoch. From then on through Upper Devonian time the geosyncline was extensively flooded, and the Arctic waters mingled with those of the Pacific. The fossils of the Threeforks limestone have been identified as of Upper Devonian age. Parts of Colorado and adjacent States were land, but the Upper Devonian sea connected eastward through the central United States with the Mississippi Valley and Appalachian regions.

CARBONIFEROUS PERIOD

The change from the Devonian to the Carboniferous occurred in southeastern Idaho without registering any marked diastrophic activity. The relations between Devonian and Carboniferous in the Montpelier and Slug Creek quadrangles are obscured by later faulting, and there is scant representation of the Devonian. In the Portneuf quadrangle, however, the Devonian is well represented and the Carboniferous lies unconformably upon it.

[42] Schuchert, Charles, op. cit., p. 673.

[43] Idem, p. 697.

MISSISSIPPIAN EPOCH

In the Randolph quadrangle Richardson[44] notes that the Madison limestone, the lowest Carboniferous formation, is apparently conformable with the underlying Threeforks limestone. Paleogeographic maps[45] of North America show a considerable decrease in the size of epicontinental seas between the Devonian and the Carboniferous and a corresponding emergence of the continent. The Cordilleran sea in early Mississippian time extended northward probably to the Arctic and had eastward connections through Texas and Oklahoma with the sea of the Mississippi Valley region.

The difference in lithology between the Threeforks and Madison limestones is marked topographically by differential erosion, for the Threeforks forms depressions and sags, whereas the Madison forms hills and rough ledges. The more calcareous nature of the Madison indicates probably greater distance from shores or gentler grades in the contributing lands than in Upper Devonian time. The thin-bedded character of the formation suggests frequent interruptions of sedimentation, though probably not because of exposure to subaerial erosion. The abundant marine fauna shows that the waters of the epicontinental sea teemed with a varied life.

Blackwelder[46] has described a "nonmarine member in the Mississippian," which Richardson[47] thinks may instead correspond with the Threeforks limestone of the Devonian. Should it prove to be in fact of Mississippian age it would indicate that at some places during this epoch and for certain intervals the shallow waters alternately came and went, leaving bare flats exposed to sun and wind for a time and then flooding them. Barrell[48] calls such bodies of water playa seas and cites the Rann of Cutch as a present example. This great area of 10,000 square miles east of the Indus delta is flooded from July to November during the southwest monsoon to an average depth of 5 feet, owing to a rise of sea level due to wind pressure. For the remainder of the year it is a barren and saline mud flat.

The change from the lower to the upper Mississippian is marked by the complete emergence of the continent, according to Ulrich,[49] who favors a division of the Mississippian into two series because of this stratigraphic break. In southeastern Idaho the evidences of such a break are not very apparent, though if the region is considered as a whole with adjacent parts of Utah there are some facts that suggest it. For example, Richardson[50] in the Randolph quadrangle has observed noteworthy variations in the composition of the lower part of the Brazer limestone (upper Mississippian).

> In some places much chert is present, occurring in layers a few inches thick and also in irregular bunches. In other localities chert is not conspicuous, and the lower part of the limestone is thin-bedded to shaly. About a mile east of Laketown a thin bed of phosphate rock, formerly assigned to the Park City (Phosphoria) formation occurs in the shaly lower part of this limestone.

Blackwelder[51] has noticed a bed of lean phosphate at a corresponding horizon in the Ogden district, and Finch[52] has mapped in detail a phosphate-bearing shale bed at the base of the Brazer limestone in the vicinity of Logan, Utah.

This shale bed had not hitherto been recognized in southeastern Idaho, but in 1920 the writer's attention was directed to some recent phosphate prospects along the western base of the Preuss Range near Montpelier and about a quarter of a mile south of Joes Gap, in an area that was formerly mapped as Madison limestone. Brazer limestone forms the foot slope of the range at Montpelier and a short distance north. The base of the Brazer probably laps a little upon the Madison near Joes Gap, and the phosphate prospects mentioned may be in the shale member mapped by Finch. The slope to the east is occupied by Madison limestone, which has some undulations but forms practically a dip slope. Phosphate float has been reported from other places on this slope. These fragments are probably erosion remnants of this shale member.

The distribution of this shale member thus appears to have been rather widespread, but its localized occurrence suggests deposition upon an eroded surface. The differences in composition at the base of the Brazer noted by Richardson may be similarly explained. The conditions that attended the formation of the shale were probably to a certain extent comparable to those under which were formed the more extensive and richer phosphatic shales of Permian age.

Richardson[53] notes that in the Randolph quadrangle the Brazer limestone is more or less sandy throughout and that locally considerable sandstone is present. In southeastern Idaho the Brazer limestone probably contains a somewhat higher percentage of calcareous matter, though here, too, cherty material, sandy beds, and even beds of sandstone are found. Near the top a dark shale bed is also

[44] Richardson, G. B., op. cit., p. 412.

[45] Schuchert, Charles, in Pirsson, L. V., and Schuchert, Charles, A text-book of geology, pp. 697, 733, New York, 1915.

[46] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21 pp. 528-529, 1910. See also U. S. Geol. Survey Bull. 430, p. 539, 1910.

[47] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, p. 412, 1913.

[48] Barrell, Joseph, Rhythms and the measurement of geologic time: Geol. Soc. America Bull., vol. 28, p. 780, 1917.

[49] Ulrich, E. O., quoted in Pirsson, L. V., and Schuchert, Charles, A text-book of geology, p. 738, New York, 1915. See also Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 346-348, 582, 1911.

[50] Richardson, G. B., op. cit., p. 413.

[51] Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, p. 539, 1910.

[52] Finch, E. H., manuscript report.

[53] Richardson, G. B., op. cit.

present. These stratigraphic differences indicate that interruptions of sedimentation and changes in the character of the sediments occurred because of minor diastrophic disturbances in the subsiding geosyncline or in the contributing lands. The massive beds of limestone, which are a noteworthy feature of the formation, indicate that these disturbances were on the whole less frequent during the Brazer epoch than in some of the other epochs.

Schuchert's[54] paleogeographic map shows that the upper Mississippian sea occupied a much smaller part of the Cordilleran geosyncline than did its predecessor. There is, however, some reason for the belief that in regions farther north, where only the Madison limestone is mapped, beds of upper Mississippian age may be included. The eastward connection of the Cordilleran sea with that of the Mississippi Valley region through the southwestern States was renewed. Marine life was abundant and varied, though its remains are not uniformly distributed through the rocks. Certain layers are remarkably fossiliferous.

PENNSYLVANIAN EPOCH

The close of the Mississippian was marked by a withdrawal of the Cordilleran sea from southeastern Idaho and adjacent parts of Utah and probably also from other parts of the geosyncline. Richardson[55] notes an unconformity at the top of the Brazer limestone in the Randolph quadrangle, and Blackwelder[56] has described a similar unconformity in the Wasatch Range. In southeastern Idaho similar relations are suggested by the local occurrence of the shale bed and of the Martinia zone near the top of the Brazer and by the variable thickness of the lower member of the Wells formation within relatively short distances. Little disturbance of the land had taken place, however, for with the return of the sea in Pennsylvanian time the deposition of limestone was resumed under much the same conditions as in the previous epoch and without marked discordance of bedding. More detrital material was furnished from the land, but this was chiefly in the form of sand. Most of the limestone beds contain more or less sand, and some of them are really calcareous sandstones. For a considerable time in the middle of the epoch little except sand was deposited, but toward the close beds of highly siliceous limestone were formed. Little organic record is left of the time when the sands that now form the sandstone and quartzite beds were laid down. The red color and cross-bedding of some of the sandstones suggest that there may have been actual emergence for part of that time.

The more calcareous layers are in places abundantly fossiliferous and indicate a rich and diversified marine life. The proportion of siliceous organisms was probably greater than it was in the earlier Carboniferous epochs, because now the concentrically banded cherts and more irregular masses and layers of chert constitute a striking feature of the limestones in the Wells formation. Silica in solution may also have been supplied from the lands by streams.

The thickness of the Wells formation, 2,400 feet, indicates a considerable subsidence of the geosyncline during the Pennsylvanian epoch, but the lithologic differences noted point to interruptions in deposition and to gentle diastrophic oscillations. Schuchert's map[57] shows that the Pennsylvanian sea entered the Cordilleran geosyncline from the southwest and spread northward nearly to the Canadian border and that it maintained eastward connections through Texas and Oklahoma with the Mississippi Valley and Appalachian regions. In the Cordilleran geosyncline limestone continued to be deposited, but coal was deposited at different places in the southern Rocky Mountain province,[58] and from northern Texas eastward, during the Pennsylvanian epoch, valuable coal beds were formed from time to time. Coal that was deposited in the Cordilleran geosyncline during the Pennsylvanian is also reported from Nevada,[59] but the occurence seems to have been purely local.

At the close of the Pennsylvanian epoch the Cordilleran sea again withdrew from the geosyncline, so far as southeastern Idaho and neighboring parts of Utah were concerned, for an unconformity intervenes between the top of the Wells and the succeeding Phosphoria formation. Farther east, in the region of the southern Rockies, mountain building of considerable proportions occurred.[60] This emergence of the so-called Rocky Mountain element had a profound influence on the development of the geosyncline. All eastward marine faunal communication from southeastern Idaho was for long ages barred.

PERMIAN EPOCH

The erosional interval that succeeded the deposition of the Wells does not appear to have been of long duration, for only the upper part of that formation was affected by it. When the sea returned in the succeeding Permian epoch conditions of deposition had changed greatly. In the first place the inundation probably came from the north or west instead of from the southwest as in previous floods.

PHOSPHORIA SEA

The outline of the Phosphoria sea is not accurately known. The sea was probably closed off on the east

[54] Schuchert, Charles, op. cit., p. 733.

[55] Richardson, G. B., op. cit., pp. 413, 415.

[56] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 530–533, 1910.

[57] Schuchert, Charles, op. cit., p. 743.

[58] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, p. 5, 1918.

[59] Emmons, S. F., Descriptive geology: U. S. Geol. Expl. 40th Par., vol. 2, p. 595. See also Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, pp. 95–98, 1892.

[60] Lee, W. T., op. cit., pp. 5–7.

and south, but possibly was connected with the Pacific northwestward through Nevada and northern California and with the Pacific and Arctic by way of British Columbia and Alaska, as suggested in Figure 22, which is modified from Schuchert's map.[61] In a comprehensive study of the late Paleozoic in North America Case [62] shows a land barrier extending northwestward from south-central New Mexico to the Canadian border. He notes that it may have been interrupted locally toward the north or was low enough there to permit the extension of red beds across it. West of this barrier red beds are generally absent, except as just noted, but toward the south they tation given in Figure 22, though he realizes that many gaps exist in present knowledge. Beds assigned to the Phosphoria epoch occur in the Uinta Mountains about as far east as the Colorado line [64] and in Wyoming nearly as far east as the Big Horn Range.[65] They have been found in western Montana [66] and Alberta,[67] and Girty [68] notes faunal resemblances that are traceable even into Alaska, Asia, and eastern Europe. The western and southern limits of the sea are less well known, but the evidence thus far available seems to indicate its closure at the south and its probable opening to the Pacific by way of northern California. Geologists of the Fortieth Parallel Survey [69] found fossils

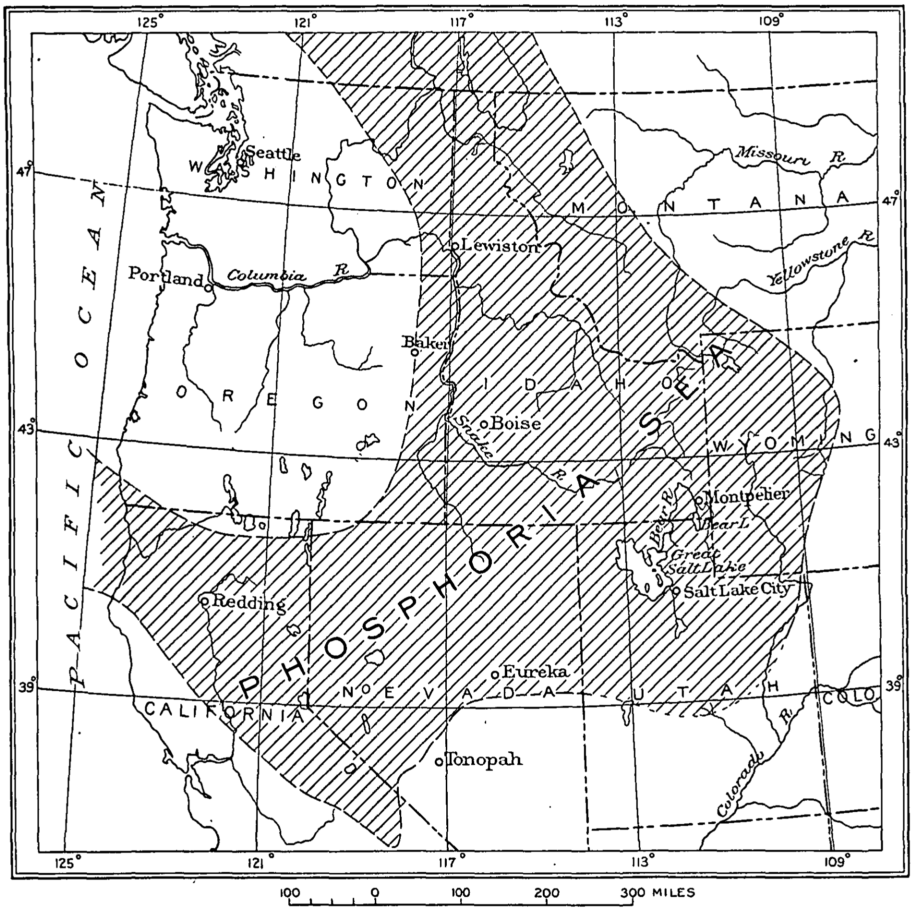


FIGURE 22.—Outline of the Phosphoria sea

gradually replace the marine beds. In this paper Case does not assign western limits to this sea, but in an earlier paper [63] he indicates its boundary as a line drawn northeastward from the southwest corner of Utah and northward through central Utah and Idaho to Montana. On this map he also shows another sea extending eastward through California and southern Oregon into Nevada and southwestern Idaho. From the evidence at hand the writer prefers the interpre- at several localities at about longitude 115° W. in east-central Nevada, which they referred to the "Upper Coal Measures." Later collections from the

[61] Pirsson, L. V., and Schuchert, Charles, A text-book of geology, 2d ed., pt. 2, p. 355, New York, 1924.

[62] Case, E. C., The environment of vertebrate life in the late Paleozoic in North America: Carnegie Inst. Washington Pub. 283, p. 261, 1919.

[63] Case, E. C., The Permo-Carboniferous red beds of North America and their vertebrate fauna: Carnegie Inst. Washington Pub. 207, pl. 4, p. 88, 1915.

[64] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pp. 31–94, 1919.

[65] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 264–266, 1916.

[66] Blackwelder, Eliot, A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 452–481, 1911. Gale, H. S., Rock phosphate near Melrose, Mont.: U. S. Geol. Survey Bull. 470, pp. 440–451, 1911. Stone, R. W., and Bonine, C. A., The Elliston phosphate field, Mont.: U. S. Geol. Survey Bull. 580, pp. 373–383, 1915. Pardee, J. T., The Garrison and Philipsburg phosphate fields, Mont.: U. S. Geol. Survey Bull. 640, pp. 195–228, 1917.

[67] Adams, F. D., and Dick, W. J., Discovery of phosphate of lime in the Rocky Mountains, Canada Commission of Conservation, Ottawa, 1915.

[68] Girty, G. H., The fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 436, p. 9, 1910.

[69] Emmons, S. F., op. cit., pp. 490, 513, 600, 670.

same or near-by localities[70] have been considered Permian by G. H. Girty.

Recent work by members of the Geological Survey[71] has shown the existence of marine Permian beds in the Tonopah and Hawthorne quadrangles, in southwestern Nevada. From collections at these localities Mr. Girty has identified a fauna that contains the brachiopod *Spiriferina pulchra* and other forms characteristic of the Phosphoria formation of southeastern Idaho. These rocks in the Toyabe Range, in the Tonopah quadrangle, and near Candelaria, in the Hawthorne quadrangle, are conglomeratic and unconformable upon the Ordovician, indicating proximity to a shore line. Knopf[72] reports in the Inyo Range east of Independence, Calif., the occurrence of fossils that suggest the *Spiriferina pulchra* fauna. These beds are assigned by Mr. Girty to the Permian. It appears also from Case's summary[73] that in northern California beds of upper Carboniferous age have been found, some of which have been correlated with formations that are elsewhere considered Permian. Marked volcanic activity appears to have taken place near the close of the depositional epoch, as indicated by both tuffs and flows. Similar conditions have been noted by F. B. Laney[74] in western Idaho, where fossiliferous tuffs that carry a Permian fauna have been recognized. According to C. P. Ross[74] these tuffs are known to extend west as far as Baker, Oreg. Elevation accompanied by volcanic activity is thought by Case to have occurred about this time from Alaska southward into northern California.

Toward the south Permian phosphate beds have been found in the Park City district, Utah,[75] and along the south side of the Uinta Range.[76] Phosphatic shale reported from the Oquirrh Range[77] may also be of the same age. Farther south, however, in Beaver, Washington, Garfield, Kane, and San Juan Counties, as shown by several writers,[78] the Permian is represented by red beds. In the San Franciscan volcanic field of north-central Arizona, according to Robinson,[79] the Permian (?) rocks consist of red and brown shales with some calcareous beds that are probably of either fluviatile or estuarine origin. After citing the work of other writers on the general region Robinson concludes that

> A portion of southwestern Arizona of unknown extent was * * * a land area of sufficient elevation to supply large quantities of waste to the lower-lying country on the north during Triassic time and in all probability during Permian time.

LITHOLOGIC VARIATIONS

Considerable variation in lithology occurs in the Permian strata from place to place. In northern Utah they are included in the Park City formation described by Boutwell[80] and named by him from Park City, Utah, where the formation is made up largely of calcareous members but also includes several sandstones and quartzites and some beds of phosphate rock. The formation at Park City is poorly exposed and shows more or less reduplication by faulting, but Boutwell considered it conformable upon the underlying Weber quartzite of Pennsylvanian age.

Schultz,[81] however, has recognized an unconformity between the Park City and the Weber at a number of places in the Uinta Mountains. He divides the formation into four parts, of which the lowermost is a limestone that probably corresponds with the upper part of the Wells formation (Pennsylvanian) of Idaho and like it is locally thickened, thinned, or even cut out altogether by the unconformity. The next member is the phosphatic shale series, in which bands of chert and limestone occur. The third member is the upper or cherty limestone, which contains a large percentage of concretionary chert nodules and lenses, and the fourth or uppermost is a thin-bedded gray limestone, which weathers readily, forming depressions and at a distance has the appearance of a clay or shale bank. The second and third members correspond fairly well lithologically with the Phosphoria formation of Idaho, but nothing in that formation quite agrees with Schultz's uppermost member of the Park City, though in the Fort Hall Indian Reservation[82] shale beds that contain a species of *Ambocoelia* were found above the cherty beds of the Phosphoria.

In Idaho also there is considerable variation in the lithology of the Phosphoria from place to place. In Georgetown Canyon in the Slug Creek and Crow Creek quadrangles the phosphatic shale member, according to two complete measured sections, ranges

[70] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, 2d ed., p. 56, 1905. Hill, J. M., Notes on some mining districts in eastern Nevada: U. S. Geol. Survey Bull. 648, pp. 56, 64, 1916.

[71] Ferguson, H. G., personal communication.

[72] Cited by Case, E. C., The environment of vertebrate life in the late Paleozoic in North America: Carnegie Inst. Washington Pub. 283, p. 141, 1919. See also Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the Sierra Nevada, Calif.: U. S. Geol. Survey Prof. Paper 110, p. 44, 1918.

[73] Case, E. C., op. cit., pp. 136–140.

[74] Personal communication.

[75] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah; U. S. Geol. Survey Prof. Paper 77, pp. 49–52, 1912.

[76] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pp. 46–53, 1919.

[77] Bulter, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 337, 375, 1920.

[78] Lee, W. T., Water resources of Beaver Valley, Utah: U. S. Geol. Survey Water Supply Paper 217, p. 10, 1908. Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Harvard Coll. Mus. Comp. Zoology Bull., vol. 42, pp. 201–259, 1904. Lupton, C. T., Notes on the geology of the San Rafael swell, Utah: Washington Acad. Sci. Jour., vol. 2, pp. 185–188, 1912. Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 634–679, 1907. Gilbert, G. K., Report on the geology of the Henry Mountains; U. S. Geog. and Geol. Survey Rocky Mtn. region pp. 4–8, 1877. Lawson, A. C., The gold of the Shinarump at Paria: Econ. Geology, vol. 8, pp. 434–446, 1913.

[79] Robinson, H. H., The San Franciscan volcanic field: U. S. Geol. Survey Prof. Paper 76, pp. 26–31, 1913.

[80] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 49–52, 113–114, 1912.

[81] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pp. 46–53, 1919.

[82] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 41, 1920.

from 140 to 175 feet in thickness and contains about 75 per cent of shale, 17 per cent of oolitic phosphate rock, and 8 per cent of limestone. About 30 miles farther northwest, near the village of Henry, a complete section of the phosphatic shales showed them to be of about the same thickness, but the percentage of shale and of phosphate rock was not much more than half that shown in Georgetown Canyon, whereas there was a somewhat larger percentage of limestone and much sandstone. The Rex chert member of the Phosphoria formation likewise shows considerable lithologic change in different parts of the region. In the districts south of Montpelier it consists in the main of black chert, dark cherty limestone, and little gray limestone. At Montpelier a shaly bed is present in the chert. Farther north, except at a few localities, the limestone is absent and the chert becomes largely a dark flinty shale, though usually some beds of massive chert are also present. Locally also there is a little quartzite in the section. Still farther north, in the Teton Basin district, as seen by the writer, the upper member of the Phosphoria is composed largely of quartzite. The lower part of the phosphatic shale member in the same district is more or less silicified, but higher beds are softer and contain much carbonaceous matter.

In Montana, as described by Stone [83] and Pardee,[84] the Phosphoria formation contains beds of phosphate rock at or near the base and these are overlain by cherty, sandy, or quartzitic beds. Limestone is practically absent, and the formation is on the whole somewhat more siliceous than it is in Idaho. Condit [85] states that the "Phosphoria is notably siliceous, being either cherty or quartzitic almost throughout."

In Wyoming the Embar formation, which includes beds correlated with the Park City formation of Utah, is present in its normal marine facies in the Wind River and Owl Creek Mountains, but it is said by Condit to change its character gradually northeastward and to become a gypsiferous red bed series in the Big Horn Mountains.[86] More recent field work in this region has thrown doubt on this interpretation, but the details must await later publication. A section of the Park City portion of the Embar formation in the Wind River Mountains contains about 145 feet of beds that may be considered to correspond with the phosphatic shale member of the Phosphoria formation of Idaho. Of these beds only 5 per cent is phosphate rock and the remainder is 138 feet of limestone, which separates the phosphate beds at the bottom from those at the top. The phosphate rock in the Wind River section is considerably poorer than the Idaho material, for the best bed contains only 48.13 per cent $Ca_3(PO_4)_2$.

[83] Stone, R. W., and Bonine, C. A., op. cit.

[84] Pardee, J. T., op. cit.

[85] Condit, D. D., Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U. S. Geol. Survey Prof. Paper 120, p. 113, 1918.

[86] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 264-266, 1916.

CONDITIONS OF DEPOSITION

These changes in the lithology and in the amount and character of the phosphate rock are undoubtedly the result of changes and differences in conditions of deposition, which may be sketched only in a broad way. In the first place, the Phosphoria sea was in all probability a long and somewhat hook-shaped body of water that entered the continent on the north and northwest and overlay in part the Pacific element on the west. The Rocky Mountain element on the east formed a relatively unbroken barrier. These two elements supplied the terriginous material now preserved in the Phosphoria formation. The red beds on the south and east borders of the phosphate-bearing areas indicate the presence in those directions of marginal playa seas analogous to the present Rann of Cutch in India or of broad and shallow lagoons that maintained an interrupted connection with the Phosphoria sea, or perhaps of estuaries at certain localities. The limestones in the section indicate that the lands from which sediment might be derived were relatively distant or so low that little waste from the lands mingled with the débris of the calcareous organisms. The presence of chert in nodules or minor bands indicates that greater or smaller numbers of siliceous organisms also inhabited the sea and that silica as well as lime was supplied in solution from bordering lands. The occurrence of great bodies of massively bedded cherts and of flinty shales, such as are found in the Phosphoria formation of southeastern Idaho, constitutes an interesting stratigraphic problem that is further discussed in Chapter VIII. The shales, sandstones, and quartzites present in certain districts indicate that these districts were nearer the shores of the sea or that the neighboring lands were high enough or steep enough to furnish clastic material. The preponderance of sandy material at certain places may indicate either that the finer waste was carried farther into the sea and deposited beyond those localities or that only sandy terranes were available for the erosive agencies to act upon. In this connection it may be well to call attention to the abundance of sandstones and quartzites and of sandy limestones in the underlying Pennsylvanian formations in different parts of the region. The sea was relatively shallow, and its bottom, in common with the adjacent lands, suffered gentle oscillatory disturbances, which led to the changes in sedimentation.

PHOSPHATE BEDS

The phosphate beds represent a special phase of sedimentation during the Permian epoch, the nature of which is discussed in Chapter VIII. It will perhaps suffice to say here that the development of the phosphatic oolites that make up the bulk of the phosphate rock may point to climatic fluctuations. Although the phosphate-producing agencies were doubtless at work throughout much of the sea during the earlier part of the Phosphoria epoch, their products were at some places so diluted with terrigenous or nonoolitic organic sediment that the resulting phosphate beds were thin or of poor quality. At other places, however, where there was less dilution, a correspondingly thicker and richer accumulation of phosphatic material occurred. Probably, too, the diastrophic oscillations which the sea bottom endured caused some differences in the rate and amount of deposition of the phosphate at different places. The district that surrounds Georgetown Canyon in the Slug Creek and Crow Creek quadrangles appears to have been particularly favorable for the development and deposition of phosphate, for there both the percentage of phosphatic material in the section and the quality of the phosphate rock itself are higher than in any other district yet explored.

The animal life of the Phosphoria sea consisted largely of invertebrates, chiefly brachiopods and mollusks of different kinds, but there were some fishes, as shown by the spines now found here and there, and probably many siliceous organisms, such as sponges, radiolarians, and diatoms, though only sponges have thus far been actually indicated by organic remains. The paucity of fossils in the beds of phosphate rock suggests the possibility that many soft-bodied animals without shells may have been present and may by their decay have assisted in the production of the phosphate. Certain types, of which the brachiopod *Spiriferina pulchra* is perhaps the most characteristic, were widely distributed, especially in the later part of the epoch.

CLIMATIC FLUCTUATIONS

The Permian in many parts of the world was marked by glaciation. In North America thus far only one area of recognized glaciation has been reported, in eastern Massachusetts, where tillite, probably of this age, has been identified. With regard to climatic fluctuations during the Permian glaciation of that district Sayles [87] writes as follows:

> Whether the two main intercalated beds [in the tillite] indicate interglacial epochs is a question of importance. That such beds indicate milder conditions there can be no doubt but that such milder conditions would mean an interglacial epoch of long duration is more difficult to prove. All that can be said, therefore, in regard to these two beds in the tillite is, that they prove milder conditions and temporary retreats of the ice-sheet, and that the cause of glacial periods fluctuated in the distant geological past much as it did during the Pleistocene period.

Probably glaciation did not occur in the Rocky Mountain region of the United States in Permian time, but climatic fluctuations such as those suggested in the discussion of the phosphate beds may have occurred in response to the strongly marked climatic contrasts that existed elsewhere during this epoch.

At the close of the Permian the Phosphoria sea withdrew from southeastern Idaho and probably from much or all of the Rocky Mountain geosyncline as well. Although in the eastern United States and in Europe this time was marked by a great orogenic revolution, the disturbances in southeastern Idaho were so gentle that the attitude of the beds deposited in the Phosphoria sea was scarcely disturbed. Nevertheless, the faunal break between the upper beds of the Phosphoria and the lower beds of the overlying Lower Triassic is so great that a stratigraphic interval of some length is suggested. Farther north, in Montana, the crustal movement was probably more pronounced and the erosion interval was longer, for from the Idaho line south of Red Rock Lakes to the vicinity of Helena,[88] the Jurassic beds truncate successively the Triassic formations and finally cut them out altogether. (See fig. 23.)

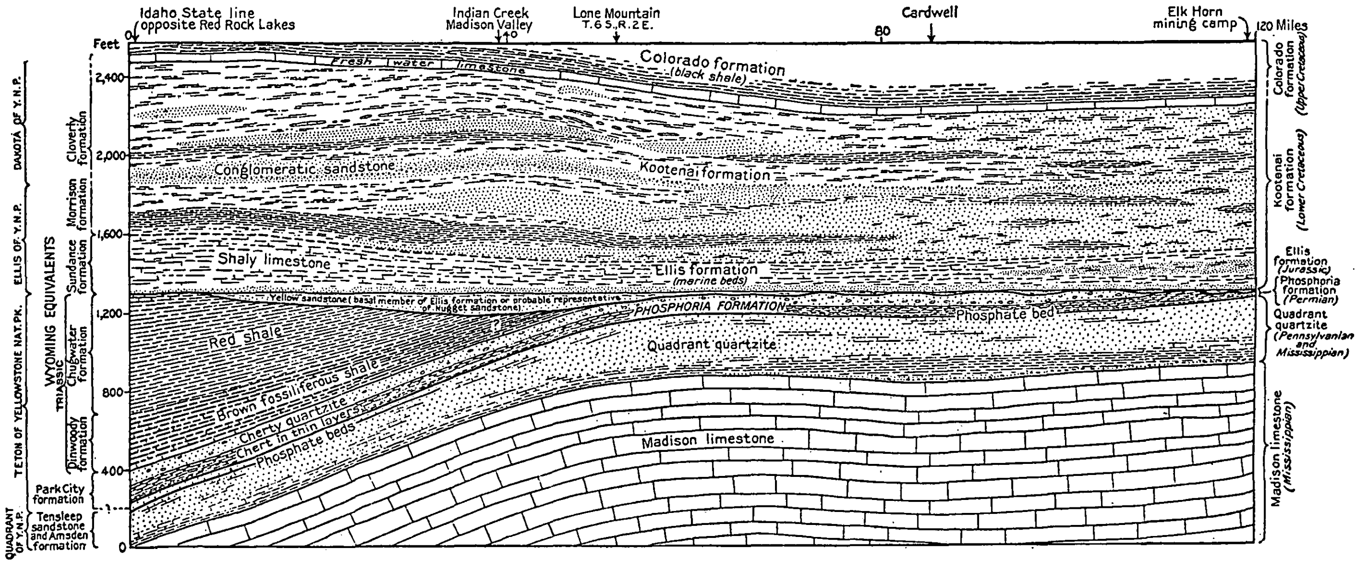


FIGURE 23.—Diagrammatic cross section from the Idaho-Montana State line near the Yellowstone National Park to the vicinity of Helena, Mont. (After Condit)

[87] Sayles, R. W., The Squantum tillite: Harvard Coll. Mus. Comp. Zoology Bull., vol. 56, Geol. ser. 10, pp. 164, 169-170, 1914.

[88] Condit, D. D., Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U. S. Geol. Survey Prof. Paper 120, p. 114, 1918.

TRIASSIC PERIOD

The North American continent was a relatively broad land area in the Triassic period, and in the East only continental sediments were deposited. The same was true of a considerable part of the Rocky Mountain geosyncline, although for at least some of the time this great structural depression was occupied in part by an arm of the sea. The Pacific coast, however, was overspread at some places by the sea throughout much of the period.

LOWER TRIASSIC EPOCH

In the early part of the Triassic the geosyncline in the region of southeastern Idaho was depressed sufficiently to admit the sea, which entered from the southwest and gradually spread eastward at least as far as the Park City district of Utah and the Wind River and Owl Creek Mountains of Wyoming. Thus the normal marine facies in southeastern Idaho begins with the Woodside formation, but in the Park City district the Woodside is composed of red beds and the normal marine beds appear first in the Thaynes. Northward the inundation ceased in the vicinity of the Idaho-Montana line, or if it extended farther its sediments have been removed by later erosion. On the east it was bordered by playa seas and continental basins much as was the sea of Permian time. Boutwell [89] describes the Woodside formation of the Park City district as composed of fine-grained dark-red shale, with ripple marks, mud cracks, and raindrop imprints throughout. Similarly in central Wyoming the normal marine beds, according to Condit,[90] give way to gypsiferous red beds. In southeastern Idaho, however, the Lower Triassic sea deposited calcareous and sandy shales and impure limestones, in which at many horizons large numbers of marine shells were entombed.

The thin and regular plates, of which many of these beds are composed, indicate that the waters, though shallow, were deep enough to allow the sandy bottom muds to be relatively undisturbed by waves. Deposition at such times was intermittent through seasonal or other causes. Some of the beds, particularly the limestones, are more massive and indicate greater continuity of deposition. The waters were open to the Pacific and faunal immigrations from different sources occurred.

Interesting faunal relationships of southeastern Idaho with Europe, Asia, and the Arctic have been pointed out by Hyatt and Smith,[91] and by J. P. Smith.[92]

[89] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 52, 1912.

[90] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 264-266, 1916.

[91] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: U. S. Geol. Survey Prof. Paper 40, pp. 18-19, 1905.

[92] Smith, J. P., Distribution of Lower Triassic faunas: Jour. Geology, vol. 20, pp. 13-20, 1912.

The subsidence of the geosyncline, though somewhat oscillatory during the deposition of the Woodside, was on the whole more and more rapid until the appearance of the *Meekoceras* fauna. The limestones for a short distance below and above that horizon are in many places massively bedded, relatively pure, and crowded with shells. The overlying beds, which are more sandy and shaly, indicate a slower rate of subsidence and renewed oscillations. With the slackening of subsidence the marginal red-bed facies encroached upon the marine facies of the geosyncline. Thus, in the Park City district [93] the Thaynes formation includes a "mid-red" shale member and the Ankareh shale is largely composed of red beds. In southeastern Idaho likewise the Portneuf limestone of the Thaynes group has a red-bed member. These beds mark more pronounced oscillations of the geosyncline during which the sea for a time withdrew to a greater or less extent from it. The Portneuf limestone in the Fort Hall Indian Reservation, where it is best developed, is a massively bedded but somewhat siliceous limestone that contains a varied and interesting fauna but little if any red beds. Farther east, however, these red beds become a pronounced feature of the formation. The interfingering of the red-bed and marine facies of the Lower Triassic, caused by the oscillations or the intermittent subsidence of the geosyncline, is illustrated in Figure 24.

After the deposition of the Thaynes group the geosyncline in southeastern Idaho was at least locally exposed to erosion, for the overlying Timothy sandstone rests unconformably on the Thaynes. The interval of erosion was probably not very long, but considerable amounts of the upper limestone of the Portneuf, which in the Lanes Creek quadrangle is 400 feet thick, were removed, and in southwestern Wyoming and in northern Utah both that limestone and some of the underlying red beds were probably worn away. The limestone thins out in that direction and has not been identified beyond the borders of Idaho. The thinning of the limestone may, however, be due in part to changes in the conditions of deposition. The suggested relationship is shown in Figure 25.

With the return of the sea after the erosion interval conditions of deposition were much as they had been during later Portneuf time except that the relative proportion of sand to calcareous material was greater. The even texture and bedding of the Timothy sandstone throughout much of its area of outcrop indicates that the sand was well sorted and uniformly distributed by the waves and currents along the coast in that part of the gently subsiding geosyncline. In some other areas, as in parts of the Montpelier quadrangle, the composition and bedding are more variable, and bits of carbonized wood or of carbonaceous material are present. These features suggest local emer-

[93] Boutwell, J. M., op. cit., pp. 55-59.

gence and local conditions of nonmarine deposition, though the carbonaceous material may have drifted to its place of burial. The area of maximum subsidence appears to have been in the vicinity of the Fort Hall Indian Reservation, for there occurs the maximum thickness of the formation, 800 feet. Farther east and southeast it becomes thinner because of scantier deposition or of erosion or perhaps from a combination of both causes. After the deposition of the Timothy the sea once more withdrew from the geosyncline in southeastern Idaho and a long time interval ensued, in which both erosion and continental deposition took place.

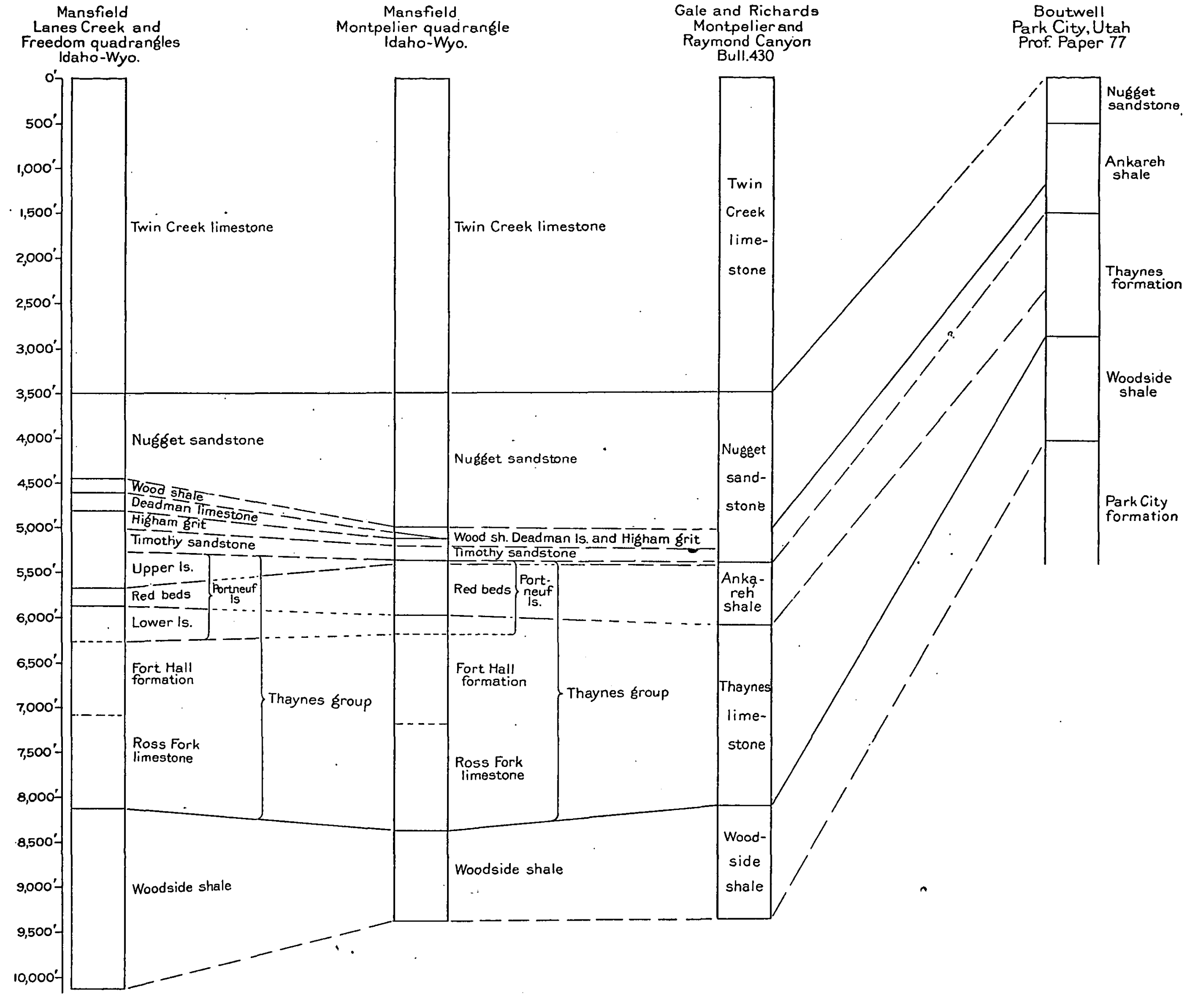


FIGURE 24.—Diagram showing the thickness, nomenclature, and relations of Triassic and Jurassic formations in southeastern Idaho and northeastern Utah

MIDDLE AND UPPER TRIASSIC EPOCHS

Marine fossils of Middle Triassic age in North America are known only from California, central Nevada, and British Columbia.[94] The retreat of the sea from the geosyncline was accompanied and caused by diastrophic movements, probably in the nature of a southwestward tilting or warping. This warping is suggested by the unconformity which now truncates the Timothy sandstone and some of the underlying beds of the Thaynes along the line from the Fort Hall Indian Reservation to the Park City district. (See fig. 24.)

The erosion which produced the unconformity was checked by a somewhat more pronounced diastrophic movement, which changed the area of erosion into a site of continental deposition. The relief of both the Pacific and Rocky Mountain elements was accentuated, so that coarse sediments spread eastward and westward, respectively, from these uplands into the depression which had formerly been occupied by the Lower Triassic sea. Southeastern Idaho lies on the western side of this former depression and received its sediments from the Pacific element, which appears to have had greater relief or closer proximity to the area

[94] Smith, J. P., The Middle Triassic marine invertebrate faunas of North America: U. S. Geol. Survey Prof. Paper 83, pp. 3-5, 1914.

of deposition in the latitude of the Fort Hall Indian Reservation than farther north or south. The Higham grit, the earliest and coarsest representative of the sediments that resulted from this deformation, is coarser and thicker there than at any other place where it has been observed. The uplands to the west were probably mountainous, for they intercepted rainfall and produced arid climatic conditions on their east side, much like the Sierra Nevada of the present day. The great thickness of the Triassic sediments in the West Humboldt Range of Nevada, 17,000 feet as reported by King,[95] also indicates the presence and persistence of a mountain range of considerable proportions between western Nevada and southeastern Idaho during Triassic time.

The open sea of Lower Triassic time did not reach the western base of the Rocky Mountain element but was separated from it by a relatively broad belt of lagoons, playa seas, or more or less isolated basins in which red beds were deposited. When the diastrophic disturbances that are credited above to the Middle or Upper Triassic came, the earlier red beds were eroded to some extent and then coarser beds, including conglomerates, together with finer materials and some gypsum were deposited as continental sediments. These, too, were dominantly reddish colored. They are included in the "Shinarump group" of Powell.[96] Schultz,[97] who has seen in the field the Triassic rocks of southeastern Wyoming, southeastern Idaho, and the Uinta Mountains, considers the "Shinarump group" of Powell to be the equivalent of the Woodside shale, Thaynes forma-

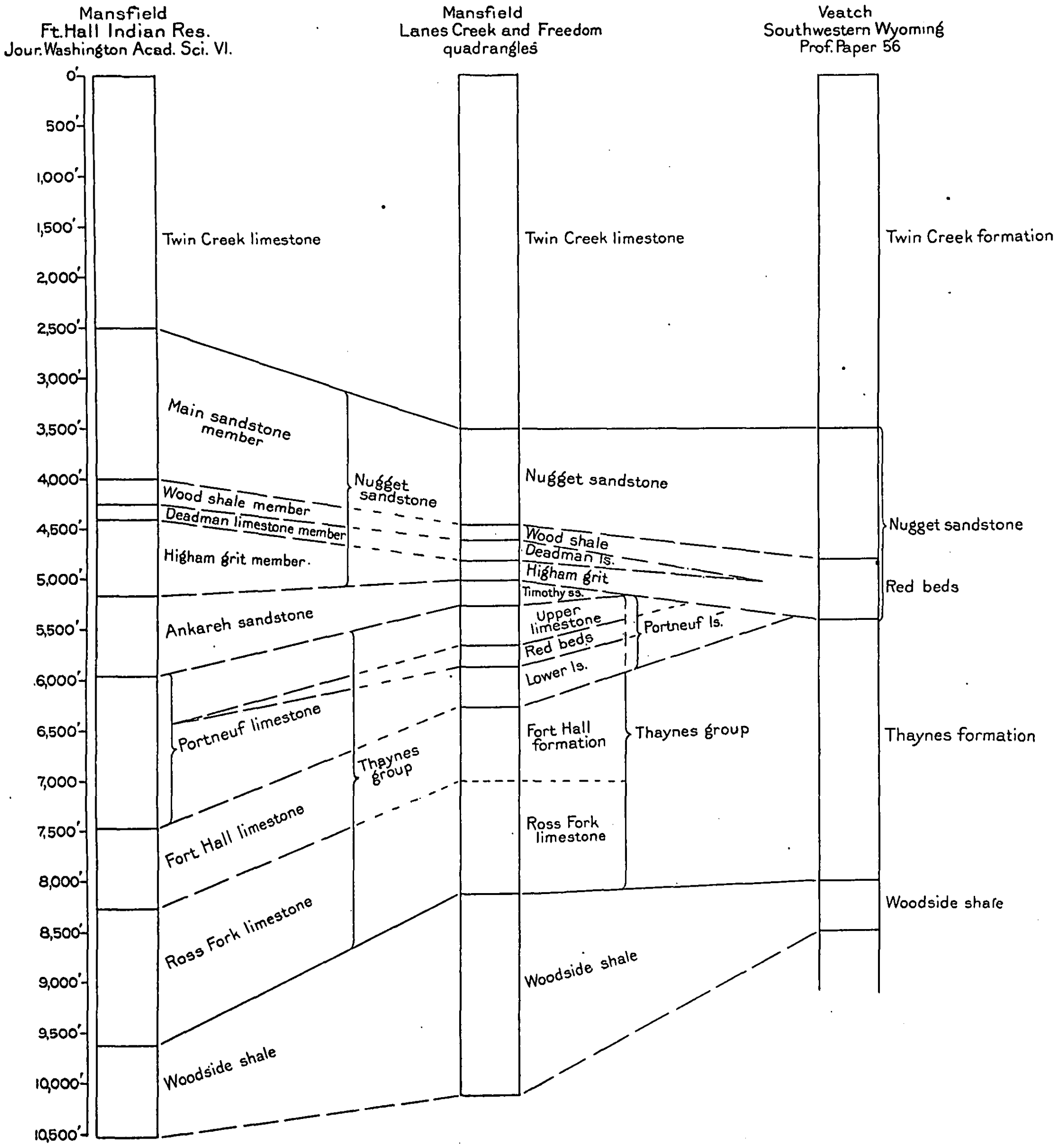


FIGURE 25.—Diagram showing the thickness, nomenclature, and relations of Triassic and Jurassic formations in southeastern Idaho and southwestern Wyoming

[95] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par., vol. 1, p. 227, 1878.

[96] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, pp. 41, 53, 68-69, U. S. Geol. and Geog. Survey Terr., 1876.

[97] Schultz, A. R., Oil possibilities in and around Baxter Basin in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, table on p. 24, 1920.

tion, and Ankareh shale, and he indicates an unconformity at the base of the Ankareh.

In view of the interfingering relationship of the marine Lower Triassic of southeastern Idaho with red beds farther east, and of the unconformities below and above the Timothy sandstone, the present writer thinks that the Timothy and the underlying Portneuf limestone will prove to be progressively truncated eastward by the upper unconformity and that the Higham grit, Deadman limestone, and Wood shale of southeastern Idaho will prove to be the equivalent of the Ankareh shale as recognized by Schultz in the report cited. (See also fig. 25.) There seems thus to be a probability that the Higham grit corresponds with the upper or Shinarump conglomerate of the "Shinarump group" of Powell in the eastern Uinta region. This formation, according to Lee,[98] is a persistent and easily recognized stratum and forms a convenient datum plane for grouping the sections of Utah and Arizona.

The Higham grit thins eastward. It consists almost exclusively of quartzitic débris, so that considerable areas of quartzitic rocks must have been exposed to erosion during its deposition. It was probably spread out in the form of overlapping fans by streams from the mountains to the west. The thickness of the formation, 500 feet in the Fort Hall Indian Reservation, suggests that some subsidence of the geosyncline was in progress at this time.

The succeeding Deadman limestone is probably of continental origin and indicates the presence and persistence for a considerable period of an extensive lake or perhaps of a series of more or less connected lakes, analogous to the later lakes Bonneville or Lahontan. Probably the lake did not have an outlet. Conditions in its waters were not very favorable for life. No organic remains have thus far been identified in the limestone, though the chert, which is a common and characteristic feature of it, may indicate that organisms that secrete silica were present. The more calcareous parts, which locally have dense lithographic, oolitic, or pisolitic facies, suggest chemical precipitation. In some places the chert and limestone are so intermingled that both substances appear to have been deposited together as a mixed calcareous and siliceous ooze. Calcium sulphate was not present to any extent in the lake waters, or, if present, the waters were not unduly concentrated by evaporation, else gypsum would have been deposited with the limestone. Beds of salt are also absent. The extent of the lake is not known, but it appears to have been localized in southeastern Idaho and to have been deepest in the Freedom quadrangle, for there the limestone is thickest.

[98] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, p. 21, 1918.

Beyond the margins of the lake red clays and sands were being deposited, and near the margins there was more or less interchange of conditions of deposition with the fluctuations of the lake level. Thus, in the Boulder Creek district of the Freedom quadrangle the lower limestone layers have shaly tendencies and a reddish color, and in the Home Canyon district of the Montpelier quadrangle the limestone is much thinner and has red shale both below and above it. Here the lake was apparently shallower, and its waters did not overspread the district until somewhat later than they did the Fort Hall Indian Reservation. The red sediments gradually encroached upon the lake and filled it, and for a time playa conditions prevailed, as indicated by the local layers of gypsum in the red beds. Finally these conditions, too, were dissipated, and the region was exposed to the activities of the winds and of desert storms.

JURASSIC PERIOD

PHASES

The Jurassic period in southeastern Idaho is divided into four distinct phases, two of which are probably continental and two marine. Each of these phases is marked in greater or less degree by subordinate changes. The first phase, which was continental, lasted throughout most or all of Lower and Middle Jurassic time. The second phase, which was marine, may have begun in the late Middle Jurassic but probably occurred chiefly in the early part of the Upper Jurassic. The third phase, which was continental or perhaps a marginal phase of marine deposition, and the fourth, which was marine, probably did not together occupy the remainder of the Upper Jurassic, for, according to Schuchert,[99] the Jurassic sea vanished before the Alaskan waters began to abound in the boreal genus *Aucella*. Each of these phases is recorded in sedimentary deposits, and those of the Upper Jurassic constitute a remarkably thick series of beds, some of which are highly fossiliferous.

LOWER AND MIDDLE JURASSIC EPOCHS

The Jurassic period was not inaugurated by any striking physiographic changes. In the latitude of southeastern Idaho there was widespread but gentle warping, which on the whole emphasized the existing differences in altitude between the Rocky Mountain geosyncline and the positive elements on either hand, for somewhat coarser sediments overspread the Wood shale of southeastern Idaho and the "Shinarump group" in the eastern Uinta Mountains. This warping was with little doubt related to the stronger deformative movement that closed the Triassic in British Columbia and Alaska, which Schuchert [1] has called

[99] Pirsson, L. V., and Schuchert, Charles, Textbook of geology, p. 850, New York, 1915.

[1] Schuchert, Charles, op. cit. p. 824.

the Chitistone disturbance. A general picture of the country at that time would show a broad lowland, something like the present Mississippi Valley, with highlands to the east and west and its head toward the south. The highlands at the west continued to be high enough to exclude much of the rainfall from Pacific sources, but there was nothing at the south comparable to the present Gulf of Mexico to temper the aridity of the great valley. There was doubtless axial and lateral drainage in the valley, but the streams were probably intermittent and dry for long intervals, and much of the distribution of the sediments was done by the wind, as suggested by the abundance of large-scale cross-bedding. The degradation of the highlands and the accumulation of desert sands upon the lowlands continued throughout much of Lower and Middle Jurassic time. The Nugget sandstone, which represents these accumulations, attained a maximum thickness greater than 1,500 feet, but the process of aggradation must have been very slow and long continued, for the existing formation at any given place indicates merely the balance between its erosional and depositional phases at that place.

Toward the close of the Middle Jurassic epoch the western highlands had been somewhat reduced and the climate of the valley became a little less arid. There was a return of conditions similar to those of later Triassic time in which the Deadman limestone was deposited. The upper part of the Nugget sandstone, as recognized at several places in southeastern Idaho, contains at least two beds of unfossiliferous nonmarine limestone, separated by red shale and associated with minor layers of gypsum. These beds indicate the presence of fairly persistent lakes, which were probably evaporation pans, whose waters were generally unfit for the support of life. The lakes were filled or desiccated and their sediments largely eroded before the marine invasion that followed. The erosion at the close of the deposition of the Nugget and the northward thinning of the Nugget suggest warping of the geosyncline at that time, though little angular discordance is noted between the Nugget sandstone and the overlying Twin Creek limestone at most places.

UPPER JURASSIC EPOCH

At the close of the Middle Jurassic, or shortly before, the great Jurassic valley was invaded by an arm of the sea that entered from the north and extended southward as far as northern Arizona. Its western edge lay probably not very far west of the region here described, but eastward the sea extended into western Colorado, eastern Wyoming, and even into the Dakotas. Thus it overspread the geosyncline and much of the Rocky Mountain element to the east. Along its southern and eastern margins it seems to have been bordered for greater or less distances by playa seas or shallow evaporation basins, in which gypsiferous sediments were deposited. The waters of this sea, which is commonly called the Logan sea, from W. N. Logan, who first described it, were probably shallow throughout much of its extent and the sea itself was of short duration, for its sediments are variable and relatively thin. In southeastern Idaho and southwestern Wyoming, however, the Twin Creek limestone is 3,500–3,800 feet thick, which indicates a gradual subsidence of the geosyncline and a somewhat deeper and more persistent portion of the sea here than elsewhere. The thin-bedded and shaly character of much of the formation indicates intermittent deposition through seasonal or other causes. The ripple-marked layers indicate water shallow enough to be disturbed by waves. The more massive layers indicate deeper water and more continuous deposition. A volcanic disturbance, presumably in the Pacific element to the west, in the early part of the great marine invasion is recorded in southeastern Idaho by the green ash bed in the lower part of the Twin Creek limestone. (See p. 97.)

The deposition of limestone was stopped by diastrophic movements, which brought the former area of deposition above sea level and subjected it to erosion. The former condition of a great valley with bordering uplands was restored for a time, and the difference in relief was such that sandy waste was spread out over certain parts of this valley. In the earlier part of this epoch there were at least local evaporation basins that persisted for protracted intervals, for beds of salt that should probably be referred to this time, have been found at a number of places along the Idaho-Wyoming border.

Locally small ponds dried out, and muddy layers on their bottoms were cracked and curled and either washed out or blown out by winds to places where they were entombed by later sands. The sands as a whole were highly oxidized by exposure to arid climatic conditions. They now constitute the red-colored Preuss sandstone. Renewed subsidence of the geosyncline permitted the accumulation of 1,300 feet or more of these beds.

With no recognized interval of erosion the sea again crept into the great valley and overspread the Preuss sandstone, rearranged some of its materials, and left a few oyster shells together with a few other scattered organic remains. Thus in southeastern Idaho there is a well-defined record of two marine episodes in Upper Jurassic time. The first, which is represented by the Twin Creek limestone, was relatively long and widespread and left behind it thick accumulations of limestone. The second was shorter and occurred after an interval in which some of the limestone had been eroded and then a thick series of red sandstone had been deposited. The record of the first marine episode is conspicuous, but that of the second is relatively inconspicuous and might readily escape detection in many places, so far as it is dependent upon fossils. The lithologic change, however, is readily recognized. The sediments deposited during the second marine episode are now represented by the Stump sandstone. Although calcareous, these beds contain much sand, so that the grades of the contributing lands must have been steeper than they were in Twin Creek time. The material contributed was much the same as that furnished for the Preuss sandstone, but as it was deposited in sea water and in the presence of marine organisms it remained unoxidized or perhaps its content of oxygen was even reduced and hence it is generally greenish rather than red, although it is locally red at the top.

The Jurassic period in much of North America was marked by erosion and degradation. The Pacific coast region in California and Nevada was in places overspread by the sea throughout most of the period, and there were warpings here and there, as attested by the sedimentary record of southeastern Idaho, but on the whole the Jurassic was a period of continental stability. This condition seems to have been in a measure true of other continents, although in Europe large areas were under water much of the time. There is, then, some ground for the view advocated by Lee [2] that the marine invasion may have been due to a rise in sea level because of the world-wide discharge of sediments from the lands into the ocean basins.

SIERRA NEVADA MOVEMENT

At the end of Jurassic time mountain-building movements of considerable proportions occurred in the Pacific coastal region. These movements with little doubt affected in some degree the whole of the geosyncline and the positive elements on either hand, but they were particularly active in the Pacific elements, where they were accompanied by deep-seated igneous intrusions on a grand scale. In southeastern Idaho this diastrophic activity is recorded in a marked change in type of sedimentation rather than in dislocation of strata or in igneous activity. In fact, little direct evidence of igneous activity of this epoch has yet been recognized there. Igneous rock has been recognized in the horizons of the Deadman limestone and Wood shale near Nugget station in southwestern Wyoming and in Raymond Canyon in the Montpelier quadrangle. Some slight mineralization, which has led to fruitless prospecting, has occurred at these horizons in the Lanes Creek and Freedom quadrangles. Possibly, too, a slight mineralization that has been noted in certain beds of the Timothy sandstone and of the Twin Creek limestone may have emanated from intrusions of this age that have not yet been exposed by erosion, but these effects may be explained equally well as the result of later igneous activity. From the fact that the Sierra Nevada originated at this time, recognized as far back as 1864 by J. D. Whitney, this orogenic disturbance, which has been given different names by different writers, may appropriately be called by Whitney's term, the Sierra Nevada movement.

[2] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, p. 37, 1918.

CRETACEOUS PERIOD

The influence of the Sierra Nevada movement upon sedimentation in the geosyncline was more pronounced in southeastern Idaho than it was farther east or north. Great thicknesses of continental gravels, sands, marls, and clays were deposited. These beds became consolidated, dislocated, and eroded, and in turn covered by a still greater thickness of similar beds, which were themselves later subjected to similar changes. The first series of beds is tentatively and the second series more definitely referred to the Lower Cretaceous, though it contains some beds that may be of later age. The change from Lower to Upper Cretaceous in the general region east and north of that here described was marked by the deposition of a considerable thickness of fresh and brackish water beds, some of which are highly fossiliferous. These and the succeeding marine beds of Upper Cretaceous age have been removed by erosion from the immediate region described in this report, if indeed they ever were deposited there.

LOWER CRETACEOUS (?) EPOCH

GENERAL FEATURES

The abrupt change from the rather fine textured Stump sandstone to the coarse, irregularly bedded Ephraim conglomerate indicates a correspondingly marked change in the conditions of erosion and deposition. The Upper Jurassic sea had withdrawn and the Stump sandstone had been subjected to erosion. The Sierra Nevada movement had elevated the uplands to the west, so that they furnished large quantities of coarse débris to the streams, but the attitude of the Jurassic beds, which were covered by these gravels, was little changed by these disturbances.

Although in Triassic and Jurassic time considerable igneous activity had been in progress in the western uplands, no igneous rocks are recognized as having contributed any material to the sediments that accumulated in the geosyncline in southeastern Idaho. The materials in the congolomerate indicate that the mountains which supplied the débris were composed in the main of Paleozoic sedimentary rocks together with some possibly of Triassic or Jurassic age.

DEPOSITION OF GANNETT GROUP

The thickness of the Gannett group, more than 3,200 feet, and its variable character indicate either intermittent subsidence of the geosyncline or corresponding elevation of the adjacent mountains during its deposition. The Ephraim conglomerate, the coarsest member of the group, lies at the base, but this formation has a maximum thickness of more than 1,000 feet and includes besides the coarse conglomerate some sandy and calcareous material, the last of which is generally nodular and forms boulders on weathering. Thus there were times when grades were gentler or when the speed of erosion slackened. Waters accumulated in local basins and became sufficiently concentrated by evaporation to deposit calcium carbonate. Again, erosion would be quickened and more sand and gravel laid down. These changes in type of sedimentation may have been due in part to climatic fluctuations of longer or shorter duration.

The Peterson and Draney limestones, each approximately 200 feet thick, represent lacustrine phases of deposition. If the waters of the lakes were at times concentrated by evaporation they were not too saline to support life. A rather scanty fresh-water fauna occurs in certain beds in each formation. The lakes must have persisted for considerable periods to permit the accumulation of such thicknesses of limestone. The similarity in lithology and thickness of the two limestones and in their fossil content indicates a recurrence after a long interval of time of practically identical lacustrine conditions.

The Bechler conglomerate, which intervenes between the two limestones, marks a recurrence of conditions similar to those which gave rise to the Ephraim conglomerate, but the grades were gentler and the material supplied by streams was finer. There was renewed subsidence of the geosyncline and possibly also there were climatic fluctuations. The formation is considerably thicker than the Ephraim and presumably represents a somewhat longer interval of time.

The Tygee sandstone, the uppermost formation of the Gannett group, is free from conglomeratic and calcareous beds and represents fairly uniform conditions of deposition. It doubtless corresponds with the distal finer-textured portions of contiguous alluvial fans rather than with lacustrine beds, though the evidence at hand is not sufficient to establish its mode of origin. The mountains which supplied the sands had been reduced to relatively low grades or had been worn back to greater distances from the seat of deposition.

POST-GANNETT EROSION

After the Tygee sandstone had accumulated to a thickness of 100 feet or more, and possibly still higher beds had been laid down, renewed diastrophic movement compressed and to some extent folded the beds of the Gannett group, together with associated lower beds, and all were then subjected to erosion. In the Freedom quadrangle a marked unconformity separates the Gannett group from the Wayan formation. Both sets of beds have been folded, but those of the Gannett group are more intensively deformed than those of the Wayan. Farther northwest, in the Caribou Range, near Fall Creek, and still farther north, in the Big Hole Mountains, where the writer has seen something of the Cretaceous rocks, the Gannett group is much reduced in thickness. At these localities the Lower Cretaceous (?) beds have not been studied in detail, but the diminished thickness of the Gannett group may there be due to lesser deposition and to unconformity. Both sets of beds have been less deformed at these localities than in the Freedom and Crow Creek quadrangles. However, the unconformity is probably rather widespread in eastern Idaho, and it may represent an erosion interval of considerable length.

In southwestern Wyoming Veatch[3] has recognized in the Beckwith formation, which includes beds here correlated with the Preuss and Stump sandstones, the Gannett group, and probably also with the Wayan formation, two rather distinct members—a lower red-bed member, composed of interbedded sandy clays, sandstones, and conglomerates 2,500 feet thick, and an upper member, composed of rather light colored interbedded sandstones and clays 3,000 feet or more thick. The line of division between these two members, as described by Veatch, probably corresponds with the unconformity above the Gannett group in southeastern Idaho.

Diastrophic movement and erosion within the Lower Cretaceous appears to have occurred at other places in the western United States though it is not known whether the disturbances were synchronous. Thus along the Pacific coast from San Luis Obispo County, Calif., northward far into Oregon, there is evidence of crustal movement during this time. The Lower Cretaceous of that region is divided into two formations, of which the lower (Knoxville) is penetrated and disturbed by dikes and masses of serpentine and accompanying peridotites. The upper formation (Horsetown) is absent in southern California, where these intruded rocks occur, and the older formations are overlain unconformably by the Upper Cretaceous beds (Chico).[4] In Montana the Lower Cretaceous beds are included in the Kootenai formation and probably also in the Morrison. The Kootenai, according to Fisher[5] and Calvert,[6] overlies the Morrison with apparent conformity. It is perhaps not without some diastrophic significance that the Lower Cretaceous formations of southeastern Idaho and of these other widely separated regions should each fall into two broad groups. As definite evidence

[3] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 58, 1907.

[4] Pirsson, L. V., and Schuchert, Charles, Text-book of geology, p. 879, New York, 1915.

[5] Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, p. 29, 1909.

[6] Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, p. 28, 1909.

of diastrophic activity within the period has been found at the other localities named, possibly later studies will reveal unconformable relations between the Kootenai and the underlying Morrison (?) beds in Montana.

WAYAN DEPOSITION

During the later part of the Lower Cretaceous epoch in southeastern Idaho there was a reversion to conditions similar to those which produced the Gannett group, except that the grades were not steep enough to favor the deposition of conglomerates as coarse as those of the Ephraim conglomerate. The sediments accumulated during this epoch are all included in the Wayan formation and are grouped somewhat arbitrarily into two divisions.

The lower division, which has an estimated thickness of 2,800 feet, consists of limestones, sandstones, and shales. Some of the shales are more or less carbonaceous. Locally they have been prospected for coal. The conspicuous yellowish sandstone near the top resembles in some places certain beds of the Nugget sandstone and elsewhere contains beds of conglomeratic sandstone.

The upper division, which if without reduplication has the enormous thickness of 9,000 feet or more, and in any event is very thick, consists largely of grayish to brownish sandstone and minor conglomeratic beds but also contains beds of shale and of limestone, including a conspicuous limestone member. The sparse and poorly preserved organic remains are of land or fresh-water forms. A single fragment of bone, though unidentifiable, indicates that there was some representation of land vertebrates.

The great mass of these beds, together with their lithologic variations, indicates a long-continued but probably intermittent subsidence of the geosyncline and a corresponding intermittent elevation of the adjoining Pacific element. Some diastrophic activity may have occurred in parts of the Rocky Mountain element, but most of the material of the Wayan formation was probably derived from westerly sources and from rocks of Paleozoic age. The general relief of the region during Wayan time was not as great as in parts of Gannett time, if judged by the coarseness of the sediments, but deposition under varying conditions continued longer.

COMPARISON WITH INDIA

The physiographic aspect of the region may perhaps be compared with that of the present Indo-Gangetic plain. To the west, corresponding with the Himalayas but probably not so high, lay the mountainous Pacific element. To the east, corresponding with the peninsula of India, lay the more subdued Rocky Mountain element. Between lay a broad valley debouching toward the north. This depression overlay in part the site of the old Jurassic sea, but the bottom of that sea had experienced many vicissitudes before the beginning of Wayan time. The valley was then occupied by a flood plain. Lateral streams, chiefly from the west, built forward gently sloping and contiguous alluvial fans, which merged below with the flood plain. Through warping or other causes the valley floor from time to time became flooded over considerable areas, so that lacustrine conditions were maintained for protracted intervals. The lacustrine phases, however, persisted for only comparatively small parts of Wayan time as a whole. By the combined processes of draining and filling the lakes disappeared and flood-plain conditions were resumed. At least once during the accumulation of the sediments volcanic ash was swept into the valley from an unknown but probably westerly source, presumably by the wind.

Lithologically and genetically the sediments of both the Gannett group and the Wayan formation bear many resemblances to those of the sub-Himalayan group of Tertiary deposits as described by Medlicott and Blanford.[7] According to these authors,

> Sandstone immensely preponderates in the sub-Himalayan deposits and is of a very persistent type from end to end of the region and from top to bottom of the series. Its form is indistinguishable from the rock of corresponding age known as Molasse in the Alps, of a clear pepper-and-salt gray, sharp and fine in grain, generally soft, and in very massive beds. The whole Middle and Lower Siwaliks are formed of this rock with occasional thick beds of red clay and very rare thin, discontinuous bands and nodules of earthy limestone, the sandstone itself being sometimes calcareous, and thus cemented into hard nodular masses. In the Sirmur group generally, and locally in the Lower Siwaliks, the sandstone is thoroughly indurated and often of a purple tint, while retaining the distinctive aspect. In the Upper Siwaliks conglomerates prevail largely; they are often made up of the coarsest shingle, precisely like that in the beds of the great Himalayan torrents. Brown clays occur often with the conglomerate, and sometimes almost entirely replace it. This clay, even when tilted to the vertical, is indistinguishable in hand specimens from that of the recent plains deposit; and no doubt it was formed in a similar manner, as alluvium. The sandstone, too, of this zone, is exactly like the sand forming the banks of the great rivers, but in a more or less consolidated condition. Thus it was suggestive, and not altogether misleading to say that the Siwaliks were formed of an upraised portion of the plains of India.

The above description might very well apply to the Wayan formation, for in that formation sandstone is the predominant rock and all the rock types and lithologic characteristics mentioned above may be recognized in greater or less degree. Some of the limestone beds in the Wayan are earthy, but others are more massively bedded and more dense. Nodular calcareous beds are rather more characteristic of the Gannett group, where they occur in the Ephraim and Bechler conglomerates, than they are of the Wayan formation, but they occur in that formation also. Conglomerates in the Idaho section are more strongly

[7] Medlicott, W. B., and Blanford, H. B., A manual of the geology of India, pt. 2, pp. 524-526, 1879.

developed in the Gannett group than in the Wayan. The upper beds of that formation, so far as recognized, in contrast to the upper Siwalik beds, are not conglomeratic to any extent.

CLIMATE

The climate of southeastern Idaho during Lower Cretaceous time was in some respects analogous to that of to-day, though it was perhaps more equable. A high and extensive mountainous region separated the great valley, in which the sediments were accumulating, from the Pacific. On the asumption, which seems justified, that the circulation of the winds of the time was similar to that of to-day, southeastern Idaho lay in the rain shadow of these mountains, but doubtless received a moderate supply of moisture, especially in the winter. There was enough moisture to supply some vegetation. Small amounts of carbonaceous material occur in some of the beds and even coaly shale may be noted here and there. The red beds suggest intervals of greater aridity, in which there was opportunity for the aeration and oxidation of the sediments, but some of the red material may have been derived from the erosion of older red beds, which have already been described.

FAULTING IN INDIA

In India, according to Wadia,[8] who has summarized the work of earlier geologists, wherever Siwalik rocks are found in contact with older formations, the plane of junction is always a reversed fault with an apparent throw of many thousand feet. This fault is known as the "Main Boundary fault." It is, however, but one of a series of more or less parallel faults in the Tertiary zone of the outer Himalayas, all of which exhibit the same tectonic as well as stratigraphic peculiarities, in that the fault has taken place along the middle limb of the folds and the lower and older rocks are thrust above the upper and younger. The Indian geologists believe that the "Main Boundary" is not merely a fault but that it marks the original limit of deposition of the strata against the cliff or foot of the then existing mountains. The other faults are of the same nature and indicate the successive limits of the deposition of newer formations to the south of and against the advancing foot of the Himalayas during the different stages of their elevation. Thus, if the rocks of the Indo-Gangetic alluvium, which at present lie against the Siwalik foothills, were to be involved and elevated in a further future phase of Himalayan upheaval, they would exhibit much the same relations to the Siwalik strata as these do to the older Tertiary, or as these in turn do to the still older systems of the middle Himalayas. These reverse faults were thus not contemporaneous but successional, and each was produced at the end of the period during which the beds immediately to the south of it were deposited. Suess [9] regards the depression of the Indo-Gangetic plain as a "fore deep" in front of the high crust-waves of the Himalayas as they were checked in their southward advance by the inflexible solid land mass of the peninsula. On this view the depression is a synclinorium.

FAULTING IN IDAHO

The lithologic and genetic similarities already noted between the rocks of the Gannett group and the Wayan formation of Idaho and the Siwalik beds of India lend interest to the fact that the Wayan formation is in many places separated at its contact with pre-Cretaceous rocks by a reversed fault, regarded as part of the Bannock overthrust. Thus, at first sight it would appear that the Bannock overthrust might correspond with the "Main Boundary fault" of the sub-Himalayas. Upon closer inspection this similarity disappears. The Bannock overthrust in different parts of its course wanders across successive geologic formations from Cambrian to Cretaceous, and, so far as having a share in the formation of the Wayan sediments is concerned, it seems no more closely related to that formation than to any of the earlier ones. If the Bannock overthrust was initiated in Lower Cretaceous time, as would have been necessary had it played the part of the "Main Boundary fault" in the production of the Wayan formation, the subsequent orogenic disturbances of post-Cretaceous and Tertiary times would have so dislocated it that its later recognition would have been well-nigh impossible. The Wayan and Gannett beds in the Lanes Creek and Freedom quadrangles have been much broken by faults, but the relationships thus far recognized do not seem to accord with those of the faults in the Siwalik beds of India, which lie parallel to and south of the "Main Boundary fault."

SUBSIDENCE OF GEOSYNCLINE

The geosyncline of Wayan time must have subsided sufficiently to permit the deposition of the thick sedimentary series. It does not appear to have been subjected to successive thrusts but rather to successive downwarpings, perhaps accompanied by moderate folding. The downwarping of the geosyncline was probably due to compressive forces acting from the west, but little is known of the conditions that prevailed in the adjoining mountainous Pacific element at that time. No evidence has thus far been recognized that would disprove a possible former southwestern extension of Lower Cretaceous sediments. However, they probably did not extend very far in that direction beyond their present limits, because along the western margins of the region here described older Paleozoic rocks are exposed, and in the Raft River Mountains of northwestern Utah there are pre-Cambrian rocks.[10]

[8] Wadia, D. N., Geology of India, pp. 232–233, London, Macmillan, 1919.

[9] Suess, Eduard, quoted by Wadia, D. N., op. cit., p. 248.

[10] Butler, B. S., and others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pl. 4, 1920.

UPPER CRETACEOUS EPOCH

The Upper Cretaceous did not leave any recognized trace in the immediate region of the seven quadrangles discussed in this report. Farther northwest, in unmapped portions of the Caribou Range, fossils of possible Bear River age have been found, and farther north, in the Big Hole Mountains, undoubted Bear River beds occur. In the last-named region also rocks of supposed Colorado age overlie the Bear River formation.

RELATIONS OF BEAR RIVER AND WAYAN FORMATIONS

The relations of the Bear River to the Wayan formation are not known. In the Big Hole Mountains the evidence suggests either a stratigraphic break or a fault between the two formations. The Bear River formation probably represents a transitional phase between the nonmarine depositional conditions of the Lower Cretaceous and the marine inundation of the Upper Cretaceous.

The Bear River phase was of considerable duration, for Stanton [11] reports a thickness of 3,420 feet for that formation at Smiths Fork in southwestern Wyoming, where it is overlain by 500 to 600 feet of Dakota (?) beds that consist of brown conglomerate and coarse sandstone. During the Bear River epoch the Pacific element continued as a barrier between the geosyncline and Pacific waters, but the Rocky Mountain element had become so low that saline waters from the gradually enlarging epicontinental sea on the east overspread it locally for longer or shorter intervals and mingled with the fresh waters of the geosynclinal basin. Thus brackish-water lakes or estuaries of varying duration were produced. These lakes and their accompanying deposits, including beds of carbonaceous shale, lay so near the region of the quadrangles here described that they may actually have covered parts of them. If so, however, no traces of their occupation have been recognized. The conglomerate and coarse sandstone of the Dakota (?) mentioned above may mean that an erosion interval was interposed between deposition of the Bear River and the succeeding sedimentation of the Upper Cretaceous.

EXPANSION OF EPICONTINENTAL SEA

With the passing of the Bear River phase the Rocky Mountain element became submerged by the great Upper Cretaceous epicontinental sea, which spread from the Gulf of Mexico far northward to the Arctic. This sea, which was part of a world-wide inundation, for a time covered the site of the Big Hole Mountains in eastern Idaho and left its sediments in southwestern Wyoming as far west as the eastern base of the Salt River Range. If it ever extended farther west its sediments have been eroded away. The shallow marginal waters of the Upper Cretaceous sea were replaced from time to time by swamps and lowlands upon which flourished abundant vegetation, part of which is now preserved as coal. These conditions point to the silting up of the sea with intermittent subsidence of the sea bottom or to gentle oscillations of portions of the continental mass which caused corresponding advances or retreats of the shore line. Towards the close of the period the fresh and brackish water phases of deposition became more frequent and of longer duration. In the region here described erosion was in progress throughout most of the Upper Cretaceous.

END OF THE CRETACEOUS PERIOD

The end of the Cretaceous period was marked by the renewal on a grander scale of crustal disturbances that had been more or less active throughout the period. The epicontinental sea withdrew from all the great interior region of the continent, which, aside from the Tertiary embayments in the lower Mississippi region, has since that time been free from marine inundation. The Rocky Mountain geosyncline and the Pacific and Rocky Mountain elements were built into the broad mountainous tract that now occupies the western part of the continent. Igneous eruptions on a grand scale took place throughout much of this great region. The sediments of the geosyncline became folded and broken in a very complex manner. The present Rocky Mountain system now includes the former Rocky Mountain element together with much of the former geosyncline. Other portions of this great negative element are now incorporated in the great belt of interior plateaus between the Rocky Mountains and the Sierra and Cascades.

The igneous activity so common elsewhere at this time produced little direct effect in southeastern Idaho, although great batholiths, as yet unexposed by erosion, may have had a large share in the regional deformation. Of the massive igneous rocks thus far studied only the andesites could reasonably be dated so far back as this disturbance, and even these may be of later origin. They constitute only a small proportion of the great body of extrusives of the region.

LARAMIDE REVOLUTION

The principal structural features of southeastern Idaho were produced during the great orogenic movement, which Dana has called the Laramide revolution. Beds that range in age from the earliest Paleozoic to the latest-deposited Cretaceous were folded, overturned, and overthrust by forces that were apparently directed from westerly sources. The overthrusting which produced the Bannock fault was a culminating feature of the disturbance, for the rocks in both the upper and lower blocks are intensely folded, whereas the thrust plane, though strongly flexed in places, has a much simpler pattern of folding

[11] Stanton, T. W., The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, pp. 112-133, 1892.

than the rocks above or below. The localization of the zone of maximum movement of the overthrust block, as shown by the convexity of its margin and of the ridges which surmount it, is thought to have a direct relation to the position of the greatest deep in the geosyncline. Great thicknesses of strata had accumulated in southeastern Idaho during Paleozoic and early Mesozoic time, and it has already been pointed out that the land masses which furnished the sediments probably were higher or stood nearer the seat of deposition there than elsewhere in the geosyncline. The great thickness of Jurassic and Cretaceous sediments indicate the persistence of this condition up to the close of Cretaceous deposition, with the probability that the highest land stood opposite the greatest geosynclinal depth. These conditions were most favorable for overthrusting and with little doubt had a directive influence upon it. The area of greatest thickness of the Cretaceous beds, so far as known, now lies actually a short distance north of the line of maximum movement, but the severe crumpling of the beds along that line may have raised a larger proportion of them above the level of erosion, while at the same time their more complex structure would facilitate the process of removal.

The height of the mountains produced by this great orogenic disturbance can only be conjectured. The stratigraphic throw produced by the fault was between 15,000 and 20,000 feet. If all this amount was added to the present elevation of the fault trace a maximum height of about 25,000 feet might be produced. Probably, however, erosion, though lagging behind upheaval, and isostatic sinking were able to greatly reduce the effect of that movement. These and other compensating factors would make the actual altitudes reached considerably lower than the figure given.

The interval between the climax of the Laramide revolution and the deposition of the next succeeding sedimentary formation was occupied by erosion and by a certain amount of structural readjustment. Some of the normal faults of the region may have occurred in this interval. The sediments removed at this time were swept beyond the confines of southeastern Idaho. They may be represented in part by the coal-bearing Evanston formation of southwestern Wyoming, described by Veatch.[12]

CRETACEOUS-TERTIARY INTERVAL

So far as southeastern Idaho is concerned the available record of the Cretaceous-Tertiary interval is a blank, but the Evanston formation just mentioned supplies a few hints about the geologic activities of the general region. This formation consists chiefly of yellow, gray, and black carbonaceous shales and irregular brown and yellow sandstones similar in appearance and composition to beds of the next lower Adaville formation (Upper Cretaceous), but the Evanston also contains beds of pronounced conglomerate below the upper coals, which suggest the beginning of conditions that produced the overlying Almy formation of the Wasatch group. The maximum observed thickness of the Evanston formation is 1,600 feet. The relations between this formation and the Almy formation are apparently conformable, and there are many lithologic similarities between the Evanston and the lower Almy, though the Almy in a section measured just east of the city of Evanston along the railroad begins with a coarse conglomerate.

Many plant remains have been identified from the Evanston formation and also a number of invertebrates, but these fossils are not sufficiently distinctive to prove the age of the beds. The plant remains are thought to resemble those of the Denver formation, which is now assigned to the Tertiary, but the invertebrates, according to Veatch, suggest rather the Laramie or Fort Union. The age of the formation is thus involved in the larger problem of the true age of the Fort Union, which has been regarded by some as Upper Cretaceous and by others as Eocene. From the stratigraphic evidence Veatch favors drawing the line between the Cretaceous and the Eocene at the base of the Evanston, for he sees no reason for placing it between the Evanston and the Almy.

The lithologic character of the Evanston formation suggests that it may have been derived largely from the Cretaceous formations by subaerial erosion. The generally fine texture of the beds and the carbonaceous accumulations suggest low grades and probably flood-plain conditions in a broad valley or in a group of such valleys. These features indicate that the reduction of the mountains of southeastern Idaho was probably well advanced by the beginning of Eocene time. The presence of the conglomerate beds indicates temporary and perhaps only local diastrophic disturbances during the epoch. With the beginning of the Almy epoch these movements were renewed and became more pronounced, so that the Almy as a whole is somewhat coarser textured than the Evanston.

TERTIARY PERIOD

EOCENE EPOCH

No beds of possible Fort Union age have been recognized in southeastern Idaho. The earliest Tertiary formation there represented is the Wasatch, which begins with a conglomerate that perhaps should be correlated with the Almy of southwestern Wyoming. The surface on which it was deposited represents one of the most marked unconformities of the region, for it truncates sharply folded Paleozoic and Mesozoic strata, but it still maintains a moderate relief where exposed along the margin of the formation. (See pp.

[12] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 76-87, 1907.

13 and 14.) There were, however, steep grades in some places, for the conglomerate beds of the Wasatch are coarse and include some boulders 3 feet or more in diameter.

WASATCH DEPOSITION

The general conditions of deposition during Wasatch time appear to have been those of a broad intermontane basin that corresponds in part to the present Green River Basin but includes territory farther west. Sediments were derived largely from the mountains at the west and were coarser in that direction. The materials consist almost entirely of Paleozoic limestones and quartzites, which were presumably derived in large measure from the great overthrust block.

Beds of limestone, sandstone, and shale, interbedded with the conglomerates, indicate changes in conditions of deposition from time to time, and the limestones at least point to lacustrine phases. The pisolitic character of some of the limestone beds suggests that at times the waters were more or less saline and hence that for certain intervals the lakes were without outlet. The red color of much of the formation as represented in southeastern Idaho indicates that vegetation was scanty and that conditions were unfavorable for its preservation. Thus the climate was somewhat arid, and there was opportunity for the aeration and oxidation of the soil. In adjacent parts of southwestern Wyoming, which were seen by the writer, the Wasatch beds are not so conglomeratic and not so dominantly red but are generally light-colored, yellowish or grayish, though red beds are present.

Fossils reported by Veatch [13] and earlier writers indicate that during Wasatch time the waters supported a meager fauna that included gastropods, pelecypods, and fishes. There were also a few reptiles and plants. Land animals roamed the country, but probably not in great numbers. Among them was the form described by Cope as *Bathmodon*, a species of *Coryphodon*, the first vertebrate described from the Wasatch.

The uncertainties regarding the subdivision of the Wasatch group of southwestern Wyoming, as described by Veatch, and concerning the relationship of the Wasatch formation of southeastern Idaho to this group, have been mentioned on page 109. The volcanic ash of Veatch's Fowkes formation is the only definite record thus far available of volcanic activity in Wasatch time in the vicinity of southeastern Idaho.

POST-WASATCH RECORD

The Eocene record in southeastern Idaho after the deposition of the Wasatch is practically a blank. The beds that now remain have an estimated thickness of 1,500 feet, but they are mere remnants of a more extensive and thicker formation. If deposition continued throughout the epoch the total accumulation may have been very great, for two other epochs of interest and importance, the Green River and Bridger epochs, were recorded in southwestern Wyoming before the end of the Eocene.

Green River formation, Wyoming.—The Green River formation, which records the first of these epochs, is remarkable for the great number and excellent state of preservation of the plant and fish remains that it contains. Many species have been described and figured by different writers, who are cited by Veatch.[14] The fine texture and even bedding of the formation together with the calcareous nature of some of the beds intercalated with the clays point to long-continued lacustrine conditions. The formation has wide extent in southwestern Wyoming, northeastern Utah, and northwestern Colorado. In the region last named it has a maximum thickness of about 2,600 feet. It has economic interest because it contains great quantities of oil shale. The oil, which may be obtained by dry distillation of the shale, is derived from organic matter, originally in the form of plant débris, that has been decomposed through the agency of bacteria and other microorganisms. The oil shale of this formation has been described by several writers, particularly by Winchester,[15] who gives a bibliography of the subject.

Bridger formation, Wyoming.—The Bridger formation, as described by Sinclair,[16] consists chiefly of volcanic ash and has a maximum total thickness of about 1,875 feet. The beds are light colored and have in many places a greenish tint. The series includes tuffaceous shales and marls that are crowded with shells. There are also beds that contain lignitic material and masses of coarse sandstone with some conglomerate. The lower and middle parts contain many vertebrate remains, including a considerable mammalian fauna. The upper part is highly gypsiferous. As interpreted by Sinclair, the material of the formation is almost entirely volcanic, though its source is unknown. The area of accumulation was probably near base-level because of the general absence of coarse detritus. Lacustrine and fluviatile conditions of deposition are indicated by the variations in the constitution of the formation. The more gypsiferous portions in the upper part probably accumulated in playa lakes and hence indicate more arid climatic conditions than those which prevailed in the earlier parts of the epoch.

[13] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 89–96, 1907.

[14] Veatch, A. C., op. cit., pp. 97–98.

[15] Winchester, D. E., Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 641, pp. 139–198, 1917; Oil shale of the Uinta Basin, northeastern Utah, and results of dry distillation of miscellaneous shale samples: U. S. Geol. Survey Bull. 691, pp. 27–55, 1919. See also, Bradley, W. H., Shore phases of the Green River formation in northern Sweetwater County, Wyo.: U. S. Geol. Survey Prof. Paper 140, pp. 121–131, 1926.

[16] Sinclair, W. J., Volcanic ash in the Bridger beds of Wyoming: Am. Mus. Nat. Hist. Bull., vol. 22, pp. 273–280, 1906.

Erosion and deformation.—The absence of recognized Green River and Bridger remnants in southeastern Idaho and the fact that the Wasatch formation is extensively eroded support the view that erosion occupied much of the Eocene epoch in that region. The presence of the Green River and Bridger formations in neighboring parts of Wyoming indicates that persistent but shallow lakes occupied that territory and may even have locally overspread parts of southeastern Idaho. The character of these formations indicates that the grades of southeastern Idaho were low during those epochs. Thus there is some indirect evidence of prolonged erosion or even of approximate base-leveling there at that time.

Umpleby has described an old erosion surface or peneplain (?) in central Idaho, which he ascribes to the Eocene, but this view has been attacked. The problem, which involves far-reaching and detailed studies of the Rocky Mountain Tertiary deposits, has not been satisfactorily solved. It is discussed in outline in Chapter VIII. If the old surface is considered Eocene its period of development would presumably cover both the erosional and depositional phases of the record farther southeast.

The thickness of the Green River and Bridger formations suggests downwarping of the lake basins during the deposition of the sediments. There was doubtless concomitant gentle upwarping of parts of the adjacent land surface.

The volcanic character of the Bridger sediments indicates renewed volcanic activity in neighboring regions during later Eocene time.

The possibility has been suggested that the Salt Lake formation, which is now regarded as Pliocene (?), may be Eocene. If this possibility should prove to be a reality the later history of the Eocene in southeastern Idaho would be considerably different from that above outlined. Strong uplift and deep erosion succeeded by extensive aggradation would have to be included in the record. This seems unlikely.

End of Eocene epoch.—Although the end of the Eocene epoch was marked by deformative movements that have been recognized at many places throughout the Cordilleran region, no movement that can be definitely correlated with that time has yet been recognized in southeastern Idaho. The Wasatch formation has been gently folded, and in the Boundary Ridge of the Bear Lake Plateau the beds are rather sharply upturned. The plane of the Bannock overthrust has also been gently folded and locally even overturned. This deformation may have occurred at the end of Eocene time, but with equal or greater probability it might be assigned to the Miocene or Pliocene.

OLIGOCENE EPOCH

No rocks of Oligocene age have been recognized in this area, but possibly a representative of that epoch may be present and may have been included in the Pliocene (?) or the Eocene as mapped in this report.

MIOCENE EPOCH

Possible rock representatives.—No sediments of recognized Miocene age have been found in the quadrangles here described. The region seems thus to have been undergoing erosion throughout that epoch. Although volcanic activity occurred in many parts of the Cordilleran region throughout the Tertiary the greatest activity seems to have occurred in the Miocene. It was during this epoch that the great accumulations of lava flows and volcanic débris that now constitute the plateaus of the Columbia River [17] region and the Yellowstone National Park [18] were largely formed, although in each of these regions extrusions of earlier and later age are found. In southeastern Idaho, however, no volcanic activity attributable to this epoch has been recognized, though it is possible that the andesitic rocks may prove to be Miocene.

Crustal disturbance.—In much of the Cordilleran region the Miocene was an epoch of crustal disturbance. According to Blackwelder,[19] the entire Pacific coastal region of North America and even part of South America was affected. The disturbed area stretched from Venezuela to the Arctic region. The strongest folding was near the coast, but in Wyoming, Colorado, and Montana Eocene and Oligocene strata are tilted and broken by normal faults in such manner as to suggest that the Miocene orogenic movements were felt in a mild way as far east as the edge of the Great Plains. The most accurate estimate of the date of the deformation seems to be that which has been made in the Coast Range of southern California by Arnold [20] and others, who show that it followed the deposition of the lower and middle Miocene sediments (Monterey group), and preceded that of the upper Miocene (Santa Margarita formation).

In southeastern Idaho no dislocations of strata have been definitely correlated with the Miocene. The Salt Lake formation was deposited in valleys, some of which, at least, were deeper than those of to-day and had a maximum width of 5 miles or more. These valleys in the main appear to be products of differential erosion, though some are bordered by faults. Some of them, like Bear Lake Valley, were formed in part by down-warping.

Upon the assumption of Pliocene age for the Salt Lake formation the valleys in which it was accumulated must have formed earlier in the Pliocene or in the Miocene. It seems probable that the disturbance

[17] Smith, G. O., U. S. Geol. Survey Geol. Atlas, Ellensburg folio (No. 86), 1903; Mount Stuart folio (No. 106), 1904.

[18] Hague, Arnold, Weed, W. H., and Iddings, J. P., U. S. Geol. Survey Geol. Atlas, Yellowstone National Park folio (No. 30), 1896.

[19] Blackwelder, Eliot, A summary of the orogenic epochs in the geologic history of North America: Jour. Geology, vol. 22, pp. 648–649, 1914.

[20] Cited by Blackwelder, Eliot, op. cit. See also Arnold, Ralph, Environment of the Tertiary faunas of the Pacific coast of the United States: Jour. Geology, vol. 17, pp. 509–533, 1909.

which elevated the lands and permitted the excavation of the valleys was approximately coincident with the marked deformation of southern California and the Pacific coast region, which has been described above as of post-middle Miocene age. It may be assumed that the low-lying lands of late Eocene, Oligocene, and early Miocene time were broadly uplifted by warping or gentle folding, perhaps accompanied or followed by normal faulting. Thus the Bear Lake and Upper Slug faults and the horst and graben structure described in the previous chapter may have been initiated at this time. The remainder of the Miocene epoch and possibly the earlier part of the Pliocene was devoted to the excavation and broadening of valleys and to general erosion of the region.

Physiographic development.—The Snowdrift peneplain, which is now preserved only as remnants (see Chapter II), probably represents the uplifted lowlands mentioned above. The widespread Tygee erosion surface could then have been formed in the late Miocene. Present evidence shows that the Salt Lake formation was in all probability not deposited upon the peneplain but in broad valleys developed in that surface by the combined processes of erosion and deformation.

The material removed during the development of the Tygee erosion surface was swept beyond the region here described and its disposition is unknown. There is little doubt, however, that the Snake River basin, which may have been developed or emphasized by post-middle Miocene warping, included the drainage of most of southeastern Idaho then as now and perhaps included also much of that now tributary to Bear River and that Snake River received and distributed these sediments. At first sight the lake beds along Snake River in western Idaho would seem appropriate repositories for some of this material, but current views regarding their constitution and age are unfavorable to this idea. Nevertheless evidence obtained by Buwalda indicates that some revision of accepted opinion regarding the age of these beds may be necessary. Some noteworthy changes in drainage have occurred in this region since Miocene time, chiefly in relation to Bear River. (See Chapter VIII.)

PLIOCENE EPOCH

The erosion of late Miocene time may have continued into the Pliocene. The record of that epoch appears to have been largely one of erosion and continental deposition interrupted by crustal disturbance and volcanism. At the close of the epoch the region was broadly uplifted.

Deposition of Salt Lake formation.—After the preparation of the broad valleys, the region became extensively aggraded. The local base-levels were raised, doubtless partly in response to crustal warping, but the accumulations may be partly ascribed to climatic changes. In some of the valleys lakes of longer or shorter duration were formed, but the main effect was the development on a relatively large scale of alluvial fans and coarse flood-plain deposits. These last-named features, together with the calcareous nature of the matrix of the conglomerates, suggest rather arid climatic conditions during parts of the epoch, whereas the fossiliferous marls point to intervals of moister climate.

So far as the quadrangles here described are concerned, the Salt Lake formation consists mostly of coarse sediments. Much of the material is local in character and in many places more or less angular and poorly assorted. It rises on the hillsides to altitudes as great as 7,850 feet and is exposed in valleys more than 2,000 feet lower. It forms patches on the sides of some of the younger valleys and on the floors of old high-level valleys. It underlies the surface of hills that stand 1,200 feet higher than adjacent valleys as in T. 12 S., R. 43 E., in the Montpelier quadrangle. Here and there it is eroded away, and the older rocks beneath are exposed or even stand forth as ridges, as in the locality cited or in Tps. 8 and 9 S., R. 46 E., in the Crow Creek quadrangle. Thus the débris, which now constitutes the Salt Lake formation, not only filled some of the valleys, but it completely overspread some of the lower mountains or hills. It may be regarded as a blanket of unequal thickness, which tended to smooth off certain parts of the country, leaving rocky hills and ridges bordered by gently sloping gravel fans on which here and there wet-weather torrents had shifting courses.

At some places the valleys were ponded, as moister climatic phases prevailed, but with the return of more arid conditions the lakes were filled and their fine deposits were overspread by coarse sands or gravels. The lakes were probably not playas but were perennial, for their waters supported fresh-water life and locally sufficient vegetation was maintained in their neighborhood to supply the meager traces now found.

Comparison with Amargosa Valley, Calif.—The conditions postulated for the accumulation of the Salt Lake formation seem to the writer analogous to those which he has observed in the Amargosa Valley of southeastern California. (See pl. 41, *A*.) There the so-called gravel washes extend far back into the mountains, in some places even to the divides. The lower fan-shaped extensions of the washes surround and isolate or even cover the lower hills. Subsequent erosion has dissected the gravels in some places and has exposed the underlying hills. Thus in Plate 41, *B*, the even, weather-darkened surface of a broad gravel fan may be seen sloping upward toward the more distant mountains. It has been dissected by the Amargosa and its tributaries, so that hills of light-colored clay, themselves further dissected and locally overstrewn with dark débris from the gravel, are exposed.

Volcanic activity.—Volcanic activity on a considerable scale occurred during the Pliocene. Ash beds in the Salt Lake formation north of Georgetown have already been mentioned. In the neighboring Fort Hall Indian Reservation rhyolite and beds of rhyolitic ash are interbedded with that formation, and the formation itself rests on andesitic tuffs that are Pliocene or older. The large rhyolitic cones in the Henry quadrangle and the other large rhyolitic accumulations were probably formed at this time. Toward the later part of the aggradation epoch flows of basalt were also outpoured. The main basaltic extrusions, however, came later. There was also later rhyolitic activity, though on a less extensive scale.

Deformation.—After the epoch of aggradation, and probably toward the close of the period, the region was broadly uplifted with gentle warping or folding succeeded by normal faulting. The Pliocene (?) beds were deformed, and the folding of the Wasatch beds and of the plane of the Bannock overthrust, previously described, probably took place at the same time. The folding followed lines of earlier deformation to a certain extent. For example, in the Left Fork of Twin Creek, in the Slug Creek quadrangle, the axis of the anticline in the thrust plane very nearly coincides with a similar axis in the underlying Jurassic formations. Probably also the normal faulting may likewise have followed in considerable measure earlier established lines. The Salt Lake formation, though bounded by faults at a few places in the region here described, is nowhere cut by them, so far as observed, except in a single place, as noted below (p. 205), but in the Fort Hall Indian Reservation faults in that formation are inferred from the structure of overlying layers of basalt. Deformation was general throughout the Cordilleran region at the close of the Pliocene and indeed in other parts of North America as well. Its effects were notable for broad uplift and warping rather than for intensive folding and overthrusting.

Physiographic development.—Blackwelder[21] considers that in central-western Wyoming the Pliocene was largely an epoch of planation in which the Wind River Summit peneplain was developed. In his arguments relating to the so-called Idaho peneplain, he would extend this view to include Idaho as well. The Tertiary sediments in the area studied by Blackwelder are supposedly early Tertiary. They could therefore have been deformed at the end of the middle Miocene, and the late Miocene and all of the Pliocene would then be available for the leveling process.

The assumption of Pliocene age for the Salt Lake formation introduces a difficulty in applying Blackwelder's conclusions to southeastern Idaho. On the assumption that peneplanation followed the deposition of the Tertiary beds and truncated them together with hard rock (which is Blackwelder's view), that event for southeastern Idaho would have to be placed late in the Pliocene or advanced to the Pleistocene. But if the peneplain antedates the Tertiary beds (here the Salt Lake formation) it might have been developed during the late Eocene, Oligocene, and earlier Miocene. This view seems to accord better with the evidence, so far as southeastern Idaho is concerned. In that region no sign of the preservation of any Tertiary beds at or near the level of the Snowdrift peneplain has been found. Their absence may readily be explained as the result of their relative structural weakness and the present elevation of the peneplain above base-level. Nevertheless their total absence raises the question whether they really were in existence when the peneplain was formed. To place the Snowdrift peneplain in the late Pliocene or early Pleistocene, as would be necessary to accord with the mode of origin advocated by Blackwelder, would allow scant time for the long and varied erosional development that the region has experienced. It will be shown, however, in a later paragraph that the length of the Quaternary period, and indeed of all the geologic periods of which there is a record, is probably greater than has commonly been supposed. Thus the suggested brevity of time may not prove a real objection. Tertiary planation is further discussed on pages 354 to 359.

Southeastern Idaho is so closely adjacent to the region described by Blackwelder that it would seem as if the larger physiographic events, such as widespread peneplanation, in the two regions should correspond in time and general method of development. Some adjustment of the two views here presented will doubtless be made when more detailed studies in the general region, particularly in the now intervening districts, have been made. A tentative comparison of the order of events in the two regions is given in Chapter II.

QUATERNARY PERIOD

From the viewpoint of a student of diastrophism the Quaternary period began with the widespread crustal movements that closed the Tertiary. The history of the period has been dominantly one of erosion, although extensive and perhaps locally thick accumulations of sediment occur in some places and there have been intermittent uplifts, warpings, and faultings. The principal stages of the erosional history have already been described under the heading "Physiographic development" in Chapter II.

Gannett cycle.—Under the view here favored Quaternary erosion began with the Gannett cycle, which was begun by an uplift perhaps as great as 1,000 or 1,500 feet. Broad areas were reduced to a late mature or old stage of erosion. Under the supposition that the Salt Lake formation was present at the time, considerable masses of that formation must have been re-

[21] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geology, vol. 23, pp. 117, 206–207, 1915.

moved, particularly from the broader valleys, in which the process of reexcavation then began. Whatever portions of the formation may have overlapped the adjacent uplands were entirely removed, for none have yet been found upon the Gannett erosion surface. The superposition of Bear River and the beginnings of many of the present drainage features probably date from this time.[21a]

Elk Valley and Dry Fork cycles.—During the Elk Valley cycle broad and relatively shallow valleys were eroded in the Gannett surface and further progress made in clearing out the Salt Lake sediments from the broad valleys of the Tygee cycle, in which they had been deposited. In the Dry Fork cycle similar valleys, though of smaller area, were sunk below those of the Elk Valley cycle and the work of clearing away Salt Lake sediments was continued. The combined uplifts that produced these two cycles probably amounted to little more than 600 feet.

Blackfoot cycle.—The Blackfoot cycle, which followed, began with a somewhat greater uplift, which permitted the erosion of canyons to depths of 500 to 1,000 feet below the Dry Fork surface. Probably the uplift was accompanied by a renewal of faulting along established lines and possibly by new faults, as shown by the occurrence of travertine, some of which is so closely identified with Salt Lake beds as to make distinction difficult. The larger canyons were cut to depths somewhat greater than those of to-day, for many of them have been aggraded since their formation. The Salt Lake formation was extensively removed from the broad valleys which it had filled. Certain fault scarps of possibly older date, like those of the Bear Lake and Upper Slug faults, with their faceted lower slopes, may have been uncovered by this erosion, being thus fault-line scarps that perhaps have been refreshed. Late mature or old valleys were opened in weak rocks or in areas of favorable rock structure, and early mature valleys in the harder rocks and the areas of less favorable rock structure.

Effects of dry climate.—No evidence of alternation of climate is available for the epoch of valley development just outlined, but after the valleys had been formed more arid climatic conditions intervened and alluvial fans in considerable number were formed at favorable places along the valley sides. Some of these fans were of large size. For example, the alluvial fans northward from Montpelier to the vicinity of Georgetown in the Montpelier quadrangle are estimated to exceed 25 square miles in area. The valley floors were also aggraded, but the sediments thus laid down were masked in certain valleys, such as Bear Lake and Upper Valleys in the Montpelier and Lanes Creek quadrangles, by later lacustrine sediments, to which further reference will presently be made.

Volcanic activity.—Early in the aggradational epoch, and even before its beginning, volcanic activity on a considerable scale occurred in the northwestern part of the region. Many of the broader valleys were flooded with basalt, which came both from fissures and from local vents that built up cones of different sizes at a number of places. Basalt also broke out along the hillsides here and there and even in some places upon the hilltops. In a number of occurrences the basalt is known to have utilized earlier lines of faulting in making its way to the surface. Such faults are numerous in the region where the basaltic outpourings took place. It is therefore inferred that these faults were reopened by the accumulating volcanic stresses and that they afforded the chief means of escape for the imprisoned lavas. By raising the local base-levels these basaltic flows assisted in the process of aggradation. Locally they were overspread with Quaternary deposits. Although the interval between successive outflows was generally rather short there were longer intervals, in which soil or volcanic débris accumulated on the surfaces of some of the flows, where it was transported by wind or stream action, before the occurrence of the next flow. Likewise toward the close of the epoch of basaltic extrusion there was some recurrence of rhyolitic outflows on a relatively small scale. The latest recognized eruptive activity in the neighboring Fort Hall Indian Reservation was latitic. The recent appearance of explosion craters between Middle and North Cones, in the Henry quadrangle, suggests that the latest eruptive activity in this region was rhyolitic. The extensive deposits of travertine are no doubt largely associated with the later phases of volcanism in this epoch.

Moister climatic conditions.—The epoch of dry climatic conditions was followed by an epoch in which the climate was more moist than it is now. The alluvial fans and aggradational deposits of the previous epoch were submaturely dissected. Bear Lake began an existence which has continued under varying conditions to the present. As shown by the constitution of the Salt Lake formation, the site of Bear Lake and the broad valley below it had been at times occupied by one or more lakes in the Pliocene (?) epoch, but owing to the vicissitudes of deformation and erosion probably none of these persisted into the Quaternary period. When the aggradational epoch came at the close of the early Quaternary erosion the climate was so dry that there is doubt if any lake existed at that time. In view of the variations in the lacustrine history of Lakes Bonneville and Lahontan,[22] in regions

[21a] W. C. Alden has recently found in neighboring parts of Wyoming and Utah older moraines on erosion surfaces that he thinks are to be correlated with the Gannett. He is therefore inclined to place the Gannett surface at the end of the Pliocene and to begin the Quaternary with the Elk Valley cycle.

[22] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890. Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 1885.

not far removed from southeastern Idaho, it is quite possible that intermittent lacustrine conditions may have been maintained in the later part of early Quaternary time by Bear Lake. But, although Bear Lake is known to have once greatly expanded beyond its present limits, no evidence of alternations, such as those described for the great Quaternary lakes above mentioned, has been found.

Expansion of Bear Lake.—The expansion of Bear Lake and the conditions attending that expansion have been described in Chapter II. It appears to have been one of the latest events of the early Quaternary and is tentatively correlated with the Wisconsin glacial stage. Local glaciation occurred both in the Bear River and Salt River Ranges, respectively west and east of the region here described, though no evidence of actual glaciation has been found within this region. Pleistocene lacustrine fossils that are found in the sediments left during the higher stages of Bear Lake indicate that its waters were fresh and that it maintained an outlet. The remains of a fossil elephant from the same beds indicate the presence of large land animals.

Basaltic obstruction.—Although the basalt in Bear River Valley is not known to have had any direct effect in ponding the waters of Bear Lake, it did produce lakes in certain other valleys, particularly those tributary to Blackfoot River, where the former Blackfoot Marsh, which is now occupied by a reservoir, Pelican Slough, and Upper Valley are good examples. Grays Lake and Cranes Flat afford similar examples for the Willow Creek drainage basin. In Pelican Slough and Grays Lake ponds of variable size remain. Upper Valley and Cranes Flat have been largely filled, but still retain broad marshy areas.

Faulting in basalt.—During the epoch of basaltic outflows normal faulting took place at some localities, particularly along the border of Outlet Valley, in the Cranes Flat quadrangle. At this place rise a number of hills, with one or more cliffed slopes, which are composed of gently dipping layers of basalt. The position of the hills and the attitudes of the slopes indicate that the longer faults have a northwesterly direction but that there are shorter cross faults in several directions. The relations of the horizontal basalt in Outlet Valley to the abrupt slopes of tilted basalt along its west side suggest that the horizontal basalt represents later flows than those which have been faulted, though no actual contacts of the two sets of basalt layers were observed. The throw of these faults is not large, probably less than 500 feet. The attitude of the basalt in Homer Valley, in the northwestern part of T. 3 S., R. 42 E., suggests that it may have outflowed along the line of one of the northwesterly faults.

Recent erosion.—Recent degradational activity in the region has accomplished little, perhaps in part because of the presence of lava in the lower valleys of the main streams. The hard basaltic layers have withstood erosion and have served as temporary base-levels. Canyons, such as those of Blackfoot River, Willow Creek, and John Grays Outlet, are now working back through the lava into the region. Blackfoot River has cut small canyons in some of the higher flows, such as those in T. 7 S., Rs. 42 and 44 E.; Grays Lake Outlet and Bear River have cut canyons along the contact of sedimentary rocks with the basalt; and below Soda Springs Bear River has cut a canyon in the basalt itself. Thus the division of some of the stream courses into reaches has come to pass. In the quiet reaches alluvial flats or meadows have been developed. The tendency of the climate toward more arid conditions since the close of the glacial epoch has favored a certain amount of aggradation. Thus some of the streams in basaltic canyons now flow on valley fill rather than on bedrock. This condition is true of Blackfoot Canyon in the northwestern part of the Henry quadrangle and of Bear River near Soda Springs. Most of the smaller canyons show little modification since the close of the early Quaternary. The main body of the filling, which was deposited in the valleys prior to the earlier stages of Bear Lake, remains undisturbed, in spite of the erosion accomplished during epochs of moister climate.

Recent faulting.—There has probably been some mild diastrophic activity in recent times. Thus the fault near Montpelier, which cuts both the Salt Lake formation and the Quaternary hill wash, is probably of recent date. The fresh appearance of the basal portions of the Bear Lake fault scarp and the hot springs along its course are probably indicative of recent movement along the fault plane, the sulphur springs in Sulphur Canyon, T. 9 S., Rs. 42 and 43 E., and the hot springs near Auburn, in the Freedom quadrangle, afford similar evidence. (See p. 169.)

Dying volcanism.—No recognized volcanic activity has occurred in the region in late Quaternary time. Travertine is still being deposited in minor amounts from springs, which formerly built sinter terraces, basins, and mounds that rivaled the now famous terraces of the Yellowstone. Similarly certain springs and vents continue to give forth large volumes of carbon dioxide (CO_2) and sulphurous fumes. These features are looked upon as the dying embers of former volcanic fires.

Geologic work of man.—The occasional finding of the skull or horn of a buffalo or bighorn recalls the primitive inhabitants of the country before the arrival of civilized man. Now the irrigation ditch, with its train of irrigated farms with cultivated fields, the dry farm, and the advent of improved farm machinery are rapidly changing the desolation of sage-covered slopes and dreary wastes into attractive and picturesque rural communities, which give added charm to the mountain scenery.

The work of man, through the construction of ditches and reservoirs, is modifying the conditions of the circulation of water, both surface and ground water. The diversion of mountain streams for irrigation interferes with their normal work of surface erosion by delaying or accelerating their degradational or aggradational effects and altering the concentration and distribution of alkalies and other soluble constituents of the soils. The stabilizing of Bear River by the construction of a canal that connects it with Bear Lake and of Blackfoot River by the construction of the Blackfoot River Reservoir are examples of the geologic work of man that may have a noteworthy influence upon future geologic activities in the region. The impounding of water in the Blackfoot River Reservoir has already had a modifying influence upon the flow of streams and the activity of ground water in the territory a few miles to the south.

LENGTH OF THE RECORD

The length of geologic time, the realization of which is one of the grandest concepts of geologic science, has long been a favorite subject for speculation among geologists and physicists. In closing the discussion of the geologic history of southeastern Idaho, which presents a fairly continuous record from the present back to the early Paleozoic, it seems fitting to refer to the comprehensive and inspiring studies along this line by the late Professor Barrell.[23]

In a paper published two years before his death he examines a wide range of geologic and physical phenomena and weaves the arguments from both sets of evidence into a unity, which he expresses in a new table of geologic time that

> is of more generous proportions than geologists would have dared to assume from the data of their field alone; but it appears on testing from various points of view to have been logically constructed and gives room for a bolder and larger treatment of earth history than has been imagined to be held within the past.

Barrell finds that the time from the present back to the beginning of the Cambrian period was between 550,000,000 and 700,000,000 years. He says:

> This may seem to be a wide latitude, but the ratio of the minimum to the maximum is no greater than those estimates now current and based on stratigraphy. The important conclusion is that time since the beginning of the Cambrian is ten to fifteen times longer than has been generally accepted by geologists.

Table 34 gives figures for the length of the successive periods, derived from Barrell's table:

[23] Barrell, Joseph, Rhythms and the measurement of geologic time: Geol. Soc. America Bull., vol. 28, pp. 745-904, pls. 43-46, 1917. (See especially pp. 751-752 and 884-885.)

TABLE 34.—*Length of the geologic eras and periods in years*

Era, period, and epoch	Minimum	Maximum
Cenozoic:		
Recent and Pleistocene (Quaternary)	1, 000, 000	1, 500, 000
Pliocene	6, 000, 000	7, 500, 000
Miocene	12, 000, 000	14, 000, 000
Oligocene	16, 000, 000	16, 000, 000
Eocene	20, 000, 000	26, 000, 000
	55, 000, 000	65, 000, 000
Mesozoic:		
Upper Cretaceous	40, 000, 000	50, 000, 000
Lower Cretaceous	25, 000, 000	35, 000, 000
Jurassic	35, 000, 000	45, 000, 000
Triassic	35, 000, 000	45, 000, 000
	135, 000, 000	175, 000, 000 [a](180, 000, 000)
Paleozoic:		
Permian	25, 000, 000	40, 000, 000
Pennsylvanian	35, 000, 000	50, 000, 000
Mississippian	[b] 50, 000, 000	[b] 40, 000, 000
Devonian	50, 000, 000	50, 000, 000
Silurian	40, 000, 000	40, 000, 000
Ordovician	90, 000, 000	130, 000, 000
Cambrian	70, 000, 000	110, 000, 000
	360, 000, 000	460, 000, 000 [a](540, 000, 000)
Present to beginning of Cambrian	550, 000, 000	700, 000, 000

[a] Barrell's figures.
[b] This inversion of maximum and minimum is Barrell's.

PRESENT GEOLOGIC CONDITION

Barrell[24] notes that

> the Neocene revolution has continued into the Pleistocene and that there is no indication that the culmination has yet been passed. * * * The magnitude of the Neocene revolution is seen not only in the breadth and height of the mountain systems, but in the pronounced warping of the continents, giving a steeper hypsographic curve, and in the drawing down of the sea, probably through continental fragmentation, giving a more elevated hypsographic curve. This great height of the continents is a most important feature bearing on the aggregate rate of denudation.
>
> [The Pleistocene] has been marked by an acceleration in crustal uplift and oscillation which has raised high the rate of total denudation. Compared to the rate for the whole of the Cenozoic era of revolution, it may be twice the mean. The concurrence of the longer rhythm in sea level, giving wide and high continents, with the rising diastrophism of a period of revolution may, however, make the present rate of continental denudation ten or fifteen or even twenty times the mean for all of earth history. * * * Estimates of geologic time based on measurements of the present rate of denudation and coupled with the assumption that this is the mean for all of the past are likely to err correspondingly.

From the above considerations it would seem that southeastern Idaho in common with other parts of the globe in spite of its apparent tranquillity and habitability may be in the midst of a geologic revolution. The recent faulting and dying volcanism described above, together with the shortness of the Quaternary period and of the Cenozoic era, in comparison with other periods and eras in the above table, are indications to the same effect. It may be inferred that a geologic revolution proceeds with extreme slowness, as mankind counts time, and that its activities are seldom, and generally only locally, of a catastrophic nature.

[24] Barrell, Joseph, op. cit., pp. 774-775.

Chapter VII.—MINERAL RESOURCES

SUMMARY

The principal mineral resource of southeastern Idaho is phosphate rock, which occurs at two horizons, upper Mississippian and Permian, but only the Permian rock has much commercial value. This rock is characterized chiefly by its oolitic texture and generally dark color and by its odor when freshly broken, which resembles that of crude petroleum. It is a bedded deposit of marine origin and will have to be mined in the same manner as coal.

The phosphate rock is really a mixture or "solid solution" of several phosphatic minerals, but the chemical composition is approximately that of tricalcium phosphate, $Ca_3(PO_4)_2$. There are numerous accessory constituents, among which vanadium is noteworthy. Some tendency has been noted toward enrichment by weathering.

The western phosphate reserve now includes 2,269,055 acres, of which 664,911 acres is in Idaho. The Idaho portion comprises 268,299 acres formally classified as phosphate land and hence released from any form of phosphate withdrawal and 396,612 acres unclassified and still remaining withdrawn. There are in addition some privately owned lands. The government-owned phosphate land is classified and made available for exploitation under regulations which are specified. Not all the reserved land has yet been examined, but 52 townships in Idaho and 6 townships in Wyoming, which are regarded as phosphate bearing, are described in this paper in some detail, and estimates of their tonnages are furnished, together with revised estimates of tonnage for other parts of the western field. The estimates thus far available for Idaho alone indicate a reserve of about 5,000,000,000 tons of high-grade phosphate rock.

The history of the western phosphate industry is briefly sketched, including an account of the litigation, its settlement, and the subsequent laws affecting phosphate lands. The producing companies are briefly described and information is given regarding the production, marketing, and utilization of the rock, together with a statement about processes of manufacture of phosphate and of phosphorus.

The water resources of southeastern Idaho include surface and ground water, both of which are reasonably abundant. The surface drainage is gathered by two systems—the Bear and the Snake. Discharge details are given for Bear and Blackfoot Rivers and some of their tributaries, together with a discussion of the quality of the surface water, so far as analyses are available. The leakage of the Blackfoot River Reservoir is described. The ground-water supply of the mountains, the broader valleys, and the lava country is briefly considered, and an extended account is given of the springs, which are numerous and of various kinds.

The water is at present utilized largely for irrigation. The Blackfoot River Reservoir is part of an extensive irrigation project for the benefit of the Fort Hall Indian Reservation and other lands outside the region here described. The ultimate use of power is also contemplated as a part of the project, but none has yet been developed. Bear River, however, is utilized for hydroelectric power and light by the Utah Power & Light Co. Other minor sources of power are available but not yet used.

Limestones of several geologic ages are a valuable resource of southeastern Idaho. The purest and best are the Carboniferous limestones, but some use might be made of the travertine, which is probably of high grade and readily accessible. Hydromagnesite of possible commercial value occurs in regions adjacent to those here described.

Cement material is abundant, but can not be utilized under present conditions.

Road metal of various sorts is available, but the better grades have been little used because they require crushing, sorting, and transportation. Poorer kinds, which for the most part require no treatment, are available for local use.

The Nugget sandstone affords promise as a building stone. Basalt, which is widespread, could also be used in this way, but its appearance is unattractive.

Salt beds of good quality and brine springs along the Wyoming border supply a small local demand and could in all probability find wider use, but they are remote from present lines of transportation.

Sulphur has been mined and marketed, but the small quantity available and the cost of production preclude any extensive exploitation of this resource.

Lead and copper have been prospected in parts of the Bear River and Preuss Ranges, and a few small shipments of ore have been made, but the outlook for any substantial development is most unpromising.

A few prospects for gold and silver have been opened in the region here described, but the geologic conditions are generally adverse to the occurence there of any metalliferous deposits in commercial quantity. In the Caribou district, however, which lies near but outside this region, conditions are more favorable, and a noteworthy amount of gold has been produced.

Gypsum, manganese, and potassium nitrate have all been recognized in the region, but in amounts too small to have other than scientific interest.

Showings of coal and oil have been reported, but little of either has actually been found, and the geologic conditions seem to be distinctly unfavorable for their occurrence in commercial quantities.

CLASSIFICATION OF RESOURCES

Southeastern Idaho contains a considerable number and variety of mineral substances, which fall into the two broad groups of major and minor mineral resources. In addition other mineral occurrences deserve description, although they could not properly be called resources. The major resources are those which are sufficiently plentiful and well distributed to give promise of long continued use, both in the districts where they occur and in outside regions. The minor resources occur in such small quantities or in such small areas as to insure only a short-lived exploitation or a local use. The other minerals mentioned occur in such small quantities or under such unfavorable conditions that they may never be expected to have commercial value. The classification here employed is arbitrary, for the mineral wealth of this part of the State is as yet largely undeveloped. Any change in classification, however, is likely to result in the reduction of the major group and the enlargement of the other two.

The major group includes phosphate rock, water and water power, lime, hydromagnesite, cement materials, road metal, building stone, and sand

and gravel. The minor group includes salt, sulphur, lead, copper, and possibly gold and silver. The other minerals embrace gypsum, manganese, potassium nitrate, coal, and oil. These resources and mineral occurrences are described in the order named.

PHOSPHATE ROCK

CHARACTER

The rock phosphate is characterized by an oolitic texture, which, however, may be lacking when the grain of the rock has been destroyed by pressure or by shearing. The ovules or oolites are rounded grains that are built up in roughly concentric structure and range in size from extremely minute specks to bodies half an inch or more in diameter. Many of these oolitic bodies are irregularly flattened, a condition which suggests that they may have actually existed as pebbles and been worn by attrition upon one another. The ovules are in general darker than the matrix, and a few of them possess a black, shiny coating. Plate 63 shows a piece of phosphate rock with both oolites and nodules and Plates 64–70 illustrate phosphatic oolites as seen in thin section.

The color of the rock at Paris is gray or almost white when air-dried. At Montpelier the phosphate rock is almost black and suggestive of coal in appearance. Generally the rock when fresh is dark brown, but the weathered material on the outcrop is predominantly a light bluish gray. The rock that has lost its oolitic texture through metamorphism by pressure appears to retain the darker original color, even after long exposure. The bluish-gray coating on weathered fragments, which is something like chalcedony in appearance, has a tendency to concentrate along lines in a netlike pattern. These lines are very apparent on the darker rock and are of assistance in following scattered float along the phosphate beds that lie near the surface.

The phosphate rock and the limestone closely associated with it yield when struck a characteristic fetid odor like that of crude petroleum, which is exceedingly penetrating. The intensity of the odor given off by the rock when struck is not an indication of its relative phosphatic content. Many of the limestones associated with the phosphate have this odor most strongly but contain only a very small percentage of phosphoric acid. Moreover, other limestones of different ages show this same characteristic.

MODE OF OCCURRENCE AND ORIGIN

The rock-phosphate deposits of Idaho, Utah, Montana, and Wyoming are original sedimentary formations that were laid down at a time when that part of the earth's surface was largely covered by water. Since the time when the phosphatic beds were deposited other rock-forming sediments have been accumulated, so that many thousands of feet of later beds have overlain or succeeded them. Deformation of the earth's crust has tilted, folded, and in many places broken these beds, which originally lay flat. Uplift of the land or recession of the sea has subjected the rock in its disturbed position to erosion by streams and the action of atmospheric agencies, so that great bodies of the more elevated parts have been removed entirely and the truncated edges of the beds are now exposed at the surface. The occurrence of the rock phosphate at the surface of the ground now depends on the geologic structure and on more or less accidental relations, such as absence of masking cover or later deposits, depth of erosion, and many minor factors.

The rock phosphate deposits are thus more properly analogous to coal and limestone and especially to the Clinton iron ores of the Appalachian region than they are to ore deposits, such as veins or lodes, or to alluvial deposits of the placer type.

Although their sedimentary origin is clearly indicated, the actual processes by which the accumulations have come into being are not well understood. A review of the available evidence and a discussion of the origin of the phosphate deposits are presented in Chapter VIII.

PHOSPHATE-BEARING BEDS

The phosphate deposits of the western field occur at two geologic horizons at least—in the shale member at the base of the Brazer limestone, of upper Mississippian age, and in the Phosphoria formation, of Permian age. In the region here described the shale member of the Brazer has been recognized thus far only in the Montpelier district, and in this district it has probably no commercial value. A description of these deposits, however, is given in the following paragraph for comparison with the more widely distributed and more valuable Permian deposits with which this report is chiefly concerned.

UPPER MISSISSIPPIAN PHOSPHATE

The phosphate deposits of the upper Mississippian are less extensive and of poorer quality than those of the Permian, but their proximity to present lines of transportation may in some measure serve as an offset for this inferiority. They have been examined in detail in only two districts—Laketown Canyon in northeastern Utah, about 15 miles south of the Montpelier quadrangle, where they were first ascribed to the Permian,[1] and near Logan, Utah.

The following summary of these deposits, which refers chiefly to the Logan area, is contributed by E. H. Finch.[2]

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[1] Gale, H. S., and Richards, R. W., U. S. Geol. Survey Bull. 430, pp. 522-526, 1910.

[2] Finch, E. H., personal communication based on manuscript report on the Logan district.

The upper Mississippian rocks occur in the region east of Ogden, Utah, and also extend northward to an area within a few miles of the Utah-Idaho State boundary, in the Bear River Range, where they have been prospected for coal and phosphate. Assays of samples from the outcrop in the Ogden district indicate that this phosphate is leaner than the Permian material, as it shows less than 20 per cent tricalcium phosphate. Much richer pieces have been found there, however, and farther north in the Logan quadrangle, east of Cache Valley, samples have been collected that contain as much as 70.29 per cent tricalcium phosphate. The deposits have a fairly wide distribution, but the best-known localities are in northeastern Utah. Old Laketown Canyon in the Randolph quadrangle, south of Bear Lake is a definitely known locality where the phosphate zone is nearly 7 feet thick and some of the material contains as much as 81.7 per cent tricalcium phosphate. This material is the richest Mississippian phosphate known in this district.

In the Logan quadrangle the phosphate rocks crop out in three basin-like areas that extend through a distance from north to south of about 25 miles. The basins are portions of a great syncline that has been cut through by large streams. The phosphatic shale zone lies directly above the Madison limestone, of lower Mississippian age, and constitutes the basal member of the Brazer limestone, of upper Mississippian age. It has a maximum thickness of about 100 feet. A large number of samples from the field have been analyzed. In 15 samples of material found in place the content of tricalcium phosphate ranges from 14.86 to 70.29.

The beds in the field that are considered minable, as determined from prospects examined in four localities, are: (1) A 2½-foot bed of 48.41 per cent tricalcium phosphate, a 16-inch bed of 31 per cent, a 9-inch bed of 40.20 per cent, a 13-inch bed of 46.80 per cent, and an 8-inch bed of 66 per cent; (2) a 6-inch bed of 70.29 per cent; (3) a 14-inch bed of 57 per cent; and (4) a 2-foot bed of 48.1 per cent. These individual beds can not be traced between these four localities on account of their variability and their cover of soil and talus, but tracing the general shale zone, together with float phosphate along the outcrop, indicates that other beds equally rich may be present. Analyses of 8 float samples show a tricalcium phosphate content that ranges from 6.36 to 63.85 per cent and 5 of these are above 30 per cent.

The area underlain by the phosphatic-shale zone in the Logan quadrangle comprises about 50 square miles, or 32,000 acres, but the factors of richness of phosphoric acid content, thickness, and depth, render only a portion of the beds, perhaps as small an area as 7,000 acres, readily available within the Logan quadrangle.

The Oquirrh Range, about 50 miles southwest of Salt Lake City, is another district in which this horizon has been found. Samples from this locality, which were analyzed by the United States Geological Survey, contain from 67.46 per cent to 75.03 per cent tricalcium phosphate. The Logan deposits are of low to medium grade. The deposits of the Oquirrh Range are apparently of somewhat higher grade, and those in the Old Laketown Canyon area are the highest grade yet found in deposits of this age. The locality last named[3] has been estimated to contain 6,750,000 long tons of phosphate rock that has an average tricalcium phosphate content of 73 per cent. A detailed section of the bed is given in Table 35.

[3] Gale, H. S., and Richards, R. W., op. cit.

TABLE 35.—*Section of phosphate rock in sec. 32, T. 13 N., R. 6 E., Utah*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	*Per cent*	*Ft.*	*in.*
134–A	Limestone, cherty, phosphate rock, gray, coarse to medium, oolitic	36. 3	79. 5	1	5
	Shale, brown				4
134–B	Phosphate rock, gray, coarse, oolitic, friable	37. 3	81. 7		5
134–C	Phosphate rock, gray, fine, oolitic	26. 4	57		5
134–D	Phosphate rock, gray, coarse, oolitic, weathers into flat concretions as much as 1 inch in diameter	36. 7	80. 4		6
134–E	Phosphate rock, fine grained, oolitic, weathered	26	56. 5		8
134–F	Phosphate rock, gray, fine to medium, oolitic	34. 1	74. 7	2	10
				6	7

PERMIAN PHOSPHATE

Most of the phosphate withdrawals in the western field are concerned with rocks of Permian age, and all the subsequent descriptions and estimates refer in the main to Permian phosphate. Much, however, of what is given regarding the general character, mineral composition, and mode of occurrence and origin of the Permian rock probably applies also to the phosphate that lies at the earlier horizon.

SPECIFIC GRAVITY AND WEIGHT

Early in the study of the phosphate beds experimental determinations of specific gravity of phosphate rock collected in Idaho, Utah, and Wyoming were made in the laboratories of the Geological Survey. No further tests have been made, but as the published results are out of print they are repeated here. The first determinations, which were made with a Jolly balance, are shown in Table 36.

TABLE 36.—*Specific gravity of specimens of rock phosphate*

Field No. of specimen	Source	P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Specific gravity	Average specific gravity
		Per cent	*Per cent*		
3	Montpelier, Waterloo claim, massive ore (two chips)	38. 3	83. 9	2. 93 2. 89	2. 91
92–D	Crawford Mountains, Sioux claim (two chips)	35. 7	78. 2	2. 86 2. 94	2. 90
94	Crawford Mountains, Arickaree mine (two chips)	37. 7	82. 6	2. 92 2. 95	2. 93
130–C	Ogden River area	31. 8	69. 6	2. 89	2. 89
	General average				2. 91

Other determinations on larger blocks of similar material were made by W. T. Schaller, in the laboratory of the Geological Survey, as follows: A specimen of compact phosphate rock (high-grade ore) from the mines of the Union Phosphate Co., near Cokeville, Wyo., which weighed 493.7 grams had a density of 2.92; a specimen of compact phosphate rock (high-grade ore) from the Waterloo mine of the San Francisco Chemical Co., near Montpelier, Idaho, which weighed 707.5 grams, had a density of 2.86. For these determinations the specimens were coated with paraffine before being weighed in water, to prevent absorption of water into the mass of the rock.

As a result of these tests the density of the more massive ore of 70 per cent grade or over (tricalcium phosphate equivalent) from this general region is without much doubt between 2.85 and 2.95; an average of 2.90 has been assumed for the calculations of tonnage. From this ratio the weight of a cubic foot of the more massive rock, such as that now being shipped from the mines in this region, is about 180 pounds.

TABLE 37.—*Analyses of phosphate rock from Wyoming, Utah, and Idaho*

	1	2	3	4
Insoluble	10. 00	1. 82	9. 40	2. 62
SiO_2	None.	. 30	Not det.	. 46
Al_2O_3	. 89	. 50	. 90	. 97
Fe_2O_3	. 73	. 26	. 33	. 40
MgO	. 28	. 22	. 26	. 35
CaO	45. 34	50. 97	46. 80	48. 91
Na_2O	1. 10	2. 00	2. 08	. 97
K_2O	. 48	. 47	. 58	. 34
H_2O	1. 04	. 48	. 61	1. 02
H_2O+	1. 14	. 57	. 75	1. 34
TiO_2	None.	None.	None.	None.
CO_2	6. 00	1. 72	2. 14	2. 42
P_2O_5	27. 32	36. 35	32. 05	33. 61
SO_3	1. 59	2. 98	2. 34	2. 16
F	. 60	. 40	. 66	. 40
Cl	Trace.	Trace.	Trace.	Trace.
Organic matter	Not det.	Not det.	Not det.	Not det.
	96. 51	99. 04	98. 90	95. 97

1. Main phosphate bed, 2½ miles east of Cokeville, Wyo.
2. Dunnellon claim, Crawford Mountains, Utah.
3. Elsinore claim, Tunnel Hollow, between Morgan and Devils Slide, Utah.
4. Preuss Range, 8 miles east of Georgetown, Idaho.

CHEMICAL COMPOSITION

The chemical composition of phosphate rock from the general region is shown by four fairly complete chemical analyses made by George Steiger in the laboratory of the United States Geological Survey and reproduced in Table 37.[4]

Gale and Richards give the following discussion of this table:

Qualitative examination of this insoluble matter indicates that it consists mainly of silica with minor amounts of kaolin. Quartz was not observed in thin sections of the high-grade ore. The CO_2 in some of the rock is apparently nearly all combined with lime in the form of calcite, as is indicated by the presence of the mineral in the sections and the fact that the gas is liberated on treating the powdered rock with dilute acetic acid; but elsewhere it is probably combined in some other way, because calcite is absent in thin sections and the gas is not liberated on treatment of the powder with the acid but comes off when hot dilute HCl is used. The nature of such a combination is problematical, but it is possible that the CO_2 may be present in a phosphatic mineral of the nature of podolite ($3Ca_3(PO_4)_2.CaCO_3$). The SO_3 may be combined with some of the lime, as gypsum or more probably anhydrite, and both minerals have been noted as present in streaks in the lower-grade rock at an exposure in the NW. ¼ SE. ¼ sec. 8, T. 11 N., R. 8 E., in the Crawford Mountains, Utah, but have not been seen in the microscopic examination of the high-grade rock. Another alternative might lie in regarding the SO_3 as combined with the alkalies, of which soda is present in an average percentage of 1.5. However, no indications of such compounds are noted under the microscope. A recalculation of the analyses given above, after the alkalies and SO_3 and enough of the lime as calcite to satisfy the CO_2 have been removed, appears to suggest that the calcium phosphate mineral closely approximates in composition a basic calcium phosphate—probably more basic than apatite because of the absence of the haloids—to which further investigation may warrant the assignment of a new mineral name. By some authorities[5] it is reported, however, that chemical examination of rock phosphates from other fields has "shown indubitably that these phosphatic bodies are members of a series of solid solutions of phosphoric acid in lime." The substance of the rock phosphates of South Carolina, Florida, and Tennessee, "like the coprolites, osteolites, phosphorites, etc., found in more limited quantities in various parts of the world, seems to be an amorphous body containing lime and phosphoric acid in proportions varying more or less from that required by the formula for tricalcium phosphate and always mixed with some calcium carbonates."

[4] Gale, H. S., and Richards, R. W., op. cit., pp. 465–466.

[5] Cameron, F. K., and Bell, J. M.: The action of water and aqueous solutions upon soil phosphates: U. S. Dept. Agr. Bur. Soils Bull. 41, p. 9.

The organic matter, which in all probability is responsible for the odor of the rock, differs in different parts of the region. In some localities, as in the Big Hole and Snake River Ranges north of the region here described, it is present in sufficient quantity to yield oil upon dry distillation.

IRON AND ALUMINA

Iron and alumina in phosphate rock in excess of 3 to 4.5 per cent are considered in the eastern fields as placing the ore below foreign contract standards. Besides acting as impurities that increase the amount of acid necessary for treatment, these substances are supposed to produce in the present process of superphosphate manufacture deliquescent salts that render difficult the drying and shipment of the product.

Samples from the western fields that have been tested in the laboratory of the Geological Survey have shown generally less than 1 per cent of either radicle computed in the oxide form. At some localities, however, appreciable amounts of these substances have been found; the largest percentage yet recorded is 17.3 for the two radicles combined. This sample came from a locality on Palisade Creek in the Snake River Range. The manufacturers of superphosphate who use the rock from the western field agree that the amounts of these substances present in the rock they have thus far used are too small to be considered objectionable.

TESTS FOR OTHER ACCESSORY CONSTITUENTS

In addition to the more complete analyses given above and to the usual determinations for P_2O_5, Fe_2O_3, and Al_2O_3, the last two ordinarily being determined together, special search has been made for other constituents that might have some bearing on the exploitation of the phosphate. In most of the material, however, the small amounts indicated by the tests have discouraged making many analyses. The substances investigated in this way are oil, chromium, manganese, nickel, vanadium, arsenic, and fluorine, and they are considered briefly in the order named.

Oil.—The phosphate beds at many localities were first prospected for coal both because of their dark and coaly appearance and because it was found that the material from certain localities would burn. The fact that oil could be obtained by dry distillation from phosphatic shales of the Phosphoria formation was made public by Bowen[6] in 1918. Condit[7] has subsequently shown from a reconnaissance of much of the western phosphate field that samples of shales associated with the high-grade phosphate rock in southeastern Idaho yielded on distillation little more than a trace of oil. The richest area proved to be that previously examined by Bowen near Dell and Dillon, Mont. At that locality the richest beds, 3 feet or more in thickness, yielded 25 to 30 gallons of oil to the ton. The phosphate beds associated with this oil shale, however, are thinner and contain considerably less phosphorus pentoxide than those mined near Montpelier, Idaho, and those known to occur in the Melrose and Garrison fields of Montana.

Chromium.—The green color of some of the solutions produced by treating western phosphate rock with sulphuric acid has been noticed by a number of observers. The suggestion was made by Dr. F. K. Cameron in a letter to H. S. Gale that this color might be due to the presence of chromium. The writer accordingly prepared three composite samples, made up respectively of high-grade, medium-grade, and low-grade phosphate rock from northeastern Utah, southwestern Wyoming, and southeastern Idaho. The first 2 composite samples each represented 20 individual samples and the last 16 individual samples. These samples were analyzed by W. B. Hicks in the laboratory of the Geological Survey. The high-grade rock yielded 0.08 per cent of chromic oxide (Cr_2O_3) and the medium and low-grade rock samples each contained 0.14 per cent. Individual samples of high-grade rock from the property of the San Francisco Chemical Co. at Montpelier, Idaho, which were analyzed by R. K. Bailey, of the Geological Survey, ranged in content from 0.11 to 0.23 per cent of chromic oxide and similar samples from Paris Canyon, Idaho, contained 0.18 per cent.

According to Clarke,[8] chromium is widely diffused in subsilicic rocks, the average proportion found in 256 analyses of igneous rocks in the laboratory of the United States Geological Survey being 0.05 per cent of Cr_2O_3. The one valuable ore is chromite, or chromic iron. No terrestrial sulphides of chromium are known, but the mineral daubréelite, $FeCr_2S_4$, occurs in some meteoric irons.

Chromite, an oxide of chromium and iron, is composed when pure of 68 per cent of chromic oxide and 32 per cent of ferrous oxide. In nature some of the chromium in chromite is replaced by aluminum or iron. Much of the rich imported ore contains 50 per cent or more of chromic oxide, but the average American ore contains only about 40 per cent.

Chromite is a common constituent of basic igneous rocks, especially of peridotite. As such rocks readily alter to serpentine and the chromite in them remains unchanged, the most common occurrence of chromite is in crystalline grains that are widely distributed in serpentine.[9]

Although the occurrence of chromium in phosphate rock can not be expected to have commercial value, it is not without scientific interest in its bearing upon

[6] Bowen, C. F., Phosphatic oil shales near Dell and Dillon, Beaverhead County, Mont.: U. S. Geol. Survey Bull. 661, pp. 315-320, 1918.

[7] Condit, D. D., Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 711, pp. 15-40, 1919.

[8] Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, pp. 702-703, 1920.

[9] Diller, J. S., Chromite: U. S. Geol. Survey Mineral Resources, 1918, pt. 1, pp. 657-658, 1920.

the question of the origin of phosphate rock. The analyses given above clearly indicate that the amount present is probably from two to four or five times greater than the average for igneous rocks. It thus represents a concentration of the chromium under special conditions. The form in which the chromium occurs has not been determined. It might have been derived from the erosion of a land area that contains basic igneous rocks. An alternative view is that it may represent cosmic dust, which accumulated in the Phosphoria sea during the slow formation of the phosphate beds.

Manganese.—No general search has been made in the western phosphate rock for manganese, but a trace of it was found in a single sample, which was tested because of its black and generally smutty appearance. The sample tested was low-grade phosphate rock which contained only about 32.5 per cent of tricalcium phosphate, but it contained 17.3 per cent of iron and alumina together, the highest recorded amount for these two substances, and 25.9 per cent of carbonaceous matter. It came from Palisade Creek, in the Snake River Range, some distance north of the region here described.

There is little probability that manganese in commercial quantity will be found in the phosphate rock, but further search for it may have scientific interest in its bearing upon the origin of the phosphate.

Nickel.—A single sample of phosphate rock from the vicinity of Driggs, Idaho, in the Teton Basin district, was tested for nickel by J. G. Fairchild, in the laboratory of the Geological Survey, but none was present.

Vanadium.—The close chemical relationship between phosphorus and vanadium made it seem probable that vanadium might be found in the western phosphate rock. Its presence was recognized by survey chemists as early as 1911 in the sample just mentioned, which was taken from the vicinity of Driggs, Idaho. Later, following a suggestion by W. F. Hillebrand,[10] an analysis of a composite sample was made in the survey laboratory by R. M. Kamm. The composite sample represented twelve individual samples of high-grade phosphate from different parts of the Idaho field and contained 0.11 per cent of vanadium pentoxide (V_2O_5). Further tests of individual samples were made by R. K. Bailey in the laboratory of the Geological Survey. Three samples from the property of the San Francisco Chemical Co. in Montpelier Canyon, Idaho, ranged from 0.40 to 0.52 per cent of V_2O_5 and two from the Western Phosphate and the Bear Lake Phosphate companies' properties in the Paris Canyon district contained respectively 0.23 and 0.28 per cent V_2O_5.

These quantities, though small, may acquire commercial significance, especially in view of the fact that in some of the processes for the manufacture of superphosphates there is concentration of the phosphorus pentoxide and presumably also of the vanadium pentoxide. Concerning this aspect of the problem Frank L. Hess says:

> The analyses quoted for the vanadium content of the Paris phosphate rock used by the Anaconda Mining Co. showed 0.23 and 0.28 per cent V_2O_5, respectively. The tailings from the chemical concentrates are said to be free from vanadium, and unless there was a loss at some other point in the operation would indicate a complete saving of the vanadium. The concentrated phosphate solution showed 0.32 per cent V_2O_5, almost 1½ times the lower content shown in the phosphate rock, corresponding very well, if 0.23 per cent of V_2O_5 in the rock is used as a basis, with the concentration of the phosphorus contained in the original rock.
>
> If 1,000 tons of phosphate rock per day, or say 360,000 tons per year, should be handled, as is said to be the company's intention, that would mean, if the ratio should continue to hold, a daily content of about 2.1 tons of V_2O_5, and a yearly content of 756 tons of V_2O_5, or 423 tons of vanadium (V). This is a much larger quantity than the average production of vanadium in ores of the United States during the six years ending with 1925 (116 tons) and is nearly as large as the average shipments from Peru (477 tons) in the same period.
>
> The percentage of the vanadium is small, and it is mixed with an element—phosphorus—from which separation is difficult, and so far as is known the problem of separating small quantities of vanadium from large quantities of phosphorus has not before been attacked.
>
> The fact that the vanadium is all held in solution during the treatment of the phosphate will probably make the separation easier, and the separation of phosphorus from vanadium is now made on a commercial scale, so that phosphorus carried into the vanadium concentrates could be removed.
>
> Should bodies of rock carrying 0.42 to 0.52 per cent V_2O_5 like those described from Montpelier Canyon be worked, giving a solution carrying one and one-half times the lower quantity, or 0.63 per cent V_2O_5, practically twice that at present carried, the problem would be still more attractive.
>
> The fact that vanadium in ferrovanadium is now worth about \$3 per pound and at its lowest has averaged at least \$2 per pound allows a considerable amount of work and expense in its isolation and makes the problem of separation sound very engaging, and it does not seem impossible of solution.

The green color of the acid solutions derived from phosphate rock, which was ascribed in earlier suggestions to chromium, may be more largely due to vanadium, for in those samples in which tests have been made for both substances a larger percentage of vanadium is present.

Arsenic.—Arsenic, like vanadium, is chemically related to phosphorus, but tests on the sample from Driggs and on the composite sample described in the previous paragraph did not reveal the presence of any arsenic. A little was found in the phosphoric acid produced in the manufacture of acid phosphate from Paris rock. (See p. 299.)

Fluorine.—In every detailed analysis of phosphate rock and in every sample tested for it fluorine has been found. The amounts as determined in the laboratory of the Geological Survey range from 0.03 to 0.93 per cent. Conflicting reports from fertilizer manufacturers indicate that some of the rock

[10] Hillebrand, W. F., Discussion of paper by the author on the phosphate resources of the United States: Second Pan-American Sci. Cong. Proc., vol. 8, p. 770, 1917.

may contain even higher percentages of fluorine. The fluorine occurs chiefly as a constituent of the phosphatic minerals, of which the rock is composed, but locally it is present in the form of the mineral fluorite, which makes coatings, seams, or stains in the rock readily detected with the naked eye. The highly corrosive nature of hydrofluoric acid, which is derived from fluorides upon treatment with sulphuric acid, may prove to be worthy of consideration in the development of methods for treating the western phosphate rock.

MINERAL COMPOSITION

The mineral composition of the western rock phosphate is not yet completely ascertained, and the problem is difficult of solution, owing to the mode of occurrence of the constituent minerals. Thin sections of the richest oolitic ore show under the microscope that the rock consists mainly of ovules or concretions of a cryptocrystalline substance, which in some concretions is surrounded by banded zones of crystalline fibers with local isotropic bands, all of which have the same average index of refraction (about 1.60) and apparently represent the phosphatic substance. In some places the interstices are filled with calcite and in others with an isotropic material which appears to be identical with the substance that forms the cores of the concretions. The extinction of the double-refracting mineral is parallel to the elongation of the fibers, but the optical character of this mineral can not be determined because of the absence of cleavage or crystal faces. The isotropic substance probably represents collophanite, $x\,[Ca_3(PO_4)_2]$ or $x\,[(CaF_2)Ca_8(PO_4)_6]+y CaCO_3+z H_2O$, and the double-refracting substance is possibly quercyite. Quercyite comprises a variable mixture of the series of lime-phosphate minerals, including collophanite, from the French phosphorites, described by Lacroix.[11] The ovules include minute curly, hairlike, and branching plant fragments.

The mineralogy of the phosphate is further considered in Chapter VIII.

ENRICHMENT BY WEATHERING

A tendency toward enrichment of the content of phosphoric acid is shown in the weathered outcrops of the rock phosphate beds. As this would naturally be expected from the chemical and mineral composition of this material, no extensive examination has been undertaken to verify this conclusion. In 1909 an average sample from a partly weathered face in the open-cut quarry on the Waterloo claim at Montpelier was tested and showed 38 per cent of phosphorus pentoxide, equivalent to 83.2 per cent of tricalcium phosphate; another average sample of the same bed, taken from a fresher face about 50 feet in the lower entry of the mine, gave 34.8 per cent of phosphorus pentoxide, equivalent to 76.2 per cent of tricalcium phosphate; and still another near the north end of the lower entry showed 33.7 per cent of phosphorus pentoxide, equivalent to 73.8 per cent of tricalcium phosphate. In 1920 the writer collected an average sample from the south face of the drift at the east end of tunnel No. 1 of the same property, which yielded 30.68 per cent of phosphorus pentoxide, equivalent to 66.96 per cent of tricalcium phosphate. This sample, which from rough field measurements was obtained 350 feet horizontally in from the hillside, 420 feet vertically below the outcrop, and 850 feet down the dip from the outcrop, represents a part of the main bed that is more remote from the direct activity of the agencies of weathering than any part of the bed previously sampled by the Geological Survey.

The data just given show a progressive decrease in content of phosphate from the surface downward or inward. How far this decrease may continue can only be conjectured. The mine is dry and hence may be considered to lie in the zone of weathering, but at such distances from the surface it would seem that the effects of weathering must be greatly reduced and that the rock itself must be very nearly in an unaltered condition. At the property of the Anaconda Copper Mining Co., in Warm Springs Canyon near Garrison, Mont., the mine is wet and may be considered to lie below the zone of weathering, though it is not so far from the surface as is the Waterloo mine. At the Warm Springs locality, however, the better material is said to contain from 30 to 32 per cent of phosphorus pentoxide, equivalent to 65 to 70 per cent of tricalcium phosphate. The rock thus far shipped from the Waterloo mine and from the corresponding thicker workable beds in other parts of the field usually maintains an average content of 32 per cent or more of phosphorus pentoxide, equivalent to 70 per cent or more of tricalcium phosphate.

Positive information about the character of these deposits at greater depth is needed, as all the data collected at present have come practically from the outcrop and only theoretical foundation exists for statements concerning the character of the greater volume of the rock included in the tonnage estimates.

The value of the phosphate deposits still in public ownership is greatly enhanced if only the outcrop of these deposits is at present of commercial value, and it is therefore highly desirable that a study of the quality of these deposits under cover should be conducted by systematic drilling prior to their disposal and development.

DETERMINATION OF PHOSPHORUS PENTOXIDE

In the laboratory of the United States Geological Survey the determinations of phosphorus pentoxide (P_2O_5) were made according to improved methods developed by John G. Fairchild,[12] who also performed many of the analyses.

[11] Lacroix, A., Sur la constitution minéralogique des phosphorites français: Compt. Rend., vol. 150, p. 1213, 1910; Minéralogie de la France, vol. 4, pt. 2, p. 555, 1910.

[12] Fairchild, J. G., The accurate volumetric determination of phosphoric acid in phosphate rock: Jour. Ind. and Eng. Chemistry, vol. 4, pp. 520-522, 1912.

SIMPLE TESTS FOR PHOSPHATES

For the benefit of those who may wish to test rocks believed to contain phosphates and who may not have access to textbooks on the subject, the following simple tests, outlined by W. B. Hicks,[13] are presented:

For field use probably the simplest and most satisfactory method of detecting phosphates in phosphate rock is to moisten the fresh rock surface with a drop of nitric acid (specific gravity 1.2) and then to place a small crystal of ammonium molybdate on the moist spot. In the presence of appreciable amounts of phosphates a yellow color, due to the formation of ammonium phosphomolybdate, will gradually spread through the crystal and over the rock surface. This test is rather sensitive and will reveal phosphates in much smaller than commercial quantities.

When the proper equipment is at hand, however, the test may be carried out more satisfactorily and made even more delicate by placing a very small quantity of the powdered rock in a test tube, adding a few drops of nitric acid (specific gravity 1.2), warming gently over the flame, diluting with a little water, and adding an excess of ammonium molybdate solution. In the presence of even very small quantities of phosphates a yellow precipitate of ammonium phosphomolybdate will form on standing in the cold and more quickly on heating.

A rough estimate of the quantity of phosphate in the rock may be made by comparing the yellow precipitate with that produced by rock samples of known composition under similar treatment. The comparison should be made with rock samples known to contain 5, 10, 15, 20, 30, and 40 per cent of phosphoric acid (P_2O_5). Exactly the same quantity of powdered rock should be taken, the same amount of reagents should be added, and the volume of the solution should be kept constant. In other words, uniform conditions must be maintained throughout the tests.

The ammonium molybdate solution for the tests is prepared by dissolving 75 grams of ammonium molybdate in 500 cubic centimeters of water and slowly pouring this solution into 500 cubic centimeters of nitric acid (specific gravity 1.2), with constant stirring. White molybdic oxide will form at first and will then redissolve. After standing and being filtered the solution is ready for use.

QUANTITY

Although, as above intimated, the character of the phosphate beds at depth is unknown, these beds have been observed in many parts of the region and under many conditions by a number of geologists and everywhere appear to be true bedded deposits analogous to coal and retain their thickness and quality over wide areas. For these reasons they are regarded as original sedimentary deposits, and probably they maintain at depth the characteristics displayed at the surface. Upon this assumption rest the estimates for the western field. The estimates for Idaho alone are nearly 5,000,000,000 long tons. If this figure were divided by 2 or by 4, to allow for any supposed depreciation in quality with increased depth, the quantity remaining would still be large.

[13] Hicks, W. B., Simple tests for phosphates: U. S. Geol. Survey Mineral Resources, 1915, pt. 2, pp. 242-243. 1916.

ACCESSIBILITY

The southern part of the region is accessible from the Oregon Short Line with truck hauls of 3 to 10 miles. Spur tracks have already been constructed from Paris to the property of the Western Phosphate Co. in Paris Canyon and from Soda Springs to the property of the Anaconda Copper Mining Co. in sec. 15, T. 8 S., R. 42 E., distances of about 3 and 6½ miles, respectively. Other spur-track construction is under consideration. The bulk of the Idaho phosphate is more or less remote from present rail facilities, but there are favorable grades for the construction of branch lines and spur tracks by which the phosphates may ultimately be brought to market.

ADAPTABILITY OF WESTERN ROCK

The western phosphate rock contains a high percentage of tricalcium phosphate and is remarkably low in its content of iron oxide and alumina. The rock possesses the further advantage that it may be shipped directly from the mine and ground and treated with acid without the preliminary washing and drying processes which add so much to the cost of production of the eastern phosphates. Some of the companies, however, dry their rock before shipping. On the other hand, the character and mode of occurrence of the rock is such that it can not be mined, except locally, by open-pit methods. Drifts, tunnels, and shafts, with more or less expensive timbering, are necessary for its successful exploitation.

WESTERN PHOSPHATE RESERVE

The phosphate lands of the Idaho field, which comprises a large share of the western phosphate reserve, are shown in Plate 42.

STATUS OF WESTERN PHOSPHATE LANDS

In Utah, Idaho, Wyoming, and Montana the great bulk of the phosphate rock is on public land, though some has passed into private ownership. The public lands are withdrawn from entry pending their examination and classification. No estimates of the acreage of phosphate land in private ownership are available, but the acreage of the outstanding withdrawals of public land in the States named is shown in Table 38.

TABLE 38.—*Outstanding phosphate withdrawals, July 31, 1927*

	Acres
Utah	301, 945
Idaho	396, 612
Wyoming	996, 539
Montana	279, 944
Total	1, 966, 390

In addition to the land embraced in the outstanding phosphate withdrawals, 268,299 acres in Idaho, 25,293 acres in Wyoming, 3,833 acres in Montana, and 160 acres in Utah—297,585 acres in all—have been examined in detail and formally classified as phosphate land. The total classified and withdrawn lands thus amount to 2,263,975 acres. The classified lands include 4,080 acres in the Fort Hall Indian Reservation, Idaho, and 20,576 acres in the Wind River Indian Reservation, Wyo. The figure just given for total classified and withdrawn lands does not include phosphates of Mississippian age, except those of the Laketown district, Utah, or the deposits privately owned. Not all this territory contains high-grade rock, but the estimates on page 292, which are conservative and incomplete, show that a vast tonnage of high-grade rock may be expected.

Under the act of July 17, 1914, agricultural entries may be made upon withdrawn phosphate lands, but the mineral rights are reserved to the United States. The lands thus far classified in the region here discussed are shown in Plate 42.

CLASSIFICATION OF PHOSPHATE LANDS[14]

Laws relating to the disposal of public lands require some grouping of the lands according to their character prior to their disposition. The duty of classifying the public lands was laid upon the Geological Survey by the organic act of its establishment in 1879. The conservation branch of the Geological Survey now has charge of this work. Regulations have been adopted for gathering and assembling data and for making a classification of various kinds of lands.

The principal factors involved in phosphate classification are (1) the quality of the rock, (2) the thickness of the bed, and (3) the depth of the bed below the surface. In present practice:[16]

Lands underlain by beds of phosphates less than 1 foot in thickness or containing less than 30 per cent tricalcium phosphate or lying at a depth greater than 5,000 feet below the surface shall be considered nonphosphate lands, except as hereinafter provided.

A. Lands underlain by beds of phosphate 6 feet or more in thickness and containing 70 per cent or more of calculated tricalcium phosphate shall be considered phosphate lands if the beds do not lie more than 5,000 feet below the surface. The depth limit for beds containing 70 per cent of calculated tricalcium phosphate shall vary from 0 to 5,000 feet in direct ratio to the variation of thickness of bed from 1 foot to 6 feet. For beds containing less than 70 per cent tricalcium phosphate the depth limit shall vary from 0 to the depth of a 70 per cent bed of any given thickness in direct ratio to the variation in tricalcium phosphate content from 30 to 70 per cent. * * *

D. Where the phosphate bed occurs at or near the surface so that the deposits may be readily mined by open-cut or stripping methods, the minimum thickness of a phosphate bed containing 70 per cent or more of tricalcium phosphate shall be 3 inches. For beds containing less than 70 per cent tricalcium phosphate the minimum thickness shall increase to 1 foot as the percentage of tricalcium phosphate decreases from 70 to 30 per cent.

The classification of the phosphate lands has in general been made in accordance with the above provisions. As the phosphate beds in the western fields are commonly inclined and lie at different depths below the surface the computations involved in paragraph A have been reduced to graphic form as shown in Figure 26, so that the depths at which a given phosphate bed may be held for classification may be readily determined.

In applying the above regulations the conservation branch of the Geological Survey has attempted to adapt them to the practical needs of the individual area. Therefore, if its decisions have not always been consistent with the literal interpretation of the regulations the departures are thought to be on the side of the public interest.

The first withdrawals in the western field were based on the best information available at that time, the maps of the Hayden surveys. Considerable changes proved necessary when investigation of the lands was undertaken. The present withdrawals are based on later geologic work and, with some qualifications probably correspond fairly well with the areas that will be considered as workable phosphate land under existing procedure.

PHOSPHATE LEASES AND USE PERMITS

Under the act of Congress which provides for the leasing and use of phosphate lands the Department of the Interior has drawn up regulations,[17] including a sample lease, which embody the provisions of the law and are given below for reference.

Department of the Interior,
General Land Office,
Washington, May 22, 1920.

Registers and Receivers, United States Land Offices.

Sirs: Sections 9 to 12, inclusive, of the act of Congress approved February 25, 1920 (Public, No. 146), entitled "An act to promote the mining of coal, phosphate, oil, oil shale, gas, and sodium on the public domain," authorize the Secretary of the Interior to lease lands belonging to the United States containing deposits of phosphates, and accordingly the following rules and regulations are prescribed for the administration of the provisions of said sections of the act:

1. *Lands to which applicable.*—The act applies to the lands belonging to the United States containing deposits of phosphates, including lands in national forests and including the phosphate deposits reserved under laws authorizing entries and patents with reservation to the United States of such deposits; also to phosphate lands in ceded or restored Indian reservations the proceeds from the disposition of which are the property of the United States. The act is not applicable to lands in the Appalachian Forest Reserve (under act of March 1, 1911, 36 Stat. 961), lands in national parks, lands withdrawn for military or naval purposes, or lands in ceded or restored Indian reservations the proceeds from the disposition of which belong to the Indians.

All leases of phosphate deposits within the limits of national forests or other reservations or withdrawals to which the act is applicable shall be subject to and contain such conditions, stipulations, and reservations as the Secretary of the Interior shall deem necessary for the protection of the forests, reservations, or withdrawals, and the uses and purposes for which created.

[14] Smith, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull 537, 1913.

[16] Idem, pp. 130-131

[17] Dept. Interior General Land Office Circ. 696, 1920.

2. *Leasing area.*—Leases may embrace not exceeding 2,560 acres of lands or deposits, in compact form, the length of which shall not exceed two and one-half times its width. If surveyed, the lands must be taken by legal subdivisions of such survey; and if unsurveyed, to be surveyed by the Government at the expense of the applicant prior to the issuance of lease. Such surveys will be made under the regulations governing public land surveys, prior to the execution of which applicants will be required to deposit with the United States surveyor general the estimated expense thereof.

3. *Qualifications of applicants.*—Leases may be issued to (*a*) citizens of the United States, (*b*) associations of citizens, and (*c*) to corporations organized under the laws of the United States or any State or Territory thereof.

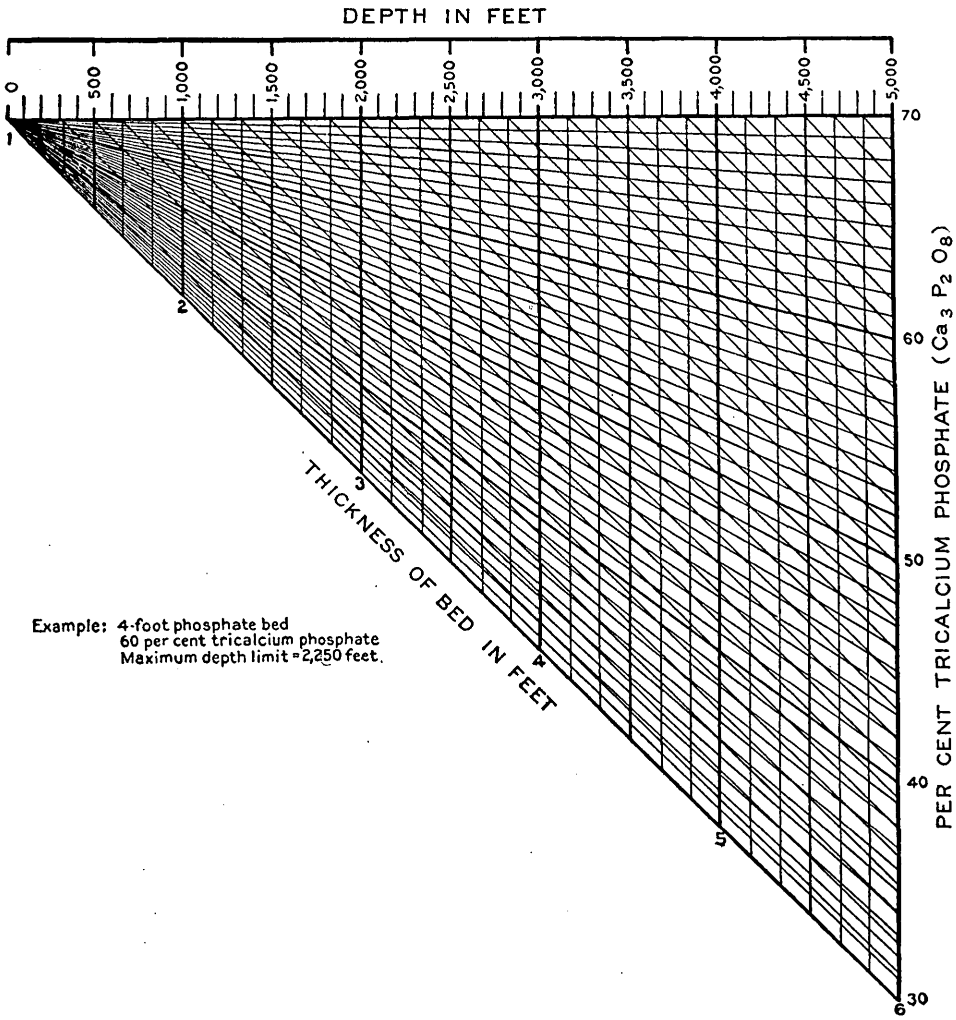


FIGURE 26.—Diagram illustrating the graphic method for determining the depth at which phosphate may be reserved in public lands. (From U. S. Geol. Survey Bull. 537, 1913)

4. *Minimum development.*—An actual bona fide expenditure for mine operations, development or improvement purposes of the amount determined by the Secretary of the Interior will be a condition in each lease as the minimum basis on which each lease will be granted, with the requirement that not less than one-third of such proposed investment shall be expended in development of the mine during the first year, and a like amount each year for the two succeeding years, the investment during any one year over such proportionate amount for that year to be credited on the expenditure required for the ensuing year or years. A bond executed by the lessee with approved corporate surety will be required to be furnished in the sum of $10,000, conditioned upon the expenditure of the specified amount of investment. After said investment has been made a similar bond in the sum of $5,000, conditioned upon compliance with the terms of the lease will be required

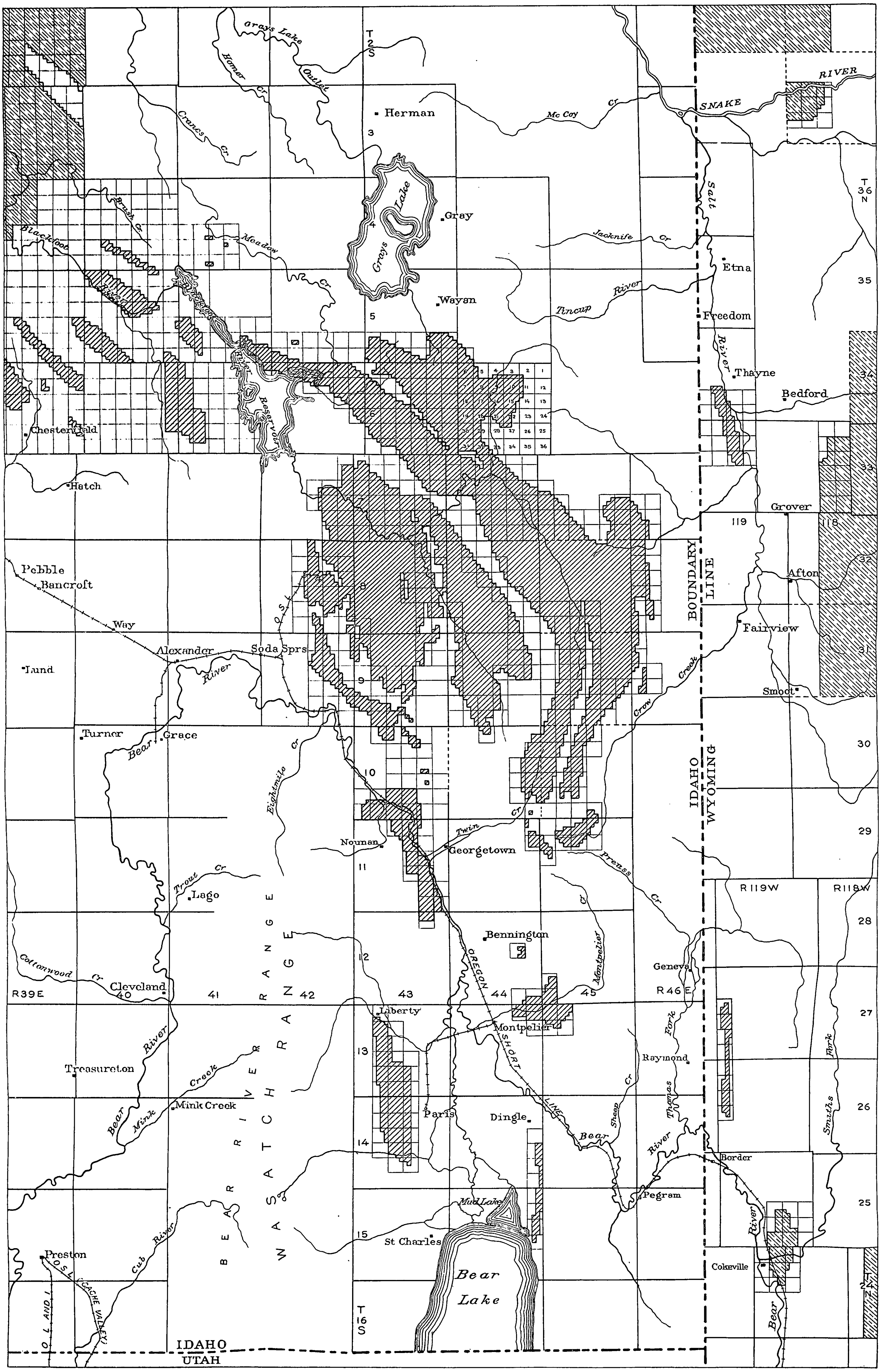
5. *Minimum production.*—Under the provision of the act requiring leases to be for indeterminate periods upon condition of a minimum annual production after the first three years, except where interrupted by strikes, the elements or casualties not attributable to the lessee, each lease will contain appropriate conditions fixing such minimum production of phosphates or phosphate rock from the land.

6. *Application for lease.*—Application for a lease must be under oath and filed in the proper district land office, addressed to the Commissioner of the General Land Office. No specific form is required and no blanks will be furnished but the application should cover the following points:

(*a*) Applicant's name and address.

(*b*) Citizenship of applicant, whether native born or naturalized; and if naturalized, furnish a certificate thereof in the form provided for use in public land matters, if one is not already on file in the Land Department; if an association, citizenship of each member must be shown; if a corporation, furnish a certified copy of its articles of incorporation and a showing as to the residence and citizenship of its stockholders.

(*c*) A statement that the applicant holds no lease of phosphate lands under said act within the State in which the land is situated; nor, as a member of an association or stockholder in a corporation, holds any interest or interests in any lease or leases of phosphate lands under said act, which, together with the lands applied for, exceed in the aggregate 2,560 acres.



MAP SHOWING THE CLASSIFIED PORTION OF THE IDAHO PHOSPHATE RESERVE, APRIL, 1925

Broken-line pattern indicates areas withdrawn but not yet classified (*d*) Description of the land, whether vacant or unclaimed; if surveyed, by legal subdivisions; if unsurveyed, by metes and bounds, and where possible by the approximate subdivisions the land will be when surveyed. If the land is unsurveyed, a survey thereof at the expense of the applicant must be provided for prior to the execution of a lease thereof, as provided in section 10 of the act.

(*e*) Description of the phosphate deposits in the land, giving nature and extent thereof; the proposed method of mining and reduction of same; and proposed investment in mining operations thereon and reduction facilities therefor if a lease be granted the applicant.

7. *Action by local office.*—Registers and receivers will assign current serial numbers to such applications when filed, promptly note their records, and require a notice of the application to be published at the expense of the applicant for a period of 30 days in a newspaper of general circulation in the county in which the deposits are situated, advising all adverse claimants or protestants that if they desire to object, or protect any interest as against the applicant, prompt action to that end should be taken, and upon proof of such publication, transmit the applications to the General Land Office with report of record status of the land described therein.

After receipt of such an application, no filing for any of the land described therein will be accepted until so directed, unless the application be rejected.

8. *Action on application.*—Upon consideration of the application in the General Land Office, if the tracts of land or deposits are found subject to lease and the application is otherwise satisfactory, a lease substantially in the form herewith will be submitted to the applicant for his execution.

9. *Action by successful applicant.*—The successful applicant will be allowed 30 days after receipt of the lease for execution within which to (*a*) file in the district office the lease duly executed by him in triplicate and in the form herein prescribed; (*b*) file evidence of citizenship and qualifications as required by paragraph 6 hereof, if not theretofore filed by him; (*c*) file the bond required by paragraph 2 *b* of the lease, or United States bonds in lieu thereof under the act of February 24, 1919 (40 Stat. 1148); and (*d*) pay the annual rental for the first year of the lease.

10. *Action by local office.*—At the end of the 30 days allowed the successful applicant, or sooner if the foregoing be complied with by him, the local officers will forward by special letter all papers with full report of action taken.

11. *Form of lease.*—Leases hereunder will be in substantially the following form:

Land Office at----------
Serial No.--------------

The United States of America, Department of the Interior

MINING LEASE OF PHOSPHATE LANDS UNDER ACT OF FEBRUARY 25, 1920

This indenture of lease, entered into, in triplicate, this ------ day of ------, A. D. 19--, by and between the United States of America, acting in this behalf by ----------, Secretary of the Interior, party of the first part, hereinafter called the lessor, and ---------- of ---------, party of the second part, hereinafter called the lessee, under, pursuant, and subject to the terms and provisions of the act of Congress, approved February 25, 1920 (41 Stat. —), entitled "An act to promote the mining of coal, phosphate, oil, oil shale, gas, and sodium on the public domain," hereinafter called the "act."

WITNESSETH:

That the lessor, in consideration of the rents and royalties to be paid and the covenants to be observed as hereinafter set forth, does hereby grant and lease to the lessee the exclusive right and privilege to mine and dispose of all the phosphate and phosphate rock in, upon, or under the following described tracts of land, situated in the State of ----------, to wit: ---
----
containing ---------- acres, more or less, together with the right to construct all such works, buildings, plants, structures, and appliances as may be necessary and convenient for the mining and preparation of the phosphates for market, the manufacture of products thereof, the housing and welfare of employees, and, subject to the conditions herein provided, to use so much of the surface as may reasonably be required in the exercise of the rights and privileges granted.

SECTION 1. That the lessor expressly reserves:

(1a) The right to permit for joint or several use such easements or rights of way, including easements in tunnels upon, through, or in the land leased, occupied, or used as may be necessary or appropriate to the working of the same or other lands containing the deposits described in said act, and the treatment and shipment of the products thereof by or under authority of the Government, its lessees or permittees, and for other public purposes.

(1b) The right to lease, sell, or otherwise dispose of the surface of said lands or any part thereof under existing law or laws hereafter enacted, in so far as said surface is not necessary for the use of the lessee in the mining and removal of the phosphates therein, and to lease other mineral deposits in the lands, under the provisions of said act.

(1c) Full power and authority to carry out and enforce all the provisions of section 30 of said act to insure the sale of the production of said leased lands to the United States and to the public at reasonable prices, to prevent monopoly, and to safeguard the public welfare.

SEC. 2. The lessee in consideration of the lease of the rights and privileges aforesaid hereby covenants and agrees as follows:

(2a) To invest in actual mining operations, development or improvements upon the land leased, or for the benefit thereof, the sum of ---------- dollars, of which sum not less than one-third shall be so expended during the first year succeeding the execution of this instrument and a like sum each of the two succeeding years, unless sooner expended; and submit annually, at the expiration of each year for the said period, an itemized statement of the amount and character of said expenditure during such year.

(2b) To furnish a bond in the sum of $10,000,[17a] conditioned upon the expenditure of the amount specified herein (2a), and after said investment has been made, a similar bond in the sum of $5,000, conditioned upon compliance with the terms and provisions of this lease.

(2c) To pay as an annual rental for each acre or part thereof covered by this lease the sum of 25 cents per acre for the first year, payment of which amount is hereby acknowledged, the sum of 50 cents per acre per year for the second, third, fourth, and fifth years, and $1 per acre for the sixth and each succeeding year during the life of this lease, all such annual payments of rental to be made to the receiver of the United States land office of the district in which said land is situated, on the anniversary of the date hereof, and to be credited on the first royalties to become due hereunder during the year for which said rental was paid.

(2d) To pay to such receiver a royalty of ------ per cent (not less than two per cent) of the gross value of the output of phosphates or phosphate rock at the mine during the first 20 years succeeding the execution of this lease. (Special provisions suited to operations under the lease may be here inserted if found necessary.) Royalties shall be payable quarterly within 30 days from the expiration of the quarter in which the phosphates are mined.

(2e) To determine accurately the weight or quantity of all phosphates or phosphate rock mined from the leased premises, and to accurately enter the weight or quantity thereof in due form in books to be kept and preserved by the lessee for such purpose.

(2f) To furnish quarterly, within 30 days after the expiration of the quarter, a written report covering such quarter, certified under oath by the superintendent of the mine, or by such other agent having personal knowledge of the facts as may be designated by the lessee for such purpose, showing the amount of phosphates or phosphate rock mined during the quarter, the character and quality thereof, and amount of its products and by-products disposed of and price received therefor, and amount of phosphates or phosphate rock and its products in storage or held for sale.

(2g) Also to furnish in such manner and form as may be prescribed by the lessor, at the end of each year, beginning on the first anniversary of the date of the lease, and at such other times as the lessor may require, a plat showing all development work and improvements on the leased lands, and other related information, with a report under oath as to all buildings, structures, or other works placed in or upon said leased lands, accompanied by a report in detail as to the stockholders, investment, depreciation, and cost of operation, together with a statement as to the amount of phosphate or phosphate rock produced and sold, and the amount received therefor, by operations hereunder.

[17a] See modification on page 219.

(2h) To keep at the mine office clear, accurate, and detailed maps, on a scale not more than 200 feet to the inch, in the form of horizontal projections on tracing cloth, of the workings in each phosphate bed in each separate mine on the leased lands, a separate map to be made for each such bed, and for the surface immediately over the underground workings, and to be so arranged with reference to a public land corner that the maps can be readily superimposed.

Blue prints or reproductions in duplicate of the maps required as aforesaid shall be furnished the lessor when made, and supplemental prints or reproductions in duplicate furnished on or before the first day of each succeeding year, showing the extensions, additions, and changes since the last map or supplement was submitted. All mine progress maps kept by the lessee shall at all times be subject to examination by lessor.

(2i) That, beginning with the fourth year of the lease, except when such operation shall be interrupted by strikes, the elements, or casualties not attributable to the lessee, the lessee shall mine each year and pay a royalty thereon, not less than ———— tons of phosphate rock from the leased premises, unless operations are suspended as provided in section 11 of the act.

(2j) That the lessee shall not assign this lease or any interest therein, nor sublet any portion of the leased premises without the written consent of the lessor being first had and obtained.

Sec. 3. It is mutually understood and agreed that the lessor shall have the right to readjust and fix the royalties payable hereunder and other terms and conditions including amount of minimum annual production, at the end of 20 years from the date hereof, and thereafter at the end of each succeeding 20-year period during the continuance of this lease unless otherwise provided by law at the time of the expiration of any such period, but in case the lessee be dissatisfied with the rate of royalty or other terms and conditions so fixed, he may terminate this lease in the manner and under the conditions provided in sections 6b and 6c hereof.

Sec. 4. This lease is made subject to the following provisions, which the lessee accepts and covenants faithfully to perform and observe, unless the laws of the State where the leased land or deposits are situated otherwise provides, in which case such State laws control:

(4a) The lessee shall carry out and observe regulations prescribed by the Secretary of the Interior and in force at the date hereof relative to (1) reasonable diligence, skill, and care in the operation of said property in accordance with approved methods and practices, (2) the prevention of undue waste, and (3) the safety and welfare of miners.

(4b) And also shall pay all miners and other employees, both above and below ground, at least twice each month in lawful money of the United States, and shall permit such miners and other employees full and complete freedom of purchase, but with a view to increasing safety this provision shall not apply to the purchase of explosives, detonators, or fuses; and shall not require or permit miners or other employees, except in case of emergency, to work underground for more than eight hours in any one workday, and shall not employ any boy under the age of 16 years or any girl or woman without regard to age in any mine below the surface.

Sec. 5. And the lessee also expressly agrees that all mining and related operations shall be subject to the inspection of authorized representatives of the lessor, and that such representatives may at all times enter into and upon the leased lands and survey and examine same and all surface and underground improvements, works, machinery, equipment, and operations.

(5a) And also shall permit the lessor to examine all books and records pertaining to operations under this lease and to make copies of and extracts from any or all of same, if desired.

(5b) And also shall permit the lessor, or its lessees or transferees, with the approval of the lessor, to make and use upon or under the leased lands any workings necessary for freeing any other mine from water or gas, or extinguishing fires, causing as little damage or interference as possible to or with the mine or mining operations of the lessee hereunder: *Provided*, That any such use by a transferee or another lessee shall be conditioned upon the payment to the lessee hereunder of the amount of actual damages sustained thereby and adequate compensation for such use.

(5c) And also shall, at the termination of this lease, as the result of forfeiture thereof, pursuant to paragraph 6d, deliver up to the lessor the lands covered thereby, including all fixtures, machinery, improvements, and appurtenances, other than strictly personal property, situate on any of said lands, in good order and condition, so as to permit of immediate continued operation to the full extent and capacity of the leased premises.

Sec. 6. It is further mutually understood and agreed as follows:

(6a) That the lessor may in writing waive any breach of the covenants and conditions contained herein except such as are required by the act, but any such waiver shall extend only to the particular breach so waived and shall not limit the rights of the lessor with respect to any future breach; nor shall the waiver of a particular cause of forfeiture prevent cancellation of this lease for any other cause, or for the same cause occurring at another time.

(6b) The lessee may, on consent of the Secretary of the Interior first had and obtained, surrender and terminate this lease upon payment of all rents, royalties, and other debts due and payable to the lessor, and upon payment of all wages or moneys due and payable to the workmen employed by the lessee, and upon a satisfactory showing to the Secretary of the Interior that the public interest will not be impaired; and the lessee may with like consent surrender any legal subdivision of the area included within the lease; but in no case shall such termination be effective until the lessee shall have made provision for the preservation of any mines or productive works or permanent improvements on the lands covered hereby.

(6c) That on the termination of this lease, pursuant to the last preceding paragraph, the lessor, his agent, licensee, or lessee shall have the exclusive right, at the lessor's election, to purchase at any time within six months, at the appraised value thereof, all buildings, machinery, equipment, and tools, placed by the lessee in or on the land leased hereunder, save and except all underground timbering, and such other supports and structures as are necessary for the preservation of the mine, which shall be and remain a part of the realty without further consideration or compensation; that the purchase price to be paid for said buildings, machinery, equipment, and tools to be purchased as aforesaid, shall be fixed by appraisal of three disinterested and competent persons (one to be designated by each party hereto and the third by the two so designated), the valuation of the three or a majority of them to be conclusive; that pending such election to purchase within said period of six months none of said buildings or other property shall be removed from their normal position; that if such valuation be not requested, or the lessor shall affirmatively elect not to purchase within said period of six months, the lessee shall have the privilege of removing said buildings and other property, except said timbering and other supports and structures, as are necessary for the preservation of the mine, as aforesaid.

(6d) If the lessee shall fail to comply with the provisions of the act or make default in the performance or observance of any of the terms, covenants, and stipulations hereof, or in the general regulations promulgated and in force at date hereof, the lessor may institute appropriate proceedings in a court of competent jurisdiction for the forfeiture and cancellation of this lease as provided in section 31 of the act, but this provision shall not be construed as depriving the lessor of any legal or equitable remedy which the lessor might otherwise have.

Sec. 7. It is further covenanted and agreed that, should the lessee fail to take prompt and necessary steps to prevent loss or damage to the mine, property, or premises, or danger to the employees, the lessor may enter on the premises and take such measures as may be deemed necessary to prevent such loss or damage or to correct the dangerous or unsafe condition of the mine or works thereof, which shall be at the expense of the lessee.

Sec. 8. It is further covenanted and agreed that each obligation hereunder shall extend to and be binding upon, and every benefit hereof shall inure to, the heirs, executors, administrators, successors, or assigns of the respective part ic.

Sec. 9. It is also further agreed that no Member of or Delegate to Congress, or Resident Commissioner, after his election or appointment, or either before or after he has qualified, and during his continuance in office, and that no officer, agent or employee of the Department of the Interior, shall be admitted to any share or part in this lease, or derive any benefit that may arise therefrom, and the provisions of section 3741 of the Revised Statutes of the United States and sections 114, 115, and 116 of the Codification of the Penal Laws of the United States approved March 4, 1909 (35 Stat. 1109), relating to contracts enter into and form a part of this lease so far as the same may be applicable.

In witness whereof—

The United States of America,

By ------------------------------

Secretary of the Interior, Lessor.

Witnesses: ------------------------------

---------------- ------------------------------

---------------- *Lessee.*

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12. *Use permits for additional lands.*—Under section 12 of the act a lessee may be granted a right to use the surface of not exceeding 40 acres of unappropriated and unentered land as may be necessary for the proper prospecting for or development, extraction, treatment, or removal of the phosphate deposits in the leased lands.

Applications for permits for such additional tracts shall be filed in the district office having jurisdiction over the lands and should identify the lease by the serial number under which issued, and be filed under the same number. Such applications must be under oath and set forth the specific reasons why the additional tract is necessary to the lessee for the use named, describe the land desired by legal subdivision if surveyed, and if unsurveyed, by the approximate description it will be when surveyed, and also set forth the reasons why the land is desirable and adapted to the uses named, either in point of location, topography, or otherwise, and that it is unoccupied and unappropriated.

FORM OF USE PERMIT UNDER SECTION 12

Land Office at----------
Serial No--------------

The United States of America, Department of the Interior
Use permit under section 12, act of February 25, 1920

Know all men by these presents, that the Secretary of the Interior, under and by virtue of the act of Congress approved February 25, 1920, entitled "An act to promote the mining of coal, phosphate, oil, oil shale, gas, and sodium on the public domain," hereby grants to ----------, holder of lease bearing serial No. -----------, the exclusive right, so long as needed, used, and occupied during the life of the aforesaid lease, the use of the surface of the following described tract of land, to wit,

----

----

for the proper prospecting for or development, extraction, treatment, or removal of the phosphate deposits covered by the aforesaid lease, all rights hereunder to cease and terminate upon the termination of the aforesaid lease.

Dated this ---------- day of ----------, 19--.

Secretary of the Interior.

13. *Repealing and saving clause.*—Section 37 of the act provides that hereafter the deposits of coal, phosphate, sodium, oil, oil shale, and gas referred to and described in the act may be disposed of only in the manner provided by the act, "except as to valid claims existent at date of passage of this act, and thereafter maintained in compliance with the laws under which initiated, which claims may be perfected under said laws, including discovery." As to phosphate claims, those claims initiated under the preexisting law may go to patent which, at the date of the act, were valid mining locations, duly made and maintained as such on lands subject to such location at the date initiated.

14. *Fees and commissions.*—(*a*) For receiving and acting upon each application for lease filed in the district land office in accordance with these regulations, there shall be paid by the applicant a fee of $2 for every 160 acres or fraction thereof in the application, such fee in no case to be less than $10, the same to be considered as earned when paid, and to be credited in equal parts to the compensation of the register and receiver within the limitations provided by law.

(*b*) Registers and receivers shall be entitled to a commission of 1 per cent of all moneys received in each register's office, to be equally divided between the register and receiver. Such commission will not be collected from the applicant or lessee in addition to the moneys otherwise provided to be paid.

It should be understood that the commissions herein provided for will not affect the disposition of the proceeds arising from operations under the act, as provided in section 35 thereof; also that such commissions will be credited on compensation of registers and receivers only to the extent of the limitation provided by law for maximum compensation of such officers.

Very respectfully,

CLAY TALLMAN,
Commissioner.

Approved May 22, 1920.

JOHN BARTON PAYNE, *Secretary of the Interior.*

Since the promulgation of these regulations a change has been made regarding the filing of a bond as required in paragraph 2b of the lease. Under the date April 19, 1921, the Secretary of the Interior wrote to the Commissioner of the General Land Office as follows:

I have to advise you that in my opinion a $5,000 bond is sufficient in such cases. The existing regulations and lease form are accordingly hereby modified so as to require the filing of a bond in the sum of $5,000 to insure the development of the land and compliance with the terms and provisions of the lease.

PHOSPHATE ROYALTIES

No general regulations have been issued as to royalties to be required under the leasing law. Under the terms of that law the minimum stipulated royalty is 2 per cent of the gross value of the output at the mine. Under current procedure the General Land Office, in submitting a request to the United States Geological Survey for an opinion about the suitability of a given area for a leasing unit, requests also a recommendation regarding the amount of royalty to be charged. The Geological Survey has considered each area on its merits, taking into account the thickness and quality of the phosphate bed, its geologic structure, its relation to suitable means of transportation, and the character of existing improvements on the given tract or on neighboring tracts of land. In addition the Geological Survey has recognized that the western phosphate industry is in its infancy and that all possible aid should be rendered to those who seriously undertake to exploit the phosphate beds. It has therefore taken the position that at the outset, at least, the royalties should be low. Later, if conditions warrant, higher royalties may be charged, but such increase in royalties would not affect leases already granted until the expiration of the 20-year period allowed by law. The royalties thus far recommended have been 2, 2¼, and 2½ per cent, corresponding respectively to 8, 9, and 10 cents per ton upon an assumed gross value of $4 per ton for the output at the mine. These royalties are fairly comparable with the royalty of 2 per cent f. o. b. the nearest shipping point, which is charged by the State of Idaho for certain State lands in Bear Lake County.

GEOLOGIC FIELD WORK

The work of the geologic field parties in the phosphate districts was of three types—(1) detailed survey and study of the phosphate and closely related beds, including plane-table mapping of the outcrop, measurements, and stratigraphic sections of the beds where exposed, and sampling and prospecting the beds both by utilizing existing prospects and by digging new prospects, some of which were trenches that extended across the entire phosphatic shale member of the Phosphoria formation; (2) detailed surveys, without plane-table, of areas with stratigraphic horizons not closely identified with the phosphate beds, including areal, structural, stratigraphic, and physiographic studies; and (3) field reviews, including the checking and correlation of the work of different field parties and elucidation of doubtful areas.

METHOD OF SAMPLING

The method of sampling phosphate rock is much the same as that set forth in the regulations of the Bureau of Mines for coal, which requires, in brief, that the face to be sampled must be cleared of weathered material, powder stains, and other impurities and channeled across the bed to obtain the sample. Material from large partings and lumps of impurities, such as limestone concretions, are rejected. The sample is collected on a sampling cloth, broken to approximately half-inch pieces, thoroughly mixed and quartered, and the alternate quarters rejected. Mixing and quartering are repeated until the sample is reduced to duplicates, each weighing about half or three-quarters of a pound. These samples are carefully sacked and forwarded to the laboratory of the Geological Survey for analysis.

METHOD OF ESTIMATING TONNAGE

In the current practice in the classification of phosphate land by the Geological Survey a detailed geologic map of the given township is prepared and geologic structure sections are constructed and, if practicable, structure contours are drawn. Upon the basis of the information thus available the areas in which phosphate beds are believed to lie within the maximum depth limit determined in accordance with the regulations cited on page 215 are outlined on a large-scale plat of the township. The boundaries of these areas are drawn along legal subdivision lines to the nearest 40-acre tract. From the acreage thus obtained and the assumed thickness of the bed based on the best available measurements, on the basis of a weight of 180 pounds per cubic foot for the phosphate rock, as determined in the specific gravity tests, the tonnage of phosphate rock in tons of 2,240 pounds may be obtained by the following formula, where a equals acreage and t the thickness of the bed in feet.

$$\frac{a \times 43{,}560 \times t \times 180}{2{,}240} = \text{long tons of phosphate rock}$$

The result gives the tonnage where the beds are horizontal. In some of the computations additional allowance has been made for the dip, but in many areas there are compensating factors and the tonnage has been computed as if the beds were horizontal. This reduces the figure for tonnage, but the estimate is more conservative.

LOCAL DESCRIPTIONS

ARRANGEMENT

The areas examined in detail during the seasons 1909 to 1916, except 1913, which was devoted to the examination of the Fort Hall Indian Reservation,[18] are shown in the maps of the Cranes Flat, Henry, Lanes Creek, Freedom, Slug Creek, Crow Creek, and Montpelier quadrangles (pls. 2–9). Local descriptions are given in the following pages, together with estimates of area and tonnage based on the somewhat arbitrary assumptions explained above. The descriptions are given in township units, because all applications for leasing phosphate ground must describe the desired land in terms of its legal subdivisions, and the areas will be more readily identified in the following text if public-land subdivisions are employed. These subdivisions have also served as the basis for the classification of the land as phosphate or nonphosphate and for the estimates of its acreage and tonnage. The order of description of the townships will be from north to south in each range, beginning with the westernmost range. Previous descriptions and estimates of tonnage[19] have been given of a number of the townships described below. Additional field work, however, has been done in many of these townships, and the classification of the phosphate land has been revised to agree with this field work and with a more practical view of the application of the regulations regarding classification. Both the descriptions and the estimates of tonnage differ accordingly from those given earlier.

As a rule in these descriptions the details of the geographic, stratigraphic, and structural features named are omitted or greatly abbreviated, because these features are described under the same names in the chapters on geography, stratigraphy, igneous geology, and structure.

EXPLOITED PHOSPHATE DISTRICTS

Certain districts which have already been more or less exploited are known by geographic names. For convenience these districts are listed in Table 39, and reference is there made to the townships with which they are associated and to the portions of the text where these townships are described.

TABLE 39.—*Exploited phosphate districts*

District	Associated townships	Page reference
Soda Springs	8 and 9 S., R. 42 E.	234–239
Sulphur Canyon	9 S., Rs. 42 and 43 E.	238, 244
Swan Lake	9 S., R. 43 E.	244
Cavanaugh	10 S., R. 43 E.	248
Georgetown Canyon	10 and 11 S., Rs. 44 and 45 E.	261–266, 273–276
Bennington	12 S., R. 44 E.	266
Montpelier	12 and 13 S., Rs. 44 and 45 E.	266–268, 277–281
Paris	13 and 14 S., R. 43 E.	251
Bloomington	14 S., R. 43 E.	251
Hot Springs	14 and 15 S., Rs. 44 and 45 E.	268–270, 281–282
Thomas Fork	27 and 26 N., Rs. 119 and 120 W. (Wyoming).	287–291

[18] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, 1920.

[19] U. S. Geol. Survey Bull. 470, pp. 371–439, 1911, and Bull 577, p. 70, 1914.

T. 3 S., R. 40 E.

A strip somewhat more than 2 miles wide along the east side of this township is included in the Cranes Flat quadrangle (pl. 2). Practically all this land is underlain by the basalt of the Willow Creek lava field, but in the SE. ¼ SE. ¼ sec. 34 the lower slopes of the Blackfoot Mountains are developed upon rocks of the Wells formation. Conditions in the adjacent township to the southeast probably indicate that the extension of the Limerock fault passes beneath cover just to the northeast of these ledges of the Wells and that northeast of this fault rocks younger than the phosphate underlie the basalt. These considerations support the belief that phosphate rock may underlie much of the basalt-covered area at depths considered workable under current regulations of the Geological Survey, but its presence can be demonstrated only by drilling, and in view of the thick covering of basalt any attempt at its recovery would be expensive. The phosphate rock of this part of the township is therefore such a remote resource that no further consideration is here given it.

Recent geologic field work in the remainder of the township has shown that such phosphate rock as may be present there is too small in amount, too much broken, or too deep to have commercial value. The entire township has therefore been classified as nonphosphate and restored for entry.

T. 4 S., R. 40 E.

General features.—A strip of this township a little more than 2 miles wide is included in the southwestern part of the Cranes Flat quadrangle (pl. 2). Most of this strip is occupied by basalt of the Willow Creek and Blackfoot lava fields, but the Blackfoot Mountains project into the area from the west and the northwestern tip of Wilson Ridge enters it on the east. The township is 25 miles or more north of the railroad at Soda Springs and an equal or greater distance southeast of the railroad at Blackfoot, but fair roads connect the township with each of these shipping points. The greater portion of it is included in the adjacent Paradise Valley quadrangle.

Geology.—The geologic formations in the part included in the Cranes Flat quadrangle range from the Brazer limestone to the Thaynes group, but the Rex chert and Woodside shale are not exposed. Basalt and some Quaternary beds complete the sequence.

The northwest extension of the Snowdrift anticline is represented by the Brazer limestone in sections 14 and 23, and the Georgetown syncline may be present beneath the basalt of sections 23 and 26, for St. John has noted (p. 142) the occurrence of "Jurassic" rocks in fault relation with the Carboniferous near his Station XI, which is probably located in the SW. ¼ SW. ¼ sec. 28 in the adjoining township to the north. The Phosphoria and Thaynes in sections 34 and 35 probably represent the northward continuation of the Reservoir syncline, which is supposedly offset by a transverse fault beneath the basalt in the township to the south. The northwest extension of the Enoch Valley fault, which is offset in section 25, is believed to pass beneath cover through sections 25, 23, and 22 and to separate the Brazer limestone on the northeast from concealed possibly postphosphate rocks at the southwest. Such rocks are exposed in sections 15 and 16. The Reservoir syncline is faulted along its eastern limb in this township so that the Woodside and Rex are not exposed, and the Thaynes group is probably brought into contact with the phosphatic shale member of the Phosphoria formation or with lower beds of the Rex chert, as suggested in the geologic structure section drawn along the line D–D′ (pl. 11). The actual relations in the area studied are concealed by Quaternary beds.

Phosphate deposits.—Although phosphate beds may occur beneath the basalt in the Georgetown syncline here as in other townships farther southeast, they are exposed only in a narrow strip extending northwest into the Paradise Valley quadrangle in sections 22, 29, 33, 34, and 35. Prior to the visit of the survey party in 1916 they had not been prospected. In that year the survey party dug a trench which exposed a partial section of the phosphatic shales in the SE. ¼ SE. ¼ sec. 34. The trench was dug at right angles to the strike of the beds. It was 50 feet long and 2 feet wide and had an average depth of 2½ feet, the maximum depth being 3 feet 4 inches. The details of the section and the chemical determinations made from the samples collected are given in Table 40.

Stratigraphically above the section just given but 138 feet farther down the slope, corresponding to about 112 feet above the highest bed included in the section, lies a bed of hard phosphate 10 inches thick that forms a ledge. Sample 15, which was taken from this ledge, yielded 20.70 per cent phosphorus pentoxide, equivalent to 45.2 per cent tricalcium phosphate. The phosphatic shales at this locality appear from these data to be at least 145 feet thick.

The section described above is unusually rich in phosphate; it contains at least 31 feet 6 inches of phosphate rock, of which 24 feet 6 inches was sampled and found to average about 63 per cent tricalcium phosphate. One of the richest beds is a few feet above the middle of the trenched portion of the section. It is 1 foot 8 inches thick and averages 72.5 per cent tricalcium phosphate. Another bed just above is 5 feet 2 inches thick and averages 56.8 per cent tricalcium phosphate. The most valuable bed which lies near the base, is 5 feet 5 inches thick and averages 70.1 per cent tricalcium phosphate. Besides the beds mentioned there are five others that range from 13 inches to 3 feet 8 inches in thickness and from 61.8 to 67.1 per cent (average of samples 7 and 8) tricalcium phosphate.

TABLE 40.—*Partial section of phosphatic shales in the SE. ¼ SE. ¼ sec. 34, T. 4 S., R. 40 E.*

[Analyst, R. M. Kamm]

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
M-129-16	Clay, sandy, yellow, top not exposed.				
	Phosphate rock, black, finely oolitic, shattered			1	3
Sample 1	Phosphate rock, brownish gray, somewhat shaly, finely oolitic	28.66	62.7	2	
	Phosphate rock, thin bedded, shaly, finely oolitic; shatter zone			2	
Sample 2	Phosphate rock, medium oolitic, brownish gray, shaly	25.03	54.6	1	4
	Phosphate rock, brown shaly fragments; shatter zone			1	10
	Limestone, brown				2½
	Phosphate rock, brownish gray, shaly				3½
Sample 3	Phosphate rock, brownish gray, thin bedded, partly shaly, medium to finely oolitic (samples 3, 4, and 5, about 20 inches each).	29.82	65.1	5 (samples 3–5)	2 (samples 3–5)
Sample 4	do	25.45	57.9		
Sample 5	do	21.73	47.4		
Sample 6	Phosphate rock, beds 1½ inches thick, brownish gray, medium to finely oolitic.	33.22 (both beds)	72.5 (both beds)		5
	Phosphate rock, thin bedded, brownish gray, finely oolitic			1	3
	Shatter zone, mostly phosphate				8
Sample 7	Phosphate rock, brownish gray, beds ¼ to ½ inch thick, finely oolitic (samples 7 and 8, 22 inches each).	31.33	68.3	1	10
Sample 8	do	30.20	65.9	1	10
	Limestone, brown, weathered				4½
Sample 9	Phosphate rock, brownish gray, thin bedded, finely oolitic	28.28	61.9	1	4
	Limestone, dark brownish gray			2	
Sample 10	Phosphate rock, brownish gray, shaly, finely oolitic	28.33	61.8	2	
Sample 11	Phosphate rock, beds ¼ to 1 inch thick, dark gray, finely oolitic	30.03 (both beds)	65.5 (both beds)		6
	Phosphate rock, brecciated and shattered, weathered almost claylike				7
Sample 12	Phosphate rock, black with yellow specks, coarsely oolitic; beds ¼ to 1 inch thick (samples 12, 13, and 14, about 21 inches each).	32.92	71.8	5 (samples 12–14)	5 (samples 12–14)
Sample 13	do	33.34	72.7		
Sample 14	do	30.21	65.9		
	Phosphate rock, shaly, finely oolitic, and brown shale			1	
	Limestone, gray, top of Wells formation, not measured, strike N. 41° W., dip 62° S.				
				33	3½

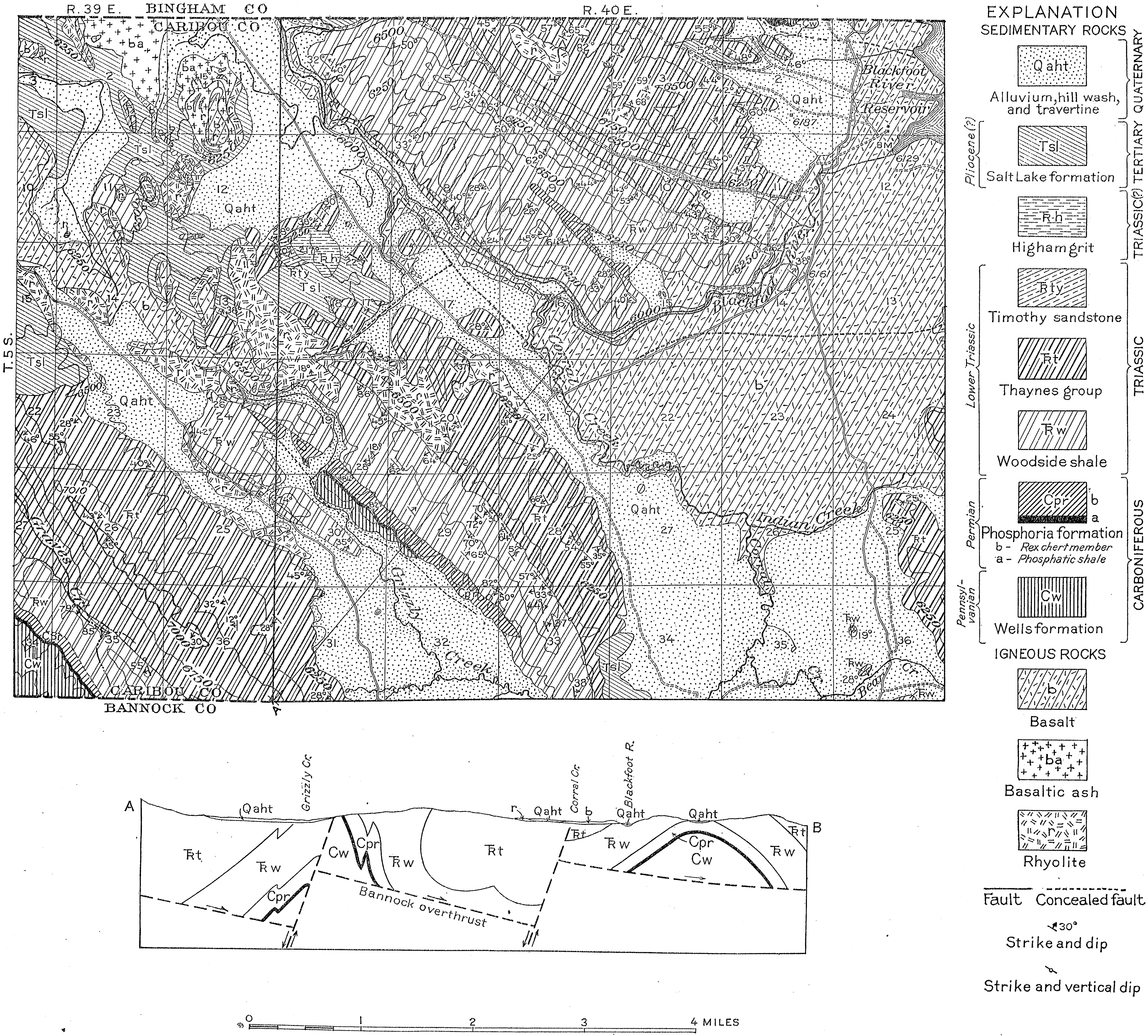
The shatter zones and the proximity of the fault already mentioned suggest that some of the phosphate beds may be repeated, but the lithologic details above given indicate sufficient differences to show that this is probably not the form of occurrence.

Ten of the samples taken from the trench above described were divided into four sets of composites and tested for iron and alumina. The first composite, including samples 3, 4, and 5, yielded 0.51 per cent Fe_2O_3 and 2.56 per cent Al_2O_3. As the combined amount of these two substances present was less than the limit usually allowed, the iron and alumina were not separately determined for the remaining composites but were grouped in a single determination for each. Thus the second composite, including samples 7 and 8, yielded only 1.96 per cent of iron and alumina together; the third composite, including samples 10 and 11, yielded 1.92 per cent; and the fourth composite, including samples 12, 13, and 14, yielded 1.19 per cent.

Estimate of tonnage.—Because of the heavy covering of basalt any phosphate that may be present in the Georgetown syncline is disregarded, and a partial estimate for this township would include only the area occupied by the phosphate beds described above and the overlying beds of the Thaynes group. The character and thickness of these phosphate beds justifies the assumption of a 6-foot bed that averages 70 per cent or more tricalcium phosphate, which fixes the depth limit for withdrawal at 5,000 feet, the maximum permitted under current regulations of the Geological Survey. On this basis 1,040 acres in this township have been classified as phosphate land (see pl. 42), but since the outline of this area must follow subdivisions of public land and thus includes much land that is not actually phosphate bearing, only 400 acres has been used in framing an estimate of tonnage. Such an area underlain by a horizontal 6-foot bed would contain about 1,050,000 long tons of phosphate rock. Allowance for the dip would increase this figure, but the presence of the fault introduces uncertainties that tend to offset any such allowance. The phosphate occurs in a small canyon half a mile to a mile from the Blackfoot or Soda Springs roads. The mapping of this township as a part of the Paradise Valley quadrangle was completed in 1925.

T. 5 S., R. 40 E.

General features.—This township lies mostly in the Portneuf quadrangle, but includes strips a mile or more wide in the Paradise Valley, Cranes Flat, and Henry quadrangles (pls. 2, 3). It has all been surveyed topographically and geologically, but only a strip a little more than 2 miles wide is included in the general region described in this report. It contains parts of the Blackfoot Mountains and of the Black-



GEOLOGIC MAP AND STRUCTURE SECTION OF T. 5 S., R. 40 E., AND PART OF T. 5 S., R. 39 E.

foot lava field, and of Blackfoot River, which leaves the reservoir of the same name in section 12 and makes a broad loop westward through the northern part of the township. Railroad facilities are 25 miles or more away, but fair roads connect the township with Soda Springs, Blackfoot, and Fort Hall, which are the chief available shipping points.

Geology.—The stratigraphic section includes parts of the Wells and overlying formations up to and including the Higham grit. (See pl. 43.) The Salt Lake and Quaternary formations are well represented, and there are patches and considerable areas of both rhyolite and basalt. The Phosphoria formation is exposed in three bands, the first of which projects into section 2 from the adjoining township. The other two extend northwestward respectively from the NW. ¼ sec. 15 and the NW. ¼ sec. 33. The Woodside shale and Thaynes group are thicker in this part of the region than they are in the Montpelier quadrangle and in some other places to the southeast. The Woodside, as measured in the T. 6 S., R. 41 E., is about 2,000 feet thick and the Thaynes more than 3,100 feet thick.

The township contains parts of six large folds. An anticline occupies parts of sections 1 and 2 in the Cranes Flat and Paradise Valley quadrangles. It is adjoined by a syncline, which occupies sections 1, 2, 11, and 12, and is probably the continuation of the Reservoir syncline (D–D′, pls. 2, 11). It consists mainly of beds of the Thaynes group, including some beds of the Portneuf limestone, but the east limb is faulted, so that the lower member of the Phosphoria is brought to the surface, which makes available the fine section described under T. 4 S., R. 40 E. The southeastern extension of this fold in sections 1, 2, and 12 is largely concealed by Quaternary sediments and basalt, but the Thaynes and Woodside beds in sections 24, 25, and 36 are parts of the Reservoir syncline. The Little Gray fault may offset this fold beneath cover. The lower part of it is probably cut off by the Bannock overthrust.

The third fold is an anticline, the axis of which extends northwestward from section 15. This fold is nearly symmetrical and upright, with beds of the Rex chert exposed at the crest. Travertine and basalt and mineralized springs in the general axial region in section 15 point to fractures and possibly dislocations which have not been otherwise recognized and which may be fully revealed only by underground exploration.

The fourth fold is a broad synclinorium which is occupied by beds of Woodside and Thaynes and which has its west limb overturned eastward. The east limb is probably broken by a normal fault with moderate throw that diminishes southeastward, because in the NW. ¼ NW. ¼ sec. 17 and adjoining territory beds of siliceous limestone that are assigned to the Portneuf limestone of the Thaynes group occur in too close proximity to the *Meekoceras* zone or base of the Thaynes, which is exposed on the hillsides east of Blackfoot River. In sections 7 and 18 this fold contains beds of Timothy sandstone and Higham grit, and in several places it is partly overspread with rhyolite and basalt. This part of the fold is offset westward about half a mile and lowered with respect to the southern part by a concealed fault along Nigger Creek.

The fifth fold is an anticline, the crest of which extends northwestward from section 33. Most probably this fold may once have had a fan form, but its crest is now broken by a supposedly normal fault that brings beds of the Woodside into contact with the Wells and Phosphoria formations. The phosphatic shales are exposed on a series of low knobs that lie along the northeast side of Grizzly Creek. Toward the northwest the crest of the anticline is overspread by rhyolite and basalt.

The sixth fold, which crosses the southwest corner of the township, is a syncline overturned eastward that contains mainly beds of the Thaynes group. A thrust fault of small throw is believed to cut out much of the lowest formation of the Thaynes, which forms a dip slope on the west flank of the ridge just outside the township.

The structural features above outlined are illustrated in structure section A–B, Plate 43, which is continuous with section D–D′, Plate 11.

Phosphate deposits.—Previous to the visit of the Survey party in 1916 no prospecting for phosphate had been done in this township. In that year the Survey party prospected and sampled the phosphatic shales on the crest of the knoll in the SE. ¼ NE. ¼ sec. 30. The Wells in prominent ledges forms the west edge of the crest and the west slope of the hill. The phosphatic shales occupy the sag and furnish an abundance of excellent float. The Rex forms the east part of the hill.

The overburden proved to be 2 feet or more thick, and then a much weathered biotite-hornblende andesite was encountered in a gently inclined dike, which cut out much of the phosphatic shales but left an eastward-pointing wedge of these rocks between the westward-dipping andesite and the nearly vertical beds of upper Wells. The phosphatic shales in this wedge had the structure of a syncline overturned eastward. This structure, however, is local, for the distribution of the shales as mapped shows that they form a steeply inclined stratum whose dips vary on either side of the vertical according to the relative position of the stratum measured with regard to the fan fold in which it appears to be involved.

Four trenches were dug. No. 1, at the base of the section, was 26½ feet long, 2½ feet wide, and 5½ feet deep (maximum depth); the strike was N. 53° E. No. 2, which was in line with No. 1 but 6 feet from it, was 8 feet long, 2½ feet wide, and 3¼ feet deep. No. 3 was offset 31 feet north of No. 2, but was so placed as to continue the phosphate section upward. It was 40 feet long, 2¼ feet wide, and 4½ feet deep (maximum depth); its strike was N. 46° E. No. 4 was offset about 100 feet N. 83° E. from No. 3. It was about 6 feet long, 2 feet wide, and 2 feet deep (maximum depth); it lay 165 feet N. 56° E. from the top of the Wells as exposed in No. 1. The lithologic details observed in the four trenches and the chemical determinations made from the samples collected in them are given in Table 41.

TABLE 41.—*Partial section of phosphatic shales exposed in four trenches in SE. ¼ NE. ¼ sec. 30, T. 5 S., R. 40 E.*

Trench No. 4

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
M-136-16	Limestone, brown, with phosphatic streaks, top not exposed			10
Sample 7	Phosphate rock, thin bedded, coarsely oolitic, with shaly streaks, brownish gray.			6
	Shale, phosphatic, brown, somewhat oolitic			6
	Phosphate rock, dense, siliceous, black; 1 bed	24. 95	54. 5	2
	Shale, phosphatic, brown			3½
	Phosphate rock, coarsely oolitic, gray to black, layers ¼ to 1½ inches thick			8
	Limestone, brownish gray with oolitic grains; 1 bed			3
	Shale, phosphatic, calcareous			8
	Limestone, brown, somewhat shaly, base not exposed			8

Trench No. 3

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
	Soil and overburden, not measured.	*Per cent*	*Per cent*	*Ft. in.*
	Limestone, brown, not well exposed, about			2 6
	Phosphate rock, much broken, mingled with soil, some pieces coarsely oolitic, black, about.			3
Sample 6	Phosphate rock, brownish gray, thin bedded, finely oolitic,	22. 27	48. 6	4
Sample 5	Partly shaly, some coarsely oolitic layers, local calcareous nodules; 2 samples, 2 feet each	18. 21	39. 3	
	Limestone, brown, weathering black, massively bedded			1 9
Sample 4	Phosphate rock, gray to black, thin bedded, finely oolitic; some shaly material that weathers reddish black or gray.	31. 40	68. 6	2 1
	Weathered zone with brownish soil; fragments of phosphate rock, shale, and brown limestone.			1 9
	Phosphate rock, thin bedded, dark gray, shaly streaks, finely oolitic			5
	Phosphate rock, thin bedded, finely oolitic, with shaly streaks and calcareous layers; much weathered and broken.			1 10
	Soil zone, brown, powdery, with pieces of phosphate rock and limestone			10
	Phosphate rock, grayish brown, thin bedded, finely oolitic, with calcareous beds.			9
	Limestone, brown, with phosphatic streaks, much broken			1 3
	Soil zone, brownish gray, powdery, with fragments of brown limestone and phosphatic shale.			2
	Phosphate rock, brownish gray, shaly, with nodules of limestone, finely oolitic, mingled with dirt, about.			1 9
	Limestone, brown, shaly, with streaks of phosphate rock, much broken			1 4
	Phosphate rock, brownish gray, shaly, finely oolitic, much broken			1 6
	Phosphate rock, very shaly, much broken, mingled with dirt and soil, apparently in syncline.			1 3
	Soil zone, brown			6
	Limestone, brown, impure			3
	Phosphate rock, brownish gray, shaly, finely oolitic, much broken			7
	Limestone, brown, shaly, thin calcite veins			6

Trench No. 2

	Only overburden and decomposed andesite exposed; no measurements.			

Trench No. 1

	Andesite, weathered into yellowish gravel, to depth of at least 2 feet below overburden.			
Sample 3	Phosphate rock, brownish gray, thin bedded, medium oolitic, much brecciated.			1
	Phosphate rock, dark gray, hard, dense, finely oolitic, single bed	32. 87	71. 7	4½
	Phosphate rock, brownish gray, thin bedded, medium oolitic			7½
Sample 2	Phosphate rock, brownish gray, coarse to medium oolitic, beds $\frac{1}{16}$ to 1½ inches thick, possibly in part equivalent to those below.	32. 53	71. 0	2
Sample 1	Phosphate rock, brownish gray, coarse to medium oolitic, beds ⅛ to 1½ inches thick, somewhat folded.	31. 33	70. 5	1 4
	Shatter zone, soil with fragments of limestone and phosphatic material			1 3
	Limestone, top of Wells formation.			

The distance across the outcrop of the phosphatic shales is about 170 feet. In spite of the generally steep dip, this distance is probably somewhat greater than the actual thickness of the shale member because of the disturbances above noted. In the trenches described a thickness of about 41 feet of beds was measured. Of this thickness 24 feet 7 inches was phosphate rock, some of it possibly duplicated and nearly half of it too broken or dirty for sampling. The 13½ feet sampled averaged about 60 per cent tricalcium phosphate. Near the base a bed 5 feet 4 inches thick, which possibly had some duplication, averaged 71.1 per cent tricalcium phosphate. From these data and from data obtained in the adjoining T. 6 S., R. 41 E., it seems safe to assume for purposes of computation a workable bed at least 5 feet thick and averaging 70 per cent or more tricalcium phosphate. The limit of workable depth for such a bed under current regulations is 4,000 feet.

The content of iron and alumina of the phosphate sampled appears to be within the prescribed limit. A composite of samples 2 and 3 yielded 1.48 per cent of iron and alumina together. A composite of the somewhat poorer samples 5 and 6 yielded 1.04 per cent Fe_2O_3 and 3.04 per cent Al_2O_3.

Estimate of tonnage.—On the basis of structure sections A–B and D–D′ a considerable part of the Reservoir syncline is omitted from consideration because the phosphate beds in it are supposedly too deep to be considered workable. Similarly the area between the fault along Blackfoot River and a line about 1,000 feet east of the boundary between the Rex and Woodside is also disregarded, but the area between that boundary and a line drawn about 3,000 feet west of the fault along Grizzly Creek is thought to contain phosphate within the limit of workable depth. Most of the area occupied by basalt is excluded from consideration, though it is probably underlain in part by phosphate within the 4,000-foot limit. In the southeastern part of the township the entire area occupied by beds of Woodside and Thaynes and some of the immediately adjacent covered areas are probably underlain by workable beds of phosphate.

From the considerations above outlined 6,760 acres in this township have been classified as phosphate land. Since the boundaries of this area, which have to follow subdivisions of public land, include more territory than that which actually contains phosphate, the area used in computing tonnage has been reduced to 4,570 acres. Such an area underlain by a horizontal 5-foot bed would contain approximately 79,983,000 long tons of phosphate rock. The dip, which ranges from about 27° to nearly vertical, would increase the area of the phosphate bed within the districts whose tonnage has been estimated and would therefore tend to increase the given figure. On the other hand, the area included in this township is believed to be part of the upper block of the Bannock overthrust. Any proposed increment from the allowance for the dip is therefore offset by the possibility that the Bannock overthrust may cut out some of the phosphate, so that it seems best to retain the given figure, which is probably conservative. The estimate includes only the "main bed" and does not take into consideration the large quantity of lower-grade material known to be present.

The phosphate beds are most accessible in the areas where the Phosphoria formation comes to the surface, particularly along the north side of Grizzly Creek and in the NW. ¼ NE. ¼ sec. 2. The location of the phosphate lands is shown in Plate 42.

T. 6 S., R. 40 E.

General features.—T. 6 S., R. 40 E., lies mostly in the Portneuf quadrangle, but overlaps the Henry quadrangle a little more than 2 miles. Most of the area is in the Chesterfield Range, but along the east side a portion of Reservoir Mountain is included. The lowland of Corral Creek, which lies between the two highland areas, forms part of the Blackfoot lava field. A number of poor roads traverse the township. These roads connect southwestward with Portneuf Valley, and thence with the Oregon Short Line Railroad at Bancroft, about 10 miles distant, or southeastward with the same railroad at Soda Springs, about 15 miles away.

Geology.—The formations range in age from Carboniferous to Quaternary, but many are missing or at least not exposed. The Wells and Brazer are present in the southwestern part. The Phosphoria is exposed in sections 12 and 13, but not elsewhere in the township. The Woodside is exposed in sections 1, 4, 6, 9, 12, and 13. The Thaynes crops out in sections 3, 4, 5, 6, and 9. The Salt Lake formation covers wide upland areas throughout much of the northeastern half of the township, but the lowlands are underlain by Quaternary sediments and some basalt.

The structure of the southwest half of T. 5 S., R. 40 E., if projected southeastward along the strike would continue into this township. The same structural features probably constitute much of the northeast half, but are concealed by the Salt Lake formation and Quaternary beds. An anticline with Wells and Brazer beds enters sections 7 and 18 and passes southeastward toward section 33. It is in large part concealed by beds of the Salt Lake formation.

In sections 12 and 13 the western part of the Wells ledge is brecciated and contains much chert and secondary quartz. The travertine to the north and south suggests faulting. The Rex chert, however, occupies the next knoll to the south of the Wells along its strike and indicates the presence of an anticline that pitches gently southward. It is inferred that the anticline is broken by a fault that brings in higher beds beneath cover to the west.

The Pelican fault, which offsets the folds in the adjoining township on the east probably enters this township in the NE. ¼ sec. 24 beneath cover and offsets the Phosphoria formation eastward as shown in the geologic map (pl. 3). The form and the relations of the faulted anticline to adjacent structures farther east are shown in the geologic structure section drawn along the line F–F′ (pl.11).

Phosphate deposits.—The phosphate in this township was not sampled by the survey party, and so far as known to the writer no prospecting for phosphate has yet been done here. In the NE. ¼ sec. 30 of the adjacent township to the east, however, the survey party prospected the phosphate beds in what is probably the southward continuation of the same anticlinal fold that is represented in sections 12 and 13 of this township. The data there gathered indicate that this township probably is underlain by a bed of workable phosphate at least 5 feet thick that contains 70 or more per cent tricalcium phosphate.

Estimate of tonnage.—The existing classified phosphate land in this township is 2,160 acres, as shown in Plate 42. For purposes of computation it seems best to consider only the area in sections 1, 12, 13, and 24, in which the phosphate probably lies within 4,000 feet of the surface. From the structure section F–F′ it appears that this area would occupy a strip about 0.7 mile wide, bounded on the west by the line between the Wells and Phosphoria formations as exposed or as extended beneath cover in the sections named. The part of this strip that lies within the borders of the township includes about 1,040 acres. To this area may be added 120 acres to allow for possible Rex and phosphatic shale beds west of the fault. This area which includes in all 1,160 acres, if underlain by a horizontal 5-foot phosphate bed would yield about 20,300,000 long tons of phosphate rock. By allowing an increase of 20 per cent on account of the dip, which ranges from 19° to 40° and in some places is overturned, the partial estimate for the tonnage of this township would amount to 24,360,000 long tons.

T. 3 S., R. 41 E.

T. 3 S., R. 41 E., which lies near the middle of the Cranes Flat quadrangle (pl. 2) is crossed diagonally southeastward by an upland that comprises parts of Sheep Mountain and of the Little Valley Hills. Northeast of the upland lies Homer Valley and southwest is Cranes Flat and the Willow Creek lava field. The rock formations include parts of the Thaynes group and of succeeding formations up to and including the Wayan formation, though some members of the series are missing.

The township is crossed diagonally along the upland by a complex group of faults, considered as members of the fault zone of the Bannock overthrust, which break the rocks into a series of more or less overlapping slices as illustrated in the geologic structure sections drawn along the lines B–B′ and C–C′ (pl. 11). Northeast of this zone the rocks are Cretaceous, and some of the rock slices themselves are of similar age. The other rock slices and the sedimentary rocks southwest of this zone are Jurassic and Triassic or even older, but they are largely concealed by alluvium and basalt.

The areas underlain by the Thaynes group, which if the rocks were horizontal might be supposed to contain phosphate beds at depths considered workable under current regulations of the Geological Survey, are here included in rock slices of complex structure and there seems little likelihood that they are underlain by workable phosphate.

The areas southwest of the upland now occupied by alluvium and basalt are quite possibly underlain by phosphate, but with the heavy cover of basalt and the uncertainties regarding structure there is much doubt if any of it can be recovered under ordinary commercial conditions. The probability that the area is underlain by a great thrust fault, which may cut out the phosphate rock, adds uncertainty to the problem. It is therefore considered inadvisable to hold any of the land of this township as phosphate land, and no attempt has been made to estimate the possible tonnage.

T. 4 S., R. 41 E.

General features.—T. 4 S., R. 41 E., is part of the Cranes Flat quadrangle (pl. 2). At the northeast it extends into the Little Valley Hills and at the southwest it includes much of Wilson Ridge, beyond which in the same direction lies the Blackfoot lava field. Between the two uplands, which have a northwesterly trend, lies a broad lowland occupied by parts of the Willow Creek lava field and of Cranes Flat. The township is 25 miles or more from the railroad, but roads connect it southward with Soda Springs or Bancroft and westward with Fort Hall or Blackfoot, which are shipping points on the Oregon Short Line Railroad.

Geology.—In Wilson Ridge the exposed sedimentary rocks are all Carboniferous and range from the Brazer limestone to the Phosphoria formation. In the Little Valley Hills the sedimentary rocks, so far as they are exposed in this township, range from the Thaynes group to the Wayan formation, but the Gannett group is absent. Quaternary beds, including an extensive travertine area in the southwest corner, are well represented. The Phosphoria formation is represented only by float of phosphate rock along parts of both foot slopes of Wilson Ridge and by the phosphate and accompanying beds exposed in the trenches dug by the Survey party. No material of the Rex or Woodside was seen in place. Beds of the upper Thaynes (Portneuf limestone) are exposed in a few areas in secs. 2 and 11. Rhyolite occupies parts of sections 24 and 25.

The part of the township occupied by the Little Valley Hills is a part of the Caribou synclinorium which is complexly folded and bordered on the west by the fault zone of the Bannock overthrust. The inferred structure here is indicated in the geologic structure section drawn along the line C–C′ (pl. 11). The area occupied by the Willow Creek lava field is in part at least the northern continuation of the Meadow Creek graben, and its structure, as indicated by conditions farther southeast, is synclinorial. Wilson Ridge, which is bounded by the Limerock and Enoch Valley faults, is a sharply folded anticline that probably represents the northward continuation of the Snowdrift anticline. It is partly broken by faults. The area covered by travertine and basalt in the southwest corner probably contains the continuation of the Georgetown syncline. The structural features just outlined are illustrated in the geologic structure section drawn along the line E–E′ (pl. 11).

Phosphate deposits.—No prospecting in the phosphatic shales of this township had been done prior to the work of the survey party in 1916. In that year the survey party dug two trenches—one in the SE. ¼ SE. ¼ sec. 20 and the other in the NE. ¼ SE. ¼ sec. 32. In each trench only that portion of the shales which included what was thought to be the main phosphate bed near the base was exposed. The trench in section 20 was 19½ feet long, 2½ feet wide, and 4 feet deep (maximum depth 5½ feet). The overburden at that place was about 1 foot 7 inches thick. At the locality in section 32 the trench was 11 feet long, 3 feet wide, and 11 feet deep (maximum depth). The overburden here was 4 feet 2 inches thick. The details of the two cuts with the chemical determinations made on the samples taken are given in Table 42.

TABLE 42.—*Partial section of the phosphatic shales at two localities in T. 4 S., R. 41 E.*

Locality 1, SE. ¼ SE. ¼ sec. 20

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
	Ledge of upper Wells, immediately west of trench; strike, N. 62° W., dip, 60° E.:	*Per cent*	*Per cent*	*Ft. in.*
M-54-16	Soil and overburden			1 7
Sample 1	Phosphate rock, horizontal, black, medium oolitic, upper bed ¾-inch thick, with underlying beds ⅛ to ¼ inch, largely decomposed.	31.95	69.8	1 10
	Clay, sandy, greenish gray to dark gray, somewhat phosphatic			2
Sample 2	Phosphate rock, earthy, fine grained, much decomposed	27.15	59.3	7
	Clay, yellow to drab, tough, sandy, with rounded to subangular pebbles of white to yellowish quartzite ½ to 1½ inches diameter, and of black chert ⅛ to 1½ inches diameter; pebbles increase in abundance downward; base not exposed.			1 4

Locality 2, NE. ¼ SE. ¼ sec. 32

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
	Ledge of upper Wells at top of hill wash:			
M-126-16	Soil and overburden, calcareous, with fragments of limestone and chert			4 2
Sample 1	Phosphate rock, shattered, gray, medium oolitic	33.22	72.5	8
	Clay, sandy, ferruginous lens			1
	Phosphate rock, shattered, medium oolitic			11
	Shatter zone, lenticular, sandy, clayey, and ferruginous material; fingers out southward.			8
Sample 2	Phosphate rock and some shale; bedding generally distinguishable but contorted.	24.91	54.4	2
Sample 3	Phosphate sand or disintegrated contorted phosphate rock and probably some shale; bedding generally indistinguishable but may be vertical.	31.01	67.7	2 7(?)
Sample 4	Selected harder pieces throughout trench	31.88	69.6	

The sections at both these localities show much disturbance. At locality 1 the discordance in dip between the Wells near by and the phosphatic shales indicates a probable subsidiary fault associated with the Limerock fault that marks the boundary of the graben. The presence of the pebbly clay is an unusual feature if it and the overlying phosphate beds are in place, as they seem to be. The clay may represent the basal member of the series here or some higher bed not elsewhere identified. The section shows a total of 2 feet 5 inches of phosphate with a clay parting 2 inches thick, and the average content for the phosphate beds is 67.3 per cent tricalcium phosphate, the average being weighted according to the thickness of the respective beds.

At locality 2 the phosphate rock is so shattered and contorted that its attitude is not clear, and some of it at least is not in place, for it fingers out into the overburden. The total thickness of the phosphate rock as measured is 6 feet 3 inches, but doubt about the attitude of the beds makes this figure of little value. The weighted average for samples 1 to 3 is 64.7 per cent tricalcium phosphate, which is somewhat lower than the figure obtained by using hand-picked material. (Sample 4.)

In spite of the poor showing at these two openings, a bed of phosphate comparable in thickness and quality to that observed in neighboring townships should perhaps be found in this township at localities where the beds have not been exposed to such disturbing and disintegrating influences. Unfortunately these areas are all underlain by basalt of unknown thickness. The structure is complex. Without systematic drilling little can be told of the distribution and quality of this hidden phosphate, and the probable presence of the Bannock overthrust beneath the township would tend to discourage expensive exploration by introducing the possibility that the phosphate may be cut out by this fault at greater or less depths.

Although 200 acres, distributed in three areas, as shown in Plate 42 are classified as phosphate land because of the actual showing of phosphate rock, commercial development of the possible phosphate resources of this township seems remote. No estimate of its possible tonnage is attempted.

T. 5 S., R. 41 E.

General features.—This township lies mostly in the Henry quadrangle, but includes a strip about 1½ miles wide in the southern part of the Cranes Flat quadrangle (pls. 2 and 3). Wilson Ridge projects into the northeastern part of the township and Pelican Ridge into the eastern and southeastern parts. The northern extension of Reservoir Mountain occupies the southwestern part. The rest of the township, which comprises nearly two-thirds of its area, lies in the Blackfoot lava field, which is surmounted in section 14 by a former volcano, called Crater Mountain, and is partly flooded by the Blackfoot River Reservoir. The township is 20 miles or more from the railroad, but is connected by fairly good roads with Soda Springs, Fort Hall, and Blackfoot, shipping points on the Oregon Short Line Railroad.

Geology.—The stratigraphic section includes beds that range in age from the Brazer limestone to the Thaynes group, besides Quaternary sediments and basalt. The Phosphoria formation is exposed only in sections 19, 20, 29, and 30. The post-Phosphoria beds are exposed chiefly in the southwestern and southeastern parts of the township, but the Woodside enters section 12 from the southeast.

Wilson and Pelican Ridges have generally anticlinal structure and form parts of the Snowdrift anticline that are offset from each other by the Little Gray fault. The western extension of Pelican Ridge contains part of the Georgetown syncline, which is broken by normal faults. An anticline concealed largely by basalt probably lies west of this syncline and is more or less broken by faulting. The Wells ledges in sections 19, 20, and 29 are believed to represent the northern extension of this anticline. The Reservoir syncline lies immediately west of this fold. The faults in this part of the township are described on page 164. The structure of Wilson and Pelican Ridges and of Reservoir Mountain is illustrated in the geologic structure sections drawn along the lines E–E′, F–F′, and G–G′ (pl. 11).

Phosphate deposits.—In 1916 the survey party trenched and sampled the phosphatic shales in sections 19, 20, and 29, which had not hitherto been prospected. They dug three trenches, in the SE. ¼ SE. ¼ sec. 19, near the north end of the exposed belt of phosphatic shales. The first of these trenches, which was near the Wells ledges, was abandoned because of the thickness of the overburden, which proved to be about 4 feet. The second, 93 feet N. 30° W. from the first and about on the same strike with it, was also abandoned for the same reason. The third, which was 86 feet S. 28° W. from the first, was 26 feet long and 2 feet deep (maximum depth); its western end was close to the Rex chert. This trench was mainly in overburden, but at its eastern end some broken pieces of brown shaly sandstone were exposed.

Another group of three trenches was dug in sections 20 and 29 nearly on the section line and at distances that ranged from 800 to 1,000 feet from the section corner. The first of these trenches, which was the one from which the sample was taken, was about 1,000 feet N. 84° E. of the section corner. It was 45½ feet long, 2½ feet wide, and 9 feet deep at the point sampled (maximum depth). The average depth was 4 feet. The overburden was about 4 feet thick, and the phosphate bed was at least 4 feet thick, somewhat crumpled and shattered, and deeply weathered.

The phosphate was of medium oolitic texture, but some beds were coarser, and some thin shaly partings, largely obscured by weathering, were observed. A layer near the top, about 1 inch thick, composed of oolitic phosphate, was reddish and somewhat shaly. Much of the weathered phosphate had a brownish or yellowish tinge. Beneath the phosphate was a yellowish-brown clayey sandstone, about 1 foot of which was exposed. The beds above the phosphate were not well exposed. The attitude of these beds varied in places, but on the whole they were nearly horizontal or had a gentle westerly dip.

Two samples were taken from the 4-foot bed; the first represented the upper 2 feet and the second the lower 2 feet as picked down from the side of the trench. Sample No. 1 contained 26.33 per cent P_2O_5, equivalent to 57.4 per cent $Ca_3(PO_4)_2$. Sample No. 2 contained 31.67 per cent P_2O_5, equivalent to 69.1 per cent $Ca_3(PO_4)_2$. A third sample selected from the harder pieces across the 4-foot face of the bed contained 32.69 per cent P_2O_5, equivalent to 71.4 per cent $Ca_3(PO_4)_2$.

The second trench of this group was 183 feet S. 68° W. from the first and was 18 feet long. It ranged in depth from 6 inches to 4½ feet and exposed 21 inches of brown shale with thin phosphatic seams. The rest of the cut was in the overburden.

The third prospect was 20 feet S. 6° E. from the second and was 28 feet long. Its lower end rested on the Rex chert. Its maximum depth was about 4 feet.

About 15 feet of the middle portion of this trench was occupied by broken pieces of brown shaly sandstone, the dip and strike of which were not clearly shown. The rest of the cut was in the overburden.

The samples taken were not very satisfactory because of the weathered and dirty condition of the phosphate rock, but if the third sample be considered representative of the fresher rock a bed at least 4 feet thick and averaging 70 or more per cent tricalcium phosphate may be assumed for this township. The limit of depth for working such a bed under current regulations is 3,000 feet. However, in T. 6 S., R. 41 E., a 5-foot bed averaging 70 per cent or more tricalcium phosphate and two 2-foot beds averaging about 61 per cent tricalcium phosphate were found. For these beds the maximum limit of 5,000 feet depth would be allowed. Similarly in T. 5 S., R. 42 E., the equivalent of a bed 6 feet 10 inches thick and averaging about 60 per cent tricalcium phosphate was found, for which a limit of 4,500 feet depth would be allowed. The area in the southwest part of the township is closely related to that in T. 6 S., R. 41 E., and the area in the southeastern part is the northwestward continuation of that in T. 5 S., R. 42 E. In view of the showing in these other townships it would seem fair to allow for this township a maximum depth limit of at least 4,500 feet.

Estimate of tonnage.—The area classified as phosphate land in T. 5 S., R. 41 E., is 2,680 acres. (See pl. 42.) If the phosphate is assumed to be equivalent to a 5½-foot bed averaging about 70 per cent tricalcium phosphate, and if the general dip is assumed to average about 30°, this area would contain more than 59,291,000 long tons of high-grade phosphate rock.

T. 6 S., R. 41 E.

General features.—T. 6 S., R. 41 E., is situated near the middle of the Henry quadrangle (pl. 3) and lies chiefly in the Blackfoot lava field, which is here largely flooded by the waters of the Blackfoot River Reservoir. The western third, however, is mostly upland and represents a large part of Reservoir Mountain. The lava field laps around the southern end of the mountain and projects into the adjoining township. Railroad facilities are 15 miles or more away, and the nearest shipping points are Soda Springs. Alexander, or Bancroft, on the Oregon Short Line Railroad, to the south or southwest. Fair roads connect the township with these places.

Geology.—The older geologic formations of the township are the Phosphoria formation, the Woodside shale, and the Thaynes group. The Salt Lake formation and Quaternary beds are well represented. A considerable area of travertine occurs in section 1. The lavas are mostly basalt, some of it in the form of cones with craters. Two of the islands in the reservoir, however, are composed of rhyolite. Detailed stratigraphic sections of the Woodside and Thaynes in this township are given on pages 87 and 89.

The structure of Reservoir Mountain is apparently that of a broad and relatively deep syncline with the west limb overturned eastward. (See pl. 36, *A*.) The east limb is probably down faulted and partly concealed beneath basalt. The syncline is offset in sections 19 to 21 by the Pelican fault. The northeast corner of the township is crossed by a concealed fault. The rocks beneath the lava field may be traversed by faults or deep fractures, which have had some influence upon the outflow of the lava and the location of the cones. The structural features of Reservoir Mountain are illustrated in the geologic structure section drawn along the line F–F′; those of the northeastern corner are suggested by the structure section along the line G–G′ (pl. 11).

Phosphate deposits.—The Phosphoria formation is exposed only in sections 19, 20, 29, and 30, where it occurs in an anticline that is truncated by the Pelican fault and offset westward on the north side of the fault. In 1916 the Geological Survey party prospected and sampled the phosphatic shales in the NE. ¼ NE. ¼ sec. 30. Prior to that time no phosphate prospecting had been done in the township. A trench 47½ feet long and 3½ to 4 feet deep (maximum depth 5 feet) was dug at approximately right angles to the strike. The entire prospect was in phosphate rock, which was contorted near the middle and from that point eastward had an eastward dip, conforming with the slope of the ground. The minimum thickness of the phosphate, 7 feet 1 inch, was obtained by measuring a portion of the beds that had a fairly uniform dip of 60° to 67° E. The rock was so weathered and dirty that individual beds could not be measured.

Three samples were taken at the place of measurement: Sample 1, which represented the lower 2 feet, contained 28 per cent P_2O_5, equivalent to 61.1 per cent $Ca_3(PO_4)_2$; sample 2, which represented the next 2 feet, contained 32.36 per cent P_2O_5, equivalent to 70.6 per cent $Ca_3(PO_4)_2$; sample 3, which represented the upper 3 feet 1 inch, contained 32.43 per cent (P_2O_5), equivalent to 70.7 per cent $Ca_3(PO_4)_2$.

A fourth sample which represented 2 feet 2 inches of gently dipping phosphate near the east end of the trench and possibly represented a higher horizon, contained 27.95 per cent P_2O_5, equivalent to 61.0 per cent $Ca_3(PO_4)_2$. The bed represented by samples 2 and 3 has a total thickness of 5 feet 1 inch, for which the depth limit under current regulations would be 4,000 feet. Samples 1 and 4 represent beds for which an additional depth of more than 1,000 feet would be allowed. Hence, for this township the maximum depth limit of 5,000 feet is assumed.

Estimate of tonnage.—From structure section F–F′ it appears that the area in which Woodside shale is exposed plus a small area underlain by beds of the

Thaynes would contain phosphate at depths less than 5,000 feet. Similarly from structure section G–G′ the area northeast of the fault in section 1 would be considered phosphate-bearing. The area occupied by basalt and by the waters of the reservoir is quite possibly underlain in part by phosphate within the limit of workable depth, but without drilling the location of this phosphate could be determined only in a very indefinite way. Moreover, the basalt presents such an obstacle to mining, when the greater accessibility of other areas is considered, that the exploitation of the phosphate beneath it seems very remote. Such areas are therefore omitted in the computation of tonnage. On this basis 4,000 acres in this township have been classified as phosphate land. (See pl. 42.)

If the phosphate beds named are assumed to be the equivalent of a 6-foot bed containing 70 or more per cent tricalcium phosphate and if the general dip is assumed to average 30°, 4,000 acres would contain approximately 96,383,000 long tons of high-grade phosphate rock.

The most favorable point of entry is the locality prospected in the SW. ¼ NE. ¼ sec. 30.

T. 7 S., R. 41 E.

T. 7 S., R. 41 E., is in the southern part of the Henry quadrangle (pl. 3), and is part of the Blackfoot lava field. Its northern boundary is a correction line that cuts off a strip about 0.3 mile wide from the northern tier of sections. With the exception of some hills in the northwestern part, which are underlain by Tertiary and Quaternary beds, the whole township is underlain by igneous rocks, chiefly basalt, though they include part of the big rhyolitic cone known as China Hat. Several basaltic cones are also scattered over the lava field.

Beneath the basalt in the southwest half of the township rocks older than the phosphate would probably be found, but in the northeast half the phosphatic shales and younger rocks may be present. However, the basalt, which is probably several hundred feet thick, presents an obstacle that will doubtless delay indefinitely any exploration and development of the phosphate.

As this land is being rapidly taken up in homesteads and converted into dry farms it seems more valuable for its agricultural than for its mineral resources. Therefore none of this township is held as phosphate land and no estimate of its possible tonnage is attempted.

T. 4 S., R. 42 E.

Although most of T. 4 S., R. 42 E., lies in the southeastern part of the Cranes Flat quadrangle (pl. 2), a strip about 1½ miles wide lies in the adjoining unmapped quadrangle to the east. The greater part of its area lies in the Little Valley Hills, but on the east parts of Outlet Valley and of Grays Lake are included and the southwest corner is in the southern part of the Willow Creek lava field.

The rocks are mostly postphosphate and so high in the series that the phosphate, if not faulted out completely, must lie at too great depths to be considered workable. In the southwestern part the Brazer limestone and Wells formation are exposed, together with considerable areas of rhyolite. Sections 30, 31, and 32 are partly included in the Meadow Creek graben and may contain the Phosphoria and later formations, but if so these are concealed by basalt and Quaternary beds.

The fault zone of the Bannock overthrust passes through the township, and the overthrust itself is believed to lie beneath it. The general structural features of the township are illustrated in the geologic structure section drawn along the line E–E′ (pl. 11).

In view of the down-faulted character of the possible phosphate-bearing area in sections 30, 31, and 32, the fact that the Bannock overthrust may cut out some of its phosphate, and the further fact that this area is underlain by a thick layer of basalt, any commercial development of its possible phosphate resources is probably too remote to receive consideration at this time. Therefore no land in this township is withdrawn because of its content of phosphate, and no estimate of the possible tonnage is attempted.

T. 5 S., R. 42 E.

General features.—Most of T. 5 S., R. 42 E., lies in the northeastern part of the Henry quadrangle (pl. 3) but includes strips nearly 1½ miles wide in the Cranes Flat quadrangle on the north and the Lanes Creek quadrangle on the east (pls. 2 and 4). The northeastern part, including section 1 and parts of sections 2, 11, and 12, lies in an area not yet topographically and geologically mapped, though some of its general features are known. The Little Valley Hills occupy parts of the northern tier of sections, but Pelican Ridge in the southwestern part, Little Gray Ridge in the northeastern part, Grays Lake in the northeast corner, and the valley of Meadow Creek between the two ridges named are the principal topographic features. The valley of Meadow Creek occupies parts of the Willow Creek and Blackfoot lava fields. Pelican Slough is a broad marsh at the lower end of this valley.

The township lies nearly 20 miles from the Oregon Short Line Railroad at Soda Springs, the nearest shipping point; but fair roads connect it with that place and with regions farther north and northeast.

Geology.—Beginning with the Brazer limestone the Carboniferous and Lower Triassic formations are present up to and including the Thaynes group. The Ephraim conglomerate is exposed in section 2. The Phosphoria formation is represented only by a small area in section 29. The Woodside shale occurs in two bands, one on each side of the more prominent member of Pelican Ridge. The Thaynes group occupies a broad area in the southwestern part and two isolated knobs in sections 16 and 17. Basalt and Quaternary beds occupy much of the valleys of Meadow Creek and of Grays Lake.

The geologic structure of the township is complex and includes two anticlines and two synclines, each broken by longitudinal faults and the whole broken by two great transverse faults. The anticlines occur in Little Gray and Pelican Ridges and represent respectively parts of the Little Gray and Snowdrift anticlines. The valley of Meadow Creek has probably synclinal or synclinorial structure, the continuation of similar structures farther southeast. This valley is also a down-faulted block or graben, here called the Meadow Creek graben, bounded by the Chubb Springs and Limerock faults. The Snowdrift anticline in Pelican Ridge is part of an upfaulted block or horst, bounded by the Limerock and Enoch Valley faults. It formerly had fan structure, to judge from the arrangement of the Phosphoria beds on its west flank. West of this anticline lies a broad syncline broken by faults and with its east limb overturned westward. This syncline represents the northward continuation of the Georgetown syncline. The Little Gray fault at the north end of Pelican Ridge and the Pelican fault at the south end are transverse faults that offset all the other structural features named and cause the ridges of Carboniferous rocks to stand farther apart in the space between these two faults than they do either to the northwest or the southeast.

The structural features above described are illustrated in the geologic structure sections drawn along the lines E–E′ and G–G′ (pl. 11). They are shown by name on the general map (pl. 1).

Phosphate deposits.—In 1916 the survey party dug a trench and sampled the phosphate beds in section 29, which had not hitherto been prospected. The trench was 15½ feet long, across the strike of the beds, 2½ feet wide, and 7 feet 7 inches deep (maximum depth). The overburden at the eastern end was about 4 feet thick. The beds were overturned southwestward, and a ledge of the underlying limestone, uppermost Wells, about 10 feet up the slope from the east end of the trench, had a strike of N. 81° W. and a dip of 30° N. 9° E. The section as exposed and the chemical determinations made upon the samples collected are given in Table 43.

TABLE 43.—*Partial section of phosphatic shales in the NW. ¼ SE. ¼ sec. 29, T. 5 S., R. 42 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
M-60-16	Fractured material, consisting of phosphate and clay with no distinct bedding but forming a dark or black powdery or clayey mass as far down as excavated; probably represents reduplication of portions of the main bed by folding, faulting, and mashing.			4 4
	Phosphate rock, broken, earthy, and more or less mingled with clay			1 7
Sample 4	Phosphate rock, brown, medium oolitic, beds ⅛ to ¾ inch thick; includes clay streak (infiltration or shear zone?) 1 to 4 inches thick, turning down slightly across the dip.	25. 92	56. 6	2 1
Sample 3	do	30. 75	67. 2	1 8
Sample 2	do	25. 40	55. 5	1 8
	Limestone, drab to brown, weathering to clay			3
Sample 1	Phosphate rock, brown, thin bedded, medium to finely oolitic	27. 40	59. 9	1 5
	Limestone, dark, thin bedded, slightly fetid			10

The section shows a bed of phosphate rock 5 feet 5 inches thick, which averages 59.5 per cent tricalcium phosphate, and a bed 1 foot 5 inches thick, which averages 59.9 per cent tricalcium phosphate, separated by a limestone bed 3 inches thick. These two beds considered together would make a bed 6 feet 10 inches thick, averaging about 60 per cent tricalcium phosphate. Probably the disturbed condition of the beds and their exposure to infiltered dirt accounts in part for their lower phosphatic content. The limit of depth for such a bed under the current regulations of the Geological Survey is about 4,500 feet.

Estimate of tonnage.—From structure section G–G′ (pl. 11) it is inferred that the line indicating a depth of 4,500 feet would pass from about the southeast corner of sec. 32 through the NW. ¼ NW. ¼ sec. 31 and that in the Thaynes and Woodside areas northeast of that line the phosphate would lie at greater depths. Similarly it is inferred that the 4,500-foot line would lie along the east base of the hills of Woodside shale that extend southeastward from section 7 and that only the area between the Limerock fault and that line would contain phosphate within the limit of depth. These hills were not included in the earlier withdrawals, and in view of the steepness of the dip and the rapidity with which the phosphate beneath the hills approaches the limit of depth it has not been considered advisable to recommend the withdrawal of this area. The Meadow Creek graben may contain phosphate within the 4,500-foot limit, but this phosphate is excluded from consideration because of the cover of basalt, which even that part overlain by alluvium probably possesses. This cover with little doubt will prevent for an indefinite period exploration or commercial development of any supposed phosphate beneath it. From these data 600 acres in this township are classified as phosphate land.

If we assume for purposes of computation that a 6-foot bed with a dip estimated to average at least 30° lies beneath an area of 600 acres, this township would contain about 14,300,000 long tons of high-grade phosphate rock. This estimate is undoubtedly conservative. The most favorable place of entry is the SE. ¼ sec. 29.

T. 6 S., R. 42 E.

General features.—T. 6 S., R. 42 E., lies chiefly in the Henry quadrangle but contains also some adjacent land in the Lanes Creek quadrangle (pls. 3, 4). The northeastern and northern parts are occupied by portions of Pelican Ridge and of Grays and Wooley Ranges, but the remainder of the township is included in the Blackfoot lava field, and is partly flooded by the Blackfoot River Reservoir. The geologic formations are described in detail in Chapters III and IV. The geologic structure is shown in part in the structure sections drawn along the lines G–G′ and H–H′ (pl. 11). The basis of the withdrawals is the presence of phosphate and postphosphate rocks in the northeastern and northern parts of the township, except in the very northeast corner. The southwestern part, though underlain by basalt, includes on the southwest side of the concealed fault the northwestern extensions of structural features favorable for the preservation of phosphate beds at depths that are thought not to be excessive as regards workability.

Geology.—A single band of the Phosphoria formation extends from the SE. ¼ SE. ¼ sec. 24 to the NE. ¼ SE. ¼ sec. 10. The continuity of the band is interrupted by lava at the point where Little Blackfoot River breaks through the ridge. The Rex chert member, which shows both the massive cherty facies and the flinty shale facies, is about 450 feet thick and the phosphate shales about 150 feet thick. The Woodside shale and the Thaynes group occupy ridges northeast of the Phosphoria formation and also the islands, which have become peninsulas by the lowering of the surface of the reservoir. Broad valleys with older Quaternary deposits lie between the ridges, and southwest of the Phosphoria belt the high ridge is composed of older Carboniferous rocks. A deposit of travertine covers many acres in and west of sections 10 and 15, including the site of the village of Henry and some adjacent territory. The travertine lies in part on the basalt and is perhaps still in the process of formation.

The principal structural features of the township, which affect the occurrence and distribution of the phosphate beds, are parts of the Georgetown syncline and the Wooley Valley anticline, described on pages 142 and 143. The basalt-covered area includes also the northern extension of the Trail Creek syncline and of several minor folds. The principal faults are the Henry, which is reverse, and the Enoch Valley, Slug Valley, and Pelican faults, which are normal, and the Pelican is also a transverse fault.

Phosphate deposits.—The phosphate beds are not naturally exposed within the township, but float lies along the outcrop of the beds on the northeast side of the main ridge. Prior to the visit of the survey party in 1912 no opening had been made in these beds.

In 1912 the survey party made a cut across the phosphate shales in the NE. ¼ SE. ¼ sec. 10. This cut was one of three cuts made under a special allotment by the Geological Survey; the other two were made in sec. 7, T. 7 S., R. 43 E., and sec. 26, T. 6 S., R. 43 E., respectively. The cut in sec. 10, T. 6 S., R. 42 E., was 350 feet long, 6 to 7 feet wide, and 4½ feet deep. It was necessary to make the cut slightly oblique to the general strike of the formation, but allowance for this is made in the measurement of the section. The overburden was relatively thin, so that it was possible to get information concerning the character of nearly the entire phosphatic shale member. The details of the section are included in Table 44.

The thickness given for the phosphatic shales in the above table, 175 feet 9 inches, is perhaps subject to some correction because of variability in strike and dip of the rocks exposed in the cut. Allowance for these differences was duly made, however, and the result checks well with the figures obtained in the cut in sec. 26, T. 6 S., R. 43 E., where a thickness of 176 feet 6 inches was obtained.

The thickness of the main phosphate bed near the base seems to be well maintained, for there is a practically continuous bed 6 feet 6 inches thick. The analyses show an average content of 62.04 per cent tricalcium phosphate. The quality of the rock appears to be somewhat poorer than that sampled in the townships to the west and south. This difference in quality may be in part due to the fact that the rock is much broken and may contain infiltered dirt. Doubtless also there may be some deterioration in quality, for shaly seams and some sandy material are noted in the section. According to the survey regulations, the limit of workable depth of a bed of this thickness and character is 4,000 feet.

Estimate of tonnage.—Structural relations in the township to the south seem to indicate that a phosphate-bearing syncline underlies part if not all of the lava-covered area in the western half of the township. The best available data indicate that such rock would correspond in thickness and quality with the rock exposed in this and neighboring townships. In view of the extensive cover of lava, however, any recovery of phosphate in that area would be indefinitely delayed, so that it is deemed best not to attempt any estimate of the phosphate content of this part of the township. Lands in that area previously withdrawn have been restored for entry.

The area classified as phosphate land contains 6,560 acres. The general dip of the rocks is as much as 20°. Under the conditions above outlined 6,560

TABLE 44.—*Section across the phosphate shales in the NE. 1/4 SE. 1/4 sec. 10, T. 6 S., R. 42 E. Boise meridian*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$.	Thickness
M-355-12	Chert (base of Rex) oolitic and somewhat sandy, with a few discinoid fragments.	*Per cent*	*Per cent*	*Ft. in.*
	Shale, brown, broken			11 6
	Sandstone, brown, broken, and partly covered with calcareous coating			27
	Phosphatic shales and shales only slightly phosphatic			1 2
	Yellow earthy zone			6
	Phosphate rock, much broken, in beds 1/2 inch thick, medium to fine oolitic			1 6
	Yellow earthy zone			8
	Phosphate rock, medium oolitic, in beds 1/2 to 1 1/2 inches thick in fragments coated white; sample 4	32.75	71.50	2
	Sandstone and shale, brown to black, much broken and coated with calcite near the top; nodule 2 feet in diameter noted, fine shale at top			10 6
	Covered zone with fragments of brown nodular sandstone			6 6
	Shale, chiefly thin-bedded and brown, somewhat nodular, and near the base apparently cherty			10 6
	Sandstone, broken, with some shale, all in broken pieces			7 6
	Earthy zone, consisting chiefly of broken brown shale and some thin fragments of fetid limestone, all streaked and covered with white calcareous coating			7 6
	Shale, brown, broken and containing some phosphate, all badly weathered			6 6
	Yellow, powdery, earthy zone			8
	Shale, black, broken, much iron-stained, beds 1/8 inch thick with 3-inch cherty layer at top			2 3
	Limestone, brown, sandy, fetid, and much broken			2
	Shale and phosphate rock, broken and weathered to black earth with white calcareous streaks; pass upward into broken shale			3
	Sandstone, brown, calcareous, in broken beds 1/2 to 3 inches thick and coated with calcite			2 6
	Shale, brown, in beds 1/8 to 1/2 inch thick, much broken			3
	Limestone, sandy, weathering yellow			1
	Limestone, brown, fetid			6
	Shale, brown, much broken and containing two or three thin beds of dark limestone coated with $CaCO_3$ and $CaCO_3.\ P_2O_8.n(H_2O)$? (collophanite); gastropods found in one piece of shale			11
	Earthy black soil, apparently a mixture of weathered phosphate and shale with phosphate predominating			3
	Limestone, fetid, dark brown to black; some pieces coated with $CaCO_3$ and collophanite? and the whole mass partly exposed and broken			19
	Broken zone, chiefly brown shale, like above			5
	Shale, brown, somewhat phosphatic and containing at least two beds of phosphate 2 inches thick			3
	Phosphate rock in beds 1/8 inch to 2 inches thick; black, weathering brown, with thin shaly seams, finely to medium oolitic. Thicker beds, sprinkled with sandy yellow spots; beds broken:			
	Sample 3 represents lower	27.21	59.42	2 6
	Sample 2 represents middle	31.21	68.12	2
	Sample 1 represents upper	26.84	58.58	2
	Broken rock chiefly fragments of brown shale with some pieces of underlying limestone; chert of the underlying limestone and soil			20
				175 9

acres underlain by a bed 6 feet 6 inches thick would yield about 159,706,000 long tons. The rock lies at depths that range from the surface to 4,000 feet below the surface. Most of the rock is probably below ground-water level, and some of it is under a basaltic cover. These facts would have a notable effect on the cost of mining operations.

T. 7 S., R. 42 E.

General features.—The north boundary of T. 7 S., R. 42 E., is a correction line, which cuts off a strip about 0.3 mile wide from the northern tier of sections. The township occupies adjacent parts of the Henry and Lanes Creek quadrangles (pls. 3 and 4). It lies mostly in the Blackfoot lava field, but in the eastern half it includes parts of the Aspen Range and the Fox Hills and is crossed by Blackfoot River. The northwestern part is overlapped by the Blackfoot River Reservoir, south of which stand three large volcanic cones that form striking topographic features. (See pls. 3 and 33, *C*.) The geologic structure is shown in part in the structure sections drawn along the lines I–I′ and K–K′ (pl. 11); the line K–K′ is drawn across the Aspen Range about half a mile south of the township.

Geology.—The Phosphoria formation occurs only in two areas. The first is a band, interrupted by faulting, that extends from the SW. 1/4 SE. 1/4 sec. 35 to the NE. 1/4 NE. 1/4 sec. 22. The other area occupies portions of sections 12 and 13. The Rex chert member is represented chiefly by the flinty shale and is about 450 feet thick. The phosphatic shales are about 150 to 175 feet thick. The Woodside shale and Thaynes group occupy ridges between the Phosphoria formation and the eastern boundary of the township.

Quaternary deposits occupy valley floors and long slopes that descend from the ridges. Travertine covers large areas within this township, especially from the vicinity of Doull's ranch, in the center, southward along the west flank of the Aspen Range. These deposits accompany springs that are still active and were once in all probability thermal. Deposition is probably still in progress, though at a less rapid rate than formerly. The thickness of the basalt is not known, but in section 3 it is greater than 400 feet, including a minor ash bed. One of the best exposures is in the gorge of Blackfoot River in section 14. (See pl. 18, *B*.) The cones in the northwest corner are rhyolitic.

The principal structural feature associated with the occurrence and distribution of the phosphate is the Trail Creek syncline, with which are associated some minor folds and faults. Overturning is noted locally along the west border of the syncline. The Blackfoot fault, a transverse overthrust, enters the township from the east but passes beneath the cover of the basalt. The Bannock overthrust also probably underlies the township. A subordinate thrust fault between the Woodside shale and the Thaynes group enters the southeast corner of the township and a normal fault passes along the west base of the Aspen Range.

Phosphate deposits.—The phosphatic shales are not naturally exposed in this township, although float of phosphate rock lies along the general line of outcrop of the shales. At the time of the visit of the Geological Survey party in 1912 no opening in the shales had been made, although in the SW. ¼ SE. ¼ sec. 35 a claim corner was found relating to a claim location by Brown, Perkins & Berch, under the placer and lode laws. The dimensions of the claim are 1,500 by 600 feet.

The nearest measured sections of phosphate rock are in sec. 7, T. 7 S., R. 43 E., and in secs. 23 and 25, T. 8 S., R. 42 E., which are given in detail in the descriptions of those townships.

From the data above mentioned it seems fair to assume that the phosphate rock of this township is of high grade, and probably contains at least 32 per cent phosphorus pentoxide, equivalent to about 70 per cent tricalcic phosphate, and that the main phosphate bed is probably as much as 6 feet thick. According to survey regulations, the depth limit for withdrawal of phosphate rock of this grade is 5,000 feet.

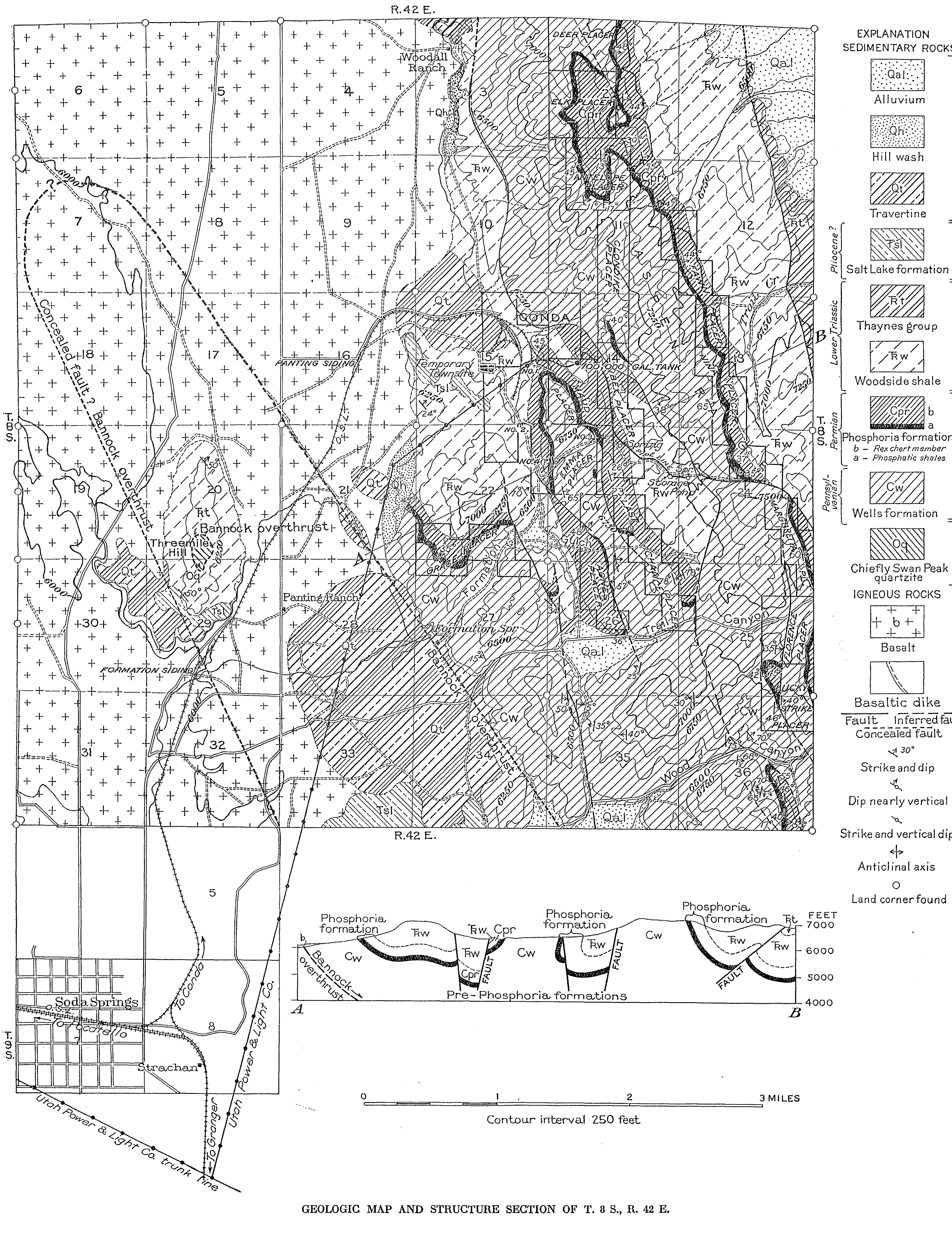
Estimate of tonnage.—The geologic structure in neighboring districts suggests that a considerable part of the basalt-covered area may be underlain by phosphate within the limit of depth imposed by existing regulations. The position and character of this phosphate, however, can not be determined without expensive drilling through the basalt. Any recovery of this phosphate will undoubtedly be indefinitely delayed. Such land is already being taken up in homesteads and seems on the whole more valuable for its agricultural than for its mineral resources. Hence, only 5,120 acres in this township are now held as phosphate land. The beds are not horizontal but have dips that average at least 20°. Under these conditions a 6-foot bed that underlies 5,120 acres would yield about 114,850,000 long tons of high-grade phosphate rock. The depth of the rock in the southeast quarter of the township is probably between 2,000 and 3,000 feet, but in sec. 12 and the NE. ¼ sec. 13 it is probably less than 1,000 feet. Much of the rock is below the level of the ground water. This fact would have a significant bearing on the cost of mining operations.

T. 8 S., R. 42 E.

General features.—Marginal portions of T. 8 S., R. 42 E., are included in the Henry, Lanes Creek, and Slug Creek quadrangles (pls. 3, 4, 6), but most of it lies in an adjoining unsurveyed quadrangle. A special map and brief description of the township have been published in an earlier report.[20] Plate 44 shows a somewhat more detailed map. The eastern half of the township lies in the Aspen Range and the western half in the Blackfoot lava field, but in the western half Threemile Hill, an isolated eminence, rises above the basalt. Its origin is not well understood, but it may represent a fault block similar in origin to the larger fault block in the Henry quadrangle called Reservoir Mountain.

Geology.—The oldest rocks exposed within the township are large boulders of Ordovician quartzite and limestone, probably remnants of a fault block, which overlie Triassic beds in Threemile Hill. These rocks were at first regarded as Cambrian but upon later examination were referred to the Ordovician. Possibly these boulders are remnants weathered out from Tertiary conglomerate after the manner of some large boulders that lie on hills east of the Portneuf Valley, in the Fort Hall Indian Reservation,[21] but in this township no other such remnants were seem, and the fault-block explanation is thought more probable, especially in view of the fault relations in the area farther south. Pennsylvanian rocks form numerous hills in the southeastern part of the township and constitute much of the high ridge near the eastern border. The Phosphoria formation occurs in a band along the eastern side of this ridge and in curved bands on some of the other hills. The phosphatic shale member has a thickness of about 112 feet and the Rex chert is 340 feet or more thick. The Rex in massive ledges forms fine dip slopes. The Woodside shale and Thaynes group are the only Triassic formations present, and the Thaynes group occurs only in the northeastern part of the township and in Threemile Hill. At Threemile Hill the red-bed member of the

[20] Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 402–405, 1911.
[21] Mansfield, G .R. ,U. S Geol. Survey Bull. 713, p. 100, 1920.



GEOLOGIC MAP AND STRUCTURE SECTION OF T. 8 S., R. 42 E.

Portneuf limestone (upper Thaynes) is present and underlies the large boulders above mentioned.

The Tertiary sediments are composed of drab to white limestones which vary in grain and degree of compactness from loosely consolidated marly varieties to a dense, nearly lithographic facies, which looks older than Tertiary. All are assigned to the Salt Lake formation, of supposed Pliocene age. Travertine occurs in a number of areas, the largest of which is Formation Spring, in sections 27, 28, 33, and 34. Here a large and elaborate group of basins has been built. Back of the outer row of hills the canyons of the principal streams open into meadows occupied by alluvium. The basalt is overlapped in part by the travertine but is younger than the Tertiary beds.

The principal structural features with which the phosphate is associated are the Trail Creek syncline along the eastern border and a group of smaller folds, both anticlines and synclines, most of which are broken by faults. It is more usual for the phosphate to be contained in synclines, but in sections 23 and 15 and sections 11 and 2 it is contained in anticlines. In section 2 the highest mountain in the township is capped by an anticlinal arch of the chert, which immediately overlies the phosphatic shales. Threemile Hill contains both anticlines and synclines. By comparison with other areas of Triassic rocks of similar constitution and area its structure as a whole is probably synclinorial, though this has not been worked out in detail. It occupies part of a great window in the Bannock overthrust. (See p. 158.) The Bannock overthrust enters the township on the south and an irregular normal fault enters from the east. This normal fault truncates two supposedly reversed faults that enter from the south. The main structural features that affect the exploitation of the phosphate are shown in the structure section that accompanies Plate 44.

Phosphate deposits.—Prior to 1920 the prospecting in this township was carried on mainly by open cuts, and most of these are in the main phosphate bed near the base of the shale. The beds in many places are nearly horizontal and the rock is much broken and jointed; elsewhere they are steeply inclined. In 1920 the Anaconda Copper Mining Co. began work on a large tunnel in the NE. ¼ SE. ¼ sec. 15, but when the writer visited the locality on September 12, this tunnel, which was being actively driven, had not cut through the Rex. The most complete section obtained was measured in 1910 in section 25 on the north side of Trail Canyon. This section is given in Table 45. It shows that 7 to 10 feet of high-grade phosphate rock is included in the lower portion of the phosphatic shale. A comparison of this section with others that have been made by L. P. Brown in different parts of the township shows that it may be considered typical. The chert at the top is Rex and the limestones below the lowest brown shale are Wells.

TABLE 45.—*Section of the Phosphoria and Wells formations in Trail Canyon, sec. 25, T. 8 S., R. 42 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
	Chert, bluish black to gray, in heavy beds alternating with cherty shales			340	
	Concealed by heavy chert talus			71	6
379-10	Phosphatic rock, brown, medium to finely oolitic	28. 5	62. 2	4	
	Limestone, gray, shaly in middle			7	6
	Shale, brown rock			1	
379-9	Phosphatic rock, brown, medium oolitic	31. 3	68. 1	2	8
379-8	Shale, brown	18. 7	41. 2	1	2
379-7	Phosphatic rock, brown, weathers gray	31. 5	68. 8	2	6
379-6	Phosphatic rock, brown, containing fossils	30. 0	65. 5	2	6
379-5	Shale, brown	18. 4	40. 6	1	4
379-4	Shale,brown	21. 3	46. 6	3	4
379-3	Phosphatic rock, brown, coarsely oolitic	34. 0	74. 2	1	
379-2	Phosphatic rock, brown, medium oolitic	33. 3	72. 7	3	
379-1	Phosphatic rock, brown, finely oolitic	33. 5	73. 2	3	
	Shale, brown			7	
	Wells:				
	Limestone, brownish gray, contains *Productus* and fucoid-like forms			10	
	Chert, bluish black				6
	Limestone, gray, one bed			6	
	Limestone and ashy-gray chert alternating			20	
	Limestone, gray to yellow, soft and in part sandy			363	6
				851	6

Many of the sections measured by the survey were incomplete, owing to the caved condition of the prospects, and the samples obtained are unsatisfactory because of the inclusion of soil in the joints of the broken phosphate, a condition that would undoubtedly not exist where mining had been done more recently. The details of these sections and the analyses are therefore omitted.

A shipment of phosphate rock from the Agnes claim, in the SE. ¼ SW. ¼ sec. 23, is reported to have been made early in the summer of 1920 by Brown, Perkins & Co. This shipment, which is said to have consisted of 40 tons, is reported to have contained 34.14 per cent of phosphorus pentoxide, equivalent to 74.6 per cent of tricalcium phosphate. A check analysis of the buyer's sample by J. G. Fairchild, in the laboratory of the United States Geological Survey, showed 34.23 per cent of phosphorus pentoxide. The prospect from which the shipment was made was examined and the section shown in Table 46 was measured.

TABLE 46.—*Section of phosphate bed in Agnes claim, in sec. 23, T. 8 S., R. 42 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
M-536-4	Phosphatic rock, brownish gray, medium oolitic	28.5	62.2	2 1
M-536-3	Phosphatic rock, brown to gray, fine to medium oolitic	33.5	73.2	2 1
M-536-2	Phosphatic rock, brown, finely oolitic, slightly sandy	33.0	72.1	2 1
M-536-1	Phosphatic rock, brown, fine to medium oolitic	33.4	73.9	2 1
				8 4

The prospect is located in the axial portion of a small westerly overturned and faulted syncline, and the apparent thickness of phosphate rock exposed in the prospect is nearly twice that of the above section.

Estimate of tonnage.—The portion of the township that is covered with basalt may be underlain in large part by phosphate and postphosphate rocks, but it is excluded from consideration because such a cover renders practically impossible any early exploration or development of these areas. The phosphate beneath Threemile Hill lies so deep that it also is excluded. In the eastern half of the township 8,320 acres are considered as phosphate land. The presence of a 7-foot bed that contains 70 per cent of tricalcium phosphate may be safely assumed. Horizontal beds of such character and extent would yield approximately 203,840,000 long tons of phosphate rock. As the beds are deformed at many places, such an assumption takes into account less than the actual content of the beds, and the estimate may therefore be regarded as conservative. The thickness of the overburden does not greatly exceed 1,000 feet, and a large portion of the phosphate is probably above the ground-water level, as indicated by the altitude of the springs.

Anaconda Copper Mining Co.'s phosphate mines.—Early in 1920 the Anaconda Copper Mining Co. acquired the phosphate properties of the Southern California Orange Grove Fertilizer Co., in the vicinity of Soda Springs, and began what promises to be large-scale phosphate mining in this township. (See fig. 27.)

C. E. Nighman, the company's superintendent at Soda Springs, has given the following description of the company's mines in The Anode (a company publication) for September, 1923. Mr. Nighman has also been kind enough to indicate on the map, Plate 44, the location of the company's improvements.

Mines.—On the company's property there are two anticlines with axes parallel to the mountain range. Due to erosion along the top of the anticlines, there are three or more pronounced outcrops within the claim boundaries. The western anticline, known as the Emma, is the one along which work is now being done.

The mines are opened through two adits which are about one-half mile apart at the portals and about the same distance underground. No. 1, the portal of which is at an elevation of 6,256 feet, reaches the eastern leg of the Emma anticline about 2,300 feet from the entrance. It will later be driven about 6,500 feet in a northeasterly direction to the main east flank of the easternmost anticline. Here backs from 300 to 1,300 feet high will be obtained. No. 2 adit enters the western leg of the Emma anticline about 750 feet from the portal.

The adits and the main drifts therefrom are identical in construction. They are heavily timbered with 10-inch by 10-inch to 10-inch by 14-inch Oregon fir sets covered with 4-inch and 2-inch lagging and in common with all other drifts or crosscuts are electrically lighted. These adits are the main haulage and airways.

Main underground and all surface tracks are laid with 6-inch by 8-inch ties and 60-pound steel rails on 36-inch gage. Standard railroad turnouts and switches are used. The standard gradient is 0.5 per cent in favor of the loads. Main haulage is done with two 16-ton General Electric storage-battery locomotives, which are completely equipped with air and hand brakes, air-operated whistles, bell, and track sanders. The locomotive can haul a 100-ton net load. In running, side-dump cars of 10-ton capacity are used. These have railroad journals, and each is equipped with M. C. B. couplers and hand brakes. Timber is hauled on large flat cars of similar design. These cars as well as the smaller ones used in development were designed by the mechanical department and were built in the company's foundry at Anaconda. Because of the width and length of the rolling stock the main haulageways are very large, being 9 feet wide and 10 feet 2 inches high inside timber, and the minimum allowable radius of curvature is 150 feet.

Because of the limitations just named it is necessary during development to follow the phosphate bed, which, since it is highly inclined, appears like a vein or lode, with a smaller heading, which is the same size as the ordinary Butte drift and is generally timbered in the same manner. In this work 25-pound rails, animal haulage, and 2-ton roller-bearing side-dump cars are employed. All shoveling on the sill is done mechanically, two Armstrong shuveloders being used. (In the future slushers will probably be employed for this purpose.)

After the heading has been driven several hundred feet, the alignment is chosen, and the heading is enlarged to full size and timbered and the light track replaced with the heavy rails and ties above mentioned.

Three-compartment raises 100 feet apart are run from the sill or adit level to the top of the ore or surface. Sub or intermediate levels are driven from the raises at 100-foot intervals. These drifts are small and almost entirely untimbered. As the backs on the Emma anticline are from 300 to 700 feet, there may be as many as six of these intermediates.

Ventilation is natural but is aided by Sirocco fans in the advance headings and in some raises. As the deposit is thoroughly blocked out, all working places are cold, and the air is fresh. There is practically no water underground, but the ore is just moist enough to prevent the formation of dust.

Jackhammer-type drills, with and without air feed, are used exclusively, and in the phosphate auger steel only is employed. The ore being soft and friable, only low-grade dynamites are used in blasting.

Up to the present underground work has been almost entirely of a development nature, but stoping will be started this fall.

Since the beginning of work about three years ago nearly 3 miles of drifts, crosscuts, and raises have been driven.

Mill.—Crushing and drying is the only treatment given the rock at Conda.

From the mines the rock is hauled over trestles about 50 feet high to the mill feed bin, the capacity of which is about 350 tons. From the feed bin it passes over shaking feeders to a large grizzly, the oversize from which is crushed in a 12-inch Traylor bulldog gyratory crusher. The grizzly undersize and crusher product are then raised in a large continuous bucket elevator and passed over a Mitchell vibrating screen. The screen oversize is passed to a pair of 22-inch by 54-inch Anaconda rolls, the crushed product being reelevated to the vibrating screen. The screen undersize, which is less than three-fourths inch in size, dumps directly into an intermediate bin of about 50 tons capacity, from which it is evenly fed by an apron conveyor to a Ruggles-Cole class A–12 rotating dryer. The dryer is 7 feet in diameter and 45 feet long. The rock from the dryer passes over a shaking discharge feeder to a housed Link Belt company chain bucket elevator. The rock then passes through a Vezin sampler to a system of belt conveyors and trippers, which distribute it to pockets in the railroad storage bins. The larger of these bins, which has a capacity of 3,000 tons, is used for loading into open cars. The other bin, whose capacity is 1,000 tons, is arranged to load box cars, an Ottumwa self-propelled electrically operated box-car loader being used.

The mill also contains a Raymond Brothers impact pulverizer in which a part of the dried rock may be re-treated.

The present capacity is 400 tons per day, but this can be doubled by the addition of another dryer, the foundations for which are in place.

The mill and bins framework are of timber. The feed bin is steel-plate lined, while the railroad bins have gunite linings 4 inches thick on the bottom, decreasing to about 2 inches at the upper edge of the walls. All bins are housed in and have, in common with the mill building, gunite walls. All machinery is motor-driven, and bin gates are compressed-air operated.

Plant.—All plant buildings are located at the adit elevation, or about 50 feet above the mill floor. There are completely equipped carpenter, blacksmith, and machine shops, large laboratory, locomotive-charging shed, refrigerating and cold-storage plant, and warehouse. All but the last are of frame and gunite construction, and all are reached or entered by the mine tracks.

Electric power is purchased from the Utah Power & Light Co., which has a 9-mile 44,000-volt branch transmission line to Conda, where the voltage is changed to 2,200 in a modern steel outdoor transformer station. Various small substations further reduce the voltage from 2,200 to 110–220–440, as required.

The power house, which is of steel and gunite construction, contains all switchboards and recording meters. Here is also located the 75-horsepower motor-generator set, which supplies direct current for charging the locomotives' batteries. This building also contains a 1,000-cubic foot Ingersoll-Rand short belt-driven air compressor.

Railroad facilities.—A branch of railroad about 8 miles long connects Conda with the main line of the Union Pacific Railroad just east of Soda Springs. At Conda the main line track extends nearly a half-mile beyond the mill to the empty storage tracks, which can hold about 100 cars. Double loading tracks lead back past the loading bins and over very large and accu-

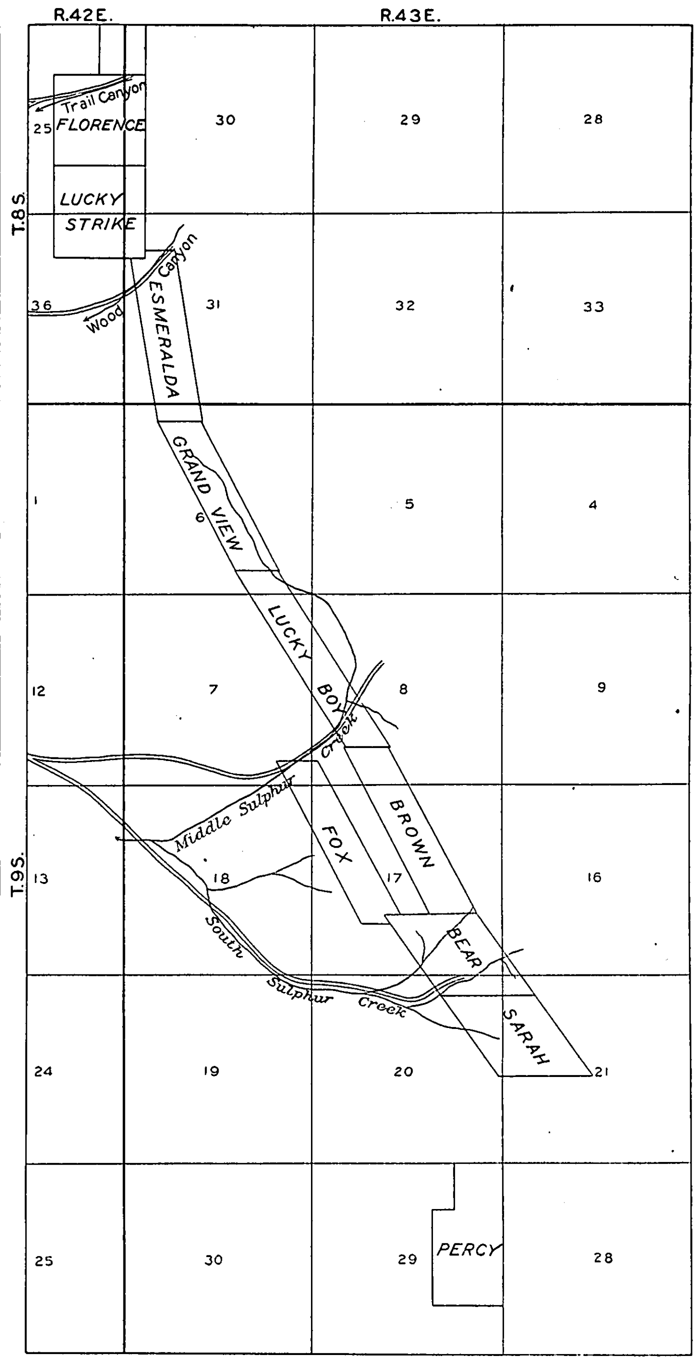


FIGURE 27.—Phosphate claims of Anaconda Copper Mining Co. in T. 8 S., Rs. 42 and 43 E., and T. 9 S., R. 43 E. Published by courtesy of the company

rate track scales to the loaded storage tracks. All this trackage has such a gradient that cars can be handled by gravity. A branch track leads to the plant site at such elevation that materials may be unloaded onto stock piles by gravity. A split from the above branch leads over coal bins of about 400-ton capacity. These bins are gunite-lined. In addition to the above tracks there are wyes at Conda and at the main line, so that trains may be turned in either direction as desired.

Water system.—Water is obtained from three springs located above and about 2 miles southeast of the plant. At each spring there is a fenced reservoir. The water is brought to a 100,000-gallon storage tank in a buried wood-stave pipe line. High-pressure wood and steel pipe lines convey the water to the plant and town. At intervals along the line are spaced gunite houses containing hydrants, hose nozzles, and tools. The mine is now being piped for fire protection.

Townsite.—The village of Conda lies about one-half mile from the mine entrance. This is being laid out as a model town. There are only eight houses per block, with a central alley through which supplies are delivered and garbage or waste removed and on which are located individual coal and wood sheds. The main streets are 40 and 50 feet wide. Lots are 60 feet by 80 feet, giving room for gardens and lawns, which, because of the rich phosphatic soil and notwithstanding the high altitude and severe winters, produce extremely fine flowers, fruits, and vegetables. At the recent Caribou County fair about 15 first and second prize ribbons were given the Conda community for flowers and vegetables. So far the company has erected 28 handsome four-room-and-bath cottages. These houses are modern in every respect, have electric light, running water, sewer connections, and high-grade plumbing and lighting fixtures. Rents are purely nominal and barely cover upkeep expense. In addition there are 18 temporary cabins, superintendent's residence and staff cabins, bunkhouse for about 110 men, offices, boarding house, and recreation hall. In the latter are given religious services, dances, community parties, and, twice weekly, motion pictures.

The community store occupies a large building adjoining the boarding house. This store is operated purely for the benefit of the employees, twice annually all profits being returned to them. In the three years of operation the amount returned has run from 10 to 12 per cent of the value of the purchases.

A grade school has been conducted for two years. A modern two-room school is now under construction and will be ready for the fall term.

There are a number of private garages as well as a large company-owned one. In winter and during bad weather the company runs a large White automobile bus over the railroad tracks to and from Soda Springs. Employees are transported free of charge.

Tennis courts and baseball diamond, together with fine fishing and small game hunting, afford additional recreational opportunities.

Since the above statement was published stoping has been in progress, and the company has been producing phosphate rock on an expanding scale, as may be judged by the increase in production officially reported for the Western States. In 1922 four companies in the Western States produced 4,481 tons of phosphate rock (Geological Survey figures). This was before the mine at Conda was fairly started. In 1925 there were again four producing companies in the Western States, of which the Anaconda Copper Mining Co., at Conda, was the largest. Production for that year was 72,631 tons of phosphate rock (Bureau of Mines figures). In a letter dated November 19, 1926, Mr. Nighman writes that the main crosscut tunnel has been advanced to a point about 3,500 feet from the portal of adit No. 1.

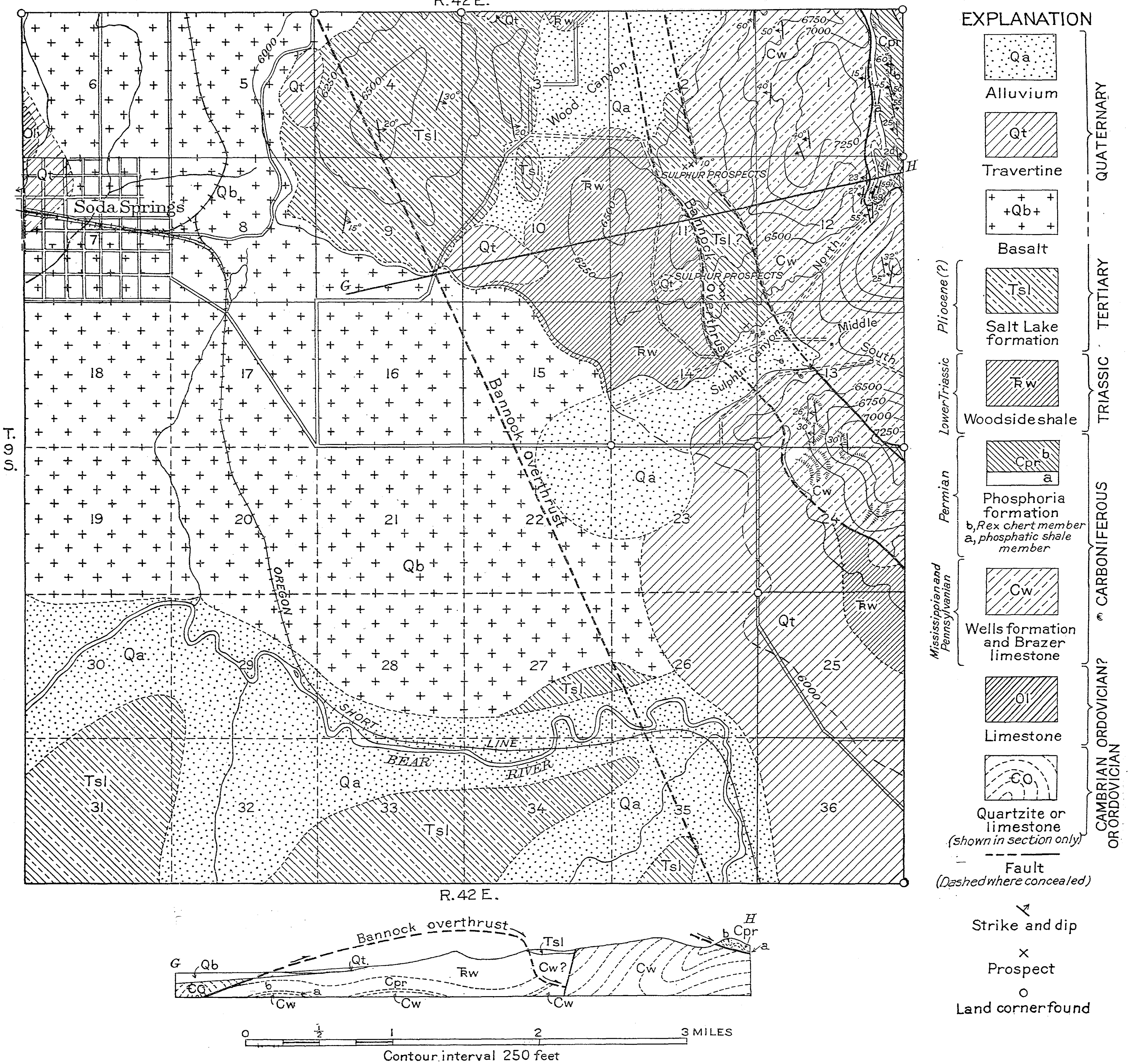
T. 9 S., R. 42 E.

General features.—T. 9 S., R. 42 E., has been described in an earlier report [22] but later work in the general region has made desirable some changes in the earlier statement. (See pl. 45.) A narrow strip along the eastern border lies in the Slug Creek quadrangle. (Pl. 6.) The township embraces parts of five broad physiographic features, namely, the Bear River Range, Bear River Valley, Blackfoot lava field, Soda Springs Hills, and Aspen Range.

Geology.—The oldest rocks, which are pre-Carboniferous, are exposed only in the Soda Springs Hills, which occupy part of section 6. They are believed to underlie much of the western half of the township, though there they are concealed by basalt and by Tertiary and Quaternary sediments. Carboniferous rocks crop out in the northeastern part of the township and include the only exposures of phosphate rock. Triassic rocks (Woodside) crop out only in sections 24 and 25, but abundant float of similar rocks in section 11 and adjoining sections probably indicates the presence of the formation beneath the float. Indeed, from relations in districts to the southeast and north it seems probable that a relatively broad belt of Triassic rocks, including Woodside shale and possibly some beds of the Thaynes group, extends northwestward from sections 36 and 25 to sections 3 and 4, though much of this area is occupied at the surface by younger sediments. Considerable areas in this township are underlain by Tertiary beds that are assigned to the Salt Lake formation, including both the close-grained nearly lithographic limestones, which are best seen in sections 3 and 4, and the soft marly limestones and calcareous conglomerates, which are best exposed south of Bear River. The area of tuffaceous breccia between the two faults in section 11 and vicinity, which in the former report was referred to the late Cretaceous, is now also referred to the Salt Lake formation, more extended study of the general region having shown that this formation includes beds of white volcanic ash. The extensive deposits of travertine are a noteworthy feature. Quaternary sediments are associated with Wood Canyon, Sulphur Canyon, and Bear River. The basalt, which covers much of the lower ground, is relatively fresh in appearance. Well sections show it to be composed of several flows of different thickness.

The northeastern part of the township lies in an area of complex structure, which is described as a whole on page 145. In the vicinity of the North Fork of Sulphur Canyon the Phosphoria formation is caught in a syncline, overturned eastward and cut on the east, south, and west by faults that are probably reverse. The thrust fault in the canyon causes the Phosphoria to overlie the Brazer with a contact dipping gently westward, which cuts out the phosphatic shales in most of the eastern limb of the syncline. South of the canyon a short normal fault connects this thrust fault with the reverse fault that forms the eastern boundary of the syncline. The structural

[22] Richards, R. W., and Mansfield, G. R., U. S. Geol. Survey Bull. 470, pp. 406-407, 1911.



GEOLOGIC MAP AND STRUCTURE SECTION OF T. 9 S., R. 42 E.

relations in the canyon are shown in Figure 28. The western fault in section 11, which is described in the earlier report as normal, is now regarded as part of the Bannock overthrust.

Phosphate deposits.—No prospects that showed oolitic phosphate rock were found in the township in 1910, but one or two shallow openings had been made in the phosphatic shales. Abundant float of the high-grade rock phosphate affords evidence of the presence of the richer beds. The area underlain by Triassic rocks presumably contains the phosphate beds at depth.

Estimate of tonnage.—The quality of the rock phosphate as inferred from the adjoining township is on the average equivalent to 70 per cent tricalcium phosphate, although the float rock would probably show a higher content. The presence of a 6-foot phosphate bed can fairly be assumed. The area west of the concealed fault that extends northwestward from section 35, though largely concealed by basalt and Tertiary or Quaternary sediments, is believed to be underlain by prephosphate rocks. East of this fault the rocks beneath cover are presumably in the main of postphosphate age. The withdrawn lands, however, are restricted to areas in which the Phosphoria formation actually crops out and to areas rather clearly underlain by Woodside shale. On this basis a total of 3,320 acres in this township is classified as phosphate land. Such an area underlain by a horizontal 6-foot bed would contain approximately 69,720,000 long tons of high-grade phosphate rock. Allowance for the dip of the beds would increase this amount, but the uncertainties introduced by cover and complicated structure tend to offset any such increase. The amount given is regarded as a conservative estimate for the township. The estimated tonnage is nowhere at much greater depth than 1,000 feet, and probably two-thirds of it lies within 500 feet of the surface.

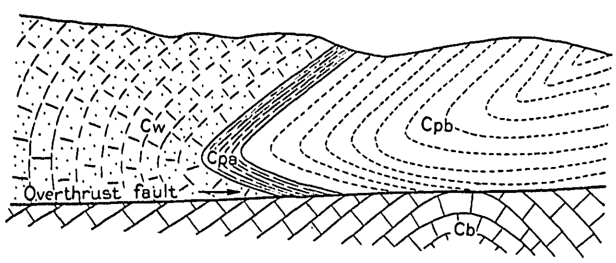


FIGURE 28.—Structural relations of the Phosphoria and adjacent formations in the North Fork of Sulphur Canyon, T. 9 S., R. 42 E. Cpa, Phosphatic shales of Phosphoria formation; Cpb, Rex chert member; Cw, Wells formation; Cb, Brazer limestone

T. 10 S., R. 42 E.

A narrow strip of T. 10 S., R. 42 E., is included in the Slug Creek quadrangle. (See pl. 6.) Most of the township is in the Bear River Range, but the northeastern part lies in Bear River Valley. The southwest half, so far as examined, is underlain by pre-Carboniferous rocks; the remainder is covered by the Salt Lake formation and Quaternary beds. The Bannock overthrust (see pp. 155 to 158) enters the township near the middle of its east border. The relations of this fault to Triassic formations in Tps. 10 and 11 S., R. 43 E., suggest strongly that these rocks underlie the Quaternary beds northeast of the fault in this township. In view, however, of the extensive cover and of the uncertainties of structure in the valley of Bear River, none of this area is classified as phosphate land under the regulations of the Geological Survey, and no estimate of tonnage is presented.

T. 5 S., R. 43 E.

General features.—A strip nearly 1½ miles wide along the northern part of T. 5 S., R. 43 E., lies in an area that has not yet been mapped. There is little likelihood, however, that this strip contains any workable beds of phosphate. The remainder of the township is in the northern part of the Lanes Creek quadrangle. Grays Range, together with its northern member, Little Gray Ridge, occupies most of the southwest half. The west flank of the Caribou Range enters the northeastern part. Between these two uplands lies a lowland drained by Gravel Creek, which comprises the southern extension of the valley that is occupied in part by Grays Lake.

The township is nearly 25 miles northeast of the railroad at Soda Springs, the nearest shipping point, but fair roads connect it with that place and with the regions to the northwest and southeast.

Geology.—The stratigraphic series extends from the Madison limestone to the Quaternary, but there are large gaps. No Triassic beds above the Thaynes are exposed. The Jurassic is represented only by the Nugget sandstone in sec. 24 and the Cretaceous by the Wayan formation in the northeastern part of the township. The only Tertiary beds are those of the Salt Lake formation. There are extensive areas of alluvium and of hill wash, and basalt covers considerable territory in the eastern, southwestern, and northwestern parts. The Phosphoria formation is represented by a narrow belt of Rex chert in sections 30 and 29 and by a somewhat discontinuous belt in sections 33 to 35.

The Bannock overthrust crosses the township mostly under cover northwestward from the SE. ¼ sec. 24 and divides the township into two structural units. The lower block at the northeast contains the Cretaceous beds, which have a generally synclinal structure. The axis of the Williamsburg syncline probably crosses the northeast corner. The upper block contains parts of the Little Gray anticline, which in the southeast corner is crossed by a transverse syncline, and the Lanes Butte syncline. Both these folds are broken by longitudinal faults, including the Chubb Springs and Limerock faults, which here outline the southern extension of the Meadow Creek graben, a noteworthy fault trough. The Chubb Springs fault is accompanied by a subparallel fault, and between the two a narrow block that contains Phosphoria and Woodside beds is caught. The Lanes Butte syncline, which is downfaulted in the graben, is broken just south of the township by a thrust fault that brings lower Thaynes and Woodside beds above upper Thaynes. The Pelican fault, which offsets these longitudinal structures, enters the northwestern part of the township.

Most of the structural features outlined above are illustrated in the geologic structure section drawn along the line H–H′ (pl. 11).

Phosphate deposits.—The phosphate beds in this township had not been prospected at the time of the writer's visit in 1914, and no opening in them was made by the survey party. In 1912, however, a cut was made by the survey party in the phosphatic shales in sec. 26, T. 6 S., R. 43 E., about 5 miles to the south. This cut revealed the presence of a 7-foot bed of phosphate that averages more than 70 per cent tricalcium phosphate.

The cut made by the survey party in sec. 29, T. 5 S., R. 42 E., showed the presence of a bed nearly 7 feet thick but of poorer quality. It seems reasonable then to assume for this township a bed at least 6 feet thick that has a content of about 70 per cent tricalcium phosphate. The limit of workable depth for such a bed under current regulations is 5,000 feet.

Estimate of tonnage.—On the basis of the geologic structure section H–H′ (pl. 11) all the area underlain by beds of the Phosphoria, Woodside, or Thaynes in this township would contain phosphate at depths less than 5,000 feet. The Bannock overthrust, however, may cut out some of the phosphate in the deeper places, though no provision for this is made in the structure section. The structure beneath the alluvium drained by Gravel Creek is unknown, except that the Phosphoria may be inferred to loop around the Woodside area in section 26 and to pass beneath the basalt in section 25. The broad alluvial area to the north may contain a syncline with postphosphate rocks but it is excluded from consideration in the computation of tonnage. The basalt-covered areas in this township that contain phosphate could quite possibly be worked from adjacent areas not so covered. They are therefore included in the computation of tonnage. With these allowances 4,880 acres in this township are considered as phosphate land. Such an area underlain by a horizontal 6-foot bed of phosphate would contain about 102,490,000 long tons of phosphate rock. Any increment allowed for the dip may be offset by the possibility of loss through the Bannock overthrust or other faults. The estimate as given is believed to be conservative.

T. 6 S., R. 43 E.

General features.—This township forms part of the Lanes Creek quadrangle (pl. 4) and includes parts of Grays and Wooley Ranges and of Enoch and Rasmussen Valleys. These physiographic features are described in Chapter II. The geologic formations are described in detail in Chapter III, and the geologic structure, which in the main forms part of the regional structural features, is more fully described in Chapter V. The classification of the phosphate lands, which, as indicated on Plate 42, include a large proportion of the township, is based on the wide occurrence of phosphate and postphosphate rocks.

Geology.—The oldest rock formation exposed in the township is the Brazer limestone (upper Mississippian) in the southwest corner. Beds of the Wells formation (Pennsylvanian) accompany these rocks and also form a diagonal northwesterly band across the township. The Phosphoria formation lies in bands along the upper margins of the Wells formation. The phosphatic shales are 125 to 175 feet thick, and the Rex chert member about 450 feet thick. All the Triassic and doubtfully Triassic formations are represented except the Wood shale. No higher formations have been recognized except the Quaternary sediments in Enoch and Rasmussen Valleys. Basalt occurs here and there along the borders of Enoch Valley.

The principal folds that contain phosphate are the Lanes Butte syncline in the northeastern part and the Georgetown syncline in the southwestern part. These folds are separated by the Snowdrift anticline, which forms a diagonal ridge through the center. The Wooley Valley anticline enters the southwest corner of the township. These large folds are not entirely simple but are complicated by minor folds and by a number of faults.

The principal faults are the Limerock and Enoch Valley faults, which lie respectively along the northeast and northwest flanks of the Snowdrift anticline the Henry fault in the southwestern part of the Georgetown syncline, and the Wooley Ridge fault, which enters the township in section 33. These folds and faults in their relations to the phosphate beds are illustrated in the geologic structure sections drawn along the lines H–H′ and I–I′ (pl. 11).

Phosphate beds.—The phosphate beds are not naturally exposed within this township and prior to the visit of the Survey party in 1912 had been prospected in only one locality, the NE. ¼ SW. ¼ sec. 16. Here two prospects were found about 100 feet apart in an eastward-trending line in the lower part of the phosphate shales. These prospects were examined by Mr. Peterson, and the following description is taken from his notes:

The west pit, P 129a, is about 12 feet long and 4 feet deep at the end. Good phosphate shows on the left side, but the thickness is not known as the digging only cuts one side of the phosphate rock (along the strike?).

The upper prospect, P 129b, about 100 feet east of the first mentioned, consists of an open cut about 25 feet long, 10 feet driven parallel to the bedding planes and 15 feet across to the right. Most of the material is like that in P 129a with some finer black shale badly disintegrated. Two good phosphate layers are shown, one about 18 inches thick like that in P 129a and one about 2 feet thick of slightly finer texture and a little more disintegrated. The prospect is in the lower part of the formation.

In the NE. ¼ NW. ¼ sec. 26 is located one of the three large cuts made under special authorization of the Survey in 1912. The cut was made on a northwestward-facing slope, where the shales are crossed by a transverse valley, and extends from the underlying limestone to the overlying chert in a direction practically at right angles to the strike. The depth of the overburden and of the zone of weathering proved to be greater than was anticipated. The cut is 300 feet long, 6 feet in average depth, and 10½ feet in maximum depth. The deeper portion is 140 feet long and 8 feet wide. The details of the cut are given in Table 47.

TABLE 47.—*Detailed section of cut in phosphate shales made by special authorization of the United States Geological Survey in the NE. ¼ NW. ¼ sec. 26, T. 6 S., R. 43 E. Boise meridian*

Field No. of locality		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
M-352-12	Remainder of cut 160 feet in float at depth 4 feet below surface without encountering bedrock in place; fragments chiefly Rex chert, including boulders as much as 3½ by 2 by 1 feet; assumed dip, 40°	*Per cent*	*Per cent*	*Ft. in.* 100
	Shale, brown, mostly weathered to clay containing fragments of shale			26
	Phosphate rock, coarsely oolitic, much weathered and broken but apparently in place and probably containing narrow shaly seams; fragments coated with mud, even at depth of 9 feet below the surface; sample 4 represents 2 feet of rock	28.85	63.00	2
	Shale, brown, not broken but weathered and largely reduced to clay			9
	Yellow band, probably a weathered sandy limestone; dip 45° E., flattening below to 22° E			6 in.
	Phosphate rock, brownish gray, thoroughly broken; the fragments are coated with mud film, and the bed probably contains some shale; the whole represents weathered rock in place, but too badly weathered, even at the depth of 11 feet below the surface, to preserve the bedding, which is shown by a yellow band just above:			
	Sample 3 represents upper 3 feet	34.20	74.70	7 (samples 3, 2, 1)
	Sample 2 represents middle 2 feet	31.92	69.74	
	Sample 1 represents lower 2 feet	32.58	71.16	
	Sandy clay, brownish and yellowish, contains small pieces of limestone and chert; no rock in place			32
	Thickness of phosphate shales			176 6

In sec. 7, T. 7 S., R. 43 E., and sec. 10, T. 6 S., R. 42 E., about 2 miles south and west respectively of the borders of this township, two other large cuts were made under special authorization of the United States Geological Survey. The details of these cuts are given in the descriptions of the respective townships. These cuts show the presence of a bed of phosphate at least 6 feet thick. Analyses of the rock sampled in the first cut show an average content of 32.90 per cent of phosphorus pentoxide, equivalent to 71.84 per cent tricalcium phosphate. The main bed in the second cut is not so high grade but has an average content of 28.42 per cent of phosphorus pentoxide, equivalent to 62.04 per cent tricalcium phosphate.

Estimate of tonnage.—These sections together with the section given above show that this township can be safely assumed to contain a phosphate bed 6 feet 6 inches thick of high-grade rock which probably carries at least 32 per cent of phosphorus pentoxide, equivalent to about 70 per cent tricalcium phosphate. The depth limit for withdrawal of areas underlain by such rock, according to survey regulations, is 5,000 feet. The area of this township underlain by phosphate rock within the maximum depth is about 19,360 acres. Under these conditions and with the further assumption of an average dip of as much as 30°, it is computed that there are about 512,709,000 long tons of high-grade phosphate rock in this township, counting only the main bed, which lies near the base of the phosphate shales. At least one higher bed of high-grade rock, which may also become economically valuable, is known to occur in the formation.

Although the phosphate beds come to the surface in three general bands the deposits as a whole lie at depths of 1,000 to 3,000 feet. The greatest depth is reached in section 13, where the beds are approximately 4,700–5,000 feet below the surface. The beds are probably below the level of ground water for the most part, and in Enoch Valley they are also in part at least below a basaltic cover. These facts would have a notable bearing on the cost of mining the rock.

T. 7 S., R. 43 E.

General features.—The northern boundary of T. 7 S., R. 43 E., is a correction line which cuts off a strip about 0.3 of a mile wide from the northern tier of sections.

This township forms part of the Lanes Creek quadrangle. (See pl. 4.) The Wooley Range and its subordinate member, the Fox Hills, form the principal highlands, but outlying portions of the Aspen Range and of Schmid Ridge are also represented. Wooley Valley and Lower Valley are the principal lowlands, but a portion of Rasmussen Valley is also included. Blackfoot River also crosses the township from east to west but makes a loop toward the south.

Geology.—The oldest rocks of the township are referred to the Brazer limestone (upper Mississippian), which lies along the east side of Wooley Valley. The overlying Wells formation (Pennsylvanian) occupies areas on both sides of the Brazer belt and also other smaller areas in the northwestern and southeastern parts of the township. The principal exposures of the Phosphoria formation occur in a northwesterly trending band in the northeastern part of the township. This band bifurcates toward the southeast. Other exposures of this formation occur in the southeastern and northwestern parts of the township. Triassic formations (Woodside and Thaynes) occupy the remaining highlands. Tertiary conglomerates (Salt Lake formation) cap several low hills west of Blackfoot River in the southwestern part and Quaternary sediments occupy the valley floors and lower slopes. Near the center there is a considerable area of basalt in Wooley Valley.

The principal structural features that contain the phosphate beds are the Georgetown syncline, which occupies the northeastern part, the Schmid syncline in the southeastern part, and the northern extensions of the Slug Creek and Trail Creek synclines in the western part. The Wooley Valley anticline separates the Georgetown syncline from the Slug Creek syncline, and minor anticlines occur in the western part.

The Blackfoot fault crosses the township from east to west near the center and cuts and offsets practically all the northeastward-trending structural features. The Henry and Wooley Ridge faults are not recognized south of the Blackfoot fault, but the Slug Valley fault, which supposedly cuts the Blackfoot fault, probably continues far to the northwest. The Johnson fault and other unnamed faults enter the township from the south. The structural features above mentioned and other structural details are shown in the geologic structure sections drawn along the lines I–I′, K′–K″, and M–M′. (See pl. 11.)

Phosphate deposits.—The phosphatic shales show the usual grouping of shales, phosphate beds, sandstones, and limestones in most places, but in section 7 they have in addition some dense, dark, somewhat siliceous members that develop in weathering colors from buff to terra cotta and resemble portions of the Rex on the one hand or portions of the Woodside on the other. This facies constitutes a variation not elsewhere well observed. The thickness of the shales is about 150 feet and of the Rex chert about 450 feet.

The Rex chert member displays both the massive chert facies, especially in section 13, where it forms a veritable wall, and the flinty shale facies, especially in section 7. Both facies are represented at most localities. The flinty shale facies appears to represent the upper part of the Rex chert member where both facies are present.

Prior to the visit of the Geological Survey party in 1912 no prospecting in the phosphatic shales had been done. In that year a partial section of the shales was made by the survey under special authorization. A cut was first attempted on the hillside in the NW. ¼ SE. ¼ sec. 7. When operations disclosed the existence of an unsuspected fault at this place, the cut was abandoned and a new prospect was opened on the top of the hill in the NE. ¼ SW. ¼ sec. 7. Only the lower portion of the shales could be examined here, but the presence of a workable bed of high-grade phosphate rock was clearly established. A detailed section of the cut is given in Table 48. The cut is 270 feet long, 7 feet wide, and 2 to 6 feet deep. The cut was started at right angles to the strike of the under limestone (top of the Wells), but owing to the synclinal structure of the shales the strike of these beds was found to swing nearly at right angles into parallelism with the line of the cut.

TABLE 48.—*Partial section of the phosphatic shales in the cut made by the Geological Survey under special authorization in the NE. ¼ SW. ¼ sec. 7, T. 7 S., R. 43 E. Boise meridian, 1912*

Field No. of locality		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
M-348-12	Limestone, purplish, drab and sandy; apparently makes remainder of cut; broken and not well exposed			4±	
	Phosphate rock, gray, medium oolitic, in layers about ½ to ¾ inch (sample 4)	34.48	75.26		9
	Phosphate rock, black with thin shale partings and shaly seams, too dirty for sampling			1	3
	Shale, black, in thin beds that show a few scattering oolites and with tiny streaks of finely oolitic phosphate				6
	Limestone, brownish drab to black			1	
	Shale, black, nonphosphatic or only slightly so			10	
	Sandstone, gray to purplish drab; calcareous material containing a few scattered oolites at base; poorly exposed and broken			4	
	Phosphate rock, gray, medium to coarsely oolitic, thinner bedded below (sample 3)	32.90	71.80	2	6
	Phosphate rock, thin, black, shaly, fine to medium oolitic, in beds $\frac{1}{16}$ to ½ inch (sample 2)	33.28	72.66	2	
	Phosphate rock, coarsely oolitic, in beds 1 to 3 inches thick with some yellow sandy material distributed through the lower portion (sample 1)	32.53	71.06	1	6
	Thin-bedded dark limestone and brown shale poorly exposed, the shale markedly micaceous; near the under limestone but not shown in the cut is a bed of coarsely oolitic phosphate rock 6 inches or more thick, which is indicated by fine float all along the underlying limestone			25±	
	Underlying limestone.				
	Thickness of exposed portion of phosphate shales			52	6

From the section shown in the above table and from the sections given in the descriptions of T. 6 S., R. 43 E., and T. 6 S., R. 42 E., the conclusion seems justifiable that the Phosphoria formation in T. 7 S., R. 43 E., includes near the base a 6-foot bed of high-grade phosphate rock that averages at least 32 per cent phosphoric acid or about 70 per cent tricalcic phosphate. The limit of depth for mining rock of this thickness and quality is 5,000 feet, according to Survey regulations (p. 215).

Tonnage and depth.—It is estimated that about 16,320 acres in this township is underlain by phosphate rock of the grade and thickness mentioned above. The rocks are not horizontal but dip on the average as much as 20°. On this basis it is estimated that 16,320 acres underlain by a 6-foot bed would yield approximately 365,377,000 long tons of high-grade phosphate rock.

The depth of the rock is probably nowhere greater than 3,000 feet below the surface, and in most places it is less than that figure. Probably much of the rock is below ground-water level. Also considerable areas are under cover of alluvium and of basalt. These factors would have a notable bearing on the cost of mining operations.

T. 8 S., R. 43 E.

General features.—This township is mainly in the Slug Creek quadrangle, but the northern tier of sections is in the Lanes Creek quadrangle. (See pls. 4 and 6.) Most of the township lies in the Aspen Range, but Schmid Ridge enters the northeastern part. The principal lowlands are the valleys of Trail, Slug, and Johnson Creeks. These physiographic features are described in the chapter on geography. The geologic formations are described in the chapter on stratigraphy, and the principal folds and faults in the chapter on structure.

Geology.—The oldest rocks exposed are of Pennsylvanian age (Wells formation). They occur in the southwest corner, in the northeastern part, and in a somewhat interrupted diagonal belt that extends from a place near the middle of the northern boundary to the southeast corner of the township. The Phosphoria formation is exposed in a broad area along the eastern side of this belt and also in belts along the northeastern and southwestern boundaries and in local smaller areas. Triassic rocks, Woodside and Thaynes, underlie most of the western half and also smaller areas in the northern and northeastern parts. Tertiary conglomerates (Salt Lake formation) cap small hills in the valley of Trail Creek and occupy low slopes west of Johnson Valley. Quaternary sediments form the valley floors and some of the adjoining lower slopes.

The principal folds with which the phosphate beds are associated are the Schmid syncline, the Slug Creek syncline, and the Trail Creek syncline. The Aspen Range anticline separates the Schmid and Slug Creek synclines at the south, but this anticline is broken by the Slug Valley fault, which bifurcates southward. An unnamed anticline separates the Slug Creek and Trail Creek synclines at the north, but in this township the anticline is broken by the Johnson fault. Other minor folds and faults are indicated on the map. The structural features of the northern part of the township are shown in the geologic structure section drawn along the line M–M′ (pl. 11). A similar structure section along the line O–O′ (pl. 12) is drawn just south of the township, but it illustrates many of the structural features of the southern part,

Other structure sections for this township are given in another report.[23]

Phosphate deposits.—The quality of the phosphate rock in this township is indicated by analyses of a rather unsatisfactory series of samples. The detailed partial section of the phosphatic shales encountered in the SW. ¼ SW. ¼ sec. 7, T. 8 S., R. 44 E., indicates that both in amount and quality the rock is inferior to that of the Georgetown Canyon section. These beds were measured in a shallow trench dug by the survey party practically on the east line of section 12, but owing to the presence of soil introduced into the many minute joints of the phosphate rock, the results may not be indicative of the actual quality of the rock where fresh. Another section measured in Trail Canyon just west of the township shows phosphate rock that is superior in quality and amount to that in the first section and compares well with the similar portion of the Georgetown Canyon section.

Samples were taken by the survey party from three openings made by Brown, Perkins & Co. on land located by them in unsurveyed section 31, just north of the Wood Canyon road. This property has since passed into the hands of the Anaconda Copper Mining Co. (See fig. 27.) The sections of the beds sampled and the analytical results are given in Table 49.

All these prospects are located a few feet back from the outcrop of the top of the gray limestone that underlies the phosphatic shales, and none of them are in high-grade phosphate rock. It appears that they are in the interval that corresponds to the 7 feet of brown shale measured at the base of the phosphatic member in the Trail Canyon section.

The upper part of a bed exposed in an opening on the Esmeralda claim, on the south side of the road (see fig. 27), yielded, according to L. P. Brown, 34.7 per cent of phosphorus pentoxide, equivalent to 75.8 per cent of tricalcium phosphate. At the time of the examination of this claim by the survey party in 1910 these pits were so filled that no measurements were made or samples taken. From data kindly supplied by R. J. Shields, of the Southern California Orange Grove Fertilizer Co., which had acquired the

[23] Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 410–413, 1911.

TABLE 49.—*Section of beds exposed in prospects north of Wood Canyon road, sec. 31, T. 8 S., R. 43 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
	Fourth prospect north of road				
		Per cent	*Per cent*	*Ft.*	*in.*
	Soil			1	
	Soil and broken phosphate rock			1	
	Phosphate rock, brown, medium oolitic, broken			1	
R-276-1	Phosphate rock, brownish black, medium oolitic, broken	28.8	63.0	1	
	Shale, phosphatic, oolitic in streaks				3
R-276-2	Phosphate rock, brown, medium oolitic	27.3	59.7	1	10
	Shale, brown				9
	Second prospect north of road				
	Limestone, brown, weathered				8
R-277	Phosphatic rock, brown, sandy, in part medium oolitic	15.5	33.8	3	10
	Shale, brown			1	6
	First prospect north of road				
	Soil			5+	
	Shale, black			2	
R-278	Phosphatic rock, brown, in part medium oolitic but mainly sandy and calcareous	11.5	25.1	3	
	Shale, brown			1	6

property from Brown, Perkins & Co., it appears that a fault occurs in the phosphatic shales north and south of the Wood Canyon road. This company drove four tunnels, with a maximum length of 130 feet, in a distance of about 2,300 feet along the outcrop and encountered the fault in three tunnels. The disturbance produced by this fault doubtless accounts for the poor showing of phosphate in the prospects above cited. The property has since passed into the hands of the Anaconda Copper Mining Co. When this township has been prospected more thoroughly the probable presence of high-grade phosphate rock will probably be clearly demonstrated.

Tonnage estimate.—In spite of the meager data available for this township, the assumption of a 5-foot bed of phosphate rock that averages as much as 70 per cent of tricalcium phosphate is regarded as conservative, as greater thicknesses will probably be found upon more thorough prospecting. An attempt to estimate the area of the portion of the township occupied by phosphate raises a question whether the northern parts of the valleys of Trail and Slug Creeks have been so greatly incised prior to the present filling of the valleys that some portion of the Phosphoria formation has been removed. This action may have happened in Slug Creek Valley more probably than in Trail Creek Valley, for Trail Creek Valley lies largely in the Thaynes group, whereas Slug Creek Valley is excavated in Woodside beds. Moreover, the portion of Trail Creek included in this township is nearer its head than is the portion of Slug Creek. Allowance for the contingency suggested is made in the computation of tonnage by considering the beds as horizontal and disregarding the increased surface produced in the beds of a given area by folding.

The area containing phosphate includes all land occupied by the Phosphoria and Triassic formations, both where these formations crop out at the surface and where they are concealed by Tertiary or Quaternary sediments. It is estimated at 16,750 acres. On account of the fact that the smallest legal subdivision for classification or restoration is 40 acres, the total area held as phosphate land is somewhat greater—19,300 acres. A 5-foot bed underlying 16,750 acres would yield more than 293,150,000 long tons of phosphate rock.

The phosphate is all regarded as ultimately available, for the greatest depth from favorable points of entry is probably not much more than 2,000 feet. The probable presence of artesian basins, however, will increase the cost of mining in a large part of the area.

T. 9 S., R. 43 E.

General features.—T. 9 S., R. 43 E., is part of the Slug Creek quadrangle. (See pl. 6.) It lies almost wholly in the Aspen Range, but its southwestern part includes part of the broad valley of Bear River, though it does not reach the river itself. The township is cut by rugged canyons and is only partly surveyed, but the upper topography is relatively gentle. (See pl. 29, *B*.) There is no road across it, but a trail up the Middle Fork of Sulphur Canyon connects it with Slug Valley on the east by way of Johnson Creek. Nearly half the township is reserved as phosphate land, but on account of the complex geologic structure this land is irregularly distributed. (See pl. 42.)

Geology.—The oldest geologic formation present is the Brazer limestone (upper Mississippian), which enters the township in the southeastern part and occurs also at several places in the southwestern part.

Much of the eastern half is underlain by the Wells formation (Pennsylvanian), and it also occupies considerable areas in the southern and western parts. The uppermost member of this formation, which in an earlier report[24] was called the lowest member of the Park City formation, is worthy of comment. It is a white massive limestone, somewhat siliceous, and contains, near the top, bands of bluish chert from 1 inch to 8 inches thick. The color of this chert is a distinctive feature, for it is different from that of the other cherts of the region. The limestone carries an abundance of poorly preserved silicified fossils that resist weathering and stand out in little crescents from their more easily weathered limestone matrix. This feature serves as a valuable guide. The rock itself forms fine ledges and cliffs. (See pls. 21, *A*, and 48, *A*.)

The Phosphoria formation is exposed in a number of discontinuous bands, more or less irregular, that outline some of the principal structural features. No complete sections are available for study. The Rex chert occurs in both the flinty shale and the more massive facies, but the flinty shale type is more common. Light colors were seen here and there in the massive facies, especially in the southern extension of the Trail Creek syncline, where the color is buff to nearly white or even pinkish. This facies is nonfossiliferous in this township, so far as observed, but in sec. 4, T. 8 S., R. 43 E., similar rock contains abundant casts of fossils, largely crinoid stems. In that locality, however, the chert is accompanied by some limestone, whereas none has been observed in connection with these cherts in this township.

Triassic rocks are represented chiefly by the Woodside, though the lowermost Thaynes enters the township in section 5 (unsurveyed). The main occurrence is in the north-central part, but smaller areas are found farther southwest. Tertiary conglomerates (Salt Lake formation) occupy low hills and slopes that border Johnson Valley in the northeast and at the mouth of Diamond Gulch at the southwest. A large body of travertine extends from the mouth of Swan Lake Gulch to the southwest corner of the township. Quaternary sediments occur near the mouth of Diamond Gulch and in Johnson Valley.

The principal structural feature associated with the phosphate is the Trail Creek syncline, which practically originates in this township. It is bordered by marginal folds and faults, and a narrow, shallow portion is extended southward between two faults. The Aspen Range anticline, lies near the eastern border. The western and southwestern parts of the township are largely occupied by a complexly folded and faulted area. The Bannock overthrust lies along the foothills at the southwest. The structural features of the township, in so far as they have been interpreted, are shown in the geologic structure sections drawn along the lines P–P′, Q–Q′, R–R′, and S–S′. (See pl. 12.)

Phosphate deposits.—The phosphate beds of the folded area from Swan Lake Gulch in section 29 southeastward to section 33 have been well prospected, chiefly by the San Francisco Chemical Co. The pits are mainly grouped in three localities—on the north side of Swan Lake Gulch near its mouth (SW. ¼ sec. 29), on the north side of Diamond Gulch (NW. ¼ sec. 33), and on the ridge north of Dry Canyon (SW. ¼ sec. 33). Most of the exposures thus made are weathered, and caving has occurred in several of the pits. During the season of 1910 development was carried on by the San Francisco Chemical Co. at Swan Lake Gulch. The tunnel at the lowest prospect was cleared out and extended nearly due north for about 70 feet. A section of the phosphate beds measured at this tunnel is shown in Table 50.

[24] Richards, R. W., and Mansfield, G. R., op. cit., pp. 413–426.

TABLE 50.—*Partial section of phosphate bed in Swan Lake Gulch, in the NE. ¼ SE. ¼ sec. 29, T. 9 S., R. 43 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	*Per cent*		
R-388	Phosphatic rock, broken and folded against the main part of the bed			1	6
R-388-2	Phosphate rock, black and soft, but in place	33. 0	72. 0	2	5
R-388-3a	Phosphate rock, black, hard, medium oolitic	32. 0	69. 9	2	
R-388-3b	Phosphate rock, black, hard, medium oolitic	28. 5	62. 3	2	
	Shale, brown				6
R-388-4	Lower 3 feet of above exposure, fresh face	29. 5	64. 5		
				8	5

The strike of the phosphate beds is nearly north, and the dip, which is somewhat wavy, averages about 45° E. Neither top nor base of the main bed is exposed in this section. Other pits are located on the same hillside along the strike of the phosphatic shales, but they were not so well opened, and no measurements were taken from them.

In Diamond Gulch at a point near the valley floor in the NW. ¼ sec. 33, almost on the line of section 28 at the mouth of a partly caved tunnel, a practically complete section of the main phosphate bed was exposed. This is the only place in the township where the entire thickness of the main bed was observed, and nowhere was seen a complete section of the phosphatic shales. The measured section is given in Table 51.

TABLE 51.—*Partial section of phosphatic shales in Diamond Gulch, in the NW. ¼ NW. ¼ sec. 33, T. 9 S., R. 43 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	Per cent	Ft.	in.
M-316-a	Rather thick bed of phosphatic, sandy, and shaly rock, brown, more or less broken	(a)		2	7
b	Thin dark shale and limestone, mostly covered	18. 4	40. 19	3	
c	Dense phosphatic dark-brown limestone, slightly fossiliferous	1. 87	4. 08		4½
d	Dark phosphatic shales	28. 3	61. 8		8
e	Fossiliferous limestone, much broken and sheared	(a)			7
f	Brown shale	24. 3	53. 07		10
g	Brown sandy and shaly phosphatic rock with a few large oolitic grains	16. 6	36. 25		7
h	Coarse oolitic phosphate rock	33. 2	72. 5	5	
i	Light-colored limestone, somewhat oolitic and fossiliferous	8. 9	19. 44		7
j	Brown oolitic shaly phosphatic rock	24. 2	52. 85		11
k	Much broken zone, mainly phosphatic shales	15. 2	33. 20	3	4
l	Light-brown shales	3. 1	6. 77		8
m	Covered			1	
n	Limestone.				
				20	1½

a Less than 1 per cent.

In the tunnel in which the section was measured, which runs approximately north and south, the available exposures are somewhat weathered and the phosphatic shales are nearly horizontal. The beds on the west side are much more broken than those on the east side, where the measurements were made. The layer marked "e" in the table apparently corresponds to the "cap lime" of the Georgetown and Montpelier districts and above that are included about 6½ feet of the overlying shales and limestones. The highest grade bed of rock phosphate is 5 feet thick; it is separated from the "cap lime" by about 17 inches of lower-grade shales and is underlain by 6½ feet of shales and limestones, some of which are oolitic and phosphatic.

Although the rocks at the tunnel are horizontal, the fact that several of the beds are broken and sheared indicates disturbance due to the proximity of faults and folds as indicated on the map.

About 1,200 to 1,300 feet southwest of the tunnel lies a series of pits that runs up the northwest side of the gulch. These pits indicate the presence of the main phosphate bed but do not afford good opportunities for measurement.

In the upper part of Diamond Gulch, in the SE. ¼ sec. 28, lies a small area of phosphate with its associated beds, apparently isolated by faults. Float of phosphate also occurs in proximity to the patch of underlying limestone (uppermost Wells) on the sag east of the valley in the SW. ¼ sec. 27 and for about 160 feet down the slope to the west, but there appears to be no actual body of phosphate rock at that place. Another occurrence at the very head of Diamond Gulch, in the NW. ¼ sec. 27, represents the southern tip of the southeastern extension of the Trail Creek syncline. This occurrence represents probably the only considerable body of phosphate in Diamond Gulch aside from that in sections 33 and 32. It is apparently continuous through section 22 with the Trail Creek syncline itself. At the time of the writer's visit in 1910 no prospects had been opened in this area, but samples of float that were analyzed at the laboratory of the Geological Survey yielded 31.9 per cent of phosphorus pentoxide, equivalent to 69.67 per cent of tricalcium phosphate.

The thickness of the phosphate series below the "cap lime" in this district appears to be somewhat greater than in the Georgetown and Montpelier sections, for it amounts to as much as 12 feet 11 inches in the Diamond Gulch section and to more than 8 feet 5 inches in the Swan Lake section, whereas in the Georgetown and Montpelier sections it does not exceed 6 or 7 feet. The greater thickness of this part of the phosphatic series in this township seems to be due to an increase in the thickness of the accompanying lower-grade phosphatic shales. This increase is, however, accompanied by a slight decrease in the thickness of the main bed itself. In the Swan Lake Gulch district some thickening should probably be ascribed to the folding that has occurred there. The syncline that extends northwestward from section 33 into section 29 becomes recumbent toward the east on the north side of Swan Lake Gulch, so that in the saddle, on the ridge top above the tunnel of the San Francisco Chemical Co., the phosphate beds are entirely reversed in position and lie horizontal but upside down. (See pl. 46, *A*.) The structure is further complicated by the thrust fault that cuts off the top of the recumbent syncline and by the normal fault that cuts off the fold on the east. The tunnel lies southwest of the axial plane of the syncline but probably near enough to it to include a part of the thickened area.

From the NW. ¼ sec. 6 and southeastward along the margin of the Trail Creek syncline extends a group of prospected claims that were originally located by Brown, Perkins & Co. but later purchased by the Southern California Orange Grove Fertilizer Co., and still later sold to the Anaconda Copper Mining Co. (See fig. 27.)

In sections 6 and 7 a thrust fault along the west flank of the Trail Creek syncline cuts out the phosphate for about 1½ miles. In the NW. ¼ sec. 17, the rocks are much disturbed by folding and by proximity to the thrust fault. In the SE. ¼ SE. ¼ sec. 17 several pits have been opened on the high point between the branches of South Sulphur Canyon. The underlying limestone here forms fine cliffs, the tops of which stand 500 feet above the valley floor. Above the cliffs the phosphate beds are worn back in a broad flat, which rises eastward into the interior of the Trail Creek syncline. (See pl. 21, *A*.) The strike of the underlying limestone here is N. 33° W. and the dip 10° NE. About 100 feet back from the edge of the cliff three phosphate pits have been opened. The deepest pit was measured and samples were collected in it for analysis. The results are shown in Table 52.

TABLE 52.—*Partial section of phosphate beds in the SE. ¼ SE. ¼ sec. 17, T. 9 S., R. 43 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	*Per cent*		
	Dark, fossiliferous limestone ("cap lime"), broken				10
M-377-a	Earthy and shaly phosphate with some organic matter	31. 7	69. 23		10
b	Main bed, rather coarsely oolitic phosphate	32. 6	71. 2	2	
	Base not exposed.				
				3	8

The general structure here seems to indicate that the phosphate beds pass with gentle dip into the Trail Creek syncline and that the beds are present in their usual thickness and in a relatively undisturbed condition.

In 1914 the Southern California Orange Grove & Fertilizer Co. was actively developing the phosphate beds in section 17. It had continued a road up South Sulphur Canyon to its properties and had driven four tunnels.

In the SW. ¼ sec. 21, near the north line, several phosphate pits occur above the high cliffs of underlying limestone that stand nearly 1,000 feet above the floor of Swan Lake Gulch. The conditions here are very similar to those in the SE. ¼ sec. 17, just described. The "cap lime" appears in one or two of the pits, but the base of the phosphatic shales is not exposed. About 1,000 to 1,200 feet northwest of this area, in a small gulch in the SE. ¼ NW. ¼ sec. 21, phosphatic float occurs in the midst of an area of Rex chert. Samples of the float at this locality yielded 26.2 per cent of phosphorus pentoxide, equivalent to 57.3 per cent of tricalcium phosphate.

In the NW. ¼ SE. ¼ sec. 29, on the north side of Swan Lake Gulch just above the bottom, there is a phosphate prospect that consists of a tunnel about 30 feet long. This prospect belongs now to the Anaconda Copper Mining Co. (See fig. 27.) About 7 feet of phosphatic shales with beds of limestone and phosphate rock with calcareous nodules is exposed. The phosphate rock is much sheared. Immediately above the prospect lie massive ledges of Brazer limestone, much brecciated but with apparently gentle northerly or undulating dips. Immediately west of the phosphate a massive ledge of limestone is let down by a small fault. The explanation of the presence of the phosphate at this locality is not clear. It may perhaps represent the Mississippian phosphate bed, which elsewhere is known to lie at the base of the Brazer limestone. This correlation is regarded as improbable because the full thickness of the Brazer does not appear to be present at this locality and the base is probably faulted out. A sharp fold that involves the Wells and Phosphoria occurs to the southeast on a low point above the canyon. This fold may be a broken anticline in which the Phosphoria at the prospect and the Phosphoria on the hillside may represent opposite limbs. Under the structural conditions at and near the prospect there seems no likelihood that the phosphate at that locality can have commercial value.

On the northeast side of Dry Fork, in the SW. ¼ NE. ¼ sec. 2, an anticlinal fold brings the underlying limestone above the valley floor in a low cliff, and the presence of the main phosphate bed is indicated by float. This section had not been prospected at the time of the writer's visit in 1910. Farther northeast, in section 1 and the adjoining township on the north, extends a faulted transverse syncline, which there depresses the axis of the Aspen Range anticline sufficiently to preserve beds of the Phosphoria formation.

So far as observed in this township the main bed lies near the base of the phosphatic shales and has a thickness of 6 inches to 3 or 4 feet of brown to black shales, more or less phosphatic, between it and the underlying limestone.

Estimate of tonnage.—In computing the acreage on which to base the estimate of tonnage for this township the areas of complicated structure underlain by Woodside shale and the small areas where phosphate is actually exposed, though probably not in commercial quantity, are omitted from consideration. The areas classified as phosphate land are bounded as nearly as possible by the actual outcrop of phosphate or postphosphate rocks. The land so classified amounts to 10,640 acres. It is assumed that the main bed is at least 5 feet thick, which is a fair average according to observations throughout the general district. On this basis it is estimated that the township contains 186,215,000 long tons of high-grade phosphate rock. Practically the entire amount may be considered as available and as ranging from the surface to a maximum depth of 1,500 feet. Proximity to the Oregon Short Line Railroad makes the deposits of the southwestern part of the township the most accessible, although those in section 31 are probably near the maximum depth. The most extensive deposits lie in the Trail Creek syncline in the northern part of the township. This area consists in the main of high ground and is difficult of access from the west. On the northeast, however, the valley of Johnson Creek leads into the very heart of the syncline and exposes the phosphate beds, which have there been arched up by a transverse anticline. The valley ascends by an easy grade to this area, and there is already an excellent trail, which could with little labor be made into a good road.

T. 10 S., R. 43 E.

General features.—T. 10 S., R. 43 E., lies in the southwestern part of the Slug Creek quadrangle. The eastern half and the southern part of the township are occupied by the outlying hills and ridges of the Aspen and Preuss Ranges, where these two ranges join. The western half is largely lowland that is included in the valley of Bear River. The river itself lies along the southwestern side of its valley and beyond rise the foothills of the Bear River Range. The distribution of the reserved phosphate land is shown in Plate 42.

Geology.—The oldest rocks exposed in the township belong to the Swan Peak quartzite (Ordovician) and occur in the southwest corner. Devonian rocks (Jefferson limestone) are found only in three small areas, in sections 3, 4, and 11, respectively. The Madison limestone just crosses the township line into sections 24 and 25, but the Brazer occupies considerable areas in sections 1 and 2 and in sections 9, 10, 11, 14, 25, and 36. The Wells formation is exposed throughout much of the northeast half of the township. The Phosphoria is confined to small folded or faulted areas in sections 2, 3, 4, 10, 13, 14, 23, and 24. Triassic rocks (Woodside and Thaynes) occupy hills on both sides of Bear River at the south and occur in isolated areas in sections 4, 5, 14, 23, and 31, though they probably underlie also much of Bear River Valley. Wasatch beds (Eocene) occur in two irregular areas of high ground in the east half of the township. Beds of the Salt Lake formation are irregularly and extensively distributed, both as small isolated areas and in broad continuous areas. Travertine extends for more than 2 miles along the northwestern boundary and occurs in several areas near the center and toward the southeast. Quaternary sediments cover many sections in the west half of the township and include both the alluvial deposits along Bear River and broad, coalescing alluvial fans.

The eastern part of the township has generally synclinal structure, for the main area of the Wells there lies between the Aspen Range anticline on the east and an unnamed, faulted anticline on the west. The structure beneath Bear River Valley is perhaps broadly and gently synclinorial with a faint central anticline which represents the northward continuation of the supposed Nounan anticline. The Bannock overthrust crosses the southwest corner of the township and brings Ordovician rocks into contact with Triassic. Under the supposition of an arched thrust plane, which is the view represented on the map, the plane of the Bannock overthrust has been eroded away over Bear River Valley, but dips again eastward beneath the Carboniferous rocks in the eastern part of the township. The trace of the overthrust along the eastern side is concealed by later sediments. Alternative hypotheses regarding the Bannock overthrust are presented on page 157. The broader structural features of the township are shown in the geologic structure sections drawn along the lines T–T′ and U–U″. (See pl. 12.)

Phosphate deposits.—In section 3 considerable prospecting was done by the San Francisco Chemical Co. and others. The openings, with the exception of one or two short tunnels, were originally shallow and in 1910 were so filled by caving that the conditions of exposure were not favorable for examination.

A short tunnel on the north side of Fossil Canyon shows a 4-foot face of squeezed and recemented phosphate and limestone lenses. A number of pits higher on the hillside show partial exposures of similar broken phosphate rock. The next canyon south of Fossil Canyon is crossed by a narrow strip of the phosphatic shales, and a number of prospects have been opened on the slope to the north, all of which are close to the top of the underlying limestone. The best exposure in the face of a 30-foot tunnel was measured. (See Table 53.)

TABLE 53.—*Partial section of phosphate bed in the NE. ¼ SE. ¼ sec. 3, T. 10 S., R. 43 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
	Soil.				
B-88-a	Phosphate rock, brown, medium oolitic, broken, soft	31. 3	68. 4		9½
b	Phosphate rock, brown, medium oolitic, broken, soft	32.	70.		9
c	Phosphate rock, brown, medium oolitic, broken, soft	32. 1	70.		11
d	Phosphate rock, finely oolitic, with some brown shale	23. 8	52.		8
				3	1½

Neither the roof nor the floor of the bed is exposed in this section, but in a tunnel a short distance to the northeast a portion of what appears to be the same bed is overlain by 1 foot 6 inches of limestone that resembles the "cap lime" of the Montpelier district. A caved prospect in the NW. ¼ NW. ¼ sec. 11 showed indications of phosphate rock of fair quality on its dump, but the face of the bed was inaccessible.

In sections 13, 14, 23, and 24, a folded and faulted area containing the Wells, Phosphoria, and Woodside formations is cut off at the northeast by an oblique normal fault that brings in Brazer limestone and Wells rocks. Southwestward the Phosphoria and its associated formations pass beneath Tertiary rocks. The general structure suggested by the exposed portions is that of a northeastward-pitching syncline, in which the highest beds are Woodside. The syncline is broken by at least two faults besides the one which cuts it on the northeast. The chert in the eastern part of the area is much brecciated and of a somewhat unusual facies but is believed to be Rex. It forms a dip slope toward the north. A prospect in the phosphatic shales at this locality, which was examined by J. H. Bridges in 1910, showed 3 feet of black phosphate rock of medium oolitic texture, which would probably run over 65 per cent of tricalcium phosphate. The base of the bed was not exposed, but the roof consisted of the typical "cap lime" of the Georgetown and Montpelier districts and contained *Omphalotrochus* and other characteristic fossils. A higher prospect approximately in the middle of the phosphatic member showed a small amount of broken and apparently dislocated phosphate rock and several feet of phosphatic shale with interbedded lenses of limestone.

At a locality in section 23, which is part of the same general area, Mr. Bridges measured the section shown in Table 54.

TABLE 54.—*Partial section of phosphatic shale in the NE. ¼ SE. ¼ sec. 23, T. 10 S., R. 43 E.*

	Ft.	in.
Shale, brown, possibly phosphatic, mashed		9
Limestone, sandy, lenticular, shattered		2
Phosphatic shale, mashed, soft	2	
Limestone.		
	2	11

The dip of the upper Wells at this locality is about 50° W., whereas that of the phosphate bed is reported to be as low as 4°. The phosphatic shale member lies against a fault that is regarded as a continuation of the one which separates the Rex and Woodside farther northeast.

At the time of the writer's visit in 1914 no further developments in phosphate exploration were noted, but some revision of the mapping used in an earlier report was made.[25] In 1920 these claims, which are owned by David Follick, of Montpelier, were exploited for a time by the Merriman Potash Co. of Nebraska, by whom a small tonnage was shipped from Cavanaugh to their Nebraska plant for experimental work.

Estimate of tonnage.—The main body of the phosphate deposits occurs in the part of the township that is underlain by Triassic rocks, either outcropping or concealed by overlying Tertiary and Quaternary beds. If all lands supposedly thus underlain by phosphate were included in the estimate the total area on which to base the computation would approximate about 12,000 acres. In view, however, of the uncertainties of structure in the concealed area, especially in relation to the hypothesis regarding the Bannock overthrust, the boundaries of the classified lands have been made to conform as closely as may be with the actual outcrop of the phosphate or of the Triassic beds. The Triassic area in section 31 is not considered phosphate land because the proximity of the Bannock overthrust and the probable depth of the phosphate make remote any probable utilization of the phosphate. The land actually classified as phosphate-bearing is therefore limited to 4,840 acres. The assumption of a 5-foot bed seems warranted from the partial sections above mentioned and from the known thicknesses in neighboring townships. On this basis 4,840 acres would contain about 84,700,000 long tons of high-grade phosphate rock. The entire amount is considered ultimately available by shafts, which would cut the beds at depths probably not greater than 2,500 feet. The phosphate beds in this township possess the advantage of location on the Oregon Short Line Railroad. They are, however, largely beneath water level, and proper disposal of the water would add to the cost of mining operations.

T. 11 S., R. 43 E.

General features.—T. 11 S., R. 43 E., is mostly in the Montpelier quadrangle, but a narrow strip along the northern boundary is in the Slug Creek quadrangle. (See pls. 6 and 9.) Most of the township lies in the foothills of the Bear River Range, but hills in the northeast corner are associated with the Preuss Range. Bear River Valley and its tributary Nounan Valley are the principal lowlands, and these together occupy nearly half the township. Bear River itself crosses diagonally the east half. The area classified as phosphate land is shown in Plate 42.

Geology.—The oldest rock exposed is the Brigham quartzite (Cambrian), which, with the Garden City limestone and Swan Peak quartzite (Ordovician) occupy most of the hills west of Nounan Valley. No other Paleozoic rocks are exposed, but rocks of the Thaynes group underlie most of the uplands east of Nounan Valley. The Wasatch and Salt Lake formations (Tertiary) are exposed here and there, and the Quaternary formations include travertine, hill wash, and alluvium.

[25] Richards, R. W., and Mansfield, G. R., op. cit., pp. 426–429, 1911.

The principal structural feature of the township is the Bannock overthrust, the trace of which is concealed in Nounan Valley. West of that valley lie the Cambrian and Ordovician rocks, whereas to the east lie the Triassic rocks. The two groups are seen in actual contact just north of the township. Under the view here presented, that the thrust plane is arched and eroded, its eastern trace lies concealed east of the Triassic hills and a part of the thrust block which contains beds of possible Carboniferous or Triassic age may be presumed to underlie the alluvial fans and Tertiary beds between Bear River and the west base of the Preuss Range. Carboniferous beds on the eastern edge of this thrust block are actually exposed in Georgetown Canyon in sec. 4 of the adjoining township.

Beneath the eroded portion of the arched thrust plane the underlying thrust block is exposed in the Triassic hills. These rocks appear to have a poorly defined anticlinal structure. The phosphate-bearing rocks are associated with this anticline. The structural features above outlined are illustrated in the geologic structure section that is drawn along the line W–W′ (pl. 12).

Phosphate deposits.—No phosphate beds are exposed in this township, so that the thickness and character of those assumed to be present beneath the Triassic rocks must necessarily be inferred from the nearest known exposures, which are those of the Georgetown Canyon district, where exceptionally thick and rich beds of phosphate occur. The depth of the phosphate beds below the surface may reach a maximum of nearly 4,000 feet.

Estimate of tonnage.—For reasons similar to those given in the discussion of the preceding township the lands in this township classified as phosphate-bearing are restricted to 5,120 acres. If a thickness of 5 feet is assumed, which is regarded as conservative in view of the showing in Georgetown Canyon, this acreage would contain about 89,609,000 long tons of high-grade phosphate rock. This estimate is subject to qualification in view of the alternative hypotheses of structure set forth on page 157. The phosphate all lies below ground-water level, so that the problem of handling water would enter into any plan for exploiting the rock. The Oregon Short Line Railroad lies along the phosphate-bearing area and would be directly accessible to suitably placed shafts.

T. 12 S., R. 43 E.

General features.—T. 12 S., R. 43 E., is in the Montpelier quadrangle (pl. 9). It lies mainly in the foothills of the Bear River Range but along the eastern side includes part of Bear Lake Valley. Since the publication of the earlier report[26] some changes have been made in the geologic interpretation of this township.

Geology.—The oldest rocks are of Brigham quartzite and are exposed in the western part of the township. A small area of the Garden City limestone extends northward from section 26 into section 23. Ledges doubtfully assigned to the Rex chert occur in section 19. Triassic rocks are exposed only in section 2. The bulk of the township is underlain by the Salt Lake formation, but, in addition to the earlier rocks mentioned, Quaternary sediments occupy small areas in parts of Bear Lake Valley or of its tributaries.

The principal structural feature of the township is the Bannock overthrust. Unfortunately this great fault is exposed nowhere in this township, but from observed conditions in townships to the south and north it seems certainly to be present and to have profoundly influenced the geologic conditions here. The ledge of supposed Rex in section 19 is referred to the underlying block, but the ledges of Garden City limestone in sections 23 and 26 are referred to the upper block and are believed to be continuous beneath Tertiary cover with corresponding ledges in T. 11 S., R. 43 E. Under the hypothesis of anticlinal arching of the thrust plane the Thaynes ledges in section 2 are referred to the lower thrust block. The general structure of the township under this hypothesis is shown in the geologic structure section drawn along the line W–W′ (pl. 12). Alternative hypotheses of this structure are discussed on page 157.

The Tertiary beds, which are chiefly marly limestones and conglomerates that have a calcareous matrix, have been deformed, and some of the dips are as high as 50°. They have been crumpled into a series of folds whose axes have a north-south alinement, in general, parallel to the deformation of the older rocks. These folds may represent a continuation of movement along the same lines.

Former shore lines of Bear Lake may be recognized in the vicinity of Bern.

Phosphate deposits.—Although phosphate beds of good quality may underlie large areas in the eastern and southwestern parts of the township at depths considered available under existing regulations, the extensive cover and the uncertainties of structure make it impossible to determine the extent of these lands without systematic drilling.

Estimate of tonnage.—Because of the extensive cover and the probable presence of the Bannock overthrust, the lands classified as phosphate have been limited as nearly as may be to the actual outcrop of the Triassic beds. A ledge of supposed Rex chert lies in the SW. ¼ NE. ¼ sec. 19 in land not previously withdrawn. In view of the extensive cover and the uncertainties of structure in that vicinity that area has not been classified as phosphate land. The lands so classified in this township therefore include only 320 acres that comprise the north half of section 2 A 5-foot bed underlying an area of 320 acres would

[26] Richards, R. W., and Mansfield, G. R., op. cit., pp. 430–432, 1911.

yield about 5,376,000 long tons of phosphate rock. The maximum depth of the phosphate below the surface probably does not exceed 2,000 feet. The rock all lies below ground-water level and, except in the northeastern part, within 2 miles of the railroad.

T. 13 S., R. 43 E.

General features.—T. 13 S., R. 43 E., is in the Montpelier quadrangle (pl. 9). It lies along the western side of Bear Lake Valley and in the foothills of the Bear River Range. The area reserved as phosphate land is shown in Plate 42, The description here given is somewhat modified from that presented in an earlier report.[27]

Geology.—The oldest rocks are of Brigham quartzite and occupy the western side of the township. A small area of Ute limestone lies east of the quartzite in section 32. The Phosphoria formation forms a discontinuous narrow band east of the quartzite in sections 32 and 29. The Woodside shale and Thaynes group form irregular areas east of the quartzite and of the Phosphoria. The Tertiary is represented by a patch of Wasatch beds in section 33 and by patches of the Salt Lake formation on the outer slopes and hills south of Lanark. The Salt Lake also forms the hills north and east of Liberty and North of Ovid. Much of the east half of the township is underlain by Quaternary sediments. Former higher shore lines of Bear Lake may be traced northward across the township.

Two notable structural features are associated with the phosphate beds. The first is the Paris syncline, the axis of which extends in a curve northward from section 33 to section 5. Southeast of section 17 the axis is slightly arched, so that beds of the Thaynes are eroded away between that section and the southern part of section 33. The syncline is overturned along its western border, so that there the beds in general dip westerly although the stratigraphically higher strata lie to the east. The eastern limb of the syncline contains some minor folds nearly parallel with the axis and is partly concealed by Tertiary and Quaternary strata. The other feature is the Bannock overthrust, the trace of which lies along the hillside from section 32 northward to section 6. The upper fault block overrides the western limb of the Paris syncline and transgresses successive beds from the Phosphoria to lower Thaynes and then passes northward beneath Tertiary cover. Under the hypothesis of an arched thrust plane, the fault trace probably loops southward again beneath the Tertiary beds in the northern part. The concealed normal fault represented in the eastern part of the township in the earlier report has been omitted from the present map for reasons stated on page 149. The general geologic structure of the township as here interpreted is shown in the geologic structure section drawn along the line X–X′ (pl. 12).

Phosphate deposits.—No measurements or analyses of the phosphate beds in this township are available, but there seems no reason why these beds should not compare favorably with those of the Paris or Montpelier Canyon sections (see Tps. 14 S., R. 43 E., and 13 S., R. 45 E.), although along the fault zone they may be expected to differ in thickness or even to be locally cut out because of the disturbances incident to the faulting. In the body of the syncline, however, these disturbances should have produced little effect on the continuity and thickness of the phosphate beds.

Estimate of tonnage.—As a conservative basis for estimate it may be inferred that a 5-foot bed of high-grade phosphate rock is present. The number of acres held as phosphate land is 4,840. Such an area would contain 84,700,000 long tons of phosphate rock.

The maximum depth of the phosphate is probably nowhere greater than 1,200 feet. The line of maximum depth lies somewhat west of the trace of the axial plane because of the overturning of the syncline, but east of that trace the depth undoubtedly diminishes. The western limb of the syncline, at least, is largely above ground-water level.

T. 14 S., R. 43 E.

General features.—T. 14 S., R. 43 E., is in the Montpelier quadrangle. (See pl. 9.) It lies along the western side of Bear Lake Valley and includes parts of this valley and of the adjacent Bear River Range. The mapping given in an earlier report[28] is revised and some new data are presented.

Geology.—The entire Cambrian section is exposed in the southwestern part of the township, but the Brigham quartzite, which occupies a belt 1½ miles wide along much of the western side, is the Cambrian formation most closely related to the phosphate. The Swan Peak quartzite, much shattered, occurs in two ledges, one in Worm Creek Canyon in section 34, where it has been quarried for road metal, and the other at the mouth of the Spomberg tunnel and in a neighboring ledge in sec. 21. The Brazer limestone forms part of a ledge south of Worm Creek Canyon in section 34 and the Wells formation constitutes the remainder of this ledge and occurs in several ledges that emerge from beneath cover farther north. The principal exposures occur in Bloomington and Paris Canyons west of the phosphate beds. The upper beds of the Wells, as exposed in these canyons, are yellowish sandy limestones that probably represent a lower horizon in the formation than the light-colored siliceous and cherty beds which underlie the phosphate in T. 9 S., R. 43 E., and elsewhere. The Phosphoria formation in a faulted and interrupted band has been traced from the divide above Bloomington Canyon in section 27 as far north as section 29 in

[27] Richards, R. W., and Mansfield, G. R., op. cit., pp. 432–434.

[28] Richards, R. W., and Mansfield, G. R., op. cit., pp. 434–436.

T. 13 S., R. 43 E. The Woodside shale is exposed in sections 21 and 16 and thence northward through the township in association with the overlying Thaynes group. The Thaynes of Paris Canyon is noteworthy for its cephalopod fossils. Wasatch beds conceal the older rocks west and southwest of Bloomington in large areas. The Salt Lake formation occupies the lower slopes of the foothills across the township from south to north. Quaternary sediments underlie the eastern part of the township. Some of the former shore lines of Bear Lake may be recognized. Paris and Bloomington occupy deltas, built when the lake stood at the 5,950-foot shore line.

The principal structural feature related to the phosphate is the Paris syncline, the essential features of which were described in the discussion of the preceding township. The Phosphoria formation is more fully exposed along the western limb of this fold than it is in the township to the north, but in Bloomington Canyon and in the side gulch to the north it is broken and offset by several faults. The Bannock overthrust, which crosses the township from south to north, brings Cambrian beds into contact with Pennsylvanian to Triassic rocks. In Slight, Paris, and Bloomington Canyons the upper fault block is eroded back along the thrust plane sufficiently to expose both the Phosphoria formation and more or less of the Wells formation. Elsewhere the Phosphoria is overridden and partly concealed by the upper block. South of Bloomington Canyon the fault trace is concealed by Wasatch beds, but its approximate position is determined by the ledges that here and there protrude through the Wasatch cover.

In Bloomington Canyon and from Worm Creek southward the Bannock fault zone becomes complex, and rock slices containing formations from widely different horizons are brought into contact with each other. Thus north of Bloomington Canyon a slice of Swan Peak quartzite is interposed between the Wells formation and the Phosphoria. At the same locality (see Table 54) the phosphate beds are most probably caught in a similar smaller slice. In Worm Creek Canyon a slice of Swan Peak quartzite intervenes between the Brigham quartzite and the Brazer limestone and Wells formation, the last two of which are largely concealed. The Swan Peak rocks here and in Bloomington Canyon represent parts of a broken fold that has been traced for about 10 miles along the margin of the upper fault block. The nature and complexity of the structural features and of the rock slices, which now represent them, are shown in the geologic structure sections drawn along the lines Y–Y′ and Z–Z′ (pl. 12). The concealed fault along the east base of the hills shown in the map accompanying the earlier report is omitted from the present map for reasons given on page 149.

In the earlier report the phosphate beds were mapped as turning back northward, beneath cover, from Bloomington Canyon, to agree with the synclinal loop of the Woodside-Thaynes contact. They are now known to be offset in Bloomington Canyon and to reappear south of the canyon, though they are largely concealed by Wasatch beds. The structure in the canyon is obscure. The apparent offset may be due to sharp folding, but it is more probable that a fault similar to those north of the canyon, though with a larger horizontal component of movement, has produced the observed effect. The course of the phosphate bed has been traced by its float as far as the crest of the ridge in the NW. ¼ sec. 27. Beyond that point it becomes entirely concealed, but it is believed to curve southward, as suggested by the dotted lines, because of the Wells ledges in secs. 27 and 34 and because of the occurrence of what is thought to be Rex chert in the SE. ¼ sec. 3, T. 15 S., R. 43 E.

Phosphate deposits.—At the time of the writer's first visit, in 1910, the only prospects which had been opened in the phosphate shales were located in Bloomington Canyon and in a dry gulch leading off to the north in sec. 21. The sections of the phosphate beds measured at these places and the analyses of the samples taken are given in Tables 54 and 55.

Immediately west of bed n (Table 54) lies the wedge of Swan Peak quartzite, much shattered and with irregular contact. The clay east of the phosphate beds is an unusual feature and may have been produced in part by movements within the phosphatic shales. The dip steepens from 40° at the face of the tunnel to 62° in the phosphate beds. The phosphate beds pinch out on the south side of the tunnel but are well exposed on the north side.

The two prospects described in Table 55 are near together but not connected. The lower one is apparently located on the main bed, but the base is not exposed.

Up to 1920 little more had been done in the way of prospecting the north side of the canyon, but the discovery of phosphate float on the south side led to the opening of prospects on that side by H. H. Broomhead, of Bloomington, who kindly went over the property with the writer. These prospects show shattered phosphate intermingled with fragments from the upper beds of the Wells formation and discolored by red material infiltered from the overlying Wasatch beds. Float of phosphate may be traced along the sidehill and up on the ridge, but it is inconspicuous and more or less affected by red material from the Wasatch. In a prospect in the NW. ¼ NE. ¼ sec. 28, where the phosphate is best shown, the strike is nearly north and the dip 10° W. Beyond this point the band swings about S. 65° E. to the crest of the hill. The shattered condition of the rock indicates considerable movement.

In 1913–14 three prospects were opened in Paris Canyon by L. W. Bach on property belonging to

TABLE 54.—*Section of phosphatic shales and associated beds exposed in Spomberg's tunnel in the SE. ¼ NW. ¼ sec. 21, T. 14 S., R. 43 E.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
	Quartzite, shattered almost to powder, stained red in cracks (Swan Peak).			
	Fault.	*Per cent*	*Per cent*	*Ft. in.*
M-185-n	Phosphate rock, gray and brown, finely oolitic	31. 3	68. 3	6
m	Phosphate rock, gray, coarsely oolitic	30. 6	66. 8	1¾
l	Phosphate rock, gray, medium oolitic	33. 6	73. 4	8
k	Phosphate rock, gray, finely oolitic	31. 9	69. 7	1½
j	Phosphate rock, gray, medium oolitic	33. 7	73. 6	4
i	Phosphate rock, gray and brown, finely oolitic	34. 0	74. 2	9
h	Phosphate rock, gray, finely oolitic	34. 1	74. 5	10
g	Phosphate rock, gray, coarsely oolitic, weathered	33. 2	72. 5	1½
f	Phosphate rock, gray, finely oolitic, much jointed, weathered	33. 1	72. 3	1 11
e	Shattered zone			1
d	Phosphate rock, shaly, gray, finely oolitic and sandy, much jointed and weathered	29. 9	65. 4	9
c	Clay, yellow to gray, sandy at west	18. 5	40. 4	15
b	Slate, dark, carbonaceous?	8. 4	18. 3	80
a	Limestone, dark, with seams of gypsum	2. 5	5. 5	
				101 2¾

TABLE 55.—*Sections of phosphatic shales in two prospects in the SE. ¼ SE. ¼ sec. 21, T. 14 S., R. 43 E.*

Upper prospect

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
M-173-a	Shale, brown, phosphatic	19. 68	42. 98	1½
b	Shale, brown, phosphatic, broken and weathered; not sampled			8
c	Shale, brown, phosphatic	17. 01	37. 15	1½
d	Shale, brownish gray, broken and weathered; not sampled			9
e	Shale, brownish gray	12. 48	27. 26	2 1
f	Broken zone			1
g	Shale, brown	19. 72	43. 07	1 2
				5

Lower prospect

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
M-173-h	Soil			3 4
i	Phosphatic shale, gray, oolitic	24. 40	53. 29	2¼
j	Phosphatic shale, dark	30. 25	66. 07	6¼
k	Phosphatic shale, coarse	32. 06	70. 82	5½
l	Phosphate rock, gray, coarsely oolitic	32. 99	72. 05	2¾
m	Phosphate rock, gray, medium oolitic	32. 56	71. 11	1 4
n	Phosphate rock, gray, coarsely oolitic	30. 84	67. 35	1½
o	Phosphate rock, gray to black, somewhat coarser near base, much broken	33. 9	74. 03	2
				8 2¼

Margaret Grandi in the SE. ¼ sec. 8. The beds on the south side of the canyon had been accidentally exposed by erosion owing to the breaching of an irrigation ditch. A pit opened at that locality exposed 8 to 10 feet of crumpled beds of gray oolitic phosphate. A tunnel close to the pit and driven 130 feet obliquely to the strike had passed through 100 feet of broken phosphate, according to Mr. Bach. At the time of the writer's visit, in August, 1914, this tunnel was in too bad a condition to be examined. Some of the rock from it, according to certified analyses kindly loaned by Mr. Bach, ran as high as 78.28 per cent of tricalcium phosphate. The third prospect was an entry 60 feet long driven on the north side of the canyon. This prospect, however, proved to be entirely in black shale with some oolitic zones but all of low grade. The main bed was not exposed. Of nine samples collected from this tunnel by Mr. Bach and analyzed by commercial chemists, the best yielded only 48.94 per cent of tricalcium phosphate.

In 1917 the Western Phosphate Mining & Manufacturing Co., which had then acquired the Grandi property in Paris Canyon, began the production and shipment of phosphate rock, which was maintained more or less continuously for a time. This company later became the Western Phosphate Co. Its operations, together with those of the more recently organized Bear Lake Phosphate Co., are described below.

Western Phosphate Co.—The Western Phosphate Co. which formerly had offices in Salt Lake City, constructed a spur track more than 3 miles long from Paris to the mine. In September, 1920, the principal workings consisted of an entry about 2,000 feet long and an exploratory crosscut tunnel about 1,000 feet from the portal and 200 feet long. About 53 stopes were arranged along the entry at intervals of about 50 feet. The ore in the stopes was being removed for a distance of about 250 feet up the dip. Pillars were left at convenient intervals, to be subsequently withdrawn when the stopes are worked out. The equipment included an engine and compressor and machinery for crushing and drying the ore. The tracks from the entry to the crusher and bins were inclosed for protection from snow. Quarters for the men were provided near the mine. Plate 47, *A*, gives a general view of the workings. With a force of 20 men production at the time of the writer's visit amounted to about 150 tons a day, but with expected improvements and an enlarged force it was planned to more than double the output in a short time. The company had accumulated debts, however, and with the weakening of the phosphate market the mine closed down by the end of 1920. The property was later acquired by R. C. McIlwee and placed under the name Idaho Phosphate Co. but has not been operated.

The bed, as exposed in the workings, runs from 5½ to 6 feet thick and is locally 13 feet thick. It is overturned and offset by small faults but is practically continuous. The crosscut tunnel is reported to have struck a second bed of phosphate rock 12 feet thick, part of which is said to be of very high grade. The dip differs locally but is about 40° W. At a point in the entry sampled by the writer the dip was 37°, the thickness was 6 feet 10 inches, and the phosphate content of the rock, as subsequently determined in the laboratory of the United States Geological Survey, was 32.41 per cent of phosphorus pentoxide (P_2O_5), equivalent to 70.72 per cent of tricalcium phosphate. The same sample contained 0.23 per cent of vanadium pentoxide (V_2O_5), 0.18 per cent of chromic oxide (Cr_2O_3) and 0.28 per cent of fluorine.

Bear Lake Phosphate Co.—The Bear Lake Phosphate Co., with offices at Paris, Idaho, controls property that extends northward from Slight Canyon, in the NE. ¼ sec. 8, through the E. ½ sec. 32, T. 13 S., R. 43 E. In 1920 the company had made an entry along the phosphate bed for 1,000 feet and had driven a raise for air. The entry was strongly timbered, double tracked, and lighted electrically throughout. The equipment consisted of an electric motor, compressors, and storage bins (see pl. 47, *B*), but plans for additional equipment and large-scale production were in hand. At the time of the writer's visit there had been no production because the lease for the subsurface mineral rights in the part of the property that borders Slight Canyon was still pending. According to a recent press announcement the Bear Lake Phosphate Co. has been combined with the Idaho Phosphate Co., as stated below.

The phosphate bed, which runs generally north, is somewhat irregular both in direction and thickness, as might be expected from its proximity to the great overthrust fault immediately to the west. The thickness in the working, however, averaged about 4½ feet, and the rock was reported to contain about 72 per cent of tricalcium phosphate. At a point in the raise where a sample was taken by the writer the bed was 5 feet thick and the dip 30° W. Upon analysis in the laboratory of the Geological Survey the sample yielded 32.76 per cent of phosphorus pentoxide, equivalent to 71.52 per cent tricalcium phosphate. The sample also contained 0.28 per cent of vanadium pentoxide, 0.18 per cent of chromic oxide, and 0.91 per cent of fluorine.

Estimate of tonnage.—In the earlier report the assumption of an area of 3,840 acres underlain by a 4½-foot bed led to an estimate of over 60,000,000 long tons. From the data now at hand it seems probable that the area used for computation might be raised to 4,760 acres and the thickness of the bed to 5 feet without departure from conservatism. On this basis the township could furnish more than 83,300,000 long tons of high-grade phosphate rock. In this estimate the area underlain by the Salt Lake and Quaternary formations is not included, although they are with little doubt underlain in part by phosphate.

The maximum depth of the phosphate bed, which is in the axial area of the syncline in the portion occupied by beds of the Thaynes group, probably does not exceed 2,000 feet.

T. 15 S., R. 43 E.

No land in T. 15 S., R. 43 E., is now withdrawn as phosphate land, but brief mention of the township is made because of occasional reported discoveries of phosphate rock in it. Its geographic and geologic features are closely related to those of T. 14 S., R. 43 E., except that if the phosphate-bearing syncline is present it lies concealed beneath the later Tertiary and Quaternary sediments in the eastern part.

In the SE. ¼ sec. 3, near the east section line, there are ledges of rock believed to be Rex chert, but no float of phosphate rock has been found associated with them, although search was made. The Phosphoria formation here is probably included in a relatively narrow rock slice of the Bannock fault zone, so that if phosphate rock is present its quantity is probably not large. The silicification of the Wasatch ledges east of the Rex chert at this locality is doubtless due to hydrothermal action associated with renewed movement along one of the thrust planes of the fault zone.

Float of phosphate has been reported from the vicinity of Dry Canyon (St. Charles), but the formations exposed there and thus far recognized are all older than the phosphate, and the structure is highly complex, as shown in the geologic structure section drawn along the line Z–Z′ (pl. 12). Possibly an unrecognized sliver of the Phosphoria formation may be present in the complex.

One reported discovery of phosphate on the property of Nels Bunderson in St. Charles proved to be in Fish Haven dolomite, exposed along an irrigation ditch between St. Charles and Green Canyons in the SW. ¼ NE. ¼ (?) sec. 15.

A possible source of phosphate float is the Wastach formation, the conglomeratic beds of which contain fragments of many of the older rocks. The phosphate rock is generally too soft to be preserved in later conglomerates, but a few beds are hard enough and might be represented. Such fragments weathered from the conglomerates would have little bearing upon the occurrence of phosphate beds at the place where the float was found. An occurrence of phosphate in Ordovician strata, of scientific interest only, is mentioned on page 57.

One of the criteria used by prospectors in locating the phosphate beds is the fact that they generally form dark soil and that a belt of dark soil follows their outcrop in some places. Thus it has been said that a belt of dark soil extends into this township and indicates the continuation there of the phosphate-bearing shales. This dark soil, however, is not a safe criterion. Dark soils occur in many places in association with other rocks than the phosphate. In this township dark soils overlie the Brigham quartzite (Cambrian) in a belt that extends between Dry Canyon and Worm Creek in the E. ½ secs. 9 and 4.

To summarize the above data, it is not denied that phosphate may occur in this township, particularly in the eastern part, where the beds are covered, and that phosphate float of good quality may actually have been found in some places, but these finds do not imply the presence of the phosphate in commercial quantity in the foothills area.

In view of the complex structural conditions in the foothills and of the absence of borings of sufficient depth to determine the presence of phosphate in the eastern part of the township, no basis exists for considering any part of the township as phosphate land under the present regulations of the Geological Survey, and no estimate of tonnage is presented.

T. 5 S., R. 44 E.

General features.—T. 5 S., R. 44 E., lies mostly in the Lanes Creek quadrangle but includes part of the unmapped quadrangle on the north and a strip nearly a mile wide in the Freedom quadrangle. (See pls. 4 and 5.) The principal highlands are part of the Caribou Range, but in the southwest corner rise the foothills of Grays Range. The principal lowlands are northward extensions of the Upper Valley of Blackfoot River.

Geology.—The geologic formations range in age from the Woodside shale to the Quaternary, but Tertiary beds occur only in three small areas in Tincup Canyon. Most of the township is underlain by the Wayan formation, which here reaches its greatest known thickness. Basalt underlies most of the valley of Chippy Creek.

The principal structural features of the township are the Williamsburg syncline, which contains most of the Cretaceous beds, the Little Gray anticline, which enters the southwest corner, and the fault zone of the Bannock overthrust, which lies between the two folds named. The general structural features of the township, as here interpreted, are shown in the geologic structure sections drawn along the lines H–H′, I–I′, and J–J′. (See pl. 11.)

Phosphate deposits.—Beds of phosphate doubtless underlie much of the township, but, except in the southwest corner, they lie at depths of more than 5,000 feet and hence are not considered recoverable under existing regulations. No prospects or openings have been made in the phosphate, for here it may be reached only by the drill or a shaft, but in the adjacent townships to the south and southwest the quality and thickness of the rock are such as to justify the opinion that a 6-foot bed of rock that contains 70 per cent of tricalcium phosphate is present.

Estimate of tonnage.—Only the district southwest of the Bannock fault zone is here considered as phosphate land, and this comprises an area of about 480 acres. Such an area underlain by a 6-foot bed could furnish more than 10,080,000 long tons of phosphate rock.

The maximum depth of the phosphate is probably about 1,500 feet.

T. 6 S., R. 44 E.

General features.—T. 6 S., R. 44 E., lies mostly in the Lanes Creek quadrangle, but includes a strip about three-quarters of a mile wide in the Freedom quadrangle (pls. 4 and 5). The highlands that comprise the eastern half are part of the Webster and Caribou Ranges. Those along the western side belong to Grays Range. The intervening lowland, with Chippy and Lanes Creeks, is part of the Upper Valley of Blackfoot River.

Geology.—The oldest rocks belong to the Wells formation and are exposed in sections 4, 9, 31, and 32. The Phosphoria formation is exposed in association with the Wells at the localities named. In sections 4 and 9 the Rex chert member is represented by the less common coarse gray limestone facies with abundant crinoid stems. The thickness of the phosphatic shales and of the Rex chert is estimated at 150 and 450 feet, respectively. Rocks of the Woodside shale and Thaynes group occupy considerable areas in the western and central parts. The Timothy sandstone, Higham grit, Deadman limestone, and Wood shale, which follow in order above the Thaynes, are all exposed in both the eastern and western highlands. The Nugget sandstone and Twin Creek limestone form the higher and more rugged uplands in the eastern part. In the northeastern part a complexly faulted area includes higher Jurassic and some Cretaceous beds. A low hill in section 5 is composed of Tertiary rocks and the lower slopes and valley bottoms are occupied largely by Quaternary sediments. Basalt extends down the valleys of Chippy and Lanes Creeks as far as section 28.

The principal folded structures are the Webster syncline in the east and the Lanes Butte syncline and Snowdrift anticline in the southwest. The Little Gray anticline intervenes between the first two folds named. There are also other minor folds. (See the general map, pl. 1.)

The faulted complex in the northeast is part of the fault zone of the Baunock overthrust. The Lanes Creek fault cuts some of the folds above mentioned and passes up the valley of Lanes Creek. Other minor faults are indicated on the quadrangle maps (pls. 4, 5). The general structural features above outlined are shown in the geologic structure sections drawn along the lines I–I′ and K′–K″, Plate 11.

Phosphate deposits.—The phosphatic shales are not naturally exposed in this township, and at the time of the survey's examination in 1912 no openings in them had been made. Float fragments along the zone of outcrop indicate that rock of good quality may be expected. From data obtained in openings made by the survey in T. 7 S., R. 44 E., and T. 6 S., R. 43 E., it seems fair to assume that this township is underlain by a 6-foot bed of phosphate rock that has an average content of 70 per cent of tricalcium phosphate. The limit of workable depth for such a bed, according to existing regulations of the Geological Survey is 5,000 feet

Estimate of tonnage.—The area classified as phosphate land in this township is 10,440 acres. If the beds are horizontal such an area underlain by a 6-foot bed would yield about 218,437,000 long tons of high-grade phosphate rock. The beds, however are not horizontal but dip at angles that are estimated to average at least 20°. This fact would tend to increase the estimate. On the other hand, the presence of the Bannock overthrust may either cause the cutting out of the phosphate beds in some places or, by increasing the thickness of the cover, render some of the phosphate unworkable on the basis of the regulations above cited. The increase due to dip may therefore be offset by these other factors, so that it seems better to retain the estimate as given.

Although the phosphate comes to the surface in small areas at the localities cited, most of it is 1,000 to 3,000 feet deep, and where the Higham grit comes to the surface it is near the limit of workable depth. The areas occupied by higher formations are probably also underlain by phosphate but at depths greater than 5,000 feet. Much of the rock is beneath the level of the ground water, a fact that would doubtless have a notable bearing on mining operations. Also the presence of a basaltic cover in a large part of the valley might hinder the development of phosphate beds beneath it.

T. 7 S., R. 44 E.

General features.—T. 7 S., R. 44 E., lies entirely in the Lanes Creek quadrangle, but its north boundary is a correction line, so that the northern tier of sections is reduced in area. The principal physiographic features are Dry Ridge and Dry Valley in the southern and southwestern parts, Wooley Ridge, Rasmussen Valley, and Rasmussen Ridge in the northwestern part, and Upper Valley and Webster Range in the eastern part. Blackfoot River, which is formed by the junction of Lanes and Diamond Creeks in Upper Valley, flows southwestward through a picturesque canyon called The Narrows.

Geology.—The geologic formations range in age from the Brazer limestone to the Quaternary, but there are no Tertiary beds and no Mesozoic strata higher than the Twin Creek limestone. A small area of basalt separates Upper Valley from Rasmussen Valley. These formations and the general geologic structure are described in Chapters III, IV, and V.

The Phosphoria formation is well exposed in three general areas within the township: In the southwest corner, extending northwestward across section 31; in a band extending northwestward from the SE. ¼ SE. ¼ sec. 33 through sections 28 and 21; and two bands in secs. 6, 5, 8, 9, and 4. In addition the Rex chert member enters the SW. ¼ SW. ¼ sec. 18 from the adjoining township on the west, and in the SE. ¼ SE. ¼ sec. 24 and NE. ¼ sec. 25 the Rex chert member is exposed in low knolls. In each of these localities the Rex chert is chiefly represented by the massively bedded cherty facies, although the dark flinty shale facies is also present. The thickness of the phosphatic shales and Rex chert member is estimated at 150 feet and 450 feet, respectively.

Several of the principal folds of the region are encountered in this township, including the Snowdrift anticline in the northeastern part, the Georgetown syncline, the Dry Valley anticline, and the Schmid syncline. The Blackfoot fault crosses the township from east to west. Other noteworthy faults are the Lanes Creek and Enoch Valley faults, which apparently originate in the Snowdrift anticline, and the Henry fault, which affects the Georgetown syncline. These folds and faults are indicated in their relation to the general region on the small-scale map (pl. 1). The general structural features of the township are shown in the geologic structure sections drawn along the lines K′–K″ and M–M′ (pl. 11).

Phosphate deposits.—The phosphatic shales are not naturally exposed in this township, and prior to the visit of the survey party in 1912 no openings had been made in them. In August, 1912, the survey party made two openings in the SE. ¼ NW. ¼ sec. 9. One pit was made near the base of the phosphatic shales and the other near the top. The sections examined are shown in Table 56.

TABLE 56.—*Sections in phosphatic shales in the SE. ¼ NW. ¼ sec. 9, T. 7 S., R. 44 E. Boise meridian*

Section near base of phosphatic shales

Field No. of sample		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	*Per cent*	*Ft.*	*in.*
R-237-7	Shale, gray	26.37	57.5	3	
6	Shale, brown	19.57	42.76		6
5	Phosphate rock	30.29	66.2	2	7
4	do	30.55	66.67		9
3	Shale, phosphatic	25.08	54.8		7
2	Phosphate rock	29.07	63.5	1	
1	Shale, brown	6.47	14.14	1	6
	Wells limestone (?) not seen, but drill encounters hard rock.				
				9	11

Section near top of phosphatic shales

Field No. of sample		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
	Soil.				
	Clay and shale.				
R-236-7	Phosphate rock	31.8	69.4		6
	Shale, brown				2
6	Phosphate rock	33.36	72.8		11
	Shale, brown				2
5	Phosphate rock	33.64	73.4		5
	Shale, brown				3
4	Phosphatic shale	31.94	69.9	1	10
	Shale, brown				4
	Clay, sandy				3
	Shale, brown				4
3	Phosphatic shale	30.71	67		6
	Shale, brown, thin, oolitic streaks				10
2	Phosphate, medium oolitic, black	33.97	74.2		1½
	Shale, brown (rejected)				½
	Phosphate, medium to coarse oolitic, black			1	6
1	Phosphate, sheared, and brown shale	26.40	57.6	1	6
	Base of pit.				
				9	8

About 2 miles northwest of the township, in sec. 26, T. 6 S., R. 43 E., on the continuation of the band represented in sec. 4, T. 7 S., R. 44 E., is located one of the large cuts made by the Geological Survey under special allotment in 1912. The details of this cut are given in the description of T. 6 S., R. 43 E. Two beds were encountered—a bed 7 feet thick about 32 feet above the base of the formation and 10 feet higher another bed 2 feet thick.

In 1911 the Geological Survey party made an opening in the SW. ¼ SE. ¼ sec. 14, T. 8 S., R. 44 E., on the continuation of the phosphate band that runs southeastward through the central part of T. 7 S., R. 44 E., and about 3 miles south of that township. The details of that cut are given in the description of T. 8 S., R. 44 E. The thickness of phosphate rock near the base of that section was 14 feet, and near the top another bed of undetermined thickness was found. Analyses showed the rock to be of high grade. It was pointed out, however, that the unusual thickness of the phosphate rock might have been due to structural disturbances.

Notwithstanding the somewhat lower thickness of the phosphate beds shown in Table 56, it should be noted that the pits which furnished samples R-236 and R-237 show only a small part of the phosphatic shales and may fail to show valuable phosphate beds. The sections in T. 6 S., R. 43 E., and T. 8 S., R. 44 E., show that high-grade phosphate rock occurs in normal or even greater than normal thickness both to the north and to the south of the township. Also the band that enters sec. 33, T. 7 S., R. 44 E., is the northward continuation of a remarkably strong and well-developed band of the Phosphoria formation.

From these considerations it seems fair to conclude that the phosphate-bearing portion of the township is underlain by a bed of workable rock phosphate 6 feet thick which contains approximately 32 per cent phosphoric acid, equivalent to about 70 per cent tricalcium phosphate. According to survey regulations, the limit of workable depth for such a phosphate bed is 5,000 feet.

Estimate of tonnage.—The area in this township classified as phosphate land is 15,000 acres. Such an area underlain by a 6-foot bed would yield about 315,032,000 long tons of phosphate rock if the beds were horizontal. The beds are, however, inclined at different angles, so that the above estimate is too low. On the other hand, the Blackfoot fault perhaps cuts out some of the phosphate bed. The structural relations under the alluvium in Upper Valley are necessarily hypothetical, and there is a possibility that in that area the Snowdrift anticline may rise high enough to bring some of the phosphate above the level of erosion. From these considerations it seems wiser to disregard the possible increment due to dip and to retain the more conservative figure above given.

Much of this rock lies at depths between 1,000 and 3,000 feet and is probably below ground-water level. This would doubtless have a notable bearing on the cost of development of the phosphate rock.

Where beds higher than the base of the Higham grit appear at the surface, it is probable that the depth of the phosphate is greater than 5,000 feet.

T. 8 S., R. 44 E.

General features.—This township is largely in the Slug Creek quadrangle, but includes a strip about a mile wide in the Lanes Creek quadrangle (pls. 4 and 6). Its principal physiographic features are Dry Ridge and Dry Valley in the northeast half and Schmid Ridge and Slug Valley in the southwest half. An earlier description of the township has been published elsewhere.[29]

Geology.—The geologic formations range in age from the Wells formation to the Thaynes group, and Quaternary sediments occupy the lower slopes and valley floors. These formations and the geologic structure are described respectively in Chapters III and V.

The Phosphoria formation appears in three more or less continuous bands that trend northwesterly across the township. The exposure of the Rex chert member in Dry Ridge is exceptionally fine. There a dip slope extends from about section 23, unsurveyed, northwestward into T. 7 S., R. 44 E. (See pl. 29, *A*.)

The structural features represented in this township are the Georgetown syncline at the northeast, the Dry Valley anticline, which separates the two great phosphate-bearing areas near the middle, and the Schmid syncline at the southwest. A minor thrust fault cuts the Dry Valley anticline in the southeastern part and the Slug Creek thrust enters the southwestern part. The relation of this township to these major structural features is shown in the general map (pl. 1). The structure is illustrated in the geologic structure sections drawn along the lines M–M′ (pl. 11) and O–O′ (pl. 12).

Phosphate deposits.—Previous to the examination by the Geological Survey in 1910 no prospecting had been done in this township. In that year the survey party, in connection with the examination of the adjacent township on the west, made a shallow opening in the phosphate shales in the SW. ¼ SW. ¼ sec. 7. The section thus obtained and the analyses of the samples taken are given in Table 57.

[29] Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, pp. 39, 40, 1914.

TABLE 57.—*Complete section of phosphate-bearing strata of Phosphoria formation on tributary of Slug Creek, in the SW. ¼ SW. ¼ sec. 7, T. 8 S., R. 44 E. Boise meridian*

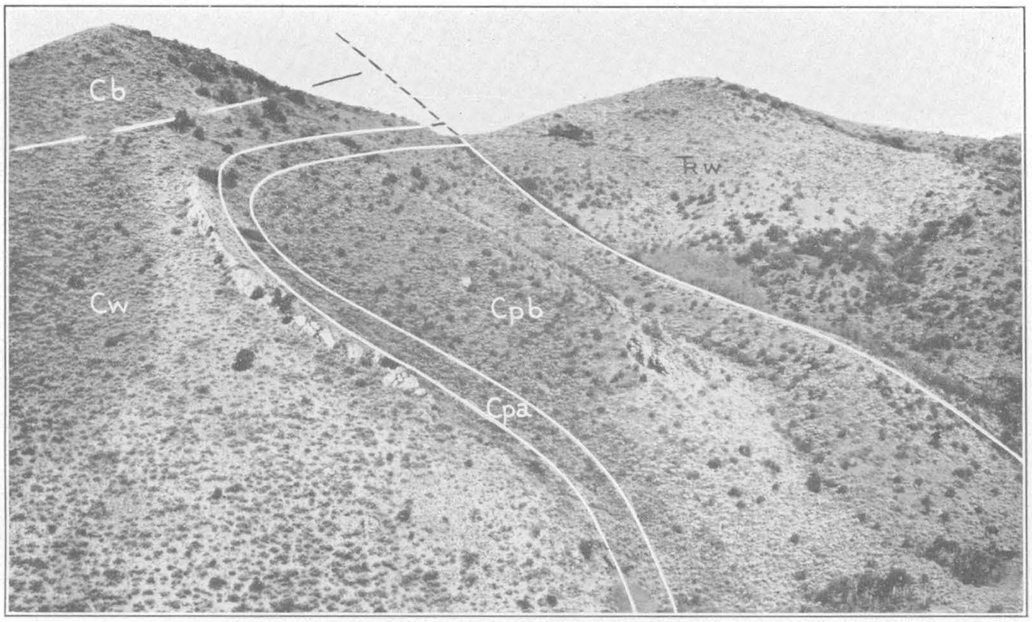
Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
	Sandstone, white, fine grained; weathers brown			10	
R-378-6	Shale, brown, sandy, with limestone lenses			47	
	Limestone, grayish black, fine grained, compact, fetid			5	
R-378-5	Phosphate rock, black, coarsely oolitic	26.3	57.5	1	
	Limestone, grayish black, fine grained, compact, fetid				6
	Shale, brown, with some oolitic streaks			1	
	Limestone, grayish black, fine grained, compact, fetid			1	6
	Shale, brown, with some oolitic streaks			1	
R-378-4	Phosphate rock, grayish black, medium oolitic	33.5	73.2		6
	Shale, brown, thin bedded, slightly oolitic			1	
R-378-3	Shale, brown, finely oolitic				10
	Shale, brownish black	6.6	14.4		8
	Limestone, gray, fine grained, fetid			2	
	Shale, brownish black				4
R-378-2	Phosphate rock, brownish black, finely to coarsely oolitic	29.4	64.3	1	7
R-378-1a	Phosphate rock, brownish black, shaly	17.2	37.6	1	4
R-378-1	Phosphate rock, brownish black, finely oolitic	27.5	60.1	1	4
				76	7

The analyses seem to show an unusually lean portion of the phosphate shales. The phosphate beds are thin and the content of phosphoric acid is low.

In 1911 the Geological Survey party made an opening in the naturally exposed phosphate shales in the SW. ¼ SE. ¼ sec. 14. Three pits were opened and offset in such a manner as to cover nearly the entire thickness of the shales. The measurements of the section and the phosphate content of samples are given in Table 58.

The table shows that the thickness of high-grade phosphate rock near the base of the shales is unusually great, amounting to 14 (?) feet, and that another bed of high-grade rock, whose thickness is not definitely known, occurs near the top of the shales, only a few feet below the chert. The map shows that both the sections referred to are in close proximity to zones of minor folding or faulting. Thus, the unusually thin and lean character of the one exposure and the unusually thick and rich character of the other may in some measure be connected with these minor movements. It seems fair, then, to assume that the phosphate deposits do not differ widely in average thickness and character from those of the neighboring townships, and that an average thickness of 6 feet of workable phosphate may safely be inferred.

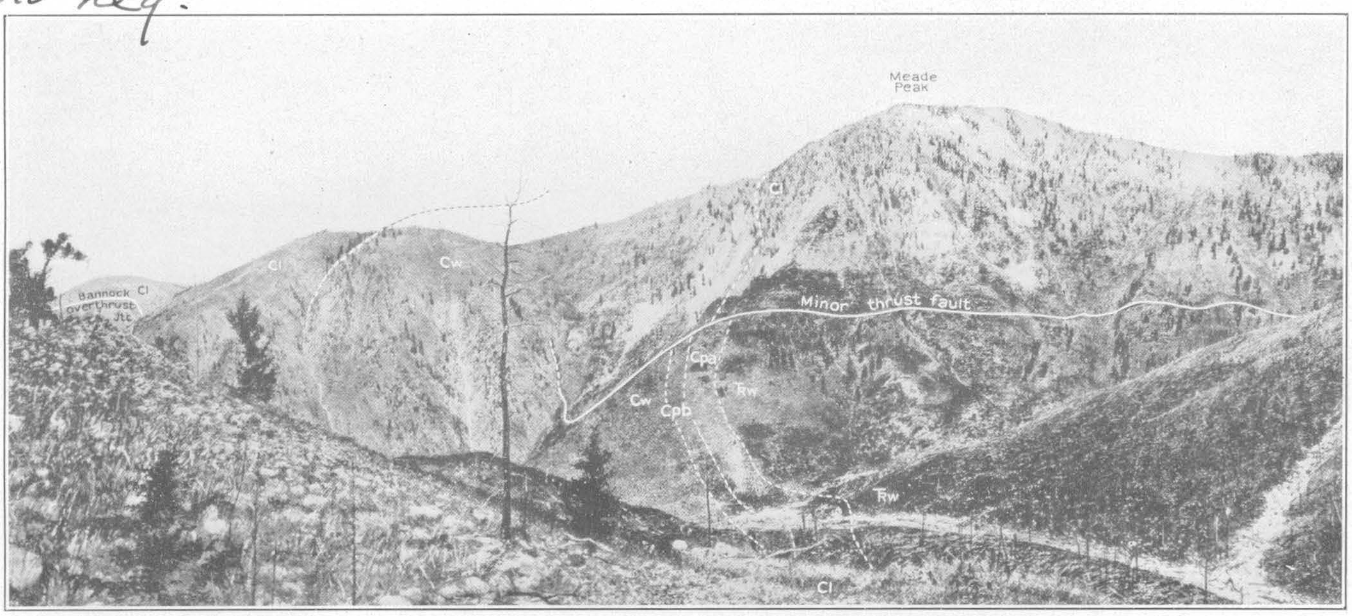
Mansfield, 10.



A. OVERTURNED AND FAULTED FOLD AT THE MOUTH OF SWAN LAKE GULCH (NORTH SIDE), T. 9 S., R. 43 E., SLUG CREEK QUADRANGLE

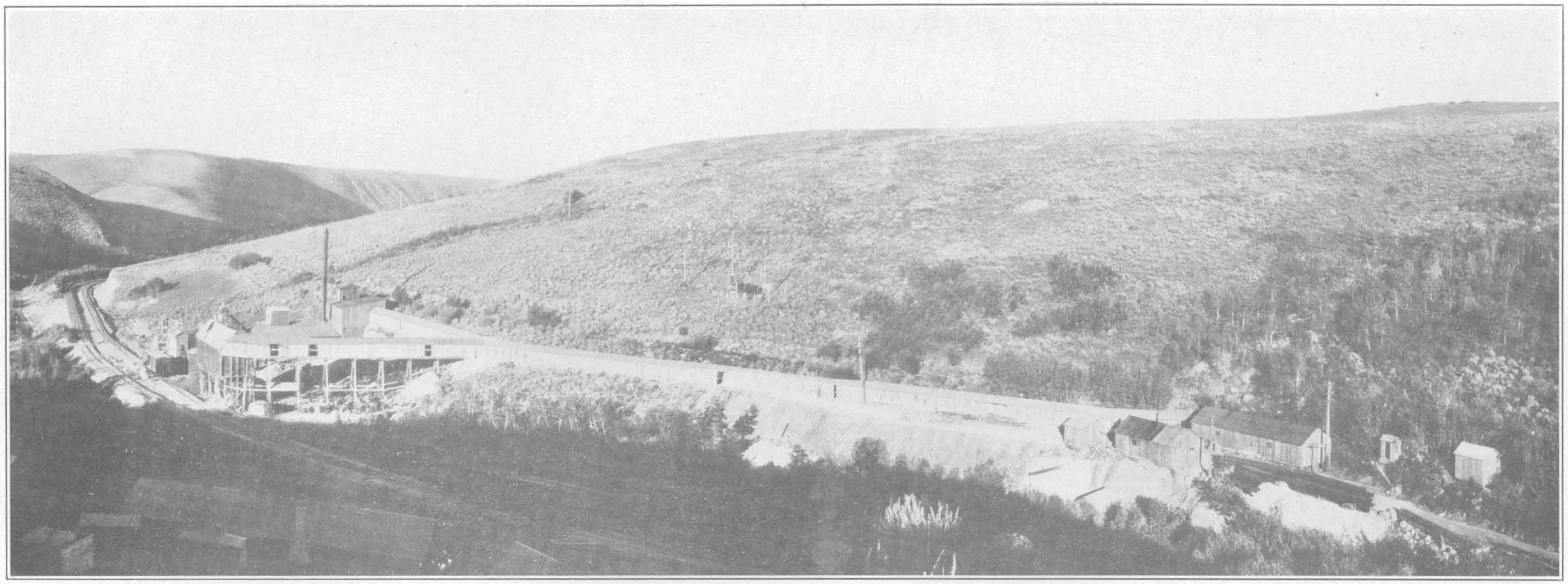
Cb, Brazer limestone; Cw, Wells formation; Cpa, Phosphoria phosphatic shales; Cpb, Rex chert member of Phosphoria formation; Ꞧw, Woodside shale

No neg.



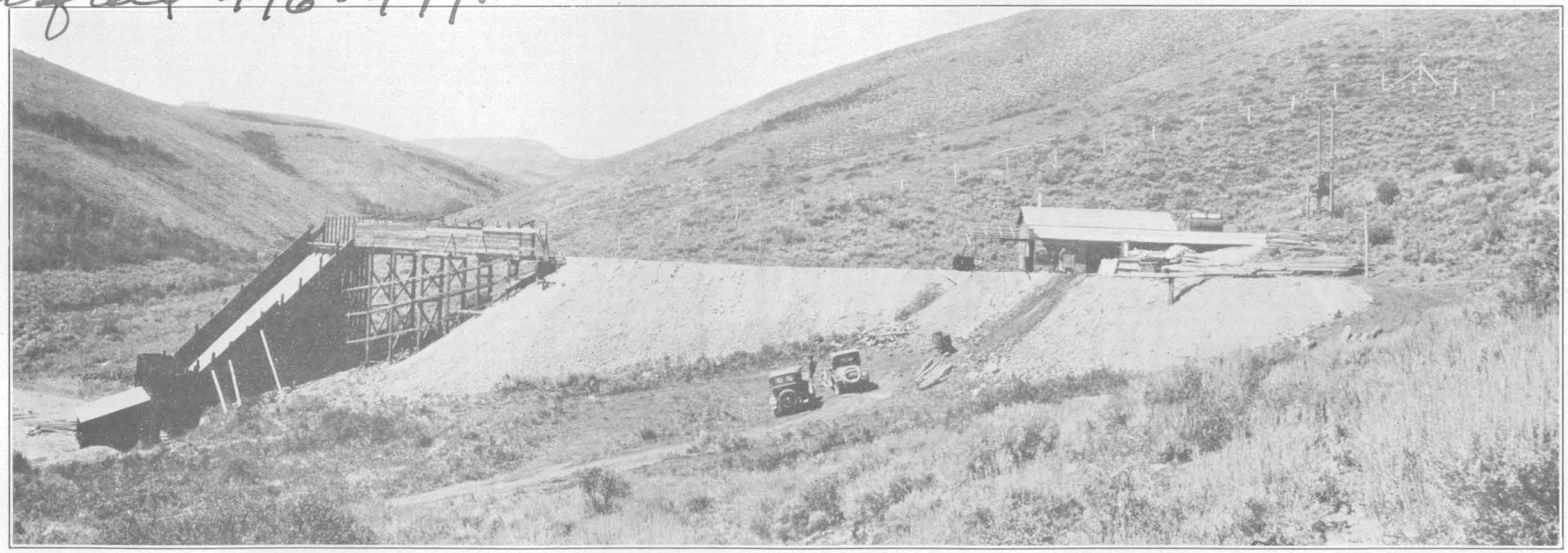
B. MEADE PEAK AND SOUTH CANYON, FROM RIDGE IN CENTER OF SEC. 12, T. 11 S., R. 44 E.

Cl, Mississippian limestone; Cw, Wells formation; Cpa, Rex chert member of Phosphoria; Cpb, Phosphoria phosphatic shale, etc.; Ꞧw, Woodside shale; Jtc, Twin Creek limestone



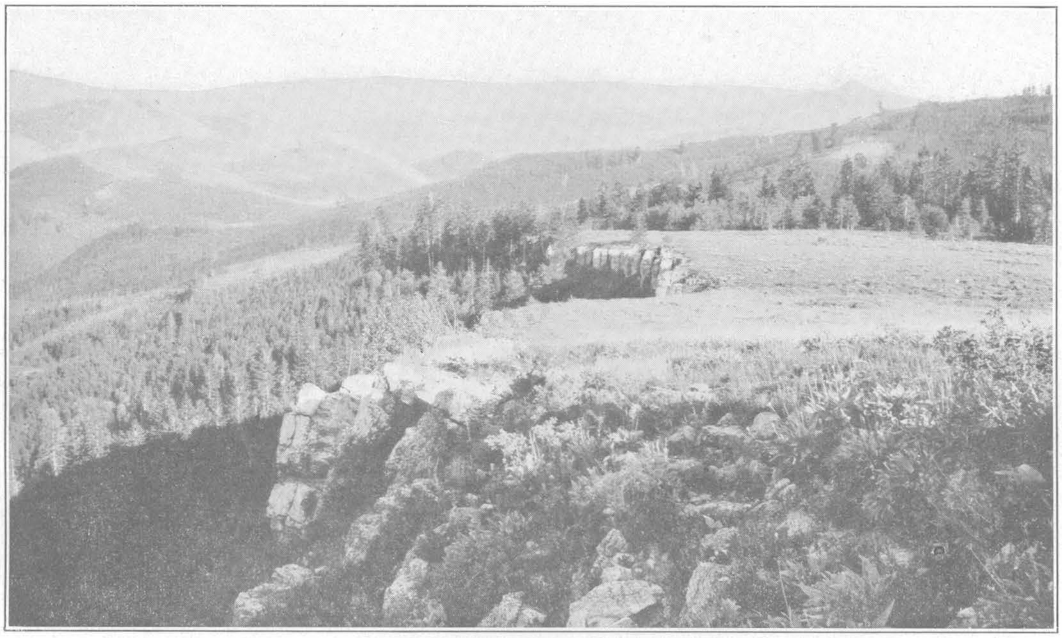
WESTERN PHOSPHATE CO.'S MINE IN PARIS CANYON, T. 14 S., R. 43 E., MONTPELIER QUADRANGLE

Mansfield 476-477.



BEAR LAKE PHOSPHATE CO.'S MINE IN SLIGHT CANYON, T. 14 S., R. 43 E., MONTPELIER QUADRANGLE

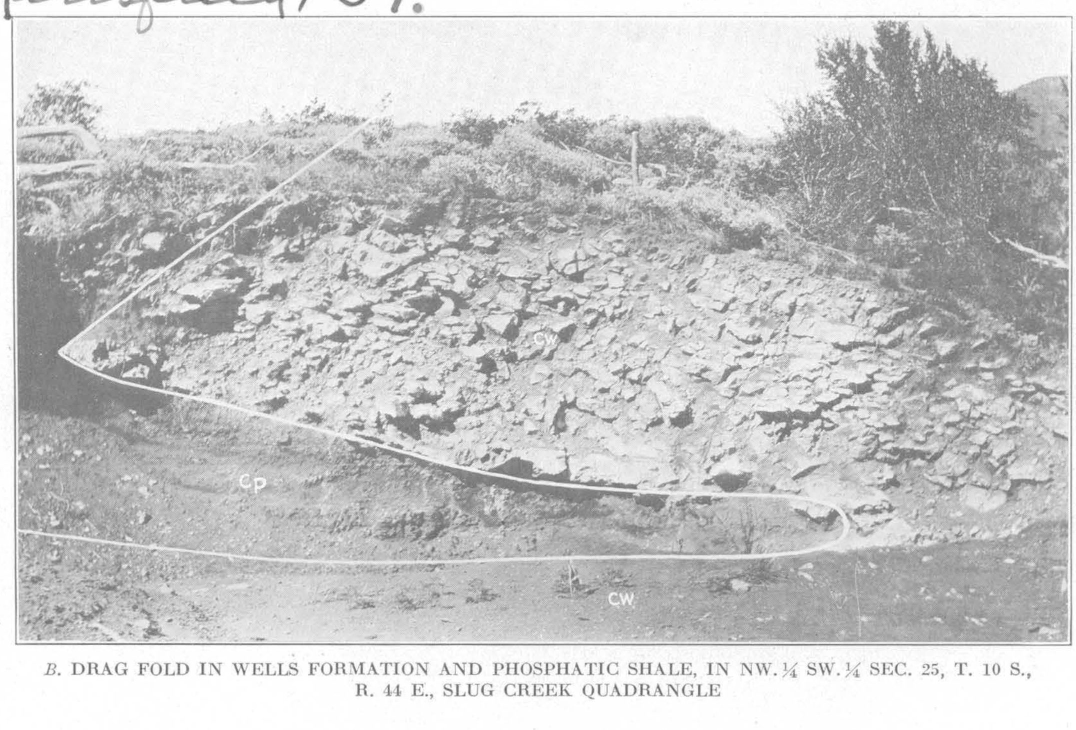
Mansfield, 61.



A. CLIFFS AT TOP OF WELLS FORMATION, WEST SIDE OF SLUG VALLEY, SEC. 18, T. 9 S., R. 44 E.

Down-faulted Triassic rocks on left; Carboniferous rocks in distance. The phosphatic shale has been largely eroded from the top of the Wells formation

Mansfield, 51.



B. DRAG FOLD IN WELLS FORMATION AND PHOSPHATIC SHALE, IN NW. ¼ SW. ¼ SEC. 25, T. 10 S., R. 44 E., SLUG CREEK QUADRANGLE

TABLE 58.—*Nearly complete section of phosphatic shales of Phosphoria formation in the SW. ¼ SE. ¼ sec. 14, T. 8 S., R. 44 E Boise meridian*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
	Remainder of section to chert covered by aspens and brush			10±	
	Limestones and shales, weathered brown			8	
	Limestone				6
M-307-7	Phosphate rock, dark gray, coarsely oolitic, dense; possible evidence of dislocation	36.0	78.6	1	8
	Limestone				6
	Shale, with thin intercalated sandstones, limestones, and very thin beds of phosphate rock, probably none as much as one-fourth inch thick			122	
M-307-6	Phosphate rock, brown, medium, oolitic	28.4	62.0	1	10
	Shale, with thin intercalated limestone and sandstone and very thin beds of phosphate rock			21	
M-307-5	Phosphate rock, brown, fine to medium oolitic	29.7	64.9	3	
M-307-4	Phosphate rock, brown, fine to medium oolitic	31.5	68.8	2	5
	Shale, dark brown			8	4
M-307-3	Phosphate rock, brown, medium oolitic	31.5	68.8	2	7
M-307-2	Phosphate rock	32.6	71.2	3	
M-307-1	Phosphate rock	31.0	67.7	3	
	Shale, brown, and limestone, dark gray, broken			5	2
	Phosphate rock, dense, coarsely oolitic				3
				193	3

Estimate of tonnage.—The phosphate beds underlie 17,600 acres in this township at a depth probably nowhere greater than about 4,000 feet. The greatest depth occurs in the northeast corner of the township, near the center of section 1. The dip of the beds varies but is generally not less than 20°, though in some places it is as much as 40°, and in a few localities considerably more. Doubtless an average dip of 30° can be safely assumed.

On the assumption, then, that a 6-foot bed of phosphate underlies 17,600 acres of land and dips on an average 30°, this township contains approximately 425,040,000 long tons of phosphate. Much of this rock is easily accessible from points of entry in Slug Valley and Dry Valley.

T. 9 S., R. 44 E.

General features.—T. 9 S., R. 44 E., which is located in the Slug Creek quadrangle (pl. 6), lies chiefly in the Aspen Range and in Schmid Ridge, but it also includes some of the western slopes of Dry Ridge. The principal lowlands are Dry Fork Valley in the southwest, upper Slug Valley, and Dry Valley. The present account of this township is a revision of that given in an earlier report.[30]

Geology.—The rock formations (see Chapter III) range in age from the Brazer limestone (upper Mississippian) to Quaternary, but no Mesozoic rocks higher than the Thaynes are found, and the Salt Lake formation is the only Tertiary representative. Basalt covers a little more than a square mile in sections 33 and 34. The rock is dark, somewhat vesicular and weathers brown. It has few outcrops and weathers into boulders that range from a few inches to 2 or 3 feet in diameter.

The Phosphoria formation underlies the valley just east of the ridge that extends from section 32 to section 19. It also spreads around a lower intervening ridge and appears on the west side of Slug Valley from section 28 to section 17. Farther north it appears in a belt that stretches north from the NE. ¼ sec. 7 through sec. 6. Southeast of the Schmid ranch the formation extends from the NE. ¼ sec. 8 obliquely across the broad range east of Slug Valley, through sections 9, 16, 15, and 14, where it plunges beneath the alluvium in Dry Valley. It reappears in the eastern half of section 2. In the NE. ¼ SW. ¼ sec. 28 the Rex chert member is horizontal and has a pseudocolumnar jointing that resembles basalt (pl. 61, *C*). The lower or phosphate-bearing portion is not exposed but may be traced by float in characteristic position between the underlying limestone and the chert. This portion of the formation finds topographic expression in the line of depressions or saddles that runs parallel to the heavy chert ledges of the upper member of the formation, as is particularly well shown in sections 32 and 29. The Rex chert member is marked by heavy chert layers, which locally, as in section 2, constitute the entire member and form great ledges. Elsewhere, as in section 20, this member is more largely composed of the chippy and flinty shale facies, which weathers into smooth slopes, with few or only subordinate ledges. No fossils were observed in either facies.

The Schmid syncline, in the northeastern part, and the Dairy syncline, in the southwestern part, are the principal folds associated with the phosphate beds; between them lies an unnamed anticline, which is broken on the west flank by the Upper Slug fault. The Dairy syncline is broken on the east by the Slug

[30] Richards, R. W., and Mansfield, G. R., op. cit., pp. 41-45.

Creek thrust (see pls. 6 and 48, *A*) and by a faulted area interpreted as a "window" in the fault plane of the Bannock overthrust. This structure is all described in Chapter V and is illustrated in the geologic structure section drawn along the line S–S′ (pl. 12).

Phosphate deposits.—The phosphate beds are not naturally exposed in this township, and prior to the summer of 1911 no openings in the beds had been made. In the NW. ¼ NE. ¼ sec. 16 the survey party in July, 1911, opened a trench 450 feet long that had a maximum depth of about 10 feet. This trench traversed the formation from the overlying chert to the underlying limestone (pl. 40, *C*). The character of the formation as there exposed is given, together with the phosphate content of samples of the more valuable phosphate beds, in Table 59.

TABLE 59.—*Section of lower and phosphate-bearing strata of Phosphoria formation in NW. ¼ NE. ¼ sec. 16, T. 9 S., R. 44 E. Boise meridian*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	Per cent	Ft.	in.
	Sandy and clayey broken rock, yellow			4	4
M-256-8	Phosphatic rock, gray, dense, medium oolitic	28.4	62.0		6
	Shale, brown, broken, streaked with white calcite			1	
	Clay, calcareous, yellow, probably weathered from earthy limestone			1	
M-256-7	Phosphate rock, gray, coarsely oolitic; interrupted by 6-inch shaly band and 2½-inch limestone lens	33.5	73.2	2	6
	Clay, yellow and brown, 2 inches; phosphate rock 4 inches; sandy clay 4 inches				10
M-256-6	Phosphatic rock, brown to gray, coarsely to medium oolitic; includes 1 to 2 inch sandy zone	24.5	53.5	2	
	Weathered sandy zone				5
M-256-5	Phosphatic rock, brown, medium to finely oolitic, broken	23.5	51.3	1	10
	Limestone, brown, earthy; wedges out toward east			1	6
	Shales, brown to black, earthy, micaceous; poorly preserved lamellibranchs and brachiopods near base; in places nodules of dense black limestone 2 feet in diameter			3	4
	Limestones and sandstones, broken and poorly exposed, about			40	
	Shale, brown, earthy, darker toward base and somewhat oolitic			3	
M-256-4	Phosphatic rock, brown, medium to finely oolitic	27.1	59.2	1	5
	Limestone, brown, earthy, phosphatic, oolitic streaks				3
M-256-3	Phosphate rock, brown, finely oolitic	19.1	41.3	3	8
	Limestone, brown, earthy and shaly, slightly oolitic				2
	Limestone, brown, broken, somewhat earthy, fetid			2	6
	Broken contorted zone of phosphate shales and thin limestones, possibly including parts of sample 2			3	
M-256-2	Phosphate rock, brown, weathers gray; fine to medium oolitic; shaly	27.8	60.7	2	
	Limestone, brown, dense, somewhat earthy and slightly fetid				7
	Shale and limestone, broken, grayish brown			1	4
	Phosphate rock, gray, medium oolitic				6
	Limestone, brown, and thin shales; weathers earthy			1	2
	Limestone, black, dense, fine grained; weathers brown			1	10
	Shale, brown, micaceous, broken, thin bedded				7
	Limestone, brown, fine grained, fetid			1	2
	Shale, brown, broken				3
M-256-1	Phosphate rock, gray, medium oolitic				4½
				83	½

The formation in this township contains two notable phosphate-bearing zones, near the top and the bottom respectively, with a broad barren zone between. Each of the phosphate-bearing zones consists of several members and includes narrow bands of lean or barren material. The upper zone contains an aggregate of 4 feet 6 inches of phosphate rock that averages 60 per cent or more tricalcium phosphate and an additional band, 1 foot 10 inches thick, that averages 51.3 per cent tricalcium phosphate. The lower zone has two beds, samples 2 and 4, which aggregate 3 feet 5 inches of phosphate rock that averages nearly 60 per cent tricalcium phosphate. The rock from which sample No. 2 was collected lies immediately beneath a broken and contorted zone of phosphatic shale and thin limestone. The position of this bed corresponds to that of the main bed in the townships to the west and south. The main bed in Georgetown Canyon is 6 feet 4 inches thick. These facts, together with the general uniformity of thickness of the main bed elsewhere, tend to show that in this section part of the bed has probably been cut out.

The phosphate beds, where exposed by trenching, were rather deeply covered by weathered surface drift, and the inclination of the beds was such that dirt could be washed into the phosphate rock by percolating waters. It was found impracticable to deepen the ditch sufficiently to obtain wholly clean material for analysis, and the figures given are probably somewhat low. As it is, the trench shows a total thickness of about 8 feet of workable phosphate rock that has an average content of about 60 per cent tricalcium phosphate.

Estimate of tonnage.—The phosphate beds underlie 12,840 acres in this township, at a depth probably nowhere greater than 1,800 feet. The dip of the beds differs and locally is steep, but these steep dips do not in all probability descend to depths greater than 500 or 600 feet. The great bulk of the deposit appears to dip 10° to 20°, and perhaps 15° may be taken as a fair average.

If only the upper bed, 4 feet 6 inches thick, is considered, and the dip is taken as 15°, there are within this township, in the upper bed alone, 211,346,000 long tons of phosphate rock that averages 60 per cent or more tricalcium phosphate. If the lower group of beds, 3 feet 5 inches thick, is added under the same conditions, the total tonnage will be approximately 372,154,000 long tons.

The entire region underlain by phosphate rock is believed to be underlain by the Bannock overthrust. The depth of the supposed fault beneath the surface is not known. It is doubtful if it is high enough in this township to cut out much, if any, of the phosphate-bearing formation, yet in the absence of definite information, such as that given by drill records, it is perhaps wiser to make ample allowance for that possibility. Thus the smaller figure given above should fall well within the limits of probability, and much of the rock is probably above ground-water level.

T. 10 S., R. 44 E.

General features.—T. 10 S., R. 44 E., which is located in the southeastern part of the Slug Creek quadrangle (pl. 6), includes some of the more rugged portions of the Aspen Range, the southern tip of Schmid Ridge, the southern extension of Dry Ridge, and the western flank of Snowdrift Mountain. Georgetown Canyon, in the eastern part of the township is the deepest canyon of the region described in this paper. This canyon and that of the Left Fork of Twin Creek, which passes north through the center, contain roads through the mountains to the broad valleys farther north and northeast. In earlier reports [31] the phosphate deposits and many of the geologic features of the township have been described. Since these articles were published additional geologic data have been gathered, particularly in connection with the older rocks. Little new work has been done on the phosphate.

Geology.—The Madison limestone is the oldest geologic formation present, and it is exposed in considerable areas in the western and eastern parts, the most striking occurrence being that where it overlies Jurassic beds and caps the hills between Georgetown Canyon and the Left Fork. The higher formations are present in order up to and including the Thaynes group. The upper Thaynes and the overlying Triassic (?) beds are absent, but the Nugget sandstone and Twin Creek limestone emerge from beneath the Carboniferous fault block. Beds in sections 34 and 35, formerly mapped as Beckwith, have upon further field study been referred to the Preuss. (See p. 99.) The Wasatch formation overlies the Carboniferous formations in sections 18, 19, and 20, and the Salt Lake formation covers considerable areas in the southwest besides making patches elsewhere. Quaternary sediments are almost negligible. Basalt overlaps the northern border and occurs in a small linear area in section 11.

The geologic structure in this area is highly complex, for many of the larger folds of the region apparently originate within this township. Among these folds are the Georgetown syncline, the Dry Valley anticline, the Schmid syncline, the Dairy syncline, and the Aspen Range anticline. Besides these folds there are a number of smaller folds, both anticlines and synclines.

The arched plane of the Bannock overthrust is eroded away in Georgetown Canyon and in the canyon of the Left Fork, thus exposing in a spectacular way the trace of the fault plane. (See pl. 38.) Several other faults, more or less closely associated with the Bannock fault, are also present. The broad structural features that are represented in this township are described in Chapter V. They are illustrated in the geologic structure sections drawn along the lines T–T′ and U–U″. (See pl. 12.)

Phosphate deposits.—The phosphate deposits lie in a synclinal trough, which is situated mainly in secs. 12, 13, and 24. The fold is modified slightly by the presence of minor folds (pl. 48, *B*) and at least one fault. The southern tip of another phosphate-bearing area enters the township in section 4. The phosphatic shales here, as elsewhere in this general region are inclosed between an underlying light-colored sandy limestone and an overlying dark chert, which in nearly all attitudes makes salient topographic features.

The main phosphate area, which is about 3 miles long and 1 mile wide, lies in the eastern tier of sections. It constitutes the southern tip of a long boatlike fold which extends far to the north, as will be seen by reference to the general map. (Pl. 1.) The margin of this area is crenulated by subordinate folds.

The other phosphate areas are much smaller but have a similar structure and shape.

In most places the outcrop is best marked by prominent ledge-supported ridges of the overlying chert; but in other places the underlying limestone makes either a well-defined cliff, a salient knoll, or a ridge. The shales are more easily eroded and are generally characterized by the development along them of minor gullies, many of which are too small to be shown on the map.

Many shallow openings have been made along the outcrop of the phosphatic shales in the course of the

[31] Gale, H. S., and Richards, R. W., Phosphate deposits in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 430, pp. 483–488, 1910.
Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, pp. 46–49, 1914.

assessment and patent work incidental to the acquirement of mineral claims of the Utah Fertilizer & Chemical Manufacturing Co. At the time of examination by the United States Geological Survey, however, nearly all the sections had been obscured by caving, and information was chiefly gained from the more extensive cuts in T. 10 S., R. 45 E. A prospect in the NE. ¼ SE. ¼ sec. 25 showed a section of the main bed measuring 6 feet 6 inches, and a sample collected here contained 37 per cent phosphoric acid, equivalent to 80.8 per cent tricalcium phosphate. The outcrop of the shale contains abundant pieces of high-grade phosphate rock, and similar pieces are also found on the dumps of many of the caved openings. The field evidence appears to indicate that this area contains rock, which will run 70 per cent or over in tricalcium phosphate, probably in beds comparable in thickness to those above cited.

Estimate of tonnage.—The area in this township actually classified as phosphate land is 3,000 acres, which, however, includes some territory estimated at 1,000 acres underlain by beds older than the phosphate and hence not phosphate bearing. On the other hand, the area of the main phosphate bed under these lands is greater than their surface area because of the folding, which is indicated in the structure section T–T′ (pl. 12). This folding is estimated to add 25 per cent to the area, and thus the main lower bed is estimated to occupy about 2,500 acres. With an assumed thickness of 6 feet the content of such a bed of phosphate is 52,000,000 long tons.

Development.—In 1911, when the Geological Survey party examined this township, little had been accomplished in the actual development of this area. Two tunnels, both of which have a southeasterly trend, had been put in by the Utah Fertilizer & Chemical Manufacturing Co. on the Superior Extension claim. One of the tunnels was about 125 feet long, but the other was less than 30 feet long. The longer tunnel ended in the limestone which underlies the phosphatic shales. The shorter one was in low-grade shales. A third tunnel about 50 feet in length on the Highland No. 2 claim showed mainly low-grade shales and a minor amount of high-grade rock. The direction of all these workings had been determined by minor folds, which complicate the laying out of a general plan of mining development for the district.

Since that date a few additional openings have been made by the company in the way of exploring the beds, but in 1920 there had been no production. It is planned, however, to continue eastward a tunnel started in the SW. ¼ NE. ¼ sec. 25 till the phosphate bed on the east side of the syncline is encountered and then to clear out the remainder of the fold to the south and to drift north and south along the main bed. A railroad spur from Georgetown into the canyon and equipment for handling 3,000 tons of phosphate rock a day are features of a plan for large-scale production, which it is hoped to put into operation.

Ownership.—The phosphate lands in this township belong in part to the United States Government and in part to the Utah Fertilizer & Chemical Manufacturing Co. The company has patented claims amounting to about 730 acres. (See fig. 29.) The remaining area, about 2,270 acres, is public land, all within the Caribou National Forest.

T. 11 S., R. 44 E.

General features.—Although T. 11 S., R. 44 E., is chiefly in the Montpelier quadrangle it includes at the north a narrow strip of territory in the Slug Creek quadrangle. (Pls. 6 and 9.) Much of its surface is high and rugged and lies in the Preuss Range, but it includes also part of the southern tip of the Aspen Range, the south end of Dry Ridge, and at the west a part of Bear Lake Valley. This township has been described in an earlier report,[32] and little geologic or development work has been done in it since; hence the present account follows fairly closely the earlier one.

Geology.—The geologic formations range in age from the Madison limestone to the Quaternary, but the Thaynes group and overlying Triassic (?) beds are absent, and no other Mesozoic rocks higher than the Preuss sandstone are present. The Salt Lake formation is the only Tertiary representative, and the Quaternary beds are chiefly contained in great alluvial fans that extend from the mountains into Bear Lake Valley.

The principal structural feature of the township is the Bannock overthrust, the plane of which is here arched and eroded, so that the upper block appears in two segments. The western segment is marked by the Madison ledges which cross Georgetown Canyon in sections 3 and 4. The eastern segment is bounded by the fault that extends from section 2 to section 13 and contains the phosphate-bearing rocks. It is cut by one or more thrust faults associated with the great overthrust. Between the two segments and extending southeastward through the township are Jurassic beds, which belong in the lower fault block.

The upper block includes the beginnings of the Snowdrift anticline and parts of other unnamed folds. The lower block contains the northern extensions of the Harer syncline, the Home Canyon anticline, and the Bald Mountain syncline, besides a number of smaller folds. The principal structural relationships above mentioned are illustrated in the geologic structure section drawn along the line W–W′ (pl. 12) and also in structure section U–U″, which crosses the southern part of the adjoining township on the north.

Phosphate deposits in South Canyon district.—The phosphate deposits of the township form two distinct

[32] Richards, R. W., and Mansfield, G. R., op. cit., pp. 49–56, 1914.

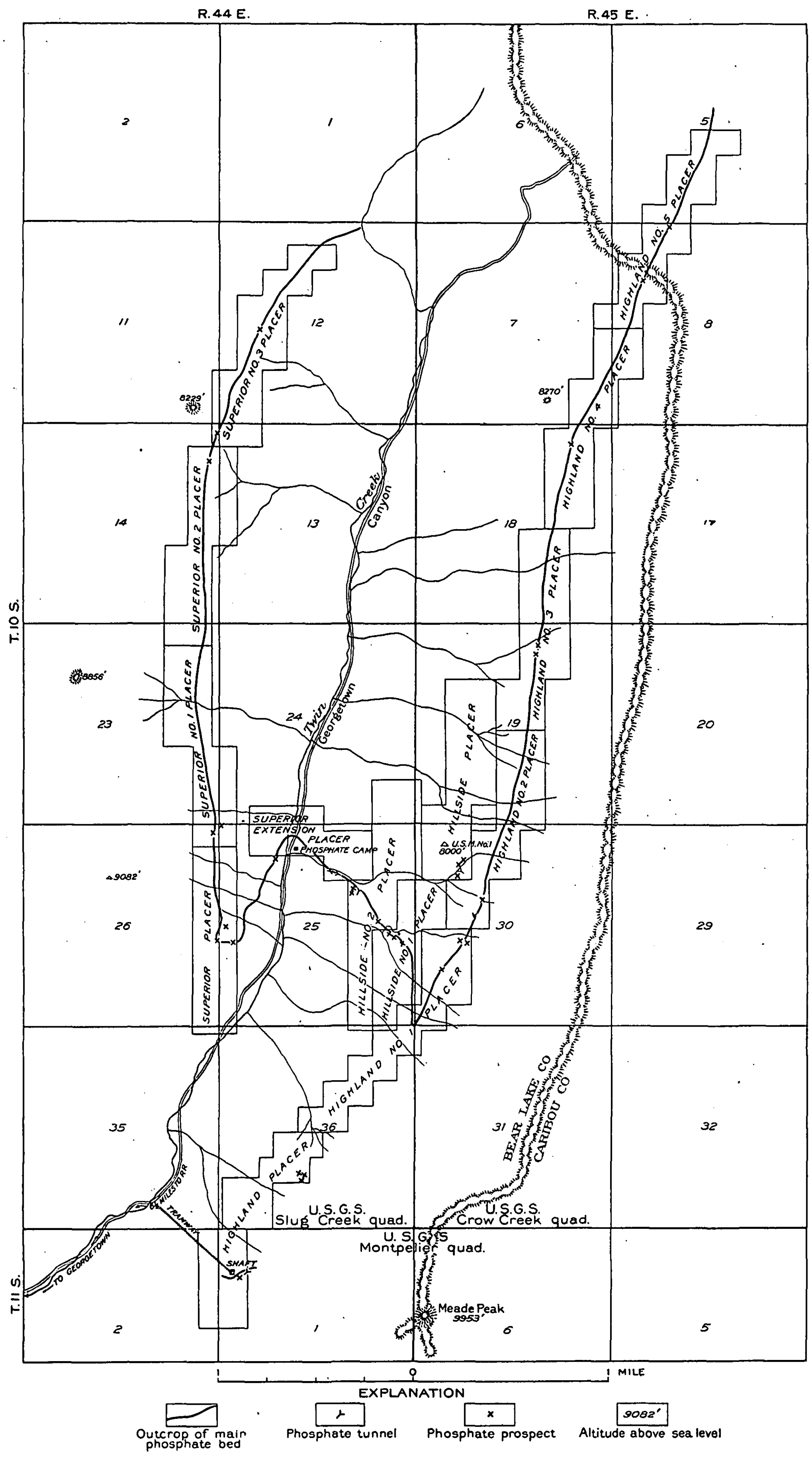


FIGURE 29.—Map of the phosphate claims of the Utah Fertilizer & Chemical Manufacturing Co in Georgetown Canyon Published by courtesy of R. J Shields

areas, the larger of which, situated in South Canyon, will be first described, and the smaller, described by Gale and Richards[33] in 1910, which lies on the western slope of Meade Peake, will afterwards be reviewed briefly. The area in this township classified as phosphate land, based on a minimum classification unit of 40 acres, amounts to 8,320 acres. For reasons stated below, however, the estimates of actual phosphate content are based on a much lower figure.

The topographic and geologic features of the South Canyon district are shown in Plate 49. (See also pl. 46, *B*.)

The prominent natural exposures of the dark phosphatic shales in the gulch on the south side of South Canyon near the present mine openings led to the original discovery, but the strong outcrop of the persistent overlying Rex chert member of the Phosphoria formation is a more useful marker of the geologic horizon. The underlying limestone is present but not prominent enough to serve as a marker. The phosphate deposits crop out in two places in South Canyon, one of which lies in the township under discussion and the other just east of the township line. The western outcrop has been known for some time, and upon it the local prospecting has centered.

The eastern outcrop was apparently unknown prior to the examination by the Geological Survey. It will be considered briefly here because of its bearing on the deposit in section 12. The eastern outcrop is marked by an equally prominent ledge of the Rex chert. Float phosphate rock was also found in considerable abundance along the trace of this outcrop. The rocks in the area between the western and eastern chert ledges, although poorly exposed, clearly consist of the iron-stained calcareous beds of the Woodside shale.

The shape of the deposit is revealed on the east and west by the distribution of the outcrops of the phosphatic shales and on the north and south by the presence of areas of rocks older than those that contain the phosphate (Mississippian limestone and Wells formation), which have presumably come into their present relation to the phosphate and the overlying rocks by faulting. The exact position of the fault planes is known in only a few places because of the scarcity of ledges and their irregular distribution. It seems clear, however, that the faults are overthrusts, whose planes have been subsequently folded and that they are doubtless closely related to the Bannock overthrust.

The areal distribution of the several formations, together with the inclination of the chert ledges, leads to the conclusion that the phosphate deposits lie in a synclinal basin, which comprises a portion of the overthrust block. Future mining development will probably demonstrate that the fold is complex rather than simple, as represented, and that it comprises a number of smaller folds.

A number of prospect openings have been made in the phosphatic shales by the Utah Fertilizer & Chemical Manufacturing Co. These openings were somewhat caved when examined by the members of the survey party, so that the information obtained is incomplete.

Near locality 1, in section 1, within a few feet of ledges of Mississippian limestone, two pits were found. One of them exposed about 3 feet of the basal or main phosphate bed immediately above the underlying limestone. The rock appeared on visual examination to be of excellent quality, and no samples were taken for analysis. The second pit is several feet higher in the shales of the Phosphoria formation and exposed 2 feet of limestone underlain by about 10 feet of brown phosphatic shales that contain a few 2 or 3 inch streaks of higher-grade oolitic rock about 3 feet from the base of the exposed section.

At locality 2 (a prospect) the section shown in Table 60 was measured:

[33] Gale, H. S., and Richards, R. W., op. cit., pp. 487–488.

TABLE 60.—*Section of phosphate bed in the SE. ¼ SW. ¼ sec. 1 (unsurveyed), T. 11 S., R. 44 E. Boise meridian*

Field No. of sample		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
	Limestone, dark gray ("cap lime" with characteristic fossils).			4
M—70–1	Phosphate rock, dark brown, fine to medium oolitic, somewhat shaly in places.	33.4	72.9	2 8
	Shale, brown, slightly sandy			[a] 3
	Limestone, buff, broken and weathered			
				9 8

[a] Exposed.

The presence of the "cap lime" as well as the basal position of the bed makes fairly certain the correlation of this bed with that which has been developed rather extensively in the Montpelier district and described by Gale and Richards.[34]

The broken condition of the "cap lime," together with the unusual thinness of the phosphate bed, makes it doubtful if the entire bed is present at this locality.

The tunnel prospect at locality 3, on the north side of South Canyon, shows a section of about 4 feet of

[34] Gale, H. S., and Richards, R. W., op. cit., pp. 457–535.

medium oolitic brown rock. The local structure is complicated, so that about 50 feet from the entrance the underlying limestone is encountered, and the tunnel makes a sharp bend at nearly right angles to the right for about 30 feet. It then resumes its original trend, about N. 23° W. At the time of the examination the tunnel terminated about 30 feet from the last turn. The geologic structure, which is roughly followed by the tunnel, may bear two interpretations. It may be either a slight fault or a sharp drag fold. The latter view seems to satisfy better the conditions observed.

The rocks cut by the tunnel at the offset and beyond are so finely broken and slickensided that the oolitic texture has largely disappeared from the phosphate rock. A sample of this material tested qualitatively contains a high percentage of phosphorus pentoxide, but no quantitative examination has been made because of the lack of definite information concerning the thickness of the bed.

Another tunnel, locality 4, has been opened on the south side of the canyon, and this affords the best information that has been obtained concerning the main bed in this district. The entrance of the tunnel is located in the phosphatic shales, and the tunnel extends westerly across the strike about 30 feet until it cuts the basal phosphate bed and terminates on the underlying brown shale. From this point a drift extends southerly along the strike for about 30 feet. The bed ranges from 5 feet 4 inches to 5 feet 10 inches in thickness. The section given in Table 61 was measured in the face of the drift:

TABLE 61.—*Section of phosphate bed in tunnel of Utah Fertilizer & Chemical Manufacturing Co., in sec. 12, T. 11 S., R. 44 E. Boise meridian*

Field No. of sample		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
	Limestone ("cap lime"); contains fossils.	*Per cent*	*Per cent*	*Ft.*	*in.*
R-117-1	Phosphate rock, brown, medium oolitic	32. 1	70. 1	2	
R-117-2	Phosphate rock, brown, medium to fine oolitic	34. 8	76. 0	2	
R-117-3	Phosphate rock, grayish brown, medium oolitic	[a]35. 8	78. 2	1	7
R-117-4	Phosphate rock, brown, shaly	32. 1	70. 1		3
				5	10

[a] The phosphate content of R-117-3 has been lowered slightly by the inclusion of the underlying shaly bench.

The average content for the full section is about 34.5 per cent phosphorus pentoxide, which is equivalent theoretically to 75.1 tricalcium phosphate.

An excellent natural exposure of the upper portion of the phosphatic shale was measured in the gulch south of the tunnel and is described in Table 62.

TABLE 62.—*Section of the upper portion of phosphatic shales in sec. 12, T. 11 S., R. 44 E.*

	Ft.	in.
Cherty limestone (base of overlying chert).		
Shale, dark brown	17	
Phosphate rock, brown, medium oolitic, thin bedded; includes local limestone lenses and about 6 inches of coarsely oolitic phosphate	1	2
Phosphate rock, brown, coarsely oolitic; weathers gray		6
Phosphate rock, gray, coarsely oolitic		9
Phosphate rock, brown, medium oolitic		2
Limestone, brown, shaly at top and bottom	1	
Phosphate rock, gray, coarsely oolitic or pisolitic, some of the pisolites being nearly 2 inches in diameter		7
Shale brown		2
Phosphate rock, medium oolitic, grading to finely oolitic at base		2
Shale, brown		2
Limestone lens, maximum thickness		4
Phosphate rock, gray, coarsely oolitic		3–6
Shale, brown		2
Phosphate rock, gray, coarsely oolitic		3
Shale, brown	1	1
Phosphate rock, gray, coarsely oolitic		6–12
Shale, dark brown, with a few oolitic streaks } Concealed }	30	
Phosphate rock, brown, medium oolitic, shaly	5±	
Shale, brown, not measured.		
	60±	

About one-sixth of the section is composed of phosphate rock, estimated to contain more than 32 per cent phosphorus pentoxide, or about 70 per cent of tricalcium phosphate. The shale, which practically comprises the remainder of the section, by comparison with similar shales that have been analyzed is estimated to contain about 25 per cent of phosphorus pentoxide, equivalent to 54 per cent tricalcium phosphate. The average content of the 60 feet measured, without taking into account the limestone lenses and lentils, would be about 57 per cent tricalcium phosphate. Such material as this, although undoubtedly of too low grade to be utilized by present practice of superphosphate manufacture, ought eventually to be of value as a source of finely ground phosphate rock meal or "floats," or possibly it could be utilized in some cement-manufacturing process with recovery of the phosphorus pentoxide as a by-product.

About 750 feet south of the natural exposure and about 200 feet higher, at locality 5, two short tunnels were visited. The more easterly tunnel is shown on the map and is located in the phosphatic shales but was so filled by caving that it was inaccessible. The other tunnel is about 100 feet to the west in a siliceous somewhat porous limestone, lower in the Pennsylvanian portion of the section than the "under lime." Abundant specimens of banded travertine were seen, which is probably to be interpreted as evidence of faulting.

The mapping of the phosphatic shales from this point south to the ridge top, where they disappear under Mississippian limestone, is based mainly on the tracing of the accompanying overlying chert to that point by means of abundant float fragments.

The area of phosphate land in this district can not be regarded as coextensive with the area of outcrop of the normally overlying chert and Woodside shale, because a fault plane related to the Bannock thrust underlies the area and truncates the synclinal fold, somewhat as indicated in the cross section W–W′ (pl. 12). This plane is estimated to cut the phosphatic shales about 1,200 feet down the dip from the level of the tunnels near the canyon bottom. The length of the outcrop from the trace of the fault termination on the north side to that on the south side is about 3,500 feet. The best exposure of the main phosphate bed indicates that it is somewhat over 5 feet in thickness. However, that figure may be taken as the basis for a conservative estimate of its contents.

The total tonnage of the basal phosphate bed included within the faulted area is estimated on the basis noted above at about 1,968,000 long tons of high-grade phosphate rock. Of this amount approximately one-third, or 656,000 long tons, may be deducted as belonging in the adjoining township. The remaining two-thirds, or 1,312,000 long tons, may be added to that of the Meade Peak district given below to form the total estimated tonnage of the township.

The complete section contains more high-grade rock than is taken for the basis of the calculation, but the data at hand do not warrant more definite estimates. If the fault plane lies in a position different from the one considered in the estimate, the actual tonnage will decrease or increase as the fault plane rises higher into or falls below the curve described by the phosphate bed in the fold.

Phosphate deposits in Meade Peak district.—The northwestern slopes of Meade Peak consist of rocks older than the phosphate-bearing rocks except in a small tract that comprises about 6 acres in the NW. ¼ sec. 1. In this tract the phosphatic shales are bent into a sharp syncline which is apparently overturned toward the southeast. This syncline is truncated on the south by a fault which is regarded as a thrust of subordinate order but which is probably a branch of the major thrust.

The lower main bed was sampled in 1909 at the breast of the main tunnel on the claim at this locality. The thickness of the bed at this point is 6 feet, and the samples were found to contain 35.7 per cent phosphorus pentoxide, which is equivalent to 78 per cent tricalcium phosphate.

The area of the outcrop of the phosphatic shales, as above noted, is about 6 acres, but the surface area of the phosphate bed is probably at least one-third in excess of this, owing to the compression of the bed in a rather sharp fold. The assumption that a single 6-foot bed of phosphate underlies an area equivalent to 10 acres of flat-lying beds gives about 200,000 long tons of phosphate rock for the main bed. The higher beds in this area in all probability do not carry a sufficient quantity of phosphate to be considered in the estimate of tonnage.

The company which preceded the Utah Fertilizer & Chemical Manufacturing Co. in the ownership of this claim began the development. Near the northeast corner of the deposit a tunnel about 90 feet in length runs in about 60 feet S. 70° W. and then turns southward and follows the bedding or the strike for about 30 feet more. A more favorable location for this tunnel would have been 150 feet lower and about 400 feet in a direction slightly west of north of the present location. The suggested location is on the axis of the syncline and at the lowest point on the phosphate bed and would therefore serve in mining out both limbs of the fold. A tramway about 3,000 feet in length was built from the elbow of Georgetown Canyon to this phosphate area. The upper end of the tramway is about 1,000 feet above its lower terminal. It has not been completed.

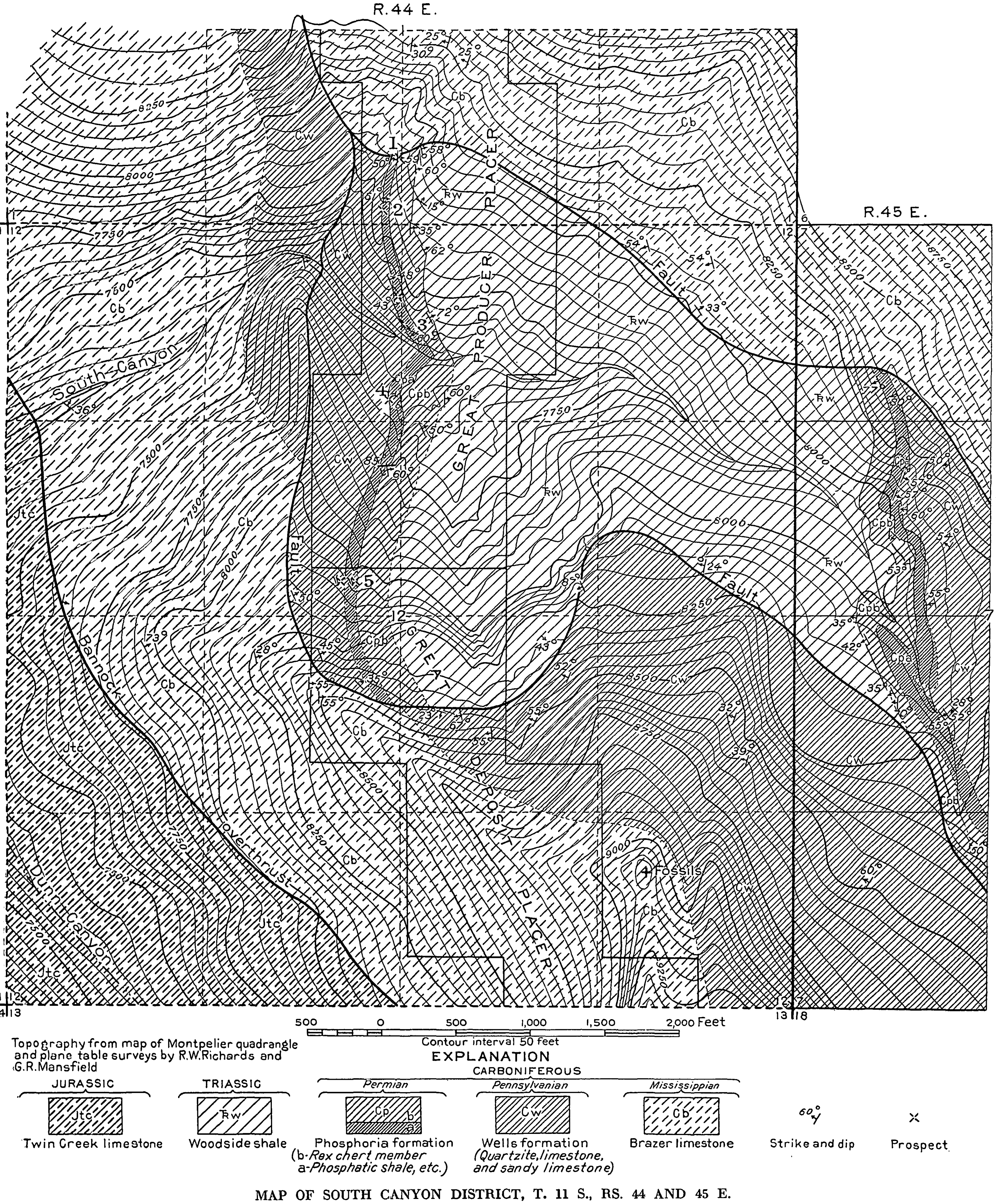
Total tonnage of township.—The 1,312,000 long tons estimated for the South Canyon district, added to the 200,000 long tons estimated for the Meade Peak district, gives a total for the township of 1,512,000 long tons.

T. 12 S., R. 44 E.

General features.—T. 12 S., R. 44 E., is in the Montpelier quadrangle. (Pl. 9.) The principal highlands are in the western slope of the Preuss Range, but foothills of the Bear River Range enter the northwestern part. Much of the area is occupied by the broad lowland of Bear Lake Valley. In a former report [35] this township was included with adjacent areas in a description of the "Montpelier-Bennington phosphate area." (See pl. 51.) It is here treated separately to agree with the general plan adopted for this report.

Geology.—The Bannock overthrust is the principal geologic feature of the township. In the southeastern part it brings the Brazer and Madison limestones into contact with Thaynes and Woodside beds. In section 14 beds of the Wells, Phosphoria, and Woodside emerge from beneath the overthrust block, but they have themselves been both folded and faulted. The northeast corner of the township is occupied by Jurassic formations, beneath which the phosphate lies too deep to be considered recoverable under existing regulations. The structure of the large area underlain by Tertiary and Quaternary sediments is entirely unknown. Under the hypothesis of folding and erosion of the plane of the Bannock overthrust, which is

[35] Gale, H. S., and Richards, R. W., op. cit., pp. 488–495.



MAP OF SOUTH CANYON DISTRICT, T. 11 S., RS. 44 AND 45 E.

Showing phosphate deposits and claims of the Utah Chemical & Fertilizer Manufacturing Co.

represented on the map and in the structure section drawn along the line X–X′ (pl. 12), Lower Triassic beds may possibly occupy the southwestern part of the township. Other interpretations of this structure are suggested on page 157.

Phosphate deposits.—As the Carboniferous fault block is bordered all along the east by beds of the Woodside and Thaynes, and as phosphate beds actually emerge from beneath it on the north, recoverable phosphate may underlie the area occupied by the fault block. At Montpelier the Triassic beds extend as far as the line between secs. 2 and 3, T. 13 S., R. 44 E., but above Bennington the phosphate beds lie in the E. ½ sec. 14. The west boundary of the supposed phosphate-bearing area may therefore be drawn northward along the west side of sections 35 and 26 and thence irregularly to the E. ½ sec. 14. On this basis about 4,000 acres might be considered as phosphate land. In view, however, of the disturbed structure and of the extensive cover, the land actually so classified has been limited to the areas in section 14 where the Phosphoria, Woodside, and Thaynes formations are exposed and in sections 35 and 36 where Thaynes and Woodside beds lie in front of the Carboniferous thrust block, a total of only 560 acres.

The only openings in the phosphate are some prospects in section 14. Measurements were made in 1909 in three of these prospects, one of which contained a 6-foot bed that carried 29.6 per cent of phosphorus pentoxide, equivalent to 64.8 per cent tricalcium phosphate. The other two prospects were in shales that carried only small percentages of phosphorus pentoxide. No work had been done on these prospects since 1909 until shortly before a visit by the writer in 1920, when the bed was again opened. The contorted, shattered, and dirty condition of the phosphate led to the early abandonment of the work.

Estimate of tonnage.—Commercial operations in Montpelier Canyon have demonstrated the presence of a bed of phosphate rock that averaged 70 per cent tricalcium phosphate and between 5 and 6 feet thick. The 6-foot bed at Bennington suggests that this thickness is maintained between the two localities. In spite of the relatively poor showing at Bennington, which is believed to be due to the local crushing and disturbance of the rock, it seems fair to assume that the bulk of the rock under cover may correspond in grade with that in Montpelier Canyon. If, then, a bed 5½ feet thick is assumed to be present, 560 acres would yield more than 10,780,000 long tons of phosphate rock if the beds were horizontal. As the beds are not horizontal, this estimate may be too low, but, because of the uncertainties of structure in the concealed areas and the presence of faults, the estimate has not been increased.

If the beds are in normal order beneath the thrust block, it is probable that the phosphate there approaches the limit of workable depth. The great depth and the fact that the beds are very largely below ground-water level will probably preclude any early development of the phosphate in this township.

Mississippian phosphate.—The lower or Mississippian phosphate beds, which are generally absent in southeastern Idaho, are probably present in this township, though their occurrence has scientific rather than commercial interest. Prospects opened by F. R. Richards, of Montpelier, in gullies on the hillside south of Joes Gap, in the SE. ¼ NE. ½ sec. 23, were reported to show oolitic phosphate.

These prospects, upon examination by the writer, were found to be cut mainly in dark-brown phosphatic limy shale and limestone, generally without oolitic texture, though some oolitic pieces were found. The material overlies massive gray limestone without recognized fossils at the locality named. The limestone along the foot slope here makes a minor anticline but again rises eastward in a general dip slope.

According to J. J. Taylor, of Montpelier, phosphate float has been found at other points on the big Carboniferous hill south of Joes Gap.

The determination of the Carboniferous rocks between Montpelier and Joes Gap as of Brazer and Madison age rests upon excellent fossil evidence. As the Madison limestone forms practically a dip slope and as the Brazer limestone lies at the base of the slope at Montpelier, the most reasonable explanation of the occurrence of the phosphate at the localities named is that it represents uneroded remnants of the phosphate-bearing shale member (p. 63), which normally lies at the base of the Brazer. The alternative explanation, that the phosphate is of Permian age (Phosphoria), is untenable, because it requires either an additional fault, of which there is no evidence, or the cutting through by erosion of the Mississippian fault block to expose the underlying Phosphoria. Of this, too, there is no evidence. On the contrary, the rocks that accompany the phosphate at this locality are of the Mississippian rather than of the Permian sequence. There seems, therefore, no doubt that the phosphate is of Mississippian age.

T. 13 S., R. 44 E.

General features.—T. 13 S., R. 44 E., which is in the Montpelier quadrangle (pl. 9), lies mostly in Bear Lake Valley, but it includes some of the western foothills of the Preuss Range and contains most of the city of Montpelier, the largest settlement of the region.

In an earlier report [36] the northern part of it was described in connection with the Montpelier district.

Geology.—Most of the township is underlain by Quaternary and Tertiary formations, which conceal the older rocks, but at Montpelier the Brazer lime-

[36] Gale, H. S., and Richards, R. W., op. cit., pp. 488–495.

stone is exposed in contact with beds of the Thaynes group and farther east the Woodside shale appears in Montpelier Canyon. In section 12 also the Thaynes group comes to the surface. The Brazer limestone is part of the upper fault block of the Bannock overthrust. The structure of the concealed areas is unknown, but from evidence gathered on both sides of the valley farther north and south the interpretation illustrated in the geologic structure section drawn along the line X–X′ (pl. 12) is suggested. Alternative hypotheses are considered on page 157. The Montpelier anticline probably passes beneath the southeastern part of the township.

Phosphate deposits.—Although no phosphate beds crop out in this township their presence at depth, at least along the eastern side, is inferred from the occurrence of Thaynes and Woodside strata in sections 1, 2, and 12 and because of the actual outcrop of phosphate beds with an appropriate strike in the adjacent township to the south. The proximity of the area to the commercially exploited beds of Montpelier Canyon, and the known fact that the phosphate beds of the region maintain their quality and thickness over considerable areas, make it highly probable that the phosphate beds of this township compare favorably with those in Montpelier Canyon and that a 5½-foot bed containing about 70 per cent tricalcium phosphate may reasonably be expected.

Estimate of tonnage.—Phosphate beds at recoverable depth may be present beneath the alluvium in much of Bear Lake Valley, but in view of the uncertainties of the structure and the absence of definite data, such as might be obtained by drilling, it is deemed best to exclude practically all that area from consideration in framing estimates of tonnage. The folds of the southern part of the Preuss Range and of the Mesozoic and older rocks in the Bear Lake Plateau are known to be relatively narrow and steep-sided. These conditions also probably exist in the Thaynes area of section 12 and beneath the area covered by Tertiary and later beds in the eastern part of the township, and the phosphate beds, though probably present, must be relatively deep. The area actually classified as phosphate land is therefore limited to 1,080 acres in sections 1 and 2, where beds of Woodside and Thaynes outcrop in front of the big overthrust. A 5½-foot bed underlying such an area would yield about 2,080,000 long tons of phosphate if the beds were horizontal. The probability that they are not horizontal would tend to increase the estimate, but the fact that the rocks are so much disturbed makes it desirable to retain the more conservative figure. The depth of the phosphate bed may range from a few hundred to 3,000 feet or more.

T. 14 S., R. 44 E.

General features.—Most of T. 14 S., R. 44 E., which is in the Montpelier quadrangle (pl. 9), lies in Bear Lake Valley, but the southeastern part includes the northwest corner of the Bear Lake Plateau. In an earlier report [37] this portion of it was included in the description of the "Hot Springs-Dingle phosphate area."

Geology.—The portion of the township in Bear Lake Valley is entirely underlain by Quaternary sediments of unknown thickness, which conceal the older rocks. In the southeastern part the Brazer limestone, Wells and Phosphoria formations, and the Woodside shale are exposed, but these formations are in part overlapped by beds of the Wasatch formation and this in turn by the Salt Lake formation. The Bear Lake fault lies along the base of the escarpment that marks the western edge of the plateau. The structure of the covered portion is unknown, but the data obtained on both sides of the valley in the latitude of this township, as well as to the north and south, suggest the interpretation illustrated in the structure section drawn along the line Y–Y′ (pl. 12).

Phosphate deposits.—A number of small prospects have been opened in the phosphatic shales in sections 25 and 36, but these were not in condition for measurement at the time of the Geological Survey's examination. In the adjoining township on the south a 5-foot bed of phosphate that averages more than 70 per cent tricalcium phosphate has been found. It is assumed that the phosphate beds in this township, which are the direct continuation of those in the township to the south, include a bed of similar thickness and quality.

Estimate of tonnage.—There seems little reason to doubt the essential continuity beneath cover of the Phosphoria-Thaynes succession south of Dingle with the corresponding beds east and southeast of Montpelier. But, in view of the concealment by Quaternary and Tertiary beds of the formations associated with the phosphate and on account of the close folding mentioned in the discussion of the preceding township, only 720 acres in sections 24, 25, and 36 are actually classified as phosphate land. The depth limit for a 5-foot bed of the 70 per cent grade of tricalcium phosphate is 4,000 feet, and the dip of the beds as shown in structure section Y–Y′ is 70°. Therefore it seems better to disregard the areal basis of computation and to consider the amount of phosphate that would be contained above the 4,000-foot level in such a bed projected through the classified area, in the general direction of the strike as observed at the south—that is, about 16,000 feet. Under these conditions the selected portion of the bed would yield approximately 2,764,000 long tons of phosphate, which is probably a conservative estimate for the area.

[37] Gale, H. S., and Richards, R. W., op. cit., pp. 495–498.

T. 15 S., R. 44 E.

General features.—T. 15 S., R. 44 E., which is located in the Montpelier quadrangle (pl. 9), lies mostly in Bear Lake Valley and is partly flooded by Bear and Mud Lakes. On the eastern side it includes part of the western escarpment and upland of the Bear Lake Plateau. The township is somewhat unusual in that it contains along its eastern margin an extra tier of 40-acre lots. In the earlier report [38] this township was included in the description of the Hot Springs-Dingle phosphate area.

Geology.—The exposed geologic sequence probably extends from the Brazer limestone to the Nugget sandstone, but some of the beds are locally concealed by Quaternary hill wash. Bear Lake Valley is underlain by alluvium of unknown thickness, which conceals all earlier rocks and structures. As shown in the structure section along the line Y–Y′ (pl. 12), the beds along the east side form part of the Hot Springs anticline, which is sharply folded, inclined eastward, and broken at the west by the Bear Lake fault.

[38] Gale, H. S., and Richards R. W., op. cit., pp. 495–498.

Phosphate deposits.—The outcrop of the phosphate-bearing strata is readily identified and traced by means of the excellent exposures of the black chert ledge, which forms so conspicuous a marker of this area. The phosphate itself has been prospected to a small extent, but none of the openings exposed a satisfactory section of all the phosphatic beds. It appears, however, that the series is much like that at Montpelier and doubtless contains similar workable beds, as well as a considerable amount of lower-grade rock, which is not at present considered to be commercially valuable.

The principal developments consist of a double set of entry tunnels which open the phosphate at the same place in a small gulch in the NW. ¼ NE. ¼ sec. 24. The duplication of work at the discovery tunnels is the result of conflict among claimants to the property. A complete section, with analyses, of the beds exposed underground in the crosscut joining the entry tunnels is shown in Table 63. It was made in 1909.

TABLE 63.—*Section of phosphate and associated beds at Hot Springs*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	Per cent	Ft.	in.
	Limestone, compact, hard			10+	
141–A	Shale, brown, earthy, calcareous	9	19.7	1	6
141–B	Shale, earthy, massive	2	4.4	2	8
141–C	Phosphate, oolitic, massive, dark gray	32.8	71.8	2	2
	Limestone, massive stratum			2	2
141–D	Phosphate, medium to coarsely oolitic, dark gray	32.3	70.7		11
141–E	Shale, brownish, earthy, calcareous	3.5	7.7	1	
141–F	Phosphate, medium grained, oolitic, dark gray	36.3	79.5	1	3
141–G	Phosphate: (a) Shale, calcareous, 5 inches; (b) phosphate, oolitic, brownish, 4 inches; (c) shale, brownish, phosphatic, 2 inches; (d) shale, brownish, phosphatic, 11 inches	27.5	60.2	1	10
141–H	Phosphate, medium to coarse grained, oolitic (main entry tunnel)	29.1	63.7	5	10
141–I	Phosphate, medium to coarse grained, including pebbly texture	28	61.3	1	5
141–K	Shale, phosphatic, dark brown, earthy	24.3	53.2	11	
	Limestone			1	
141–L	Shale, phosphatic, dark brown, earthy	12.9	28.3+	10	6
	do			4	11
141–M	Shale, phosphatic, somewhat oolitic	20.3	44.5	1	8
141–N	Shale, phosphatic, dark brown, earthy	5.2	11.4	4	6
				64	4

A section of a workable bed opened in a prospect tunnel 600 feet S. 15° W. of the main entries described above exposed material of apparently higher grade than any included in the preceding section. The correlation of this bed with any particular part of that section can not now be positively made, but the 64 feet of strata exposed in the crosscut of the main entry described above probably do not include all of the best material that may be present in that section. The section is given in Table 64.

TABLE 64.—*Section of phosphate beds in prospect near Hot Springs*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	Per cent	Ft.	in.
137–A	Phosphate, coarsely oolitic, dark gray	36.2	79.3	1	3
137–B	do	24.7	54.1		5
137–C	do	34.8	76.2	1	8
137–D	do	37	81	1	8
	Average	35	76.5		

One of the intended but uncompleted developments was the so-called North Lake tunnel, which was begun in the NE. ¼ SW. ¼ sec. 12. This tunnel was planned to run about 3,000 feet east through the older rocks, to cut the phosphate bed and thus to provide a low-level outlet for a group of mining claims farther back in the plateau. When visited in 1912 it had been abandoned at 220 feet. Little work has since been done in the Hot Springs district.

Estimate of tonnage.—The uncertainties regarding the structure beneath Bear Lake Valley are so great that none of that part of the township is considered to have recoverable beds of phosphate.

In the eastern part, however, a narrow strip that includes part of the extra tier of 40-acre lots, comprising about 1,000 acres, has been classified as phosphate land. The dip of the beds at the line of structure section Y–Y′ (pl. 12) is about 70°. In this township it ranges from 40° to 60° and for purposes of computation may be assumed as 50°. The phosphate beds are probably truncated by the Bear Lake fault in about sec. 25, beneath the lake. For a tonnage estimate the length of the phosphate outcrop within the township may be assumed as 18,000 feet. The depth limit under the regulations for a 5-foot bed of rock with 70 per cent of tricalcium phosphate is 4,000 feet. Under such conditions and when allowance is made for the dip this portion of the bed would yield about 37,606,000 long tons of phosphate rock.

T. 16 S., R. 44 E.

Bear Lake conceals all of T. 16 S., R. 44 E., except a narrow strip along the eastern side. Steeply dipping beds that range in age from Thaynes to Twin Creek form the face of the escarpment which here descends from the Bear Lake plateau. Patches of Tertiary and Quaternary rocks here and there conceal the older strata. The Thaynes beds form part of the western limb of the Indian Creek syncline, which is so deep and narrow that the phosphate beds contained in it undoubtedly lie at greater depths than the maximum that is considered workable under existing regulations. The general character of the syncline farther north is shown in the structure section drawn along the line Y–Y′ (pl. 12). The syncline is probably obliquely truncated on the west by the continuation of the Bear Lake fault. No estimate of tonnage is presented.

T. 7 S., R. 45 E.

General features.—T. 7 S., R. 45 E., is in the southwestern part of the Freedom quadrangle (pl. 5) and lies mainly in the Webster Range, but in its southwestern part it includes a portion of Upper Valley and a few foothills of Dry Ridge. It is unsurveyed and rugged and accessible only by indifferent trails from poor roads in Upper Valley at the southwest and Stump Creek at the northeast.

Geology.—The principal geologic formations range in age from the Wells formation to the Preuss sandstone. The extreme northeast corner contains a small patch of the Salt Lake formation. At the same locality and in the southwest along Diamond Creek Quaternary sediments are present.

The Phosphoria formation is exposed only in a relatively small area at the southwest. The Woodside and Thaynes are unusually well developed and are about 1,200 and 2,800 feet thick, respectively. The red-bed member of the upper Thaynes or Portneuf limestone is well exposed on the slopes about Horse Creek and elsewhere. It was first recognized in this township. The Timothy sandstone, which has here its type locality, and the doubtfully Triassic formations are well represented, and the Higham grit and Deadman limestone occupy considerable areas. The Higham grit forms a fine arch in Boulder Canyon.

Several of the larger structural features of the region cross the township. These features include the Boulder Creek anticline, which has formed the arch above mentioned and also the lower arch of Woodside in Webster Canyon; the Webster syncline, which is strikingly developed in the head of Webster Canyon; and the Snowdrift anticline, which causes the exposure of the Phosphoria formation. In the southwest corner part of the Georgetown syncline is present.

The West Stump branch of the Bannock overthrust crosses the northeastern part and the East Stump branch just touches the northeast corner. The Bannock overthrust itself is believed to pass beneath the township though at unknown depth. Other noteworthy faults are the Boulder Creek fault at the northeast and the Lanes Creek and Enoch Valley faults, which originate in the Snowdrift anticline at the southwest. The Blackfoot fault, which is well developed in the township to the west, probably originates in section 18 of this township. The general structural features of the township are shown in the geologic structure section drawn along the line L–L″ (pl. 11).

Phosphate deposits.—Except in sections 31 and 32 the Phosphoria formation does not come to the surface and in these sections there are no exposures by which the nature of the phosphate rock may be judged. Float fragments of phosphate, however, suggest that material of good quality is present. The nearest openings where phosphate beds were measured and sampled are in the SW. ¼ SE. ¼ sec. 14, T. 8 S., R. 44 E., and in the SE. ¼ NW. ¼ sec. 29, T. 8 S., R. 46 E. At the first locality, two beds of phosphate rock near the base, separated by about 8 inches of shale, have an aggregate thickness of 14 feet and an average content of about 60 per cent tricalcium phosphate. The thickness of the phosphate here is unusual and may be in part due to reduplication by minor folding or faulting, but in any event a thick bed of good quality is present. At the other locality, the main bed, though present and apparently 5 feet or more thick, was not in condition to be sampled. The same section, however, near the top, contains six phosphate beds that have an aggregate thickness of 7 feet 7 inches and an average content of about 75 per cent tricalcium phosphate, distributed through a thickness of 12 feet 7 inches of strata. From these two sections, therefore, this township can be fairly assumed to contain the equivalent of a 6-foot bed of workable phosphate rock that averages about 70 per cent of tricalcium phosphate. The depth limit for such a bed under existing regulations is 5,000 feet.

Estimate of tonnage.—On the basis of the known thicknesses of the overlying formations, if present in full force, and the assumed thickness and quality of the phosphate bed 6,880 acres in this township have been classified as phosphate land. However, the Bannock overthrust is known to pass beneath much of this township at unknown depth, and most probably it cuts out part, perhaps half, of the phosphate beds. For purposes of computation, therefore, only about half of the classified acreage is assumed. Thus, 3,400 acres under the above conditions should yield more than 71,400,000 long tons of phosphate rock if the strata were horizontal. The fact that the strata are inclined rather than horizontal would tend to increase the estimate, but the uncertainties regarding the effects of the Bannock overthrust tend to offset any increase. The estimate given seems sufficiently conservative.

Much of the rock is probably below ground-water level. Webster Canyon gives practically the only favorable entry to the deposit on the eastern side. On the western side entries might be made at several places along the outcrop of the Rex in sections 31 and 32.

T. 8 S., R. 45 E.

General features.—T. 8 S., R. 45 E., is mostly in the Crow Creek quadrangle but includes a narrow strip in the southwestern part of the Freedom quadrangle. (Pls. 5 and 7.) Dry Ridge forms the highland in the western side and the Webster Range occupies more than the eastern half. Freeman Ridge projects northward between the two sets of highlands nearly to the middle of the township. Diamond Creek, one of the principal head streams of the Blackfoot, passes through the township east of Dry Ridge and its valley affords the only roadway.

The township is unsurveyed, rugged and relatively inaccessible. A fairly good trail leads from Stewart Flat eastward into Smoky Canyon and thus connects with Crow Creek and Star Valleys by way of Sage, Tygee, and Stump Valleys. Trails of some sort lead into the mountains up most of the larger canyons. Little additional work has been done in this township since the publication of the earlier report.[39]

[39] Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, pp. 56–58, 1914.

Geology.—The principal rocks range in age from the Wells formation to the Thaynes group inclusive. There are no Tertiary beds, but Quaternary sediments occupy the valleys of Diamond Creek and some of its tributaries and some of the adjacent lower slopes.

The township includes parts of the major structural features of the region. Thus, from northeast to southwest the Boulder Creek anticline, the Webster syncline, the Snowdrift anticline, the Georgetown syncline, and the Dry Valley anticline are encountered. There are also unnamed minor folds. The depression of the axis of the Snowdrift anticline which causes the Woodside to overlap the axis in the northwestern part is due to the presence of a broad transverse synclinal fold. (See general map, pl. 1.)

A thrust fault that originates in a minor fold in Dry Ridge at the southwest passes into the adjoining township on the west. The Bannock overthrust is believed to underlie the township at unknown depth. Its plane, which was originally almost horizontal, is now considerably deformed. Below this fault the geologic structure differs from that above, and the rock formations in general are of later age.

The principal structural features of the township are illustrated by the geologic structure section drawn along the line O′–O″, Plate 12.

Phosphate deposits.—No prospecting had been done in the phosphatic shales in this township at the time of the Geological Survey's examination in 1911, and no openings were made there by the survey party. The nearest sections from which data regarding the quality and thickness of the phosphate rock may be obtained are those previously cited in sec. 14, T. 8 S., R. 44 E., and in sec. 29, T. 8 S., R. 46 E. From the data thus available it seems reasonable to assume for this township a 6-foot bed of phosphate rock that averages about 70 per cent tricalcium phosphate.

Estimate of tonnage.—The area classified as phosphate land in this township is 22,360 acres, which necessarily includes some land in which rocks older than the phosphate outcrop. By drawing the boundaries a little closer than can be done along the legal subdivisions, the area of lands made up of the rocks of the formations which normally overlie the phosphate is estimated at 21,900 acres.

In estimating the tonnage of the main phosphate bed two factors have to be considered—the increase of area due to folding and also a possible decrease due to the removal of phosphate by truncation of the synclines by the thrust fault. The increase can be approximated with a fair approach to accuracy, but the decrease, quantitatively at least, is so purely a matter of conjecture that practically it can not be introduced, although it must diminish the actual tonnage of phosphate to some extent. Theoretically, perhaps, the two factors may be regarded as equivalent, although when actually determined they may be found to differ widely. The assumption that 21,900 acres is underlain by a horizontal 6-foot bed of phosphate rock gives a total of 459,900,000 long tons.

The depth of the main phosphate bed in the township ranges from the outcrop at the surface to a maximum probably not in excess of 2,000 feet from favorable points of entry. Much of the rock is probably below ground-water level.

T. 9 S., R. 45 E.

General features.—T. 9 S., R. 45 E., which is in the western part of the Crow Creek quadrangle (pl. 7), includes parts of Dry Ridge, Freeman Ridge, the Webster Range, and the Preuss Range, as here defined. It is unsurveyed, high, and rugged. The valley of Diamond Creek, which heads near the center, contains a poor road that connects southward by way of Georgetown Canyon with Bear Lake Valley and northward with the valley of Blackfoot River. The branches of Sage Creek and Deer Creek have poor trails that connect with the Crow Creek road to Montpelier and Star Valley. The valley of the South Fork of Deer Creek contains a road that connects Georgetown Canyon with Wells Canyon and the Crow Creek road. Little additional work has been done in this township since the publication of the earlier report.[40]

Geology.—The geologic formations are the Brazer limestone and succeeding strata up to and including the Thaynes group. There are no Tertiary beds, and Quaternary sediments are only scantily represented.

Some of the largest folds of the region traverse this township, including the Boulder Creek anticline, the Webster syncline, the Snowdrift anticline, the Georgetown syncline, and the Dry Valley anticline. There are also a number of minor folds. The folds are in general not symmetrical but are inclined eastward, and the eastern (Webster) syncline is broader and shallower than the other.

Several faults that originate in minor folds along the borders of the synclines displace or locally cut out the phosphate beds. A notable fault in the older rocks lies along the west flank of Dry Ridge. A branch of the Bannock overthrust brings Brazer and Woodside strata into contact in the southeast corner of the township. This great fault underlies the township at unknown depth and may affect the phosphate beds in the larger synclines. The rocks beneath the fault plane are in general of later age than those which comprise the formations that appear at the surface. The principal structural features are illustrated in the geologic structure section drawn along the line S″–S‴, Plate 12. The structure sections along the lines O′–O″ and T′–T″ also show details.

Phosphate deposits.—The phosphate deposits lie in two northward-trending belts across the township. The western belt has a constant width of about a mile, whereas the eastern belt ranges in width from about 2½ miles at the northern to half a mile at the southern boundary.

Prior to 1911 no prospecting had been done in the phosphate shales. Members of the survey party explored the natural exposure in the NW. ¼ SE. ¼ sec. 34 and obtained a partial section about 10 feet above the underlying limestone. Table 65 gives the measurements thus obtained and the results of the analyses of the samples taken.

[40] Richards, R. W., and Mansfield, G. R., op. cit., pp. 58–60.

TABLE 65.—*Partial section of phosphatic shales in NW. ¼ SE. ¼ sec. 34, T. 9 S., R. 45 E. Boise meridian*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
R–446	Shale and phosphatic limestone, "cap lime" sheared (?)			1	4
R–446–3	Phosphate rock	32	69.9	1	11
R–446–2	do	29.6	64.6	2	2
R–446–1	Shale, black (sheared)	4.4			5
	Shale			10	
	Limestone.				

The above section shows a bed about 4 feet thick, represented by samples 2 and 3, that averages 65 per cent or more tricalcium phosphate. These figures are somewhat lower, both as regards thickness and quality, than those for the phosphate beds in adjoining townships to the northwest and southwest.

The upper portion of the shales, near the overlying chert, has not been explored, and there may be, as in Tps. 8 to 10 S., R. 44 E., beds of high-grade phosphate at that horizon. However, at this time it is safe to assume only the presence of the 4-foot bed measured.

Estimate of tonnage.—On the supposition that the Bannock overthrust, which is believed to underlie the township, cuts off a portion of the bottom of the western syncline, as shown in structure section S″–S‴ (pl. 12), some of the phosphate deposits may have been destroyed. If a fair allowance is made for this loss, and if the average dip is assumed to be 60°, the western syncline contains about 4,400 acres underlain by phosphate deposits. The eastern syncline, which has an assumed average dip of 30°, contains about 8,160 acres, and thus the total is approximately 12,560 acres, or somewhat less than the area actually classified as phosphate land, which is 14,680 acres. The 4-foot bed of phosphate rock that underlies this township in the two synclines as indicated is estimated at 171,400,000 long tons. Much of the phosphate probably lies below the level of ground water, and all of it probably lies at depths less than 2,000 feet below the surface.

The deposits of the western syncline are accessible from the road along Diamond Creek, built by the Forest Service in 1911. The east side of the eastern syncline may be reached with little difficulty by the trails through the forks of Sage Creek. The interior of the eastern syncline and the west side of the western syncline lie in relatively high country, to which there is no available means of access at the present time. However, several deeply cut canyons extend far back into the ridges, and in these canyons roads can be constructed without much difficulty. Trails used by sheep outfits are now found in most of the larger canyons.

T. 10 S., R. 45 E.

General features.—T. 10 S., R. 45 E., is in the southwestern part of the Crow Creek quadrangle. (Pl. 7.) It lies largely in the northern part of the Preuss Range and includes the high ridge known as Snowdrift Mountain. The northwest corner, however, contains part of Dry Ridge and the eastern part contains marginal members of the Gannett Hills, which are separated from the Preuss Range by the valley of Crow Creek. Most of the township is high and rugged, and less than half of it is surveyed. The road from Montpelier to Star Valley passes along Crow Creek, and in Wells Canyon a road connects the Star Valley road with Bear Lake Valley by way of Georgetown Canyon. Poor roads connect Crow Creek Valley with Ephraim and Elk Valleys farther east. This township has been described in an earlier report,[41] but more recent field work has led to some minor changes in the mapping.

Geology.—The geologic formations range in age from the Brazer limestone to the Ephraim conglomerate, and there are besides some Quaternary beds. The Phosphoria beds occur chiefly in somewhat irregular bands that are associated with the Webster and Georgetown synclines.

The Webster syncline is unsymmetrical and so shallow that it is nearly cut through by branches of Wells Canyon. Considerable areas of it are occupied by beds of Rex chert, and only part of the Woodside shale is present. The Georgetown syncline, also unsymmetrical, is deeper and contains beds of the Thaynes. Its eastern side is steeper and hence the belt of Rex chert is much narrower. A fault that originates in a subordinate anticline forms a break along the axial plane of the syncline. The Snowdrift anticline, which separates the two synclines, is closely appressed and appears to be the eroded remnant of a fan fold. It brings Brazer limestone to the surface along the ridge. The Boulder Creek anticline east of the Webster syncline brings Brazer limestone to the surface in the northeastern part of the township. A broken syncline east of this anticline includes beds of the Phosphoria, Woodside, and Thaynes in section 34 and at intervals northeastward through the township. Subordinate folds in the Phosphoria formation occur along the margins of the big synclines. They probably also occur in the bottoms of these synclines as suggested by the six canoe-shaped remnants in section 33. The Jurassic and Cretaceous formations along the east side form part of the Red Mountain syncline, the axis of which lies in the adjoining township.

The Bannock overthrust in several branches passes through the township along the general line of Crow Creek. One branch cuts off the phosphate-bearing portion of the Webster syncline. The other branches in Crow Creek have the combined effect of bringing beds that range in age from the Brazer limestone to lower beds of the Thaynes into contact with Jurassic formations. The Bannock overthrust passes beneath the area west of Crow Creek, but at probably too great a depth to affect the phosphate beds in the synclines, unless possibly in part of the Georgetown syncline. The general structural features of the township as here interpreted are illustrated in the geologic structure sections drawn along the lines T′–T″ and V–V′. (Pl. 12.)

Phosphate deposits.—The phosphate deposits of this township have been prospected along only one of the four lines of outcrop—that on the west flank of Snowdrift Mountain. Many openings, mostly shallow trenches, have been made by the Utah Fertilizer & Chemical Manufacturing Co. in the course of its assessment and patent work. Many of these openings show the character of the main basal bed, whereas others are superficial and do not penetrate to bedrock. Two cuts are especially complete and expose practically the entire section of the phosphatic shales.

The section in one of these cuts is given in Table 18 (p. 77), and that in the other is given in Table 66.

The sections measured at these localities probably give a representative view of the quality and quantity of phosphatic materials which would be found in the unprospected portions of this township. Nearly all the strata appear to be highly phosphatic, and there are several high-grade beds.

The main bed, as in the Montpelier district, in T. 13 S., R. 45 E., occurs at the base of the phosphate section. It differs in thickness from place to place but appears to average about 6 feet in places where it has been fully opened. The rock phosphate is of high grade and carries about 37 per cent phosphorus pentoxide, equivalent to about 80 per cent tricalcium phosphate, as shown by the analyses. Its texture is medium to coarse oolitic and its color is dark grayish-brown, almost black when fresh. It contains little foreign matter in the form of partings. It is capped by a single 2-foot stratum of dark fine-grained fossiliferous limestone.

[41] Richards, R. W., and Mansfield, G. R., op. cit., pp. 61–64.

TABLE 66.—*Section of basal portion of Phosphoria formation in Georgetown Canyon, in SE. ¼ NW. ¼ sec. 30, T. 10 S., R. 45 E. Boise meridian*

[Land lines theoretical]

Field No. of specimen		P_2O_5 [a]	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
		Per cent	*Per cent*	*Ft.*	*in.*
144-A	Shale, calcareous, or muddy limestone, brown, weathering into irregular chip fragments; effervesces vigorously	3.5	7.7	25	6
144-B	Phosphate rock, oolitic, weathering brown or gray; effervesces slightly; 1½ inches somewhat cherty	35.8	78.4		6
144-C	Shale, hard, brown, calcareous at the top; effervesces vigorously	Trace	----------	1	
144-D	Phosphate rock, coarsely oolitic, gray; effervesces vigorously	37.6	82.1	2	11
144-E	Shale, brownish, earthy; contains 6 inches of phosphate; effervesces considerably	10	21.9	1	
144-F	Phosphate rock, including phosphate rock, oolitic, hard, gray, calcareous 7 inches; phosphate rock, medium, gray, oolitic, 6 inches; shale, phosphatic, light brown, 4 inches; sample shows considerable effervescence	21.9	48	1	5
144-G	Phosphate rock, including phosphate rock, coarsely oolitic, gray, brittle, 1 foot 2 inches; phosphate rock, finely oolitic, brownish gray, 4 inches; phosphate rock, coarsely oolitic, dark gray, 2 inches; phosphate rock, finely oolitic, brownish gray, 4 inches; phosphate rock, coarsely oolitic, gray, 7 inches; phosphate rock, finely oolitic, thin bedded, 3 inches; phosphate rock, coarsely oolitic, gray, 1 foot 4 inches; sample effervesces slightly	33.3	72.7	4	2
144-H	Phosphate rock, including phosphate rock, medium to finely oolitic, brownish gray, 7 inches; shale, phosphatic, brownish, somewhat oolitic, 10 inches; phosphate rock, coarsely oolitic, 2 inches; phosphate rock, shaly brown, 3 inches	29.3	65.3	1	10
144-I	Phosphate rock, including phosphate rock, coarsely oolitic, brownish-black streaks, 1 foot 1 inch; phosphate rock, shaly, brown, thin bedded, 5 inches; phosphate coarsely oolitic, crumbly, 4 inches; phosphate rock, medium to coarsely oolitic, 3 feet; sample effervesces considerably	34.7	75.8	4	10
144-K	Shale, brownish to black, earthy composition, thin bedded, with a few limestone lenses, effervesces slightly	24.2	53	8	9
	Limestone, dark, compact, fetid	----------	----------	1	9
144-L	Shale, brownish to black, earthy; effervesces slightly	11.7	25.6	12	
144-M	Shale, including shale, brownish black, earthy, 7 feet; concealed, not included in sample (probably same as bed just above and below), 4 feet 7 inches; shale, brownish black, earthy, 5 feet 5 inches	15.1	33.1	17	
144-N	Shale, black, earthy; effervesces slightly	19.9	43.6	12	
144-O	Shale, brownish black, earthy, 4 inches; limestone, single stratum (not sampled), 2 inches; shale, brownish black, earthy, 4 inches; limestone, single stratum (not sampled), 2 inches	21.2	46.4	12	
144-P	Shale, black and dark brown, calcareous, earthy; effervesces considerably	25.8	56.3	6	2
144-Q	Shale, black and dark brown, calcareous, earthy; effervesces considerably	24.6	53.9	12	
144-R	Limestone, shaly, brownish gray, effervesces vigorously	17.8	39	4	10
	Limestone, single stratum	----------	----------		11
	Limestone ("cap lime"), fine, dark gray, fossiliferous	----------	----------	2	3
144-S	Phosphate rock, main bed prospected, coarse to medium oolitic, brown; contains two or more minor streaks of shaly material; effervesces slightly	36.8	80.4	6	4
144-T	Shale, brown, earthy; effervesces slightly	3.7	8.1		9
	Limestone, massive, underlying the phosphatic series; thickness not determined.				
				139	11

[a] Phosphorus pentoxide determinations by W. H. Waggaman, U. S. Dept. Agr. Bur. Soils, 1909.

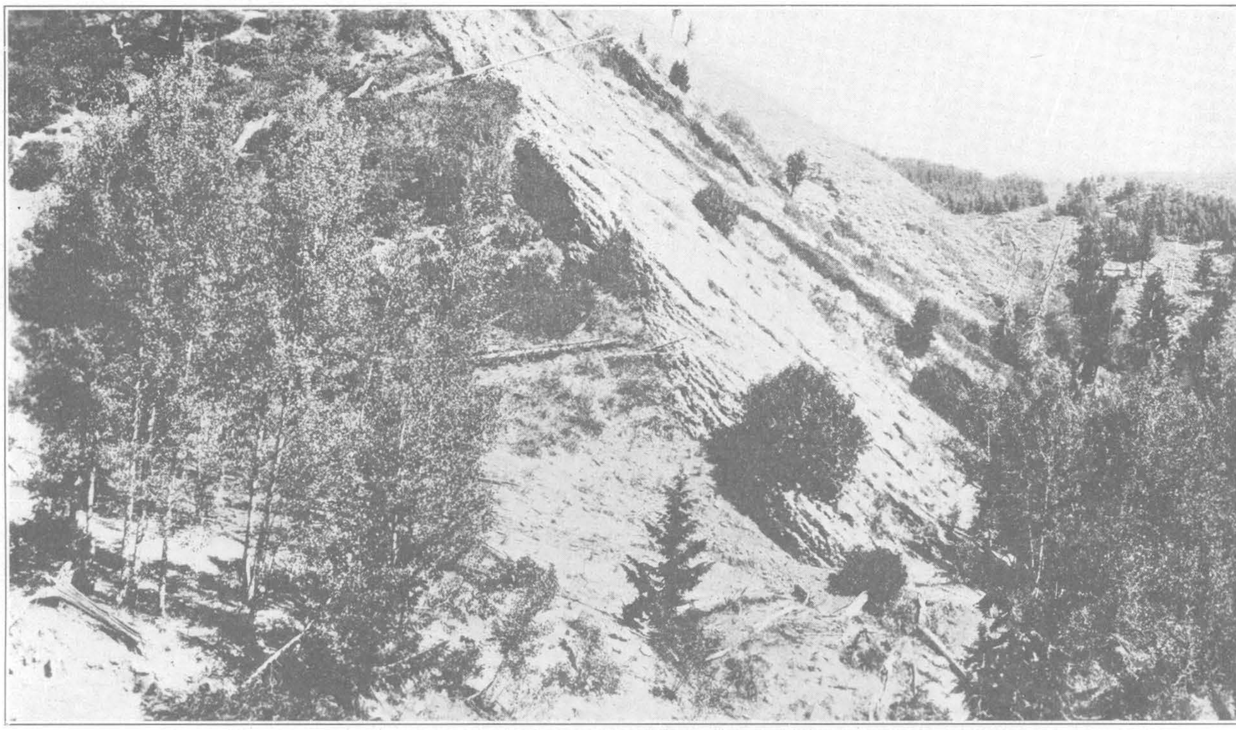
Estimate of tonnage.—Although the area classified as phosphate land in this township is 6,480 acres, the area actually underlain by workable phosphate is estimated to be 3,967 acres. Of this amount about 2,336 acres lies on the western syncline and 1,631 acres on the eastern fold. The surface area of the main phosphate bed as bent up on the western fold is approximately two-fifths greater than that of the surface area of the land, so that the main basal bed comprises an area equal to about 3,889 acres. The difference between the area of the overlying lands and the extent of the main bed is much less in the eastern fold, where the area of the bed is estimated to exceed that of the lands by one-eighth. A deduction has been made in this estimate for the area of phosphate which probably has been displaced by the subordinate thrust from its position under the normally overlying chert and Woodside shale in sections 28 and 29.

The total area of the main basal bed, which may serve as the basis of an estimate of tonnage, is thus about 4,236 acres. On the assumption that the average thickness of the bed throughout this extent is 6 feet, the contained tonnage of high-grade phosphate rock is 88,900,000 long tons. All the high-grade rock included in this estimate is ultimately available, as the greatest depth from favorable points of entry is less than 2,000 feet.

The phosphate content of the entire section of the phosphatic shales is probably several times the above estimate—that is, in high-grade rock alone—and an enormous tonnage of low-grade material is present, which may at some future time prove of great value.

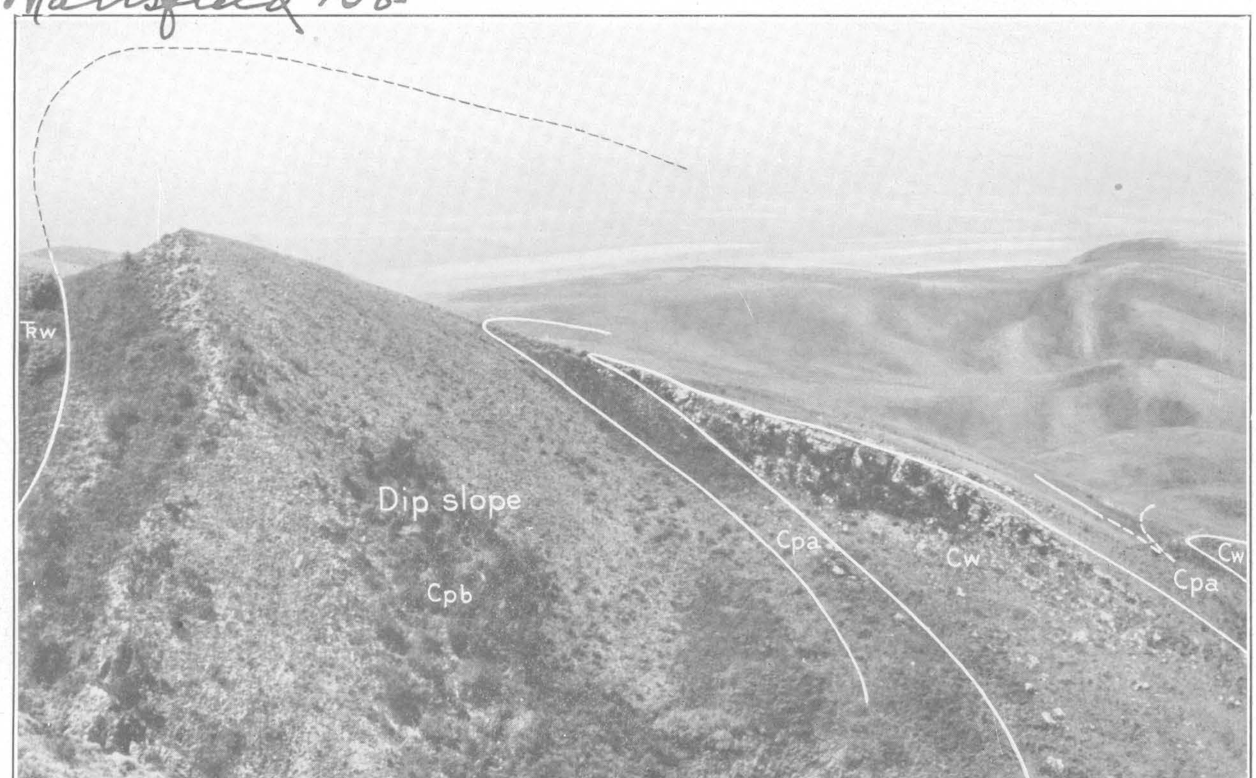
Development.—The development of the phosphate beds west of Snowdrift Mountain will be dependent to a greater or less extent upon the plans worked out for the recovery of the phosphate in the extension of the

Mansfield, 79.



A. DIP SLOPE OF REX CHERT NEAR THE HEAD OF CROW CREEK, T. 11 S., R. 45 E., MONTPELIER QUADRANGLE

Mansfield 138-



B. DRAG FOLDS ON WATERLOO HILL, SECS. 5 AND 6, T. 13 S., R. 45 E., MONTPELIER QUADRANGLE

Looking southwest. Cw, Wells formation; Cpa, Phosphoria phosphatic shale; Cpb, Rex chert member of Phosphoria formation; Ꞧw, Woodside shale phosphate-bearing area in the township to the west. Partial plans for this development have been outlined in the discussion of that township. Georgetown Canyon is the natural outlet for that area. The eastern phosphate-bearing area is now relatively inaccessible and will be dependent for its development on railroad construction into Star and Crow Creek Valleys. The side canyons, notably those of Wells and Deer Creeks, afford suitable points of entry.

Ownership.—The title to about 5,220 acres of the total area of classified phosphate land in this township is vested in the United States Government. The Utah Fertilizer & Chemical Manufacturing Co., under claims filed under the provisions of the mineral-land laws, holds 780 acres. The State school land in section 16 includes 480 acres that carry phosphate.

T. 11 S., R. 45 E.

General features.—T. 11 S., R. 45 E., is chiefly in the Montpelier quadrangle, though it includes a narrow strip in the southwestern part of the Crow Creek quadrangle. (Pls. 7 and 9.) The township is generally high and rugged, and it contains Meade Peak, the highest summit in the entire region described in this report. Most of the area lies in the Preuss Range, but the eastern part is in the Gannett Hills. Trails of some sort may be found in most of the canyons. The Star Valley road, which passes through the eastern part of the township, is the only highway, and this has steep grades and bad places. The township has been described in an earlier report,[42] but more recent field work has modified the earlier mapping, particularly in the eastern part.

Geology.—The principal geologic formations range in age from the Madison limestone to the Ephraim conglomerate, but the Timothy sandstone and overlying doubtfully Triassic formations have not been recognized. Certain red beds in the SE. ¼ SE. ¼ sec. 10 suggest the Wood shale, but they are considered instead to belong in the upper Nugget. Beds of the Salt Lake formation lie along the west flank of Red Mountain from section 1 to section 13. In the northern part these beds are well-defined white marly grits and conglomerates. Farther south they are more influenced by the red material from the adjacent red beds, and their boundaries are less well defined.

A somewhat crescent-shaped area of travertine is found in portions of sections 3 and 10. In some places, notably on the spur above Crow Creek in the north part of section 10, the travertine contains pebbles of other rock and resembles to some degree the marly beds of the supposed Pliocene. Elsewhere the banded calcareous material bears evidence of deposition from springs, and the resemblance to the Pliocene (?) deposits is not close.

The Phosphoria formation is well developed in two localities in the northwestern part of the township. The first is a continuation of the South Canyon area which is described, in the discussion of T. 11 S., R. 44 E.; the second is along the north side of Crow Creek in sections 4, 5, and 8. The lower or phosphate-bearing portion of the formation is not actually exposed by open cuts or prospects in this township, but its presence may readily be determined by float along the line where it approaches the surface. Topographically it is represented by depressions or saddles on the ridges and by valleys. In sections 4 and 5 it occurs in a small canyon tributary to the Crow Creek system. The Rex chert member is well represented in both localities and, so far as observed, consists solely of heavy chert layers without fossils. In sections 4 and 8 and 3 and 9 the chert forms remarkably fine dip slopes of bare rock along the north side of Crow Creek. (See pl. 50, *A*.)

The geologic structure of the township is divided by the Bannock overthrust into two distinct units. The upper block, which occupies somewhat more than the northwest quarter, includes the older group of rocks and contains the southern ends of some of the larger folds that are so prominent farther north.

The Boulder Creek anticline enters the northwestern part of the township in section 5 and the Snowdrift anticline at the extreme northwest corner. The faulted syncline of South Canyon, in sections 7 and 18, may represent a fragment of the Webster syncline, detached from the main structure by branches of the Bannock fault. The other phosphate-bearing area is part of an unnamed syncline that lies generally east of the Boulder Creek anticline but is caught in the marginal area of the Bannock fault and very nearly cut out just north of the township line, though it is probably represented by the narrow strip of Phosphoria and Woodside beds between the Sage Valley and West Crow Creek branches of the Bannock overthrust in the township to the north.

The lower block, which occupies the larger part of the township, is revealed, where it emerges from beneath the upper block, as a closely folded mass of Jurassic and later rocks, the folds being more appressed in the thin-bedded and shaly Twin Creek limestone than in the more massively bedded lower and higher rocks.

The Red Mountain syncline, which skirts the eastern border of the township, and the Home Canyon anticline, which enters the southwestern part, are relatively open folds. The intervening more closely appressed folds are given names (see general map, pl. 1) because they are thought to be the northern continuations of more open folds distinguished farther south. Of these folds the Giveout anticline deserves special mention, for it is almost diagrammatically exposed in the hills immediately west and northwest of Giveout. (See pl. 36, *C*.)

[42] Richards, R. W., and Mansfield, G. R., op. cit., pp. 65–70.

The Bannock overthrust, which enters the township in the NW. ¼ sec. 19, branches in the eastern part of section 20. The western branch separates the Carboniferous from the Triassic (Thaynes group), and the eastern branch separates the higher parts of the Thaynes group from the top of the Nugget sandstone. The western branch diminishes northward in stratigraphic throw and dies out in the southern part of the adjoining township on the north. The eastern branch continues northward with increasing throw and becomes the dominant thrust in regions to the north. The relations of the thrust block to the underlying rocks may be very clearly seen on the north side of the upper canyon of Montpelier Creek, in sections 19 and 20, where rocks of Madison and upper Mississippian (Brazer) age, marked by rough craggy topography, overlie the splintery shaly limestones of the Twin Creek formation. The topographic contrast is very striking, and the contact may easily be traced along the sides of the valley. The stratigraphic displacement here amounts probably to not less than 8,500 feet.

The thrust block itself was probably contemporaneous with the earlier folding and represents a great eastward movement of the older rocks from the west over the younger formations to the east. Subsequently the mass seems to have suffered compression from the east, for the eastern branch of the fault now has a steep westerly hade, whereas the western branch, in section 8, has an easterly hade of about 42°. It seems clear, nevertheless, that this western branch is really a part of the thrust fault and not an independent normal fault, because it may easily be traced along the saddles at the base of the ridge into the thrust fault in Montpelier Canyon, and the hade changes from east to west as the branching point is approached. The later folding is also shown by a subsidiary thrust that marks off the phosphate basin in sections 18 and 7. Here, too, the fault plane has been folded, and from the unequal thicknesses of the existing portions of the formations that accompany the phosphate the inference is drawn that the bottom portion of the phosphate syncline has been truncated by the fault.

The boundary between the Twin Creek limestone and the Preuss sandstone is marked locally by slight faulting, particularly in sections 2, 11, and 22.

The two formations, which have discordant dips, occupy opposite sides of deeply cut valleys, and varicolored clays, suggestive of fault clay, are exposed here and there along the general contact line. To the north the fault plane is apparently steep and may be normal, but perhaps this fault is related to the east Crow Creek branch of the Bannock overthrust. Farther south the contact between the formations is less regular and has a much more gentle inclination.

The structural features above described are illustrated in part in the geologic structure section drawn along the line W–W′. (See also structure sections T–T′′, U–U′′, and Y–Y′, pl. 12; and pl. 37.)

Phosphate deposits.—Phosphate rock comes to the surface in sections 3, 4, 5, 7, 8, and 18, but it probably underlies most of the rest of the township, except the areas occupied by Carboniferous rocks that are older than the phosphate rock, at depths too great to make it available. No openings have thus far been made in the phosphate beds in this township, so that the character of the rock can be determined only by the fragments of float on the surface, which seem to indicate deposits comparable in nature and thickness with the neighboring deposits in Georgetown Canyon, to the northwest, where numerous prospect pits have been opened.

Estimate of tonnage.—The area classified as phosphate land is 2,120 acres, but the estimated area underlain by phosphate rock at depths not greater than 2,500 feet, bounded at the surface by the *Meekoceras* zone or base of the Thaynes group, is 1,260 acres, or nearly 2 square miles. On the assumption that the high-grade phosphate bed is 5 feet thick, a reasonable assumption in view of the known thicknesses in neighboring townships, this area would contain over 22,000,000 long tons if the rocks were horizontal. The dips within the district are somewhat variable, but perhaps 40° may be taken as a fair average. On this basis the above estimate would be increased 30 per cent. If the estimate were made to include rock as much as 3,000 to 3,500 feet below the surface there would be added the area underlain by the Thaynes group, which would increase by a little more than 2 square miles the total already mentioned and would more than double the estimated tonnage.

It should be remembered, however, that this entire area constitutes part of a great thrust block and is underlain by a fault plane, which may cut out much or all of the deeper parts of the deposit. In the absence of drill records the depth at which the fault plane lies is uncertain. Possibly too, the assumed thickness of the phosphate bed may be greater than the actual thickness, although this seems unlikely. In view of these circumstances it seems wiser to adhere to the estimate as first given—namely, 22,000,000 long tons, which is surely conservative. This amount includes the 656,000 tons excluded from the estimate given for the South Canyon district in T. 11 S., R. 44 E.

The phosphate deposits are accessible through the valleys of Crow Creek and the south fork of Georgetown Canyon, respectively. Much of the phosphate rock is above water level.

T. 12 S., R. 45 E.

General features.—T. 12 S., R. 45 E., is in the Montpelier quadrangle (pl. 9) and in the Preuss Range. It is in general high and rugged, though the upper topography is relatively gentle. Montpelier Canyon and its tributaries contain roads to Star and Thomas Fork Valleys. Secondary roads also lie in Home Canyon and some of the other canyons. This township is part of the Montpelier district as described by Gale and Richards,[43] whose map is reproduced in Plate 51. Since the publication of that report additional work has been done both in the details of mapping the main phosphate bed and in working out the areal and structural geology of the township.

Geology.—The exposed beds comprise the Madison limestone and most of the succeeding formations up to and including the Preuss sandstone. The Brazer limestone, however, is absent, and in the mapping the Higham grit, Deadman limestone, and Wood shale are not separately distinguished, though their presence as a group of formations is indicated.

The red-bed member of the upper Thaynes is present in great thickness and is especially well represented in Home Canyon.

The Phosphoria formation occurs in an irregular band associated with broken folds in the southwestern part. The Rex chert member consists partly of fossiliferous limestone in which the fossils are numerous and characteristic, The phosphatic shales, which are about 200 feet thick, are dark brown and black and contain some beds of limestone, notably the "cap lime" 2 feet thick above the main phosphate bed. (See pl. 52, *B*.)

The fold that causes the exposure of the phosphate beds is the Montpelier anticline, which extends southward into the adjacent township. This anticline is bifurcated at the north by a minor syncline and is cut off by a thrust fault in the same direction. This fault is joined by another thrust fault, with westerly hade, which cuts out part of the east flank of the anticline and brings first the Woodside and then the Thaynes into contact with beds of the Wells formation. A third thrust crosses Montpelier Canyon roughly parallel with the second and joins it farther north. The combined effect of these faults is to reduce greatly the representation of the Thaynes northward. The basis for drawing the third fault on the map is the fact that on both the north and south sides of Montpelier Canyon the red beds of the upper Thaynes lie abnormally close to the lower member of the same formation.

[43] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 488-495, 1910.

These faults and the eastward inclination of the Montpelier anticline are doubtless closely related to the disturbances introduced by the Bannock overthrust, which overlaps the southwestern border of the township and brings Madison limestone into contact with Thaynes and Woodside beds.

The remainder of the township is traversed by a series of folds (see general map, pl. 1), of which only the Bald Mountain syncline and the Home Canyon anticline have possible significance as carriers of phosphate beds. The Home Canyon anticline is slightly faulted along its west flank. The other folds doubtless contain phosphate but at depths too great to be considered recoverable under existing regulations.

The general structural features above described are illustrated in part by the geologic structure section drawn along the line X–X′, which passes close to the south border of the township.

Phosphate deposits.—The general distribution of the phosphate lands, which coincides in general with that of the Thaynes group, is shown on the map of the quadrangle. (Pl. 9.) A more detailed map showing the outline of the phosphate outcrop and the location of many prospects is given in Figure 30. The prospects numbered 4 to 15 on the map by Gale and Richards were measured and sampled in 1909 with the results shown on that map. (Pl. 51.) The section measured at locality 15 is given in Table 67.

TABLE 67.—*Section of phosphatic shales at locality 15 in Montpelier Canyon in SW. ¼ SE. ¼ sec. 31, T. 12 S., R. 45 E.*

	P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
	Per cent	*Per cent*	*Ft.*	*in.*
Shale, soft, phosphatic; top not reached			40	
Limestone stratum, brecciated; weathers to an earthy or muddy color			2	6
Shale, soft, black, mixed with earth	12	25. 8	2	
Shale, including soft, thick limestone nodules			3	
Shale, black; appears somewhat phosphatic			2	
Shale, black, containing one large limestone nodule (not included in sample)	12. 6	27	6	
Limestone; cross section of nodule embedded in black shale; measured at its thickest part				8
Shale, black, claylike; shows little or no sign of oolitic structure	16. 6	35. 4	5	
Limestone, hard, dark; similar to nodules that occur in the overlying shale; appears phosphatic at top	2. 6	5. 7	1	5
Shale, black, phosphatic	14. 8	31. 4	2	4
Limestone, somewhat fossiliferous; forms roof of the main phosphate bed ("cap lime")			2	
Phosphate, main bed not measured at this place, approximate thickness			5	
			71.	11

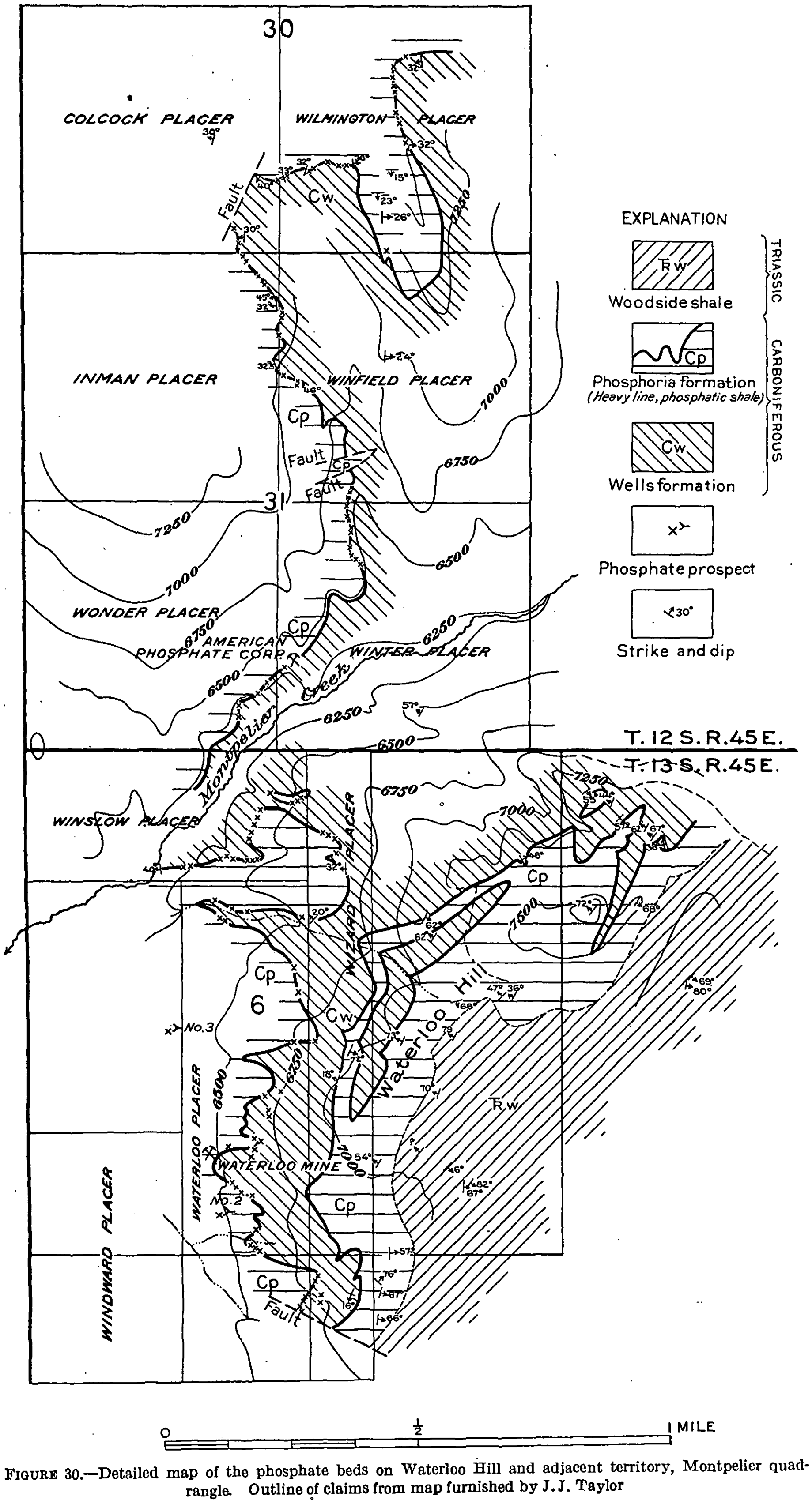


FIGURE 30.—Detailed map of the phosphate beds on Waterloo Hill and adjacent territory, Montpelier quadrangle. Outline of claims from map furnished by J. J. Taylor

Numerous other sections were examined in 1909 and also in 1910, when the detailed map (fig. 30) was made. These sections were measured chiefly on the main bed, but the pits in which many of them were exposed were so badly caved that they did not afford much evidence of the actual condition of the beds. Extensive, almost continuous prospecting along the outcrop northward from the waterworks dam has traced the main bed in Phosphate Gulch and across a dividing spur to the west side of Home Canyon in the eastern part of section 30. There it is cut out by one of the thrust faults above mentioned.

In 1920 the American Phosphate Corporation, having leased ground from the San Francisco Chemical Co., opened a phosphate mine on the north side of Montpelier Canyon about 1,000 feet north of the dam in the SE. ¼ sec. 31. In their entry, which at the time of the writer's visit ran about 400 feet north along the strike, the main bed is about 6 feet thick and is said to average 70 per cent or more of tricalcium phosphate. A sample collected by the writer in the third stope at a place where the main bed was 58 inches thick yielded on analysis in the laboratory of the Geological Survey 31.73 per cent phosphorus pentoxide, equivalent to 69.26 per cent tricalcium phosphate. The sample also contained 0.44 per cent vanadium pentoxide, 0.23 per cent chromic oxide, and 0.42 per cent fluorine.

In view of this showing and of the essential continuity of the main bed with that in the Waterloo claim in the adjoining township at the south, where a 5½-foot bed of phosphate that averages 70 per cent or more of tricalcium phosphate has been mined for several years, it seems fair to conclude that the main bed in this township is in all probability similar in thickness and quality to that of the Waterloo claim.

Estimate of tonnage.—In view of the faulted condition of the post-phosphate rocks and of the closeness of the folding, the area classified as phosphate land has been limited to 880 acres in sections 30 and 31, although it is quite possible that phosphate at workable depths may underlie as much as 5,000 acres. The 880-acre tract underlain by a horizontal 5½-foot bed would yield more than 15,400,000 long tons of phosphate rock. Although the dips of the beds range from 24° to more than 70° and therefore the surface of the phosphate bed contained in the given area is increased considerably above what it would be if horizontal, the presence of faults, which may cut out phosphate beds beneath some of the Triassic rocks, would tend to offset this increase. The estimate is therefore presented without allowing any increase for dip.

American Phosphate Corporation.—This company, which began operations on leased ground in February, 1920, had by August 30 of the same year driven an entry along the phosphate bed 400 feet and opened six stopes, each about 100 feet up the dip, leaving 30-foot pillars. The workings had developed the presence of small folds and of two systems of faults, north-south and east-west, respectively, the throw of which ranges from 18 inches to 12 feet. Shipping was in progress at the rate of 64 to 72 tons a day, and the rock was hauled on 8-ton trucks 4½ miles to the railroad. Storage space was available for 150 tons of rock, but new construction in progress was intended to provide space for 1,200 tons. Plans were well advanced for the installation of a crusher and drier of 500 tons capacity at an estimated cost of about $15,000, and part of this machinery was already on the ground. In the following December construction of this plant was in progress. Shipments up to September 15 had amounted to more than 4,100 tons, but during the business depression of the succeeding winter the property was closed. Small shipments to California were made by the corporation in the summer of 1920. Until 1925 the company operated intermittently under its lease and shipped a total of about 20,000 tons. Then it ceased operations and turned the proprety back to the lessor, the San Francisco Chemical Co.

T. 13 S., R. 45 E.

General features.—T. 13 S., R. 45 E., which is in the Montpelier quadrangle (pl. 9), lies in the Preuss Range and is high and hilly, especially its eastern part, but is less rugged than some of the townships previously described. The Star Valley road passes through the northwest corner along Montpelier Canyon, and one of the roads to Thomas Fork strikes the northeast corner. Roads to Cokeville and places on Bear River pass through the southwestern part. Most of the township, however, is untouched by roads, though trails of some sort extend in many directions through it and all of it is accessible to horsemen.

The township forms part of the Montpelier district as described by Gale and Richards[44] and contains the Waterloo mine of the San Francisco Chemical Co., which has been the longest operated and the most continuous producer among the phosphate mines of the region here described.

Geology.—The older beds range from the Wells formation up to and including the Twin Creek limestone. A considerable area in the southwestern part of the township is underlain by the Salt Lake formation and there are small areas occupied by Quaternary beds.

The exposures of the Wells and Phosphoria are all in the northwestern part of the township, in connection with the Montpelier anticline, which is complex and faulted. The faulted area, which curves southward from section 4, may represent the southward continuation of the Bald Mountain syncline, here overturned and broken. The Home Canyon anticline lies immediately east of this area, and farther

[44] Gale, H. S., and Richards, R. W., op. cit.

east lies a series of close folds in the Jurassic formations, the axes of which are represented on the general map. (Pl. 1.) The principal structural features of the township are illustrated in the structure section drawn along the line X–X′. (Pl. 12).

Phosphate deposits.—The principal phosphate developments in this and the adjoining township on the north are on the property of the San Francisco Chemical Co., which is shown with adjacent territory on the map forming Figure 30. The map also shows in considerable detail the outcrop of the main phosphate bed. Although the phosphate is exposed chiefly along the west flank of the Montpelier anticline, that fold is complicated by the presence of drag folds, which duplicate the phosphatic shales on the slopes of Waterloo Mountain, so that one may cross the main phosphate bed from four to seven times in making a traverse over the mountain at right angles to the strike. The drag folds have sharp crests marked by ledges of the upper Wells and long gentle westerly slopes. (See pl. 50, *B*, and fig. 31.) The reduplication of the main bed is greatest at the north end of the mountain. (See also pl. 52, *A*.) This tendency for the occurrence of drag folding in the phosphate beds has been noted in the discussion of other townships. It may account for some of the difficulties encountered by the American Phosphate Corporation in following the phosphate bed in their mine in the adjoining township.

Waterloo claim.—The Waterloo claim is located on the west slope of Waterloo Hill, in Montpelier Canyon. (See fig. 30.) It is 1 mile long from north to south and one-fourth mile in width, including the SE. ¼ NW. ¼ and the E. ½ SW. ¼ sec. 6 and the NE. ¼ NW. ¼ sec. 7, T. 13 S., R. 45 E. Near the center of the claim an open cut was quarried some years ago, that covered an area about 200 feet square and exposed the bare ledges of the upper part of the Wells formation on the western dip slope of the hill. These rocks dip 30° to 32° W. In 1909 mining tunnels had been run in below the open cut. Both are under shallow cover; the upper one starts directly from the outcrop and the lower one crosscuts a short distance into the same bed. A shaft had been sunk near the mines just west of the Waterloo claim but had not been completed at the time the property was visited.

A number of tests and measurements of the main phosphate bed on this claim were made in 1909, and the results, indicated by the numbers 17 to 22 are shown graphically on Plate 51. The phosphate bed here occurs at the base of the phosphatic shales and is everywhere overlain by a fossiliferous stratum of dark fine-grained limestone—the "cap lime." The phosphate rock itself is black, of a shaly or thin-bedded structure, and much resembles coal in general appearance, especially in a natural exposure or weathered outcrop, though it lacks the pitchy luster of coal. Wherever it lies within 30 or 40 feet of the surface, the main phosphate bed has proved sufficiently soft to be mined with a pick, and the entries are advanced with a breast auger drill, as in coal mining. The detailed measurements obtained at the mouth of the upper tunnel on the Waterloo claim are shown in Table 68.

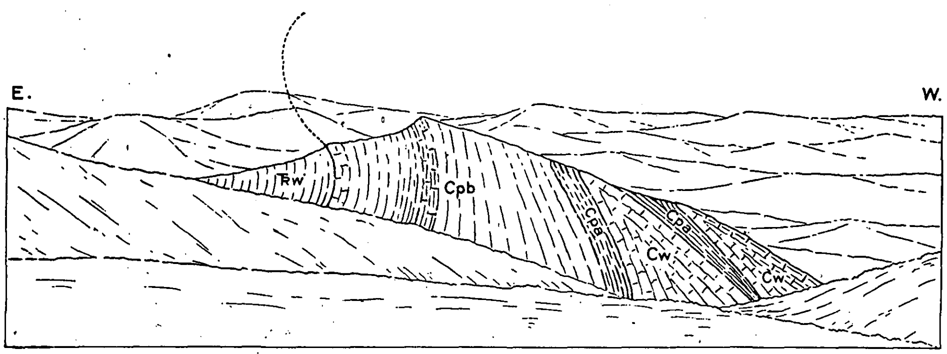
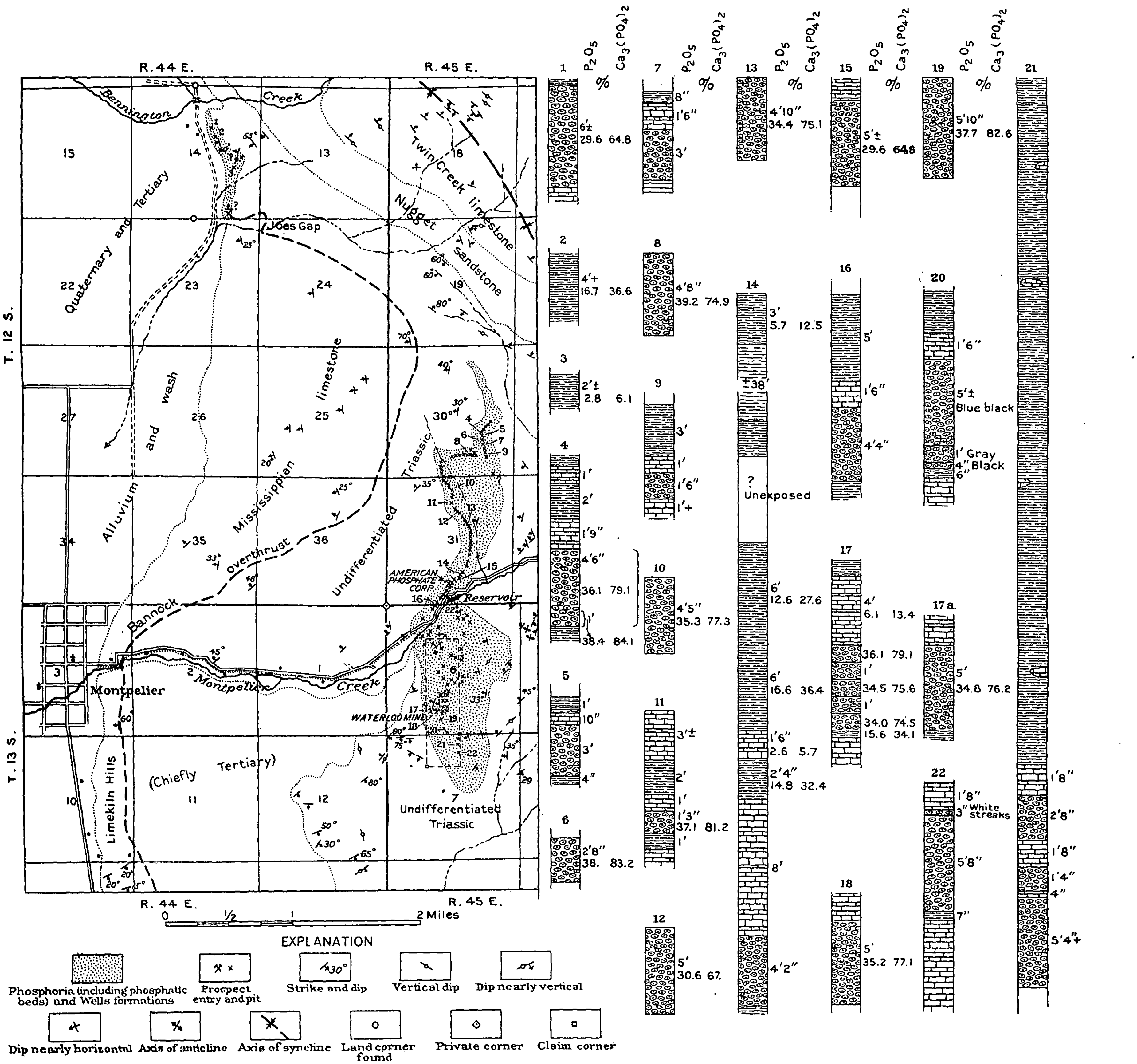


FIGURE 31.—Structure of the Phosphoria and adjacent formations on Waterloo Hill, near Montpelier, Idaho. Cw, Wells formation; Cpa, phosphatic shales of Phosphoria; Cpb, Rex chert member; Ŧw, Woodside shale

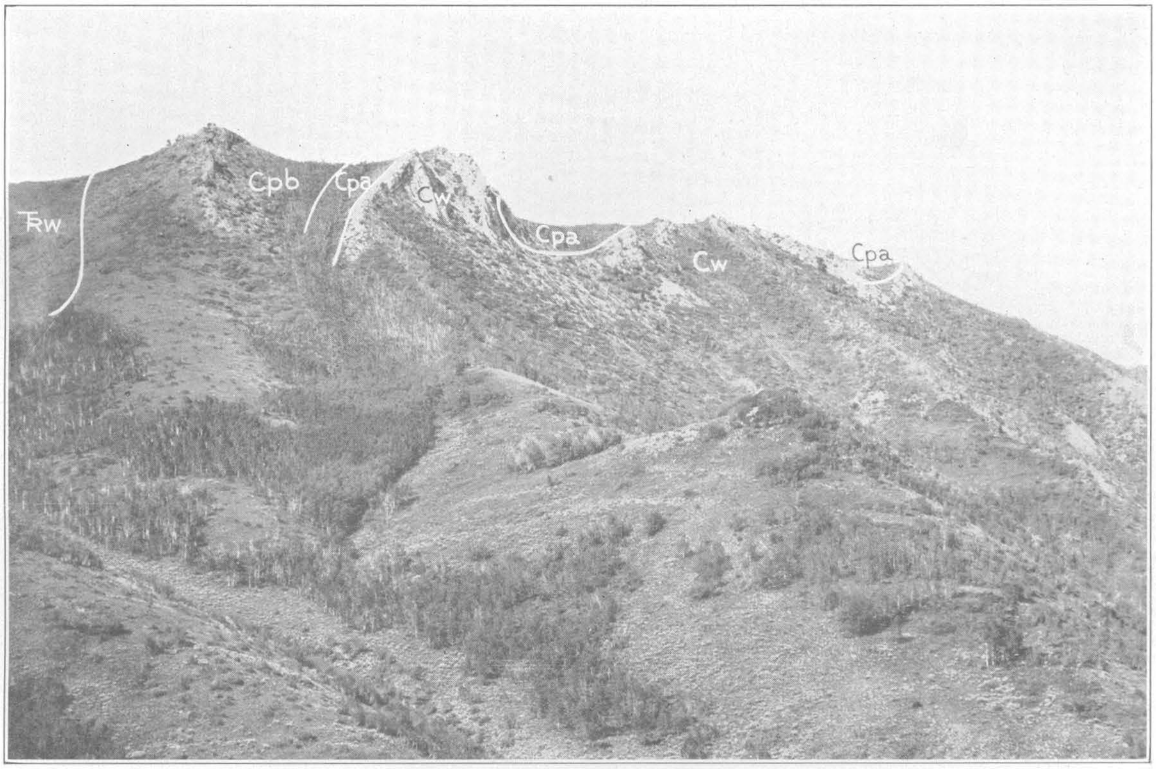
Samples collected by the writer from the Waterloo mine in 1920 did not show so high a content of phosphate as that given in Table 68. A sample representing 5 feet 3 inches of phosphate rock that dips 28°, which was taken at the north end of the drift from tunnel No. 2, 800 feet beyond the tunnel, yielded upon analysis at the laboratory of the Geological Survey 30.91 per cent phosphorus pentoxide, equivalent to 67.52 per cent tricalcium phosphate. The sample also contained 0.52 per cent vanadium pentoxide, 0.11 per cent chromic oxide, and 0.03 per cent fluorine. A second sample taken at the south face of the drift at the east end of tunnel No. 1, representing 5 feet of phosphate rock that dips 33°, yielded 30.68 per cent phosphorus pentoxide, equivalent to 66.96 per cent tricalcium phosphate. This sample contained also 0.40 per cent vanadium pentoxide, 0.16 per cent chromic oxide, and 0.03 per cent fluorine. The run of mine material is said to have averaged about 70 per cent tricalcium phosphate.



MAP OF THE MONTPELIER DISTRICT, WITH SECTIONS AND ANALYSES OF THE PHOSPHATE BEDS

After Gale and Richards, U. S. Geol. Survey Bull. 430, pl. 6, 1910

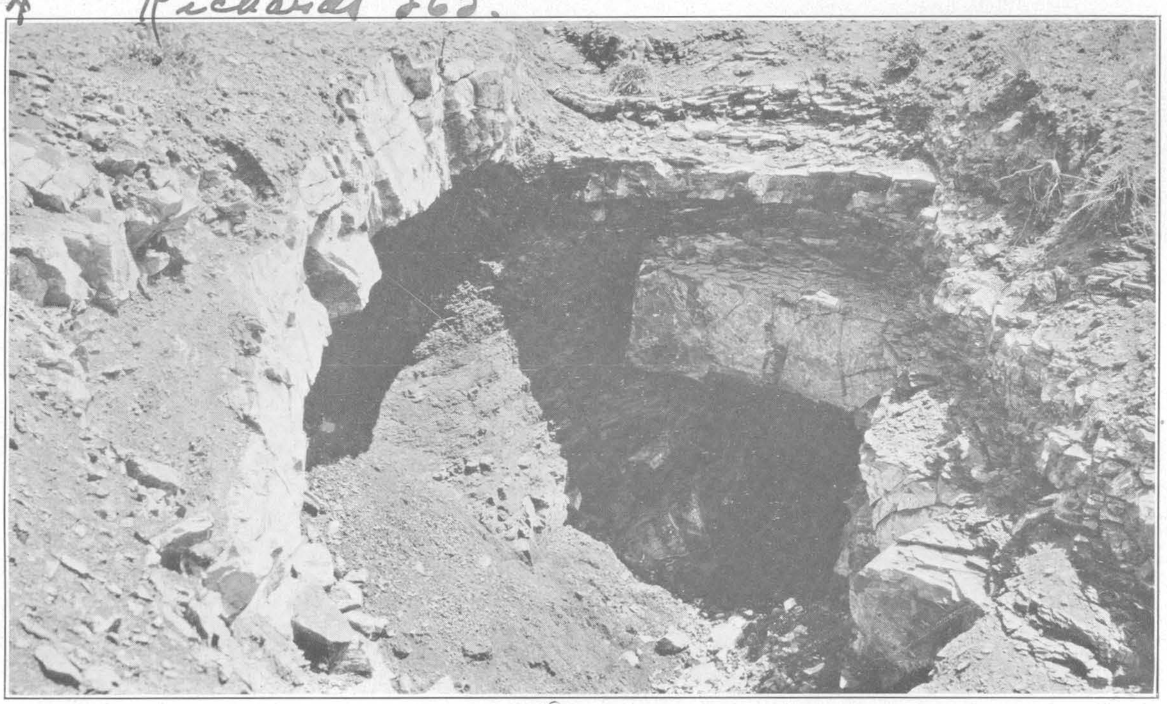
Mansfield, 135.



A. FOLDED STRUCTURE AT THE NORTH END OF WATERLOO HILL, T. 13 S., R. 45 E., MONTPELIER QUADRANGLE

Cw, Wells formation; Cpa, Phosphoria phosphatic shale; Cpb, Rex chert member of Phosphoria; Ŧw, Woodside shale

Richards 263.



B. PROSPECT IN PHOSPHATIC SHALE AT THE SOUTH END OF THE WATERLOO CLAIM, IN SEC. 6, T. 13 S., R. 45 E., MONTPELIER QUADRANGLE

Showing "cap lime" and "main bed" slightly faulted

TABLE 68.—*Section of phosphatic shales at Waterloo claim, Montpelier Canyon*

	P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
	Per cent	*Per cent*	*Ft.*	*in.*
Shale			10+	
Limestone, black, fossiliferous			1	6
Shale, gray to brown, phosphatic (?)			2	6
Limestone ("cap lime"), very fossiliferous	6. 1	13. 3	1	10
Phosphate, main bed	38. 0	82. 0	5	6
Shale, brown to black			1	
Limestone, black, massive strata (upper Wells) underlying the phosphate-bearing section (not measured).				
			22	4

The beds on the Waterloo claim dip westward at angles that range from 17° to 42° and also show considerable irregularity of strike, even within the limits of the claim. The large open cut above the upper tunnel reveals small displacements or faults of a type that is apparently significant of the character of the larger structural features of the whole general region. Slivered fractures in the "cap lime" pass into folds and crumpled zones in the phosphate bed itself and cause thickening and thinning in that bed. Plate 52, *B*, shows a small displacement of the phosphatic shales at the south end of the Waterloo claim.

The phosphatic shales are cut off by a fault near the south ends of the Waterloo and adjoining Wizard claims, and beds of the Thaynes group there lie athwart the axis of anticline.

The equipment at the Waterloo mine consists principally of a 50-ton loading bin, a blacksmith shop, and an air compressor. Mr. J. J. Taylor, superintendent at Montpelier, thus summarizes the operations of his company:

When we first started we mined several thousand tons from the surface as open quarry work. Since then we have driven three cross-cut tunnels into the hill to cut the deposit. We then drive tunnels on the deposit and leave the "cap rock" as the roof of the tunnel. We put up raises about 100 feet apart and stope the rock. We stope practically all the rock, leaving only small pillars to protect the raises, and we generally manage to get out most of them. It is very clean mining, with very little waste. * * * We have been shipping around 6,000 tons a year for several years.

Estimate of tonnage.—Gale and Richards offer an estimate for the Waterloo claim alone of 2,500,000 long tons of phosphate. Somewhat more than half the township is underlain by rocks older than the top of the Thaynes group and in regular sequence. Probably most of this area is underlain by high-grade phosphate. The rocks, however, are sharply folded, and hence a large part of this phosphate may lie deeper than 4,500 feet, the limit of workable depth for a 5½-foot bed of 70 per cent grade. Thus for practical considerations the area classified as phosphate land has been limited to 1,400 acres in sections 5, 6, 7, and 8, where only Woodside and older beds appear at the surface. A horizontal phosphate bed 5½ feet thick and 1,400 acres in extent would yield approximately 26,953,000 long tons of phosphate rock. Although the inclination of the beds, which are folded rather than horizontal, would tend to make the actual content greater than the estimate, the shattering of parts of the bed by intense folding and faulting would tend to reduce the amount of recoverable phosphate and might offset any increase allowed for the attitude of the beds. The figure given is conservative.

The phosphate ranges in depth from the surface at its outcrop to perhaps 4,500 feet. The deposits in the vicinity of Montpelier Canyon are nearest the surface and are otherwise the most accessible, though probably no locality would require hauls to the railroad greater than 5 or 6 miles.

T. 14 S., R. 45 E.

General features.—T. 14 S., R. 45 E., is in the Montpelier quadrangle (pl. 9) and is divided into two nearly equal parts by the intrenched meandering valley of Bear River. The northeastern part includes some of the southern hills of the Preuss Range, but the southwestern part lies in the Bear Lake Plateau. The hills are relatively smooth and free from timber. Roads and a railroad pass through the valley of Bear River, and a well-traveled road crosses the northern uplands. The southern uplands have no transverse road above Bear River Valley, but a secondary road passes southward from that valley and connects with the road that runs eastward from Bear Lake through the valley of Indian Creek.

Geology.—No beds older than the Woodside shale are exposed in this township. The highest Mesozoic formation is the Twin Creek limestone. Tertiary formations are present, and the Quaternary beds occur in the valleys of Bear River and some of its tributaries, notably Sheep Creek.

The principal folds represented, from west to east, are the Indian Creek syncline, the Home Canyon anticline, the Harer syncline, the Sheep Creek anticline, and the Pegram syncline. (See general map, pl. 1.) No noteworthy faults have been recognized. The general structural features of the township are illustrated in the geologic structure section drawn along the line Y–Y'. (Pl. 12.)

Phosphate deposits.—The Phosphoria formation comes to the surface a short distance west of the southwestern part of the township. A section of the main phosphate bed near Hot Springs in T. 15 S., R. 44 E., indicates that a 5-foot bed of 70 per cent grade may reasonably be expected to underlie this township. The limit of depth at which such a bed is considered workable under existing regulations is 4,000 feet. Unfortunately, owing to the steepness, depth, and inclined attitude of the folds, much or all of the phosphate lies at depths probably greater than 4,000 feet. Accordingly, no land in this township is classified as phosphate land, and no estimate of tonnage is attempted. However, the township contains much phosphate that may be regarded as ultimately available, when and if deep mining ever becomes profitable. The rock is below the level of ground water, which would be a factor in any plan for its mining. The presence of the railroad would be favorable.

T. 15 S., R. 45 E.

General features.—T. 15 S., R. 45 E., contains the southward continuation of the geographic and geologic features of T. 14 S., R. 45 E., and most of the description given for that township applies equally well to this one. The eastern part of the township is largely occupied by the valleys of Bear River and of Pegram Creek, but the remainder is plateau country. The Indian Creek road gives the only outlet to the west, but roads northward in the western part and in Pegram Valley connect with those in Bear River Valley. The view westward through the gateway of Indian Creek, showing Bear Lake with its background of mountains, is one of the finest in the entire region.

Phosphate deposits.—The section measured in the township immediately to the west indicates that a 5-foot bed of phosphate which averages 70 or more per cent tricalcium phosphate is probably present. Unfortunately throughout much of the township this bed lies at depths greater than 4,000 feet, the greatest depth at which a bed of this thickness is considered workable under existing regulations. Accordingly, no land in this township is classified as phosphate land and no estimate of tonnage is presented. Considerable phosphate may, however, be regarded as ultimately available.

T. 16 S., R. 45 E.

T. 16 S., R. 45 E., which is fractional, contains the southward continuation of the geologic structure present in the township to the north but the features are largely concealed by the Wasatch formation. It is probable that at least in section 3 the Thaynes group is present beneath the Wasatch, but the Sheep Creek anticline, which causes the uparching of the Thaynes, pitches gently southward. This effect, combined with the Wasatch cover, makes it highly improbable that the phosphate beds in the anticline lie within 4,000 feet of the surface. In the rest of the township, so far as may be judged from surface indications, the phosphate must lie at still greater depths. None of this township is therefore regarded as phosphate land, and no estimate of tonnage is presented.

T. 7 S., R. 46 E.

General features.—T. 7 S., R. 46 E., which is also fractional, is in the southern part of the Freedom quadrangle. (Pl. 5.) It is generally rugged and only partly surveyed. The deficiency of area is along the east side, where the State line passes from north to south through the eastern half of the second tier of sections. The valleys of Stump and Tygee Creeks form a lowland that extends from northwest to southeast through the middle of the township. Northeast of this lowland lie the southern part of the Caribou Range and the northern part of the Gannett Hills, which are separated by the transverse canyon of Stump Creek. Southwest of the lowland stretches the Webster Range. The old Lander Trail passes up the valley of Stump Creek, and to the south roads up Tygee Valley connect with Sage Valley and Crow Creek. Auburn, 2 miles to the east, in Star Valley, is the nearest town, but it is more than 50 miles from the railroad.

Geology.—The geologic formations include the regular sequence from the Thaynes group to the Wayan formation, but the Draney limestone and Tygee sandstone are not represented. The Salt Lake formation and Quaternary beds occupy the lower slopes and bottoms along Tygee and Stump Creeks and some of their tributaries. The Thaynes group, which is exposed in the southwestern part of the township, occupies the only area in which phosphate beds lie near enough to the surface to be considered workable. The group is present in nearly full development, including the red-bed member of the Portneuf limestone, the uppermost formation of the group.

The fault zone of the Bannock overthrust passes northwestward through the township through Tygee and Stump Valleys and along the eastern slope of the Webster Range. Southwest of the fault zone lies the east flank of the Boulder anticline, the axis of which passes southwest of the township. This fold has caused the up-arching of the Thaynes group and the underlying formations. Northeast of the fault zone several folds and faults occur in the Jurassic and Cretaceous formations. (See general map, pl. 1.) The most striking of these folds is the Spring Creek syncline, which is well exposed in and about the transverse canyon of Stump Creek in the southeastern part of the township. The fault zone itself is occupied by broken folds in Jurassic beds. Some of the structural features above described are illustrated in the geologic structure section drawn along the line N–N′ (pl. 11), which passes a short distance south of the township.

Phosphate deposits.—The nearest opening from which the character of the beds that underlie this township may be determined was made by the Survey party in the SE. ¼ NW. ¼ sec. 29, T. 8 S., R. 46 E. At this locality the main bed, though present and apparently 5 feet or more thick, was not in condition to be sampled. The same section of phosphatic shales, however, contains near the top six phosphate beds that have an aggregate thickness of 7 feet 7 inches and an average content of about 75 per cent tricalcium phosphate distributed through a thickness of 12 feet 7 inches of beds. At another cut, in the SW. ¼ SE. ¼ sec. 14, T. 8 S., R. 44 E., two beds of phosphate rock, near the base of the section and separated by about 8 inches of shale, have an aggregate thickness of 14 feet and an average content of about 60 per cent tricalcium phosphate. This township, then, can be safely assumed to contain a 6-foot bed of workable phosphate that averages about 70 per cent tricalcium phosphate. The limit of workable depth for such a bed under existing regulations is 5,000 feet.

Estimate of tonnage.—On the basis of the distribution of the Thaynes group and of the inferred structure 1,440 acres in this township is classified as phosphate land. Such an area underlain by a horizontal 6-foot bed would contain about 30,243,000 long tons of phosphate rock. Although the inclination of the beds would tend to increase this figure, the presence of the Bannock overthrust beneath this part of the township would tend to offset this increase by adding an element of uncertainty, for it may cut out a part of the phosphate.

The depth of the phosphate probably ranges from about 2,000 to 5,000 feet. It is all below groundwater level.

T. 8 S., R. 46 E.

General features.—T. 8 S., R. 46 E., is mostly in the Crow Creek quadrangle but includes a strip nearly a mile wide in the southern part of the Freedom quadrangle (pls. 5 and 7). It is a fractional township, in which the deficiency of area is along the east side, where the State line passes through the eastern half of the second tier of sections. The western part is unsurveyed and is relatively high and rugged. The eastern part is lower and is surveyed, but it is more or less dissected. Sage Valley and Tygee Valley are connected lowlands of different elevation that divide the township into western highlands that are part of the Webster Range and eastern highlands that lie in the Gannett Hills. The Webster Range supports some timber, but the Gannett Hills in this township are practically bare.

Passable roads in Tygee and Sage Valleys and Hardmans Hollow connect this township with the Montpelier and Star Valley road in the valley of Crow Creek to the south, and a trail through Smoky Canyon connects westward with Diamond and Blackfoot Valleys.

Geology.—The exposed geologic section includes formations that range from the Wells to the Quaternary. The Timothy sandstone and overlying doubtfully Triassic formations are absent, and the Twin Creek limestone is largely faulted out. The Wasatch formation is also absent. Considerable areas in and adjoining the central lowland belt are underlain by Tertiary and Quaternary rocks.

The Phosphoria formation enters the southwest corner of the township and extends northward into sections 17 and 18, where it crosses the axis of the Boulder Creek anticline and forms a loop marked at the northern tip by subordinate folds. Smoky Canyon has been cut across the anticline at the boundary of the Rex and Woodside, and the Rex is exposed in a fine dip slope on the south side of the canyon. The Rex is represented chiefly by the massive chert facies and forms a fine dip slope also along the west flank of the anticline. The east flank of the anticline is cut by the Sage Valley branch of the Bannock overthrust, and the phosphatic shales are cut out for more than a mile at the south.

The covered area between the Sage Valley and West Tygee branches of the overthrust is in all probability underlain by Thaynes and Woodside beds, together with some of the Rex at the southwest. The covered area between the two Tygee branches is apparently chiefly Nugget but probably contains also a narrow faulted rock slice of salt-bearing lower Preuss sandstone.

The Twin Creek limestone and the Preuss and Stump sandstones are caught in broken, close folds between the East Tygee and Hardman branches of the overthrust and are much reduced in thickness by faulting. Limestone that is probably the Draney but possibly Peterson lies above the Ephraim in fault relation in sections 14 and 23, and a slice of the Wayan formation in section 14 is also caught in the fault zone that accompanies the Bannock overthrust in the eastern part of the township. The axis of the Spring Creek syncline lies along the eastern boundary of the township, but this fold is broken by the Spring Creek fault and by an unnamed transverse fault.

The structural features above outlined are illustrated in the geologic structure sections drawn along the lines N–N′ (pl. 11) and O′–O″ (pl. 12).

Phosphate deposits.—Prior to the survey's examination in 1914 the phosphate beds in this township had not been opened or prospected. In October, 1914, a cut was made in the phosphatic shales in the SE. ¼ NW. ¼ sec. 29 by the survey party with the intention of exposing for study and sampling the entire phosphatic shale section. A trench was dug at right angles to the strike, extending from a ledge of Rex to a ledge of the upper Wells, the underlying limestone. After digging had started it was found necessary to make an offset, so the trench was accordingly dug in two sections, one 20 feet 6 inches and the other 117 feet 6 inches in length, with a total length of 138 feet. The offset ends were supposedly at approximately the same horizon. The average depth was 3½ feet and the maximum depth 5½ feet. The overburden was 2 to 3 feet thick or even more in some places. The phosphate proved to be weathered and to contain much infiltered dirt. Any enrichment by weathering was, however, probably fully offset by the dirt. It was not practicable to deepen the trench sufficiently to obtain fresh, clean rock, but care was exercised to exclude as much of the dirt as possible from the samples collected. The details of the section and the analyses of the samples are given in Table 69. The inclined attitude of the Boulder Creek anticline causes the section to be overturned eastward.

TABLE 69.—*Section of phosphatic shales exposed in survey cut in SE. ¼ NW. ¼ sec. 29, T. 8 S., R. 46 E. Boise meridian*

[Analyst, W. C. Wheeler]

Locality and sample Nos.		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	*Per cent*	*Ft.*	*in.*
Locality F-3a	Rex chert ledge forming small ridge on hillside; strike, N. 6° W.; dip, 59° W.				
	Covered area between ledge of Rex and east end of trench, 7 feet 6 inches equivalent to			6	6
	Clay, dense, drab; contains fragments of black chert and whitish-gray to drab dense limestone, in pieces ¼ inch thick; bedrock not exposed; comprises entire first section of trench 20 feet 6 inches, equivalent to			17	8
	(Rectangular offset a few feet to second section.)				
	Clay, similar to last			1	10
	Phosphate rock, cherty, nodular, weathered				3
	Shale, drab weathering, brownish gray, somewhat oolitic				4
	Phosphate rock, gray, medium to finely oolitic, weathering dark to light gray				5
	Shale, brown to drab, somewhat oolitic			1	2
	Clay, reddish to yellowish				1
Sample 1	Phosphate rock, dark gray, medium to coarsely oolitic in beds ¼ to 1 inch thick; crumbles to a dark-gray oolitic sand	34.96	76.3	1	6
Sample 2	Phosphate rock, thin bedded, shaly, with much infiltered dirt	33.58	73.4	1	1
Sample 3	Phosphate rock, coarsely oolitic light-gray rock, beds ¼ to 1½ inches thick, including some beds partly limestone	34.05	74.4	1	
	Clay, yellowish to drab			1	4
Sample 4	Phosphate rock, upper 7 inches light gray and somewhat calcareous in beds ½ to 1½ inches thick; lower 6 inches thinner bedded and darker gray	34.74	75.8	1	1
	Clay, drab			1	2
	Phosphate rock, finely oolitic				3
	Clay, drab				4
	Phosphate rock, broken, somewhat nodular and irregularly bedded; beds ½ to 1½ inches thick, with thin shaly partings			1	1
Sample 5	Phosphate rock, medium to coarsely oolitic, in beds ½ to 2 inches thick	33.90	74.0	1	11
	Shale, black to brown, thin bedded				10
Sample 6	Phosphate rock, gray, light colored, beds ½ to 1½ inches thick, much broken, weathering with reddish surface, crumbling to an oolitic sand, poorly exposed	35.11	76.6	1	
	Phosphate rock, thin bedded, shaly, very much broken, poorly exposed			1	
	Clay, grayish; occupies entire cut to depth of 3 feet, probably in part phosphatic			1	(?)
	Clay and soil with fine fragments of shale, chert, and weathered limestone; no exposures of bedrock for distance of 70 feet, equivalent to			60	
	Phosphate rock, "main bed" (?); beds ¼ to ½ inch thick, much broken, attitude not clear, top not exposed, too dirty and fragmentary for sampling; exposed in cut to depth of 5 feet, underlain by 6 inches of black shale and gray clay to bottom of cut at 5 feet 6 inches			5	(?)
	Soil and clay with fragments of shale, chert, and limestone of the upper part of Wells formation, for distance of 14 feet 6 inches, equivalent to			14	3
	Ledge of upper Wells, much broken, apparent strike N. 12° W. and apparent dip 79° W.				
				123	

Determinations of iron and alumina were made on composites of these samples as follows: Nos. 1–3: Fe_2O_3, 0.55 per cent; Al_2O_3, 1.48 per cent. Nos. 4–6: Fe_2O_3, 0.42 per cent; Al_2O_3, 1.18 per cent. These figures show that the low content of iron and alumina noted in material from other parts of the field obtains also in this township.

The upper portion of the section shows six beds of phosphate that have an aggregate thickness of 7 feet 7 inches and an average content of 75 per cent tricalcium phosphate, distributed through a thickness of 12 feet 7 inches of beds. The main bed, which was too poorly exposed to be measured and sampled, seems to be at least 5 feet thick.

From this section and the one in sec. 14, T. 8 S., R. 44 E., this township can be fairly assumed to contain a workable bed of phosphate rock 6 feet thick that averages about 70 per cent tricalcium phosphate.

Estimate of tonnage.—Although on the basis of the mapping and the inferred structure nearly 10,000 acres might be considered phosphate land the area actually so classified has been reduced to 3,720 acres, because of the large area in which the older formations are concealed and because of the presence of the Bannock overthrust beneath the entire phosphate-bearing area. The overthrust in all probability cuts out some of the phosphate, especially toward the north, where the phosphate bed lies deeper, but the depth of the overthrust is not known and, in the absence of data obtained by drilling, no evidence is at hand by which to determine the loss of phosphate in this way. For similar reasons no allowance has been made for the dip of the phosphate beds.

Upon these assumptions 3,720 acres underlain by a horizontal 6-foot phosphate bed would contain in round numbers 78,127,000 long tons of phosphate rock. The depth of the rock ranges from zero at the outcrop to 3,000 feet or more. Smoky Canyon and Pole Canyon, near the south boundary, afford favorable points of entry.

Although the phosphate beds may be easily reached the township is so far from existing railroads that development of mines will probably be long delayed. There are, however, favorable grades for road or track construction whenever railroad facilities are brought within reach of the township.

T. 9 S., R. 46 E.

General features.—T. 9 S., R. 46 E., is in the Crow Creek quadrangle (pl. 7). It is a fractional township in which the deficiency of area is along the east side, where the State line passes through the east half of the second tier of sections. Sage Valley with its extensions forms a lowland that stretches northward through the western half of the township and separates the Webster Range in the western part from the Gannett Hills to the east. The valley of Crow Creek enters the southwest corner and extends northeastward through the township. The highlands to the southeast of this valley are part of the Gannett Hills. There is some timber along the eastern slopes of the Webster Range, but the remainder of the township is relatively bare. The Montpelier and Star Valley road follows Crow Creek, and secondary roads lead northward through Sage Valley and Hardmans Hollow and southward into the Gannett Hills.

Geology.—The geologic section includes formations that range from the Brazer limestone to the Quaternary, but the Timothy sandstone and the overlying Triassic (?) formations are apparently absent, as are also all the Cretaceous formations above the Ephraim conglomerate. The Wasatch formation is not represented. The formations most closely related to the phosphate are confined to the western half.

The geologic structure is complex. The Boulder Creek anticline along the western side causes the exposure of the Phosphoria formation on both its flanks, but it is inclined eastward and the Phosphoria beds along the east flank are overturned and partly faulted out by the Sage Valley branch of the Bannock overthrust. The fault zone of this overthrust is more widely spread in this township than elsewhere and includes, besides the Sage Valley branch, the east and west Tygee branches and the east and west Crow Creek branches. These branches are described in the discussion of the Bannock overthrust. The area between the Sage Valley and West Tygee branches is underlain by beds that range in age from Phosphoria to Thaynes. Farther east lies a slice of Nugget sandstone and still farther east a broken fold of higher Jurassic beds. The structure of these rock slices is largely concealed by Tertiary strata.

Southeast of the Bannock fault zone is a series of folds in Upper Jurassic and Cretaceous beds that strike into and probably pass beneath the rock slices of the upper fault block. These folds include an unnamed anticline, the Giraffe Creek syncline, the Sublette anticline, and the Red Mountain syncline. The structural features above outlined are illustrated in part in the geologic structure section drawn along the line S′′–S′′′, Plate 12. (See also structure section O′–O′′.) The axes of the folds and their relations to the faults are shown on the general map. (Pl. 1.)

Phosphate deposits.—At the time of the examination by the survey party in 1914 no prospecting for phosphate had been done in this township. The phosphatic shales in the northwestern part lie near the summit of steep eastward-facing slopes of ridges, the crests and back slopes of which are composed of massive ledges of the Rex chert. In the vicinity of the NW. ¼ sec. 18, the phosphatic shales have been involved in minor folds broken by faults. In the SE. ¼ sec. 18 and the E. ½ sec. 19 the phosphatic shales appear locally but are largely faulted out, and the longitudinal fault which affects the shales is with them offset by minor cross faults.

Although no sections of the shales were available for study and sampling and no openings were made in this township by the Geological Survey party, there seems no reason for supposing that the phosphate deposits are inferior in quality and thickness to those of adjoining townships, where definite data are to be had. This township is therefore inferred to contain a 6-foot bed that averages about 70 per cent tricalcium phosphate.

Estimate of tonnage.—On the basis of the distribution of the Phosphoria and post-Phosphoria rocks up to and including the Thaynes, an area of 5,400 acres in this township might be regarded as phosphate land. Though all this area may possibly be underlain by workable phosphate, the facts that the phosphate beds east of the Boulder Creek anticline are overturned and that the Thaynes area represents a rock slice underlain by a branch of the Bannock overthrust make it likely that much of this Thaynes area may be barren. For these reasons the land actually classified as phosphate land has been trimmed rather closely to the exposures of the Phosphoria formation and amounts to only 1,040 acres. The estimate of tonnage is given as if the beds were horizontal, because if allowance were made for the dip, the increment thus provided would in all probability be offset by a loss due to faulting along the underlying thrust plane. Thus 1,040 acres underlain by a horizontal 6-foot bed would yield approximately 21,842,000 long tons of phosphate rock. This estimate is believed to be conservative. The phosphate rock is accessible through canyons tributary to Sage and Crow Creeks and can be delivered at the Star Valley road by hauls not exceeding 5 miles. Unfortunately the township is so far from present railroad facilities that development of the phosphate deposits is likely to be indefinitely delayed.

T. 10 S., R. 46 E.

T. 10 S., R. 46 E., in the Crow Creek quadrangle (pl. 7), is fractional, like those of the same range farther north. It is on the whole relatively rugged and unsurveyed and forms part of the Gannet Hills. It has little timber and practically no roads, though a poor road enters Elk Valley from the southwest.

Except in the extreme northwest corner, where a slice of the Woodside shale is caught in the fault zone of the Bannock overthrust, the rocks are all Jurassic or later and belong in the lower fault block of the overthrust. The exposure of the Woodside shale at the surface would ordinarily suggest the presence of workable phosphate rock beneath, but here, because of its relationship to the overthrust, there seems no likelihood that any phosphate of commercial value can be present.

The Red Mountain syncline, Sublette anticline, and Giraffe Creek syncline, which are the principal structural features of the township, are illustrated in the geologic structure section drawn along the line T′–T″. (Pl. 12.)

T. 34 N., R. 119 W. (WYOMING)

General features.—Somewhat more than a 2-mile strip of fractional T. 34 N., R. 119 W. (Wyoming), is included in the northeastern part of the Freedom quadrangle. (Pl. 5.) The State line cuts away nearly two and one-half tiers of sections along the western side, and the quadrangle boundary cuts off one and a half tiers on the eastern side. Most of the area represented is in Star Valley, but the southwestern part includes outlying ridges of the Caribou Range. This range supports some timber, and the valley is agricultural land. There are good roads in the valley and secondary roads up some of the canyons. The town of Thayne lies in section 23 of this township and the town of Freedom in section 33 of the adjoining township on the north. The township is 60 miles or more from existing railroads, but railroad connection of Star Valley with existing lines farther north has been proposed and some preliminary surveys have been made.

Geology.—The stratigraphic section includes formations that range from the Madison limestone to the Quaternary, but there are large gaps. The Brazer, Wells, and Phosphoria are missing, together with the Timothy sandstone and the overlying Triassic (?) formations. The Preuss and Stump sandstones are absent, and the Ephraim conglomerate and a part of the Wayan formation are the only Cretaceous representatives. The Wasatch formation is also absent.

The geologic structure of the township is complex. The central feature is the Hemmert anticline, which supposedly brings phosphate beds of good grade within depths that are considered workable under existing regulations. This fold is broken by the Hemmert fault, a normal (?) fault that has a small downthrow to the west. Northward this fold is obliquely cut off by the Freedom normal fault, which has also let down and kept from erosion, a fragment of the Star Valley overthrust block composed of Madison limestone and now exposed in sections 16, 9, and 4. The Jurassic beds west of the Freedom fault are part of a second and lower thrust block bounded on the west by the Auburn fault and perhaps related to the Star Valley overthrust. The structural features above outlined are illustrated in the geologic structure sections drawn along the lines K″–K‴ and L′–L″. (Pl. 11.)

The geologic formations are largely concealed by beds of the Salt Lake formation and by travertine and other Quaternary deposits. The structure indicated is inferred from the available field data.

Phosphate deposits.—This township is far removed from localities where samples of phosphate rock have been taken for analysis. However, the Phosphoria formation is well developed in the Salt River Range[45] east of Star Valley, and some beds of high-grade material are there present, though few sections have been studied in detail and the rock thus far examined seems generally inferior to the Idaho rock. The nearest sampled section in Idaho is that in T. 8 S., R. 46 E., where the main bed, though not well enough exposed for sampling, appeared to be 5 feet or more thick and other high-grade beds in the upper part of the section aggregated more than 7 feet in thickness. If a reduction in thickness is allowed to offset a possible deterioration in content of phosphate it may be assumed for purposes of land classification and computation of tonnage that a 4-foot bed of phosphate which averages 70 per cent tricalcium phosphate is present in this township. The limit of depth at which such a bed is considered workable under existing regulations is 4,000 feet.

Estimate of tonnage.—The area within the depth limit above assigned, as suggested by the structure section along the line L′–L″ (pl. 11), corresponds approximately with that in which the Woodside shale and Thaynes group crop out at the surface. It would

[45] Mansfield, G. R., A reconnaissance for phosphate in the Salt River Range, Wyo.: U. S. Geol. Survey Bull. 620, pp. 331–349, 1916.

also include a narrow strip of country beneath the alluvium of Star Valley. But in view of the fact that the phosphate in that strip is practically at the limit of workable depth and because the value of the land for agricultural use is probably greater than its potential value as mineral land, it seems unwise to consider it a phosphate tract. There is, too, some reason for supposing that a fault passes east of the valley wall and cuts out the Thaynes beneath cover.

Under the conditions named 1,200 acres in this township are classified as phosphate land. Such an area underlain by a horizontal 4-foot bed of phosphate would yield approximately 16,801,000 long tons of phosphate rock. No increment has been allowed for the dip because of the sharpness and faulted condition of the fold, which may cut out or render unavailable part of the phosphate.

The location of this deposit at the edge of Star Valley is favorable if a railroad should be constructed in the valley. The depth of the beds, which ranges from 1,200 to 4,000 feet, would be unfavorable, for its development would require deep-mining methods and all of it would be below the level of ground water.

T. 33 N., R. 119 W. (WYOMING)

General features.—Only a little more than a 2-mile strip of this fractional township is included in the Freedom quadrangle. (Pl. 5.) The State line on the west cuts off a strip more than 2 miles wide and the quadrangle boundary passes through the east half of the second tier of sections on the east side. The highlands west of Salt River are part of the south end of the Caribou Range, and the lowlands are part of Star Valley, but are divided into two parts by the Narrows of Salt River in sec. 13. The Caribou Range supports some timber. The town of Auburn lies on the south border in sec. 35. There are good roads in Star Valley and secondary roads in the larger canyons. The township is remote from present railway facilities.

Geology.—The stratigraphic section includes formations that range from the Phosphoria to the Quaternary, but there are gaps in the sequence. The Timothy sandstone and the overlying Triassic (?) formations are absent, and the Draney limestone and Tygee sandstone of the Gannett group and the Wasatch formation are not represented.

The rocks assigned to the Phosphoria are of a somewhat unusual type. They include some brecciated quartzite which resembles that of the Wells formation but consists mainly of a banded and apparently bedded chert that strikes north and dips 30°–60° E. The chert is light colored and finely banded, unlike any other facies of the Rex thus far observed. It lacks the nodular and limestone facies seen in many places, and its color is lighter than is usual for the Rex. No fossils were observed in it. The chert is much brecciated. No trace of the phosphatic shale member was seen.

The Hemmert anticline is the most notable structure economically, for it contains phosphate beds at depths considered workable. The general features of this fold are given in the description of T. 34 N., R. 119 W. Other noteworthy structural features that enter the township are the Auburn fault and the Miller Creek and Smith Creek synclines. These features are figured in the geologic structure section drawn along the line L′–L″ (pl. 11), which passes a short distance north of the township.

Although the portion of the township outside of the quadrangle has not been studied in detail, reconnaissance observations show that the structure of the Narrows of Salt River in section 13 is synclinal and that the Twin Creek limestone dips west on the east side of the river in a fine dip slope and reappears again on the west side of the river, where it dips east. It is followed at the west by the Nugget sandstone, which in turn is succeeded after a covered interval by beds of middle to upper Thaynes. A fault probably marks the boundary between the Thaynes and the Nugget, for there seems insufficient room for all the Nugget and the strata that should intervene between the two sets of exposed beds. The supposed fault should pass beneath the alluvium of Star Valley in the NE. ¼ sec. 2, proceed thence northwestward down the valley, and perhaps join the Hemmert and Freedom faults in the adjoining township. The beds in sections 1 and 12, east of Salt River, are Twin Creek and Nugget, more or less concealed by Tertiary strata.

Phosphate deposits.—For reasons cited in the discussion of T. 34 N., R. 119 W., this township is supposed to be underlain by a bed of phosphate rock that contains approximately 70 per cent tricalcium phosphate and is at least 4 feet thick.

Estimate of tonnage.—On the assumption that was made for the township just cited, that the area within which beds of Woodside and Thaynes are exposed contains workable phosphate, including part of the township outside the limits of the quadrangle, 1,480 acres have been classified as phosphate land. Such an area underlain by a horizontal 4-foot bed would contain about 22,122,000 long tons of phosphate rock. For reasons stated on page 286 it seems more conservative to allow no increment on account of the dip.

As in the township last cited the location of the phosphate deposits is favorable with regard to Star Valley, but their commercial development must await the establishment of railroad facilities.

T. 27 N., R. 120 W. (WYOMING)

T. 27 N., R. 120 W., is a fractional township in the Montpelier quadrangle (pl. 9), which consists only of a narrow strip of land less than a mile wide bounded on the west by the State line. It is part of the Sublette Mountain phosphate area described by Gale and Richards,[46] whose map is reproduced in Plate 53. In section 1 Nugget sandstone and some of the underlying formations, including the Timothy sandstone and perhaps even some of the upper beds of the Thaynes group, are exposed, and in section 25 the Thaynes group as mapped barely crosses the township line. The rest of the strip is occupied by Quaternary hill wash and alluvium.

The older rocks beneath the Quaternary sediments form part of the west flank of the Sublette anticline, the general character of which is shown in the geologic structure section drawn along the line X–X′. (Pl. 12.)

Although phosphate beds of high grade undoubtedly underlie the township, the steepness of the fold indicates that these beds lie at depths too great to be considered workable under existing regulations. Therefore no part of this township has been withdrawn as phosphate land and no estimate of its phosphate content is attempted.

T. 26 N., R. 120 W. (WYOMING)

General features.—Like the township to the north which has just been described, T. 26 N., R. 120 W., is represented by only a narrow strip of land along the State line. The older rocks crop out only at the south end of the strip, in section 36, where Nugget sandstone is exposed. Quaternary sediments occupy the rest of the area. Less than half a mile east of the northern part of the strip beds of the Wells and Phosphoria formations outcrop in a very steep or nearly vertical position. These and other strata are well exposed in Raymond Canyon. (Pl. 54.)

The axis of the Sublette anticline, with which the Wells and Phosphoria beds are associated, lies a short distance east of the township line, The anticline pitches gently southward, so that the belt of phosphatic shales crosses the axis and returns northward beneath cover, probably striking the township line at about the southeast corner of section 12 and thence proceeding approximately along that line to the northeast corner of section 1, where it probably enters section 31 of the adjoining township. With so steep a dip the phosphatic shales doubtless rapidly descend westward below the limit of workable depth, so that little of this township may be considered phosphate land and none is so classified.

[46] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 498–503, 1910.

T. 27 N., R. 119 W. (WYOMING)

General features.—Less than a 2-mile strip of the western part of T. 27 N., R. 119 W., is included in the Montpelier quadrangle (pl. 9), but this portion occupies parts of the west flank and crest of Sublette Ridge. Immediately west is Thomas Fork Valley, in which roads southward connect with the Oregon Short Line Railroad at Border, nearly seven miles south of the southern boundary of the township.

Geology.—The consolidated rocks range from the Wells formation to the Twin Creek limestone, and all intervening formations are probably represented, but the Timothy sandstone and the overlying Triassic (?) formations have not been differentiated in the mapping. Quaternary hill wash occupies the lower western slopes and conceals parts of the older formations.

The Phosphoria formation is exposed in two areas, one a narrow and irregular oval that extends from the middle of section 18 into section 30, and the other the northern end of a narrow band that extends southward from the middle of section 31 halfway through the adjoining township. The Rex chert member is about 80 feet thick and consists of brownish-black chert, which in some places is massive and in others is distinctly thin bedded.

The Sublette anticline is the principal structural feature of this part of the township. The axis passes southward through the west tier of sections and is slightly depressed in section 30 by a faint oblique transverse syncline, which causes a slight bend in the axis and permits beds of the Thaynes group to cross it, thus causing the separation and offsetting of the areas in which the Phosphoria formation is exposed. The narrow oval area of the Phosphoria owes its form to a corresponding transverse anticlinal fold and to the erosion of the low minor arch thus produced. The sharpness of the Sublette anticline and its inclination eastward are shown in the geologic structure section drawn along the line X–X′. (Pl. 12.)

TABLE 70.—*Section of phosphate beds in the NW. ¼ NE. ¼ sec. 19, T. 27 N., R. 119 W., Wyoming*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness	
		Per cent	Per cent	Ft.	in.
44	Phosphate rock, grayish black, oolitic	38. 6	84. 5	6	
	Interval, concealed			8+	
43-A	Limestone, grayish black, hard; contains fossils	7. 1	15. 5	3	4
43-B	Shale, black, in part oolitic, soft	19. 8	43. 4		9
43-C	Shale, black, in part oolitic	15. 1	33. 1	1	8
43-D	Shale, black, in part oolitic, massive	12. 2	26. 7	2	6
	Limestone			1	6
43-E	Phosphatic rock, black, coarsely oolitic, soft	18. 4	40. 3	3	4
	Limestone				4
43-F	Shale, black, soft, oolitic	21. 9	48. 0	3	6
43-G	Shale, brownish black, oolitic	28. 6	62. 6	3	4
				34	3

Phosphate deposits.—The best section measured in this township, though it is incomplete, is given in Table 70. Its location and character are shown graphically in Plate 53.

The cross section of the axial part of the anticline is well exposed in the gulch in which the above section was measured. Immediately beneath the portion of the section given in detail lies a series of dark shales that contain limestone lenses which indicate the total thickness of the phosphatic shale member of the Phosphoria formation as somewhat less than 100 feet at this place. The sandy limestones of the upper Wells and the overlying cherty beds make prominent cliffs directly above and east of the prospects.

In the southeast corner of section 31 there are several prospects, but the beds were measured in the tunnel opened by the San Francisco Chemical Co. The direction of the tunnel is nearly northeast and it cuts the approximately vertical beds at right angles. The section measured at this point comprises 74 feet of beds. The lithologic details and the results of the chemical determinations obtained from the samples are given on the map by Gale and Richards. (Pl. 53.) The section contains at the top a bed 4 feet 10 inches thick that yields 73.3 per cent tricalcium phosphate. Another prospect a little farther south (pl. 53) exposed a phosphate bed 4 feet 6 inches thick, which contained 69.4 per cent tricalcium phosphate. Unlike the most of the region examined, the better grade rock in this district seems to be near the top rather than near the base of the phosphatic shales.

Although the section given in Table 70 shows a 6-foot bed that contains 84.5 per cent tricalcium phosphate the other sections in this and in the adjoining township show less thickness and poorer quality. For purposes of comparison with other areas Gale and Richards assume a 5-foot bed of high-grade ore that contains at least 70 per cent tricalcium phosphate. That assumption seems fully warranted and is employed here. The limit of workable depth for such a bed under existing regulations is 4,000 feet. On the basis of observed and inferred structure an area of 2,040 acres might be considered as phosphate land.

Estimate of tonnage.—The phosphate bed may be assumed to form a narrow, eroded fold with vertical sides. The west limb enters the township in the very southwest corner. The fold pitches about 19° N. from the center of section 18 and the phosphate bed passes beneath the limit of workable depth in about the SW. ¼ NW. ¼ sec. 6. The east limb passes out of the township in the SW. ¼ SE. ¼ sec. 31. For practical purposes, however, the concealed area is disregarded and the exposures of the phosphoria and Woodside are rather closely followed. Accordingly, only 1,080 acres are actually classified as phosphate land. The area selected is estimated to contain above the limit of workable depth 46,588,000 long tons of high-grade phosphate. This estimate, in conjunction with those for the adjacent townships, is larger than that given by Gale and Richards chiefly because the depth limit is increased from 2,000 to 4,000 feet to accord with current regulations.

T. 26 N., R. 119 W. (WYOMING)

General features.—Much that has been said about the geography and geology of T. 27 N., R. 119 W., applies with equal force to this township, except that this township has the advantage of being nearer to the railroad. The Sublette Ridge and anticline continue through it.

Phosphate deposits.—The Phosphoria formation probably forms two bands, one along each limb of the anticline. That along the eastern limb is exposed from section 6 to section 19, but the western band is concealed by Quaternary beds.

Raymond Canyon, at the north, cuts the Sublette Ridge in a steep, narrow, and rocky gorge transverse to the trend of the ridge and to the axis of the anticline. The phosphate beds are exposed by prospecting in the NW. ¼ NE. ¼ sec. 6, by entry tunnels through the slide rock on the south side of the canyon. The Rex chert forms a most prominent exposure in the canyon, in which it stands nearly vertical like a massive rock wall about 80 feet thick, through which the creek passes in a gap hardly wider than its channel and the wagon road. (See pl. 54.) The phosphate bed exposed in the principal prospects occurs in the upper part of the phosphatic shale member rather than near the base. A partial section measured in Raymond Canyon is given in Table 71. The location of this section and of others mentioned below is shown on the map by Gale and Richards. (Pl. 53.)

TABLE 71.—*Partial section of phosphatic beds in Raymond Canyon, Wyo.*

Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness
		Per cent	*Per cent*	*Ft. in.*
42–A	Shale, grayish brown	8.9	19.5	4 5
	Limestone			6
42–B	Phosphate, massive, compact, black, oolitic	32	70.1	3 1
42–C	Limestone, dark, fine grained	9.3	20.4	5
				18 6

From this point southward the cherty ledge and phosphatic shales may be traced in almost continuous outcrop for 3 miles. These exposures cross the spurs running off from the main range, so that the outcrop itself follows an irregular profile, and is intersected by the many lateral gulches that drain this mountain slope. The principal prospects are found at the bottoms of the larger canyons, and in them the beds dip east or west at steep angles.

All the better-grade phosphate in this area is exceedingly compact and hard, so that it requires blasting in running in the entry tunnels. It is dark and displays oolitic texture as elsewhere.

Coal Canyon, approximately on the section line at the south side of section 6, affords one of the most complete sections. The dark shaly beds were originally prospected for coal in several entries that extend to a considerable depth. An open-cut trench, partly caved, revealed a clear section for part of the series, from which the measurements given in Table 72 were made. The hillsides above the trench are covered with a heavy growth of vines and scrubby brush, and the outcrops there are concealed in slide rock. (See pl. 55, *A*.)

TABLE 72.—*Section in Coal Canyon, Sublette Ridge, Wyo.*

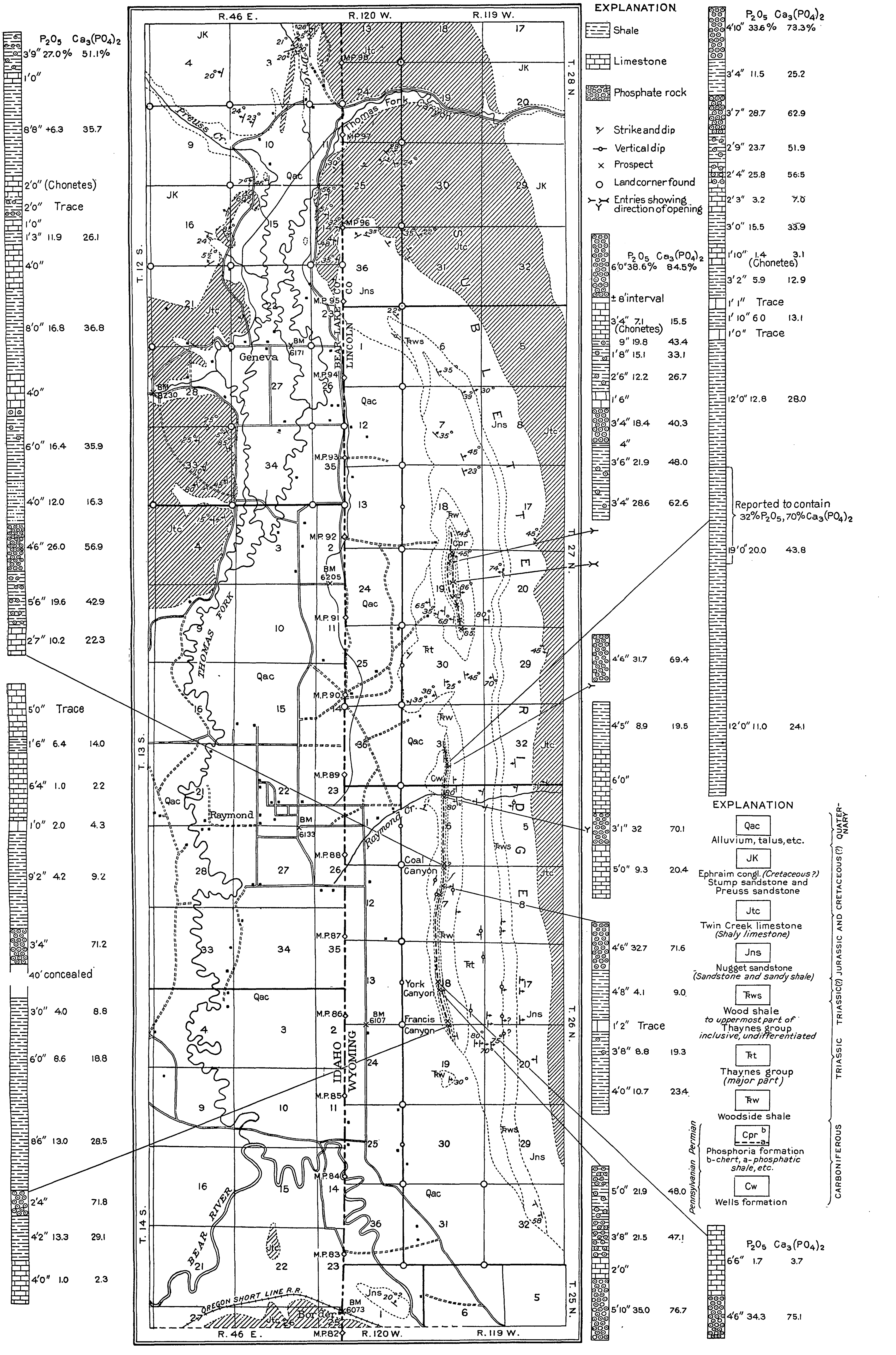
Field No. of specimen		P_2O_5	Equivalent to $Ca_3(PO_4)_2$	Thickness Ft.	Thickness in.
	Cherty limestone, massive; *Productus* abundant.	Per cent	Per cent		
	Limestone, shaly and shattered			1	9
	Limestone, blocky			3	2
	Limestone, shaly, oolitic, crushed			1	10
	Limestone, black, shattered, fossils (*Chonetes*)			9	8
	Phosphate rock, shaly, oolitic, impure				5
	Limestone, black, coarse, and shale, in part sandy			7	8
	Limestone, black, hard, with 3 inches of crushed shale, fossils			1	8
	Phosphate rock, oolitic (in Francis Canyon, 3 feet 4 inches; 7.2 per cent)			5	10
	Limestone, dark gray, blocky, fossils			2	1
41-A	Shale, brownish black, somewhat oolitic	27	51. 1	3	9
	Limestone, gray, fossils			1	
41-B	Shale, brownish black, calcareous	16. 3	35. 7	8	8
	Limestone, dark gray, hard, fossils			2	
41-C	Shale, brown, with oolitic layers	Trace.	Trace.	2	
	Limestone			1	
41-D	Shale, soft brown, calcareous	11. 9	26. 1	1	3
	Limestone, gray, massive, fossils			4	
41-E	Shale, black and brown, thin bedded	16. 8	36. 8	8	
	Limestone, gray, shattered; oolitic at base			4	
41-F	Shale, grayish brown, calcareous, oolitic medium to fine, in part sandy	16. 4	35. 9	6	
41-G	Shale, grayish brown, calcareous, sandy	12	16. 3	4	
41-H	Phosphate rock, coarse, oolitic	26	56. 9	4	6
41-I	Phosphate rock, oolitic in part	19. 6	42. 9	5	6
41-K	Limestone, grayish black, sandy	10. 3	22. 3	5	
	Interval covered to underlying limestone (about)			90	
	Total phosphate series (about)			184	

A "main bed" of rock phosphate, 4 feet 6 inches thick, in Jackson Canyon, about a quarter of a mile south of Coal Canyon, was sampled and showed 32.7 per cent phosphorus pentoxide, equivalent to 71.6 per cent tricalcium phosphate.

Prospects on the north side of York Canyon, in the NE. ¼ SW. ¼, sec. 18, revealed a bed of phosphate 4 feet thick, which showed on test 34.3 per cent phosphorus pentoxide, equivalent to 75.1 per cent tricalcium phosphate. A prospect on the south side of the same canyon opens a bed of phosphate 5 feet 10 inches thick that yields 35 per cent of phosphorus pentoxide, equivalent to 76.7 per cent of tricalcium phosphate.

A considerable series of beds was sampled and tested from prospects and exposures in Francis Canyon, in the NW. ¼ NE. ¼, sec. 19. Here two beds 3 feet 4 inches and 2 feet 4 inches thick ran 32.5 and 32.8 per cent of phosphorus pentoxide (equivalent to 71.2 and 71.8 per cent of tricalcium phosphate). They are separated by an interval of 57 feet 6 inches. Numerous other beds contain more or less phosphatic material similar to that in the Coal Canyon section.

Just south of the prospects in Francis Canyon the outcrop of the cherty ledge associated with the phosphate beds appears to bend sharply eastward, so that this bed flattens against the slope of the hill. This feature is perhaps of local significance, and is possibly entirely superficial, but the phosphate has not been discovered south of this point, and the anticline by which this outcrop has been brought up probably plunges here or is covered by the gravel boulders and alluvial deposits. The structure of the main range south of Francis Canyon is apparently regular and forms a direct continuation of the structure in the northern part, but as the valley areas enter progressively farther into the range toward the south, the outcrops are truncated at the valley margins, and further tracing of the phosphate becomes impossible.



MAP OF THE SUBLETTE RIDGE PHOSPHATE AREA, WYOMING AND IDAHO

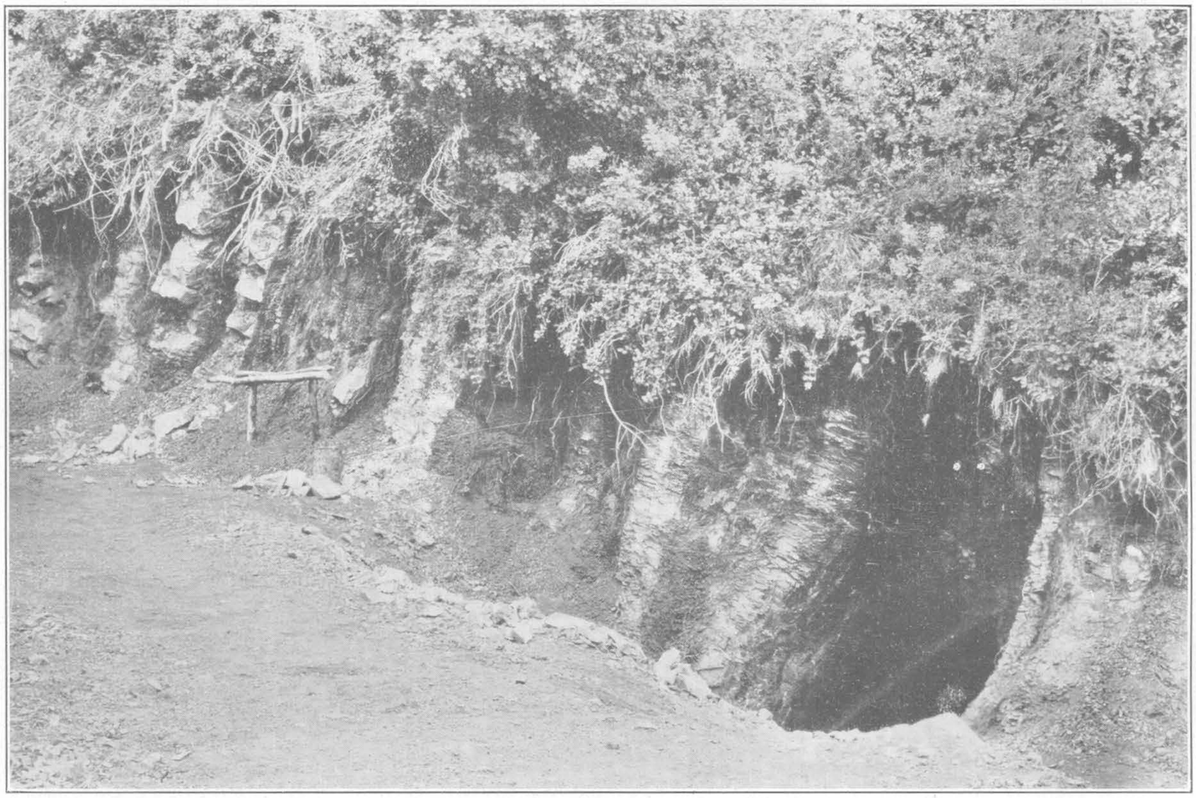
Showing extent of known phosphate outcrops, with sections and analyses of phosphate beds. After Gale and Richards, U. S. Geol. Survey Bull. 430, pl. 8, 1910

Richards 278-280

GATEWAY IN REX CHERT MEMBER OF PHOSPHORIA AND RELATED FORMATIONS IN RAYMOND CANYON, T. 26 N., R. 119 W., MONTPELIER QUADRANGLE

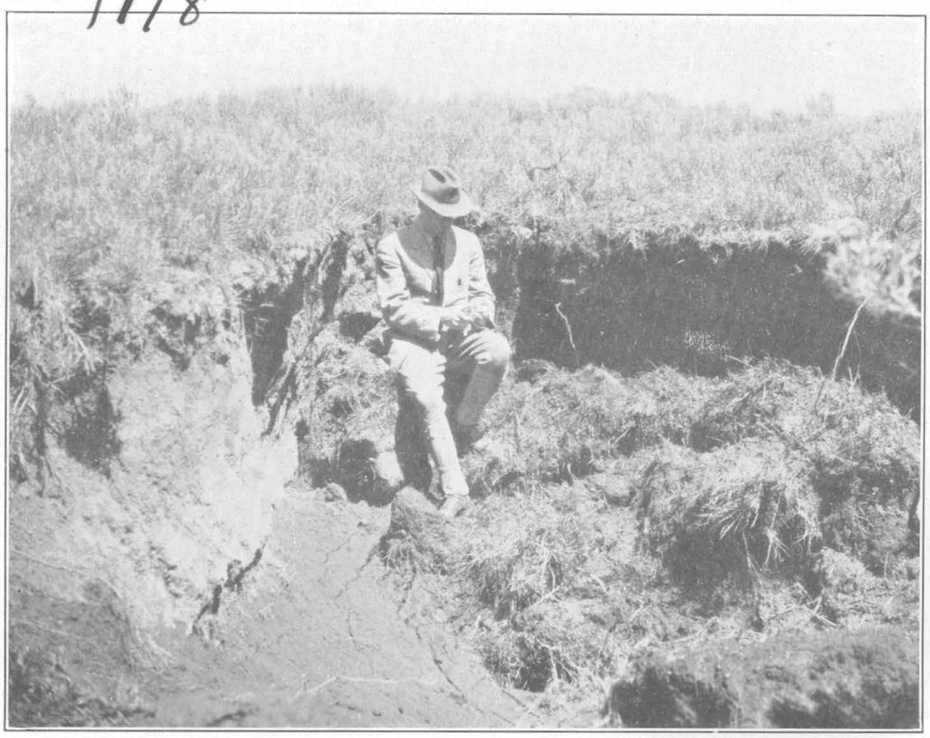
a, Rex chert member; b, Woodside shale; c, Thaynes group

Gale 461.



A. PROSPECT IN THE PHOSPHATIC SHALE IN COAL CANYON, T. 26 N., R. 119 W., MONTPELIER QUADRANGLE

Umpleby 178



B. FRESH SINK 600 FEET WEST OF THE BASE OF CHINA HAT AND ABOUT 1 MILE SOUTH OF BLACKFOOT RIVER RESERVOIR, HENRY QUADRANGLE

On the conservative basis adopted for the preceding township, 960 acres in this township is classified as phosphate land.

Estimate of tonnage.—As in the discussion of adjacent townships the presence of a high-grade phosphate bed with a minimum thickness of 5 feet is assumed, the limit of workable depth for such a bed is 4,000 feet. The phosphate bed is also assumed for purposes of computation to be a vertical bed on the east side of an eroded fold. In the selected area such a vertical bed 5 feet thick and 4,000 feet deep would contain more than 25,043,000 long tons of phosphate rock.

United States Phosphate Co.—The United States Phosphate Co., which has headquarters at Salt Lake City, opened a mine in York Canyon in the winter of 1913–14 and erected a mill, boiler house, bins and other buildings, preliminary to mining and shipping phosphate rock. The following account of operations at this mine is taken from an unpublished report of Mr. Rath, of the General Land Office, dated February 4, 1915:

The phosphate rock is mined by overhead stoping. The drifts are timbered with tunnel stulls, and these are securely covered with planking. The rock is blasted onto the planking and is drawn off through chutes into 1-ton cars for tramming to the bins at the mill. The broken rock packs badly and requires a steep sliding angle, much of it as great as 70°, and so the chutes must be placed close together to avoid much shoveling in the stopes.

Both hanging and foot walls are solid, and by leaving a few pillars of phosphate rock very little timbering is required and no particular mining difficulties arise. All drilling is done by hand, and the rock is easy to mine. The phosphate bed has been stoped to the surface at one place and good ventilation obtained. The mine is comparatively dry.

At the mill the rock passes through a jaw crusher and two sets of rolls and then passes to the dryer and thence to a tube mill. A draft of air blows the finely ground powder from the tube mill against a 100-mesh screen. From this screen the pulverized product falls into a hopper, which discharges into an automatic weighing device by which it is weighed into burlap or paper sacks of 100 pounds capacity. Steam power is used, and the mill has a capacity of 14 tons a day of 8 hours.

The pulverized rock is hauled by wagon to Border station on the Oregon Short Line Railroad about 5 miles distant. Most of it is sent to a warehouse at Salt Lake City and distributed from there. The product is sold under guaranty of 32 or more per cent of phosphorus pentoxide, equivalent to 70 or more per cent tricalcium phosphate, for direct application to the soil without preliminary treatment with sulphuric acid.

Production at this mine was discontinued about 1917. When visited by the writer in September, 1920, the plant had been partly dismantled.

SUMMARY OF ESTIMATES OF TONNAGE

The estimates of tonnage in the preceding township descriptions include revised figures for a number of townships that have been previously reported as well as estimates not heretofore published. They thus bring the quantitative data abreast of the latest available geologic information. Although approximate they relate chiefly to the main bed, which lies near the base of the phosphatic shales, and thus exclude some workable high-grade rock and much lower-grade material that may eventually become workable. Numerous areas of considerable size that may contain phosphate deposits at workable depths are also excluded because they are covered with late deposits which conceal the underlying structure to such extent as to make hazardous any estimate of the quantity of phosphate. The estimates are based on the best data available and are believed to be conservative. Table 73 gives revised estimates for all of the Idaho field examined prior to 1925, but extensive areas in the outstanding withdrawals remain unexplored. Table 74 includes estimates for other parts of the western field, revised so far as practicable, and for the country.

TABLE 73.—*Estimates of phosphate rock available in the townships in Idaho described in this paper*

	Long tons
T. 3 S., R. 40 E	0
T. 4 S., R. 40 E	8, 400, 000
T. 5 S., R. 40 E	79, 983, 000
T. 6 S., R. 40 E	24, 360, 000
T. 3 S., R. 41 E	0
T. 4 S., R. 41 E	0
T. 5 S., R. 41 E	59, 291, 000
T. 6 S., R. 41 E	96, 383, 000
T. 7 S., R. 41 E	0
T. 4 S., R. 42 E	0
T. 5 S., R. 42 E	14, 300, 000
T. 6 S., R. 42 E	159, 706, 000
T. 7 S., R. 42 E	114, 850, 000
T. 8 S., R. 42 E	203, 840, 000
T. 9 S., R. 42 E	69, 720, 000
T. 10 S., R. 42 E	0
T. 5 S., R. 43 E	102, 490, 000
T. 6 S., R. 43 E	512, 709, 000
T. 7 S., R. 43 E	365, 377, 000
T. 8 S., R. 43 E	293, 150, 000
T. 9 S., R. 43 E	186, 215, 000
T. 10 S., R. 43 E	84, 700, 000
T. 11 S., R. 43 E	89, 609, 000
T. 12 S., R. 43 E	5, 376, 000
T. 13 S., R. 43 E	84, 700, 000
T. 14 S., R. 43 E	83, 300, 000
T. 15 S., R. 43 E	0
T. 5 S., R. 44 E	10, 080, 000
T. 6 S., R. 44 E	218, 437, 000
T. 7 S., R. 44 E	315, 032, 000
T. 8 S., R. 44 E	425, 040, 000
T. 9 S., R. 44 E	211, 346, 000
T. 10 S., R. 44 E	52, 000, 000
T. 11 S., R. 44 E	1, 512, 000
T. 12 S., R. 44 E	10, 780, 000
T. 13 S., R. 44 E	2, 080, 000
T. 14 S., R. 44 E	2, 764, 000
T. 15 S., R. 44 E	37, 606, 000
T. 16 S., R. 44 E	0
T. 7 S., R. 45 E	71, 400, 000
T. 8 S., R. 45 E	459, 900, 000

	Long tons
T. 9 S., R. 45 E	171, 400, 000
T. 10 S., R. 45 E	88, 900, 000
T. 11 S., R. 45 E	22, 000, 000
T. 12 S., R. 45 E	15, 400, 000
T. 13 S., R. 45 E	26, 953, 000
T. 14 S., R. 45 E	0
T. 15 S., R. 45 E	0
T. 16 S., R. 45 E	0
T. 7 S., R. 46 E	30, 243, 000
T. 8 S., R. 46 E	78, 127, 000
T. 9 S., R. 46 E	21, 842, 000
Additional classified lands in Portneuf quadrangle	86, 554, 000
	4, 997, 855, 000

TABLE 74.—*Estimates of phosphate rock available in the Western States*

	Long tons
Wyoming:	
Revised estimates for townships mentioned in this report:	
T. 27 N., R. 120 W	0
T. 26 N., R. 120 W	0
T. 34 N., R. 119 W	16, 801, 000
T. 33 N., R. 119 W	22, 122, 000
T. 27 N., R. 119 W	46, 588, 000
T. 26 N., R. 119 W	25, 043, 000
Other areas (Gale and Richards)	5, 200, 000
Utah	326, 745, 000
Montana (revised)	391, 323, 000
Idaho (this report)	4, 997, 855, 000
Total for Western States	5, 831, 677, 000

TABLE 74a.—*Estimate of phosphate rock in the United States available December 31, 1925, in long tons*

Field	Estimated quantity available	Field	Estimated quantity available
Eastern field:[a]		Western field:	
Arkansas	20, 000, 000	Idaho	4, 997, 855, 000
Florida	291, 000, 000	Montana	391, 323, 000
Kentucky	878, 000	Utah	326, 745, 000
South Carolina	8, 788, 000	Wyoming	115, 754, 000
			5, 831, 677, 000
Tennessee	83, 500, 000	Less approximate quantity mined since 1906	350, 000
	404, 166, 000		5, 831, 327, 000
			404, 166, 000
			6, 235, 493, 000

[a] Figures for the eastern field revised from author's chapter on Phosphate rock, U. S. Bur. Mines Mineral Resources, 1924, pt. 2, p. 88, 1925, to allow for decreases on account of rock mined.

WESTERN PHOSPHATE INDUSTRY

DISCOVERY, EARLY DEVELOPMENT, AND EXPLORATION

The original discovery[47] of the western phosphate fields is claimed by Albert Richter, of Salt Lake City,[48] who, according to his own report, first recognized the true character of the deposits somewhere in the vicinity of La Plata, Cache County, Utah, in 1889. Richter traced them as far as Bear Lake and located a number of claims and excavated discovery pits on them. He states that in 1901 he laid the matter before several of the larger fertilizer manufacturers in the Central States, who made analyses of the samples that proved them to contain high-grade phosphate, but evidently these firms did not at that time deem it worth while to investigate the deposits further, probably because of their remoteness from the market.

Later, according to C. C. Jones,[49] the phosphate beds were independently recognized by R. A. Pidcock, who in the summer of 1897 found some old prospects, presumably located for gold, in a soft black formation on Twelvemile Creek, a branch of Woodruff Creek in Rich County, Utah, and obtained an analysis of the rock which showed it to be phosphate. In May, 1903, according to his own statement, Mr. Jones examined the deposits on Woodruff Creek, and after studying them in the field he succeeded in tracing their outcrops in many places throughout southeastern Idaho, southwestern Wyoming, and northeastern Utah. The deposits had previously attracted the attention of many prospectors, who had made locations on them for their possible content of the precious metals and because of the superficial resemblance of the outcrop to coal blossom. Mr. Jones, however, became a pioneer in the first actual development of the field for its phosphate, and to him much credit is due for the systematic, scientific way in which his field investigations were prosecuted. His papers cited above give an account of his methods and fields of work.

Commercial development of the fields has undoubtedly been retarded by their situation, remote from fertilizer markets, where such material might be utilized, which necessitates rail transportation at high cost. Without much question, development has also been more or less impeded by legal difficulties that have arisen in regard to the method of location and the

[47] Gale, H. S., Preface to U. S. Geol. Survey Bull. 577, pp. 7-8, 1914.

[48] Richter, Albert, Western phosphate discovery: Mines and Methods, vol. 2, No. 9, p. 207, 1911.

[49] Jones, C. C., Phosphate rock in Utah, Idaho, and Wyoming: Eng. and Min. Jour., vol. 83, pp. 953-955, 1907; The discovery and opening of a new phosphate field in the United States: Am. Inst. Min. Eng. Bull. 82, pp. 2411-2435, October 1913.

titles of these lands. Methods of acquiring private ownership of this type of mineral deposit had not previously been specifically provided for in the public land laws. However, when the more detailed work of the Geological Survey was first undertaken in these fields in 1909, many of the properties more readily accessible to existing railroad lines had already passed into private control, although a vastly greater area still remained, literally unprospected, as a part of the public domain.

The first lands withdrawn in these phosphate fields comprised an area of about 7,000 square miles in Idaho, Utah, and Wyoming. This withdrawal was made by direction of the Secretary of the Interior under date of December 9, 1908. This action thus preceded specific land examinations for the purpose of accurately defining the field. The area withdrawn was outlined by the aid of an interpretation of the geology of the region as shown on the map made by the Hayden Survey in 1877. This interpretation was made in the light of more recent knowledge of the geologic relations of the deposits.

The United States Geological Survey's investigations in the western phosphate fields began in 1906. From 1909 to 1916 detailed study and classification of phosphate and nonphosphate lands was made a part of each summer's field work. The participation of the United States in the World War interrupted this program, but it has since been resumed and carried forward as rapidly as limited funds and personnel would permit.

LITIGATION

The legal difficulties which furnished the basis of the unfortunate litigation have been discussed by Gale and Richards [50] from whose account the following summary is in part compiled.

Under the then existing laws of the United States mining claims, except for coal lands, might be of two classes, placer and lode. When the western phosphate deposits were discovered and the lands came to be staked and claimed in mineral locations no recognized precedent had been established as to the proper form of entry upon such lands. Phosphate deposits of a true placer type exist and form a valuable part of the Florida and South Carolina fields, but the rock-phosphate deposits of Idaho, Utah, and Wyoming are undoubtedly more properly analogous to coal than to either of the types of mineral deposits specified in the other mining laws.

In the Idaho phosphate field the first patent, which was issued for the Waterloo claim at Montpelier, was granted as a placer and prior to that time all phosphate locations in that field were made under the placer law. A little later, however, the Bradley claims in the Crawford Mountains, Utah, were allowed to patent as lodes. Soon many of the original placer claims were relocated as lodes, as a rule by other persons than the first holders. When the original locators had fulfilled the legal requirements for their placer claims and made application to the United States Land Office for final patents the adverse claimants carried their cases to court to determine their possessory rights and thus began litigation, which continued for a period of about three years. Cases were instituted in the latter part of 1910 in both the eighth district (Wyoming) and the ninth district (Idaho) United States courts. The defendant in each case was the San Francisco Chemical Co., the original claimants. The plaintiff in the first case was Morse S. Duffield "and another" and in the second case Morse S. Duffield and Lewis A. Jeffs, the adverse claimants.

The San Francisco Chemical Co., which located its claims in good faith and had complied with all the provisions of the placer law, held that the adverse claimants were trespassers under that law and had no rights. The adverse claimants held that the original placer locations were void inasmuch as the land was not properly open to that form of location and that they were therefore entitled to make discoveries and enter lode claims upon it. In the Eighth District Court the case was decided in favor of the plaintiff, but in the Ninth District Court the decision was in favor of the defendant.

Each case was appealed. On November 21, 1912, the Circuit Court of Appeals for the Eighth Circuit (Wyoming) affirmed the decision of the district court in favor of the plaintiff.[51] The affirmation held that the court had power under the law to determine the proper form of location, that phosphate rock, which is "rock in place" is properly a lode and not a placer, and that the defendant's placer claims were unlawfully located and therefore were void and were open to the peaceful entry of the plaintiff and to discovery and location as lode claims. The Circuit Court of Appeals for the Ninth Circuit (Idaho) on May 5, 1913, reversed the decision of the district court [52] on grounds similar to those just stated.

Thus in the later decisions the defendant lost in both courts. Meanwhile the Department of the Interior [53] on December 12, 1912, decided a similar case in Utah (the Harry lode) in favor of the lode claimant. In the final adjustment of the disputed claims, which was effected out of court, the San Francisco Chemical Co. retained its property in Montpelier Canyon which comprised two placer claims that had been patented, and eight lode claims. Its remaining placer claims in Wyoming and Utah were surrendered to the lode claimants.

[50] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 532–535, 1910.

[51] Federal Reporter, vol. 201, pp. 830–836, 1913.

[52] Idem, vol. 205, pp. 480–486, 1913.

[53] Decisions of the Department of the Interior in cases relating to the public lands, vol. 41, pp. 403–408, 1913.

UNSATISFACTORY ASPECTS OF DECISION

Since the establishment of the lode and placer laws, and aside from the law relating to coal lands, separate enactments of Congress have authorized the application of the provisions of the placer mining law, first to lands chiefly valuable for building stone and later to lands that contain petroleum or other mineral oils and that are chiefly valuable for these materials. Still a third enactment has extended the placer form of entry to deposits of salt in any form. Thus exception to the definition of a lode deposit as necessarily "rock in place" is officially recognized. No cognizance of these changes in the interpretation of the placer mining law was taken in the court decisions above mentioned.

The decision to regard beds of phosphate rock as lodes left much to be desired. The most serious objection to the application of the lode law to the western rock phosphate fields was the interpretation that was thereby placed on the so-called extralateral rights. A recognition of the inapplicability of this proviso to coal lands was early brought out by the necessity for providing for their disposition. On account of the bedded character of the phosphate deposits and the great uniformity of the beds throughout wide areas there is not the uncertainty as to their continuity at depth that prevails with respect to typical mineral lodes or veins in the stricter definition of the terms. Under this proviso of the law title would be granted not only to the outcrop of the phosphate beds but also to the beds in depth as far as they continue to dip, even if the dip is but very slight. This method would enable the locator of a single lode to extend his extralateral rights for long distances, even for a number of miles in regions where the rocks continue to dip for that distance.

LATER LAWS AFFECTING PHOSPHATE LAND

The withdrawal of land from entry pending its examination and classification caused hardships to some settlers who were planning to make agricultural entries in lands which they later found were included in the phosphate reserve. Some agricultural entries which had been made in good faith before the withdrawals were held up pending the classification of the land or revoked as a result of that classification. These difficulties were finally obviated by the passage on July 17, 1914, of the law (38 Stat. 509) which separates the agricultural from the mineral rights.

The application of the lode-mining law to phosphate rock in the western phosphate fields was superseded by the so-called leasing law, the act of February 25, 1920 (41 Stat. 437), "an act to promote the mining of coal, phosphate, oil, oil shale, gas, and sodium on the public domain." Under the provisions of this law the United States retains the title to phosphate deposits on the public domain but may lease portions, not to exceed 2,560 acres for each lease "to citizens of the United States or to any association of such persons, or to any corporation organized under the laws of the United States, or any State or Territory thereof." The leased areas are "to be described by the legal subdivisions of the public land surveys, if surveyed; if unsurveyed, to be surveyed by the Government at the expense of the applicant for lease." These provisions of the law prevent further award of phosphate lands in mining claims to private individuals or corporations and do away with the objectionable extralateral rights.

A royalty "not less than 2 per centum of the gross value of the output of phosphate or phosphate rock at the mine" is provided for and made payable in quarterly installments. An annual rental graduated in succeeding years from 25 cents to $1 per acre is also charged, but the rental for any year is credited against the royalties that accrue for that year. The leases are for indeterminate periods, but readjustments of conditions may be made at 20-year intervals. Section 12 of the law also permits the use by a lessee of additional unappropriated and unentered lands, not exceeding 40 acres, "for the proper prospecting for or development, extraction, treatment, and removal of such mineral deposits."

General provisions are included in the law to prevent monopoly, to permit easements or rights of way, to regulate assignments, subletting, or relinquishment of rights, conditions of labor, and for other purposes, and to divide the income from royalties, bonuses, or rentals between the United States and the State on a fixed basis and for specified purposes.

OPERATING COMPANIES

Although only four companies[54] mined phosphate rock in the Western States in 1925, there are several others which have held or still hold phosphate lands. The companies interested in this field are mentioned briefly below.

American Phosphate Corporation.—In February, 1920, the American Phosphate Corporation, which had obtained a 10-year lease from the San Francisco Chemical Co., opened a phosphate mine in Montpelier Canyon opposite the mine of the leasing company and about 3½ miles above the mouth of the canyon. In the same month a franchise was granted by the city council of Montpelier to construct a railway through one of the streets. Further details regarding this mine are given on page 279. No work on the construction of the proposed railroad has yet been undertaken. A small production was reported from this mine each year from 1920 to 1924, but in 1925 it was idle.

Peter B. and Robert S. Bradley.—The Bradley Bros., of 92 State Street, Boston, own phosphate properties in the Crawford Mountains near Randolph, Rich County, Utah. These properties have been described

[54] Information furnished informally by Mineral Statistics Division, Bureau of Mines.

in an earlier report[55] and have not since been visited by a representative of the Geological Survey. One of the mines was in operation for several years but the production was small. The mines have been idle since 1920.

Anaconda Copper Mining Co.—At the plant of the Anaconda Copper Mining Co. at Anaconda Mont., large quantities of sulphuric acid are derived from smelter fumes. High freight rates and the distance from the market have made it practically impossible for the company to market this sulphuric acid. The metallurgical department therefore conducted experiments for a considerable time at Anaconda in the utilization of this acid in the manufacture of fertilizer and finally established a plant there.

The Anaconda Co. owns phosphate beds at Melrose and Garrison, Mont., and has done some development work at both places.

After experimenting with Montana phosphate rock, the company for a number of months bought its supply from Paris, Idaho. Meanwhile it had acquired an extensive property near Soda Springs, Idaho, and began its development. The developments in progress at Conda, near Soda Springs, are described on page 236. The manufacture of "Anaconda treble superphosphate" was begun at Anaconda in the summer of 1920 in a plant that had a capacity of 50 tons of raw material a day. Its capacity has since been increased to 120 tons. The process is described on page 298.

Bear Lake Phosphate Co.—The Bear Lake Phosphate Co. was established in 1920 in Slight Canyon near Paris, Idaho, about 1¼ miles north of the property of the Western Phosphate Co. For most of that year only development work was done, but toward the end of the year several hundred tons of phosphate rock was mined, though none was shipped. Shipments began in January, 1921, and were consigned to a fertilizer plant on San Francisco Bay, but the mine was soon closed on account of the general business depression. No production was reported after 1922. It was recently reorganized as the Keystone Phosphate Co. and has also figured in press statments in connection with the Idaho Phosphate Co. Further details about the property and development work of this company are given on page 254.

Merriman Potash Products Co.—A mine was operated by the Merriman Potash Products Co., in sec. 14, T. 10 S., R. 43 E., about 3½ miles northeast of Cavanaugh, a siding on the Oregon Short Line Railroad between Montpelier and Soda Springs, Idaho, and shipments were made during the first four months of 1920. The company ceased operations early in the summer of that year and has apparently gone out of business.

San Francisco Chemical Co.—The Waterloo mine, about 3 miles east of Montpelier, Idaho, had been developed by the San Francisco Chemical Co. to a depth of about 850 feet on the dip by short adits from 50 to 350 feet long. Drifts have been driven on the strike for 2,000 feet, and phosphate has been mined by back stoping. The bed is about 5½ feet thick. During much of the year 1920 the mine was shipping at the daily rate of about 100 tons of phosphate rock, but because of the falling off in the demand for its product the mine was temporarily closed at the end of the year. Further details about the San Francisco Chemical Co. are given on pages 280 and 281, under the heading "Waterloo claim."

Union Phosphate Co.—The mine of the Union Phosphate Co. at Cokeville, Wyo., has been described in an earlier report[56] and has not since been revisited by a representative of the Geological Survey. Production at this mine began about 1907, but none has been reported to the Survey since 1917.

United States Phosphate Co.—In addition to its property in T. 26 N., R. 119 W., in the Sublette Ridge, Lincoln County, Wyo., the United States Phosphate Co. formerly controlled properties in Bear Lake County, Idaho, and in Morgan and Rich Counties, Utah. There was no production from the Wyoming property after 1915. The Idaho property had not been developed in 1921. In 1922 the company reported that it was merely a holding company for lode and placer claims in Idaho. In the same year its Utah and Wyoming charters expired and these properties were divided among the stockholders. Further details regarding the operations of this company are given on page 291.

Western Phosphate Co.—A mine developed on property acquired in May, 1917, 3 miles from Paris, Idaho, has been operated for several years by the Western Phosphate Co. The mine has modern equipment, including ventilating system, compressor, and small rotating jack hammers. A mill for drying the rock has been completed and has four 250-ton rotary driers and a 5-ton Raymond pulverizer that has a daily capacity of 80 tons. Early in 1921 the company was in the hands of a receiver pending reorganization. It has since become the Idaho Phosphate Co. Further details about the Western Phosphate Co. are given on page 253.

Idaho Phosphate Co.—The Idaho Phosphate Co., formerly the Western Phosphate Co., is reported[57] to have combined with the Bear Lake Phosphate Co. under the management of R. C. McIlwee, Paris, Idaho. The original property of the Idaho Phosphate Co., which is in Paris Canyon, has standard-gage railroad connections with the Oregon Short Line Railroad. The developments are said to include a

[55] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 516–518, 1910.

[56] Gale, H. S., and Richards, R. W., op. cit., p. 507.

[57] A large western phosphate operation: Rock Products, vol. 29, p. 65, June 26, 1926

2,500-foot tunnel and a winze 200 feet deep, which shows the presence of phosphate to that depth. The Bear Lake Co.'s property is in Slight Canyon to the north and includes a 1,000-foot tunnel. The two properties as combined will extend approximately 4½ miles along the phosphate beds. By sinking a shaft 400 feet deep on the Paris Canyon property and drifting northward along the phosphate bed it is planned to develop both properties and to ship all the ore over the railroad spur in Paris Canyon.

Cokeville Phosphate Co.—According to press statements[58] the Cokeville Phosphate Co. at Cokeville, Wyo., is growing rapidly and now markets its product in California, Oregon, and Washington. The phosphate bed is 6 feet thick and dips 75°. It is mined by the shrinkage system, and as it is taken out of stopes on the lower level it is filled in from a stope above. In this manner the lower stopes are always kept full of ore ready to be trammed out to the mill. About 100 tons are mined daily. The workings extend only 700 feet from the entrance of the lower tunnel. The cars run out by gravity to the mill. The rock is crushed, dried in a rotary drier until it contains less than 1 per cent of moisture, and is then pulverized so that 95 per cent of it passes a 100-mesh screen and 65 per cent of it passes a 200-mesh screen. The storage bins hold about 1,100 tons. A market for pulverized rock has been developed on the Pacific coast and since the output is sold on five-year contracts a steady demand is assured. With no excessive selling costs a low price is maintained.

The original plant was built in 1913. It is about 2 miles from the railroad and is completely electrified. In that year only 4 cars were shipped. In 1925, 149 cars were loaded. F. M. Breese is president and general manager of the company.

[58] Producing pulverized rock phosphate by the shrinkage system: Pit and Quarry, vol. 12, no. 2, pp. 85–87, Apr. 15, 1926.

PRODUCTION

The production of phosphate rock in the western phosphate field began in October, 1906. Since that time production has been fairly continuous but small and fluctuating. Table 75 shows the production and value of the western phosphate rock from 1906 to 1925 in comparison with like features for the entire country for the same period. The data are compiled from the volumes on Mineral Resources of the United States, formerly published by the Geological Survey but now issued by the Bureau of Mines.

TABLE 75.—*Phosphate rock produced in the Western States and in the United States, 1906–1925*

Year	Western States			United States		
	Quantity (long tons)	Value	Average price per ton	Quantity (long tons)	Value	Average price per ton
1906	[a] 5, 100	$28, 800	$5. 65	2, 080, 957	$8, 579, 437	$4. 12
1907	[a] 12, 145	47, 098	3. 86	2, 265, 343	10, 653, 558	4. 70
1908	[a] 13, 110	47, 483	3. 62	2, 386, 138	11, 399, 124	4. 78
1909	[a] 9, 493	34, 040	3. 56	2, 330, 752	10, 772, 120	4. 62
1910	9, 634	32, 819	3. 41	2, 654, 988	10, 917, 000	4. 11
1911	10, 505	39, 882	3. 80	3, 053, 279	11, 900, 693	3. 90
1912	11, 612	49, 241	4. 24	2, 973, 332	11, 675, 774	3. 93
1913	5, 053	18, 167	3. 60	3, 111, 221	11, 796, 231	3. 79
1914	5, 030	15, 488	3. 08	2, 734, 043	9, 608, 041	3. 51
1915	3, 837	12, 613	3. 29	1, 835, 667	5, 413, 449	2. 95
1916	1, 703	5, 350	3. 14	1, 982, 385	5, 896, 993	2. 97
1917	15, 096	41, 756	2. 77	2, 584, 287	7, 771, 084	3. 01
1918	11, 955	42, 161	3. 53	2, 490, 760	8, 214, 463	3. 30
1919	16, 935	69, 855	4. 12	2, 271, 983	11, 591, 268	5. 10
1920	55, 609	304, 006	5. 47	4, 103, 982	25, 079, 572	6. 11
1921	6, 291	25, 872	4. 11	2, 064, 025	12, 270, 070	5. 94
1922	4, 481	19, 692	4. 39	2, 417, 883	10, 482, 846	4. 34
1923	30, 335	175, 713	5. 79	3, 006, 706	11, 576, 049	3. 85
1924	38, 570	194, 569	5. 04	2, 867, 789	10, 252, 083	3. 57
1925	72, 631	319, 498	4. 40	3, 481, 819	11, 545, 678	3. 32
	339, 125	1, 524, 103	4. 04	52, 696, 739	217, 395, 533	4. 10

[a] Includes a small amount from Arkansas.

The figures of production for the Western States have generally been a mere fraction of 1 per cent as compared with the production for the entire country, except that in 1920, 1923, 1924, and 1925 the figures for the Western States were more than 1 per cent of the total production. The average production of the Western States as compared with that of the entire country for the given period is 0.64 per cent and the average value 0.70 per cent. The price per ton of the western rock has usually been a little lower than the average price for the entire country, the two averages for the 20-year period being, respectively, $4.04 and $4.10 per ton. The early interest in the development of the western phosphate field languished for awhile, but in 1917 there came a renewal of activity. The maximum production for the period was in 1925, when 72,631 long tons valued at $319,498 was produced. This production represented an increase of 88 per cent in quantity and of 64 per cent in value over that in 1924.

There were four operators in the western field in 1925, two in Bear Lake County and one in Caribou County, Idaho; the other in Lincoln County, Wyo. There was no production in Utah in 1925. The average price of phosphate rock in Idaho in 1925 ranged from $3.75 to $5.44 per ton: in Wyoming the price per ton averaged $4.48.

MARKETS

The most extensive use of the western phosphate hitherto has been in the citrus fruit belt of southern California.

In the grain-producing sections of the State the use of superphosphates is said to be increasing. The newly developed cotton industry in the Imperial Valley region and Arizona may prove an attractive market. Some demand has come from Japan and the Hawaiian Islands, but strong competition for these markets may develop from the companies that are exploiting the deposits of the islands of the Pacific and Indian Oceans. A local market for finely crushed phosphate rock has recently developed in Idaho and Washington, as the deterioration of wheat lands in those States necessitates the use of fertilizer. The shipments already made to the Central and Eastern States give promise of the development of markets in those areas, but until more favorable freight rates are obtainable or until processes are perfected for producing commercially more concentrated forms of phosphatic fertilizers, any large demand for the western phosphate will hardly come from those sources. Another factor in the situation is the probability that in the near future phosphate rock from the extensive deposits in Morocco and other north African countries will largely displace the Florida and Tennessee phosphate in the European markets, and thus a larger proportion of the output from these States will be thrown upon the domestic markets in the eastern part of the United States.

UTILIZATION OF PHOSPHATE ROCK

The chief use of phosphate rock is as a fertilizing agent, either applied directly to the soil or manufactured into acid phosphates or other compounds and included in prepared fertilizers. Small quantities are used in the manufacture of phosphorus. These uses are briefly discussed below.

Phosphate applied directly to the soil.—Phosphate rock as it occurs in nature is not soluble in water and is not readily soluble in weak acids, and hence the phosphoric acid that it contains is not regarded by fertilizer manufacturers as "available" for plant food. Nevertheless, under normal conditions of soil moisture and temperature it does slowly decompose and enrich the soil. Agricultural experiment stations in many of the States have tested pulverized raw phosphate rock both on unlimed and limed soils and with and without the admixture of decaying organic matter. The results of these experiments have led to somewhat differing opinions, but in those States in which the tests have been most consistently followed out, as in Ohio, Massachusetts, Illinois, Maryland, Pennsylvania, Maine, and Rhode Island, the conclusion has been reached that the use of ground, raw phosphate rock is both economical and beneficial for certain crops and where a heavy yield the first year is not a necessity. The Illinois Agricultural Experiment Station has been a leader in advocating the use of this material in connection with green or other manures as part of a system of permanent soil improvement for the farms of the State.[59]

According to J. R. Bent,[60] of the Illinois Agricultural Association, the farmers of Illinois consume approximately two-thirds of all the ground raw phosphate that is used in the United States for direct application to the soil. He writes:

> Although the Illinois University Agricultural Experiment Station and the Illinois Farmers' Institute have for 15 to 20 years been diligent in preaching the doctrine of the so-called "Illinois system of permanent agriculture" originally formulated by the late Dr. Cyril G. Hopkins, the demand as yet has not been very general, but it may be safely asserted that the Illinois system strongly predominates in this State to the extent that soil treatment is practiced at all, and those who have been active in the movement believe that there will be a great development in the future. This manner of using phosphate, I think, has passed its experimental stage and is without doubt a proven success. Farmers who have adopted this system very seldom drop it, and others have been converted from other systems to it. It may also be said that those of our members who use raw rock phosphate may be numbered among our most progressive and successful farmers.

According to reports received by the Geological Survey[61] the use of raw phosphate rock for direct application to the soil has grown considerably during the last few years, which seems to indicate that excellent results have been obtained in increased crops. Several companies, especially those in the Florida and Tennessee phosphate fields, are handling this product. Beginning with 1914 the Geological Survey in its annual statistical inquiry asked the producers to state the quantity of raw rock phosphate sold for direct application to the soil. The total of such direct returns from the miners, however, does not represent the total quantity of raw rock phosphate now sold for direct application, because some lump rock is sold to grinders who do not report directly to the Geological Survey or, now, to the Bureau of Mines. The figures given in Table 76 may be of interest and suggestive of the trend of this phase of the fertilizer business. In this table both soft phosphate and finely ground hard rock phosphate are included.

[59] Hopkins, C. G., Shall we use natural rock phosphate or manufactured acid phosphate for the permanent improvement of Illinois soils: Illinois Univ. Agr. Exper. Sta. Circ. 127, 1909, 2d ed., 1910.

[60] Personal communication.

[61] Stone, R. W., op. cit., p. 35.

TABLE 76.—*Raw phosphate rock sold for direct application to the soil, 1914–1925*

	Long tons		Long tons
1914	48, 317	1920	72, 801
1915	50, 468	1921	13, 503
1916	70, 233	1922	16, 029
1917	75, 861	1923	10, 548
1918	45, 294	1924	14, 320
1919	79, 189	1925	31, 999

Acid phosphate.—According to Waggaman,[62] the acid phosphate industry in the United States has grown to enormous proportions. In spite of the fact that numerous other forms of phosphatic fertilizer have been proposed or patented from time to time, and the application of raw ground rock phosphates has been recommended by some agronomists and agricultural chemists, the annual production of superphosphate continues to increase. There is little doubt, therefore, that this material will continue to be the basis of most of our commercial fertilizers.

The general manufacture of acid phosphate is summarized by Waggaman as follows:

In the manufacture of acid phosphate the rock is first ground to pass a 60-mesh sieve, and then mixed with an equal weight (approximately) of "chamber acid." The quantity, strength, and temperature of the acid used have an important influence on the quality of the product.

After thorough mixing in a cast-iron pan the material is discharged into a "den" just below the mixer or into a car which takes it to a shed and dumps it on a pile. When the "den" system is used the reactions take place rapidly and the product can be dug out in 24 to 36 hours, practically ready for shipment. The method of emptying the "dens" by hand, however, is attended with some risk owing to the poisonous nature of the fumes evolved from the freshly made acid phosphate and to the danger of large masses of the material falling on the laborers.

In the open-dump system the acid phosphate requires a long time to reach its maximum availability, and unless it is properly made may never be fit for use.

The storing of acid phosphate in large piles for protracted periods sometimes causes reversion, owing to the pressure on the material in the lower part of the pile; this pressure also tends to compact the material. The storing of well-made acid phosphate in medium-sized piles, however, should cause no ill effects.

Properly made acid phosphate should require no artifical drying, since the calcium sulphate formed in the process takes up the water to form gypsum. It is nearly always necessary, however, to disintegrate and screen the material before shipping. This is often done by simply throwing the product upon inclined screens, but sometimes disintegrating machines must be employed.

Acid phosphate is sold on the basis of its so-called available acid * * *. The marketed product contains from 14 to 21 per cent of phosphoric acid, depending on the raw material used in its manufacture.

The processes employed for the manufacture of superphosphate or acid phosphate from the Idaho phosphate rock are essentially in accord with the description given above, except that the Anaconda Copper Mining Co. is making a "high-grade superphosphate" under the trade name of "treble superphosphate."

At the plant of the San Francisco Chemical Co., where the ore is said to contain about 32 per cent phosphorus pentoxide, it has been found that the ovules or oolites of the rock resist grinding and become concentrated in the mill. A sample taken at this point shows that these bodies contain 35.7 per cent of phosphorus pentoxide or 3.7 per cent more of this substance than the average content for the rock as a whole.

The product of the California plants that use the western phosphate rock averages about 17 per cent "available phosphoric acid," and the physical character of the product appears to be uniform.

High-grade superphosphate.—One of the methods suggested for overcoming the disadvantage of high freight rates is the manufacture of "high-grade superphosphate," in which the percentage of "available phosphoric acid" is much higher than that in the ordinary superphosphates. This method seemed particularly appropriate for the Montana phosphates, which are conveniently located with respect to smelters, the sulphurous fumes of which might well be utilized in making fertilizers. The general process was described some years ago by Wyatt.[63] These "high-grade supers" contain about 45 per cent of phosphoric acid in "water soluble" and "citrate soluble" form. Their preparation involves two steps, the first being the preparation of a commercial grade of free phosphoric acid and the second the use of this acid in the treatment of more raw phosphate rock.

The theoretical chemical reactions in the first step of the process are as follows:

$$Ca_3(PO_4)_2 + 3(H_2SO_4) = 3(CaSO_4) + 2(H_3PO_4).$$

The further treatment of the raw phosphate with the commercial phosphoric acid is described as resulting in the following reactions in which both the "water soluble" (monocalcium) and the neutral or "citrate soluble" (dicalcium) phosphates are produced:

$$Ca_3(PO_4)_2 + 4(H_3PO_4) + 6(H_2O) = 3[CaH_4(PO_4)_2(H_2O)_2].$$

$$2Ca_3(PO_4)_2 + 2(H_3PO_4) + 12(H_2O) = 3[Ca_2H_2(PO_4)_2(H_2O)_4].$$

Anaconda treble superphosphate.—In 1920 the Anaconda Copper Mining Co. began the manufacture of high-grade superphosphate at its experimental fertilizer plant at Anaconda, Mont. In September of that year, through the kindness of E. L. Larison, superintendent of the company's acid and fertilizer works, the writer was permitted to visit the plant and view its operations. According to Mr. Larison, the normal product is a mixture of monocalcium and dicalcium phosphate in which the P_2O_5 in the monocalcium phosphate content is about 42 per cent and the P_2O_5 in the dicalcium phosphate content about 6 per cent, making a total of 48 per cent "available phosphoric acid."

[62] Waggaman, W. H., The manufacture of acid phosphate: U. S. Dept. Agr. Bull. 144, 28 pp., 1914.

[63] Cited by Gale, H. S., Rock phosphate near Melrose, Mont.: U. S. Geol. Survey Bull. 470, pp. 449–451, 1911.

The process of manufacture includes the following operations:

The raw rock is fed to a Blake crusher and broken to about half-inch pieces. It then passes to driers and thence to a Hardinge mill, where it is ground to pass through an 80-mesh screen, the oversize going back to the mill. The screened product goes into a bin, from which it is taken by conveyers to a battery of three Dorr agitators. Thence the pulp goes to a battery of three Dorr thickeners, as shown in the accompanying flow sheet (fig. 32). From the thickeners the pulp goes to a filter, where it is sprayed, washed, and filtered. The cake, which consists mainly of calcium sulphate, is waste. The filtrate is led back through the third and second thickeners to mix with the pulp. The overflow from the second thickener is piped to the first agitator, where it becomes a part of the fresh mix. The overflow from the first thickener, which contains most of the phosphoric acid generated in the agitators, passes to a storage tank and thence to an evaporator, where it is concentrated to the desired strength. From the evaporator the concentrated phosphoric acid passes to a mixer, where it is mingled with freshly ground raw phosphate rock in the proportion of two parts of acid to one of rock. After the final processes of drying and grinding the product is sacked as a fine gray powder.

Samples of the phosphoric acid used for the final mix and of the tailings, furnished by Mr. Larison, have been analyzed at the laboratory of the United States Geological Survey to determine their content of phosphorus pentoxide and of certain other constituents, particularly vanadium. The results of the analyses are given in Table 77. The metals are reported in the usual form of oxide, though arsenic and vanadium may be present partly as lower oxides.

TABLE 77.—*Partial analyses of phosphoric acid and of tailings in process of manufacture of "Anaconda treble superphosphate"*

[Analyst, J. G. Fairchild]

	Tailings (per cent)	Acid (per cent)
P_2O_5	1. 91	43.65.
SO_3	Not determined	1.82.
As_2O_5	None	1.43.
Cr_2O_3	0. 03	0.29.
MnO	None	0.05.
NiO	do	Not detected.
V_2O_5	do	0.32.
ZnO	Not determined	Trace.
CuO	do	0.14.

Comparatively little of the P_2O_5 is lost in the tailings. The amount present in the acid represents a concentration of 57.2 per cent orthophosphoric acid (H_3PO_4). Thus the extraction of the P_2O_5 from the raw phosphate rock is fairly clean. The SO_3 in the acid corresponds to 2.23 per cent H_2SO_4. Cr_2O_3 is present in small amounts both in the tailings and in the acid. The amount present in the acid represents some concentration, for in a sample of the Paris rock from the mine of the Western Phosphate Co. the Cr_2O_3 amounted to 0.18 per cent. The chromium can probably have no commercial significance. Similarly the presence of MnO in the acid has only scientific interest. The arsenic, like the chromium, indicates some concentration, for previous tests for arsenic in phosphate rock from Idaho have been essentially negative.

The V_2O_5 in the sample cited from Paris was 0.23 per cent, whereas in the acid it proved to be 0.32 per cent, or about 1.4 times the amount present in what may correspond with the original sample of the raw rock. None was lost in the tailings. The acid solution contains all the vanadium present, and there is some concentration of the vanadium. Some of the phosphate rock from Montpelier contains as much as 0.52 per cent

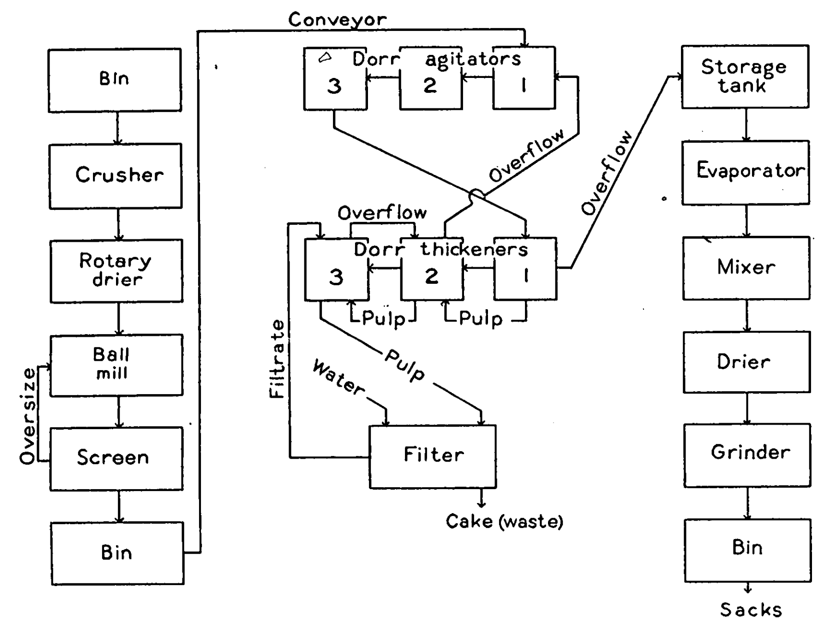


FIGURE 32.—Flow sheet of the Anaconda Copper Mining Co.'s treble superphosphate plant at Anaconda, Mont.

V_2O_5. In view of the relatively low content of some of the vanadium ores used commercially there may be some question of the possibility of the production of vanadium as a by-product in the manufacture of superphosphates. This subject has been discussed by F. L. Hess. (See p. 212.)

No search has been made for zinc and copper in the western phosphate rock, but traces of these metals appear in the above analyses. Possibly these substances may have been derived from the valves and other fittings in the machinery used in making the phosphoric acid.

Electric-furnace process.—The Federal Phosphorus Co., of Anniston, Ala., of which Theodore Swann is president, has developed a process whereby a charge of raw phosphate rock mixed with coke and relatively pure quartz sand is placed between and around the electrodes of a powerful electric furnace. Sufficient air is admitted to the furnace to burn the liberated phosphorus to phosphorus pentoxide. Batteries of these furnaces are operated together, and the resulting fumes pass through cooling galleries to Cottrell precipitators. When the fumes are cooled to a certain temperature they absorb moisture from the air, so that the product is recovered from the galleries and from the precipitators as a highly pure liquid phosphoric acid. The acid is, however, carried through an additional refining process and is marketed in tanks and barrels or manufactured at the plant into a number of commercial salts, including ammonium phosphate, which is mixed with potash to form a complete and concentrated fertilizer.

By adding iron trimmings to the charge in some of the furnaces ferrophosphorus, an alloy used in the steel industry, is produced.

Nonacid fertilizers.—In 1920 the Merriman Potash Products Co. was conducting experiments with the A. L. Kreiss process to make a nonacid fertilizer, using Nebraska potash and Idaho phosphate. These experiments did not lead to successful commercial operations. In October, 1922, the Nonacid Fertilizer & Chemical Co., of Lakeland, Fla., as licensee of this process, began operating a plant near Lakeland that does give promise of commercial success. Local phosphate containing about 60 per cent tricalcium phosphate is mixed with an alkali flux—potassium carbonate—imported from Germany and heated in a rotary kiln to a temperature of about 2,000° F. A clinker, which resembles that of cement and which is said to contain 16 per cent available phosphate and 6 per cent available potash, is formed. This clinker is ground and mixed in any desired proportion with other ingredients to make a complete fertilizer. The phosphate so treated contains no free acid and tends to reduce rather than to increase soil acidity. The plant at Lakeland is said to have a capacity of about 100 tons a day and to have produced "potassium phosphate" at the rate of about 40,000 tons annually.

The possibilities of employing some such process with western phosphate as a means of combating high freight charges do not seem to be exhausted. The presence of sources of potash and of great bodies of phosphate rock in the Western States lends attractiveness to the idea that some means may be devised by which these two valuable ingredients may be combined in a fertilizer cheap enough to compete with present types of fertilizer in the eastern markets.

Experiments by United States Bureau of Soils.—For the past few years scientists of the United States Bureau of Soils have been experimenting with the production of phosphoric acid by volatilizing the acid and collecting the fumes by means of the Cottrell electric precipitator. By such methods it is possible not only to treat relatively low grade material but to obtain a product sufficiently concentrated to permit the expense of long freight hauls and heavy handling. From the account given by Waggaman and Turley [64] it appears that in spite of certain difficulties and limitations in the conditions of experimentation the results obtained are on the whole satisfactory, and the investigation has probably been carried to the point where the commercial feasibility of the process has been demonstrated and its ultimate economic success practically assured.

The furnace used in these experiments is a combination of the open-hearth and blast-furnace types and is heated by two Lalor fuel-oil burners, one at either end of the elongated slag chamber. The charge chamber has a capacity of 700 pounds of briquets composed of ground phosphate rock, sand, and coke. (See U. S. patent No. 1334474, p. 303.) A steel tank that holds 500 gallons of fuel oil is used as the main fuel reservoir, and the oil is fed by gravity to a pump, which forces it to the burners under a pressure of 50 to 200 pounds. The air for the combustion of the fuel is preheated and is furnished by three Leiman positive-pressure blowers. The fumes and gases pass to a dust catcher and thence to three stoves, which are used for burning the combustible gases. From the stoves the gases are led to the Cottrell electric precipitator where the acid is collected. A Monel metal exhaust fan serves to withdraw the gases from the furnace and to discharge them into the precipitator pipes.

In the last part of the final run made with this apparatus the authors cited were able to obtain a volatilization of 97 per cent of the phosphorus pentoxide present in the original charge. The yield of phosphorus pentoxide amounted to 5.56 pounds to the gallon of fuel oil. Estimates of the cost of manufacture of phosphorus pentoxide by the furnace method indicate a cost of $49.83 a ton, or 2.49 cents a pound, as compared with a selling price of 6.25 cents a pound. The cost of producing a ton of phosphorus pentoxide in the

[64] Waggaman, W. H., and Turley, T. B., Investigation on pyrolitic production of phosphoric acid: Chem. and Met. Eng., vol. 23, No. 22, 8 pp. (reprint), Dec. 1, 1920.

form of acid phosphate, as estimated from figures furnished by three large manufacturers, is $81.25 a ton, or 4.6 cents a pound.

The composition of the briquets used in this process has been made the subject of a special study.[65] Various organic and inorganic binders were tried on mixtures of sand, coke, and high-grade washed Florida phosphate, but none of them proved very satisfactory. However, the claylike material which occurs in many of the deposits intimately mixed with the phosphate rock was found to act as a very efficient binder if 8 to 12 per cent of water was present in the final mix. Numerous experiments were also made with Tennessee phosphates. In addition to the binding material the ultimate mechanical composition of the mix was found to depend upon the amount of sand or rock that must be added to obtain the proper ratio of silica to lime in the furnace charge. The fitness of run of mine phosphate for briquetting and subsequent treatment in the furnace must therefore be determined by chemical analysis. The proper ratio of silica to lime, SiO_2:CaO, in briquet mixtures is given as 59:41. Powdered coke, bituminous coal, and peat were tried as reducing agents in these mixtures. The coke gave satisfactory results. The volatile hydrocarbons of the coal decomposed within the briquets and deposited their carbon content, thus giving additional reductive potency to the charge. The peat was less effective.

W. H. Ross and A. L. Mehring are perfecting a process whereby low-grade phosphate and low-grade coal, together with some sand or sandstone and shale, are treated in an electric furnace to produce red phosphorus. The process gives promise of cheap and effective commercial development, but the details are not yet available.

Other processes of phosphate manufacture.—Numerous ways of utilizing phosphate rock to make its content of phosphorus pentoxide more "available" have been suggested, and many patents have been issued that cover different processes and phases of phosphate manufacture. These patents from 1856 to and including 1914 have been summarized by W. H. Waggaman and W. H. Fry.[66] These authors present classified lists of patented processes together with a brief discussion of each list. The earliest patent included in these lists is dated 1856 and provides for the mixture and heating together of feldspar, phosphate of lime, and lime and their treatment with water. The products are a double silicate of aluminum and lime, phosphate of lime, and lime, all insoluble in water; and caustic potash and a little caustic lime soluble in water.

The range and character of the processes described and the number of patents included under each group are shown in Table 78.

[65] Waggaman, W. H., Easterwood, H. W., and Turley, T. B., Briquetting mineral phosphates: Chem. and Met. Eng., vol. 25, No. 11, pp. 517-522, Sept. 14, 1921.

[66] Waggaman, W. H., and Fry, W. H., Phosphate rock and methods proposed for its utilization as a fertilizer: U. S. Dept. Agr. Bull. 312, 37 pp., 1915.

TABLE 78.—*Patented processes for the manufacture of fertilizers from phosphate rock, 1856–1914*

	Number of patents issued
Production of soluble or available phosphates by acid treatment	72
Production of phosphoric acid by combined acid and heat treatment	8
Production of soluble or available phosphates by decomposition with a silicate, alkali, or alkaline earth	37
Use in connection with the iron and steel industries for the production of soluble or available phosphates	17
Production of phosphorus and phosphoric acid by volatilization	20
Production of soluble or available phosphates containing two or more fertilizer ingredients	50
Production of soluble phosphate by electrolysis	4
Enrichment of phosphates	5
Processes and apparatus for the mechanical treatment of phosphate rock and soluble phosphates	13
Production of soluble or available phosphates by miscellaneous processes	20
	246

United States patents issued from 1915 to 1924.—In a general way the classification given in Table 78 is followed in the list of United States patents relating to the manufacture of phosphates issued in the years 1915 to 1924, inclusive, which is given below. Some overlapping in classification is unavoidable. Many of the processes indicated do not appear to be practicable commercially. The interest of the inventors appears to have centered chiefly in attempts either to decompose the phosphate rock, and thus to obtain its content of phosphorus pentoxide in some less bulky or more available form than it has in the raw rock or in the ordinary superphosphates, or to cause the phosphorus pentoxide contained in phosphate rock to combine with some other substance that has value as a fertilizer. These efforts are due on the one hand to the desire to utilize lower-grade material than that ordinarily shipped and on the other to the necessity of meeting high freight rates with either decreased bulk or increased value of shipments. Copies of these patents may be obtained from the United States Patent Office for 10 cents each.

Processes for the production of soluble or available phosphates by acid treatment

1137531, April 27, 1915, G. L. Pratt. Acid phosphate is manufactured by mixing phosphatic dust and acid. The resultant viscous mixture is delivered into a den for initial curing. It is then removed as a dry, friable solid acid phosphate and discharged by gravity into an underlying carrier and transported from beneath the den, without reelevation of the mass, to a point from which it is dumped by gravity into an underlying storage place for final curing.

1313379, August 19, 1919, I. Hechenbleikner. Phosphoric acid is made by treating phosphate rock with a mixture of dilute hydrofluosilicic and hydrofluoric acids.

1383912, July 5, 1921, W. T. Doyle. Acid phosphate is produced by mixing ground phosphate rock and sulphuric acid, storing the mixture for a period, pulverizing the mixture and adding to it pulverulent phosphate rock to take up the free sulphuric and phosphoric acids therein, and removing the steam and fumes from the mixture.

1459124, June 19, 1923, H. A. Webster. Phosphoric rock is powdered, suspended in H_2O, and treated with H_2SO_4, then further diluted with H_2O and heated to above 60° (preferably about 85°).

1461077, July 10, 1923, H. A. Webster. Powdered phosphate rock is introduced into a mixer simultaneously with H_3PO_4 or a quantity of 52° Baumé H_2SO_4 less than that theoretically required to convert all the tricalcium phosphate into monocalcium phosphate, the powder and acid are mixed, and the free H_2O present is eliminated by aerating while hot to produce superphosphate.

1493099, May 6, 1924, C. Bramson. Phosphate rock is treated with H_2SO_4 and the soluble product separated and limed. An alkali sulphate such as Na_2SO_4 is added to the limed and unfiltered material to recover dicalcium phosphate from the monocalcium phosphate previously precipitated with iron, aluminum, and CaF_2 impurities.

1517687, December 2, 1924, A. Voerkelius. Phosphate-bearing materials, such as Algiers phosphate, are treated with HNO_3 to form $Ca(NO_3)_2$ in the presence of K_2SO_4 or other soluble sulphate, thus producing $CaSO_4$ and nitrate of potassium by reaction with the soluble sulphate.

Processes for the production of phosphoric acid by combined acid and heat treatment

1235025, July 31, 1917, Walter Glaeser. Phosphate rock is heated with hydrochloric acid and cooled to about 30° C. The liquid product is then treated with calcium hydroxide to secure amorphous dicalcium phosphate, soluble in ammonium citrate.

1326533, December 30, 1919, S. S. Sadtler. Comminuted phosphate rock is subjected to the action of sulphur dioxide and steam, in a temperature not materially below or greatly above 100° C., to make dicalcium phosphate.

1351672, August 31, 1920, C. C. Meigs. Double superphosphate is made by treating phosphate rock with about one-half the amount of acid used in producing ordinary superphosphate and treating the resulting mass with an excess of a solution of sodium sulphate to produce disodium phosphate. The products of the reaction are filtered, and the free sodium sulphate is separated from the filtrate. The remaining liquid is subjected to crystallization, and the crystals formed are separated, heated to a temperature of at least 100° F., and treated with dilute hydrochloric acid. This solution is used to treat fresh phosphate rock, and the resulting product is dried.

1475959, December 4, 1923, H. H. Meyers. A slurry is formed by adding ground phosphate rock to dilute H_3PO_4 of a strength so low that complete reaction will not be effected without application of heat, and the mixture is heated to complete the reaction and dry the product.

1485406, March 4, 1924, H. H. Meyers. Phosphate rock is wet ground and then acidulated, heated, and dried to produce available phosphate.

Processes for the production of soluble or available phosphates by decomposition with a silicate, alkali, or alkaline earth, with or without furnacing

1137065, April 27, 1915, W. S. Landis. Citrate-soluble phosphoric acid is produced from tricalcium phosphate by mixing finely divided phosphate rock, an alkali-metal salt, and carbon in suitable proportions. The mixture is subjected to heat sufficient to eliminate the acid material from the salt and is then further heated to a temperature high enough to cause incipient fusion or clinkering of the mass. The mixture is then discharged and finely ground.

1158711, November 2, 1915, S. B. Newberry and H. N. Barrett. Phosphate rock is made citrate-soluble by calcining the powdered, insoluble calcium phosphate in the presence of 5 to 15 per cent of an accelerating material, which is volatile at the temperature of calcination and consists of a salt of an alkali metal.

1162802, December 7, 1915, S. B. Newberry and H. N. Barrett. Natural phosphate of lime is pulverized and mixed with an alkali-metal compound, convertible by calcination into an alkali-metal oxide and capable of imparting to the mixture a porous and permeable character. The porous mixture is exposed to heat in such manner as to be penetrated and traversed by a rapid current of hot gases until the alkali metal compound is substantially converted into an oxide with the evolution of its volatile constituents. The calcination is continued until the phosphate is rendered substantially citrate soluble.

1162944, December 7, 1915, S. B. Newberry and H. N. Barrett. Natural phosphate of lime is pulverized and mixed with a compound that contains an alkali metal. The mixture is calcined in contact with a rapid current of hot gases, while it is agitated to present renewed surfaces to heat at increasing temperature, until the alkali metal compound is substantially decomposed with the evolution of its volatile constituents. Finally the calcination is continued at a high temperature until the phosphate becomes substantially citrate soluble.

1163130, December 7, 1915, J. H. Connor. Blast-furnace slag and phosphatic material are mixed with soda ash, all in a fine condition. The mixture is then calcined, and a portion of the phosphoric acid is rendered water soluble.

1172420, February 22, 1916, H. P. Bassett. Feldspathic rock and an acid sulphate of an alkali metal are heated in the presence of a reducing agent to a temperature sufficient for reaction. The fumes given off during this process are made to react upon phosphate rock.

1173303, February 29, 1916, S. B. Newberry and H. N. Barrett. An intimate pulverized mixture of natural phosphate with 5 to 25 per cent of an alkali-metal bisulphate is heated in an oxidizing atmosphere at a temperature of 2,500° to 2,800° F. until the bisulphate is substantially decomposed, with the liberation of sulphur dioxide and oxygen, and the natural phosphate is rendered citrate soluble.

1174176, March 7, 1916, S. B. Newberry and H. N. Barrett. Natural phosphate of lime is calcined with a chloride of an alkali metal and a substance yielding sulphur dioxide at the temperature of calcination.

1194219, August 8, 1916, S. B. Newberry and G. R. Fishburn. Citrate-soluble phosphate is prepared by grinding phosphate rock to pass through a 100-mesh screen, calcining with a reagent to the point of fusion or semifusion, and grinding the calcined product to a powder.

1204238, November 7, 1916, E. S. Bishop. Phosphate rock is made available for plant food by subjecting to a sufficiently high temperature in the presence of steam, a mixture of the rock with a suitable metal chloride and an excess of silica sufficient to combine with the metal of the chloride and with part of the calcium of the phosphate rock.

1229684, June 12, 1917, Vittorio Volpato. Assimilable phosphatic fertilizer is made by roasting a mixture comprising 100 parts of phosphorite, containing about 60 per cent tricalcium phosphate, and about 6 parts of a mixture of 40 per cent dolomite, 25 per cent sodium carbonate, and 35 per cent sodium sulphate, at a temperature of about 750° C., and thereafter treating the calcined mass with water.

1236812, August 14, 1917, J. E. Zilk. An intimate mixture of phosphate rock, coke, limestone, and a flux is heated and rolled under conditions capable of producing the combustion of the coke at a temperature of 1,300° to 1,400° F.

1247059, November 20, 1917, J. E. Zilk. Phosphate rock, coke, limestone, and niter cake are intimately mixed and heated under conditions capable of producing the combustion of the coke at a temperature sufficient to convert the mass into readily crushed nodules, though avoiding such high temperature as would produce complete clinkering of the mass.

1261116, April 2, 1918, R. F. Gardiner. Phosphate rock, pebble phosphate, apatite, alunite, muscovite, orthoclase, and leucite are ground separately to 130 mesh and then mixed and ammonium sulphate added. The mixture is heated at temperatures from 150° to 400° C. until the gaseous decomposition products of the ammonium sulphate are copiously evolved.

1267473, May 28, 1918, Ermenegildo Stoppani. Roasted phosphorite and a roasted alkaline oxygen salt, the salt amounting approximately to one-tenth of the content of calcium phosphate in the phosphorite, are mixed and hydrated.

1281681, October 15, 1918, E. C. Soper. Insoluble phosphatic material is converted into citrate-soluble form by adding thereto water and a suitable salt of an alkali metal to form a liquid or plastic mixture, which is allowed to flow on to a highly heated surface and to form thereon a sheet or layer of uniform thickness. This material, which is quickly dried and rendered porous, is then calcined.

1293220, February 4, 1919, P. M. Shuey. Molten niter cake is mixed with phosphate-bearing material in the manufacture of fertilizer.

1372051, March 22, 1921, F. J. Tromp. Citrate-soluble phosphates are produced from iron or aluminum phosphates by treating them with a caustifiable compound of an alkali metal and lime in the presence of water, this compound not exceeding 4 equivalents reckoned as carbonate to 20 parts of phosphate reckoned as phosphoric pentoxide, and the lime not less than 30 parts reckoned as calcium oxide to 20 parts of phosphate reckoned as phosphoric pentoxide.

1387152, August 9, 1921, Walter Glaeser. Phosphate rock is ground to pass through a 60-mesh screen, mixed with finely divided soda ash, coke, and sand, and heated in the presence of air above a low red heat. The water-soluble phosphate is leached out and carbonic acid gas is passed through the resulting solution. The sodium carbonate thus formed is crystallized out.

1463959, August 7, 1923, B. G. Klugh. Phosphatic material, such as natural phosphate, is electrically smelted together with siliceous flux and carbon or other reducing material to produce phosphorus and carbon monoxide; these are treated with a restricted amount of air to oxidize the solution without appreciable oxidation of the carbon monoxide.

1493100, May 6, 1924, C. Bramson. Addition to 1493099 (p. 302). An excess of lime is added to the washed waste product obtained in purifying crude H_3PO_4 from phosphate rock, and the product is dried and calcined to render it suitable for further treatment with H_2SO_4 to recover phosphate.

1511929, October 14, 1924, H. E. Alcock. A solution of H_3PO_4 to be purified is caused to react with NaOH and Na_2CO_3 The solution of sodium phosphate thus obtained is reacted on with barium sulphide and the barium phosphate formed by this reaction is then decomposed by somewhat less than a chemically equivalent proportion of H_2SO_4.

Processes for the production of phosphorus and phosphoric acid by volatilization

1334474, March 23, 1920, W. H. Waggaman. Phosphorus and phosphoric acid are produced by intimately mixing a finely ground charge of natural phosphates, silica, and a solid fuel, with some suitable binder, pressing the mixture into briquets, charging the briquets into a furnace, volatilizing phosphorus and phosphoric acid from the phosphate minerals contained in the briquets, while converting them into a molten mass by means of burning fuel, and driving off and subsequently collecting the balance of the phosphorus and phosphoric acid contained in the slag by playing flames and hot gases from burning fuel over the surface of the slag.

1360248, November 23, 1920, G. R. Brobst. A mixture of phosphate rock, feldspar, limestone, iron ore, furnace slag, and sodium carbonate is calcined and the volatilized gases are collected by a spray of ammoniated water. The product contains available phosphate and potash. The nitrogen is recovered as ammonium carbonate, a by-product.

1368379, February 15, 1921, W. H. Allen. Phosphoric acid is produced from crushed phosphate rock, sand, and coke, which are fed into a highly heated reaction zone where the phosphorus pentoxide of the phosphate rock is liberated and passes off with the other products of combustion of the fuel. The gases are cooled and the phosphoric acid is recovered.

1497173, June 10, 1924, I. Hechenbleikner. In the production of P_2O_5 and H_3PO_4 from the smelting of a charge containing phosphate rock, coke, and sand in an electric arc furnace, a jet or current of air is introduced substantially at the slag level in the furnace to oxidize the phosphorus and produce P_2O_5.

1497727, June 17, 1924, Federal Phosphorus Co. This patent for an electric method in the production of phosphoric acid has been assigned to the Federal Phosphorus Co. by Bethume G. Klugh. Tricalcium phosphate is reduced by silica and carbon in an electric furnace. The charge is introduced around the electrodes and the vapors are burned while in contact with the entering charge, so as to transfer directly as much of the heat of combustion as possible. The oxidized products then pass through checkerwork regenerators to coolers and electric precipitators. These are in duplicate, and on reversal the air for combustion is preheated in the first regenerator while the hot gases reheat the second regenerator.

1518019, December 2, 1924, R. C. Tolman. A charge of sand, phosphate rock, or similar nonmetallic phosphatic material, and carbonaceous reducing material, such as coke, is incorporated with a relatively small proportion of ferrophosphorus or a similar catalytic metal-phosphorus compound, and the charge is furnaced at a temperature high enough to volatilize a quantity of phosphorus approximately equal to that of the chief phosphatic material under treatment. The metal-phosphorus compound is recovered from the charge and used for continuing the process with further charges.

Processes for the production of soluble or available phosphates containing two or more inorganic fertilizer ingredients

1126408, January 26, 1915, Alfred H. Cowles. Potash feldspar and calcareous phosphate rock are heated together at a temperature at least as high as the sintering point, and the resulting mass is treated with solvents that will not cause insoluble phosphates or aluminates to form. Thus phosphoric acid is separated from the mass. The product contains dicalcium silicate, free phosphoric acid, and a soluble potassium salt.

1127840, February 9, 1915, T. L. Willson and M. M. Haff. Acid phosphate is dried and then ammoniated by adding ammonia gas to it. The product is a dried, ammoniated acid phosphate, substantially free from insoluble phosphate.

1145107, July 6, 1915, T. L. Willson and M. M. Haff. Phosphoric acid and potash are added to phosphate rock to produce a superphosphate with potash. Ammonia gas is then introduced into the mixture in quantities greater than would be sufficient to merely neutralize the acid present.

1146222, July 13, 1915, T. L. Willson and M. M. Haff. Pyrophosphoric acid (produced by boiling ordinary phosphoric acid at a temperature of 209–220° C. or by heating natural phosphate rock with siliceous material in an electric furnace) is added to natural phosphate rock and mixed with it according to present methods of manufacture of ordinary commercial phosphoric acid. The mixture sets in a cake like plaster when dry. Ammonia, which is introduced in the form of a gas, combines with monocalcic phosphate to produce ammonium monocalcic phosphate.

1149330, Agust 10, 1915, C. N. Meriwether. Phosphatic material is pulverized and mixed with a proportion of cold iron. Lime and magnesia salts are added, and the mixture is then heated in a furnace until it fuses. Potash and soda are added to the mixture while it is still fused. Then the whole is allowed to run out and cool and when pulverized it is ready for use.

1191615, July 18, 1916, W. H. Ross and A. R. Merz. A concentrated fertilizer that has the composition $KH_2PO_4+NH_4H_2PO_4$ is produced by treating 1 equivalent of phosphate rock with 10 equivalents of phosphoric acid to form 3 equivalents of calcium monophosphate with an excess of 6 equivalents of phosphoric acid, then adding ignited alunite in such quantity that the sulphate present shall be equivalent to the calcium in the calcium monophosphate, filtering off the precipitated calcium sulphate and adding gaseous ammonia to the filtrate until neutral to cochineal; when with proper concentration the whole mass on cooling becomes solid and consists of potassium and ammonium phosphate.

1166104, December 28, 1915, T. L. Willson and M. M. Haff. A substantially dry fertilizer is prepared, which contains monocalcium ammonium phosphate and a little ammonium phosphate but no free acid.

1196910, September 5, 1916, F. S. Washburn. A fertilizer mixture is produced by mixing commercial calcium cyanamid with ammonium sulphate and adding sufficient acid phosphate to prevent the escape of ammonia.

1214346, January 30, 1917, Anton Messerschmitt. Potassium-containing minerals, mixed phosphates, and basic substances are calcined or smelted and treated while in the heated condition with a substance that contains nitrogen oxide—for example $Ca(NO_3)_2$—to effect a combination of nitrogen with the calcined material.

1232452, July 3, 1917, W. D. Richardson. Material containing calcium phosphate and a fluoride and a potash-bearing silicate rock are mixed with an acid capable of decomposing the fluoride. The insoluble potash in the silicate rock is rendered water-soluble.

1251742, January 1, 1918, Henry Blumenberg, jr. Finely powdered phosphate rock and an ammonium salt are intimately mixed to form ammonium phosphate.

1255829, February 5, 1918, Henry Blumenberg, jr. The finely pulverized calcareous phosphate rock is mixed with acid sludge from oil refineries, the sludge being taken in sufficient quantity to convert all the phosphate rock into phosphoric acid and calcium sulphate. The mixture is treated in an open furnace at a temperature of 350° to 500° C. until all volatile matter is driven off and residual carbon from the hydrocarbonaceous matter is left disseminated throughout the mass in a finely divided state.

1258106, March 5, 1918, R. F. Gardiner. Apatite is ground to a size between 60 and 200 mesh and fused with ammonium sulphate, the temperature being increased to the dissociation point of the ammonium sulphate.

1266198, May 14, 1918, Henry Blumenberg, jr. A fertilizer is produced by mixing ground feldspar, sodium nitrate, and acid sludge containing sulphuric acid, heating the mass to liberate nitric acid from it, and collecting the nitric acid. The mass is heated further to a temperature sufficient to fuse it and produce aluminum, potassium, and sodium sulphates. Calcium phosphate is treated with the nitric acid to form soluble calcium phosphate and calcium nitrate, which are mixed with the fused mass.

1266199, May 14, 1918, Henry Blumenberg, jr. A fertilizer is produced from a fused mass that contains sodium nitrate and tricalcium phosphate.

1272001, July 9, 1918, Guido Borghesani and Giuseppe Stampa. A phosphoric mineral, a potassic mineral, and sodium bisulphate are mixed and heated sufficiently to fuse the mass, which is then cooled and reduced to a powder that contains phosphoric acid and potash soluble in 2 per cent citric acid.

1276555, August 20, 1918, T. C. Meadows. Finely divided glauconite is mixed with water to form a sludge, to which is added commercial acid phosphate. The mixture is digested at a pressure above three atmospheres until monopotassium phosphate and dipotassium phosphate are formed.

1282385, October 22, 1918, A. F. Delacourt. A mixture of phosphate rock, potassium-bearing rock, and free silica is heated only to the point of softening the mass, thereby producing a phosphatic and potassic fertilizer.

1285122, November 19, 1918, Walter Glaeser. A potassium-bearing silicate is heated, suddenly cooled, and ground to pass a 100-mesh screen. This material is mixed with sodium phosphate in the proportion of 100 parts of the silicate to 25 parts of the phosphate and is then heated to a temperature above 1,000° C.

1292293, January 21, 1919, Antonius Foss. Raw phosphates associated with calcium carbonate are treated with sufficient nitric acid to render them soluble. The mass is stirred while in a semiliquid state and simultaneously a current of air is passed through it.

1310080, July 15, 1919, Abraham Henwood. Finely divided phosphate rock, niter cake, and potassium feldspar are mixed in the presence of a definite quantity of water to render the phosphoric acid and the potash soluble and to make innocuous to plant life the fluorides in the phosphate rock.

1350591, August 24, 1920, J. N. Carothers. Calcium phosphate is treated with a concentrated solution of nitric acid that has a nitric acid content of 40 per cent by weight to form monocalcium phosphate and calcium nitrate. Sufficient calcium cyanamid that contains free lime is added to convert substantially the monocalcium phosphate to dicalcium phosphate.

1357120, October 26, 1920, S. S. Sadtler. Calcium monohydrogen phosphate is treated with potassium sulphate. The resulting potassium monohydrogen phosphate is treated with ammonium hydrogen phosphate to form potassium ammonium hydrogen phosphate.

1360401, November 3, 1920, P. C. Hoffman. Calcium cyanamid is treated with concentrated phosphoric acid in such proportions as to convert it into monocalcium phosphate and monoammonium phosphate.

1360402, November 30, 1920, P. C. Hoffman. Calcium cyanamid is treated with dilute phosphoric acid in such proportion as to convert it into dicalcium phosphate and ammonium phosphate.

1367846, February 8, 1921, F. S. Washburn. A new fertilizer is produced, which consists of a mixture of ammonium sulphate, monoammonium phosphate, and a mixed crystalline combination of ammonia with sulphuric and phosphoric acids, the total mixture containing a ratio of phosphorus pentoxide to ammonia substantially as 3 to 2.

1369763, February 22, 1921, H. C. Hetherington and J. M. Brahm. A concentrated solution of phosphoric acid containing at least 60 per cent H_3PO_4 is treated with sufficient gaseous ammonia to form monoammonium phosphate with a slight excess of phosphoric acid. The solution is maintained at a temperature in excess of 105° C. and at a concentration sufficient to promote the separation of the monoammonium phosphate in the solid form, in which it is collected.

Processes for the production of a phosphatic fertilizer containing organic nitrogen

1132171, March 16, 1915, Alexander Dickson. Insoluble phosphates are added to the recovered solids from sewage waste and the like and the mass desiccated at such a temperature as will not destroy the organic constituents of the sludge, the acids of which are thus concentrated and react upon the phosphates and render them available.

1212196, January 16, 1917, G. H. Earp-Thomas. Eel grass is ground and mixed with ground phosphate rock to form a fertilizer.

1212484, January 16, 1917, Emile Herzka. Steffens waste water, osmosis water, and other waste waters from sugar manufactories are concentrated to 55° Baumé and acidified with the quantity of sulphuric acid chemically equivalent to the lime and alkaline content of the waste waters. Calcium superphosphate, nitrogen-containing animal wastes, and sawdust are added and the mixture dried to form a fertilizer.

1254365, January 22, 1918, J. P. Schroeder. Peat is digested with sulphuric acid. Ground phosphate rock is added to neutralize the excess acid. The product is a material rich in available nitrogen, phosphoric acid, and humous matter in the form of a fine dry nonhygroscopic powder.

1275276, August 13, 1918, Egil Lie. A cyanamid, superphosphate material, and water are mixed and allowed to react. The nitrogen of the cyanamid is converted largely into urea compounds.

1279838, September 24, 1918, P. H. Carter. A fertilizer is made by treating niter cake with a tricalcium phosphate in the presence of water. "Fertilizer stick" is subjected to the action of the resultant composition, and the mass is allowed to dry and harden.

1280650, October 8, 1918, Carl Bosch. A fertilizer is produced that contains calcium-urea phosphate and ammonia.

1282805, October 29, 1918, R. F. Gardiner. Calcium chloride and minerals containing potash and phosphoric anhydride are mixed with wood waste like sawdust and heated at a bright-red heat to make a mixed fertilizer that contains available phosphoric anhydride and potash.

1283678, November 5, 1918, J. H. Connor. A fertilizer is produced by digesting potassium-containing vegetable matter, tricalcium phosphatic material, and an alkaline reagent in a vat under steam pressure, and then drawing off the liquor and boiling it down.

1341598, May 25, 1920, P. McG. Shuey. Fertilizer is produced by mixing molten niter cake, phosphate-bearing material, and organic nitrogenous material.

1354719, October 5, 1920, A. C. Bohre. An insoluble phosphate is treated with urea nitrate to produce a fertilizer that contains both soluble phosphate and nitrogen.

Processes and apparatus for the mechanical treatment of phosphate rock and sobluble phosphates

1266730, May 21, 1918, H. A. Webster. Phosphatic material in low-grade phosphatic limestones is concentrated by heating the limestone until a substantial part of the carbon dioxide present has been driven off; finely dividing the burnt rock thus obtained, and suspending the finely divided mass in a moving fluid (moving air currents) to carry away the lighter phosphorus-free particles and to permit the heavier phosphate particles to settle.

1375115, April 19, 1921, Mark Shoeld. Wet precipitated phosphate is dried by having as an ingredient in the mixture a material (H_2SO_4) to prevent dusting.

1434749, November 7, 1922, H. Plausen. Insoluble phosphate material, such as Thomas phosphate meal, is subjected to thorough mechanical disintegration together with humic acid containing material—for example, bituminous brown coal and caustic alkali.

1439054, December 19, 1922, E. H. Armstrong. Acid phosphate is cured by treatment with a rising current of air in vertical towers or chambers through which the acid phosphate descends, followed by similar treatment with unheated air. The mass is subjected to centrifugal action during its downward movements.

1445167, February 13, 1923, H. Plausen. Slag phosphate is ground and then subjected to intensive mechanical disintegration in the presence of a large amount of H_2O acidulated with H_2SO_4 or other acid, with or without heating or use of protective colloids.

1470968, October 16, 1923, S. D. Gooch. A calcium acid phosphate is prepared by subjecting phosphate rock or phosphatic clay in finely divided form to the direct action of P_2O_5 while the material is agitated.

1535120, April 28, 1925, S. B. Kanowitz, Greensburg, Pa., and H. A. Webster, Columbia, Tenn. Kanowitz, assignor to Raymond Bros. Impact Pulverizer Co., Chicago. A method of air separation of high-content phosphate from low-grade phosphate and clay.

Miscellaneous processes for the production of phosphatic fertilizer

1129504, February 23, 1915, Samuel Peacock. A phosphate is heated in the presence of carbon in an atmosphere devoid of free oxygen at a temperature above 900° C. to form a carbide of phosphorus.

1147926, July 27, 1915, W. B. Chisolm. A ground mixture of sulphur and phosphate rock is moistened to initiate the formation of sulphuric acid and phosphoric acid in the mass. After the moistening operation the material is packed tightly to prevent the evaporation of the moisture.

1161473, November 23, 1915, M. M. Haff and T. L. Willson. A phosphatic material is dried and enriched by placing it in a closed container and introducing gas and air under pressure.

1192545, July 25, 1916, C. G. Memminger. Raw phosphatic material containing free silica is heated sufficiently under oxidizing conditions to decompose the calcium carbonate and to cause the calcium oxide thus formed to combine with free silica.

1214008, January 30, 1917, E. Ciselet and C. Deguide. Natural phosphates are made more assimilable by dissolving the phosphate rock in melted calcium chloride and eliminating the calcium chloride by washing.

1222112, April 10, 1917, J. G. Lipman. Finely divided sulphur, phosphate rock, and fertile soil are mixed. The sulphur is oxidized by bacterial action to combine with the phosphate rock and to form citrate-soluble phosphate.

246636, Nolvember 13, 1917, H. H. Meyers. Phosphate rock or other insoluble phosphatic material is converted into available or soluble phosphates by treating the moist phosphatic material with a mixture of gases containing sulphurous and sulphuric anhydrides.

1251741, January 1, 1918, Henry Blumenberg, jr. Ground tricalcium phosphate is subjected to the action of sulphur dioxide in the presence of water to form calcium sulphite and phosphoric acid, which are separated.

1252318, January 1, 1918, Henry Blumenberg, jr. Powdered calcareous phosphatic material is treated with ammonia and carbon dioxide in the presence of water to form calcium carbonate and ammonium phosphate, which are then separated.

1316396, September 16, 1919, W. O. Snelling. A fertilizing explosive is prepared by associating with explosive material small masses of pulverized fertilizing material held together by a cement of low binding power.

1348495, August 3, 1920, C. C. James. A phosphatic fertilizer is prepared from 80 per cent acid phosphate, 15 per cent ground calcium carbonate, and 5 per cent lime (CaO).

1437456, December 5, 1922, E. C. Soper. Phosphate rock is mixed with $NaHSO_4$, 22½ per cent, and ground corn cobs or sawdust, 7½ per cent, and with such a limited amount of H_2O as to leave the mixture in pulverulent condition, and it is then calcined at a temperature of about 1,320°–1,430° to form a fertilizer.

1447544, March 6, 1923, W. Glaeser. Sodium phosphate is formed by treating phosphate rock with a solution containing niter cake and NaCl, heated to about 500°.

1453571, May 1, 1923, E. P. Stevenson. Pebble phosphate initially containing tricalcium phosphate, $CaCO_3$, moisture, and organic materials is heated alone to a temperature of about 1,000°–1,100° to decompose the $CaCO_3$ and cause a substantially complete conversion of the resulting free lime into phosphate. The product is adapted for use as a fertilizer.

1468741, September 25, 1923, S. Peacock. $Ca_3(PO_4)_2$ is reacted upon with six molecular proportions of NaCl at a temperature of about 1,100° in order to form $POCl_3$ and Na_2O. The chloride formed is separated from the oxide and is treated with H_2O to form a mixture of HCl and H_3PO_4, and the latter is separately recovered.

1495270, May 27, 1924, J. M. A. Stilleson. Available phosphate is prepared by treating a nonavailable phosphate with CO_2 and H_2O. A mixture of calcium phosphate and carbonated "lime nitrogen" may be similarly treated.

1504339, August 12, 1924, W. Glaeser. Dicalcium phosphate is reacted upon with sodium binoxalate in the presence of H_2O while the mixture is agitated. The NaH_2PO_4 is separated from the calcium oxalate by filtration and is then evaporated to recover it in solid form.

1504340, August 12, 1924, W. Glaeser. This patent specifies the treatment of phosphate rock or similar phosphatic material with H_2SO_4 and H_2O to produce monocalcium phosphate, followed by treatment of the latter with sodium oxalate to produce NaH_2PO_4.

1513088, October 28, 1924, H. W. Charlton. A fluid mass of phosphate rock and sand is disintegrated and the slag is caused to form matted threads adapted for use as slag wool. P_2O_5 is carried off by air currents and is recovered.

Late foreign patents

GREAT BRITAIN

184206, November 10, 1920, J. G. Williams. Mineral or precipitated $Ca_3(PO_4)_2$ or bone ash is mixed with a solution of sodium, potassium, or ammonium sulphate and the product treated with SO_2. The reaction products are $CaSO_4$ and a soluble phosphate corresponding to the sulphate used, a soluble sulphite being also formed. The formation of sulphite can be avoided if one of the three molecules of sulphate required for the reaction is replaced by one of H_2SO_4, and this may be accomplished, with Na_3PO_4, by the use of niter cake. No sulphite is formed when precipitated $CaHPO_4$ is treated, and in this case the SO_2 can be recovered by heating the filtered reaction liquid. Other acids readily volatile from hot solutions, such as HOAc or formic acid, or CO_2, or H_2S, may replace SO_2.

186223, April 9, 1921, Eisenwerk Ges. Maximilianshütte. Phosphoric compounds suitable for fertilizers are made soluble in citric acid and partly soluble in citrates by intimate grinding with about 1 to 1½ parts of sulphate, chloride, silicate, or nitrate of the alkali or alkali-earth metals, ammonia, or magnesium. Double salts of the alkali metals and magnesium also may be used.

191129, October 1, 1921, L. Adelantado. Phosphates are rendered assimilable by treatment with a neutral sulphate in the presence of H_2O and organic matter at temperatures of 60° to 130°. When the phosphate contains alkaline materials it is desirable to add a small quantity of H_2SO_4. The addition of small quantities of carbonates, if these are not naturally present, is advantageous, since they react with the added acid and so render the mass porous.

191642, February 1, 1922, H. G. C. Fairweather. H_3PO_4, $H_4P_2O_7$, and HPO_3 are obtained by treating phosphatic material, coke, silica, and iron in an electric furnace, oxidizing the liberated phosphorus in the furnace by admitting a regulated quantity of air, cooling the gases, and separating the acids by an electric precipitator or other means. When the gases are cooled to 70°–120° H_3PO_4 of 70 to 80 per cent strength is obtained, at 120°–210° H_3PO_4 of 80 to 97 per cent strength, at 210°–315° $H_4P_2O_7$, and at 315°–400° HPO_3. In each case the H_2O vapor is present in the gases cooled, being introduced in the oxidation air and as moisture in the charge, but additional H_2O may be introduced into the gases.

194208, May 25, 1922, Soc. anon. produits chimiques et engrais L. Bernard. A homogeneous mixture of a phosphate rock, blast-furnace slag, or feldspar is heated with by-products containing alkalies, such as residues from sugar mills or distilleries or wool grease. The residue containing alkalies may be employed as such or may be first calcined and ground. The mixture of the materials may be effected wet or dry, and the heating may be at 900° to 1,300°.

195655, June 28, 1922, Plauson's (parent company) (Ltd.). Phosphates, feldspar, and other raw materials are rendered colloidal for use as fertilizers by high-speed mechanical disintegration in the presence of a large quantity of H_2O and a soluble silicate such as water glass. A small quantity of free alkali or substances, such as carbonates or sulphides, having an alkaline reaction may also be present. Organic colloids, such as sulphite cellulose liquors, tanning agents, proteins, or gums, may be added with the water glass.

215813, January 18, 1923, B. Laporte (Ltd.) and H. E. Alcock. In the production of pure H_3PO_4, acid barium phosphate is prepared from di or tri sodium phosphate (or potassium or ammonium phosphates) and barium sulphide and then decomposed with H_2SO_4.

CANADA

226546, November 28, 1922, A. L. Kreiss. Phosphate rock is fed into a heated drier containing a solution of an alkali metal salt, and the mixture is dried.

228247, January 23, 1923, A. Kelly. Mineral phosphates are roasted to carbonize the organic matter; the latter is then removed by oxidation, and the roasted phosphate treated with an acid to produce H_3PO_4.

JAPAN

41223, December 22, 1921, Ryûichi Hayashi and the Taisei Kwagaku Kogyo Kabushiki Kaishi. Insoluble aluminum or iron phosphate ores are made soluble in citric acid or ammonium citrate. The mineral is put into a heated rotating or muffle furnace and heated for 30 minutes at 400° to 700° according to the condition. Then the contents are quickly cooled by blowing cold air or transporting them through a cooled tube and dissolved in citric acid or ammonium citrate, about 95 per cent being dissolved in the former and about 70 per cent in the latter. From these solutions ammonium, potassium, or calcium phosphates are easily isolated.

41224, December 22, 1921, Sen Kawamura. One hundred parts of powdered iron or aluminum phosphate ore are boiled and then evaporated to dryness with 11 parts of NaOH, 27 parts of $Ca(OH)_2$ and 100 to 150 parts of H_2O. The residue is powdered. By this treatment 77 per cent of the total phosphoric acid is dissolved in 2 per cent citric acid or ammonium citrate. As the product is not hygroscopic it is used for fertilizer and material for manufacture of other phosphates.

41377, January 11, 1922, Chuzo Imaizumi. When 100 parts of $Ca_3(PO_4)_2$ are mixed with 90 to 100 parts of H_2SO_4 of 55° Baumé $Ca(H_2PO_4)_2$ is produced in grains, and the remaining $Ca_3PO_4)_2$ becomes a powder. The two salts can therefore be separated mechanically.

41977, March 14, 1922, Ryûichi Hayashi. Crushed ore of iron or aluminum phosphate is throughly mixed with about 20 per cent SiO_2 and 5 per cent powdered coal and heated at 500° to 700° in a furnace until the coal is burned away; 98 per cent of the phosphate in the product is soluble in ammonium citrate, and it remains soluble during storage.

42273, April 10, 1922, Yoshisaburô Kida. When $AlPO_4$ is decomposed into Na_3AlO_3 and Na_3PO_4 by the action of NaOH a large amount of alkali is consumed. If $FePO_4$ is mixed with $AlPO_4$ the consumption of NaOH is decreased to one-fourth to one-eighth, the product is a mixture of sodium-iron phosphates and sodium-aluminum phosphates.

42304, April 13, 1922, Sadao Yonemura and Kômei Hayashi. Addition to 41056. By heating a mixture of insoluble phosphates and organic and inorganic acids at 200° to 500° during 10 to 20 hours 90 per cent of the phosphates in the product is made soluble in citric acid or ammonium citrate. As acids to be added, $AcOH(COOH)_2$, H_2SO_4, HCl, or some acid salts are used in amounts of 33.5 to 35 parts as AcOH for 100 parts of P_2O_5 in the material.

43205, April 13, 1922, Kômei Hayashi. Insoluble phosphates are made soluble in ammonium citrate by heating with a mixture of 8 to 12 per cent H_2SO_4, HNO_3, or HCl and some salts such as SiO_2, kieselguhr, $(NH_4)_2SO_4$, K_2SO_4, etc., at 250° to 350°. The same change is produced by heating a mixture of insoluble phosphates and 5 to 8 per cent inorganic acid in a vacuum kettle.

42606, May 15, 1922, Yoshisaburô Kida. H_3PO_4 is produced from phosphate ore containing calcium, iron, or aluminum phosphates by treating with H_2SO_4 and extracting with Me_2CO or alcohol; $(NH_4)_3PO_4$ is precipitated by means of NH_3.

44239, December 19, 1922, Ryûichi Hayashi, Kômei Hayashi, Sadao Yonemura, Etsuzo Hosoi, and Kako Kuroki. A powdered mixture of 100 parts of aluminum or iron phosphate and 40 to 50 parts of $NaHSO_4$ is heated at 300° to 400° for 10 to 15 minutes in a reverberatory furnace until the color of the mixture is changed to yellow. The product is soluble in ammonium citrate.

NORWAY

38643, December 24, 1923, Edouard Krebs. A material containing P_2O_5, such as raw phosphate, apatite, etc., is treated with sulphite cellulose waste liquor. The mixture is evaporated and burned.

39076, June 16, 1924, Erling Johnson. The dust or vapor from a thermic or electrothermic process for the production of phosphoric acid is precipitated with other waste gases containing basic compounds, such as cement-kiln gases or ammoniacal gases.

SWEDEN

51749, May 24, 1922, F. Liljenroth. The material is elutriated with phosphoric acid, and the liquid is separated from the insoluble residue. The H_3PO_4 is regenerated by precipitating the dissolved calcium with H_2SO_4 and is partly used for treating further quantities of the materials, while the excess is utilized as such or for the production of soluble phosphates.

54116, March 28, 1923, Aktiebolaget Alkaliverken. Raw phosphate is decomposed by a mixture of HCl and H_2SO_4 obtained by the action of Cl_2 (from alkali chloride electrolysis) upon aqueous SO_2.

55083, September 12, 1923, Aktiebolaget Før Kem. och Elektrokem. Produktion and E. Lustig. Phosphates are reduced by coal or other reducing material. The phosphorus is oxidized by air drawn into the oxidation chamber, which is placed above the outlet for the combustion gases from the furnace. The heat liberated by the oxidation may be utilized for preheating the charge in the furnace or for other purposes.

PHOSPHORUS

The following notes on the manufacture and uses of phosphorus by R. W. Stone [67] are included here to complete the discussion of phosphate rock and its uses.

METHOD OF MANUFACTURE

Phosphorus is manufactured in the United States by two companies, the Oldbury Electro-Chemical Co., Niagara Falls, N. Y., and the American Phosphorus Co., North Third and Dauphin Streets, Philadelphia, Pa. Domestic phosphate rock is used. The following paragraphs on the method of manufacture and uses are abstracted from the Encyclopedia Britannica and chemical dictionaries.[68]

In the electrothermal process of manufacturing phosphorus calcium phosphate (phosphate rock) mixed with sand and carbon is fed into an electric furnace that is provided with a closely fitting cover and that has an outlet leading to a condenser. At the temperature of the furnace the silica (sand) attacks the calcium phosphate, forms silicate, and sets free phos-

[67] Stone, R. W., Phosphate rock in 1917: U. S. Geol. Survey Mineral Resources, 1917, pt. 2, pp. 16-18, 1918.

[68] Thorpe, Sir Edward, A dictionary of applied chemistry, vol. 4, 1913. Rogers, Allen, Manual of industrial chemistry, 1915. Phosphorus: Encyclopedia Britannica, 11th ed., vol. 21, pp. 478-483, 1911.

phorus pentoxide, which is attacked by the carbon and forms phosphorus and carbon monoxide. As phosphorus boils at 290° C. (554° F.), it is produced in the form of vapor, which mingles with carbon monoxide and passes to the condenser, where it is condensed. It is then cast under water. The calcium silicate remains in the furnace in the form of a slag, which may be run off, so that by letting in fresh raw material at the top the action is made practically continuous.

The crude phosphorus is purified by melting it under water and then filtering it through bone black and afterward through chamois leather, or by treating it when molten with chromic acid or a mixture of potassium bichromate and sulphuric acid. This treatment causes the impurities to rise to the surface as a scum that can be skimmed off. Phosphorus is usually marketed in the form of sticks, which are made by conducting the phosphorus from the melting pot through a pipe surrounded by water. It solidifies in the pipe and can be removed as a continuous rod.

PROPERTIES

Perfectly pure phosphorus is a white, transparent, waxy solid, but commercial phosphorus is generally yellowish, owing to its content of allotropic "red phosphorus." At 25° to 30° C. it is soft and flexible, but it hardens when cooled and can then be cut only with difficulty. Phosphorus is nearly insoluble in water, but dissolves in carbon disulphide, sulphur chloride, benzine, and oil of turpentine. Its density at 0° is 1.836.

It is highly inflammable; it takes fire in air at 34° C., burns with a bright white flame, and forms dense white clouds of the pentoxide. When exposed to the air a stick of phosphorus undergoes slow combustion, which is revealed in the dark by a greenish-white phosphorescence.

ALLOTROPIC PHOSPHORUS

Red phosphorus is produced by heating yellow phosphorus to about 230° C. for 24 hours in an inert atmosphere or in closed vessels that are heated to 300° C., when the change is effected in a few minutes. The same form is also produced by submitting ordinary phosphorus to the electric discharge, to sunlight, or to ultra-violet light. As this form does not inflame until it is heated above 350° C., it is manufactured in large quantities for use in making matches. It is usually made by heating yellow phosphorus in iron pots provided with airtight lids, which, however, carry a long pipe that is open to the air. A small quantity of the phosphorus combines with the oxygen in the vessel, and the operation is then practically conducted in an atmosphere of nitrogen, which affords additional safety from explosion. The product is ground under water, and any unchanged yellow phosphorus it may contain is eliminated by boiling it with caustic soda. The product is then washed and dried and finally packed in tin boxes. The red variety is remarkably different from the yellow. It is a dark-red microcrystalline powder, insoluble in such solvents as carbon disulphide and oil of turpentine, and has a density of 2.2. It is stable to air and light and does not combine with oxygen until it is heated above 350° C. in air or 260° C. in oxygen, when it forms the pentoxide. It is also nonpoisonous.

USES

Therapeutics.—There are many medicinal preparations of phosphorus. Owing to its remarkable influence on the growth of bone in young animals, it has been used in the treatment of rickets and osteomalacia. Its most effective use, however, is as a nerve tonic in paralysis agitans, locomotor ataxia, impotence, and nervous exhaustion. It is also a remedy for some skin diseases. The hypophosphites have been recommended as a remedy for pulmonary affections, as the phosphorus in these substances is said to act as free phosphorus without being irritant, and the glycerophosphates are certainly useful to stimulate metabolism. Dilute phosphoric acid is used as a gastric stimulant. It does not resemble phosphorus in its physiologic action and can not be used as a substitute.

Toxicology.—Phosphorus is frequently taken or administered in poisonous amounts, either criminally or accidentally, as it is easily accessible to the public in the form of matches or of vermin pastes. A chronic form of industrial poisoning in the manufacture of lucifer matches is necrosis of the jaw, known as phossy jaw, a localized inflammatory infection of the periosteum that ends with the death and exfoliation of part of the bone.

Safety matches.—Red phosphorus was used for making the well-known safety matches by J. E. Lundstrom, of Jonkoping, Sweden, in 1852. Red phosphorus is in itself perfectly innocuous, and no evil effects arise from freely working the compositions of which it forms an ingredient. The striking surface on the box, and not the match itself, contains the phosphorus required for ignition.

Phosphor bronze.—Bronze is improved in quality and strength when fluxed with phosphorus. The alloys prepared in this way, known as phosphor bronze, may contain only about 1 per cent of phosphorus in the ingot, which may be reduced to a mere trace after casting, but the phosphorus nevertheless enhances their value for use in making implements which require a hard, strong metal, such as pump plungers, valves, and the bushes of bearings.

Signals and screens.—One of the constituents of the material used in distress signaling at sea is phosphorus in the form of calcium phosphide. The dense white smoke that is made by various phosphorus compounds when oxidized is utilized to screen or conceal vessels in danger of attack or whose movements should be hidden and it is also used in trench warfare.

WATER RESOURCES

SURFACE WATER

GENERAL FEATURES

The surface water of the region described in this paper is all collected by two river systems, the Bear and the Snake. The Bear River and its tributaries drain all but a small part of the Montpelier quadrangle and the southwestern part of the Slug Creek quadrangle, including the western slopes of the Aspen and Preuss Ranges, and in addition most of Tps. 8 S., Rs. 41 and 42 E., which receive some consideration in this paper, though they lie for the most part outside the quadrangles mapped. The principal tributaries of Bear River within the areas mentioned are Thomas Fork, Bear Lake Outlet, Montpelier, Georgetown Canyon (Twin), and Soda Creeks, though there are numerous other smaller affluents.

The remainder of the area belongs to the Snake River Basin, although it is not directly touched by that river. The principal tributaries of the Snake that drain this region are Salt and Blackfoot Rivers and Willow Creek. Nearly half the Cranes Flat quadrangle and considerable other territory to the east and north is drained by Grays Lake Outlet, which is a branch of Willow Creek. Besides these streams a small area in the southwestern part of the Henry quadrangle, drained by Tenmile Creek, is tributary to Portneuf River, which is also an affluent of the Snake.

With the exception of portions of Star Valley and of Bear Lake and Bear River Valleys the surface of the region stands at an altitude greater than 6,000 feet above mean sea level. Hence the winters are long and much of the precipitation during half the year is in the form of snow. The average annual snowfall in the broader valleys is over 5 feet (p. 41), and it is probably greater in the mountains, where the snow tends to accumulate. With the arrival of warmer weather during spring and early summer the melting snow greatly increases the flow of all the streams until their maximum discharge is reached, usually in May or June, after which the flow decreases until late in the summer. Fall rains generally increase the flow slightly, but are followed by a further decrease with the arrival of the first extreme cold weather.

In cooperation with the States of Idaho, Wyoming, and Utah, and with the United States Forest and Indian Services and the Utah Power & Light Co., the Geological Survey has maintained for different periods records of gage height and discharge of streams at a number of places within the region here described. With the exception of the records for Grays Lake Outlet the available data are all concerned with Bear and Blackfoot Rivers and their tributaries. Similar data should ultimately be made available for other streams of the region, such as Willow Creek in the Cranes Flat quadrangle, Crow Creek in the Crow Creek quadrangle, and Tincup and Salt Rivers in the Freedom quadrangle.

The available discharge data for the streams named are summarized from the monthly discharge tables that are published in the water-supply papers of the United States Geological Survey and are presented in tables below. For details of discharge measurements, daily and monthly discharge in any given year, the reader is referred to the annual water-supply papers on the surface water supply of the United States. Part X, The Great Basin, gives records on Bear River and tributaries, and Part XII, B, Snake River Basin, gives records on streams tributary to the Snake. In the tables presented the discharge records have been summarized to show in a general way the stream flow which can be expected to prevail for a given month of an average year. Opposite each month is given, first, the maximum daily flow which has been observed for that month during the period covered by the table; second, the minimum daily flow which has been observed for that month during the period covered by the table; third, the mean flow for that month during the entire period covered by the table. Column 4 gives the run-off in acre-feet corresponding to the monthly rates of flow in column 3. The maximum and minimum figures at the bottom of the table are the maximum and minimum daily flows that occurred during the period covered by the table. The mean discharge for the period was obtained by averaging the monthly means for the period of record and not by averaging the mean flows in the body of the table. The run-off in acre-feet for the period is a summation of the quantities in acre-feet in the body of the table. In the preparation of the tables all fractional months were omitted. Also records were not available for several of the stations during the winter months because no records of stage were obtained for these months or because the presence of ice in the stream so disturbed the relation of stage to discharge that reliable computations of daily and monthly discharge could not be made.

BEAR RIVER DRAINAGE BASIN

BEAR RIVER

Discharge.—The course of Bear River and some of its other features have already been described. Gaging stations have been maintained at Evanston, Wyo., at Harer and Dingle, Idaho, in the Montpelier quadrangle and at Alexander, Idaho, in T. 9 S., R. 41 E., about 10 miles west of the Slug Creek quadrangle. As considerable diversions of the river have been made both above and below the Evanston station, its records have little bearing on the discharge of the river in the Montpelier quadrangle. Similarly, the record at Dingle station is affected by diversions above the station for irrigation and by the fact that in the spring of 1911 the Telluride Power Co. began at a point about 2 miles above the station to divert water for storage in a branch of Bear Lake known as Mud or North Lake. This water, which is stored during the spring, is released during the summer, returned to the river about 30 miles above Alexander, and used for development of power at plants below Alexander and for irrigation along Bear River. There are no large diversions within the Montpelier quadrangle above the station at Harer. Some water is diverted for irrigation above the station at Alexander, but the records at these two stations give a fair idea of the discharge of Bear River in the general region here described.

The station at Harer (Table 79) is located in the SE. ¼ sec. 22, T. 14 S., R. 45 E., about three-quarters of a mile north of Harer siding, on the Oregon Short Line Railroad, Bear Lake County, 7 miles by road above Dingle and 14 miles southeast of Montpelier. The drainage area above the station is 2,780 square miles.

TABLE 79.—*Monthly discharge of Bear River at Harer, Idaho, for the periods June, 1913, to September, 1916, and January, 1919, to September, 1924*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
January	360		232	14, 300
February	2, 700		251	13, 900
March	3, 610		608	37, 400
April	3, 770	360	1, 400	83, 300
May	3, 860	340	2, 140	132, 000
June	3, 860	158	1, 710	102, 000
July	1, 850	93	620	38, 100
August	815	83	325	20, 000
September	608	81	286	17, 000
October	886	144	363	22, 300
November	640		370	22, 000
December	460		266	16, 400
The period	3, 860		724	519, 000

TABLE 80.—*Monthly discharge of Bear River at Alexander, Idaho, for the periods April, 1911, to September, 1916, and May, 1919, to September, 1924, except August, 1921*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
January			900	55, 300
February		422	828	46, 000
March	1, 940	380	849	52, 200
April	4, 650	622	1, 550	92, 200
May	4, 520	411	1, 720	106, 000
June	4, 180	521	1, 990	118, 000
July	2, 550	596	1, 250	76, 900
August	1, 840	506	1, 040	64, 000
September	1, 650	415	921	54, 800
October	2, 390	430	782	48, 100
November	1, 260		755	44, 900
December			883	54, 300
The period	4, 650		1, 150	813, 000

The station at Alexander (Table 80) is located in the NW. ¼ sec. 18, T. 9 S., R. 41 E., about half a mile upstream from the post office at Alexander, Caribou County (formerly part of Bannock County), 4 miles above the intake of Last Chance Canal, 6 miles above the plant of the Utah Power & Light Co. near Grace, and 30 miles below the confluence of Bear Lake Outlet and Bear River. The tributary drainage area has not been measured.

QUALITY OF WATER

The only available analysis of water from Bear River is that given by Clarke [69] for a sample collected at Evanston, Wyo. It is unlikely that the character of the water changes much if any between Evanston and the point where the river enters the Montpelier quadrangle. Thus it may be assumed that the analysis given is fairly representative of the character of the water of the river in the region here described.

The analysis as given by Clarke is in ionic form, expressed in milligrams per liter, but this, as he points out, is practically equivalent to parts per million in waters as dilute as that of Bear River. He also presents the analysis in the form of percentage composition. In Table 81 the present writer has rearranged the analysis and included with it another form of statement following that advocated by Palmer [70] and by Rogers,[71] in which the reacting values of the different ions, expressed both by weight and in percentages, are given. This form brings out more clearly the characteristics of the water.

TABLE 81.—*Analysis of water from Bear River at Evanston, Wyo.*

	1. Milligrams per liter	2. Percentage composition	3. Reacting values; weight	4. Reacting values; per cent	5. Reacting values, group totals; per cent
Alkalies: Na+K	8. 2	4. 48	0. 28	4. 1	4. 1
Earths:					
Ca	43. 2	23. 59	2. 15	31. 0	45. 9
Mg	12. 5	6. 83	1. 03	14. 9	
Strong acid:					
SO_4	10. 5	5. 73	. 22	3. 1	5. 1
Cl	4. 9	2. 68	. 14	2. 0	
Weak acid:					
CO_3	96. 8	52. 87	3. 22	44. 9	44. 9
SiO_2	7. 0	3. 82			
	183. 1	100. 00	7. 04	100. 0	100. 0

In columns 3–5 silica has been disregarded, for in such waters it is usually presumed to be present in colloidal form.

In Palmer's system, as elucidated by Rogers, the alkalies or strong bases are designated primary constituents; the alkaline earths are designated secondary constituents; and hydrogen and the metals, the weak bases, are designated tertiary constituents. Salinity

[69] Clarke, F. W., Water analyses from the laboratory of the U. S. Geol. Survey: U. S. Geol. Survey Water-Supply Paper 364, pp. 27, 28, 1914; The composition of the river and lake waters of the United States: U. S. Geol. Survey Prof. Paper 135, p. 184, 1924.

[70] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 31 pp., 1 map, 1911.

[71] Rogers, G. S., The interpretation of water analyses by the geologist: Econ. Geology, vol. 12, pp. 56–88, 1917.

is the property in which the strong acid radicles participate, for these radicles yield salts that retain their saline properties in solution. The weak acids also form salts, but in solution their salts hydrolyze and form bases (hydroxides) whose energy greatly exceeds that of the weak acids. Thus the tendency of such solutions is to become alkaline. In combining these terms, the strong acids in combination with the alkalies induce the property of primary salinity; in combination with the alkaline earths, secondary salinity; and in combination with metals or hydrogen, tertiary salinity or acidity. The terms primary, secondary, and tertiary alkalinity are similarly derived, the combinations being made with weak acids instead of strong acids. Secondary salinity is the property commonly known as permanent hardness, and secondary alkalinity is temporary hardness.

To determine the characteristics of the water whose analysis is stated in Table 81 the values of the different groups are balanced against each other, beginning with the strong acids and alkalies. Thus 4.1 per cent of alkalies is combined with an equal amount of strong acids to make 8.2 per cent of salts that impart the property of primary salinity. The excess strong acid (1 per cent) is combined with an equal amount of the alkaline earths to make 2 per cent of the so-called secondary salts, and so on. The properties of the water as thus derived are indicated in Table 82.

TABLE 82.—*Properties of reaction and concentration of water from Bear River*

[See Table 81]

	Per cent
Primary salinity	8. 2
Secondary salinity	2. 0
Secondary alkalinity	89. 8
	100. 0
Concentration (milligrams per liter)	183. 1

The most conspicuous property of the water as shown in Table 82 is secondary alkalinity or temporary hardness. Secondary salinity is present but is practically negligible.

The water falls in class 3 of Palmer's classification, the class in which the strong acids exceed the alkalies in reacting value but are less than the alkalies and alkaline earths combined. It is, however, very near class 2, in which the strong acids are equal to the alkalies.

GEORGETOWN CANYON CREEK

One of the larger tributaries of Bear River in this region is Georgetown Canyon (Twin) Creek, which emerges from Georgetown Canyon in the northwestern part of T. 11 S., R. 44 E. A station was maintained on this creek from October 23, 1911, to September 30, 1914, when it was discontinued (Table 83). The station was located in sec. 4, T. 11 S., R. 44 E., 50 feet below the power house of the Bear Lake Power Co., 3 miles northeast of Georgetown post office and 4 miles from Georgetown railway station. The stream drains some of the higher portions of the Preuss and Aspen Ranges and has a drainage area of 22 square miles, according to Forest Service records. The station is located in the main canyon of Twin Creek and takes no account of the Left Fork, which in its lower course has a flow perhaps equal to 50 or 60 per cent of that of the main stream. There are practically no diversions for irrigation above the station, but much of the flow is utilized for that purpose farther down.

TABLE 83.—*Monthly discharge of Georgetown Canyon Creek near Georgetown, Idaho, for the period November, 1911, to September, 1914, excepting April to July, 1913*

Month	Mean discharge in second-feet	Run-off in acre-feet
January	28. 7	1, 760
February	29. 3	1, 630
March	27. 7	1, 700
April	32. 0	1, 900
May	63. 6	3, 910
June	81. 4	4, 840
July	49. 2	3, 030
August	41. 3	2, 540
September	37. 3	2, 220
October	33. 7	2, 070
November	32. 3	1, 920
December	30. 0	1, 840
The period	38. 7	29, 400

NOTE.—Throughout the record the gage readings were infrequent, and monthly mean discharge was usually estimated from incomplete data.

SODA CREEK

Soda Creek, another large tributary of Bear River, occupies part of the general region under discussion, but lies outside of the quadrangles mapped. This stream drains the eastern side of the Soda Springs Hills and part of the Blackfoot lava field. Its drainage area has not been measured, but is probably smaller than that of the main fork of Georgetown Canyon Creek, though its flow at the point of measurement is more than 60 per cent greater. A station was established on this creek in March, 1913, and a summary of the records is presented in Table 84. The station is located in sec. 24, T. 8 S., R. 41 E., at George Schmidt's ranch, about a quarter of a mile below his house, 4 miles north of Soda Springs, below the junction of the branches of the creek. Practically none of the water is diverted for irrigation, as it is highly mineralized. The flow is very uniform.

TABLE 84.—*Monthly discharge of Soda Creek near Soda Springs, Idaho, for the period April, 1913, to September, 1924*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
January	75	38	52. 8	3, 250
February	73	40	51. 6	2, 870
March	150	38	57. 7	3, 550
April	324	45	96. 3	5, 730
May	170	52	77. 5	4, 770
June	149	46	70. 9	4, 220
July	128	45	66. 8	4, 110
August	94	45	62. 9	3, 870
September	101	45	61. 1	3, 640
October	104	44	61. 8	3, 800
November	87	44	60. 2	3, 580
December	72	42	55. 2	3, 390
The period	324	38	65. 0	46, 800

BLACKFOOT RIVER DRAINAGE BASIN

BLACKFOOT RIVER

"The head of the Blackfoot," as the expression is ordinarily used, is the junction point of Lanes and Diamond Creeks in Upper Valley, in the Lanes Creek quadrangle, and by extension it is made to apply to the entire Upper Valley district. Blackfoot River drains probably more than half of the Peale Mountains, small areas in the Caribou Range, Little Valley Hills, and Willow Creek lava field, and much of the Blackfoot lava field and of the Blackfoot and Chesterfield Ranges, together with some intervening and adjoining territory

The flow of the Blackfoot and its tributary streams is conserved in the Blackfoot River Reservoir of the United States Indian Service, in the Henry and Cranes Flat quadrangles, and is used for the irrigation of Indian Reservation lands in the vicinity of Fort Hall, Idaho. The capacity of this reservoir is about 200,000 acre-feet.

Gaging stations have been maintained for several years above and below and at the reservoir and at several places farther downstream. For present purposes it seems sufficient to cite only the records for the two stations respectively above and below the reservoir.

The station above the reservoir (Table 85) is located in sec. 9, T. 7 S., R. 42 E., at the bridge on the stage road from Soda Springs to Henry, about 7 miles south of Henry, 13 miles north of Soda Springs, and about 1½ miles above the flow line of the Blackfoot River Reservoir. No large tributaries enter in this distance. There are no diversions of consequence above the station and there is no regulation, so that the records show what may be regarded as the normal flow of the river.

The station below the reservoir (Table 86) is located in sec. 11, T. 5 S., R. 40 E., about 200 feet below the wagon bridge at Rocky Ford Crossing, about 1 mile below the Blackfoot-Marsh dam of the United States Indian Service, and about 12 miles northwest of Henry. The flow past the station consists entirely of stored water from the reservoir and is controlled by gates at the dam. The outlet and spillway of the dam are shown in Plate 61, *A*. As there are no diversions of consequence above the reservoir, practically the entire flow of the river plus the drainage of the marsh which formerly occupied the reservoir site passes by the station, except such water as may be lost by leakage from the reservoir. This leakage was considerable in 1911–1914, when the water level was 12 to 18 feet higher than it was in 1916, but since the water has been lowered to approximately the level in 1916—6,142 to 6,157 feet according to maximum and minimum gage readings at the dam—the leakage has been greatly reduced. The level of the reservoir, 6,111 feet in August, 1914, as indicated on the maps of the Henry and Cranes Flat quadrangles (pls. 2 and 3), is about 50 feet lower than the elevations given for that level for the same month and year by the Indian Service records. at the dam.[72] As there has been no change in the datum used in recording gage heights at the dam, this correction should doubtless be applied in any comparison of water levels obtained by such gage readings with those based on the topographic map.

The drainage area tributary to the station above the reservoir is 360 square miles. That above the lower station has not been measured.

No analyses of the waters of Blackfoot River or its tributaries are available.

TABLE 85.—*Monthly discharge of Blackfoot River above the reservoir near Henry, Idaho, for April to November, 1914 to 1924, except November, 1916, April, 1917, and October and November, 1924*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
April	1, 350	53	360	21, 400
May	2, 060	142	596	36, 000
June	992	38	294	17, 500
July	362	30	131	8, 060
August	182	23	92. 0	5, 660
September	154	24	81. 7	4, 860
October	124	42	90. 7	5, 570
November	180	66	89. 6	5, 330
The period	2, 060	23	220	104, 000

TABLE 86.—*Monthly discharge of Blackfoot River below the reservoir near Henry, Idaho, for the period September, 1908, to September, 1924*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
January	262	12	66. 8	4, 110
February	200	9	95. 8	5, 320
March	735	9	97. 4	5, 990
April	1, 330	8. 6	228	13, 600
May	1, 640	3	335	20, 600
June	1, 440	5	514	30, 600
July	1, 150	78	605	37, 200
August	1, 040	108	564	34, 700
September	756	13	372	22, 100
October	916	12	185	11, 400
November	741	9	96. 7	5, 750
December	522	10	86. 7	5, 330
The period	1, 640	3	271	197, 000

Records are available for two of the tributaries of Blackfoot River, the Little Blackfoot and Meadow Creek.

LITTLE BLACKFOOT RIVER

The Little Blackfoot drains part of Grays Range, Enoch Valley and its surrounding ridges, and the valley west of the northern part of Wooley Range in the Lanes Creek and Henry quadrangles. Its drainage area has not been measured. A gaging station was

[72] U. S. Geol. Survey Water-Supply Paper 393, p. 54, 1916.

established on this stream in March, 1914. The station (Table 87) is located in sec. 10, T. 6 S., R. 42 E., on Skinner's ranch at Henry, a short distance above the flow line of the Blackfoot River Reservoir, about 20 miles north of Soda Springs. A ditch for watering stock diverts water around the station, and a small ditch takes water from the warm springs that enter the river between the station and the reservoir.

TABLE 87.—*Monthly discharge of Little Blackfoot River at Henry, Idaho, for the period April, 1914, to September, 1924*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
January	23	7. 2	13. 1	805
February	26	8. 4	13. 2	733
March	50	9. 2	15. 4	947
April	176	11	39. 0	2, 320
May	177	13	37. 7	2, 320
June	50	10	21. 7	1, 290
July	33	6. 9	17. 7	1, 090
August	32	9. 7	15. 7	965
September	22	9. 3	15. 0	893
October	24	11	15. 2	935
November	25	12	15. 2	904
December	25	8. 7	14. 4	885
The period	177	6. 9	19. 7	14, 100

MEADOW CREEK

Meadow Creek drains parts of the Willow Creek and Blackfoot lava fields and of their inclosing ridges in the southern part of the Cranes Flat quadrangle and adjacent parts of the Henry and Lanes Creek quadrangles. Its drainage area has not been measured, but a gaging station (Table 88) has been maintained upon it for several years. The station is located in sec. 3, T. 6 S., R. 42 E., about 1½ miles northeast of Henry, about half a mile above the backwater from the Blackfoot River Reservoir, and three-quarters of a mile below Pelican Slough. There are no diversions above the gage and there is no regulation. Observations were not made during the winter months on account of ice. Thus the available records are only partial, but they serve to show much regarding the flow of the stream.

TABLE 88.—*Monthly discharge of Meadow Creek near Henry, Idaho, for May to September 1914 to 1924, except May, 1919, 1920, 1922, 1924, and September, 1924*

Month	Discharge in second-feet			Run-off in acre-feet.
	Maximum	Minimum	Mean	
May	408	19	91. 5	5, 630
June	186	2. 1	24. 8	1, 480
July	25	--------	8. 1	498
August	29	1	10. 2	627
September	22	2. 3	10. 2	607
The period	408	1	24. 3	8, 840

GRAYS LAKE OUTLET

The basin drained by Grays Lake Outlet includes a relatively small area in the northern part of the Peale Mountains, part of the western slope of the Caribou Range, and the eastern slopes of the Willow Creek Basin Ridges. Grays Lake, in the upper part of the basin, lies opposite and a few miles west of Caribou Peak, the highest summit of the Caribou Range, but it receives little surface inflow from the adjoining mountains. The lake affords an excellent natural reservoir site from which water is now being diverted to the Blackfoot system. (See p. 324.)

Within the area studied the outlet receives only two tributaries worthy of note—Brockman Creek, which joins it in sec. 29, T. 2 S., R. 42 E., and Lava Creek, which joins it in sec. 13, T. 2 S., R. 41 E. Homer Creek, which has an extended course in the Cranes Flat quadrangle, joins it a short distance north of the boundary of the quadrangle. Grays Lake Outlet itself is tributary to Willow Creek, which it joins in the southern part of T. 1 N., R. 40 E., outside the area studied. The course of the outlet lies chiefly in the broad Outlet Valley, which is mostly lava covered, and the stream occupies a shallow trench in the lava for much of its length. At the southeast end of Outlet Ridge, however, and again below Lava Creek it flows through a canyon.

A gaging station has been maintained on Grays Lake Outlet since April, 1916. It is located in sec. 15, T. 3 S., R. 42 E., about 3 miles below the bridge at the outlet of the lake and 3½ miles west of Herman, Bonneville County. A summary of the available records is given in Table 89.

No analyses of the waters of Grays Lake Outlet are available.

TABLE 89.—*Monthly discharge of Grays Lake Outlet near Herman, Idaho, for May to September, 1916 to 1924, except August and September, 1917, May to July, 1919, and May, 1920 and 1922*

Month	Discharge in second-feet			Run-off in acre-feet
	Maximum	Minimum	Mean	
May	1, 350	10	354	21, 800
June	659	--------	134	7, 970
July	132	8	36. 3	2, 230
August	29	. 5	5. 4	332
September	5. 1	. 6	2. 5	149
The period	1, 350	--------	93. 4	32, 500

GROUND WATER

GENERAL DISTRIBUTION AND AVAILABILITY

No special study of the ground-water conditions in the region here described has been made, but the supply is believed to be abundant, well distributed, and in most places sufficient to meet the needs of residents even if the country becomes much more thickly settled than it is at present. Consideration of this supply falls naturally into a discussion of three types of areas—the mountains, the broader valleys, and the lava country. A special feature is the great abundance and variety of springs, and these springs are considered separately from the areas mentioned.

THE MOUNTAINS

By far the greater part of the region is mountainous, and the rocks which underlie the mountains are complexly folded, faulted, and jointed, so that the ground water conditions are correspondingly complex. The water-bearing beds are fractured or dislocated, so that the water is returned to the surface at many places in the form of springs, which give rise to the streams that are so plentifully distributed. There are few valleys, especially in the higher parts of the mountains, in which such springs are not found. The location of springs in relation to lines of faulting is in some places very striking, as where the Bannock overthrust crosses Georgetown Canyon.

In the Bear Lake Plateau, where surface waters are relatively scarce, the structure and texture of the Wasatch formation west of the Boundary Ridge suggest conditions favorable for artesian water. The valley of Pegram Creek, however, cuts far back into the plateau and probably precludes any considerable development of such waters within the Montpelier quadrangle.

In certain localities the streams sink in the alluvium or débris in the valley bottoms before emerging from their canyons. Some of this water reappears farther down the valleys. The place of final disappearance of the water in a given valley may change with the season or even with the time of day. Thus, in the head of Johnson Creek, T. 9 S., R. 43 E., in the Slug Creek quadrangle, the water was observed to flow alongside the trail from Middle Sulphur Canyon 100 feet or more farther down the valley in the morning, after the cooling influence and restricted evaporation of the previous night, than in the late afternoon of the same day, which had been clear and warm. Practically every valley that is deep enough to contain stream-laid débris almost certainly contains some underflow of ground water which could be made available by shallow wells. Most of the ranches that are located in the narrow valleys or at the mouths of canyons depend upon surface water or springs for their water supplies.

THE BROADER VALLEYS

The principal broader valleys of the region, such as Bear Lake, Bear River, Star, and Thomas Fork Valleys, are occupied by streams that receive lateral tributaries, many of which have alluvial fans at the mouths of their canyons. The underflow from these streams adds to the ground water of the main valleys, and much of their surface water, which is diverted for irrigation, is distributed and absorbed by the soil and thus also becomes part of the ground-water system. The materials of which the valley fill is composed are favorable for the storage of water, and in many of the valleys the water actually comes to the surface locally in marshy areas. Ranches along the foothills derive their water supply mainly from surface drainage or from springs, but those farther out in the valleys must depend upon shallow wells. The supply of water for this purpose appears to be abundant and of suitable quality for domestic use. No attempt has been made in the present study to gather data regarding these wells.

The water table slopes generally downward from the sides of the valleys toward their central areas but is with little doubt somewhat deeper near the margins than in the middle portions. It is probably not deep enough anywhere in these alluvial valleys to require deep wells. On the bench lands which border some of these valleys and which are underlain by older alluvium or Tertiary beds dry farming is practiced. There the water table is somewhat lower, and wells 100 to 200 feet or more deep are necessary to procure water for stock and for domestic use.

THE LAVA COUNTRY

The problem of water supply in the lava-covered areas is more difficult than it is in the mountains or in the broad alluvial valleys. The lava flows are practically horizontal. Soil and alluvial deposits cover them here and there, but the fractured condition of the lava flows described on pages 36 and 325 enables them to drain away water that might otherwise be held in the overlying sediments. For similar reasons springs and surface streams are few. Hence settlers who take up the land in the lava country, unless they are fortunate enough to be located near a stream or spring, must haul water in some places several miles or else they must sink wells into or through the lava to procure an adequate supply.

At the time of the writer's visit in 1916 land in the Blackfoot and Willow Creek lava fields was being rapidly taken for dry farms. Some of the settlers were hauling their water from the Blackfoot River Reservoir, but others had sunk wells. The depth required to reach water was generally greater than 100 feet and in some localities was more than 200 feet.

Ground-water conditions in parts of the Blackfoot lava field were investigated in 1923 by H. T. Stearns, of the Geological Survey. He obtained the logs of 16 wells within that part of the Henry quadrangle south of the Blackfoot River Reservoir, which he used as the basis for drawing contours on the water table in that area. These water-table contours, as reproduced from his unpublished map, are shown in Plate 3. The water level of the reservoir, which in August, 1914, was 6,111 feet and is now somewhat lower, is nearly 100 feet higher than the water table at the north side of China Hat as determined by Mr. Stearns. The descent of the water table from the south arms of the reservoir to China Hat is very steep so that the water must form almost a veritable cascade underground. From that area southward the descent is more gentle. These contours also show that the ground water from the Aspen Range moves westward until it merges with that coming from the north. Then all the water moves southward down the center of Soda Creek Valley, beneath the city of Soda Springs, and finally makes its way into Bear River beyond the limits of the area here described. The logs of the wells utilized by Mr. Stearns are given in Table 90; their locations are given in Plate 3.

TABLE 90.—*Records of wells in the Henry quadrangle, Idaho, October, 1923*

[By H. T. Stearns]

No. of well	Location	Owner	Altitude (barometer)	Depth (reported)	Depth to water (reported)	Soil (thickness)	Basalt (thickness)	Remarks
			Feet	*Feet*	*Feet*	*Feet*	*Feet*	
1	NE. ¼ sec. 15, T. 7 S., R. 41 E.	John Gronewald	6, 215	275	195	5	270	
2	SW. ¼ sec. 13, T. 7 S., R. 41 E.	Levi Hussey	6, 240	230	Dry.	------	------	Considerable quantity of red cinders was encountered. Well not completed because of crevice in bottom. Practically all basalt.
3	NE. ¼ sec. 18, T. 7 S., R. 42 E.	H. T. Burchett	6, 145	30	27	30	------	Dug well.
4	NE. ¼ sec. 30, T. 7 S., R. 42 E.	Charles Rudd	6, 215	291	221	12	279	Driller reported red cinders at 240 (and?) 280 feet.
5	SE. ¼ sec. 25, T. 7 S., R. 41 E.	Harriman & Hussey	6, 210	231	224	5	226	
6	NE. ¼ sec. 27, T. 7 S., R. 41 E.	Andrew Andreason	6, 200	218	190	3	215	Driller reported 9 feet of red cinders at 120 feet and 20 feet of cinders at 180 feet.
7	NE. ¼ sec. 4, T. 8 S., R. 41 E.	George Gorton	6, 175	212	200	4	208	Driller reported red cinders at 80 and 175 feet; mud at 210 feet.
8	NW. ¼ sec. 1, T. 8 S., R. 41 E.	William Sessions	6, 095	128	113	12	116	Driller reported red cinders at 90 feet.
9	NE. ¼ sec. 1, T. 8 S., R. 41 E.	Meadowville School	6, 080	126	112	10	116	
10	SE. ¼ sec. 1, T. 8 S., R. 41 E.	E. S. Bell	6, 040	55	43	10	45	
11	NE. ¼ sec. 1, T. 8 S., R. 41 E.	Eugene Cummings	6, 025	56	44	12	40	Driller reported 4 feet of mud at 50–54 feet.
12	SW. ¼ sec. 6, T. 8 S., R. 42 E.	Mr. Calkins	5, 994	37	22	22	15	
13	NE. ¼ sec. 6, T. 8 S., R. 42 E.	Charles Skinner	6, 140	165	147	7	158	
14	NE. ¼ sec. 5, T. 8 S., R. 42 E.	Mike Harrington	6, 161	168	108	4	164	Red clay at 155 feet; at 160 feet tools dropped 8 feet into soft red material. Small quantity of water at 145 feet.
17	NE. ¼ sec. 7, T. 8 S., R. 42 E.	William Gates	5, 994	25	23	23	2	Dry well.
18	NW. ¼ sec. 8, T. 8 S., R. 42 E.	William Shufeldt	6, 195	135	100	5	130	

The ground-water supply in the lava-covered area south of the Blackfoot River Reservoir has been increased locally by leakage from the reservoir. Since the installation of gages on Soda Creek and at the Blackfoot Dam it has been possible to compare the rate of discharge of Soda Creek in succeeding years and to note the effect of changes in level of the reservoir upon that discharge. Plate 59 shows in graphic form the daily discharge of the creek in second-feet for the period March 5, 1913, to September 30, 1916, and also the variations in level of the Blackfoot River Reservoir within the same period. The length of available record is too short for accurate comparison, but the evidence seems to indicate a diminution of the mean discharge of Soda Creek when the mean level of the water in the reservoir is lowered and an increase in the discharge of the creek when the water in the reservoir stands at higher levels.

The preponderance of the discharge for the years 1913 and 1914 over that for the two succeeding years appears to be greater than would be expected from the differences in mean level of the reservoir in the same time intervals. The discrepancy is perhaps due to unusual conditions of precipitation for the years 1913 and 1914, which are suggested by the sharp peaks in the discharge curves of Soda Creek for these years.

25021—27——22

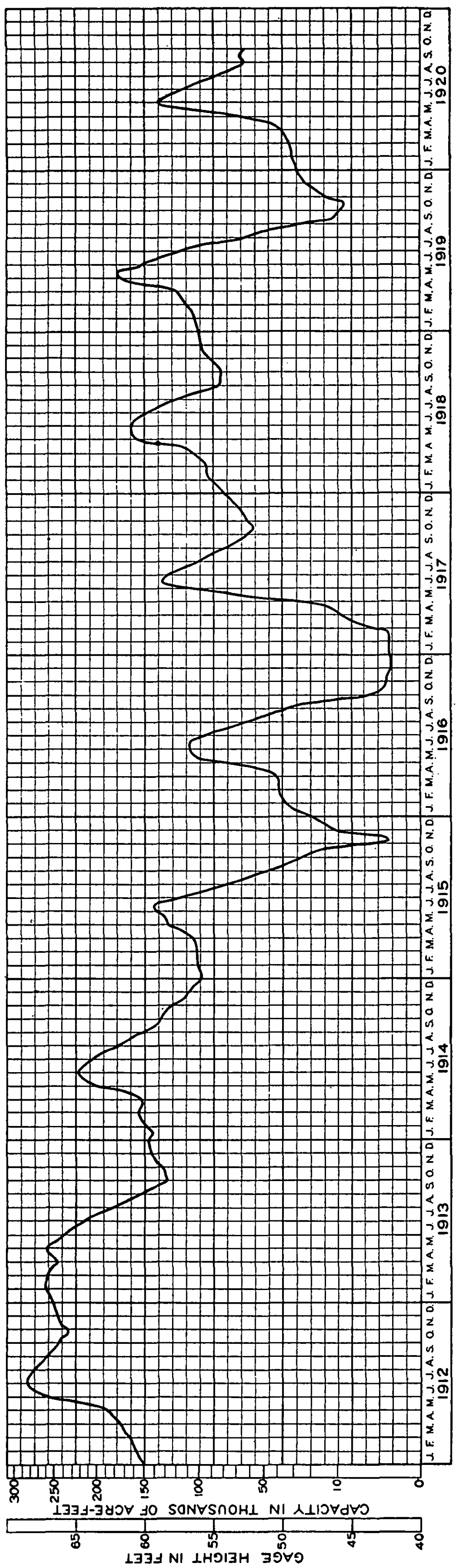


FIGURE 33.—Curve showing the changes of level of the Blackfoot River Reservoir, 1912-1920

The relative uniformity in the flow of the creek may be in part due to seepage from the reservoir.

Figure 33, kindly furnished by W. G. Hoyt, shows the variations in stage and capacity of the Blackfoot River Reservoir for the years 1912 to 1920. The level and capacity of the reservoir are shown to have been unusually low for the years 1915 and 1916, especially for the latter part of those years.

SPRINGS

GENERAL CHARACTER

Most of the springs of the region may be classed as normal. They doubtless contain some mineral matter in solution, but they are not noticeably saline to the taste and they form no mineral deposits. No analyses of their waters have been made. Other springs are mineralized. They contain dissolved mineral matter and dissolved gases under pressure. The gases escape at the surface, and the mineral matter is deposited in different ways. The waters have a noticeable taste, pleasant or unpleasant, according to the substances that they contain. Some of these springs are thermal. Associated with them are vents from which escape gases, but no water. The waters of some of the mineralized springs have been analyzed.

NORMAL SPRINGS

One of the largest springs of the region is that in Swan Creek, Utah, about a mile south of the Montpelier quadrangle and a mile west of Bear Lake. (See pl. 58, *B*.) The water appears to come from a cave at the base of a limestone cliff, but its level has been artificially raised, so that a pool 25 to 30 feet deep conceals the actual opening. The flow from this spring as measured by the Utah Power & Light Co. is about 30 to 35 second-feet in winter but more than 200 second-feet in May. As seen in the pool, the water has a clear blue color. Springs of comparable size occur in Bloomington and Paris Canyons near the west border of the Montpelier quadrangle and apparently emerge from the Bloomington formation. Each of these springs appears to supply the main flow of the creek. Another spring of comparable size occurs in sec. 4, T. 15 S., R. 43 E., in the Montpelier quadrangle, and gives rise to Spring Creek, a short stream that joins St. Charles Creek in section 12 of the same township. On the eastern side of Bear Lake Valley many normal springs flow out along the western base of the escarpment and supply the waters of Meckley Lake and the lake to the north. Other springs furnish part at least of the waters of Mud Lake. Some of these springs that well up from the bottom of the lake are shown in Plate 17, *A*.

The surface flow of the left fork of Twin Creek in T. 10 S., R. 44 E., in the Slug Creek quadrangle, is entirely supplied by large springs in the NW. ¼ sec. 33 (unsurveyed). Above these springs the canyon is dry to the divide. In the neighboring Georgetown Canyon, which has a permanent stream (Twin Creek) for practically its entire length, the flow is greatly increased by the large springs, already mentioned, in the southern part of section 35 (unsurveyed). Numerous other smaller springs occur in this canyon and its tributaries. One of these springs in the NW. ¼ sec. 7 (unsurveyed), T. 10 S., R. 45 E., is rather spectacular. At a place where the road runs nearly due east for a few hundred yards water bursts out on the north side of the canyon about 250 feet above the level of the road and is distributed by a number of irregular streams over a narrow triangular area. Slickensided surfaces of the lower Thaynes near by indicate that the water probably emerges along a fissure in that formation. The flow in ordinary times would approximately fill a 6-inch pipe, but in unusually dry seasons the spring is dry. The spring water deposits small amounts of calcium carbonate and the algae that flourish in its waters color the slope with tints of brown, green, yellow, and red.

The branches of Slug Creek and Trail Creek contain many springs that are sufficiently noteworthy to be shown on Plate 6. The Smith ranch in the vicinity of the common corner of secs. 17, 16, 20, and 21, T. 8 S., R. 43 E., and Smith's ranch in sec. 30, T. 8 S., R. 44 E., are located near springs of large flow in these two valleys.

In the Crow Creek quadrangle the springs in Elk Valley, T. 10 S., R. 46 E., Lone Pine Spring, T. 8 S., R. 45 E., and the springs above Allemans ranch, T. 10 S., R. 45 E., deserve mention. The salt springs in the valleys of Crow and Tygee Creeks are described on page 322.

In the Freedom quadrangle the springs in the lower part of Webster Canyon and branches of Spring Creek, Tps. 7 and 8 S., R. 46 E., are evidently associated with faults. They have deposited some calcium carbonate, which in the form of steps or terraces occupies small areas. (See pl. 5.) Other springs that are worthy of note occur in Smith Canyon, T. 34 N., R. 119 W., in the south fork of Miller Creek, T. 5 S., R. 46 E., and in the South Fork of Tincup River, Tps. 5 and 6 S., R. 45 E. In this fork the valley floor for some distance is occupied by springs and morasses and a small tributary contains a big spring and water hole. These springs likewise are thought to be related to lines of faulting.

In the Lanes Creek quadrangle a number of springs are located in the valley fill of Upper Valley, T. 7 S., R. 44 E., and along the east base of Grays Range, T. 6 S., R. 44 E. The lower dairy in Lanes Creek valley is located near one of these springs.

In the Henry quadrangle normal springs are not so numerous as in the areas previously described. Some are mapped in the valley of Bear Creek, T. 6 S., R. 41 E. Others occur in section 29 of the same township, and at the north end of Crag Lake. Chubb Springs, in sec. 11, T. 5 S., R. 42 E., is one of the well-known springs of the region, and a ranch is located there. The Chubb Springs fault takes its name from these springs.

The Cranes Flat quadrangle contains a number of normal springs sufficiently noteworthy to be shown upon the map. One group occurs along the west base of Little Gray Ridge in T. 5 S., R. 42 E. Others emerge along the west and east flanks of the Little Valley Hills in T. 4 S., Rs. 41 and 42 E. A conspicuous group, presumably connected with faulting, is found in secs. 31 and 32, T. 4 S., R. 41 E. Some appear in the lava country, as in sec. 30, T. 3 S., R. 41 E.; sec. 35, T. 3 S., R. 40 E.; and secs. 35 and 26, T. 2 S., R. 40 E. Still others occur in the Caribou Range, Pine Mountain, and Outlet Ridge.

The Dairy Springs in sec. 31, T. 5 S., R. 40 E. are also large springs, worthy of mention.

MINERALIZED AND THERMAL SPRINGS

TYPES

No sharp line of distinction may be drawn between the so-called normal springs and the mineralized springs. Some of those already mentioned in the discussion of normal springs might, except for convenience of description, be classed as mineralized springs. On the whole, however, the mineralized springs have more readily distinguishable mineral constituents. In this group four types may be described—calcareous, chalybeate or iron-bearing, sulphureted, and saline springs. With the exception of the last, these types might all be included in a group designated as carbonated springs, for they all yield carbon dioxide gas in greater or less quantity. The distinction is made on the basis of additional constituents that are more or less pronounced.

CALCAREOUS SPRINGS

Many calcareous springs occur in the region. They are distinguished by deposits of travertine, and their general distribution has already been given in the discussion of travertine. A number of springs that once deposited large amounts of travertine are not now active, and those that are still active are less effective than formerly. Of those that are still active the largest are Formation Spring in secs. 27 and 28, T. 8 S., R. 42 E., which was described and figured many years ago by Peale[73]; Woodall Spring in secs. 27 and 34, T. 7 S., R. 42 E.; the Swan Lakes in secs. 29 and 30, T. 9 S., R. 43 E.; and the group about the lower end of the Blackfoot River Reservoir, in secs.

[73] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 593-594, 1879

30, 31, and 32, T. 4 S., R. 41 E., sec. 36, T. 4 S., R. 40 E., and sec. 1, T. 5 S., R. 40 E. Another large area that contains calcareous springs lies in the vicinity of Henry, in secs. 8, 9, 10, 16, and 17, T. 6 S., R. 42 E. At this locality there are a number of good-sized springs, one of which is iron-bearing.

In general, the waters of these springs have no noticeable taste and are cool or even cold, but along the courses of their outlets carbonate of lime in some places has recently been deposited. In some, as in the Swan Lakes, the waters are apparently slightly thermal, but the outflow from these lakes is relatively small and the apparent thermal effect may be due simply to the exposure of the water in these lakes to the sun's heat. No study of the temperature in and about these lakes has been made. Formation and Woodall Springs and some of the springs near the foot of the reservoir give rise to considerable streams. The flow of Formation Spring as measured by survey engineers was 23.9 second-feet on June 3, 26.4 second-feet on June 25, 24.9 second-feet on July 17, and 25.4 second-feet on August 30, all in 1923. Similarly the total outflow from the tule lakes at Woodall Springs was 23.5 second-feet on June 1 and 29 second-feet on July 18, 1923.

The structure of the travertine deposits that accompany these springs, where it is still preserved, is that of basins and terraces. (See pl. 60, *A*.) The extent and nature of these deposits indicate the former greater activity of the springs and suggest that they were once thermal.

CHALYBEATE SPRINGS

These springs also have deposited and are still depositing carbonate of lime in the form of travertine, but the structures formed are cones and mounds rather than basins and terraces. Thus the springs were apparently eruptive rather than quietly and steadily flowing. The waters are acidulated and contain sufficient iron to impart an unpleasant taste to the water and to color the travertine more or less vividly with tints of yellow, brown, or red. Some of the springs are thermal. The warm spring west of Henry, sec. 8, T. 6 S., R. 42 E., is of this type. It has built a flat travertine cone, perhaps a quarter of a mile across, that is stained with iron from a deep red to an intense reddish brown. Some carbon dioxide gas is being evolved. The water has an unpleasant taste.

Similar smaller springs and extinct spring cones are found in the NW. ¼ sec., 19, T. 6 S., R. 41 E. There, in a marshy and springy area, stands a group of about 10 spring cones, the largest of which is about 100 feet in diameter, though most of them are only 10 to 15 feet across. The cones are mostly flat, but some are 3 to 5 feet high and 3 feet in diameter. In two of them a small quantity of water is still flowing. It is cold, and there is a slow or spasmodic evolution of carbon dioxide. There is no taste or smell of sulphur, but the water has an unpleasant taste of iron. A similar group of extinct and nearly extinct cones occurs in the NE. ¼ sec. 13 of the adjoining township. (See pl. 60, *B*.)

Another similar spring, somewhat larger, occurs in the NW. ¼ sec. 15, T. 5 S., R. 40 E. The cone here is about 12 feet high and 75 feet in diameter at the base. A pool of carbonated water 13 feet in diameter and 33 feet deep, as determined by soundings, occupies the crater. The water is cool and has a very bad taste and smell, which is in part due to the presence of decaying algae.

In sec. 1, T. 6 S., R. 41 E., there is a fine carbonated spring which has a basin about 20 feet in diameter and 5 or 6 feet deep. The water has an acid taste and a trace of iron, and there is some ebullition of carbon dioxide gas. The little island in sec. 35, T. 5 S., R. 41 E. (pl. 3), is a travertine cone that shows some ebullition of carbon dioxide. It has a small basin about a foot in diameter that contains dirty water. Since the lowering of the surface of the reservoir this "island" has become part of the mainland.

A considerable number of springs of this type occur near the town of Soda Springs and have been described by Peale,[74] who furnishes a map showing the location of many of them, together with analyses and lists of observations on temperature. These springs fall for the most part outside the area here considered.

Steamboat Spring, which is similar in many respects to the springs above described, deserves mention because it shows what these springs must have been like when active. This spring, which was named by Frémont, is on the bank of Bear River about 4½ miles west of Soda Springs. As described by Peale:

> It has a small cone about 2 feet in diameter, rising several inches above the surrounding level. The opening is coated with a bright-red deposit of iron. There is a large escape of carbonic acid gas, which agitates the water so violently that it appears to be boiling. It is thrown about 2 feet at the highest, although this is only at intervals. It is accompanied by a subterranean noise, from which fact it was named. The deposit is hard and almost like porcelain. An analysis is given in Frémont's report, which is quoted below:

Analysis of travertine from Steamboat Spring, Idaho

Carbonate of lime	92. 55
Carbonate of magnesia	. 42
Oxide of iron	1. 05
Silica, alumina, water, and loss	5. 98
	100. 00

> The water is not very agreeable in taste. It is slightly sharp, with a metallic and sweetish taste. Its temperature at 1.30 p. m., when the air was at 80° F., was 88° F. The following day it was 87¾° F. In 1871 the temperature was given as 85½° F. The difference is probably due to a difference in thermometers. The temperature given by Frémont is 87°, showing that there has been but little or no change in temperature. There is a very slight overflow of water.

[74] Peale, A. C., op. cit., pp. 590–596.

Though written nearly 50 years ago this description is still applicable. In the absence of more recent analyses the analysis of travertine quoted above may be taken as showing the general composition of these spring cones.

SULPHURETED SPRINGS

There are three areas worthy of description in which sulphureted springs occur. Only one of these areas actually falls within the limits of the quadrangles with which this report is mainly concerned, but the other two lie just outside and were studied in connection with adjacent territory within. These areas are the Sulphur Springs at the mouth of Sulphur Canyon in T. 9 S., R. 42 E.; the Hot Springs in T. 15 S., R. 44 E., Montpelier quadrangle; and Auburn Hot Springs in T. 33 N., R. 119 W. just east of the Freedom quadrangle. In addition to these springs there are a number of vents from which sulphurous gases escape but which yield little or no water.

Sulphur Springs.—Peale [75] described these springs many years ago in the following words:

A few miles east of the village of Soda Springs at the mouth of a small canyon there is a collection of sulphur springs and a pool or lake, the surface of which is agitated by the escape of carbonic acid gas and sulphureted hydrogen, which fills the surrounding atmosphere. The water is cold and acid in reaction. The earth and stones surrounding are coated with sulphur.

During the present series of investigations these springs were studied in detail by Richards and Bridges, from whose report [76] the following description is chiefly taken. The springs range in size from holes comparable to a washbasin to some that are large enough for a good-sized swimming pool. The milky or cloudy color of the water, which is cold, is due to the presence of free sulphur. The springs are very numerous, and no attempt was made to determine the actual number. Many small ones are concealed in the marsh.

On the south side of Sulphur Canyon, in the SE. ¼ NW. ¼ sec. 13 there are two groups of springs. The surface area of the largest spring of the western group at the time examined was estimated at about 500 square feet. The water is very milky, and a large amount of gas, carbon dioxide and hydrogen sulphide, is discharged both through the water of the spring as bubbles and through the gravel and holes higher on the hillside to a distance of some 150 feet from the spring.

The eastern group is between 300 and 400 feet northeast of the western and consists of smaller springs, in which, however, the gas is discharged with greater force, as is indicated by the greater height to which the water is lifted by the bubbles. The same gases, carbon dioxide and hydrogen sulphide, are liberated by these springs and also through crevices and holes in the ground over an area possibly half an acre in extent. At this place the cementation of the gravel by the deposition of sulphur in the interstices can be seen in process.

The group concealed in the marsh in the SW. ¼ NW. ¼ sec. 13 includes a great number of springs that occupy a zone, 150 feet or more in width, between Sulphur Canyon and the group on the north side. A sample of water taken from one of these springs gave a strong acid reaction with litmus and had the bitter, repulsive taste that is characteristic of the water in all the springs It is remarkable that notwithstanding its taste the horses of the outfit drank this water freely.

The largest of the springs on the north side of Sulphur Canyon, in the NW. ¼ NW. ¼ sec. 13, has an estimated surface area of about 2,000 square feet and is probably the remnant of the lake mentioned by Peale. The water is extremely cloudy, and the deposition of sulphur in the small ditch which takes the overflow can be seen at the present time. E. N. Largillière, of Soda Springs, reports that the best quality of sulphur obtained in this vicinity was taken out of this spring.

Sulphurous vents.—In the SW. ¼ sec. 19 and the NE. ¼ NW. ¼ sec. 30 T. 9 S., R. 43 E., Slug Creek quadrangle, there are vents that emit hydrogen sulphide in considerable quantities. Some travertine at these localities indicates that formerly there was a flow of water from these vents, but at the time of the examination there was none. The rocks about the vents are discolored white to reddish and may easily be seen from a distance from favorable points of view.

In the NE. ¼ NW. ¼ sec. 14, T. 10 S., R. 43 E., on the south side of a small canyon, hydrogen sulphide gas escapes through vents or through interstices in the limestone, which is altered thereby. Native sulphur occurs in crusts and interpenetrating masses in a porous white material like travertine in general appearance, which sounds hollow under the hammer. Some prospects for sulphur have been opened at these places.

In sec. 20, T. 11 S., R. 45 E., Montpelier quadrangle, there appears to be another vent or series of vents approximately on the trace of the Bannock overthrust. This spot was not visited, but as seen from a distance it resembled exactly those in T. 9 S., R. 43 E., described above.

Hot Springs, Bear Lake County.—In the SW. ¼ sec. 13, T. 15 S., R. 44 E., Montpelier quadrangle, a group of hot springs occurs along the base of the escarpment and a few feet above the road. Water from these springs is piped to a modern bathhouse, which contains a swimming pool that is used by residents throughout Bear Lake Valley. There are no large pools, but there is a considerable flow of water that is clear where it emerges and uncomfortably hot to the touch, though algae flourish in it. The water gives forth an odor of

[75] Peale, A. C., op. cit., p. 595.

[76] Richards, R. W., and Bridges, J. H., Sulphur deposits near Soda Springs, Idaho: U. S. Geol. Survey Bull. 470, pp. 499-503, 1911.

hydrogen sulphide and deposits free sulphur on rocks over which it flows. (See Tables 92 and 93, p. 321.)

The two principal springs, which are utilized for the bathhouse, were examined in August, 1914. At the first, 1,100 feet north of the turnpike, the pool, which has been walled in artificially, is only a few feet across and shallow. Water comes up from several places at the bottom. The temperature of the water, taken at 5.30 p. m., as recorded by three thermometers, averaged 48° + C., which is equivalent to about 119° F. A sample of water, consisting of 7 quart bottles, was also taken for analysis. The second spring, 890 feet farther north, is of similar size and apparently similar character, but has a somewhat larger flow of water and a somewhat greater evolution of hydrogen sulphide. About a mile north of the two main hot springs there are several other small springs which have a temperature slightly above normal. In the group as a whole the more southerly springs are warmer.

It is a well-known fact that temperatures within the earth increase from the surface downward, at least in the outer crustal portions that are subject to observation. The rate, however, differs from one place to another and even at different depths at the same place in some localities. In regions of sedimentary rocks the depth required for an increase of 1° is ordinarily greater than in regions of relatively recent volcanic activity. The curve of temperature increase is also more regular in the former type of region than in the latter. Thus in West Virgina, according to Darton,[77] the rates in some of the deep wells range from 56 feet to 101 feet for 1° of increase in temperature. In southwestern Idaho, on the other hand, in a region of volcanic rocks, the rate of change is much more rapid and ranges from 9½ feet for 1° in one locality to 30 feet for 1° at another locality.

In southeastern Idaho, where the rocks are sedimentary and yet not many miles removed from igneous areas, it would be expected that an intermediate rate between the extremes above cited might obtain. According to C. E. Van Orstrand,[78] 45 feet to 1° would be a reasonably safe assumption.

The mean annual temperature of the region is about 41°, so that the excess of temperature in the hot springs, or the difference between 119° and 41°, is 78°. On this assumption the waters would have risen from a depth of about 3,500 feet.

Auburn Hot Springs.—In the E. ½ sec. 23, T. 33 N., R. 119 W., there is a group of hot springs about 2½ miles north of the village of Auburn and just east of the boundary of the Freedom quadrangle. There are three large oval or rounded pools, 75 to 100 feet across, besides numerous smaller pools. The two more northerly large pools lie within 100 feet of each other and the third is perhaps 200 yards farther south. The middle pool is the hottest, and water is taken from it to supply the neighboring swimming pool. Travertine deposits surround the springs. The water has some taste of hydrogen sulphide in addition to a distinctly saline taste that is due largely to the presence of common salt. There is a rapid evolution of gas, probably a mixture of carbon dioxide and hydrogen sulphide, from many local centers in the pools, and in the travertine mounds between the two upper pools there are numerous tiny and larger openings, from which water escapes and gas is evolved. There is also an efflorescence of sulphur at favorable places.

Travertine mounds lie about a mile south of the springs in the same general line with them and with other travertine mounds that lie to the north of them. A few small sulphureted springs also lie along the road on the same line. The travertine mounds and sulphur springs are probably related to the Freedom and Hemmert faults.

Temperature observations were made in the three larger pools and in some of the smaller springs between the upper two. The results of these observations are set forth in Table 91. The time allowed at each reading for the thermometer to come to the maximum temperature was 3 minutes.

TABLE 91.—*Observations of temperature at Auburn Hot Springs, Wyo.*

[E. H. Finch, observer, Oct. 8, 1914]

Field No.	Description of locality	Degrees centigrade
1	South end of middle pool on bottom at depth of 3 feet and 6 feet from shore; water quiescent; temperature of atmosphere in sun, 72° F	34
2	East end of middle pool; same conditions in water and atmosphere	34½
3	Aperture 6 inches, 20 feet north of large pool; water bubbling from south side of cone; same atmospheric conditions as above	34
4	Top of small cone 4 feet north of locality 3; bubbling period about 5 minutes; 4-inch vent	55
5	Irregular pool 5 feet northwest of locality 4; two readings	30
6	6-inch hole with water slightly bubbling; 18 feet northwest of locality 3	50½
7	3-foot pool, violently bubbling; 15 feet northwest of locality 6	22
8	Triangular pool just north of large middle pool, roughly 20 feet on each side, steaming and violently bubbling; reading at center of pool on bottom; same reading in a mass of bubbles above bottom	47
9	Cone 3 feet high just south of large upper pool; three vents; one at top violently bubbling, not intermittent	50
10	Vent 2 inches in diameter 1 foot south of top; too hot for the hand	61
11	Vent about same size 1 foot north of top	48
12	1-foot hole with 5-foot basin; westernmost bubbling pool from large middle pool	54
13	South side of upper large pool 8 feet from shore	22¼
14	Small pool 1½ feet in diameter 5 feet south of large pool; bubbles periodically	58

[77] Darton, N. H., Geothermal data of the United States: U. S. Geol. Survey Bull. 701, pp. 36-37, 89-95, 1920

[78] Personal communication.

The lowest temperature reading is that at locality 7, which is 22° C., equivalent to about 72° F., or just about the temperature of the air when the observations were taken. The temperature of the other pools measured ranges from 22¼° at locality 13 to a maximum of 61° C., or about 142° F., at locality 10. Upon assumptions similar to those made in the discussion of the hot springs at Bear Lake the waters of the Auburn Hot Springs should have risen from depths that range between 1,400 and 4,500 feet.

A 9-quart sample of water was taken from the middle pool for analysis.

Comparison of waters of hot springs.—The analyses of the waters of the Hot Springs in Bear Lake County, and of Auburn Hot Springs are given for comparison in Table 92, in which the ionic form of statement is followed by statements of reacting values expressed both in weight ratios and percentages, according to Palmer's system.

TABLE 92.—*Analyses of waters from Hot Springs, Bear Lake County, and Auburn Hot Springs, Wyo.*

[Chase Palmer, analyst]

	A. Hot Springs, Bear Lake County				B. Auburn Hot Springs			
	Parts per million	Reacting values			Parts per million	Reacting values		
		Weight ratios	Per cent	Group totals; per cent		Weight ratios	Per cent	Group totals; per cent
Alkalies:								
Na	149	6.48	8.3	10.4	1,314	57.16	29.2	30.7
K	41	1.05	2.1		114	2.92	1.5	
Earths:								
Ca	213	10.63	14.5	39.5	431	21.51	11.1	19.5
Mg	221	18.17	25.0		97	18.17	8.4	
Metals: Fe	2	.11			Trace.			
Strong acids:								
SO_4	797	16.58	23.0	27.1	1,904	39.60	21.7	48.2
Cl	92	2.59	4.1		1,725	48.65	26.5	
Weak acids:								
HCO_3	1,030	16.89	23.0	23.0	154	2.53	1.4	1.6
H_2S	Trace.				Trace.			
SiO_2	26	[a].68			20	[a].52		
	2,571	73.18	100.0	100.0	5,759	191.06	100.0	100.0

[a] Computed as SiO_2.

In all such analyses the sum of the reacting values (weight ratios) of the positive radicles should equal the sum of the reacting values of the negative radicles. Discrepancies of balance in these two sums are due either to errors in analysis or to the presence of some undetermined radicle. In the two analyses given above the errors amount, respectively, to 0.4 and 4.4 per cent. In the computation of the reacting values on the percentage basis, Palmer's "character formula,"[79] these errors have been distributed proportionally in the manner suggested by Rogers[80] and the iron and silica have been disregarded.

The properties of the two waters, as derived from the columns representing the group totals of the reacting values in Table 92, are shown in Table 93, in which the concentration of the waters is also indicated.

TABLE 93.—*Properties of reaction and concentration of waters from Hot Springs, Bear Lake County, and Auburn Hot Springs*

	Hot Springs, Bear Lake County	Auburn Hot Springs
Primary salinity ......per cent..	20.8	61.4
Secondary salinity ......do....	33.4	35.0
Secondary alkalinity ......do....	45.6	3.2
Tertiary alkalinity ......do....	.2	.4
	100.0	100.0
Concentration ......parts per million...	2,571	5,759

[79] Palmer, Chase, op. cit., pp. 10–11.
[80] Rogers, G. S., op. cit., pp. 66–68.

Both waters fall in class 3 of Palmer's classification; that is, in each analysis the reacting value of the strong acids exceeds that of the alkalies but is less than that of the alkalies plus the alkaline earths. B, however, is very close to class 4, in which the reacting value of the strong acids is equal to that of the alkalies plus the alkaline earths.

Although theoretically in the same class, the waters of the two sets of springs show a number of notable differences. Both waters have nearly the same percentage of secondary salinity or permanent hardness, about 35, but as the concentration of B is more than double that of A the actual quantity of mineral matter present is correspondingly greater.

Primary salinity is a well-defined characteristic of A, but its principal property is secondary alkalinity or temporary hardness. In B, on the other hand, primary salinity overshadows all other properties, and secondary alkalinity, though present, is practically negligible.

An interesting feature of B is the relatively large percentage of the chloride radicle as compared with A. Whether this is an original property of the water at depth or an acquired property gained from contact with salt-bearing beds or solutions nearer the surface is an interesting problem. (See p. 340.) Another suggestive contrast in the two waters is the greater magnesium content of A.

SALINE SPRINGS

Saline springs occur at intervals along the general line of Crow, Tygee, and Stump Creeks in the Crow Creek and Freedom quadrangles. These have been described by Breger,[81] from whose description the following account is partly taken.

Most of the springs occur in valley bottoms in barren patches of stony clay or gravel, which are rendered soggy by the content of brine. These salty places may be recognized at a distance by their gray color; in some of them a little salt incrusts the barren surface. As a rule the springs have been artificially enlarged to holes that differ in size but that are not smaller than 3 or 4 feet in diameter and about 3 feet in depth. These holes soon fill with water which is so saturated with salt that it commonly has a sirupy consistency or appearance when dipped up.

The brine from these springs was formerly boiled to produce salt, but of late years there has been little activity in this direction.

The southernmost spring is in the NE. ¼ NE. ¼ sec. 26, T. 10 S., R. 45 E., in White Dugway Canyon in the Preuss sandstone. The water has a slight salty taste, and the white incrustation that surrounds the spring has a strong and somewhat bitter salty flavor. Another spring, formerly owned by John W. Booth, of Afton, occurs in the NE. ¼ NE. ¼ sec. 14 of the same township. When visited by the writer in 1911 there were two brine pits here, one 8 feet square and 3 feet deep, which contained brine and also showed incrustations of salt 2 or 3 inches thick, and the other about 6 feet by 18 feet, which was partly logged in and covered with salt but contained little brine.

The springs in the NE. ¼ NE. ¼ sec. 28, T. 9 S., R. 46 E., opposite Lowe's ranch, which are owned by John W. Booth, are perhaps the most valuable of all. When these springs were deepened in 1902 a bed of rock salt was encountered 6 feet below the surface, which was said to have been penetrated to a depth of 20 feet without reaching the bottom. When visited by the writer in 1914 there were two pits, one of which had been fitted with a derrick. The pits were not being worked at that time and were filled with water, so that the salt bed was concealed. A tunnel had been started on the hillside near by and some track had been laid, but no other salt bed had been discovered. When the pits are being operated the water is removed in barrels by means of the derrick and horse power.

The Draney Spring, in Tygee Valley, in the SE. ¼ sec. 16, T. 8 S., R. 46 E., as seen in 1914, apparently had not been operated for some time. Near the mouth of Tygee Creek, in the NE. ¼ sec. 33, T. 7 S., R. 46 E., there is another spring and salt works, which were owned and formerly operated by Soren Petersen of Auburn. The McGrew Spring, about half a mile northwest of the junction of Tygee and Stump Creeks, about on the line between sections 27 and 28 of the same township, and the Reed Spring, near the center of section 21, had been recently worked at the time of the writer's visit. The methods of operation are described on page 339. The old Stump and White Springs, in section 6 of the same township, have not been worked for many years.

No analyses of the brines from these springs are available, but analyses of the rock salt and of the commercial salt boiled from one of the Stump Creek brine springs, show that the original brines had much in common with the waters of the Auburn Hot Springs, being high in strong acids, chiefly chlorides, and in primary salinity and low in weak acids and secondary alkalinity. The chief differences are the great preponderance of the chloride over the sulphate radicle in the brines and their much lower content of the alkaline earths.

These saline springs all lie along the fault zone of the Bannock overthrust, and it seems highly probable that the springs bear some definite relation to that zone. Wildcat drilling for oil in Tygee Valley in recent years has disclosed the presence of several salt beds. Similar salt beds are, with little doubt, the source of the salt contained in these springs.

UTILIZATION OF WATER

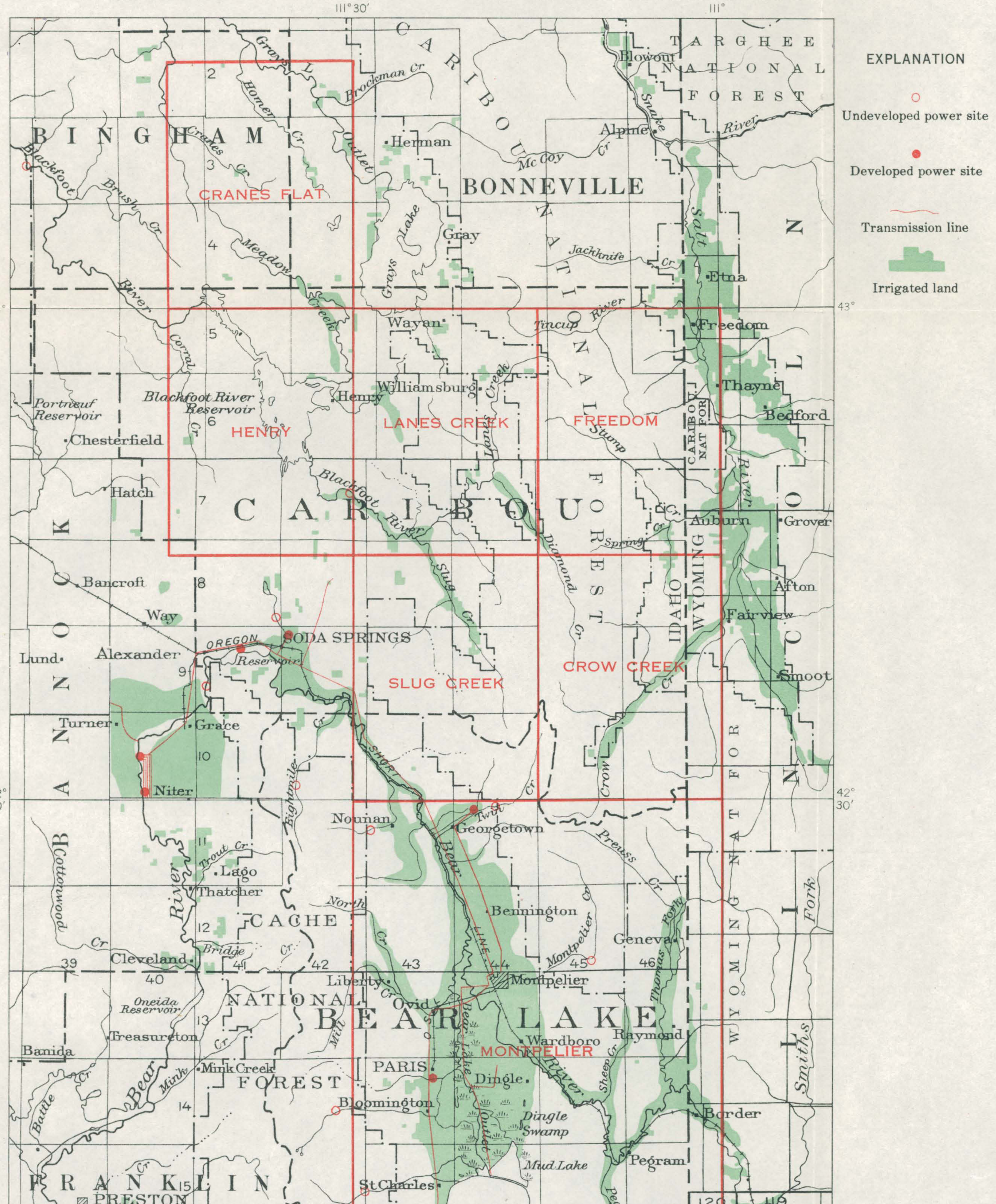
DOMESTIC USE

The mountainous portions of the region are, in general, well provided with water that is available for domestic use and for watering stock, and the future needs of the region will hardly require any extensive development of water for these uses in the more rugged areas. Ranches along the foothills can ordinarily procure sufficient supplies from springs or surface streams.

In the broader valleys and in the lava country most ranches must depend on wells that range in depth from perhaps 30 feet in the gravels to as much as 300 feet in the lava. The quantity available is believed to be ample and the quality excellent.

The cities of Montpelier and Soda Springs have developed water-supply systems by which water is impounded in reservoirs and delivered by pipe lines. The water for Montpelier comes from Montpelier Creek, and measures have been taken to protect the watershed from pollution. Soda Springs uses ground water from springs or wells located about 1½ miles to the north.

[81] Breger, C. L., The salt resources of the Idaho-Wyoming border, with notes on the geology: U. S. Geol. Survey Bull. 430, pp. 555–569, 1910.



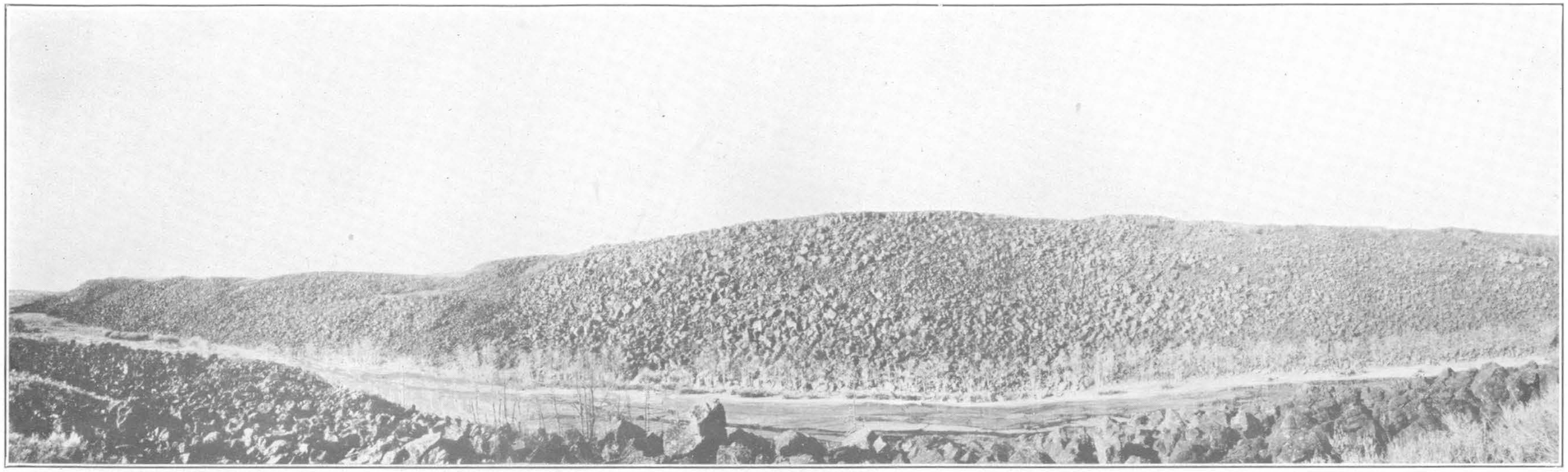
MAP SHOWING IRRIGATED LAND AND WATER-POWER SITES IN SOUTHEASTERN IDAHO

Compiled by W. G. Hoyt and associates.

0 10 20 30 Miles

1927

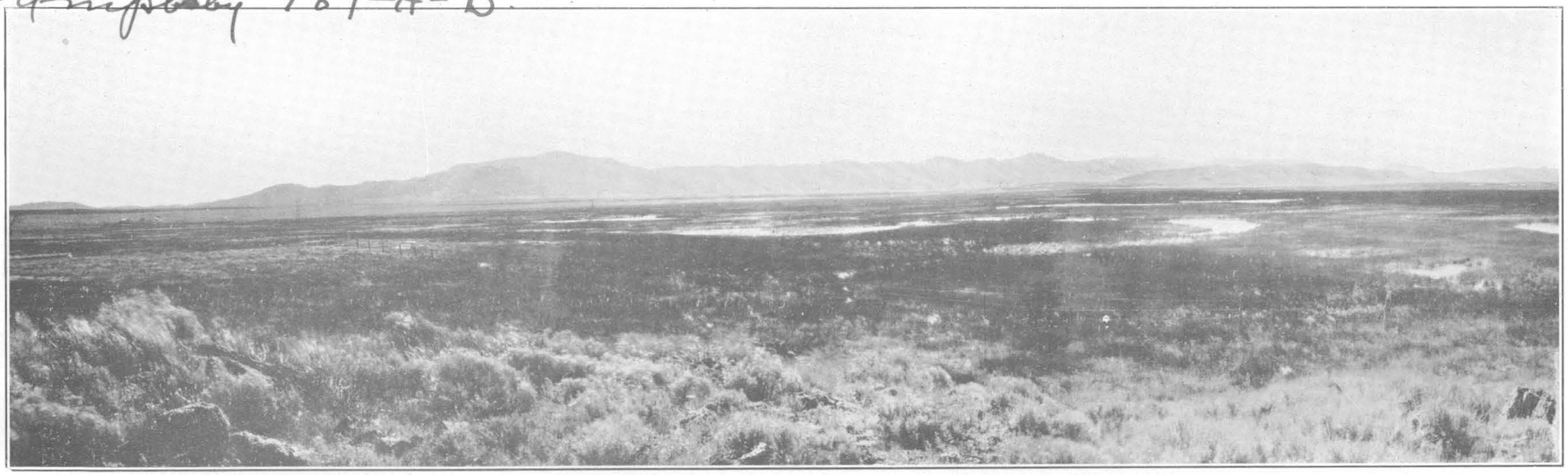
Roundy 67-69.



A. EAST SIDE OF CRAG LAKE, HENRY QUADRANGLE

Showing wall of basaltic débris and succession of basaltic flows together with former higher water levels and mud filling of Crag Lake

Umpleby 187-A-B.



B. UPPER (FIVEMILE) MEADOWS, T. 8 S., RS. 41 AND 42 E.

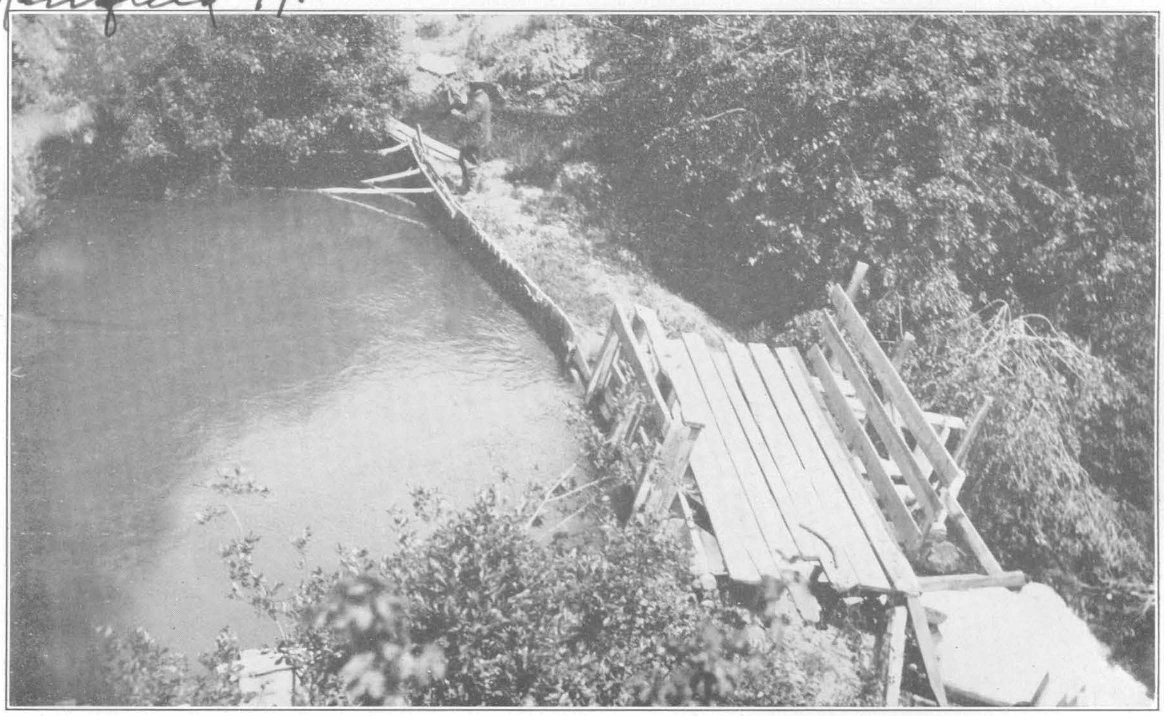
Looking east. Note windmill in area now flooded but formerly good hay land

Umpleby 183.

A. SMALL DAM AT LOWER END OF UPPER (FIVEMILE) MEADOWS, SEC. 13, T. 8 S., R. 41 E.

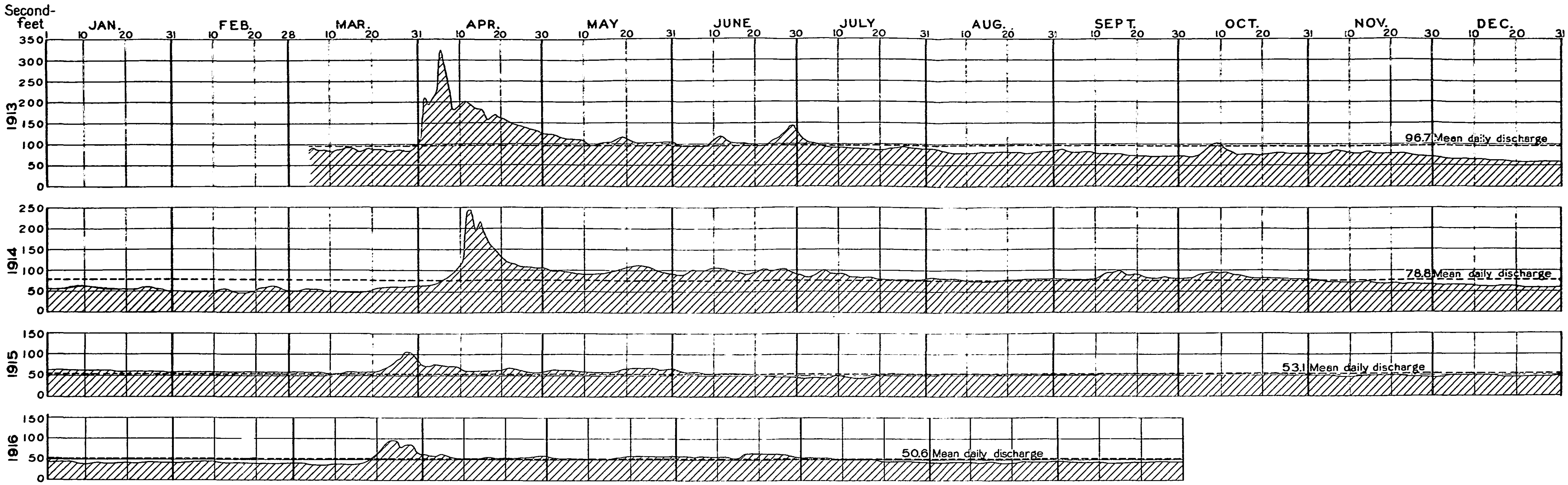
Now breached but formerly used for holding spring flood waters

Mansfield 99.

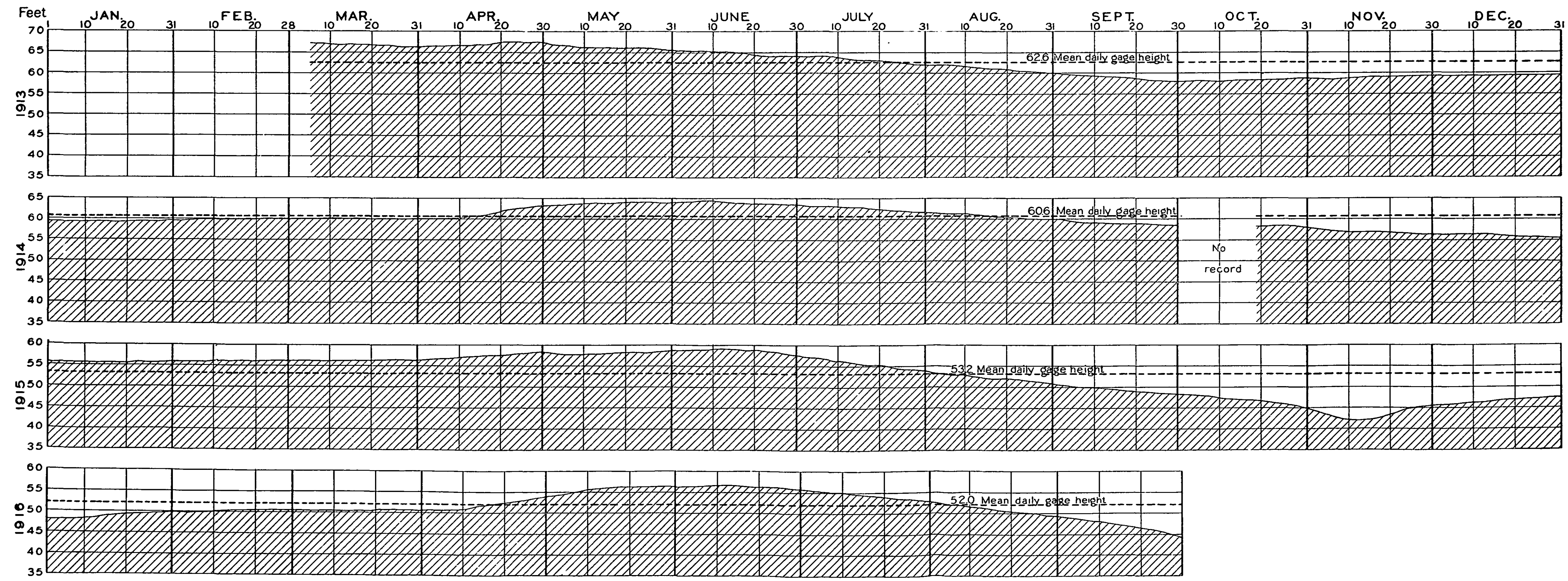


B. LARGE SPRING IN LOWER SWAN CREEK, UTAH

About three-quarters of a mile west of Bear Lake and 1 mile south of the Montpelier quadrangle



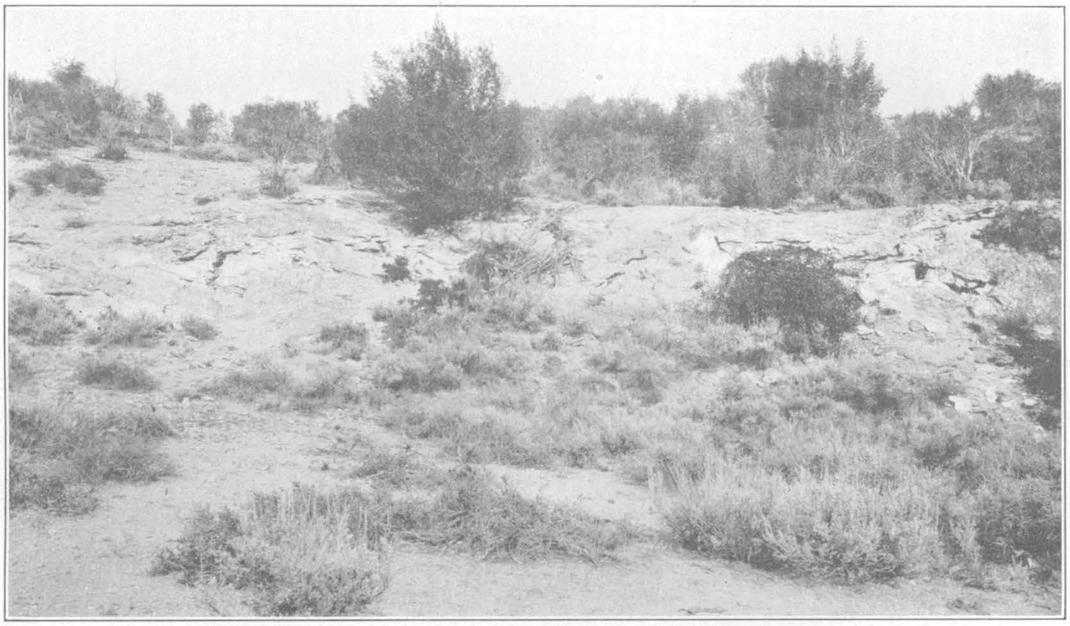
A



B

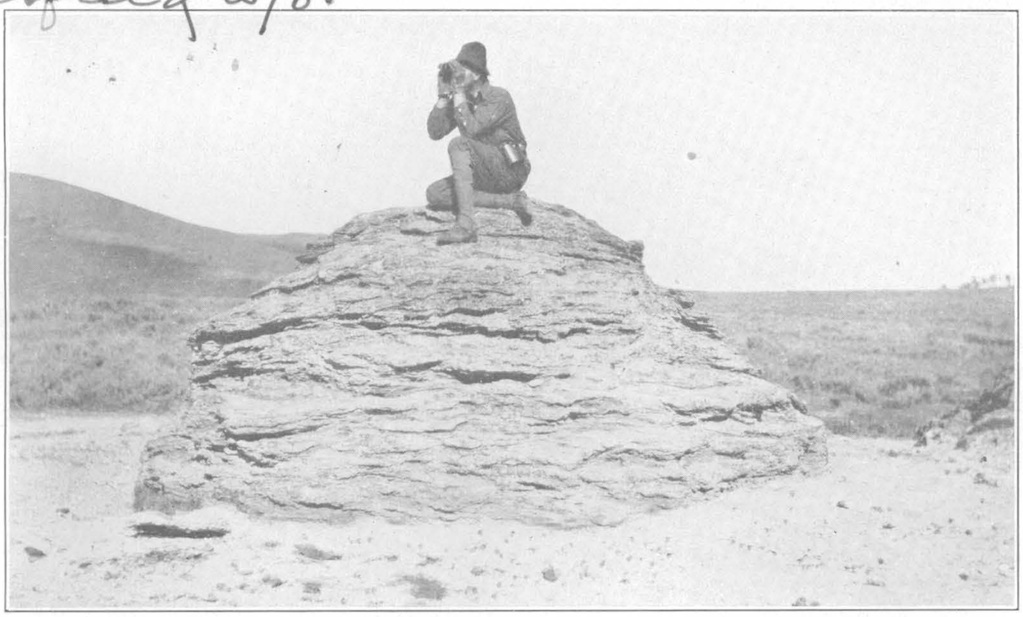
CURVES SHOWING DAILY DISCHARGE OF SODA SPRINGS CREEK (A) AND DAILY GAGE HEIGHT OF THE BLACKFOOT RIVER RESERVOIR (B), 1913–1916

Mansfield, 16.



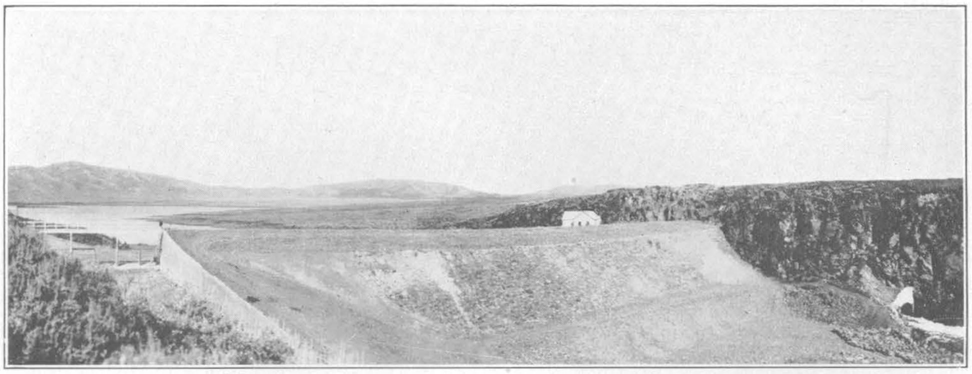
A. TRAVERTINE DEPOSITS NORTH OF SWAN LAKES, IN SEC. 30, T. 9 S., R. 43 E., SLUG CREEK QUADRANGLE

Mansfield 298.



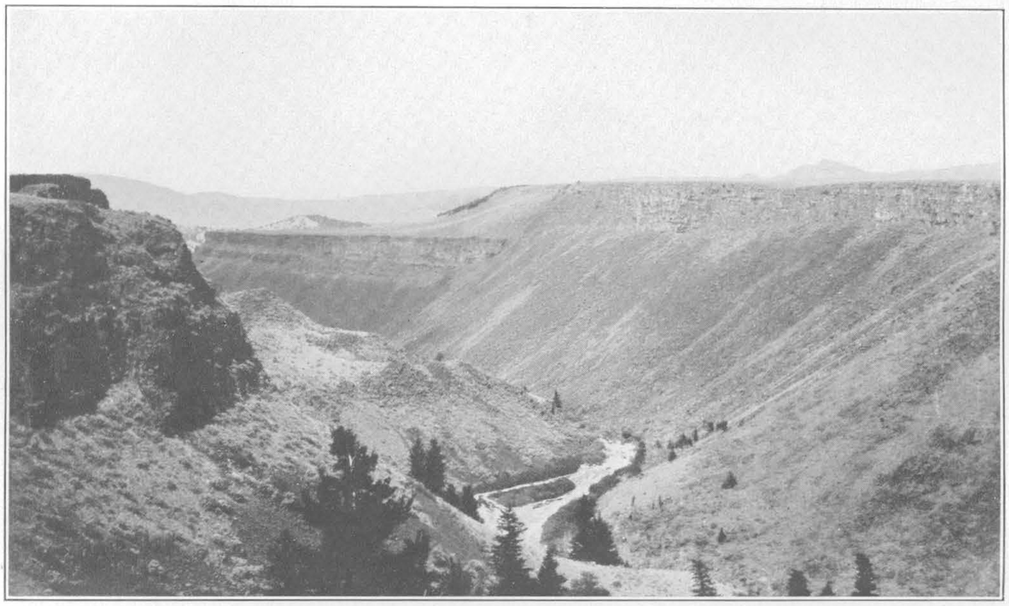
B. SPRING CONE IN THE NE. ¼ SEC. 13, T. 6 S., R. 40 E., HENRY QUADRANGLE

Mansfield
736-
737.



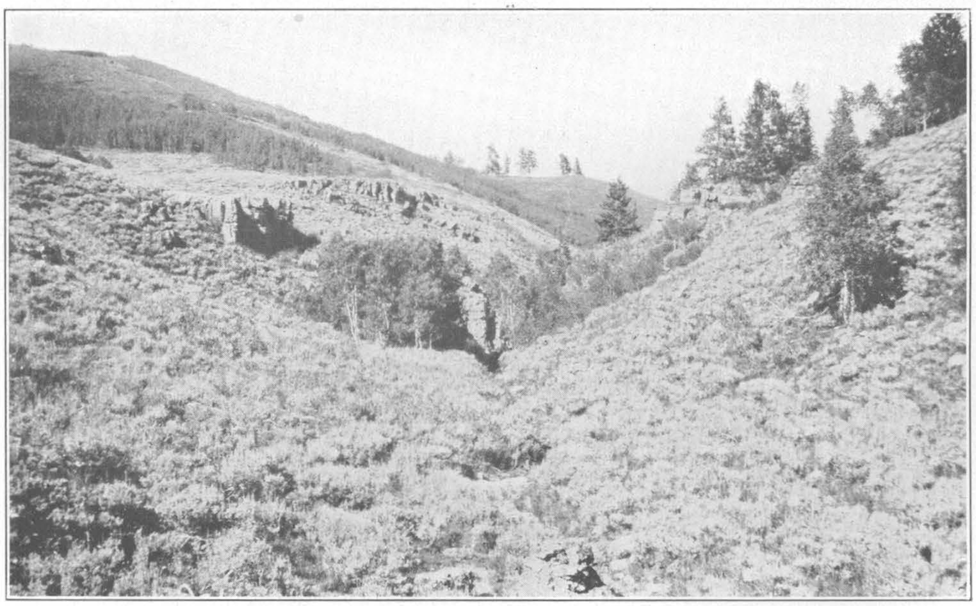
A. DAM OF BLACKFOOT RIVER RESERVOIR IN SEC. 12, T. 5 S., R. 40 E., CRANES FLAT QUADRANGLE

Mansfield
197.



B. CANYON OF BLACKFOOT RIVER ALONG NORTH SIDE OF FORT HALL INDIAN RESERVATION, IN T. 3 S., R. 38 E.

Richards
177.



C. LEDGES OF HORIZONTAL BEDS OF THE REX CHERT MEMBER OF THE PHOSPHORIA FORMATION, SEC. 28, T. 9 S., R. 44 E., SLUG CREEK QUADRANGLE

Pseudo-basaltic appearance is due to jointing and weathering of the chert

IRRIGATION [81a]

GENERAL FEATURES

Among the natural factors of chief importance in the use of water for irrigation are climate, soils, and topography, as well as water supply. These factors, as disclosed by the available records, vary within wide limits. A comparison of the climatologic data in Tables 4 and 11 shows that the station which has the longest growing season (158 days) is Pocatello, and this station has a mean annual precipitation of 13.88 inches. Afton has the shortest growing season (46 days) and there the mean annual precipitation is 17.06 inches. Idaho Falls has a growing season of 118 days and Grace one of 111 days. The mean annual precipitation at these stations is 13.69 and 13.63 inches, respectively. Under climatic conditions such as prevail at Pocatello, Idaho Falls, and Grace, diversified farm crops can be produced only with irrigation. Within the area under consideration, however, the average growing season is only about 87 days and the mean annual precipitation about 14 inches, so that crop production on irrigated land is largely limited to hay, though alfalfa, sugar beets, and potatoes are raised locally. The only important exception to these general climatic conditions occurs along Bear River and is discussed below.

The land that has soil and physiographic conditions suitable for farm development comprises only a very limited percentage of the total area. Practically all areas susceptible of irrigation at a moderate cost are now irrigated and are shown on Plate 56. Some additional lands that lie principally in the foothills and on slopes where irrigation is impracticable are being used to produce grain crops successfully during some years by dry-farm methods of cultivation. Even with irrigation the short growing season would limit crop production on most of these areas to hay and grain and the increased returns obtainable would not be materially greater than can be obtained without irrigation. There are in addition to the irrigated and dry farm areas tracts of natural meadows, chiefly in intermontane valleys, which produce native hay without artificial irrigation, and these meadows play a notable part in the agricultural industry of the region.

BEAR RIVER DRAINAGE BASIN

In the Bear River drainage basin the use of water for irrigation is very intimately associated with its use for power,[82] and the development for both uses has been extensive. Under the laws of Wyoming, Idaho, and Utah, the use of water for irrigation has preference over its use for power, and therefore the development of irrigation can not be impeded by prior power installations. Owing to natural conditions, however, the two uses in Bear River Basin are largely compatible. The quantity of water available is variable, depending on climatologic conditions, and there are periods when the natural run-off of Bear River is inadequate to supply the needs for both irrigation and power. This deficiency is offset by use of Bear Lake as a storage reservoir, and the present development of this lake will provide regulation for the entire flow of Bear River. Bear Lake, which lies half in Rich County, Utah, and half in Bear Lake County, Idaho, includes an area of about 168 square miles. In addition there is a large swamp or shallow lake at its north end called Mud Lake. The immediate drainage area tributary to Bear Lake is about 250 square miles, but by means of a canal from Bear River about 3,000 square miles more is made tributary to it.

As early as 1889[83] a reconnaissance of Bear Lake was made, and later about 6,000 acres of land adjacent to it was recommended[84] for a reservoir site and for reservation from sale or settlement. Since that time the United States Reclamation Service[85] and private interests have made many detailed surveys of the Lake to determine its real value as a storage reservoir. In 1901 the Telluride Power Co. started a plan to use the lake as a reservoir and constructed a canal to divert the flood waters from Bear River to the lake for use both in developing power and in irrigation. The canal was about 4½ miles long and had a drop of about 60 feet. It was designed to carry 2,000 second-feet but was found to be unsafe for more than 1,000 second-feet on account of its steep grade.

At about the same time the Utah Sugar Co. undertook to build another canal from Mud Lake to Bear River, contemplating the utilization of the water in its irrigation system and power plant in the northern part of Utah.

The outlet of Bear Lake passes north through Mud Lake and through 14 miles of bottom land to Bear River. Although considerable work was done in 1902 to construct the inlet canals the carrying capacity of the outlet was not improved until 1909. In that year the Telluride Power Co. started to dredge this channel and to increase its capacity. The work was completed in 1914 by the Utah Power & Light Co., successor to the Telluride Power Co. The new company also built another inlet canal from Bear River, increasing the capacity of the inflow from that source to about 4,500 second-feet, and installed a pumping plant on the "causeway" at the north end of the lake for drawing down the water in the lake. The capacity of the outlet canal was increased to 1,200 second-feet or more, and the pumping plant has a capacity of 1,500 second-feet under a 13-foot lift. The location of the canals and pumping plant is shown in Plate 9.

[81a] The writer is indebted to Messrs. W. G. Hoyt and J. F. Deeds, of the U. S. Geological Survey, for much of the information presented on irrigation and power sites.

[82] Woolley, Ralf R., Water powers of the Great Salt Lake Basin: U. S. Geol. Survey Water-Supply Paper 517, 1924.

[83] U. S. Recl. Service Third Ann. Rept., p. 110, 1904.

[84] U. S. Geol. Survey Thirteenth Ann. Rept., pt. 3, p. 451, 1893.

[85] U. S. Recl. Service Second Ann. Rept., p. 475, 1903.

The capacity of Bear Lake as a reservoir is approximately 1,375,000 acre-feet in a drawdown of 21 feet, and the pumping plant will make available all water in the lake to that depth, although during a year of average flow in Bear River the maximum variation in the lake level to equalize the flow would not exceed 3½ feet, and the hydraulic gradient of the outlet is adequate to permit utilization of the storage capacity to a greater extent without resort to pumping.

It is reported that during July and August, 1919, Bear River became almost dry, that the natural flow at Dingle was as low as 12 second-feet on many days, and that all of this water supply would have been required to satisfy old established rights from the river in Utah. During such a year without the use of Bear Lake the irrigated crops would have been practically a failure. The use of Bear Lake as a reservoir has demonstrated that where natural conditions are favorable development for irrigation and power can exist together without impairment of the possibilities of either and that a harmonious simultaneous development of both is conducive to industrial progress in the region.

From a point near the town of Alexander in T. 9 S., R. 41 E., to the mouth of Bear River, approximately 1,571 second-feet of water have been decreed for irrigating an area of about 100,000 acres. An additional amount of 1,500 second-feet has been decreed for power in that section. The total area irrigated from Bear River and its tributaries in 1920 was 642,500 acres, of which 340,000 acres was irrigated from Bear River direct in Wyoming, Idaho, and Utah. It therefore appears that approximately 240,000 acres of the area irrigated from Bear River direct lies above Alexander. A considerable part of this irrigated acreage is located within the limits of the area under discussion. Cultivated crops in the drainage area above Alexander in general are limited by the short growing season to the production of native hay and here and there crops of grain. Between Dingle and Soda Springs along the main river valley, however, in addition to the native hay produced by a large acreage of meadows such crops as alfalfa, wheat, oats, barley, potatoes, and garden vegetables are extensively produced. Below Alexander, particularly in the vicinity of Grace, there is a wider diversification of crops, and alfalfa is grown more extensively there as well as all small grains, potatoes, sugar beets, and garden truck.

SNAKE RIVER DRAINAGE BASIN

In the part of the area here discussed that lies in the Snake River drainage basin the principal development of irrigation is the Blackfoot River Reservoir. This reservoir is used to regulate the flow of Blackfoot River for irrigating about 50,000 acres of land outside the limits of the area in the Fort Hall project in Tps. 3, 4, 5, and 6 S., Rs. 33, 34, and 35 E. The reservoir supplements the water supply obtained by direct diversion from Snake River. Water is released from it when needed and allowed to flow down the natural channel of the river to two points 50 and 51 miles below the reservoir. The supply from this reservoir has been augmented by the building of a dam at the outlet of Grays Lake in sec. 26, T. 3 S., R. 42 E., and the diversion of the water thus impounded into Blackfoot River Reservoir by means of a canal beginning at a point near the southeast corner of T. 6 S., R. 42 E. It is estimated that by means of these structures an added annual supply of 40,000 acre-feet will be made available for the Fort Hall project.

A plan that has been proposed for utilizing the Blackfoot River Reservoir to extend the irrigated acreage contemplates the purchase of storage rights in the American Falls Reservoir on Snake River and the exchange of such rights for stored water in Jackson Lake Reservoir at the headwaters of Snake River. The Jackson Lake water could thus be delivered to the Fort Hall lands, now irrigated by Blackfoot River, through the existing diversion canal from Snake River. Then the Blackfoot water could be diverted at a higher altitude and thus used to irrigate lands not susceptible of irrigation at a reasonable cost directly from Snake River. Under these plans the water of Blackfoot River Reservoir would probably be diverted at a point about 13 miles below the present Blackfoot dam, and it has been estimated that approximately 100,000 acres of new lands could be irrigated with the water supply from Blackfoot River and Grays Lake thus released from its present use.

The dam which creates the Blackfoot River Reservoir is located in sec. 12, T. 5 S., R. 40 E. It is a loose rock and hydraulic fill structure with a concrete core wall that extends to a height of 40 feet above the bed of the river. (See pl. 61, *A*.) The reservoir is 20 miles long and 6 miles in maximum width. At the height of the spillway its surface area is 17,000 acres and its capacity 200,000 acre-feet, but the available records indicate that the quantity of water available for storage under normal conditions is 166,000 acre-feet per annum. Figure 34, which is based on data in the files of the survey, indicates roughly the variation in capacity of the reservoir with different gage heights.

LEAKAGE OF BLACKFOOT RIVER RESERVOIR

Area affected.—In June and July, 1914, at the request of the Office of Indian Affairs, the Geological Survey made an examination of the lands affected by leakage from the Blackfoot River Reservoir to determine the cause of the leakage and the nature of the damage and to suggest means of control. The following account is compiled chiefly from the unpublished report of J. B. Umpleby, who was detailed for the work.

The area involved in the leakage included parts of four townships—Tps. 7 and 8 S., Rs. 41 and 42 E.

Most of the leaks occurred in secs. 6 and 7, T. 7 S., R. 42 E., immediately north of the hill known as China Hat, in the Henry quadrangle. (Pl. 3.) The principal damage was done in secs. 7, 18, and 19, T. 8 S., R. 42 E., and in secs. 11, 12, 13, 14, 23, and 24, T. 8 S., R. 41 E., in a district called Fivemile Meadows, where a large area of productive hay land was converted into a marsh that was unfit for use, even for pasture. The general area affected is shown in the accompanying map. (Fig. 35.)

The principal topographic feature of the area affected by the leakage is a broad valley that rises gradually northward from an altitude of 5,779 feet at Soda Springs to 5,980 feet at Fivemile Meadows and thence upward more abruptly to about 6,250 feet at a place 3 miles north of Fivemile Meadows and the same distance south of the reservoir. Beyond this divide the descent is gradual to the shore line of the reservoir, about 6,100 feet (6,111 feet in August, 1914, pl. 3) above sea level. In escaping from the reservoir, therefore, the water sank at an altitude of about 6,100 feet, passed beneath a divide that attains a general elevation of 6,250 feet, and emerged 6 to 9 miles away at an elevation of about 5,980 feet.

Basaltic characters that favor leakage.—The leakage took place principally through the basalt that underlies this valley. Some of the surface, textural, and structural features of the basalt have been described elsewhere in this paper. The basalt is a dark, fine-grained rock that is characterized by small, closely spaced spherical cavities and innumerable joints and fissures. (See pls. 14, *C*, and 18, *A*, *B*.) These features are not local but occur throughout the basalt field. They are due to gases in the molten lava, to rapid cooling, and to stresses developed during flowage. The crevices range in width from a small fraction of an inch to 4 or 5 feet. The large ones are of somewhat local occurrence, as near the margins of a flow, but the small ones are everywhere present. The large cracks may extend with more or less continuity for several hundred feet and may be 50 feet or more deep, but the small ones bound five or six sided columnar blocks about 2 feet in diameter in most places. The short fractures connect with one another and with the large fractures, so that openings, mostly narrow and extremely zigzag, may be continuous throughout great stretches of basaltic flows. Many of these crevices are doubtless filled with soil from the surface, but others are simply bridged over by soil and remain as open cavities. One such crevice about 4 feet wide extends southward beneath about 30 feet of soil, but northward the arch has slumped and reveals for a distance of perhaps 30 feet the otherwise concealed fissure. Sinks similar in origin to this one, though most of them do not disclose the firm basalt beneath the soil, occur in many parts of the basaltic area. The sides of most of the sinks are sodded over in the upper three-fourths of the slope, but near the bottom the soil is commonly bare of vegetation and little, steplike drops indicate that settling is still in progress. These sinks are widely

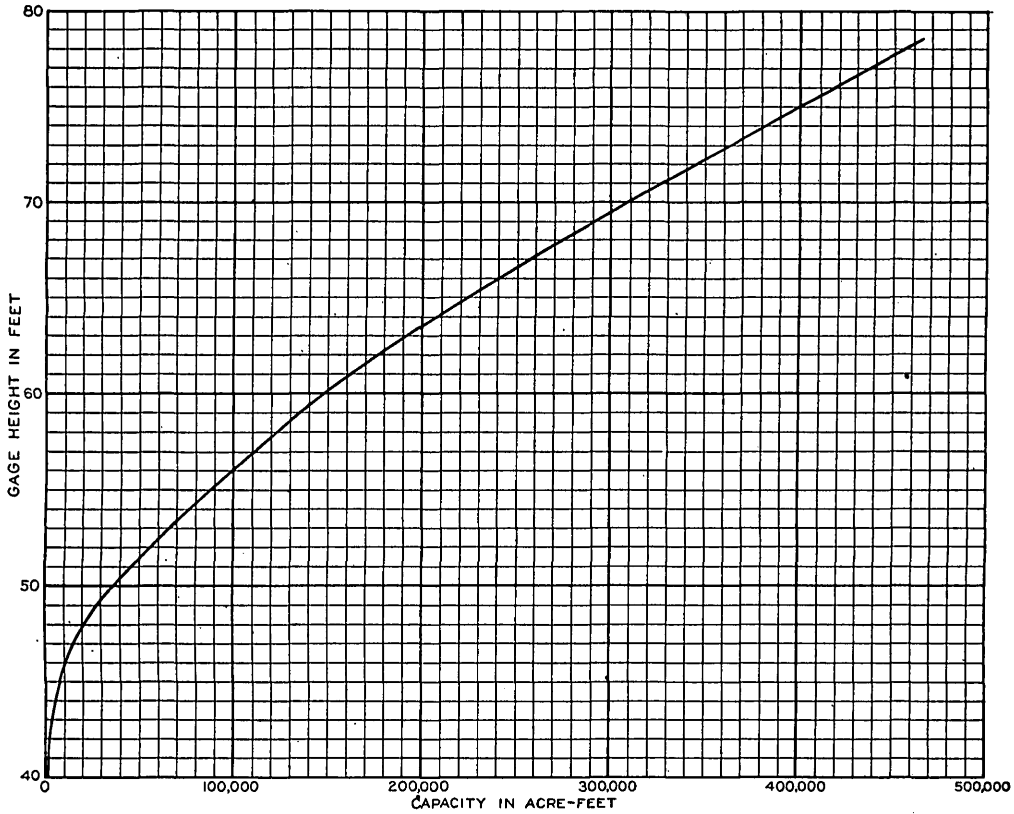


FIGURE 34.—Curve showing the relation between gage height and capacity of the Blackfoot River Reservoir. Zero of gage at elevation 6,048.40 feet above sea level (1921)

distributed and thus indicate the prevalence of structural cavities throughout the basaltic area even where the bedrock is thickly covered with soil.

Evidence of leakage.—Along the arms of the reservoir near China Hat there are numerous sinks, into one of which water was pouring at the time of Mr. Umpleby's visit. These sinks were then so recent that there could be no doubt that the waters from the reservoir were their direct cause. Ten of them were observed, and probably there were several more beneath the water of the reservoir. The side of the sink into which water was pouring was lowered by Mr. Umpleby until the inflow was increased from a small stream to perhaps 2 second-feet, in order to get some idea of the quantity of water that the connecting crevices could handle. When the inflow was perhaps 1 second-foot the depression began to fill, and quickly the water in it rose to the level of that in the reservoir. There was then no swirl at the surface to suggest the loss of the water beneath. There were at least five fresh sinks near the end of the westernmost area of the reservoir. The most southerly one was about 600 feet west of the base of China Hat, about a mile from the reservoir. It was about 7 feet wide, 15 feet long, and 6 feet deep. (Pl. 55, *B*.) Similar sinks, so fresh that grass and sagebrush still grew on the slumped portion and the sides remained vertical or even overhung, occurred near the end of the middle southward-extending arms of the reservoir. A sink was also observed on the divide between the lake at North Cone and the reservoir. This sink was about 50 feet above the water line of the reservoir and was exceedingly fresh in appearance. It was cistern shaped, about 9 feet in diameter at the top and 6 feet deep. Water is known to pass beneath this divide, and it seems certain that this sink is merely the surface manifestation of the movement of the water about 50 feet below.

Lakes near China Hat.—In 1914 there were four lakes within a mile of the reservoir, three of which developed after the reservoir was filled. These lakes were Crag Lake, the two Crater Lakes between Middle and North Cones, and a lake in the NW. ¼ sec. 17, T. 7 S., R. 42 E. (See pls. 33, *C*, and 57, *A*.) The level of these lakes rises and falls with that of the reservoir, as is clearly shown by high-water marks around the several bodies of water and aneroid readings along their existing shore lines. The Crater lake at the east base of Middle Cone was in existence before the reservoir was filled, but many trees along its former shore have been killed by the rise of the water, and their dead trunks now stand well out in the lake. Plate 57, *A* shows higher shore lines in Crag Lake. In two places roads that crossed the sites of the lakes have been abandoned.

Three of the lakes came into existence as the water rose in the reservoir, and when the water level was later drawn down their levels also dropped. This decline, which amounted to 4 or 5 feet in 1914, was sufficient to split up the southernmost lake into a number of ponds. Since that date the waters of the reservoir have been lowered still more (p. 36), and these ponds have practically disappeared, though the three other lakes remain.

Effect on Soda Creek.—Soda Creek drains the only near-by area that is lower than the reservoir. Here about 1,800 acres of meadow land developed into an inaccessible marsh shortly after the reservoir was filled. The upper waters of Soda Creek rose above the approach to a bridge in sec. 24, T. 8 S., R. 41 E., washed out a dam used for holding flood waters in section 13 of the same township (pl. 58, *A*), and, according to local residents, added to the flow of the creek so that it more than doubled in size within a period of two or three days. A gaging station has since been established on this creek.

Damage.—The damage due to leakage of the reservoir is confined to the area of Fivemile Meadows and includes approximately 1,800 acres of land from which about 1 ton of hay to the acre, then worth on the average about $5 a ton, had been cut each year for more than a decade. In July, 1911, during the haying time, these meadows began to get wet and before the end of the summer were in large part submerged. Springs are said to have developed at hundreds of places in the meadows at about the same time. In the lower meadows there were large "soda" springs before the flooding of the hay land. These springs were said to be more dilute and of greater volume than formerly. In this vicinity, however, there were fresh-water springs of recent origin, most of which welled up from the bottom, their positions being marked by little conical piles of sand clearly visible from a rowboat. About 600 feet west of the southeast corner of sec. 14, T. 8 S., R. 41 E., there were five springs whose waters emerged from crevices in the basalt about 4 feet above the level of adjacent standing water. The largest of these springs probably did not yield a flow of more than 1 miner's inch. No hay was cut from the meadows during 1912 or succeeding years, and at the time of the examination swamp grass and expanses of water occupied their area. (Pl. 57, *B*). Several section corners found by the topographers of the Geological Survey and indicated on the topographic map were then inaccessible.

Nature of the leak.—Water which disappeared in many places along the reservoir certainly came to the surface again in even a greater number of places 6 to 9 miles away. Mr. Umpleby concluded that the leakage took place through the innumerable crevices in the basalt, and that as this is a very insoluble rock the leak should not be expected to become more serious than it then was, so long as the same head of water was maintained in the reservoir. On the other hand,

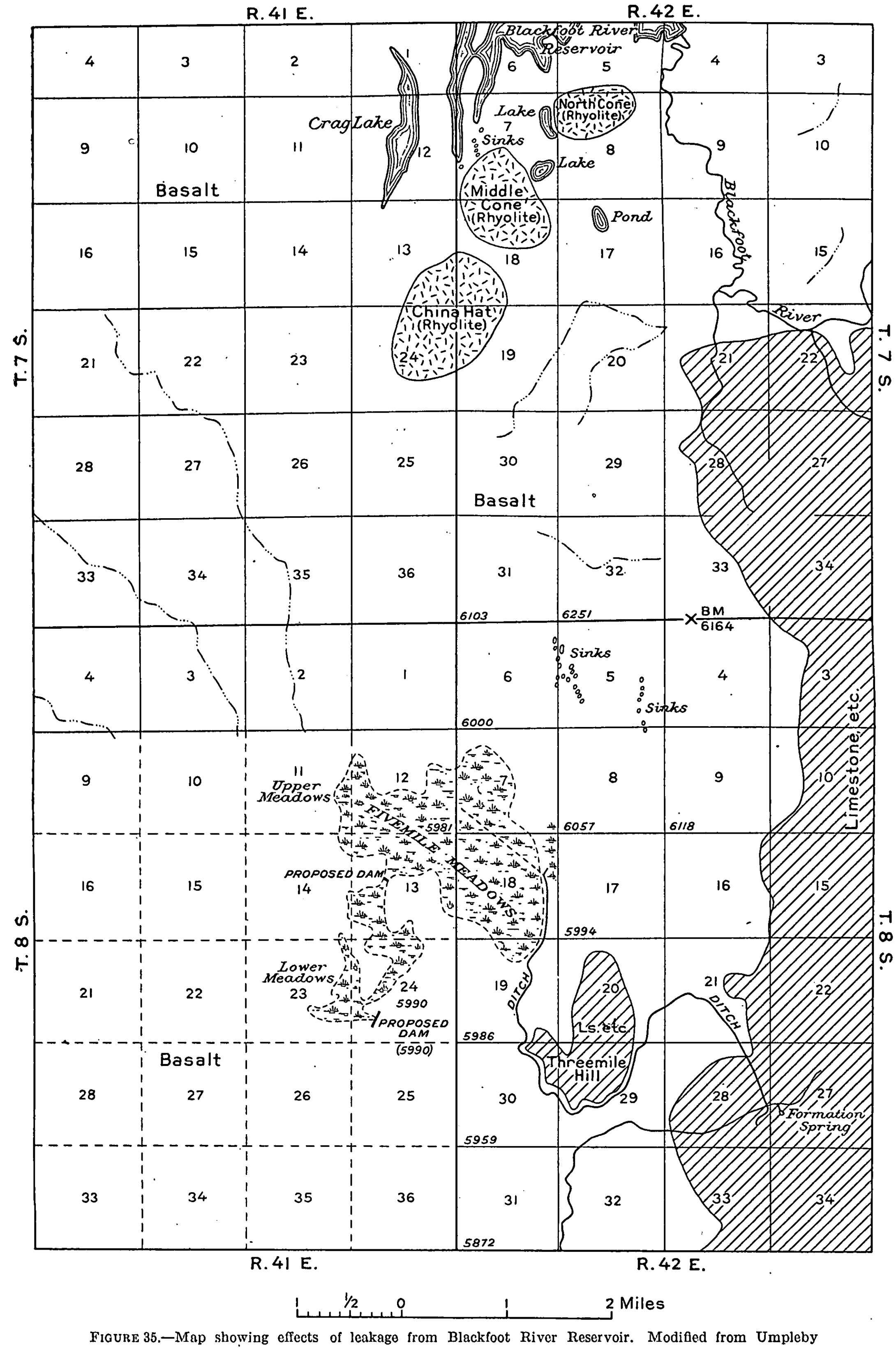


FIGURE 35.—Map showing effects of leakage from Blackfoot River Reservoir. Modified from Umpleby

the crevices would gradually become filled with silt, but as the water in the reservoir is quiet and free of sediment, the process would be too slow to be worthy of consideration.

Suggested remedies.—Mr. Umpleby made several suggestions regarding the control of the leakage, two of which he considered at some length. The first was to grout the principal leaks. This work he believed would be expensive and uncertain of success. The second was to conserve the water lost from the Blackfoot River Reservoir and to divert it to the reclamation of lands below the town of Soda Springs. This plan he was inclined to favor. It involved the purchase of the damaged land and the construction of two dams, the locations of which are shown on the map (fig. 35), and the sale of the impounded water. Other suggestions were to reduce but probably not stop the leakage by lowering the level of the water in the reservoir sufficiently to withdraw the water from the arms in the vicinity of the sinks, or to build dams across these arms.

In order to eliminate that part of the losses from Blackfoot River Reservoir which enters the Soda Creek drainage of the Bear River Basin, the China Hat Dam has been built in sec. 6, T. 7 S., R. 42 E., near the south end of the reservoir. This structure is 1,100 feet long and has a maximum height of 27 feet.

There has been considerable development of irrigation in Star Valley in Tps. 34 and 35 N., R. 119 W., Wyoming, with water diverted from Salt River and tributaries. Owing to the short growing season the principal crop produced is hay, although grain has been produced successfully by dry-farm methods, for the most part on the higher lands adjoining the valley, where damage from frosts is less likely to occur. Owing to the remoteness of the area from markets the crops produced are fed to stock, and stock-raising is the principal industry. There is also considerable dairying activity in the valley and creameries are located at several points in the area.

WATER POWER

GENERAL CONSIDERATIONS

The utilization of water for the generation of electric energy within the area under consideration dates from about 1905. The first development was on Georgetown Creek and Paris Creek, and the combined installation of less than 600 horsepower was used for supplying the public utilities in Montpelier, Bennington, Georgetown, Bloomington, and St. Charles. During 1908 the first large development was made on Bear River to meet the rapidly increasing demands for power which came largely from outside the area here considered. The years 1914, 1915, and 1925 each marked the completion of additional plants on Bear River, and at the present time the capacity of water wheels at developed sites is practically 100,000 horsepower, of which over 98,000 horsepower is installed at hydroelectric plants on Bear River.

The growth of the art of electric transmission was coupled with the merging of local power companies into one large group, so that to-day transmission lines of the Utah Power & Light Co. connect practically all the plants and furnish energy to the principal towns within the area. (See pls. 6, 9, and 56.) The surplus energy is transmitted either southward into the area contiguous to Salt Lake City or northwestward to cities and towns on the Snake River Plains.

With the exception of small plants which may be constructed to serve isolated communities, future growth will depend largely on the cost of developing sites within the area as compared with the cost of developing sites within an area stretching from Twin Falls on Snake River at the northwest to Flaming Gorge on Green River at the southeast. Available information indicates that there is only one more undeveloped site on Bear River within the area and possibly 10 or 12 small sites on tributaries to the Bear, on Blackfoot River, and on some of the minor streams. However, if all these sites are developed it is unlikely that their installed capacity will exceed 20,000 horsepower. In general, therefore, the power resources of the area are 85 per cent developed.

The data here given, regarding the developed and undeveloped sites in Bear Valley Basin, are largely taken from Water-Supply Paper 517.[86] Data regarding undeveloped sites outside of Bear River drainage have been compiled largely from unpublished data available to the survey.

DESCRIPTION OF POWER PLANTS

The developed power sites in the area here discussed are described chronologically below and the date o construction is given.

Georgetown plant.—Plant located on Georgetown Creek in sec. 3, T. 11 S., R. 44 E. (unsurveyed), 2½ miles from Georgetown. Constructed in 1904–5 by Montpelier Electric Light Co. Sold in 1908 to Bear Lake Power Co. Sold in 1914 to Utah Power & Light Co. Development consists of a concrete and earth-fill dam 15 feet high; 4,900 feet 33-inch wood-stave pipe; wooden power house, with installation of one 30-inch 300-horsepower Leffel turbine direct-connected to a 180-kilowatt 6,600-volt 3-phase 60-cycle Westinghouse generator. Operating head, 130 feet. Current generated at 6,600 volts and transmitted 14 miles to main system of Utah Power & Light Co. Installed capacity of plant requires about 20 second-feet. Estimated Q90 flow, 17 second-feet; corresponding power capacity about 190 horsepower. Estimated Q50 flow,[87] 25 second-feet; corresponding power capacity 260 horsepower. No regulation of stream flow.

Old Grace plant.—Plant located on Bear River in sec. 21, T. 10 S., R. 40 E., near Grace. Constructed in 1906–1908 by Tel-

[86] Woolley R. R., Water power of Great Salt Lake Basin: U. S. Geol. Survey Water-Supply Paper 517, 1924.

[87] Q90 flow is the flow available for 90 per cent of the time; Q50 flow is the flow available for 50 per cent of the time.

luride Power Co. Sold to Utah Power & Light Co. in 1913. Development consists of timber crib dam 38 feet high; crest length, 160 feet. Wood-stave and riveted-steel pipe line about 5 miles long, ranging in diameter from 7½ feet to 8½ feet, with capacity of 450 second-feet. Concrete power house with installation of two 8,500-horsepower Allis-Chalmers turbines direct-connected to two 5,500-kilovolt-ampere 2,300-volt 3-phase 60-cycle Westinghouse generators. Static head, 448 feet; effective head, 440 feet. Stream flow is regulated by storage on Bear Lake, and to some extent by pondage at the diversion dam. Estimated Q90 flow, 900 second-feet; corresponding power capacity, 38,000 horsepower. The Q50 flow is practically the same as the Q90 flow. Current generated at 2,300 volts; stepped up to 44 kilovolts and carried over 134 miles of transmission line to the terminal station at Salt Lake City. This plant was the first of the large power plants remote from the market to be served to be constructed in this region.

Soda Springs plant.—Plant located on Soda Creek, in sec. 6, T. 9 S., R. 42 E., near the town of Soda Springs. Constructed by private individuals about 1908; acquired by Soda Springs Electric Co. the same year. Development consists of small timber dam 40 feet long and 8 feet high and an open canal 3,000 feet long used jointly for irrigation and power. Brick power house with installation of one 250-horsepower Leffel turbine, direct-connected to one 150-kilowatt 2,300-volt 37.7-ampere Allis-Chalmers generator. Operating head. 50 feet. Current all used at Soda Springs. Stream flow largely from springs and very uniform. Q90 and Q50 flows estimated to be 42 second-feet; corresponding power capacity, 170 horsepower.

Paris plant.—Plant located on Paris Creek in sec. 9, T. 14 S., R. 43 E. Constructed in 1910–11 by Bear Lake Co.; sold to Utah Power & Light Co. in 1914. Development consists of timber dam; open canal about 3.5 miles long, used jointly for irrigation and power; steel penstock 1,370 feet long, 30 inches in diameter; stone masonry power house, in which are installed one 1,180 horsepower Allis-Chalmers turbine direct-connected to one 650-kilovolt-ampere 6,600-volt 3-phase Allis-Chalmers generator. Operating head, 346 feet. Outgoing line connected with Georgetown plant. Branch line to Montpelier substation, where connection is made with general system of Utah Power & Light Co. Estimated Q90 flow, 17 second-feet; corresponding power capacity, 480 horsepower. Estimated Q50 flow, 23 second-feet; corresponding power capacity, 640 horsepower.

New Grace plant.—Plant located on Bear River in SW. ¼ sec. 21, T. 10 S., R. 40 E., adjoining Old Grace plant. Constructed in 1913–14 by Utah Power & Light Co. The same dam is used as for the Old Grace plant. Conduit is wood-stave pipe 11 feet in diameter, 23,000 feet long, and crosses Bear River on a reinforced concrete bridge 576 feet long. Two steel penstocks, 2,530 feet long, extend from surge tank to power house, which is of concrete. Installation consists of three 17,000 horsepower, I. P. Morris vertical-shaft turbines and three 12,222-kilovolt-ampere 6,600-volt General Electric Co. generators. Static head, 524 feet; effective head, 480 feet. Energy distributed through system of Utah Power & Light Co.

Cove plant.—Plant is located on Bear River in sec. 33, T. 10 S., R. 40 E. Constructed in 1916–17 by Utah Power & Light Co. Development consists of reinforced concrete dam 21½ feet high, 141 feet long. Concrete flume. wood-stave pipe, and steel penstock with a total length of 6,700 feet conducts water to a concrete and hollow-tile power house. The installation consists of one 10,500 I. P. Morris turbine, direct-connected to General Electric Co. 7,500-kilowatt 3-phase 60-cycle generator. Static head, 98 feet. Current is generated at 6,000 volts and transmitted to Grace plant, where it is stepped up and fed into the main distribution system. Stream flow is regulated by storage on Bear Creek. Estimated Q90 and Q50 flow, 900 second-feet; corresponding power capacity, 7,100 horsepower.

Soda plant.—Plant located on Bear River in NW. ¼ sec. 17, T. 9 S., R. 41 E. Constructed in 1923–24 by Utah Power & Light Co. Development consists of a reinforced-concrete dam, creating a head of about 75 feet, which forms a reservoir in sections 9, 10, 11, 12, 13, 14, 16, and 17 that has a capacity of 12,500 acre-feet with 20-foot drawdown. Power house is a part of the dam. The installation consists of two 10,000-horsepower Allis-Chalmers turbines and two 12,000-kilowatt generators. The energy is fed into the system of the Utah Power & Light Co. Q90 flow, 900 second-feet; Q50 flow, 1,300 second-feet, corresponding to power capacities of 5,400 horsepower and 7,800 horsepower, respectively.

UNDEVELOPED POWER

BEAR RIVER DRAINAGE BASIN

Lava site.—The so-called Lava site is the only undeveloped site that has been given serious consideration on Bear River within the area. This site is located in the southwestern part of T. 9 S., R. 41 E., below the Soda plant and the Grace plant. Here a static head of 85 feet could be obtained by a dam across the river. The Q90 and Q50 flows are estimated to be 900 second-feet and 1,300 second-feet, corresponding to 5,400 and 7,800 horsepower, respectively. Energy generated at this site would properly feed into the system of the Utah Power & Light Co.

St. Charles site.—About 2 miles northwest of St. Charles and above the irrigation canals on St. Charles Creek. Available head in a 3-mile stretch, 175 feet, which could be developed by a low diversion dam and penstock. Estimated Q90 flow, 45 second-feet; Q50 flow, 70 second-feet, corresponding to capacities of 630 horsepower and 980 horsepower, respectively.

Bloomington site.—On Bloomington Creek about 4 miles west of Bloomington in T. 14 S., R. 43 E. Stream has its source near crest of Bear River Range. A head of about 750 feet could be obtained by means of low diversion dam and 2 miles of conduit. Estimated Q90 flow, 18 second-feet; Q50 flow, 29 second-feet. Power capacity 90 per cent of the time, 1,080 horsepower; for 50 per cent of the time, 1,740 horsepower.

Montpelier site.—On Montpelier Creek about 6 miles east of Montpelier. Power stretch limited to sites above the intake for water supply. Head of about 200 feet could be obtained with 4 miles of penstock. Estimated Q90 and Q50 flow, 15 second-feet and 24 second-feet, respectively, corresponding to 240 horsepower and 380 horsepower.

Georgetown site.—Immediately above the intake to the power plant on Georgetown Creek, about 4 miles above Georgetown. Estimated that a static head of 175 feet, available in 2 miles, could be developed by means of low diversion dam and penstock. Estimated Q90 and Q50 flow, 15 second-feet and 24 second-feet, corresponding to a capacity of 210 horsepower and 340 horsepower, respectively.

Co-op site.—On Co-op Creek, a small creek flowing through Nounan Valley in T. 11 S., R. 43 E. Creek has a fall of about 400 feet above the highest irrigation canal. Head could be developed by a low diversion dam and 1 mile of conduit. Estimated Q90 and Q50 flow, 5 second-feet and 8 second-feet corresponding to capacities of 160 and 260 horsepower, respectively.

Eightmile site.—On Eightmile Creek south of Soda Springs. This creek is entirely used for irrigation below sec. 29, T. 10 S., R. 42 E. Above this point the grade is steep and a static head of about 350 feet might be obtained with a low diversion dam and 3 miles of conduit. Estimated Q90 and Q50 flow, 5 second-feet and 8 second-feet, with a corresponding power capacity of 140 and 220 horsepower, respectively.

Soda Springs site.—On Soda Springs Creek, about 1 mile north of Soda Springs. Many irrigation diversions are made from this stream, the largest ones being below the northwest corner of T. 9 S., R. 42 E. velopment only a low diversion dam could probably be constructed, reducing the power head to 120 feet. Estimated Q90 and Q50 flow, 50 second-feet and 100 second-feet. Corresponding power capacities, 500 horsepower and 1,000 horsepower, respectively. Using the high dam with storage the corresponding capacities would be about 700 horsepower and 2,100 horsepower. A profile of part of Blackfoot River, including this power site is shown in Figure 36.

Blackfoot No. 2.—Several schemes for power development have been considered in the lower canyon stretch between sec. 33, T. 2 S., R. 38 E., and sec. 13, T. 3 S., R. 38 E. (See pl. 61, *B*.) Each contemplates a diversion dam near the upper end of the canyon and a pipe line to the point of use. Depending upon the method of development static heads ranging from 430 feet to 600 feet could be obtained. The

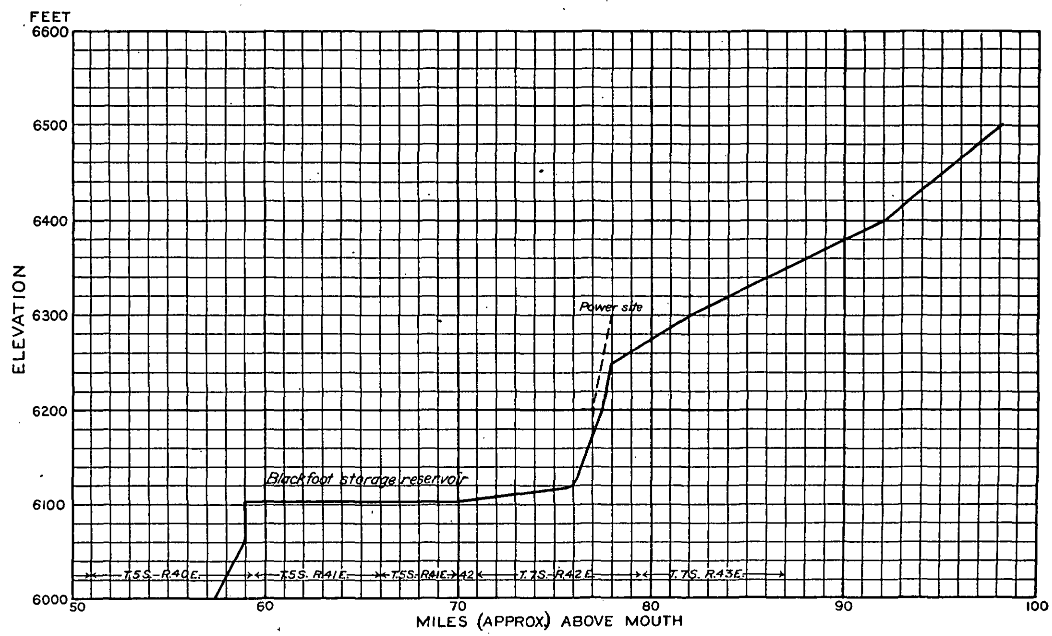


FIGURE 36.—Profile of Blackfoot River above its canyon in T. 5 S., R. 40 E.

In the first 3 miles above this point a static head of about 130 feet is available. The estimated Q90 and Q50 flow is 42 second-feet, corresponding to a power capacity of 440 horsepower.

SNAKE RIVER DRAINAGE BASIN

The undeveloped sites in the area tributary to Snake River are, in general small and comparable with the undeveloped sites on tributaries to Bear River. The largest sites are on Blackfoot River, and reference is made to three possible sites on this stream and also to possible smaller sites on minor streams.

Blackfoot No. 1.—A dam 50 feet high and about 400 feet long in sec. 14, T. 7 S., R. 42 E., on Blackfoot River above Blackfoot Reservoir would create a reservoir having a capacity of about 38,000 acre-feet. By constructing a penstock 1¼ miles in length along the south side of the river a head of about 125 feet could be obtained. If the site were utilized for power de- higher head would require a dam 75 feet high. The operation of Blackfoot Reservoir for storage for irrigation results in an erratic flow at the site seriously affecting the power value. It is roughly estimated that the Q90 flow does not exceed 15 second-feet and the Q50 flow, 150 second-feet, with corresponding power capacities of 720 and 7,200 horsepower.

Blackfoot No. 3.—A dam 15 feet high with crest length of 200 feet in sec. 7, T. 2 S., R. 38 E., and a pipe line, 2,200 feet long would create a head of about 45 feet. Flow same as for site 2. Power capacity, 54 horsepower for 90 per cent of the time and 540 horsepower for 50 per cent of the time.

OTHER SITES

Although no detailed investigations have been made either of water supply or feasibility of dam sites it is probable that small plants could be located on some of the minor streams, at sites near communities which are not now tied in with large systems. Such sites may be found on Grays Lake Outlet in secs. 14 and 33, T. 2 S., R. 41 E., and sec. 3, T. 3 S., R. 42 E. Fragmentary records of run-off of Grays Lake Outlet are given on page 313.

Tincup River falls 400 feet in 6 miles through T. 5 S., R. 45 E., part of which might be utilized. At the lower canyon of Stump Creek in sec. 27, T. 7 S., R. 46 E., a dam 150 feet high and 800 feet along its crest could be constructed. The feasibilty of the site depends largely upon the stream flow, records of which are not available. A similar site exists on Crow Creek in sec. 17, T. 31 N., R. 119 W., where a dam 150 feet high will have a crest length of 1,000 feet. Sites of the latter type will probably not be developed until the demand for power becomes more acute.

LIMESTONE

Limestone is one of the most abundant and most widely distributed mineral resources of the region. Its formation took place at intervals from the Cambrian to the Quaternary, as shown by Table 12. There are many textural varieties that range in composition from rocks that might be classed as calcareous shales and sandstones to nearly pure limestones. Some beds, such as members of the Langston and Nounan limestones, are thoroughly and coarsely crystalline, but there are no rocks that could be classed as marble.

EARLIER PALEOZOIC LIMESTONES

The earlier Paleozoic limestones are practicaly confined to the Bear River Range, in the western part of the Montpelier quadrangle, though a few small areas of Devonian limestone occur in the Aspen Range, in the Slug Creek quadrangle. These earlier limestones are more or less magnesian, and some of them have actually been called dolomites, as the Fish Haven and Laketown dolomites, which contain, according to analyses by W. C. Wheeler, of the Geological Survey, 21.3 per cent of magnesia(MgO). The Jefferson limestone, which contains 19.2 per cent MgO, is hardly less magnesian.

CARBONIFEROUS LIMESTONES

The Carboniferous limestones are better adapted for general purposes than most of the others. The Madison and Brazer limestones and the lower part of the Wells formation contain many beds that appear to consist of relatively pure limestone. These formations are widely distributed, as may be seen by reference to the geologic maps (pls. 2–7 and 9). On the whole the Brazer beds appear to be more nearly pure than the others, though this formation contains beds of sandstone and shale in addition to limestone. The Rex chert, which, as the name implies, is normally a formation that consists almost entirely of chert, locally contains beds of relatively pure limestone, as, for example, the "upper Productus limestone" near Montpelier and in sec. 4, T. 10 S., R. 45 E.

The Brazer limestone is the source of the lime formerly burned at the limekilns at Montpelier and is locally reported to have yielded a fine product. An analysis made in the Geological Survey laboratory of an average sample collected from the Montpelier quarry is given in Table 93. The sample represents the 20 feet of thick-bedded, broken and calcite-seamed rock exposed along the quarry wall.

TABLE 93.—*Analysis of limestone (field No. M-153) from quarry at Montpelier, T. 13 S., R. 44 E.*

[W. C. Wheeler, analyst]

Silica (SiO_2)	2. 55
Alumina (Al_2O_3)	. 43
Iron oxide (Fe_2O_3, total)	. 44
Magnesia (MgO)	1. 35
Lime (CaO)	51. 96
Carbon dioxide (CO_2)	41. 08
Loss on ignition, less CO_2	1. 80
	99. 61

This limestone has been burned in a kiln owned and operated by W. F. Owen, of Montpelier. The kiln was running for about five years, ending 1913, and the product was all sold within the State of Idaho. Since that year no production has been reported to the Geological Survey and the quarry and kiln have been practically idle. As the limestone contains approximately 93 per cent of calcium carbonate the product obtained by proper burning would be classed as high-calcium lime.

About 100 yards west of the quarry sampled there is another opening in which the limestone has chert bands and contains large cup corals and Bryozoa, characteristic fossils of the Brazer limestone. Some lime has been burned from this rock, but the product shows hard blue streaks in seams that before burning look like thin seams of calcite. Another type of limestone near by is sandy.

TRIASSIC LIMESTONES

The upper beds of the Woodside shale and the lower beds of the Thaynes group locally consist of relatively pure limestone in quantity apparently sufficient for commercial production, especially along the west side of Diamond Creek, in Tps. 8 and 9 S., R. 45 E. These localities are at present relatively inaccessible, and no tests or analyses have been made to determine the character of the limestone.

The Portneuf limestone of the Thaynes group has massive beds that are exposed in the Freedom, Lanes Creek, and Cranes Flat quadrangles, but these beds are probably too siliceous to have commercial value.

The Deadman limestone is also in large part too siliceous to be utilized.

JURASSIC LIMESTONES

The Twin Creek limestone, which is well exposed over considerable areas in all the quadrangles here described except the Henry, consists largely of shaly limestone. Samples collected in Georgetown Canyon have been analyzed in the laboratory of the United States Geological Survey with results shown in Table 94.

TABLE 94.—*Analyses of Twin Creek limestone from Georgetown Canyon, T. 11 S., R. 44 E.*

[W. C. Wheeler, analyst]

	Field No. M-169a	Field No. M-169b
Silica	15. 06	10. 41
Alumina	2. 03	3. 57
Iron oxide (total)	. 68	1. 41
Magnesia	. 55	1. 69
Lime	44. 76	44. 39
Carbon dioxide	35. 89	37. 01
Loss on ignition less CO_2	. 60	1. 00
	99. 57	99. 48

There is some doubt about the locality from which these samples were taken and some possibility that they may represent beds of the Thaynes rather than of the Twin Creek. However, if they are at all representative of either of these two formations, there would be a vast body of rock admirably adapted for the manufacture of Portland cement, which would require only slight additions of silica and alumina that could readily be supplied from beds of the Woodside shale or of the Thaynes group in neighboring areas.

CRETACEOUS LIMESTONES

The Peterson and Draney limestones of the Gannett group and the similar bands of fresh-water limestone in the Wayan formation are rather widely distributed in the Crow Creek and Freedom quadrangles, and limestone beds of the Wayan formation occur in the Cranes Flat quadrangle. These limestones may sometime prove to be of commercial value, but they have not yet been utilized or even tested.

TERTIARY LIMESTONES

The Salt Lake formation contains marls and limestones, some of which might possibly be utilized. The Pliocene (?) hills east of Soda Springs, in secs. 3, 4, 9, and 10, T. 9 S., R. 42 E., and secs. 33 and 34, T. 8 S., R. 42 E., contain drab and white limestones that vary in degree of compactness from loosely consolidated marly varieties to a dense, nearly lithographic facies. This dense variety also occurs in the low knolls south of Threemile Hill, in sec. 29, T. 8 S., R. 42 E. The commercial possibilities of these limestones have not been investigated, but they may prove usable.

A magnesian marl of probable Pliocene age has been prospected in the vicinity of Bern. Its analysis is given on page 111.

QUATERNARY LIMESTONES

Deposits of travertine of Quaternary age occur in many places throughout the region, but especially in the vicinity of the Swan Lakes, in T. 9 S., R. 43 E., and Formation Spring, in T. 8 S., R. 42 E. If the analysis cited on page 318 is at all typical for the travertine as a whole, this source could supply large quantities of high-grade lime, much of which would be readily accessible to the Oregon Short Line Railroad.

CLASSIFICATION OF LIMESTONES

Aside from textural varieties, limestones may, according to Burchard,[88] be classified by means of their composition as high-calcium limestone, magnesian limestone, dolomite, argillaceous limestone, and arenaceous and siliceous limestone.

High-calcium limestone.—High-calcium limestone carries from 93 to more than 99 per cent of calcium carbonate, and may embrace all physical varieties of limestone except the cherty rock. So far as composition is concerned high-calcium limestone makes the purest and most active lime.

Magnesian limestone.—Magnesian limestone is limestone that contains magnesium carbonate in any quantity up to 45.65 per cent. Magnesian limestone may embrace several textural varieties, and if physically suitable it may be burned to lime, which will be a mixture of calcium oxide (CaO) and magnesium oxide (MgO).

Dolomite.—Dolomite is a mineral composed of the double carbonate of calcium and magnesium ($CaCO_3 \cdot MgCO_3$). It contains 54.35 per cent $CaCO_3$ and 45.65 per cent $MgCO_3$. In practice, magnesian limestone that contains 20 per cent or more magnesium carbonate has generally been called a dolomite. The texture of magnesian limestone and so-called dolomite is commonly more or less rough on weathered surfaces. Rock that contains a higher percentage of magnesium carbonate than true dolomite may be termed supermagnesian limestone, and by further replacement of the calcium carbonate this rock grades into magnesite. The process of replacement, known as dolomitization, is accompanied by contraction, which is believed to produce porosity in the rock under conditions in which the pressure is not sufficiently great to close the pores of the rock.

Argillaceous limestone.—Argillaceous limestone contains a considerable proportion of clayey material that consists mainly of silicate of alumina. If this material is present in certain proportions mortar made from the lime burned from this stone has the property of setting under water, and is therefore called hydraulic lime. Not much of this lime is now made in the United States.

[88] Burchard, E. F., and Emley, W. E., The source, manufacture, and use of lime: U. S. Geol. Survey Mineral Resources, 1913, pt. 2, pp. 1518-1520, 1914.

Arenaceous and siliceous limestone.—Arenaceous and siliceous limestone is a rock that contains fine silica deposited with the calcareous sediments. Other varieties contain silica introduced by ground water into the pores and cavities of the rock. Silica, where present to the extent of 4 per cent or more, is an undesirable impurity. Arenaceous or siliceous limestones are rarely suitable for making lime.

Commercial classification of lime.—As regards commercial value magnesia is not considered an impurity, and limes are classified by the National Lime Manufacturers Association according to their composition as follows:[89]

High-calcium lime contains 0–5 per cent magnesia.
Magnesian lime contains 5 per cent to 25 per cent magnesia.
Dolomitic lime contains 25 per cent to 45 per cent magnesia.
Superdolomitic lime contains over 45 per cent magnesia

USES OF LIMESTONE

Limestone from certain localities, such as that from Bedford, Ind., has wide use as a building stone. Limestone, however, is more widely used as crushed stone in road making, railroad ballast, concrete, and other materials. It is also sold extensively for use as a flux for smelters and for open-hearth and blast furnaces. Large quantities are utilized for burning to lime and for the manufacture of cement. Other notable uses are for paving, curbing, flagging, rubble, and riprap. Limestone is also sold to sugar factories, alkali works, glass factories, paper mills, and other industries. Statistics relating to these uses are given in the chapters on stone in the annual volumes of Mineral Resources of the United States, formerly published by the Geological Survey but now issued by the Bureau of Mines.

USES OF LIME

Lime is manufactured by burning limestone in a suitable kiln. It has many uses, which have been grouped into the following four classes by Emley,[90] who discusses these uses in some detail.

(1) Building lime, used either alone or with cement in making mortar for masonry work, or for the scratch or brown coat of plaster, or for stucco.
(2) Finishing lime, used either alone or with plaster of Paris for the white coat of plaster.
(3) Agricultural lime, used as a fertilizer,
(4) Chemical lime, used in the chemical industries.

For most uses the high-calcium lime is most satisfactory, but magnesian lime may for some purposes be used with equal advantage or may even be superior to the high-calcium lime. The last statement is particularly true with reference to some of the chemical uses of lime.

[89] Burchard, E. F., and Emley, W. E., op. cit., p. 1556.
[90] Idem, pp. 1581–1593.

UTILIZATION OF IDAHO ROCK

Except for the brief period of operation of the kilns at Montpelier noted above and for a little use as road metal, the limestones in the part of southeastern Idaho here described have not been utilized. It seems certain, however, that limestone of suitable quality exists there in sufficient variety and quantity to form a potential resource of great future value. In view of the mountainous nature of the country there seems little likelihood of any rapid increase in the settlement of the region unless an unexpected impetus should be given to the phosphate industry. The utilization of the limestone will accordingly be slow, and the quantity available should prove practically inexhaustible.

HYDROMAGNESITE

Hydromagnesite has been reported from the vicinity of Soda Springs by E. V. Shannon,[91] but the location is not given very closely. It is possibly included in this report in some of the Tertiary or Quaternary limestones cited from that locality. Shannon's account is quoted below for reference.

Hydromagnesite occurs as several deposits within 4 miles of Soda Springs, in Bannock [Caribou] County, Idaho. The mineral forms small discontinuous and disconnected surface deposits. One of these has a surface area of 13 acres, another of 8 acres, and another of 2 acres. The hydromagnesite is from 2 to 4 feet thick, although below 2 feet the material is somewhat discolored.

An average and typical specimen of this material in the National Museum (catalogue No. 94140) is white and earthy in texture and is somewhat friable. It is very similar in appearance to other white earthy materials and might be mistaken for chalk, clay, diatomaceous earth, or tripoli. It is not plastic. Under the microscope the material is apparently amorphous, and no definite optical properties can be determined. The mineral could not be identified without chemical tests. An analysis of this material made by the writer in the laboratory of the National Museum, gave the following results:

Analysis of hydromagnesite from Soda Springs, Idaho

Insoluble and silica (SiO_2)	7. 52
Alumina and ferric oxide (Al_2O_3, Fe_2O_3)	1. 77
Magnesia (MgO)	38. 28
Lime (CaO)	1. 18
Carbon dioxide (CO_2)	34. 97
Water (H_2O) above 105° C	15. 41
Water (H_2O) below 105° C	1. 06
	100. 19

From the nature and occurence of this earthy hydromagnesite it would be expected to be impure. Deducting as impurities the silica, insoluble matter, lime, iron, alumina, and water below 105° C. the remaining constituents, recalculated to 100 per cent, compare as follows with the theoretical composition of hydromagnesite:

	Original percentage	Recalculated percentage	Theoretical percentage
MgO	38. 28	43. 18	43. 90
H_2O	15. 41	17. 38	19. 80
CO_2	34. 97	39. 44	36. 30
	88. 66	100. 00	100. 00

[91] Cited by Yale, C. G., and Stone, R. W., Magnesite in 1920: U. S. Geol. Survey Mineral Resources, 1920, pt. 2, pp. 12–13, 1921.

These figures show that the sample analyzed consisted of approximately 90 per cent of hydromagnesite and 10 per cent of various impurities. These deposits are quite probably of economic value as a source of magnesite for refractory materials and for the other uses for which magnesite is suited, as the material is of a fair degree of purity and can be cheaply mined.

CEMENT MATERIALS

Cement materials and the cement industry of the United States have been described by Eckel,[92] from whose valuable work the following excerpts have been taken, as germane to the discussion of cement materials in southeastern Idaho:[93]

Very erroneous ideas appear to be current concerning the value of deposits of cement materials. It should be clearly understood that in most parts of the United States excellent cement materials are common, and that the commercial value of undeveloped deposits of such materials is necessarily slight. * * * The value of the deposit depends less upon the character of the materials than upon other factors, prominent among which are the general scarcity of limestone and the demand for good limestone in each particular area. * * *

The determination of the possible value for Portland cement manufacture of a deposit of raw material is a complex problem, depending upon a number of distinct factors, the more important of which are (1) chemical composition, (2) physical character, (3) amount available, (4) location with respect to transportation routes, (5) location with respect to fuel supplies, (6) location with respect to markets. Ignorance of the respective importance of these factors frequently leads to an over estimate of the value of a deposit of raw material. * * *

The following are analyses of Portland cement mixtures ready for burning, as used at various large cement plants in the United States:

Analyses of Portland cement mixtures

	1	2	3	4
Silica (SiO_2)	12.85	12.92	13.52	14.94
Alumina (Al_2O_3)	4.92	4.83	6.56	2.66
Iron oxide (Fe_2O_3)	1.21	1.77		1.10
Lime carbonate ($CaCO_3$)	76.36	75.53	75.13	75.59
Magnesium carbonate ($MgCO_3$)	2.13	4.34	4.32	4.64

The usual mixtures carry from 75 to 77 per cent of lime carbonate. If this be borne in mind, it is obvious that there is a great advantage in using, as one of the raw materials, a limestone of about this degree of purity. If rock of this composition occurs in sufficient quantity, it would require but little admixture of other materials to keep the cement correct in composition.

Economy in excavating and crushing requires that the raw materials should be as soft and as dry as possible. On this account cherty limestones, very wet chalky limestones, and wet sticky clays are disadvantageous raw materials.

Each barrel of cement made will require the use of approximately 450 pounds of limestone and 150 pounds of clay or shale. A plant making 1,000 barrels per day will therefore use, in the course of an ordinary year about 66,000 tons of limestone and 22,000 tons of clay or shale; * * * a 1,000-barrel plant will use up almost 1,000,000 cubic feet of limestone in a year, together with 250,000 cubic feet of shale.

As the investment in plant is heavy it would be folly to locate a cement plant, under ordinary circumstances, with less than 20 years' supply of raw materials in sight. A 1,000-barrel plant, therefore should have 20,000,000 cubic feet of limestone and 5,000,000 cubic feet of clay or shale on its premises.

Portland cement is bulky; * * * the cement business is therefore much affected by transportation rates. To locate a plant on only one railroad, unless the railroad officials are financially connected with the cement plant, is simply to invite disaster. * * *

Each kiln in the plant will, with its corresponding crushing machinery, use up from 6,000 to 9,000 tons of coal a year. The item of fuel cost is therefore highly important, for in the average plant about 30 to 40 per cent of the total cost of the cement will be chargeable to coal.

In order to achieve an established position in the trade, a new cement plant should preferably have a local market area, within which it may sell practically on a noncompetition basis, and easy access to a larger though competitive market area.

From the statements regarding markets and transportation in the above excerpts it is clear that under present conditions no cement industry could successfully be established in the part of southeastern Idaho here described. Nevertheless it is pertinent to inquire if the raw materials are available should the conditions named become favorable.

A comparison of the analyses given on page 332 for the Twin Creek limestone with those of cement mixtures cited above shows that this limestone is very nearly a natural cement rock. The analysis of the Brazer limestone at Montpelier shows that in this formation at least there is very pure high-calcium limestone. The travertine is also believed to be a high-calcium limestone.

There is little question of the abundance of any of these three rocks. Bodies of all three of the formations mentioned lie within a mile of the railroad at different places within the region and in sufficient quantity for exploitation.

The shales of the region, especially the Woodside shale and members of the Thaynes group, tend to be somewhat more siliceous than is desirable for cement mixtures. These formations, however, occur near the railroad, and probably sufficient material of suitable quality may be found in them. At least two sets of shaly beds occur in the older Paleozoic rocks west of Bear Lake Valley, either of which would probably be sufficient in quantity and suitable for use in cement manufacture. These beds are the Spence shale member of the Ute formation and the Hodges shale member of the Bloomington formation (pp. 53 and 55). These shales lie between 2 and 3 miles from the railroad in Paris Canyon, the nearest point now available for transportation by rail. The phosphatic shales of the Phosphoria formation are more conveniently available, but it is doubtful if they contain enough suitable material at any given place to be usable.

There is no proper fuel for cement manufacture in the region itself, but in southwestern Wyoming there is abundance of coal that could be readily shipped in by rail and utilized.

[92] Eckel, E. C., Portland cement materials and industry in the United States: U. S. Geol. Survey Bull. 522, 381 pp., 19 pls., 1913.

[93] Idem, pp. 63-66.

Cement materials of good quality are abundant in the region, but until present conditions change they must be regarded purely as a potential resource.

ROAD METAL

Supplies available.—The supplies of rock suitable for road metal in southeastern Idaho are practically inexhaustible. The formations more commonly used for this purpose are the Woodside shale, the more shaly beds of the Thaynes group, and the Twin Creek limestone. These rocks in many places break down into fragments properly sized for direct application to roads without preliminary crushing. Ledges of shattered Swan Peak quartzite and Laketown dolomite that occur in sec. 34, T. 14 S., R. 43 E., and in secs. 22 and 27, T. 15 S., R. 43 E., in the fault zone of the Bannock overthrust, have local use for road metal on the west side of Bear Lake Valley.

The Rex chert member of the Phosphoria formation in its more shaly facies makes a useful material for surfacing roads. At many places it occurs in a minutely shattered or fractured condition on the outcrop, and where it is not actually broken up it can easily be prepared for such use. Paleozoic limestones and quartzites and Jurassic sandstones afford abundant material that can be broken for use in foundations or crushed to finer sizes for surfacing. The basalt, which is so abundant in parts of the region, if properly crushed and sized would make roads well adapted to heavy traffic.

Although a beginning has been made in certain parts of the region by the United States Bureau of Public Roads in cooperation with the State, comparatively little has yet been done in the way of constructing properly ballasted and surfaced roads. Repairs in general include merely the smoothing of the surface with such material as may be at hand. For such purposes the Woodside, Thaynes, or Twin Creek ordinarily serve very well, especially under light traffic. Under heavy wear, however, they are quickly worn down to a fine dusty pulp, and in wet weather they become muddy. With so much broken material at hand in the form of shattered rock or of talus accumulations there has been thus far little incentive to incur the expense of purchasing the necessary machinery for crushing and sizing rock and of using modern, approved, methods of road construction; but with the rapid increase in the use of automobiles and heavy trucks the question of proper construction and maintenance of roads is assuming increasing importance.

Qualities of crushed stone.—The qualities of different kinds of crushed stone used in road construction have been under investigation for years by the Bureau of Public Roads, United States Department of Agriculture. Reports on this work by Jackson[94] and Lord[95] have been summarized by Loughlin,[96] from whose account the following notes that bear on the utilization of Idaho road metal have been compiled.

Where rock is intended for water-bound macadam construction, the most essential qualities to be determined are hardness (resistance to abrasion), toughness (resistance to impact of traffic), and binding power or cementing value (ability of the rock powder when in contact with water to bind or cement the larger rock fragments and prevent their displacement under the shearing action of traffic). The specific gravity and weight per cubic foot of the stone are important in the calculation of the quantity of stone required for a certain area of road. The results of the tests made are stated as follows:

The percentage of wear is taken as the percentage by weight of rock particles below one-sixteenth of an inch in size worn off during the abrasion test.

The French coefficient of wear is obtained by dividing 40 by the percentage of wear. A coefficient of wear below 8 is called low; from 8 to 13 medium; from 14 to 20 high; above 20 very high.

Hardness is taken as the loss of weight of a faced core of rock by abrasion by sand fed upon a steel disk during 1,000 revolutions. In order to report the results on a convenient scale one-third of the loss of weight in grams is subtracted from 20; with results below 14 rocks are called soft; from 14 to 17, medium; above 17, hard.

Toughness is expressed by the height in centimeters of a standard weight required to rupture the test piece. Results below 13 indicate a low, from 13 to 19 a medium, and above 19 a high degree of toughness.

The cementing value is determined by the number of standard blows of a small hammer required to destroy a briquet of rock powder that has been mixed with water into a stiff paste and dried. Cementing values below 10 are called low; from 10 to 25 fair; from 26 to 75, good; from 76 to 100, very good; and above 100, excellent.

The generally inferior qualities of sedimentary as compared with igneous rocks are due in limestones to the softness of their essential minerals, calcite and dolomite, and in sandstones to the incomplete cementation of the constituent grains. Although it might be assumed that the relatively high degree of solubility of pulverized calcite, as compared with that of silicate minerals, should give limestones an "excellent" cementing value, results of laboratory tests prove them to have only a "good" average cementing value—54 for limestone and 33 for dolomite—as compared with averages of 118 for rhyolite, 188 for andesite, and 144 for altered basalt. The average cementing values for unaltered basalt and for the coarser-grained igneous rocks are nearly all below the cementing values of limestone and dolomite. Limestones and dolomites that contain an appreciable amount of quartz together with some kaolin or clay

[94] Jackson, F. H., Jr., Methods for the determination of the physical properties of road-building rock: U. S. Dept. Agr. Bull. 347, 27 pp., 1916.

[95] Lord, E. C. E., Relation of mineral composition and rock structure to the physical properties of road materials: U. S. Dept. Agr. Bull. 348, 26 pp., 1916.

[96] Loughlin, G. F., Stone in 1915: U. S. Geol. Survey Mineral Resources, 1915, pt. 2, pp. 837-841, 1916.

are tougher and have lower percentages of wear and higher cementing value than the purer varieties.

Tests on sandstones show them to average as high as limestones and dolomites in cementing value, or even higher, and to surpass them in toughness. Sandstones are approximately equal to limestone and dolomite in hardness but have a higher average percentage of wear. Calcareous sandstones give average results superior in all respects to limestones, dolomites, and other sandstones, except that feldspathic sandstones have a higher cementing value. Laboratory tests of sandstones, however, do not agree so closely as they should with results in practice, especially as regards wearing and binding qualities; for although these tests frequently run high in the laboratory, it is undoubtedly true that, with some exceptions, sandstones are suitable only for foundation courses. The principal test for ordinary sandstone is therefore to determine whether it has sufficient strength to withstand the weight of the roller. The difference between tests of sandstone and the results of their actual use may be due in large part to their relatively high degree of porosity and to the nature of the matrix that binds the sand grains. Absorption of water tends to soften the stone and to lessen its wearing qualities; the matrix may become so softened or leached by weathering as to promote rapid disintegration, especially in regions where frosty weather is common.

Tests of chert by the Bureau of Public Roads prove its average percentage of wear (9.4) to be distinctly inferior to that of both limestones and sandstones, its average hardness (18.2) to be superior to that of both limestones and sandstones, its toughness (12) superior to that of limestones and quartzose sandstones, but somewhat inferior to that of feldspathic sandstone, and its cementing value (30) inferior to that of both limestones and sandstones. It has been found, however, to develop good binding qualities on the road. Quartzite, which is composed essentially of the hard mineral quartz with its grains thoroughly cemented, is superior to all other sedimentary rocks and equal to or superior to most igneous rocks in percentage of wear, hardness, and toughness, but is inferior to all in cementing value.

Screenings of coarser-grained igneous rocks are more rectangular than those of fine-grained or dense rocks, which are splintery and wedge shaped, whereas those of the more loosely textured sandstones are of more rounded shape. Dense, massive limestones tend to give wedge-shaped fragments. Wedge-shaped screenings tend to produce a firmer and more permanent mechanical bond with the coarser fragments than screenings of rectangular or rounded form.

The foregoing remarks apply to stone to be used as water-bound macadam. Where bituminous material or Portland cement forms the binder, the cementing value of the stone used as surface stone is of less importance. For the road foundation crushing strength is the property of most critical value. It may be inferred that, as a rule, a stone of satisfactory wearing qualities for surface use has a requisite crushing strength. Some sandstones, limestones, and altered igneous rocks whose hardness and toughness are inferior have crushing strength sufficient for use in road foundations.

Utility of the Idaho rock.—So far as known to the writer no tests of the road-making qualities of the rocks of southeastern Idaho have been reported. The foregoing accounts, however, seem to indicate that crushed stone obtained from the older Paleozoic limestones or from the Nugget sandstone, which is feldspathic, or from the basalt would be better for use in any program of permanent road building in the region. For simple surface coating or patching, such as has hitherto been the customary method of road improvement, it is probably more economical to use the Woodside, Thaynes, or Twin Creek material, though more frequent dressings will doubtless be required to keep the roads in good condition.

BUILDING STONE

The only native building stone that has thus far been used in the region described in this report is the Nugget sandstone, which has been quarried at two places and used from each place for the construction of a single building. One of these places, which is in the SE. ¼ SE. ¼ sec. 32, T. 14 S., R. 45 E., Montpelier quadrangle, has been described by Loughlin [97] as follows:

> The prospect near Dingle lies about 5 miles southeast of Dingle village and 3 miles southwest of Harer (Hear) siding on the Oregon Short Line, near the head of Pine Springs Gulch. The deposit is a part of the Nugget sandstone, of Jurassic or Triassic age, and is exposed along the north side of the gulch for a height of 400 or 500 feet, the beds striking a little west of north and dipping 35° to 50° W. The stone is fine, even grained, and nearly all of light reddish-brown color, some of uniform appearance, and some with conspicuous thin bands of light and dark brown and occasionally of creamy white. At the east end of the exposure is a thin-bedded outcrop of creamy-white sandstone with little or no brown coloring matter. The constituent grains are quartz with considerable feldspar, and the principal cementing materials appear to be silica and ferric oxide. The outcrops are largely of thin-bedded appearance, owing to more pronounced weathering along certain seams or bedding planes. Single layers range from a few inches up to 1, 2, and 3 feet in thickness. It is probable that these seams will not be so conspicuous below the weathered surface and will not prevent the quarrying and use of thicker beds. Near the west end of the property, blocks measuring 5 feet or more in thickness and 10 feet or more in length are exposed in the broken outcrops at three or more distinct horizons. Thus far only talus blocks have been quarried, furnishing mostly small blocks of less than 3 feet in length and a foot or less in thick-

[97] Loughlin, G. F., in Burchard, E. F., The stone industry in the United States in 1913: U. S. Geol. Survey Mineral Resources, 1913, pt. 2, pp. 1285–1410, 1914. (Idaho, by G. F. Loughlin, p. 1386.)

ness; but some finished blocks 6 feet or more in length have been dressed for steps, copings, and sills.

The only test thus far made on the stone was a crushing test of a 2-inch cube by Prof. Solon Shedd, at Pullman, Wash., which was found to have a crushing strength of 12,000 pounds to the square inch, a much greater strength than is possessed by several well-known sandstones. The only example of the stone seen in use is the dwelling house on Ream's ranch, Dingle, where the stone has been in place for 10 years with no sign of weathering. In view of the scarcity of stone of this color in the Northwest, this prospect is well worthy of consideration.

The second locality is on the north side of Poison Canyon in the SE. ¼ sec. 9, T. 9 S., R. 46 E., Crow Creek quadrangle. The rock here is a light-colored yellowish or almost white sandstone of fine and even grain, which seems to split easily along planes parallel to the bedding. The strike is N. 17° E. and the dip 58° W. to nearly vertical. Farther west reddish-brown rock generally similar to that at the Dingle quarry is exposed along the canyon. Very little has been done in the way of excavation, most of the material used having come from the talus. Blocks 2 feet thick could be obtained, but most of the pieces in sight were less than a foot thick.

Stone from this locality was used in the construction of the Mormon tabernacle at Afton, the most conspicuous and pretentious building in upper Star Valley. When examined by the writer in 1914 the structure had been standing a number of years and the stone appeared to have withstood well the effects of weathering.

Samples of this rock submitted to the United States Bureau of Standards were tested, with the results shown in Table 95.

TABLE 95.—*Tests of Nugget sandstone, sec. 9, T. 9 S., R. 46 E.*

Compressive strength (pounds per square inch)

Dry stone	Wet stone	Comparative strength wet and dry samples (gain in wet samples)
13, 426	16, 257	
13, 432	16, 474	
12, 126	18, 002	
Av., 12, 995	16, 911	3, 916

Absorption, specific gravity, and porosity

Absorption (per cent)	Apparent specific gravity	True specific gravity (4 determinations on powdered stone)	Porosity
3. 16	2. 309		
3. 15	2. 309		
3. 15	2. 322		
Av.,3.15	2. 313	2. 643	12. 490

TABLE 95.—*Tests of Nugget sandstones, sec. 9, T. 9 S., R. 46 E.*—Continued

Comparative compressive strength (pounds per square inch) of original and frozen samples, and changes of weight on freezing

Original sample	Frozen sample	Change in strength by freezing		Percentage change in weight by freezing	
		Loss	Gain	Loss	Gain
13, 426	20, 485				
13, 432	21, 441				0. 003
12, 123	21, 678				. 012
Av., 12, 995	21, 201	0	8, 206	0	. 006

The average crushing strength of the dry stone, as given in Table 95, compares very favorably with that of such well-known building stones as the limestone from Bedford, Ind., and the Berea sandstone of Ohio, which is not much more than half as great. The greater strength indicated by the wet samples does not imply any marked change in the chemical composition of the rock by the addition of water but suggests rather that the pieces tested wet were in all probability more thoroughly silicified than the others and that they would have given, if tested dry, higher results than those that were so tested.

The percentage of absorption of the samples tested is also low, only one-fourth or one-fifth as great as the corresponding percentage of Berea sandstone. The true specific gravity is very close to that of quartz, indicating that the rock is very nearly a pure quartzite. The porosity is also low as compared with that of Berea sandstone.

The differences shown in the freezing tests can probably be satisfactorily explained in the same way as those in the tests of the comparative strengths of dry and wet rock. The number of tests and the number of pieces tested is too small to indicate anything more than variation in degree of cementation of the different samples.

The results of the tests as a whole, however, are satisfactory in showing that the rock is more durable than some of the best known building stones of the East. The greater crushing strength of the stone from Idaho would imply that this stone may be more difficult to work than the other building stones mentioned.

The Nugget sandstone is widely distributed in the region here described, and its characteristics appear to be relatively uniform over considerable areas. It would seem, then, that in this rock southeastern Idaho has a building stone that may prove to be a very valuable resource. At present many of the areas of its occurrence, as in the Freedom and Lanes Creek quadrangles, are remote from the railroad, but in a number of places in the Montpelier quadrangle, as in T. 14 S., R. 45 E., it is directly accessible to railway transportation.

Of the other sedimentary rocks in the region it seems probable that the Nounan limestone and the Brigham quartzite afford the best possibilities for utilization as building stone. The general character and distribution of these formations are described on pages 52 and 55. They have not been prospected or tested, but they occur in sufficient abundance to justify extensive development should market and other conditions warrant their exploitation. Still other sedimentary formations might be utilized locally for building stone, but their lithologic character, bedding, or fractured condition probably render most of them unfit for this purpose.

Of the igneous rocks, the hornblende andesite porphyry, though of attractive appearance, is too much fractured and occurs in too small quantity to offer any promise of utilization for building stone. The rhyolite in this region is largely of such a porous and friable nature that it, too, except perhaps very locally, may be rejected from consideration. The basalt, which is plentiful, may find some use in building operations.

With reference to the use of basalt in other parts of the State, Loughlin[98] remarks:

> Basalt has been extensively used as rubble and in the side and rear walls of many buildings, where the colors and shapes of the blocks were of no great consequence. Dressed blocks have also been used in a few cases. The Zion Cooperative Mercantile Institution Building at Idaho Falls, built in 1884, has a front entirely of basalt in dressed blocks, with both rock face and finely tooled surface; some blocks are 6 feet long. The stone is of nearly black color and contains several small to large irregularly spaced vesicles. It gives a somber appearance but shows no weathering effects after 30 years of exposure, and doorsills where loaded trucks have been passing back and forth have not suffered any noticeable abrasion. Basalt has also been used, and with good effect, in the base of the Methodist Episcopal church, at Lewiston, erected in 1907. Here the blocks are mostly small, with rock face exposed.

SAND AND GRAVEL

Sand and gravel for cement work or other uses are available at a number of places in Bear Lake Valley, chiefly from the shore-line deposits of the former higher levels of Bear Lake and from the alluvial fans of streams that entered that lake at those levels. No study of these materials has been made, but the supply seems ample, at least for local needs. The position of the most prominent of these shore lines is indicated on Plate 9.

MINOR RESOURCES

SALT

Historical sketch.—The saline springs in the Crow Creek and Freedom quadrangles have already been noticed. (See p. 322.) In the old days, before the advent of railroads in the West, relatively large amounts of salt were boiled from these brine springs and were hauled by ox team to supply mining camps in Idaho and Montana. Emigrants to the Northwest along the route by Landers Cut-off also drew upon this region for their salt. In the reports of the Hayden Survey this area was briefly described as containing the finest salt works west of the Mississippi.

The salt resources of this region were described some time ago by Breger[99] and have since been reviewed by Phalen.[1] In the present account data from Breger's report have been supplemented by additional data gathered by the writer.

Chemical composition and quality.—The rock salt has a reddish-brown color owing to the presence of a small quantity of clay that contains ferric oxide. When the rock salt is dissolved in water and evaporated, the iron oxide disappears, leaving a brilliant white salt, such as forms incrustations on the ground near the shafts and along the ditches of the salt works.

Analyses of the crude rock salt and of the dissolved salt were made in the laboratory of the Geological Survey and are given in Table 96.

TABLE 96.—*Composition of rock salt from sec. 28, T. 9 S., R. 46 E.*

[Chase Palmer, analyst]

Crude salt		
Soluble "salt"		91.79
Insoluble material:		
Red clay—		
SiO_2	4.36	
Fe_2O_3	.27	
Al_2O_3	.88	
MnO	Trace.	
Lime and magnesium sulphates and carbonates—		
MgO	.13	
CaO	.67	
SO_3	.11	
CO_2	Not determined.	
		6.42
Moisture		.85
		99.06
Soluble salt		
Sodium chloride (NaCl)		98.900
Calcium sulphate ($CaSO_4$)		.817
Potassium chloride (K Cl)		.261
Magnesium chloride ($MgCl_2$)		.022
		100.000

As shown in Table 96, the soluble salt is very nearly pure sodium chloride. A partial analysis of commercial table salt boiled from one of the Stump Creek springs was also made by Palmer. This analysis probably represents the usual quality of the salt boiled from the brine springs of the Tygee-Stump Creek district. The analysis shows only a trace of magnesium and 0.73 per cent of lime (CaO), equivalent to 1.77 per cent of calcium sulphate ($CaSO_4$). The salt is thus

[98] Loughlin, G. F., op. cit., p. 1379.

[99] Breger, C. L., The salt resources of the Idaho-Wyoming border, with notes on the geology: U. S. Geol. Survey Bull. 430, pp. 555–569, 1910.

[1] Phalen, W. C., Salt resources of the United States: U. S. Geol. Survey Bull. 669, pp. 131–137, 1919.

similar chemically to the Crow Creek rock salt in the low or almost negligible content of magnesium and the high percentage of pure salt or sodium chloride. The percentage of potash in the salt is too low to have commercial interest.

The salt of this district is above the average of the commercial salts of the United States in purity and compares favorably with some of the best salt produced. As generally prepared, little or no precaution as to cleanliness is taken. With ordinary care, however, a brilliant pure-white salt can readily be obtained.

Rock salt.—The salt bed on Crow Creek was being worked in 1925 by its owner, J. N. Booth, and a few tons of salt was being mined and sold locally each year, though he reports a decreasing market. According to Osborn Lowe, Afton, Wyo., present owner of Lowe's ranch on Crow Creek, the bed occupies a basin-like depression about 100 yards in diameter and lies only 1 to 3 feet below the surface. The salt is spotted and dirty near the surface, but clear, hard, glassy, and relatively pure below. The bed has been penetrated 10 to 12 feet (20 feet, in Breger's account) but the bottom has not been reached, as on blasting out holes to that depth water comes in and forces a change of operations to another locality. The salt is ordinarily sold in large lumps or is broken down to smaller fragments and sacked.

Boiled salt.—As described by Breger the brine is dipped in pails by hand and poured into sheet-iron shovel-shaped troughs or pans about 10 feet long, 3 or 4 feet wide, and 10 inches deep. Each pan rests on a three-sided fire box, about 3 feet high, built of rough stones cemented with clay. The salt is stirred with a shovel as the water boils off. The product is medium to fine grade. There is no equipment for milling or grinding. Two or three such pans are inclosed in a log cabin. Fuel, consisting of fallen logs and timber cut from near-by patches, has to be hauled to the works, which is the most laborious and costly item in the manufacture of the salt.

Salt industry.—The production of salt, which in the late sixties and early seventies amounted to about 325 to 425 short tons a year,[2] had dwindled by 1906 to about half that amount. The decrease has continued, but a small and varying amount is still produced for local consumption by operators who live at Auburn and Afton, Wyo. Most of the material comes from the salt bed that was discovered in 1902 at the brine spring opposite Lowe's ranch on Crow Creek and from the McGrew and Reed springs in Stump Creek. McGrew sold a little in 1924 but more in 1925. The production from 1906 to 1925 and the average price per ton of the product for the last five years of that period are given in Table 97.[3]

[2] Hayden, F. V., U. S. Geol. Survey Terr., Fifth Ann. Rept., p. 161, 1872.

[3] Data from U. S. Geol. Survey Mineral Resources, 1906–1920, inclusive, chapters on salt; and A. T. Coons, Bur. Mines, personal communication.

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TABLE 97.—*Production of salt on Idaho-Wyoming border, 1906–1920, in barrels and short tons, and price of salt per ton*

Year	Quantity		Value
	Barrels	Equivalent in short tons	
1906	1,574	220	$1,867
1907	1,600	224	2,040
1908	1,114	156	1,413
1909	793	111	1,118
1910	885	124	1,127
1911	314	44	532
1912	(a)	(a)	(a)
1913	(a)	(a)	(a)
1914	300	42	520
1915	(a)	(a)	(a)
1916	314	44	511
1917	114	16	216
1918	(a)	(a)	(a)
1919	278	39	530
1920	(a)	(a)	(a)
1921	------	------	------
1922	150	21	240
1923	221	31	310
1924	236	33	350
1925	(a)	(a)	(a)

[a] Small production reported but not published separately.

Average price per ton of Idaho salt, 1921–1925 [a]

	1921	1922	1923	1924	1925
Rock salt	--------	$10.00	$10.00	$10.00	$10.00
Evaporated salt	--------	16.00	--------	13.33	--------

[a] Coons, A. T., Bur. Mines, personal communication.

The higher price of the brine salt is probably due to its use for the table, whereas the rock salt is more commonly sold in lumps for salting stock.

The market formerly served by the salt industry of this region is now largely supplied by salt from works near Salt Lake City, which have the advantage of accessibility to railroads.

Outlook.—Until a railroad is constructed in Star Valley, of which there is no immediate prospect, though some preliminary surveys have been made along Snake River (p. 47), there can be no possibility of any other than a local market for the Idaho salt.

If the question of markets be set aside there remains the question whether the deposits are of sufficient size to warrant large-scale development. On the basis of certain assumptions regarding its origin Breger estimates the content of the salt bed opposite Lowe's ranch on Crow Creek at 5,000,000 short tons of soluble salt. The present writer considers the evidence too meager to justify definite estimates and would advocate a much more conservative figure. Since this bed underlies what was formerly a brine spring it is probable that the other brine springs are underlain by similar beds of salt. The occurrence of salt beds in the Wallace-Wyoming Oil Co.'s well on Tygee Creek, described below, supports this conclusion. The outflow of brine from the springs is apparently small, so that unless salt beds were present plants that relied upon brine for their salt would have only small supplies for their daily operation. Possibly the flow of brine could be increased by drilling, blasting, or otherwise, but further exploration would be necessary before this could be determined.

There is a question, too, whether the respective brine springs have any connection with each other. The answer to this question depends in considerable measure upon the views that may be held regarding the origin of the deposits. This question is discussed briefly below.

Origin of the salt.—Breger's views on the age and origin of the salt are given below:[4]

The salt was originally disseminated in small amount in the red sandstone, conglomerates, and shales of the Beckwith formation[5] at the time these rocks were laid down in the shallowing and disappearing Jurassic-Cretaceous seas. The anticlines into which the porous Beckwith rocks are folded have localized the underground water circulation. On the crest of one of these anticlines are located all the productive salt areas on Stump Creek and lower Tygee Creek; the Draney spring is near the crest of the same anticline. The Crow Creek rock-salt area is on the crest of a prominent dome, at the mouth of a small tributary, Rock Creek.

The present productive salines were deposited during pre-Pleistocene time in the form of alkali flats at or near the mouths of incoming lateral streams or valleys. The salt-bearing waters reaching the main valleys sank into the gravels or spread over the surface. On evaporation or partial evaporation of the waters the salt was left behind, either on the surface or in the gravels.

The hypothesis of pre-Pleistocene alkali flats and saline evaporation in the valleys to account for the present deposits is favored by the ideal conditions presented by the anticlinal folding of the salt-bearing, porous Beckwith rocks, coupled with the climatic aridity which has been shown to have preceded the Pleistocene. The long duration of the arid conditions, which may have extended nearly as far back as the period of the Oligocene (?) conglomerates [Salt Lake formation], and the antiquity of the existing drainage features also support this hyothesis.

With the resumption of humid climatic conditions in the Pleistocene period the alkali flats were buried under an outwash of the stony red clays. These clays have blanketed the salt with a nearly waterproof cover which has protected the soluble mineral from being eroded or from being dissolved and carried away. Where recent erosion has washed the covering of Pleistocene red clays from the river bottoms the buried alkali flats yield their salt in the present productive brine spring areas.

The views above quoted are preceded in Breger's account by an outline of so much of the geologic history of the general region as bears upon the origin of the salt deposits. More detailed study has shown that the stratigraphic, structural, and earlier physiographic conditions here are more complex than was postulated in Breger's outline, and that the geologic history is accordingly more complex.

[4] Breger, C. L., op. cit., pp. 566-567.

[5] The term Beckwith as here used includes the beds now assigned to the Preuss and Stump sandstones and to the Gannett group. (See pp. 99 and 101.)

Boring by the Wallace-Wyoming Oil Co. in 1922 in Tygee Valley has shed new light on the origin of the salt. According to the log of the well furnished by Ben Jackson, manager of the company, through V. R. D. Kirkham, about 456 feet of salt-bearing strata, including six beds of actual salt that range in thickness from 6 to 29 feet and aggregate 96 feet, were penetrated in the well. The interstratification of these salt beds with beds of shale, gray lime (anhydrite?), conglomerate, and gypsum leaves little doubt that the salt beds were originally deposited with the accompanying sediments, which, according to the best evidence now available, are tentatively assigned to the lower part of the Preuss sandstone. They were probably limited originally to a local basin, for the Preuss sandstone is not known to be salt-bearing elsewhere than along the line of the valleys of Crow, Tygee, and Stump Creeks. They may have been marine, but were more probably nonmarine, like the salt-bearing beds that accompany the niter-bearing clays of Amargosa Valley in southeastern California.[6] Whatever may have been their former extent they now lie in a fault zone which consists of rock slices that include a number of formations. The salt beds are therefore probably not continuous along the line mentioned and are not of great breadth, but they may be cut off here and there by faults.

The location of the well, as reported by Mr. Jackson, is not clearly shown. In one letter it is given as in the NW. ¼ SW. ¼ sec. 3, T. 8 S., R. 46 E., and in another as in the SW. ¼ SW. ¼ sec. 34, T. 7 S., R. 46 E. (See pl. 5.) The log is presented in Table 98.

TABLE 98.—*Log of well of Wallace-Wyoming Oil Co., Caribou County*

[January 1, 1923, elevation about 6,200-6,300 feet]

	Thickness	Depth
	Feet	*Feet*
Soil, gravel, water; with some shale	24	24
Shale, brown to pinkish	99	123
Salt, conglomerate, and reddish shale	50	173
Salt, light red	14	187
Shale, brown	7	194
Salt	29	223
Shale, brown, and salt	41	264
Salt	20	284
Shale, brown, heavy; some salt	91	375
Gray lime (anhydrite?)	1	376
Shale, brown, and "talc"	13	389
Shale, brown, salt	5	394
Salt and gypsum	5	399
Shale, brown	40	439
Salt, pure; very little color	20	459
Shale, brown	18	477
Conglomerate, pinkish	22	499
Shale, brown	10	509
Shale, red	40	549
Salt, red	7	556
Shale, brown	1	557
Salt, pure	6	563
Shale and salt	16	579
"Conglomerated shale," light in color	15	594
Conglomerate, yellow	40	634
Lime; showing of oil at bottom of hole	60	694

[6] Noble, L. F., Mansfield, G. R., and others, Nitrate deposits in the Amargosa region, southeastern California: U. S. Geol. Survey Bull. 724, pp. 31-34, 1922.

SULPHUR

Occurrence.—Sulphur springs and deposits of sulphur occur in T. 9 S., R. 42 E., in the vicinity of Sulphur Canyon. The deposits were exploited commercially for a time, but the plant was dismantled about 1912, and the sulphur has been practically untouched since that time. In 1918, in response to the more active demand for sulphur as a war mineral, the Idaho Sulphur Co. was organized to reopen and again exploit these deposits.[7] A retort plant was built that had an estimated capacity of 50 tons of finished product a day. Superheated steam was to be used for melting the native sulphur out of the gangue in closed retorts. Practical tests made with these retorts indicated that a large percentage of the sulphur in the ore could be extracted.

It was expected that the plant would be completed and in full operation during the spring of 1919, but with the signing of the armistice and the relaxation of the demand for sulphur the project had to be abandoned.

In 1920 the writer's attention was drawn to some recently opened sulphur prospects in T. 10 S., R. 43 E. Both of these districts are briefly described below.

Deposits in T. 9 S., R. 42 E.—As a part of the present series of investigations, the sulphur deposits in T. 9 S., R. 42 E., were studied by Richards and Bridges,[8] from whose report the following account is largely taken.

Sulphur was formerly mined at several places in two groups of workings in sections 2, 11, and 14, between Wood and Sulphur Canyons. Some prospecting has also been done in section 13. The greater part of the excavation in both groups was done 50 to 200 feet above the level of the present springs. Both quarrying and tunneling methods were employed. About 2,000 cubic yards were excavated in the open work. The underground workings were reported to comprise several hundred feet, but the condition of the tunnels was such that no examination of them was possible. The plant for extracting the sulphur from its gangue was located on the side of the divide toward Wood Canyon.

The sulphur, which is associated with small crystals of gypsum, occurs as the cement of a fault agglomerate or breccia composed of fragments of tuff, limestone, and quartzite. The tuff is composed of angular fragments of volcanic glass and makes up the most conspicuous part of the agglomerate. It is white and weathers to an infertile soil, the barren nature of which was noted by the early explorers. Gases that escape from crevices in the rock near by have injured or retarded vegetation and have proved injurious to animals, as indicated by the dead rabbits and birds found in some places. The tuff, which was assigned by Richards and Bridges to the Cretaceous, is here regarded as part of the Salt Lake formation, in which somewhat similar tuff has been found elsewhere.

The sulphur occurs in small pyramidal crystals that line cavities and in crystalline and amorphous masses in the interstices of the breccia. Stalactites of sulphur were noted in vertical crevices in the breccia in the south wall of the quarry near Wood Canyon. This variety, which has almost a canary-yellow color on fresh fracture, changes rapidly on exposure to a dull submetallic gray. No analyses are available, but Richards and Bridges made a tentative estimate that the material exposed in the quarry face would run about 10 per cent native sulphur.

Alum has been reported as present in the ore, but none has yet been found by representatives of the Geological Survey.

Deposits in T. 10 S., R. 43 E.—A group of prospects has been opened by F. R. Richards, of Montpelier, on the south side of a canyon in about the NE. ¼ sec. 14, T. 10 S., R. 43 E. The sulphur-bearing area was said by Mr. Richards to be about 360 feet long and to have a vertical range of about 40 feet. As seen by the writer the actual opening in the hillside was about 70 feet long and 20 feet wide and the whole group of vents extended about 225 feet S. 50° W. Several small openings, each only a few feet across, had been made. Hydrogen sulphide was escaping from these openings, and in one of them were found some dead birds and a dead woodchuck.

Native sulphur occurs in crusts and in masses that interpenetrate a porous white material which resembles travertine but which makes little if any response when tested with hydrochloric acid. It probably represents the residue of the impure Carboniferous limestone in which the vents are located. This limestone has been leached by acidulated waters and permeated by sulphurous vapors. Some gypsum in small crystals is interspersed in the limestone mass. The occurrence of the sulphur and its mode of origin are similar to the corresponding features of the deposit in T. 9 S., R. 42 E., described above. The sulphur-bearing rock in T. 10 S., R. 43 E., has not been opened more than 4 feet below the surface, and the sulphur is mostly near the surface. The sulphur occurs in two varieties, a yellow crystalline type and a grayish mammillary or stalactitic type. Hand-picked samples of these two types of ore were analyzed in the laboratory of the Geological Survey. The yellow crystalline sample contained 79.92 per cent of native sulphur and 0.33 per cent of sulphur in the form of sulphate. The gray sample contained 90.55 per cent of native sulphur and 0.45 per cent of sulphur in the form of sulphate. The run-of-mine material would have a much lower content.

[7] Bell, R. N., Twentieth annual report of the mining industry of Idaho, p. 106, 1919.

[8] Richards, R. W., and Bridges, J. H., Sulphur deposits near Soda Springs, Idaho: U. S. Geol. Survey Bull. 470, pp. 499–503, 1911.

Origin of the sulphur.—According to Clarke,[9] native sulphur is commonly a companion of gypsum and both may be produced in many ways. Sulphur is known as a volcanic sublimate and is a product of reactions between sulphur dioxide and hydrogen sulphide. It is also formed by the incomplete combustion of hydrogen sulphide, probably in accordance with the equation $2H_2S + O_2 = 2H_2O + 2S$. Where oxygen is in excess, as at the surface, hydrogen sulphide is completely oxidized and sulphuric acid is formed. A short distance below the surface oxygen is deficient, and then sulphur is liberated. Probably actual conditions are more complex. Sulphur dioxide must be produced to some extent, and that substance reacts with the hydrogen sulphide to form sulphur also.

Hydrogen sulphide may be generated either by the action of acid waters upon sulphides or through the reduction of sulphates such as gypsum by microorganisms, or the gas may be of volcanic origin. The interpretation of the origin of the sulphur at any given locality is not easy, for different conditions govern in different places.

Southeastern Idaho contains no large deposits of gypsum, and the small amount of that mineral associated with the sulphur appears rather to have had a common origin with it than to have served as a source. The proximity of these deposits to volcanic centers suggests that a volcanic origin for the hydrogen sulphide and the associated carbon dioxide is plausible.

Quantity of sulphur.—Drilling operations and surface exploration carried on by the Idaho Sulphur Co. about 1918 led the prospectors to believe that the deposits contained more than a million tons of sulphur-bearing rock of good grade.[10] In the opinion of the writer such an estimate should be received with due caution. Upon the assumption that the sulphur has been deposited in crevices and openings in the rock by means of the imperfect oxidation of hydrogen sulphide and by the reaction of this gas with sulphur dioxide, these activities could take place only near the surface in those openings to which air had access. In a similar deposit examined by the writer in Jemez Canyon, Sandoval County, N. Mex., it was found that in four cuts made in the most promising part of the area the sulphur ore had a depth of only 2 feet 4 inches to 3 feet 4 inches and that the rock beneath contained no native sulphur, though it did contain small amounts of sulphur in the form of sulphate. It seems doubtful therefore if the quantity of available sulphur ore in such deposits is sufficient for commercial exploitation, unless the area affected is large. Thus far no actual measurements of the total area affected are available. This area is not continuous throughout but consists of a number of more or less distinct minor areas, as shown in Plate 62.

[9] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, pp. 586–588, 1924.

[10] Bell, R. N., idem.

Commercial development.—The ore from the deposits in T. 9 S., R. 42 E., was smelted for a time by the Western Sulphur Co., of Duluth, Minn., in a plant located near the workings, but the company failed, although the equipment appears to have been well selected and well installed. It consisted of two coal-burning boiler units, a battery of five or six cylindrical retorts, and a crushing plant. The system of smelting consisted of introducing the handsorted ore in perforated iron cars of about half a ton capacity into a retort which would hold one car at a time, melting the sulphur from the gangue by the introduction of steam into the retort, and drawing off the sulphur into suitable molds. The sulphur cake was then put through a crusher and grinder, reduced to a fine powder, and sacked.

The later project of the Idaho Sulphur Co. was abandoned before it had a chance even to get well started.

The deposit in T. 10 S., R. 43 E., has been sold to the Willamette Paper Co., which has offices in Portland, Seattle, and San Francisco. No further development of the property has been reported.

Outlook.—The outlook for a sulphur industry in southeastern Idaho is not bright. The available quantity of ore is probably not sufficient to justify large-scale development. Two companies, one of which was apparently well equipped and well established, have failed, and there is little inducement for others to start, especially when the needs of the country for sulphur are so largely met by the mines of Texas.

LEAD

Occurrence.—Lead and copper deposits that are reported to carry silver and gold occur in the Bear River Range near the western border of the Montpelier quadrangle. Some of these were observed by Hayden[11] in 1871, who made the following comments regarding them:

> The lower quartzites appear to have been partially metamorphosed and contain some quite rich silver ores. These ores do not appear to be found in regular lodes but in pockets or irregular cavities.
>
> From all evidence that I could obtain I formed the opinion that these mines would never become profitable, though they are quite interesting from a scientific point of view.

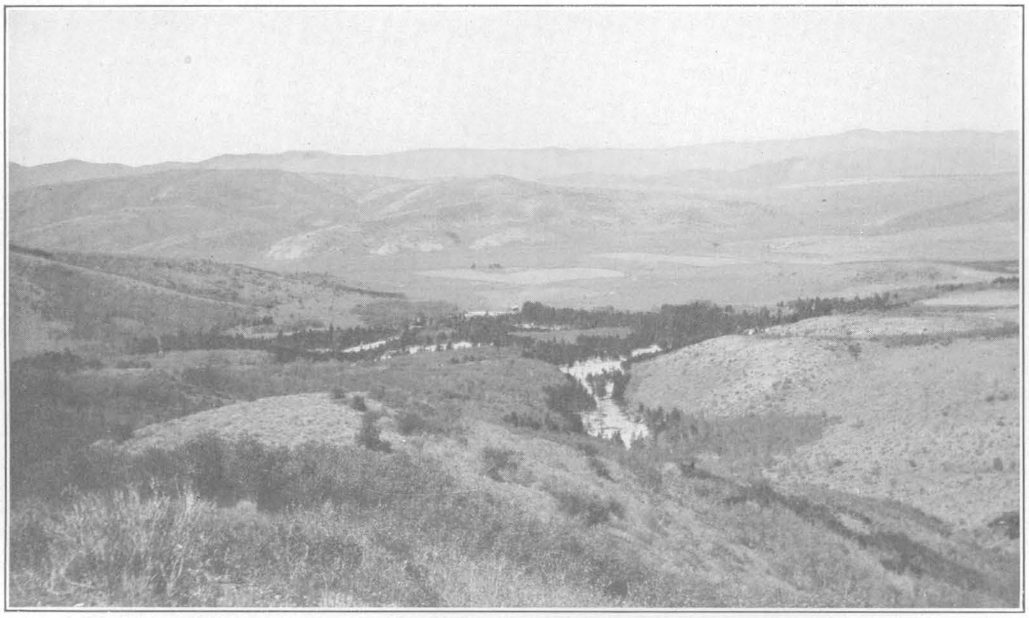
Hayden's opinion seems to have been justified by the later development at these properties. Although the deposits have been worked in a desultory way nearly to the present time and some ore has been shipped, the mines have practically been allowed to fall to ruin, and there seems to be no prospect of any sound commercial development.

The deposits have been described by Richards,[12] from whose report, supplemented by observations of other survey field parties under the direction of the writer, the following account is compiled.

[11] Hayden, F. V., U. S. Geol. Survey Terr. Fifth Ann. Rept., pp. 156–157, 1872.

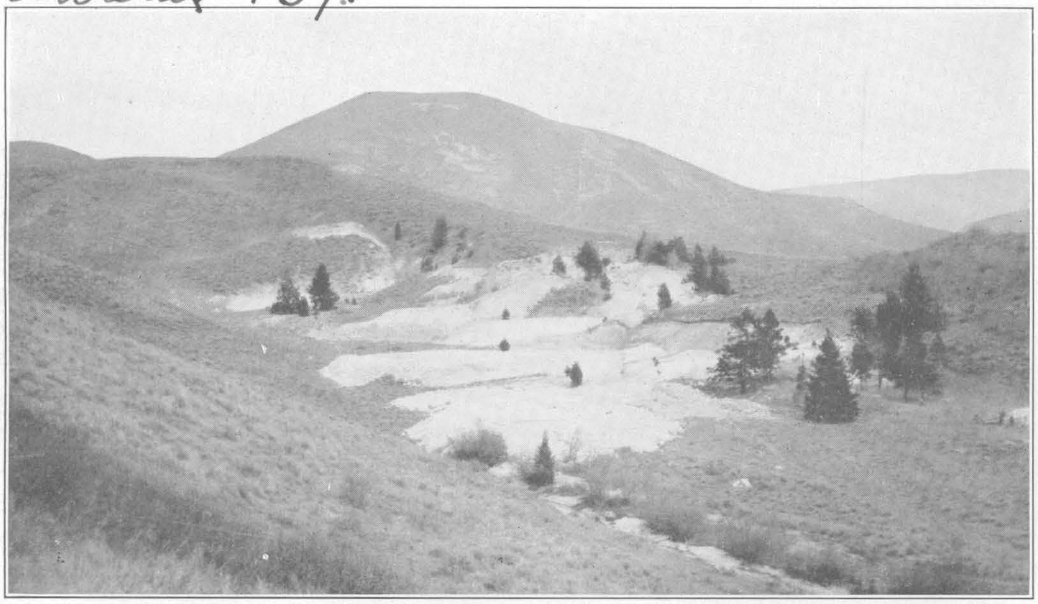
[12] Richards, R. W., Notes on lead and copper deposits in the Bear River Range, Idaho and Utah: U. S. Geol. Survey Bull. 470, pp. 177–187, 1911.

Richards 135.



A. GENERAL VIEW

Richards 137.



B. NEARER VIEW OF SOME OF THE WORKINGS

SULPHUR DEPOSITS NEAR THE MOUTHS OF WOOD AND SULPHUR CANYONS, IN T. 9 S., R. 42 E.

Mineralized area.—The prospect pits are so numerous that only a few of them were visited. They are scattered over the east side of the range from the vicinity of Woodruff, Utah, north to Soda Springs, Idaho. The lead ores consist of galena with small amounts of cerusite and wulfenite in a gangue of iron-stained calcite and dolomite and are found at Swan Creek, Utah, and near St. Charles and Paris, Idaho. They appear to be replacement deposits in limestone, more or less parallel to the bedding and cut and limited by fissures. The lead deposits occur in the main along the general contact zone of the Blacksmith (?) and Ute (?) limestones, of Cambrian age. The upper contact of the Blacksmith (?) limestone is also locally mineralized, but with copper minerals instead of lead. These two mineralized zones are traceable for many miles along the outcrops of the formations named.

Blackstone mine.—The most extensive lead workings are probably those of the Blackstone mine, in the SE. ¼ SE. ¼ sec. 17 and the NE. ¼ NE. ¼ sec. 20 (unsurveyed), T. 15 S., R. 43 E. The mine is owned by the Blackstone Mining & Power Co. (Ltd.), a corporation controlled by Edgar B. Cloud, of Twin Falls, Idaho. The only shipments from the property are reported by W. H. Cloud to have been made in 1896 and to have consisted of 3 carloads of ore that ran 80 per cent of lead and of 16 carloads of concentrates that averaged 78 per cent of lead. The property at that time was controlled by W. M. Dodge and operated by W. M. Raht under lease. The concentrating plant built by Mr. Raht was burned, which put an end to shipments. In 1910, however, preparations were in progress for undertaking further work on several of the claims. Little has been accomplished since that time, and the mine structures have been allowed to fall to ruin.

The ore at the Blackstone mine consists of crystalline aggregates of galena, much broken and surrounded by a thin alteration zone of dark cerusite, the whole mass held in a gangue composed of iron-stained limestone and a small amount of siderite. In one of the neighboring prospects wax-yellow tabular crystals of wulfenite, lead molybdate, are associated with the galena. Sphalerite in brown rounded crystals was also noted, but only in small quantities. The ore of the Blackstone mine was reported by the owners to be nonargentiferous and zinc free, but the prospects to the north, which carried traces of zinc, were said to contain amounts of gold and silver that tended to offset the lower percentage of lead. According to R. N. Bell,[13] however, the ore of the Blackstone mine runs about 27 per cent of lead, 50 cents in gold, and 4 ounces of silver to the ton. He also states that the shipment of three carloads mentioned above was probably the highest grade of lead ore ever shipped from the State.

[13] Bell, R. N., Ninth annual report of the mining industry of Idaho, p. 50, 1908.

The developments at the Blackstone mine comprise about 800 feet of tunnels and drifts with adjoining stopes as illustrated in Figure 37.

The rocks in the mineralized area strike N. 20° W. and are cut by a set of nearly vertical fissures that strike N. 60° W. and appear to dip northeastward—that is, "the fissures dip into and strike about midway between the strike and the dip of the bedding of the limestone." In part of the mine a fissure that has a northeasterly trend limits the ore body. The miner-

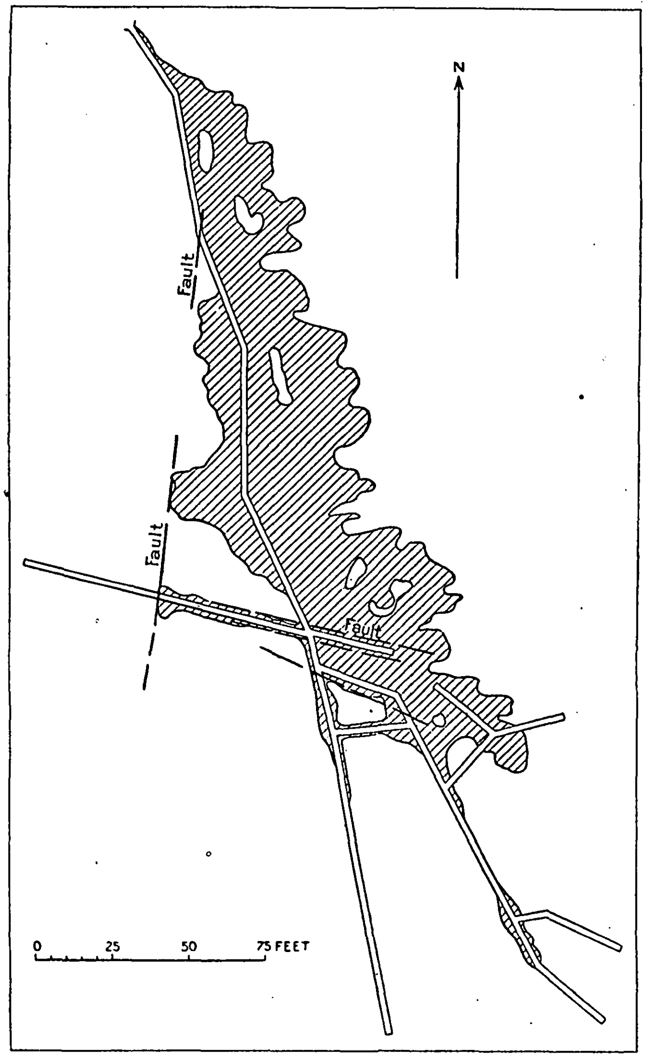


FIGURE 37.—Plan of the Blackstone mine

alized area appears to be tabular and to have its longest dimension parallel to the strike of the beds. The ore is richest at the top; its maximum thickness is estimated at 8 feet. The dimensions of the ore body are probably not much greater than those of the present workings.

Idaho Gem.—In the NE. ¼ sec. 17 (unsurveyed), on the south side of Dry Canyon, in the same township, a group of claims is clustered about a mine called the Idaho Gem. The mine consists of a housed shaft equipped with a horsepower hoist. Little evidence of valuable mineral was seen on the dump.

There has been no activity at this mine since about 1910.

Boulder mine.—The Boulder mine lies on the steep eastward-facing slope in the SE. ¼ SW. ¼ sec. 1 (unsurveyed), T. 14 S., R. 42 E. As seen by the writer in 1914 the underground workings consisted of an adit 300 feet or more long that had a crosscut at about 200 feet. In the right arm of the crosscut at about 50 feet was a shaft 50 feet or more deep. The other arm of the crosscut had an oblique raise at about 50 feet and another raise at the end. There was no vein or continuous ore body, and no pay mineral was observed. In 1912 a member of the survey party reported having seen about 15 tons of good galena on the dump at this mine. In 1914 the writer was informed that a pocket opened a year or two ago had furnished a carload of lead ore that carried a little silver. This ore was doubtless the ore seen in 1912. The mine is apparently in the Ute limestone and perhaps extends back into the Blacksmith. No further activity has been reported there.

Boulder-Bonanza group.—On Richards's map this group is given approximately the location indicated above for the Boulder mine, but in his verbal account the group is stated to lie a mile or more north and east of the Humming Bird mine, a copper property, discussed below. The location given would correspond fairly well with that of the prospect in sec. 36, T. 13 S., R. 42 E., described below. According to Richards, one of the prospects in the Boulder-Bonanza group is said to have shown lead ore, but not in place; the prospect shaft was sunk in a mixture of soil and loose boulders to a depth of 15 feet or more. Some of the ore taken from the Boulder-Bonanza claim showed vein mineral composed of brecciated white quartz and jasper, somewhat iron stained, containing galena in disseminated grains. According to report, prior to 1909 a total of 13 tons of ore which was said to have yielded a good percentage of lead had been shipped from this claim.

Prospect in sec. 36, T. 13 S., R. 42 E.—In about the NW. ¼ NE. ¼ sec. 36, T. 13 S., R. 42 E., a prospect was visited in 1914. Two men were working on a short tunnel in surface débris about 350 yards west of the road and halfway up the hill to the divide. No ore was in sight, but the men reported that a pocket of lead ore had been found in the tunnel and that a carload of ore running about 70 per cent of lead had been shipped from there. Samples of the ore had shown both sulphides and carbonates.

Spence mine.—The Spence mine is in the SE. ¼ SW. ¼ sec. 19, T. 14 S., R. 43 E. The workings include two inclines each about 20 feet deep and a shaft about 60 feet deep. The inclines show nothing of value in the face, and in one of them two drifts have been driven, one on each side and each 10 or 15 feet long. In the calcite masses found on the dump a few small crystals of galena were seen, but no similar rock was observed in the workings. The shaft is old, and nothing of value was seen on the dump. A fracture on the south side showed some iron oxide, but no evidence of lead or copper was seen. The mine appears to be in the Ute-Blacksmith contact zone.

Origin of deposits.—There is no apparent connection of the lead ore with any igneous rock. The lead, which was formerly disseminated in the sedimentary rocks, appears to have been leached out by circulating ground water and redeposited in favorable places by the replacement of limestone, chiefly along bedding planes. By local rock falls masses of lead ore have at some places become included in talus or other waste accumulations.

Outlook.—The impressions of Hayden, previously mentioned, were independently gathered by the writer. Occasional pockets of greater or less size exist here and there but no noteworthy veins. The development at the places where pockets have been found has outrun the value of the ore, and in general the quantity and character of the ore is not such as to justify the expense of tunnels, shafts, and hoisting machinery.

COPPER

OCCURRENCE

Copper has been found in at least four geologic associations in the region treated in this report and has been sought in others. The first is a mineralized belt in Cambrian rocks that lies generally parallel to and perhaps half a mile west of the so-called "lead belt" in the Bear River Range; the second is in Ordovician limestones near Nounan but also in the Bear River Range; the third is an impregnated zone in the Triassic red beds in the Preuss Range in the Montpelier quadrangle; and the fourth is an association with some metamorphic minerals in T. 6 S., R. 43 E. This last occurrence has already been noticed. (See p. 123.) The others are considered below. The developments thus far have not led to any very encouraging results.

BEAR RIVER RANGE

The copper deposits of the Bear River Range have been described by Richards,[14] from whose report, supplemented by other observations, the following account is taken. The ores consist mainly of the carbonates, azurite and malachite, in quartz veins and locally of the sulpharsenite and sulphantimonite, tennantite and tetrahedrite, in a brecciated quartz and jasper gangue. The general zone of occurrence is the line of contact between the Blacksmith limestone (?) and the Bloomington formation (?), of Cambrian age.

Swan Creek, Utah.—A group of claims on Swan Creek in Utah, a short distance south of the Mont-

[14] Richards, R. W., op. cit.

pelier quadrangle, is centered about a prospect called the Victoria No. 1. The wall rock is massive limestone. The ore consists of malachite, azurite, accompanying barite, and calcite in a much-brecciated zone that is approximately parallel to the bedding. The quantity of ore is insufficient to make the property commercially valuable.

Humming Bird mine.—The Humming Bird mine, in Paris Canyon, is the center of a group of claims near the northeast corner of T. 13 S., R. 42 E., and about a quarter of a mile west of the boundary of the Montpelier quadrangle. Several hundred feet of tunnels, inclines, and shafts have been driven on this property and a considerable quantity of ore-bearing rock has been thrown out on the dump. Ore, chiefly lead has been shipped from several properties in the vicinity, but none of these has been regularly worked on a commercial basis. The copper ores occur in association with Cambrian limestones and shales, probably the Blacksmith limestone and the Hodges shale member of the overlying Bloomington formation.

The vein strikes N. 60° W. and dips 40° W., as developed in the lower entry. It lies approximately parallel to the bedding and is "presumed to occupy a bedding thrust," doubtless occasioned by the readjustment of stresses between the more massive limestone beds on either side of the Hodges shale. These formations have been folded and now form part of the east limb of the Bear River syncline. The vein is continuous throughout the present workings and is several feet thick.

The ore consists of brecciated quartz and jasper vein material, in which secondary quartz and malachite were deposited contemporaneously. It contains tetrahedrite-tennantite (gray copper ore) reacting in the closed-tube test for both antimony and arsenic. There are also secondary veins of azurite and some patches of radially fibrous malachite.

When seen in 1912 by William Peterson, of the survey party, the tunnel had caved badly. There was a good steam hoist, but the boiler had fallen down the shaft with the decay of the timbers. It was then estimated that there was perhaps 300 tons of ore on the dump, which was reported to carry 7 per cent of copper and a little gold and silver. When visited by the writer in 1914, the decay of the property was still in progress. Picked ore on the dump showed copper carbonates and sulphate (brochantite?) in thin coatings, which form apparently less than 1 per cent of the ore. The character of the ore in sight would not seem to justify much expenditure.

Deposits near Nounan.—A group of copper prospects about half a mile southwest of Nounan post office, in T. 11 S., R. 43 E., shows copper carbonates, malachite and azurite, and the sulphate brochantite (?). The country rock is a gray dolomite, the Garden City limestone, of Ordovician age, which weathers brown, and the soil derived from it has a reddish color. The bedding is indistinct, but the strike and dip appear to be N. 15° E. and 65° E. respectively. The ore occurs in fissures filled with quartz, some of which strike N. 65° W. and have an easterly dip of about 55°, but the attitude of others is indeterminate. The principal opening is a shaft, inaccessible when visited, but estimated to be 100 feet deep. The dump showed a small amount of commercial ore.

Co-op Creek.—A prospect in the SE. ¼ NE. ¼ sec. 19, T. 11 S., R. 43 E., on Co-op Creek, was examined by William Peterson, of the survey party, in 1912. Two veins about 10 feet apart appear on the north side of the canyon and show best at about 100 feet above the stream. The west vein, which is about 18 inches wide, is filled with quartz, iron oxide, and copper carbonate. The country rock, which is Garden City limestone, strikes about N. 10° W. The formation is badly shattered, but seems to dip about 83° E. A tunnel about 100 feet long had been driven on the west vein, but it did not show clearly whether the ore pitched. The east vein had been opened only 8 or 10 feet, but the showing was similar to that in the other vein. A tunnel in the canyon bottom had been driven apparently to intercept the vein below the upper tunnel. The lower tunnel was inaccessible, but the dump showed no indication of ore.

COPPER IN TRIASSIC RED BEDS

Copper deposits in Triassic red beds near Montpelier have been described by H. S. Gale,[15] from whose report, supplemented by later observations, the following account is taken. Gale's map, which shows the location of the ore-bearing zone and of the copper prospects, is reproduced in Figure 38. Gale assigns the copper deposits to a particular stratigraphic horizon in what he identified as the Ankareh shale. This formation, however, is no longer recognized in this region, and the copper-bearing beds are here assigned to the Timothy sandstone. The deposits occur on the east limb of the unsymmetrical Home Canyon anticline, which is illustrated on the geologic map (pl. 9) and in geologic structure sections X–X′ and Y–Y′ (pl. 11).

As shown at the surface, the copper stains consist chiefly of malachite and azurite. These minerals occur in joints along the bedding of both the massive, usually somewhat calcareous, sandstone and in the more shaly rocks. There is no well-defined mineral streak.

At one place where the development had been carried down on the mineralized zone to a depth of 100 feet or more the sulphides chalcocite and covellite have been found in evident replacement of the woody fibers of fossil plants, roots, or tree stems. Several prospects are described below.

Bonanza claim.—The principal development is on the Bonanza claim, in sec. 10, T. 14 S., R. 45 E., which

[15] Gale, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: U. S. Geol. Survey Bull 430, pp. 112–121, 1910.

is said to belong to the Bonanza Mining Co., of Montpelier, organized in December, 1908. Though visited at different times from 1909 to 1914 by members of survey parties, the shaft has been inaccessible and more or less filled with water. It is said to be about 400 feet deep. No shipments of ore from this mine have been reported to the Geological Survey. A mineralized zone exposed in a small prospect about 130 feet east of the shaft is figured by Gale.

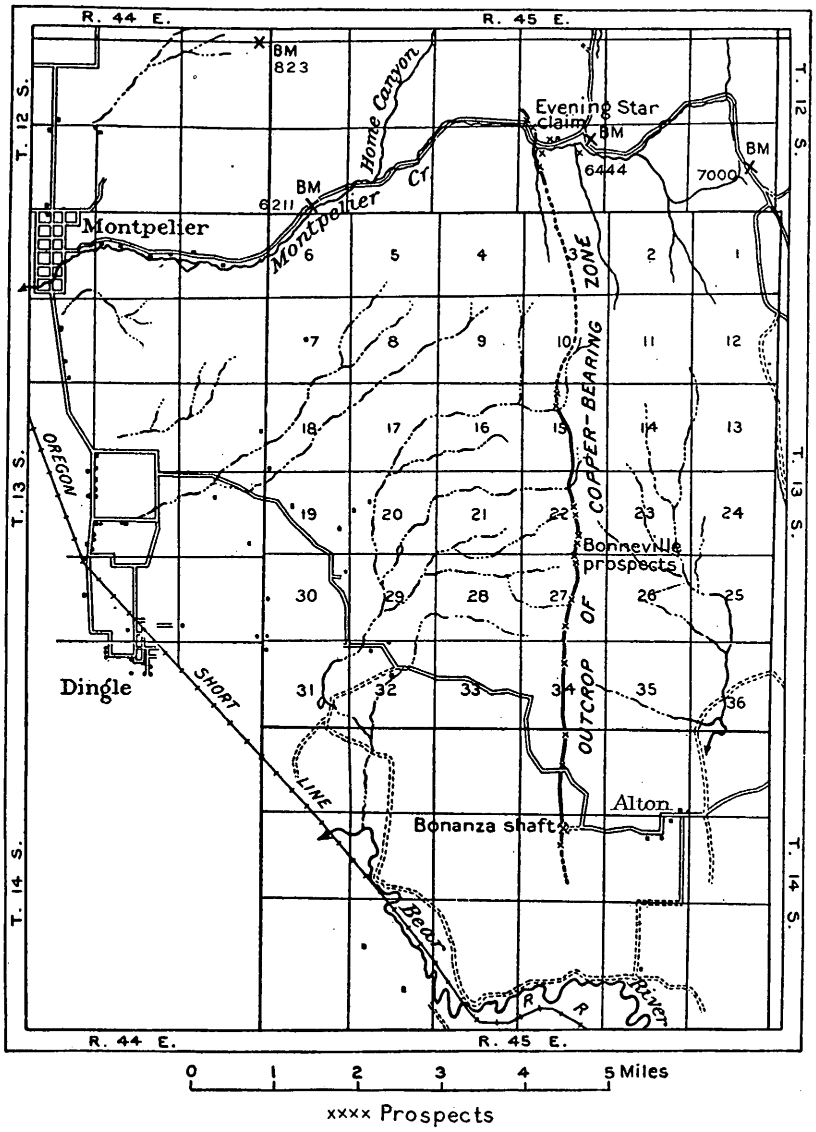


FIGURE 38.—Map of the copper prospects in the Montpelier quadrangle. (After H. S. Gale)

A claim controlled by the same company is situated on the top of the ridge about a quarter of a mile south of the Bonanza shaft. Here an incline has been sunk for 50 feet along the dip of copper-stained strata that strike N. 10° W. and dip 66° W. The ore at the surface evidently lies at the same stratigraphic horizon as that shown near the Bonanza shaft, but occurs in brecciated zones that are locally more completely saturated with the carbonate minerals. The mineralization is not confined to any particular bedding plane or stratum, but is distributed in a very irregular way through 5 feet or more of clayey and sandy rock included between strata of massive, even-bedded red sandstones. At the bottom of the 50-foot incline, which pitches somewhat toward the north, a level has been cut to meet a timbered shaft that is said to have been sunk to a depth of 200 feet. Selected ore contains much that is evidently fossil wood in which the carbonaceous material has been replaced by chalcocite. An indigo-blue iridescent mineral of metallic luster which is also present is probably covellite formed by alteration of the chalcocite, and seams or veins of malachite cut both of the other minerals as well as the country rock.

This property may be the same as the Duke claim, from which was reported a shipment of ore in 1905 that amounted to two carloads and netted $1,300.

Bonneville claim.—Another claim on which considerable work has been done is known as the Bonneville, in sec. 27, T. 13 S., R. 45 E., which was formerly owned by the Claire Mining Co. It is reported that 70 tons of sorted ore running about 18 per cent of copper has been shipped from this claim. Gale says: [16]

Near the head of a gulch on this property are several prospects, a shaft, and two tunnels of considerable depth. The strike here is N. 27° E. and the dip 55° W. The principal ore-bearing stratum is a light-colored calcareous sandstone, which is very hard. Ore appears to occur at more than one horizon here, a feature not noted elsewhere. Two tunnels run in on the north side of the gulch, opening up beds at separate horizons. The eastern of these is the main tunnel. The stratigraphic interval between the two is 60 feet.

The main tunnel has been driven to a depth of about 200 feet; from it a crosscut has been opened to the northwest, and a stope and incline have been driven on several lenticular and mineralized streaks. The mineralized beds are at least four in number within a stratigraphic thickness of 10 or 15 feet. The copper minerals are found in thin foliated shaly lenses, containing seams of black carbonaceous material, reported to constitute the richest ore. This is locally referred to as "black" copper ore, but some specimens tested showed the black substance to be largely, if not wholly, carbonaceous matter upon which the copper carbonate minerals are deposited. Surrounding such lenses of more concentrated mineralization are zones in the sandstone impregnated with the green and blue carbonates, but none of these form continuous ore bodies, nor are they well defined.

[16] Gale, H. S., op. cit., pp. 118-119.

The western tunnel on the Bonneville claim, about 120 feet somewhat south of west of the main entry, was driven to follow an iron-stained ledge apparently accompanied by a smaller indication of copper minerals. The mineral here is associated with a light-colored calcareous sandstone, included in dark-maroon shale, resembling the typical occurrences noted farther south. There is relatively little copper-stained rock on the dump of this entry, which shows, however, some iron-stained sandstone.

About one-fourth of a mile north of the Bonneville tunnels and shaft, near the top of the ridge, is an old incline shaft showing copper-stained rock in striking exposure. The copper minerals are exhibited across a face about 8 feet thick, although the rock is not uniformly saturated, the minerals being chiefly thin vein fillings in joints or cracks. Some portions of the rock are more richly impregnated, these being the thin-bedded foliated material associated with the black carbonaceous plant remains.

Other prospects in red beds.—The only other noteworthy copper prospects are those in Montpelier Canyon in and near sec. 34, T. 12 S., R. 45 E., near the Star Valley road, about 7 miles from Montpelier. Among these prospects is the Evening Star claim in the NW. ¼ sec. 34, where copper-stained clay and sandy rock are shown under a hanging wall of maroon shale similar to the wall rocks of the copper ledge near the Bonanza claim. A sample taken by Gale, which represents a section 14 inches thick taken across the mineralized zone at the discovery monument, was tested at the laboratory of the Geological Survey and showed 2.85 per cent of copper. This specimen, though doubtless of poorer quality than much of the material shown at some of the prospects farther south, may serve as a conservative guide in estimating the general grade of the oxidized ores in this belt.

The Deadman limestone has been prospected for copper at a number of places in Tps. 6 and 7 S., R. 44 E. This formation may properly be grouped among the red beds, but it represents a stratigraphically higher horizon than that of the prospects above described. No showing of copper minerals that could be regarded as at all favorable has been observed in it.

Later developments.—Most of the developments above described had already been completed by 1909, when Gale studied the deposits. Interest in these properties, however, continued several years longer, and some further exploratory work was done on at least the Bonanza and Bonneville groups of claims. About 1912 there was talk of reorganizing the developing companies and conducting large-scale operations. The moving spirit in these projects was R. J. Eckloff, manager of the Bonanza Mining Co. Since his death in 1914 interest in the copper deposits in this region seems to have flagged, and development has come practically to a standstill.

PROSPECTS IN THE TWIN CREEK LIMESTONE

The lower part of the Twin Creek limestone contains a dense, fine-grained green band, the ash bed described on page 97, that has been prospected at a number of places, presumably for copper. So far as the writer's observations have gone, however, there is little evidence of mineralization at this horizon.

ORIGIN OF THE DEPOSITS

With regard to the origin of the copper deposits of the Triassic beds Gale[17] remarks:

> Deposits of copper in the "Red Beds" of presumed Triassic age belong to a well-recognized type. The constant association of copper minerals with carbonaceous matter, such as with coal or, as in this region, carbonized plant fragments, is considered good evidence that the carbon has acted as the precipitating agent which has caused the accumulation of the copper. It is assumed that copper may be or probably was present in widely distributed though minutely disseminated form in the sedimentary rocks as they were originally laid down. Such copper may have been taken into solution in the ground waters, to be precipitated again and concentrated when these waters came into contact with the carbon. It is known that organic matter acts as a reducing agent in some places and that by its action sulphide minerals may be formed. Later oxidation of the sulphides has to a certain extent disseminated the carbonate minerals throughout the country rock, especially in brecciated zones. This theory is confirmed by the finding of chalcocite replacing the woody fibers of plant stems at the only place where these deposits have been opened in depth.

There is little doubt that this general theory of origin is also applicable to the copper deposits of the Bear River Range described above. In these occurrences, however, the carbon for the precipitation of the copper-bearing solutions was not present in the form of plant remains, but a disseminated bituminous matter which resulted from the slow decomposition of animal remains entombed in the early Paleozoic limestones. The formation of sulphides, their subsequent oxidation, and the impregnation of the country rock with carbonates, has probably followed in the same way as in the occurrences in the red beds. An alternative source for the copper in these deposits might be solutions emanating from deeper-seated igneous intrusions of which the ore minerals themselves would be the only evidence.

OUTLOOK

The outlook for successful commercial exploitation of the copper deposits of the region is not encouraging. Many of the prospects located in green rocks have been made under the mistaken impression that the green color was an indication of copper, whereas the coloring substance is a form of iron, possibly reduced through contact with organic matter.

The prospects above described, however, in which copper minerals are present, have not been demonstrated to carry copper in sufficient quantity for exploitation, even though a few carloads of good ore have been mined and shipped.

[17] Gale, H. S., op. cit., p. 120.

GOLD AND SILVER

Small amounts of gold and silver have been reported from assays of the lead ores mined in the Bear River Range, as previously stated. Some other occurrences remain to be noted.

Deposits near Bern, Idaho.—According to Richards,[18] northwest of Bern, in sec. 26, T. 12 S., R. 43 E., E. A. Jonely, of Montpelier, has a prospect from which he reports amounts in gold, silver, and lead that range from 70 cents to $20 a ton. This prospect is located in the upper block of the Bannock overthrust and west of the axis of a small anticline in dense bluish-black limestone, which is here regarded as part of the Garden City limestone (Ordovician). This limestone forms an inlier of old rock in the midst of Tertiary beds. The prospect, called the Tiptop, is situated on the highest point in section 26. It consists of a 125-foot shaft, a 60-foot drift or crosscut to the west at the 100-foot level, and at the 125-foot level a 110-foot crosscut to the northeast, which had just been started when the prospect was visited in 1910. The western 20 feet of the crosscut on the 100-foot level is in a red and blue clay or talcose selvage which is reported to contain gold and silver. The crosscut on the 125-foot level is said to have cut several mineralized fissures, and at its heading, nearly under the crest of the fold, iron oxide that contained free gold was found. The prospect is equipped with horsepower hoist and shaft house.

In the SE. ¼ NW. ¼ sec. 26 a tunnel driven in white marly limestone of Tertiary age is reported by Mr. E. A. Jonely to have furnished samples that upon assay yielded about 75 cents in gold to the ton. The only mineralization in sight at this prospect was a thin bluish dendritic deposit, probably pyrolusite (manganese oxide). No further activity at these prospects has been reported to the Geological Survey.

Deposits near Pegram, Idaho.—The Colorado-Idaho Mining & Milling Co., of Denver, which is said to have been incorporated about 1915, has developed a project that is located approximately in the SE. ¼ NE. ¼ sec. 2 and the SW. ¼ NW. ¼ sec. 1, T. 15 S., R. 45 E., about a mile northwest of Pegram, Idaho.

In 1920, according to J. A. Kurtz, of Denver, stockholder and resident custodian of the property, the principal development consisted of a tunnel 800 feet long driven east through red sandstone (Nugget) to a soft, green, waxy-looking body of ore that is said to be 300 feet wide. An old tunnel at the south end of the property, in the SW. ¼ SW. ¼ sec. 1, had been driven north 1,800 feet along the contact of the Nugget sandstone and Twin Creek limestone. The ore, according to Mr. Kurtz, assayed from $2 or $3 to $73 a ton and averaged $6 to $9 a ton in gold and silver. A carload had been shipped for testing to Denver, where the company has a 100-ton mill.

[18] Richards, R. W., op. cit., pp. 186–187.

There has been no opportunity to visit the property or to verify the stated assays. No further activity at the mine has been reported to the Geological Survey.

The horizon at which the gold and silver are said to have been found is in the lower part of the Twin Creek limestone. This formation is not known to be mineralized elsewhere in the region, though the dense, green, waxy-looking band near the base has been prospected, presumably for copper, at a number of places. Judgment regarding this property should be reserved until the character, quality, and quantity of the ore have been more fully demonstrated.

Adverse geologic conditions.—The geologic conditions in the region thus far studied are adverse for the occurrence of the precious metals, and indeed for metallic minerals generally. The principal rocks of the region are sedimentary and practically free from metamorphism. There are no intrusive rocks, except on a very small scale, and hence there has been little opportunity for the type of mineralization that commonly accompanies such rocks. As placers derive their valuable minerals from lodes, which at some time have been exposed to erosion, the lack of such lodes is reflected in a corresponding lack of placer accumulations.

The converse of the last statement is fully illustrated by the Caribou district, which lies east of Grays Lake, in T. 4 S., R. 44 E., and was not included in the present investigation. There the placer deposits, which in the seventies are said to have yielded $250,000 in gold annually, owe their gold content to lodes, some of them located and prospected, which were produced by mineralization that accompanied igneous intrusions. Of late years there has been little mining in this district, but in 1920 there was some revival of interest and plans were being made for the installation of gold dredges.

OTHER MINERAL OCCURRENCES

GYPSUM

Gypsum claims owned by David Follick, of Montpelier, lie about 1,000 feet above the bottom of Montpelier Canyon, in the SW. ¼ SW. ¼ sec. 32, T. 12 S., R. 45 E., and in the adjoining part of sec. 5, T. 13 S., R. 45 E. The gypsum occurs in rocks of the Wells formation beneath a sugary reddish-yellow sandstone and above a yellowish-red porous breccia, which lies unevenly upon and fills cracks in a massively bedded limestone. The rocks that contain the gypsum are involved in the folds at the north end of Waterloo Mountain. (See pl. 52, *A*.)

The gypsum, as exposed in ledges and in small openings, is sugary or massive and apparently quite pure in some places. In other places it is thin bedded and mixed with sandy clay. At the locality in section 5 the observed thickness of gypsum was about 20 feet. A 4-foot bed at a locality in section 32 was sampled and later analyzed at the laboratory of the Geological Survey with the following results:

TABLE 99.—*Composition of gypsum from Montpelier Canyon, Idaho*

[W. C. Wheeler, analyst]

SiO_2	4. 14
Al_2O_3	. 89
Fe_2O_3	. 10
MgO	. 99
CaO	31. 40
CO_2	2. 33
SO_3	41. 13
H_2O, loss at 200° C	18. 39
	99. 37

Pure gypsum contains 32. 5 per cent of lime (CaO) and 46. 6 per cent of sulphur trioxide (SO_3). Ordinarily gypsum contains impurities, such as the oxides of iron and aluminum and the carbonates of calcium and magnesium, besides other impurities. The analysis shows that the bed sampled contains relatively high-grade material that compares favorably with gypsum mined in other parts of the Western States.

The available data are insufficient for any accurate estimates of the quantity of gypsum present. However, it is probably not large enough to warrant commercial exploitation. The Wells formation in this region is not usually gypsiferous. The accumulation represented by these claims is regarded as a secondary deposit of purely local occurrence.

Loose fragments of gypsum are strewn here and there along outcrops of the Wood shale or along similar beds referred to the upper Nugget, as in sec. 10, T. 11 S., R. 45 E.

MANGANESE

The presence of manganese in one of the gold prospects near Bern has already been mentioned. The Eocene conglomerate (Wasatch formation) contains here and there pockets of manganiferous material. Such a pocket is exposed in a prospect opened by Myron Welker, of Bloomington, in the NE. ¼ SE. ¼ sec. 28, T. 14 S., R. 43 E. The conglomerate there is deep red and of medium texture, and its largest pebbles have a diameter of about 4 inches. The pocket as opened was about 4 feet wide and 2½ feet deep. Black, powdery material was distributed throughout the conglomerate, the pebbles of which were also so thickly coated as to resemble lumps or nodules of manganese oxide. On breaking the lumps open, however, they were found to contain pebbles. A tunnel that was driven only a few feet below the prospect showed no sign of manganese.

Bell[19] reports an occurrence of manganese oxide in Paris Canyon. According to his statement this deposit occurs as a network of high-grade seams and bunches of pure manganese ore in a sandy contact between limestone and red conglomerate in a zone 10 feet wide. Its development was confined to shallow open cuts. A few hundred pounds of sacked ore, which was said to run 50 per cent of manganese, was on the ground.

These occurrences are interesting, but too small to justify hope of commercial development.

POTASSIUM NITRATE

In the SW. ¼ sec. 1, T. 7 S., R. 44 E., in the Lanes Creek quadrangle, there are some prospects for potassium nitrate that have been the subject of considerable local interest. They are located in a short steep-sided ravine called Blue Jay Gulch, which is cut mostly in Nugget sandstone, though Twin Creek limestone occupies the higher slopes on the east side. The prospects themselves are in the Nugget. They lie on the west flank of a broad syncline which causes the rocks to have a general northeasterly dip that ranges from 5° to as much as 35°. The syncline, however, bifurcates northwestward and permits a southeastward-pitching anticline to occupy the space between the branches of the syncline. The prospects are almost in the axial line of the intervening anticline produced, so that the rocks in that vicinity are unusually jointed and the dips are variable. A description of the occurrence has been prepared by Gale, from whose unpublished manuscript the following account is in part taken.

The locality was visited in June, 1911, by Robert Stewart,[20] who states that potassium nitrate occurs in a cave in red sandstone, where it was formed on the roof, presumably as an efflorescence or crust left by the evaporation of percolating waters which had come in through crevices. The total quantity of nitrate in the cave was estimated at 25 pounds. Analyses of samples taken at this place were made with the results shown in Table 100.

TABLE 100.—*Composition of crude nitrate and sandstone from sec. 1, T. 7 S., R. 44 E.*

	1	2	3
Residue insoluble in water	4. 22	2. 73	98. 21
Nitric nitrogen	11. 12	11. 48	. 127
Ammoniacal nitrogen	None.	None.	None.
Calcium	2. 91	2. 12	None.
Magnesium	. 11	. 17	None.
Potassium	30. 89	31. 55	. 18
Sulphur	1. 54	1. 58	--------
Chlorine	Trace.	Trace.	--------
	50. 79	49. 63	98. 517

Nos. 1 and 2 were samples of the nitrate-bearing salts in the roof of the cave and No. 3 was a sample

[19] Bell, R. N., Twentieth annual report of the mining industry of Idaho, p. 110, 1919.

[20] Stewart, Robert, The occurrence of potassium nitrate in western America: Am. Chem. Soc. Jour., vol. 33, No. 12, pp. 1952-1954, 1911.

of sandstone from the face of the cliff about 100 yards above the cave. These results can be recalculated as percentages of potassium nitrate in the original samples: No. 1, 79.88; No. 2, 81.58; No. 3, 0.46.

In each analysis there is a very slight excess of nitric acid, which may represent a trace of calcium or of sodium nitrate.

Nos. 1 and 2 are evidently selected portions of the clearest crystalline salts. No idea is given in the account as to what these samples may represent, but it is supposed that they are composed of surface material from individual spots only and do not represent average lots or any large bulk of nitrate, for the conclusion is stated that the nitrate is not found in sufficient quantity to be of commercial value.

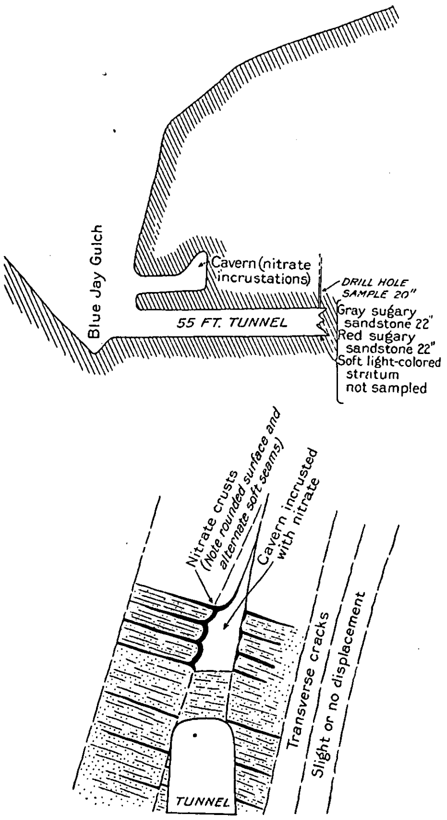


FIGURE 39.—Sketches of tunnel and cave at nitrate prospects at Blue Jay Gulch, in sec. 1, T. 7 S., R. 44 E., Lanes Creek quadrangle. (After Earl Pembroke)

Earl Pembroke, a mining engineer of Salt Lake City, says in a letter on file at the Geological Survey that he visited this locality in April, 1913. At that time several claims had been taken up. A tunnel, which had been driven in 55 feet just under the cavern from which the specimens for the analyses given above were taken, is supposed to have proved the existence of the soluble salts within the mass of the sandstone. This statement is based on the report of the man who excavated the tunnel. Mr. Pembroke says that the sandstone from the tunnel soon takes on a whitish soluble coating when exposed to the air on the dump, and that this coating has a characteristic niter taste. The tunnel and cave occur in a zone of nearly vertical fractures in gray and red laminated sandstone. Sketches of the tunnel and cave, furnished by Mr. Pembroke, are shown in Figure 39.

Gale comments on the letter as follows:

> It is not distinctly stated but it appears that the old tunnel has been standing quite a while, and it is more or less natural to suppose that under any hypothesis as to origin of the salts saline crusts containing nitrate might accumulate on the walls and even in the cracks and seams to whatever depth evaporation might have removed the ground water. It is clear that the principal showings of nitrate were from the old cave above the tunnel and that the rocks are cut by vertical seams or fissures, through which saline solutions might readily percolate deep into the mass of the ledge. It is also evident that the results of the explorations for nitrate in the tunnel below were not very encouraging, as the work has not been actively prosecuted since.

In 1914 the tunnel and several other prospects in the vicinity were visited by Robert Ferron, a member of the Geological Survey party, who noted the incrustation on the sides and measured a section at one of the other prospects. The samples collected were damaged in transit and could not be used for analysis.

In 1916 the writer paid a hurried visit to the tunnel. No recent work had been done. The rock appeared to be ordinary Nugget sandstone with some white bands. Incrustations were noted here and there on the walls. Some of these sputtered slightly when touched by the candle flame. The writer saw nothing to justify hopes of a commercial deposit and did not consider the material in sight worth sampling in view of his previous experience with similar occurrences elsewhere.[21]

In addition to the areas prospected efflorescences of nitrate have been found at a number of places in the Nugget sandstone in sec. 12, T. 7 S., R. 44 E., and in sec. 7, T. 7 S., R. 45 E., unsurveyed.

The nitrate in all these occurrences is probably not different in origin from the so-called cave deposits, which are common in many parts of the country.[22]

The slopes above the prospects support considerable vegetation, which by decay and by the action of soil bacteria could be converted into nitrates. The rock slides of the district are occupied here and there by small animals, which supply more or less guano. Thus there appears to be sufficient organic nitrogenous material to supply percolating waters with nitrate salts in the observed quantity. The numerous joints and pores in the rock provide suitable channels for the activity of these waters, and caverns or protected slopes afford places for its concentration by evaporation and for its preservation.

Gale [23] summarizes the data regarding this deposit as follows:

> The locality is interesting, for it is one in which active investigation for saltpeter has been periodically revived and where the

[21] Mansfield, G. R., Nitrate deposits in southern Idaho and eastern Oregon: U. S. Geol. Survey Bull. 620, pp. 19-44, 1915.

[22] Gale, H. S., Nitrate deposits: U. S. Geol. Survey Bull. 523, p. 9, 1912.

[23] Gale, H. S., manuscript at U. S. Geol. Survey.

hope of the prospector survives against all condemnatory evidence, even to the present day. Certainly persistence of this kind has occasionally been rewarded in other enterprises, but one can not find in the logic of the matter much excuse for encouraging continued prospecting here.

COAL

The carbonaceous shales of the Wayan formation locally contain enough organic matter to form an impure coal. This material has no economic significance, but it has been prospected at a number of places, chiefly in the Willow Creek-Caribou and Pine Creek districts [24] north of the region here described.

In the NW. ¼ NW. ¼ sec. 5, T. 32 N., R. 119 W., about a mile west of Auburn, in the Freedom quadrangle, a prospect has been opened in these shales by J. W. J. Harrison on patented land. The prospect consists of a timbered tunnel about 40 feet long. The strike of a sandstone bed below the shales is N. 20° W. and the dip is 56° W. Most of the material removed was a carbonaceous shale that slacks on drying. Some pieces, about a bucketful, burned well. This prospect, when seen in 1914, had not been worked for three years and had caved. Another prospect, an inclined shaft about 100 feet farther southwest, had also been abandoned. No other coal has been found or reported in the areas considered in this paper.

OIL

Rumors of the occurrence of oil in this region have thus far proved without foundation except for the showing of oil reported in the well of the Wallace-Wyoming Oil Co. Some reported occurrences of oil scum in marshes along Crow Creek near Lowe's ranch proved upon examination to be films of iron oxide.

The phosphatic shale at some localties, notably near Dell and Dillon, Mont., has been found to yield upon dry distillation as much as 25 to 30 gallons of oil to the ton. The phosphate beds of southeastern Idaho are richer in phosphate than the beds in the Dell and Dillon areas, and so far as examined yield only a trace of oil when distilled.

Bituminous matter has been observed locally in the Woodside shale. Thus, in the SW. ¼ SE. ¼ sec. 29, T. 13 S., R. 43 E., a dense dark-gray limestone bed of the Woodside, which was practically horizontal and overlain by shales, contained bituminous pockets about an inch long. The limestone is somewhat fossiliferous.

The petroleum possibilities of southeastern Idaho have been discussed by Kirkham,[25] who designates two areas in this region among those which he describes as the "least unlikely for the production of oil." These are the "Border and Phosphoria areas." The Border area comprises Tps. 5 S., Rs. 45 and 46 E.; T. 7 S., R. 46 E.; Tps. 8 and 9 S., R. 46 E.; and T. 11 S., R. 45 E. These townships lie in a belt of strata that has been highly disturbed by both folding and faulting and in the fault zone of the Bannock overthrust, which locally subdivides into as many as five branches. The possibility that any reservoir of sufficient size to contain a commercial oil pool may persist in this belt would seem to be slight.

The Phosphoria area is comprised in T. 8 S., R. 45 E., and is traversed by the Snowdrift anticline, which is locally depressed by a transverse syncline and by the Webster and Georgetown synclines. It is barely possible that this portion of the Snowdrift anticline and of the subordinate anticline present in the Webster syncline might serve as reservoirs for small oil pools. However, the general intensity of folding in the region and the probability that these folds are cut at greater or less depth by the Bannock overthrust are distinctly unfavorable to the occurrence of oil in commercial quantities.

Kirkham makes recommendations regarding locations for test wells, but his cautionary phrase that he does not "guarantee that petroleum or natural gas will be found at any of the points recommended for testing" should not be overlooked.

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[24] Mansfield, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716, pp. 12-136, 1920.

[25] Kirkham, V. R. D., Petroleum possibilities of certain anticlines in southeastern Idaho: State of Idaho Bur. Mines and Geology Bull. 4, 1922. See also Bull. 8, 1924.

Chapter VIII. BROADER PROBLEMS OF THE REGION

SUMMARY

The broader problems of the region are discussed under five heads, as physiographic, stratigraphic, igneous, structural, and economic problems.

The physiographic problems include the course of Bear River, Tertiary planation in Idaho, and the Snake River Basin.

It is suggested that the peculiar course of Bear River may be due to diversion by uplift from a former union with Snake River and to superposition upon older structural features from a former course on Tertiary beds.

Tertiary planation in Idaho has been a subject of controversy, some advocating Eocene or older age for the resulting erosion surface or peneplain and others postmiddle Miocene age. The evidence for southeastern Idaho is thought to favor premiddle Miocene age.

The Snake River Basin is an ancient feature, and conflicting opinions regarding its age and method of formation have been expressed. Regional studies are needed to reconcile apparent discrepancies in existing accounts.

The stratigraphic problems include the origin of the Permian phosphate and of the Rex chert, the Permian-Triassic interval, Triassic and Jurassic physiography and sedimentation, and the interpretation of Cretaceous and Tertiary formations.

The phosphate is believed to have been formed by biochemical agencies from phosphatic solutions or colloids on the sea bottom under conditions which largely excluded oxygen from the deeper waters. The accumulation was slow and long continued. Climatic changes may have played a notable part. Under present conditions mineralogic studies can shed little light on the problem, but bacteriologic and chemical investigations afford promise of definite information.

The Rex chert was probably formerly continuous over thousands of square miles. Although undoubtedly in part of organic origin, it is believed to be more largely the result of physicochemical processes.

The Permian-Triassic interval in southeastern Idaho is represented by beds that may correspond with the Dinwoody formation of the Wind River Range in Wyoming, now considered to be of Lower Triassic age.

The Triassic and Jurassic record of southeastern Idaho is unusually full and comprises 12 formations that have an aggregate thickness of nearly 12,000 feet. Many similarities with sections in the southern Rocky Mountains and with the plateau country, as well as differences, are pointed out. Some attempt at comparison and correlation is made.

Nonmarine Cretaceous rocks are developed in southeastern Idaho in great thickness. Two epochs of abundant sedimentation separated by an epoch of deformation are recognized. Relationships of the beds in Idaho with similar beds in Wyoming and Montana are suggested, but regional studies are needed to test these suggestions.

The Tertiary record is fragmentary and some of the evidence regarding it is of a conflicting nature. A systematic search for fossils and regional studies are needed to determine the relationships of formations in southeastern Idaho with those of other areas.

Only two igneous problems are considered—first, the relation of the lavas of southeastern Idaho to those of other eruptive centers and, second, volcanism and deformation.

Brief comparison is made of the igneous rocks of southeastern Idaho with those of the Yellowstone National Park and of the Fort Hall Indian Reservation. The general absence of volcanic activity in association with the major deformation of southeastern Idaho places the mountains of that region in the "thin-shelled" group, as defined by R. T. Chamberlin.

Under structural problems are included overthrust faulting, circumferential shortening, tension faulting, and the building of the northern Rockies.

The overthrust faulting in southeastern Idaho is considered in relation to that of the whole Rocky Mountain region northward from Colorado, and it is seen that the overthrusts were maintained over a considerable period and that they were progressively younger eastward. As between overthrusting and underthrusting the available evidence seems to favor the former.

Measurements of crustal shortening in southeastern Idaho indicate an actual shortening equivalent to 21.5 per cent of the original length by folding alone, or of 52.3 per cent by both folding and faulting. The earth's crust was probably more deeply affected during the earlier stages of compression than during the later stages. The present visible folds are parts of larger structures or major folds.

Normal faults, and in particular horst and graben structures, are being ascribed by recent writers to compressive rather than tensional forces. Southeastern Idaho seems to afford definite evidence in favor of tension as a condition of the formation of horsts and grabens and that the current view of tensional faulting as a method of relief for overstrained or overcompressed structures is well founded.

The building of the northern Rocky Mountains presents a special phase of the fundamental problem of orogeny. The study of this problem requires the consideration of contrasted views on crustal movements and on isostasy. Contraction induced by many causes set in motion gravitative readjustments and magmatic movements which resulted in folding and overthrusting. Two phases of compressive activity are illustrated in southeastern Idaho. The earlier phase was localized and intensified by a heavily loaded geosyncline. The mountains formed were probably comparable to those of to-day or even higher. They were reduced by erosion before the second phase, which was not localized and was hence of a more gentle type, was begun. The mountains in their present form do not seem to have been completely compensated isostatically.

The most notable economic problem of the region that is related to its geology is the question of the continuity and the maintenance of quality of the phosphate beds in the deeper synclines, where they are far removed from surface influences and are subject to possible loss by faulting. Only deep boring which is not yet practicable, may solve this problem.

NATURE OF THE PROBLEMS

In the foregoing chapters, which give a reasonably complete account of the districts treated, it is hoped that a foundation has been laid for further studies in the broader field, of which the areas described are but a part. Some of the physiographic and geologic features mentioned, though of local significance, represent merely incidents in the geologic history of the Rocky Mountain region as a whole. Other features pass beyond the confines of the areas studied, either continuing unmodified or undergoing changes, and thus require for their understanding and description more extended areal study. Still others bear upon fundamental geologic problems, whose solution, if obtained, must await the patient gathering of data from many sources and over wide areas in the Rocky Mountain region or elsewhere.

In concluding this paper the writer has decided to outline briefly some of the broader problems of the region, and for some of them at least to suggest possible means of solution. He has grouped the problems under five heads, as physiographic, stratigraphic, igneous, structural, and economic problems and considered them in the order named.

PHYSIOGRAPHIC PROBLEMS

COURSE OF BEAR RIVER

The course of Bear River has long been a source of interest to geologists and others who are familiar with geologic and geographic conditions in the general region here studied. Bear River rises in the Uinta Mountains of Utah and flows generally northward or northwestward through southwestern Wyoming into southeastern Idaho as far as Soda Springs. Thence it turns westward and southward, forming an open loop, and empties into Great Salt Lake at a point only about 90 miles from its source. Its upper course in Utah and Wyoming is largely in Tertiary beds, though here and there the underlying older formations are exposed, and in such places the river usually follows the strike of the older beds.

Veatch[1] notes some relatively late minor changes in its course in southwestern Wyoming, which he ascribes to the overloading of the stream by glaciers in its headwaters. The changes to which attention is here directed, however, occurred at a much earlier date, and it may not now be possible to decipher the earlier course of the river.

Upon entering the Montpelier quadrangle the river turns northward into the lower end of Thomas Fork valley and then turns westward in an intrenched meandering course across the Preuss Range. As previously explained there seems little doubt that this course is the result of superposition from a former course on Tertiary beds. The abrupt change from a northerly to a westerly course suggests that originally Bear River flowed northward into Salt River, a tributary of the Snake, either by way of what is now Thomas Fork, Preuss Creek and Crow or Stump Creeks, or by a route now occupied in part by Smiths Fork, which lies mainly east of the Sublette Ridge, and Star Valley. The present elevations and grades of the stream beds afford little clue to the earlier drainage, which must be worked out from the older topography and from the distribution of stream-laid deposits.

No detailed studies have been made of the Smiths Fork route and no modern topographic map is available for Smiths Fork, though the Afton quadrangle includes Star Valley nearly to its head. The Thomas Fork route, however, is shown on the topographic and geologic maps of the Montpelier, Crow Creek, and Freedom quadrangles. No systematic study has been made of the older topography as it relates to Bear River, for this would involve consideration of the course of the river above the point where it enters the Montpelier quadrangle, and for much of this part of its course no suitable topographic maps are available.

There are no Quaternary gravels that appear to bear upon the question of a former course for Bear River, but the distribution of certain remnants of the Salt Lake formation may have some significance in this connection. On the west flank of Red Mountain in T. 11 S., R. 45 E., there is a patch of conglomerate about half a mile wide and nearly 3 miles long that extends southward into the valley of Preuss Creek. These old gravels now stand at altitudes that range from about 7,300 to 7,850 feet . About 4 miles farther south in sec. 7 (unsurveyed), T. 12 S., R. 46 E., at an elevation of about 7,200 feet, well up on the southwest side of the same valley, there is another patch of similar conglomerate but much smaller. Still farther south, in sections 31 and 32 of the same township a somewhat larger patch of the same conglomerate lies above Thomas Fork Valley at altitudes that range from about 6,500 to 7,000 feet. If these remnants may be regarded as marking the site of an old valley, the former floor of that valley, as indicated by present altitudes of the old gravels, now slopes southward instead of northward.

In the Crow Creek and Freedom quadrangles rather extensive remnants of the Salt Lake formation occupy parts of Crow Creek and Sage Valleys, and of Hardmans Hollow, Tygee, and Stump Valleys. Numerous similar patches also lie along the border of Star Valley. The altitude of these patches outside of Star Valley ranges from about 6,200 to nearly 7,400 feet; the lowest remnants are near the junction of Stump and Tygee Creeks, in the southern part of the Freedom quadrangle. In Star Valley the altitudes thus far recognized range from about 5,800 feet in the northern part of the Freedom quadrangle, to about 7,050 feet in the Crow Creek quadrangle.

The data thus far presented show merely that at the time of the deposition of the Salt Lake formation there were extended depressions or valleys farther north along the general line now occupied by Bear River above its bend at Thomas Fork. Besides, the Snowdrift peneplain, in which the valleys of the Tygee cycle were cut, appears to have been gently arched along a line that extends about east through Meade Peak. (See A′–A″ and G–G″, pl. 10.) The time when this movement occurred is not known, but itwas probably before the development of the Gannett erosion surface, because the highest and least reduced parts of that surface now lie near the crest of the arch and constitute

[1] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 100, 1907.

the divide between the present Bear River and Snake River drainage. Such an arching movement may well have caused the diversion of Bear River westward parallel with the trend of the arch. If the Salt Lake formation was deposited before the arching occurred the valley floor on which the formation was laid down would be tilted in opposite directions on opposite sides of the arch and the sediments themselves would tend to be eroded over the arched area.

It is suggested that the course of Bear River through the gap west of Soda Springs was determined by superposition from a former course on beds of the Salt Lake formation. Whether the southerly course beyond that point was determined by the presence of a southward-flowing river west of the Bear River Range or by some other cause must be left for future determination. Probably the basaltic outflows in Bear River valley in the vicinity of Soda Springs produced only local effects in displacing the channel of the river, for the basalt passes through the same gap, merely crowding the river against one side.

TERTIARY PLANATION IN IDAHO

SUMMARY OF LITERATURE

In 1912 Umpleby,[2] combining the work of earlier writers with his own observations, described a peneplain in the Salmon River Mountains of Idaho, which he thought was present in a large part of the State and which he referred to the Eocene. Blackwelder[3] criticized Umpleby's argument and undertook to show that the peneplain is younger than Eocene and is probably post-middle Miocene. Umpleby[4] replied, maintaining his original view and for a time the matter rested. It was revived, however, when Atwood[5] published a paper on the Butte district in Montana and the Bingham district in Utah, in which he accepted Umpleby's view and made use of it in a study relating to ore enrichment. This paper drew further criticism by Blackwelder[6] along the lines of his earlier contention and elicited a reply from Atwood,[7] who adhered to the Eocene view. Rich,[8] the next participant in the discussion, gave a critical review of the evidence set forth by Umpleby, Atwood, and Blackwelder, with additional arguments of his own, and strongly coincided with Blackwelder's view of post-middle Miocene age for the peneplain. Rich's paper called forth remarks from Lindgren[9] and Livingston,[10] both of whom advanced data in support of the Eocene age of the peneplain. Thus the controversy rests. The writer would not reopen it except for the fact that certain aspects of it bear upon the interpretation of the erosional history of southeastern Idaho, which is a part of the present task. The places mentioned in the discussion are shown in Figure 1.

EOCENE AGE

The existence of the peneplain, or at least of an old erosion surface, is recognized by all geologists who have worked in the general region. Its Eocene age is assumed by Umpleby because basins that contain Miocene "lake beds" now lie within it, and he thinks that these basins were eroded after the development of the peneplain. He attaches considerable significance to supposed former shore lines in these basins, as indicated by the position of the lake beds. A number of the basins that are now occupied in part by the lake beds are crossed by streams that enter and leave by steep-sided gorges. These gorges are attributed by Umpleby to headward erosion by the streams. The lake beds at exceptional places are considerably deformed, but Umpleby notes that faulting and folding have affected the plateau area, though they have not destroyed its plateau character, which has persisted in a remarkable degree.

Atwood in his discussion of conditions about Butte uses much the same arguments as Umpleby for the age of the peneplain. In his reply to Blackwelder he points out that no evidence of peneplanation of the Oligocene and Miocene sediments has been found and he cites the lake-shore features reported by Umpleby. As evidence which he considers most helpful in the discussion he cites the occurrence of stream-cut notches in some of the ridges, which have been excavated to depths of 500 feet or more below the peneplain and partly filled with Tertiary sediments.

Lindgren, upon consideration of the criticisms of Blackwelder and Rich, remarks that nobody has a right to assert the Pliocene or Miocene age of the high peneplain who has not critically examined the relations of the Columbia River lava to that surface as exposed in the region of the western margin of the Clearwater Mountains. There the Columbia River lava extends as a beautifully developed plateau at an elevation of about 4,000 feet in front of the Clearwater Mountains. The age of the Columbia River lava of that area, according to Lindgren, is generally conceded to be Miocene. To the east of this area the Clearwater plateau rises to elevations of 7,000 feet above the sea. Lindgren thinks that the crucial point of the argument is the Miocene or pre-Miocene

[2] Umpleby, J. B., An old erosion surface in Idaho; its age and value as a datum plane: Jour. Geology, vol. 20, pp. 139–147, 1912.

[3] Blackwelder, Eliot, The old erosion surface in Idaho; a criticism: Jour. Geology, vol. 20, pp. 410–414, 1920.

[4] Umpleby, J. B., The old erosion in Idaho: Jour. Geology, vol. 21, pp. 224–231. 1913.

[5] Atwood, W. W., The physiographic conditions at Butte, Mont., and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology vol. 11, pp. 697-740, 1916.

[6] Blackwelder, Eliot, Physiographic conditions and copper enrichment: Econ. Geology, vol. 12, pp. 541–545, 1917.

[7] Atwood, W. W., Physiographic conditions and copper enrichment: Econ. Geology, vol. 12, pp. 545–547, 1917.

[8] Rich, J. L., An old erosion surface in Idaho; is it Eocene?: Econ. Geology, vol. 13, pp. 120–136, 1918.

[9] Lindgren, Waldemar, The Idaho peneplain (discussion): Econ. Geology, vol. 13, pp. 486–488, 1918.

[10] Livingston, D. C., The Idaho peneplain (discussion): Econ. Geology, vol. 13, pp. 488–492, 1918.

age of the basalt flows. Until that can be disproved he considers the age of the peneplain as Eocene or older.

Livingston also defends the Eocene age of the peneplain on the basis of the Miocene age of the Columbia River basalt. He points out that the drainage of the basalt plateau in northern Idaho, where the plateau borders mountains that are composed of older rocks, is in a much more youthful condition than it is in the adjacent areas of older rock. Between the heads of the canyons and the mountains the streams flow on the surface of the plateau in shallow, alluvial valleys which are developed in the wind-blown silt that covers the plateau. In the mountains the streams follow more mature valleys than those that have been cut through the basalt. Livingston thinks it inconceivable that the adjacent mountain country could have been reduced to a peneplain and the peneplain elevated and eroded to a condition of maturity while the drainage system of the adjacent plateau did not advance beyond the condition of youth. The irregularities of the present drainage, including the backward pointing of certain tributaries of Salmon River where they join the main stream, do not, he thinks, indicate an earlier drainage system entrenched by the elevation of the peneplain. He considers the Payette, Pahsimeroi, Lemhi, and some other valleys as structural valleys that represent the northward extension of the block faulting of the Great Basin, which is supposed to be late Miocene or early Pliocene. If this idea is correct he sees no reason why Salmon River should not be antecedent to the structure and should not have cut the deep canyon between Pahsimeroi and Lemhi Creeks while the folding and faulting were taking place.

Pardee, who has worked in the region about Philipsburg in western Montana and in the Blue Mountains of Oregon, has recognized[11] an old erosion surface, which he regards as older than the Tertiary "lake beds" that now occupy the numerous broad valleys among the mountains. The Drummond, Sapphire, Philipsburg, and Bonner quadrangles, Mont., contain well-defined remnants of an old dissected peneplain that is now warped. The basin-like valleys contain Tertiary beds, and the streams now enter and leave these basins through deep canyons. A good example is Rock Creek, in the Sapphire and Bonner quadrangles. The slope of the peneplain in this valley is now such that were the original surface restored the stream could not flow upon it in its present path. Pardee thinks that the course of the stream was antecedent to the warping and that the warping was slow enough to enable the down cutting of the stream to keep pace with it. The warping of the peneplain, according to his view, caused the ponding of the waters, which escaped at the lowest point in the rim of the basin thus formed. Thus changes in drainage were brought about, among which was the development of the canyon through which Flint Creek now escapes from Philipsburg Valley. Lake beds were deposited in the down-warping basin. They now lie horizontal in the central part of the basin but rise gently upward toward the margins, as shown in Figure 40. The lake beds are composed largely of fine material, chiefly of pure volcanic ash and of volcanic ash mixed with sand. Only the marginal phases are at all coarse and these only moderately so, and the pebbles, which consist of local materials have a maximum diameter of 3 or 4 inches. The beds contain Miocene fossils. The grades of the country that surrounds the basin were apparently gentle at the time of the deposition of the sediments. The conditions described above are illustrated in Figure 41.

Pardee finds that the lake beds in a given basin maintain a fairly constant upper level, above which lies old soil on the older rocks. There is no sign of isolated patches of lake beds at higher levels. No actual shore features are now preserved. The present benches very gently truncate the upper slopes of the lake beds or appear practically to coincide with the upper surface of the beds. In some basins faulting has occurred at one side or the other and the lake beds are sharply tilted near the fault. According to Pardee, Miocene lake basins were developed in the streams that flowed from a former center of outward drainage in the Blue Mountains. The relief of the region was gentle. Basalt outflowed and overspread the lake beds and some of the lower hills but did not cover all of them. Later drainage from the same areas has developed in a similar arrangement.

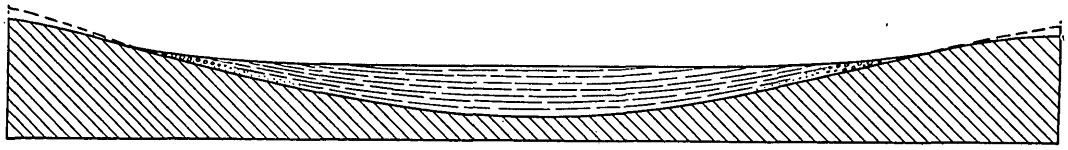


FIGURE 40.—Diagram showing the structure of certain Tertiary lake beds in Montana

POST-MIDDLE MIOCENE AGE

Blackwelder and Rich, who uphold the post middle Miocene age of the peneplain, have not had an opportunity to study the question in the districts described by Umpleby, Lindgren, Livingston, and Pardee, though Blackwelder has spent 10 or 12 field seasons in the Rocky Mountains, "including districts immediately adjacent to those discussed by Mr. Atwood."

Although Blackwelder recognizes the possibility that the lake beds may have been deposited in valleys

[11] Pardee, J. T., personal communication.

eroded in the peneplain, he suggests two alternative hypotheses. The first is that weak Tertiary beds may have been "down folded or down faulted between masses of harder rock and subsequently eroded to lowlands on account of the difference of resistance to denuding process." The second is that "the broad valleys occupied by the sediments were excavated and filled before the old peneplain was made." These views are illustrated in Figure 42. Under either hypothesis the peneplain would be younger than the Tertiary beds, which would be remnants of a blanketlike deposit that formerly overlay all but the higher ridges. From the degree of disturbance of the Tertiary beds Blackwelder is inclined to favor the first of the two alternatives. He finds it

> difficult to see how any Eocene peneplain could retain an approximately horizontal attitude and nearly uniform elevation over a large part of two or more States while sediments that have been subsequently deposited upon it were tilted, folded, and faulted to this extent.

Rich's paper is a critical study of the evidence presented by Umpleby and Atwood, the results of which lead him to reject the Eocene view and adopt instead the hypothesis favored by Blackwelder. In view of the emphasis placed by some upon the supposed Miocene age of the Columbia River lavas it is well to note Rich's comment that

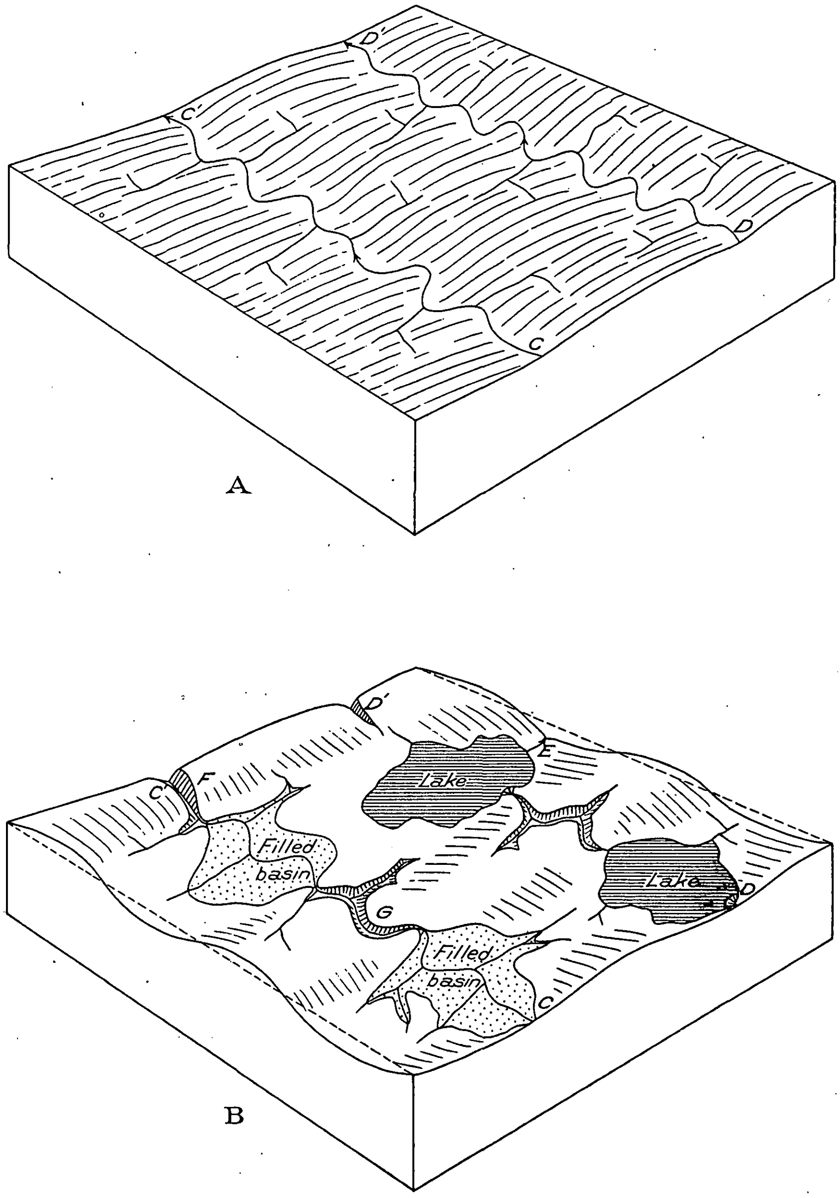


FIGURE 41.—Diagrams showing the warping of a peneplain and the development of lake basins and of antecedent and diverted drainage. A, Peneplain with parallel adjusted streams *C-C'* and *D-D'*. B, Same peneplain warped. *D-D'* has been diverted at *E*, and *C-C'* has become antecedent at *F* and *G*

> the old erosion surface of supposed Eocene age is as well developed, with as large flat areas on the summits, across the supposedly Miocene lavas, as it is elsewhere and at the same levels.

He explains the course of Salmon River with reference to the Lemhi and Pahsimeroi basins as a result of superposition from a peneplain that was developed after these basins were formed and filled. Similarly he considers that the stream notches, which are now partly filled with Tertiary sediments, as described in some Montana ridges by Atwood, were cut and filled before peneplanation and were later partly reexcavated.

DISCUSSION

The clear reasoning of Blackwelder and the critical analysis of Rich seem at first sight so convincing that apparently little would remain to be said in favor of the Eocene age of the peneplain. However, some of the geologists who are familiar with the fields of northern and central Idaho and of western Montana still feel that there are difficulties in the way of accepting the post-middle Miocene age and that the view that the age is Eocene is not without the support of sound field evidence.

Much is made by Blackwelder and Rich of the apparent discordance between the disturbed Tertiary beds on the one hand and the relatively undisturbed peneplain on the other. But the proponents of the Eocene age feel that too much emphasis is placed on discordance of attitude and not enough on accordance, and that on the whole the dislocations suffered by the peneplain are comparable with those suffered by the Tertiary beds, when the differences in the character of the rocks involved in the movements are considered. According to Pardee, there are many places like Philipsburg Valley, where the warped surface of the peneplain appears to pass beneath the gently dipping or horizontal lake beds, as if these beds were laid down in hollows progressively deepened by the warping of the peneplain. If Livingston's view of the origin of certain valleys mentioned above is correct it seems highly probable that lake beds which were forming in these valleys might suffer more or less dislocation during the progressive diastrophic movements to which the valleys were subjected.

The evidence of shore lines as cited by Umpleby and Atwood for the Tertiary lake basins is apparently completely discredited by Rich. Nevertheless in the light of Pardee's observations it is not satisfactorily disposed of. To be sure, no actual shore features are now preserved. Such features are geologically evanescent, but the general accordance of level of the lake-bed surfaces in many of the basins, together with the nearly horizontal attitude of the beds and the total absence of lake-bed remnants above that level, lends strong support to the view that these old lake-bed surfaces actually represent very nearly the original surface of the deposits. It may be argued that the present upper surface of these beds marks simply an erosion stage in the process of excavating the formerly completely filled valleys. On the other hand, until some remnants of the former filling or blanket are found at higher levels such large-scale excavation can not safely be assumed. From the relatively weak nature of the Tertiary beds, as compared with neighboring older rocks, it would hardly be expected that their surface could withstand erosion from the Miocene to the present, but if they stood near base-level for much of that interval little erosion could occur until that condition was changed.

Blackwelder argues from his observations in Wyoming, and probably with considerable justification, that large masses of Tertiary sediments, chiefly of fluviatile origin, have been swept away from surfaces or valleys which they once covered or filled. These sediments thus once formed a great blanket over much of the surface of the country. In southeastern Idaho the preserved remnants clearly show that beds of this type formerly covered much larger areas than they do at present. In northern and western Idaho and western Montana no remnants of these beds have been

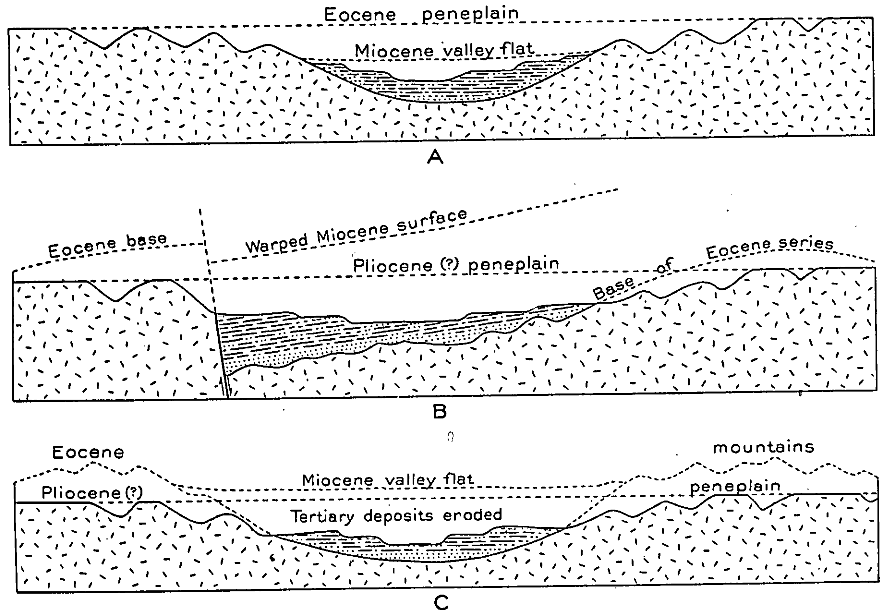


FIGURE 42.—Diagrams illustrating Blackwelder's discussion of hypotheses of Tertiary peneplanation. A, Eocene peneplain with later valleys partly filled with Oligocene and Miocene sediments; B, an early Tertiary surface with thick cover of Tertiary sediments warped or faulted and, in post-Miocene time, peneplaned; C, early Tertiary erosion and deposition followed by Pliocene (?) peneplanation. A represents the supposed conditions under the hypothesis of Eocene age for the peneplains, and B and C the conditions under Blackwelder's alternative hypotheses. (After Blackwelder)

found above the upper level of the beds that now occupy the various basins. In the absence of such remnants the former widespread occurrence of anything like a blanket deposit of sediments may well be questioned. It therefore seems probable that there may have been notable differences in the topographic development of this region and that of regions farther east and southeast.

The course of the Salmon River is thought by Rich to indicate superposition from a former course upon a peneplain, which was developed over both the hard older rocks and the weaker Tertiary rocks. This explanation would be satisfactory if the existence of such a peneplain is granted. Livingston and Pardee would find an equally satisfactioy explanation in regarding the stream as an antecedent one that maintained its course over a progressively warping or otherwise dislocating surface of an older peneplain in which the waters in the developing hollows became ponded. Umpleby's idea of headward erosion is discredited by Rich and is probably inapplicable.

Rich remarks that the Eocene peneplain, as described by Umpleby, "is as well developed, with as large flat areas on the summit, across the supposedly Miocene lavas, as it is elsewhere, and at the same levels." This statement raises the question of the age of the Columbia River lavas, which Lindgren writes is the crux of the problem. If, as Umpleby[12] states, "all the lavas occupy valleys developed after the elevation of the Eocene erosion surface" and "date from late Oligocene or early Miocene to about the close of the Pliocene," Rich's criticism seems well taken. Some of the lavas of the Columbia River region, however, are of Eocene age, as recognized by Smith[13] and Lindgren.[14] Thus, if the lava mapped at peneplain levels by Umpleby should prove to be Eocene Rich's objection would have little weight. The presence of Eocene lavas and of lavas of later date than Miocene in the region, as recognized by both Umpleby and Lindgren, throws doubt on any general assumption of Miocene age for the Columbia River lavas. To be sure, many of the lavas from their association with fossiliferous sediments are known to be Miocene, but in other places lavas which occupy critical positions with reference to the discussions of the peneplain are not associated with sediments of known age and the assumption of Miocene age for these lavas is hazardous.

The sediments themselves afford at times conflicting evidence with regard to age. Thus the Payette formation, which was at first regarded as Miocene, was later referred by Knowlton to the Eocene on the basis of floral evidence. It now seems likely that this reference may need to be changed once more, and as the age of this formation has been used as evidence of the early Tertiary or pre-Tertiary age of the peneplain the bearing of such a change is manifest. Buwalda[15] writes, regarding erosion surfaces in Idaho:

> As the age of peneplains is determined so largely through ascertaining their relations to strata whose age is known, the finding of vertebrates in the supposed Eocene at Payette in the summer of 1920 will aid considerably in fixing the age of these physiographic features. It can not yet be stated with certainty that the Payette is throughout younger than Eocene, but certainly large parts of it are middle or upper Miocene and some parts are apparently lower Pliocene. The effect of this evidence is obviously to make the surfaces younger than has previously been supposed.

If Buwalda's views are substantiated the difficulties regarding the age of the so-called Idaho peneplain may largely disappear. In the meantime it is well to emphasize the point brought out earlier in the discussion—that there may have been notable differences in the topographic development of the region that includes western and northern Idaho and adjacent parts of Montana and the region of southeastern Idaho and western Wyoming. Atwood expresses the idea well when he says:

> I have given up the thought that there was one period of widespread peneplanation when the entire Cordilleran region was near to base-level, and now favor the working hypothesis that while certain regions were high others were low, and the relief has been different in degree, yet of the same general type that we now have in the Cordilleran provinces.

EVIDENCE OF SOUTHEASTERN IDAHO

According to present knowledge, the Eocene history of southeastern Idaho is largely a record of erosion. During the epoch of Wasatch deposition, which came between earlier and later epochs of erosion, grades for a time were steep, but throughout the Green River and Bridger epochs the grades were low, and it is not unlikely that southeastern Idaho then stood near base level. This condition seems to have lasted until the middle Miocene, when orogenic disturbances were general throughout the Cordilleran region. There seems thus to have been ample time for the development of a peneplain or at least a very old erosion surface before that disturbance.

The formation of valleys in the uplifted peneplain would fall naturally in the late Miocene and may have been continued into the Pliocene. There was time enough for the opening of the broad valleys in which the Salt Lake formation was laid down and for the deposition of that formation before the close of the Pliocene. The deformation at the close of the Pliocene and the erosion and minor deformative movements of the early Pleistocene seem sufficient to account for the observed erosion stages, which have been described in Chapter II.

[12] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, p. 48, 1913.

[13] Smith, G. O., U. S. Geol. Survey Geol. Atlas, Mount Stuart folio (No. 106), 1904.

[14] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Silver City folio (No 104), 1904.

[15] Buwalda, J. P., personal communication.

If peneplanation of the region occurred subsequent to the deposition of the Salt Lake formation, as would be necessary under the hypothesis favored by Blackwelder and Rich, the time allowable for that process, though perhaps sufficient, is considerably less than under the previous supposition. Moreover, a large share of erosional history in the development of the successive stages mentioned above must be crowded into the early Pleistocene.

If the peneplain were developed across the Salt Lake formation as well as over the harder and older rocks it would seem that some patches of that formation might be preserved at or near the level of the peneplain. No such remnants have been found, however. The highest patch of Salt Lake sediments thus far recognized lies on the west flank of Red Mountain, in the Montpelier quadrangle, and attains a maximum elevation of about 7,850 feet. It has variable dips that are as high as 63° and lies just below the general level of the Gannett erosion surface. It seems to be a fluviatile deposit that was formed in a valley, either carved in that surface or of earlier date. On page 15 reasons are given for assigning it tentatively to an epoch intermediate between the Snowdrift peneplain and the Gannett erosion surface. The steep dip observed may be due to some local minor disturbance, for the other dips noted at this locality are gentle. Elsewhere the Salt Lake formation is associated with the lower erosion surfaces of the series above mentioned. It therefore seems probable that the Snowdrift peneplain was uplifted and eroded to form the Tygee erosion surface. The Salt Lake formation was deposited next. Then followed the arching of the peneplain, previously mentioned, and the development of the Gannett and lower erosion stages.

According to this view, the age of the Snowdrift peneplain might be pre-middle Miocene; the Tygee surface, late Miocene and perhaps early Pliocene; the filling of the broad valleys in that surface, Pliocene; and the rejuvenation and reexcavation of these valleys with the development of the Gannett and later erosion stages, early Pleistocene. (See p. 204.)

The course of Bear River south of the Preuss Range and north of the Bear River Range (see pls. 9 and 15) suggests superposition as already stated. At the first-named locality there seems little reason to doubt this explanation, for patches of Wasatch sediments occur on the uplands both north and south of the river. Valleys which are now tributary to Bear River at this locality and which still contain remnants of the Salt Lake formation suggest that this superposition took place perhaps at the beginning of the Gannett erosion. At the second locality Bear River passes through a relatively short and narrow gorge between broad valleys on the east and west. The valley on the east side of the range contains abundant remnants of the Salt Lake formation. The valley on the western side has not been studied by the writer, but it contains conglomerates that were thought by Peale to be of Quaternary age, though farther south well-recognized Pliocene(?) beds occur. The gap may have been cut by the outlet of a lake on the east side of the range which found the present site of the gorge to be the lowest point in its inclosing rim. The present constitution and distribution of the Salt Lake formation, however, are rather unfavorable to this view. Though locally composed of marls that are suggestive of lacustrine conditions, the formation as a whole is conglomeratic and in large part apparently of fluviatile origin. It now forms a blanket of irregular thickness that covers low hills and attains altitudes greater than those at the top of the present gorge. It is thus thought that before the reexcavation of the valleys to the form they now have, this blanket of Salt Lake sediments may have afforded a means for the superposition of Bear River upon a low place in the Bear River Range at about the same time as the similar event at the south end of the Preuss Range.

CONCLUSIONS

The idea of post-middle Miocene planation across earlier Tertiary and older rocks, as advocated for Idaho by Blackwelder and Rich, is not proved by the available evidence. There seems a probability that the erosional history of western and northern Idaho and of western Montana was somewhat different from that of southeastern Idaho or of western Wyoming. For southeastern Idaho the evidence seems to favor pre-middle Miocene planation succeeded by middle Miocene deformation; late Miocene and perhaps early Pliocene erosion; Pliocene deformation, erosion, and deposition; and late Pliocene or early Pleistocene deformation or rejuvenation and subsequent erosion. Further detailed studies are necessary before the physiographic interrelationships of different parts of the Rocky Mountain Province or of the Cordilleran region as a whole may become known.

SNAKE RIVER BASIN

One of the questions that arise from the discussion of Tertiary peneplanation is the relation of that process to the origin and development of the Snake River basin. The general belief of those who have worked in the Snake River country is that the basin is a relatively ancient feature.

Lindgren,[16] in writing of the region around Boise, states that

> before the beginning of the Neocene period the chief features of the topography were outlined—the broad uplift of the Boise Mountains and the depression of Snake River Valley. The latter is not unlikely a sunken area, separated by old fault lines from the mountains to the north.

[16] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Boise folio (No. 45), 1898.

He thinks that after the general topographic features were thus roughly blocked out erosion in early Tertiary or Cretaceous time planed down the uplands to gentle profiles or to a peneplain.

In a later publication Lindgren[17] notes that the whole course of Snake River below Weiser, Idaho, was changed by the eruption of Columbia River lavas during the Miocene, since which time slow movements have taken place. Besides local warpings these movements included the general subsidence of a large part of the lava-covered area and the elevation of the high plateau near the Seven Devils, through which Snake River has cut its deep canyon, the cutting of which kept pace with the uplift.

Russell's observations[18] tend to confirm those of Lindgren that the Snake River basin is very old and has been produced by deformative movements, mainly faulting.

In Umpleby's account of the old erosion surface of supposed Eocene age in central Idaho, which has been discussed in the preceding section, he makes no direct reference to the relation of that surface to the Snake River basin but considers the Miocene lavas to have been outpoured in valleys eroded in that surface. Elsewhere[19] he notes that along the southeast border of the Mackay region the mountains break off abruptly and the valleys expand as they unite with the great basalt-flooded valley that constitutes the Snake River Plains.

Livingston and Laney,[20] in their account of the Seven Devils country, conclude that the Columbia River lavas were outpoured upon an old erosion surface, which represents the westward extension of the "Eocene peneplain described by Lindgren and Umpleby." This surface has been affected since the outpouring of the lavas by folding or faulting, incident to the differential uplift of the country, and subsequently by erosion.

These authors think that between Huntington and the mouth of the Grande Ronde

> Snake River has flowed in its present general course for a very long time and was, in fact, one of the principal streams that drained the old Eocene surface.

They have found gravel at two places which seem to indicate in part the position of the old channel before its burial by lava. They say:

> It is evident that there has been an orogenic movement since the Miocene, consisting of a general uplift of the Wallowas, Seven Devils, and central Idaho, and a downward movement in the case of many structural valleys in eastern Oregon, * * * but this movement seems to have had little effect upon the course of the Snake, showing that uplift was slow.

Pardee[21] thinks that the Snake River basin originated by the warping of the peneplain of northern Idaho in the same way that the lake basins near Philipsburg, Mont., were formed. He notes that if the present surface was restored in the vicinity of Snake River along the western Idaho border the river would escape westward and northwestward across Oregon. Instead it goes against the grade across the Seven Devils region and is clearly antecedent to the warping of that region.

As regards the eastern part of the Snake River basin, Blackwelder[22] notes that

> the whole western slope of the Teton Range in the vicinity of the north fork of Pierre River is a gently inclined plain rising from the general plateau level of about 6,000 feet to the bases of the more rugged peaks at 9,000 to 9,500 feet. Although it has been incised by deep canyons, there are still broad, smooth remnants on the divides. The fact that the canyons are much deeper near their heads than farther west suggests that the surface has been tilted by being raised on the east. Although it is underlain by rocks of various types and structures, the plain is but little modified by structure.

From the foregoing accounts it seems reasonably certain that the Snake River basin is one of the oldest topographic features of southern and eastern Idaho. In its earliest recognized condition it appears to have been one of the main drainage areas in an old erosion surface that may date back to the Eocene. Its present form is due to obstruction by lava, with its resulting sedimentation, and to deformation. If the Snowdrift peneplain may be correlated with the so-called Eocene erosion surface of central and northern Idaho it was probably drained in large measure by the ancestral Snake River system. The possibility that Bear River was a member of this system has already been considered.

The deposition of Tertiary sediments appears to have begun earlier in the western part of the present basin than in the eastern, and to have been induced by the outpouring of the Columbia River basalt. Later Tertiary deposition, however, appears to have been widespread not only in parts of the Snake River basin but in adjoining basins.

Practically all observers agree that the Snake River basin has undergone deformation since its obstruction by the Columbia River lavas, but as yet no agreement has been reached as to the number and time of the disturbances. Lindgren[23] refers the uplift of the basalt-covered area and the accompanying development of the great canyon of the Snake in western Idaho to the Miocene. Livingston and Laney, as above noted, consider that these events have occurred since that time. The warping along the Teton Range noted by Blackwelder occurred after his Union Pass

[17] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, p. 115, 1904.

[18] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 47-49, 1902.

[19] Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, p. 18, 1917.

[20] Livingston, D. C., and Laney, F. B., The copper deposits of the Seven Devils and adjacent districts: State of Idaho Bur. Mines and Geology Bull. 1, pp. 5-10, 1920.

[21] Pardee, J. T., personal communication.

[22] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geology, vol. 23, p. 311, 1915.

[23] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 104), 1904.

cycle, which he places in the earliest Pleistocene. The warping of the Snowdrift peneplain in southeastern Idaho, as previously noted, probably occurred before the Gannett cycle, which is tentatively correlated with the Union Pass cycle.

Regional studies are needed to adjust the apparent discrepancies in the existing accounts and to determine the number, order, and nature of the deformative movements.

STRATIGRAPHIC PROBLEMS

ORIGIN OF THE PERMIAN PHOSPHATE

A general description of the phosphate is given in Chapter III under the head of the Phosphoria formation, including a list of fossils, a detailed section of the phosphatic shales, and data in regard to the distribution of the formation within the quadrangles here described. In Chapter VI the broader regional distribution of the formation is outlined and some of the geographic conditions of the time of deposition are postulated. In Chapter VII the physical, chemical, and mineralogic characteristics of the phosphate are described, and in the same chapter, in the description of individual townships, numerous sections or partial sections of the phosphate beds are given, together with analyses that show the phosphate content of the rock at the given localities. In the present chapter the intention is to show the bearing of the facts already presented and of other available data upon the origin of the phosphate, which constitutes the economically valuable portion of this unique formation.

BEDDING OF THE PHOSPHATE

The generally even bedding of the phosphate beds and their accompanying strata has been noted by all observers. Individual beds range in thickness from about one-sixteenth inch to 6 or 8 inches, but generally they are less than an inch thick and have a maximum thickness of not more than 2 or 3 inches. Except in one doubtful instance ripple marks have not been observed in the beds, no rill or current markings, mud cracks, or raindrop impressions have been identified in them, and cross-bedding has not been recognized. Beds of phosphatic shale and impure limestone are interstratified with beds of phosphate. Shaly streaks occur in some of the phosphate beds and streaks of oolitic phosphate and scattered phosphatic oolites in some of the shale beds. In some beds also phosphate merges into sandstone and sandy streaks trail out into phosphate, so that the sandstone seems to be more or less irregularly interbedded with the phosphate.

TEXTURE AND COMPOSITION

The most characteristic feature of the phosphate rock is its oolitic texture. Scattered nodules of phosphate from a fraction of an inch to 2 inches in diameter occur in some of the beds, and at some localities nodules of dark, fetid limestone a foot or more in diameter have been found in the midst of the phosphate, but nodules of either kind are relatively exceptional in the better rock. The phosphatic grains are true oolites with concentric structure and not casts of Foraminifera or other organisms. The most valuable beds commercially are made up of aggregates of phosphate oolites cemented by minor amounts of the same phosphatic substance.

Although glauconite commonly accompanies recent phosphatic nodules, as shown in the dredgings of the *Challenger* expedition,[24] and is found in many of the European and north African phosphate deposits, particularly those of the Cretaceous and Tertiary,[25] it has not been recognized in the Phosphoria formation. The small percentages of potash given in the analyses on page 210 show that little if any glauconite is present.

The basal beds at some localities are nodular or even conglomeratic, and the pebbles of the conglomerate consist largely of oolitic phosphate. A good example of a nodular bed was found in sec. 7, T. 7 S., R. 43 E., in the Lanes Creek quadrangle and both nodular and conglomeratic phases are well shown in the hills west of the Teton Basin farther north. At other places beds of shale, sandstone, limestone, or even phosphate rock lie immediately above the underlying Wells formation. Plate 63 illustrates a piece of phosphate rock in which both nodules and oolites are shown.

FOSSIL CONTENT

As previously noted, the phosphate beds themselves are largely nonfossiliferous, although some of the accompanying strata carry a considerable fauna. Thus the "cap lime," which occurs just above the main phosphate bed in the Georgetown and Montpelier districts and in sec. 36, T. 5 S., R. 38 E., in the Fort Hall Indian Reservation, is abundantly fossiliferous. At the last-named locality also and at places in T. 9 S., R. 43 E., in the Slug Creek quadrangle, a bed of fossiliferous limestone occurs at the base of the Phosphoria formation and contains large forms of *Productus* and *Spirifer*. In the NE. ¼ NE. ¼ sec. 21, T. 4 S., R. 37 E., in the Fort Hall Indian Reservation, at the base of the shales lies a bed of phosphate rock about 8 inches thick, which is composed largely of fragments of shells. These shells were originally composed of carbonate of lime but are now phosphatized, for an analysis of the rock shows the presence of 74 per cent of tricalcium phosphate. This rock contains in addition large numbers of

[24] Murray, John, and Renard, A. F., *Challenger* Rept., Deep-sea deposits, p. 391, 1891.

[25] Cornet, F. L., On the phosphatic beds near Mons: Geol. Soc. London Quart. Jour., vol. 42, pp. 325-339, 1886. Credner, H., Die phosphatische Knollen des Leipzig Mitteloligocene: K. sächs. Gesell. Wiss. Abh., Band 22, 1895. Ficheur, E., Étude géologique sur les terrains à phosphate de chaux de la région de Boghari: Annales des mines, 9th ser., vol. 8, pp. 248-280, 1895.

linguloid and discinoid shells and some pieces of bone.[26] A somewhat similar bed has been found in sec. 2, T. 8 S., R. 42 E. In sec. 36, T. 5 S., R. 38 E., a fish spine was found in the middle of the main phosphate bed.

In the Wind River and Owl Creek Mountains, according to Condit,[27] the Embar group, which includes the Phosphoria formation, contains two phosphate beds which are fossiliferous. In the upper bed *Productus nevadensis* is commom, and *Lingulidiscina utahensis* is extremely abundant in the lower bed. The phosphate beds in these mountains, however, are generally of much poorer quality than those in southeastern Idaho.

THICKNESS

In some of the richest sections, as in Georgetown Canyon, the total thickness of phosphate beds ranges from about 24 to 30 feet. At some other localities, as in the trench dug by the Geological Survey party near Henry, T. 6 S., R. 42 E., it is nearly 15 feet, and ordinarily in southeastern Idaho it is probably not much less than 10 feet, of which the main bed represents 5 or 6 feet. These thicknesses apply only to the oolitic phosphate beds, but these beds are accompanied by shales and limestones that are also more or less phosphatic.

DISTRIBUTION AND CONDITIONS OF DEPOSITION

The distribution and conditions of deposition of the phosphate have been outlined from available data in the discussion of the Phosphoria sea on page 184.

COMPARISON WITH OTHER PHOSPHATES

Phosphate deposits have been formed at different times and in different ways in many parts of the world. A digest of many of these occurrences and of the chemical reactions involved in their formation is given by Clarke,[28] who cites numerous references.

A considerable literature on the subject has been produced, but this can not be considered in detail here.

Blackwelder[29] has divided the world's phosphate deposits into six genetic varieties, comprised in two groups, as follows:

Primary: (1) Pegmatitic (Norway), (2) guano (Redonda Island), (3) marine sediments (Tunisia).

Secondary: (4) Surface residual concretions (Quercy), (5) phosphatized limestone and other rocks (Florida hard phosphate), and (6) detrital deposits (Florida River pebble).

The Idaho phosphate deposits belong in the third class (marine sediments). They thus resemble the phosphates of Algeria and Tunisia, Belgium, Wales, Sweden, and Tennessee (Devonian only) but are unlike those of Estremadura (Spain), southern France, Norway, Florida, Tennessee (brown phosphate), South Carolina, and the Peruvian Islands.

PREVIOUS VIEWS ON ORIGIN

The first detailed accounts of the western phosphates are contained in papers of Gale and Richards[30] and Blackwelder.[31] These authors regard the phosphates as original marine sedimentary deposits, and Gale and Richards give a very brief summary of the hitherto recognized sources of phosphorus and the method of its accumulation as phosphates through the agency of organic and physicochemical processes.

Breger,[32] in describing the oil-bearing phosphate near Lander, Wyo., considers the phosphate as derived from a microorganic ooze on the bottom of a shallow sea. From this slime both phosphatic and oily shales were developed. He thinks that the oolites were formed by rolling or that they represent Foraminifera, and he notes that the teeth and shells found in the phosphate have not been sources of phosphate but instead have had phosphate added to them. He cites German writers to show the work of bacteria in the extraction of phosphate from solution and thinks that they have extracted the calcium phosphate from sea water.

Blackwelder has contributed two valuable later papers. In one[33] he gives an interesting and suggestive account of the cycle of changes undergone by phosphorus from its mineral form in apatite through solution, assimilation by plants or animals, deposition on the sea bottom or on land, accumulation into deposits, burial, deformation, and metamorphism back to apatite again. Many subcycles are included, and individual atoms of phosphorus may have had widely different histories. In the other he gives in abbreviated form as derived from available literature a view of organic accumulation, which is substantially repeated here for reference.[34] In the ocean special conditions of currents and temperature, together with other factors not yet understood, may have induced the wholesale killing of animals over large areas and the accumulation of putrefying matter on the sea floor in moderate and shallow depths. Decomposition through the agency of bacteria produced ammoniacal solutions, which dissolved all tissues and the solid calcium phosphate in bones, teeth, and brachiopod

[26] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pp. 39–41, 1920.

[27] Condit, D. D., personal communication.

[28] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, pp. 523–534, 1924.

[29] Blackwelder, Eliot, Origin of the Rocky Mountain phosphate deposits: Geol. Soc. America Bull., vol. 26, pp. 100–101, 1915. (Abstract.)

[30] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457–535, 1910.

[31] Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S Geol. Survey Bull. 430, pp. 536–551, 1910.

[32] Breger, C. L., Origin of the Lander oil and phosphate: Min. and Eng. World, vol. 35, p. 632, 1911.

[33] Blackwelder, Eliot, The geologic rôle of phosphorus: Am. Jour. Sci., 4th ser., vol. 42, pp. 285–298, 1916.

[34] Blackwelder, Eliot, Origin of the Rocky Mountain phosphate deposits: Geol. Soc. America Bull.. vol. 26, pp. 100–101, 1915. (Abstract.)

shells. The abundance of putrefactive material also prevented the existence of organisms attached to the bottom, and most of the calcareous shells that descended from the surface were probably dissolved by the abundant carbonic acid arising from decaying organic substances. For physicochemical reasons, already partly understood, the phosphatic material was quickly redeposited in the form of hydrous calcium carbophosphates, locally, increasing, and replacing shells, teeth, bones, and similar objects, but especially forming small rounded granules of colophanite and finally a phosphatic cement among all particles. The granular texture is ascribed chiefly to physicochemcial conditions, such as result in oolitic greenalite, limonite, aragonite, and similar minerals. After having been formed in quiet water some of the granules were reached by bottom-scouring currents and incorporated in clastic deposits and in some places were strewn over eroded rock surfaces and so became constituents of basal conglomerates.

Pardee [35] is inclined to look with disfavor upon the view that unusual or abundant sources supplied phosphates rapidly to the sea. He points to the existence of glacial conditions elsewhere in Permian times and suggests that cool temperatures may have prevailed during the deposition of the western phosphates. Carbon dioxide (CO_2) is retained most abundantly by waters of low temperature, and this gas is supplied not only from atmospheric sources but also from organic substances that decompose in sea water or on the sea floor. Conditions would thus be unfavorable for the growth of coralline limestone or for the chemical precipitation of lime. Moreover, in such waters calcareous objects would tend to be dissolved, and the formation of limestones composed of shells and skeletons of marine organisms would be hindered. But if the precipitation of phosphate was not checked that material would accumulate in relatively pure form. The great volume of the deposit, as shown by the tonnage estimates, needs no further explanation than the continued or extensive application of the process that started the formation of the phosphate.

In an earlier paper [36] the present writer proposed a tentative working hypothesis for the origin of the western phosphate, based on the idea that the oolites were first formed as carbonate of lime in the form of aragonite through the agencies of denitrifying bacteria in warm waters, such as those off the Floridian coast; they were subsequently phosphatized when the water became too cold to permit the activity of such bacteria and when in consequence the available quantity of decaying organic matter was greater.

[35] Pardee, J. T., The Garrison and Philipsburg phosphate fields, Mont.: U. S. Geol. Survey Bull. 640, pp. 225-228, 1917.

[36] Mansfield, G. R., Origin of the western phosphates of the United States: Am. Jour. Sci., 4th ser., vol. 46, pp. 591-598, 1918.

DISCUSSION

Reconsideration of the problem in the light of additional data has led the writer to abandon the idea of the formation and later phosphatization of oolites of calcium carbonate, and of inferences dependent thereon. The stratigraphic details given above appear to demonstrate conclusively that the oolitic grains of phosphate were built into successive layers in the same manner as the clastic materials with which they are to a greater or less extent associated and that they must have existed in the form of phosphate when they were thus assembled. Some secondary activity of solutions bearing calcium carbonate and phosphates is indicated by the formation here and there of nodules of limestone in the phosphate beds and by the phosphatization of the shell fragments previously noted. Some thin sections of oolitic phosphate show that calcite, both in the oolitic grains and in the matrix of the rock, has been replaced by phosphate.

The mode of origin of the oolites is not clearly understood, but the presence on the sea bottom of solutions rich in phosphate or perhaps of phosphatic colloids is certainly indicated. Whether bacteria have had a part in the formation of these substances, as suggested by Breger, must be determined by future biochemical studies. Calcareous oolites are now forming at a number of places, notably in the region of the Florida Keys and the Bahamas, where they have been studied by Drew [37] and Vaughan.[38] Drew has shown that in these regions denitrifying bacteria are very active and are precipitating enormous quantities of calcium carbonate.[39] Vaughan shows that this chemically precipitated calcium carbonate forms spherulites or small balls, composed chiefly of aragonite, which by accretion may become oolitic grains of the usual size, or it may accumulate around a variety of nuclei to build such grains. Harder [40] has described the geologic activities of iron-depositing bacteria and attributes the formation of certain types of sedimentary iron ores in large measure to the activities of these organisms. No such studies are available for phosphatic oolites, though Breger [41] states that Stoklasa and others have established the potency of a group of phosphate bacteria, which

[37] Drew, G. H., On the precipitation of calcium carbonate in the sea by marine bacteria, and on the action of denitrifying bacteria in tropical and temperate seas: Carnegie Inst. Washington Pub. 182, Papers from the Tortugas Laboratory, vol. 5, pp. 9-45, 1914.

[38] Vaughan, T. W., Preliminary remarks on the geology of the Bahamas, with special reference to the origin of the Bahaman and Floridian oolites: Carnegie Inst. Washington Pub. 182, Papers from the Tortugas Laboratory, vol. 5, pp. 47-54, 1914.

[39] This conclusion has recently been challenged by Lipman. See discussion by Twenhofel, W. H., Treatise on sedimentation, pp. 238-240, Baltimore, Williams & Wilkins Co., 1926.

[40] Harder, E. C., Iron-depositing bacteria and their geologic relations: U. S. Geol. Survey Prof. Paper 113, 1919.

[41] Breger, C. L., op. cit.

specialize in the assimilation of phosphate from soil solutions. It is not known whether similar bacteria are active in marine habitats, but the fact ascertained by Alilaire [42] that bacteria of various kinds contain appreciable percentages of phosphoric acid makes it seem highly probable that these and possibly other organisms may play a noteworthy part in the preparation of the phosphatic material from which the oolites are derived. The hairlike and branching bodies shown in some of the thin sections of phosphate rock as noted on page 213, may have some bearing in this connection.

Oolites have formed directly from other substances than calcium carbonate. According to Smyth[43], the oolitic grains of the Clinton iron ore were thus formed, and Hayes [44] shows a similar origin for the oolites of the Wabana iron ore. According to Hayes, algae are plentifully preserved in some of the ferruginous phosphatic nodules of the ore, and many of them have been found in spherules composed of hematite and chamosite. These tiny plants are thought to have played a part in the formation of the iron ore and its accompanying silicates, but the concentric layers of the spherulites are ascribed to physical causes. The iron silicates greenalite and glauconite, which are locally very abundant, are oolitic, but the oolites do not have concentric or radial structure. Leith[45] thinks that the granules of greenalite in the Lake Superior iron ore may possibly have developed directly from the abstraction, through the agency of organisms, of iron in solution in sea water, whence it was contributed from adjacent land areas.

The formation of glauconite granules has been ascribed by Murray and Renard [46] to transformations that took place through the agency of organic matter in mud inclosed in shells of Foraminifera and other organisms. More recently Cayeux [47] has shown that organic matter, though commonly the primordial condition of the production of glauconite, has in many localities had no part in the genesis of this mineral. The actual formation of the spherulitic grains in all these localities appears to have been due in large part if not wholly to physical causes. It therefore seems probable that the phosphatic oolites of southeastern Idaho and of the western phosphate field generally were formed directly from solutions rich in phosphate or from phosphatic colloids rather than by phosphatization of calcareous oolites and that the oolites themselves were formed partly by chemical precipitation and partly by physical or mechanical accretion.

The sources and quantity of the phosphatic materials in the phosphate beds are significant elements in the problem of their origin. Blackwelder [48] points out that animals of the sea are almost never permitted to die of old age but are devoured sooner or later by other animals and that any that die in other ways are at once eaten by scavengers, even bones of fishes being devoured by echini and other animals. It is conceivable, he thinks, that on rare occasions the quantities of animal matter might be too great for the scavenger population and that a local accumulation might result. Upon such an idea Murray [49] based a hypothesis to explain the origin of the phosphatic nodules dredged up from the sea bottom in different parts of the world. In a later work [50] he cited the remarkable incident in 1883, when the tilefish were killed by hundreds of millions along the Atlantic coast of the United States, presumably by a sudden fall of temperature of the water brought about by the shifting of the position of the cold northern current between the Gulf Stream and the coast. Other examples of similar destruction of fish on a large scale have been noted in other parts of the world. Thus Oldham [51] describes the wholesale killing of fish in certain Indian rivers by earthquake shocks. One river for days was choked with dead fish floating downstream. Blanford [52] too mentions the periodic destruction of fish life along the Malabar coast at the change of the monsoon, chiefly in October and November. Blackwelder's view that wholesale killing of animals may have been a notable factor in the formation of the western phosphate therefore has some justification. On the other hand, in spite of the activities of scavengers and of prolonged trituration, it would seem that fish spines, teeth, and similar objects should be more numerous in the phosphate beds than they are if such postulated destruction of life had occurred; witness the finely preserved fish remains in the Green River formation of Wyoming and in the well-known Kupferschiefer of Germany. The fish in the Kupferschiefer are generally considered to have been killed suddenly by mineralized waters directly or indirectly attributable to volcanic causes. These beds, like those of the western phosphate, are more or less bituminous and are of Permian age.[53]

Detrital material from the land is largely absent from the phosphate beds of better grade. Analyses of rock from the main bed at several localities show generally less than 12 per cent of SiO_2, Al_2O_3, Fe_2O_3, and

[42] Alilaire, M. E., Sur la présence dù phosphores dans la matière grasse des microbes. Compt. Rend., vol. 145, pp. 1215–1217, 1907.

[43] Symth, C. H., jr., On the Clinton iron ore: Am. Jour. Sci., 3d ser., vol. 43. pp. 487–496, 1892.

[44] Hayes, A. O., Wabana iron ore of Newfoundland: Canada Dept. Mines, Geol. Survey Mem. 78, pp. 70–80, 1915.

[45] Leith, C. K., The Mesabi iron-bearing district of Minnesota: U. S. Geol. Survey Mon. 43, p. 259, 1903.

[46] Murray, John, and Renard, A. F., *Challenger* Rept., Deep-sea deposits, p. 389, 1891.

[47] Cayeux, Lucien, Contributions à l'étude micrographique des terrains sédimentaires: Soc. géol. Nord Mém., vol. 4, pt. 2, pp. 176–184, 1897.

[48] Blackwelder, Eliot, The geologic rôle of phosphorus: Am. Jour. Sci., 4th ser., vol. 42, p. 290, 1916.

[49] Murray, John, and Renard, A. F., op. cit., pp. 396–399.

[50] Murray, John, Changes of temperature in the surface waters of the sea: Geog. Jour., vol. 12, pp. 129–131, 1898.

[51] Oldham, R. D., Report on the Indian earthquake of June 12, 1897: Geol. Survey India Mem., vol. 29, p. 80, 1899.

[52] Discussion of paper by Cornet, F. L., On the phosphatic beds near Mons: Geol. Soc. London Quart. Jour., vol. 42, pp. 325–339, 1886.

[53] Geikie, Archibald, Text book of geology, 4th ed., vol. 2, p. 1073, London, 1903

MgO all added together. Silica forms the greater part of this amount and some of this may be of organic origin. This condition may be explained in several ways. The deposit may have been laid down in relatively deep water, like some of the modern oozes; or the water of deposition, though shallow, may have been too far from land to receive much detritus from that source; or the lands adjacent to the waters of deposition may have been so low, through base-leveling or otherwise, that they furnished little clastic material to the sea; or, according to an earlier suggestion of Hayes,[54] strong marine currents may have swept away the fine terrigenous material, leaving only the phosphatic oolites.

The even bedding above noted is opposed to the idea that the water was deep and indicates that the phosphatic material accumulated within the reach of wave and current action. The better deposits do apparently lie far from the former shore, for the beds in the Wind River and Owl Creek Mountains, which were nearer the shore, are distinctly inferior to those of southeastern Idaho, but the supposition of peneplanation of adjacent lands is not excluded. As previously shown the eastward shores of the Phosphoria sea appear to have been low.

The physiographic conditions changed from time to time during the deposition of the phosphatic shales, for beds of shale, sandstone, and limestone, some of which are more or less phosphatic, are interbedded with the more nearly pure phosphate.

The period of deposition may have been long. The time required for the deposition of the phosphate beds and the accompanying Permian strata is not known, but some data permit suggestive comparisons. Though there is at least local unconformity at the base of the Phosphoria formation, this unconformity is not regarded as indicating any great time interval. The top of the formation is also marked by an unconformity, and the faunal change above is very pronounced. The time interval here is probably large. The phosphatic shales, with which are grouped some nonphosphatic or lean shales, sandstones, and limestones, are about 150 feet thick, and of this thickness the actual beds of phosphate rock form only a small proportion. The Phosphoria formation as a whole, which includes all the known Permian of the region, is about 500 feet thick. In Kansas the Permian section, according to Prosser,[55] is about 2,000 feet thick; in Texas the Permian formations are reported to be 5,000 feet thick;[56] and in Oklahoma they are reported to be 2,600 feet thick.[57] If those deposits may be regarded as occupying time intervals at all similar, it is obvious that the deposition of the Phosphoria formation of Idaho was at a much slower rate than the accumulation of Permian strata in the regions named farther east. The occurrence in phosphate rock of chromium in amounts unusual for sedimentary rocks suggests concentration from the slow accumulation of cosmic dust and thus supplements the evidence of the Permian sections cited. It therefore seems at least reasonable to attribute the thickness and richness of the phosphatic strata to long-continued, slow deposition under conditions which excluded for considerable intervals of time the accumulation of terrigenous material and of carbonate of lime. This view is further supported by the fact that some of the earlier-formed oolitic beds became sufficiently consolidated for material derived from them to be incorporated as pebbles in later-formed beds, as noted along the west side of the Teton Basin. The area of deposition, though of great extent, must have been separated or nearly so from the main ocean because the fauna according to Girty,[58] is entirely different from the Carboniferous faunas of the Mississippi Valley and even among western faunas has an extremely individual and novel facies.

The water circulatory system throughout much of this area must have been poor, otherwise the conditions of the bottom would not have become so foul. Breger[59] compares it with the sargasso eddy of the North Atlantic. Probably the inflow of sea water from the North Pacific or Arctic was impeded, and temperature contrasts between higher and lower latitudes may not have been so pronounced as they are to-day. At any rate, conditions were not as favorable for replenishment of oxygen in the deeper waters of the Phosphoria sea as they are in the open oceans. This prevented the growth of organisms such as ordinarily inhabit the sea floor and devour organic matter that might otherwise accumulate. On the other hand, it promoted the anaerobic type of bacterial decay, so that decomposition products such as carbon dioxide and ammonium phosphate might readily be produced.

According to Credner,[60] the calcium phosphate of fish remains, after its extraction with water containing carbon dioxide, will, in the presence of ammonium carbonate, react to form calcium carbonate and ammonium phosphate. This last substance, with the addition of more calcium carbonate changes again to calcium phosphate and ammonium carbonate. These conditions, which have been reproduced in the laboratory, are believed to be present on the sea bottom, where a cycle of chemical reactions takes place among such solutions by which bits of shell and other objects become phosphatized. Tricalcium phosphate in the

[54] Hayes, C. W., Tennessee phosphates: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 534, 1896.

[55] Prosser, C. S., Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, pp. 703-737, 1902.

[56] Cummins, W. F., Report on the geology of northwestern Texas: Texas Geol. Survey Second Ann. Rept., p. 398, 1891.

[57] Beede, J. W., Invertebrate paleontology of the upper Permian red beds of Oklahoma and the Panhandle of Texas: Kansas Univ. Sci. Bull., vol. 4, No. 3, p. 136, 1907.

[58] Girty, G. H., The fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 436, p. 8, 1910.

[59] Breger, C. L., op. cit.

[60] Credner, H., Die phosphatische Knollen des Leipzig Mitteloligocene; K. sächs. Gesell. Wiss. Abh., Band 22, p. 26, 1895.

form of collophanite or of carbophosphates, such as dahllite, may be precipitated chemically in colloidal or amorphous form or may be abstracted from solution by bacteria as above suggested. Larger objects, such as teeth or fragments of bone (see pl. 63), serve as nuclei for phosphatic nodules. Smaller pieces of bone or shell, grains of quartz, and similar objects become nuclei for oolites or these may form without any core of foreign material.

The climatic conditions, though unknown, probably exerted a great influence upon the formation of the phosphate. Pardee's suggestion of cool temperatures accords with the results of Drew's studies previously mentioned. Drew found that the activities of denitrifying bacteria, which, as he showed, cause the precipitation of calcium carbonate, are greater in tropical waters than in the waters of the Temperate Zones. Denitrifying bacteria reduce the nitrate content of sea water and hence curtail the growth of marine plants and of animals dependent on them. In cooler temperatures there would be less favorable conditions for the deposition of carbonate of lime and at the same time better opportunities for the development of the plant and animal life necessary to furnish the supply of phosphate. Cool temperature seems the more probable because of glacial conditions elsewhere at the time, as noted by Pardee. The rather widespread occurrence of two or more phosphate beds may mean that there were noteworthy climatic oscillations during the period accompanied by cooler and milder temperatures similar to the successive glacial and interglacial stages of the Pleistocene epoch.

The bituminous matter which is included in the phosphate and which in the Lander district, Wyo., is actually accompanied by oil, with little doubt owes its origin to the same organic material that in general supplied the phosphate. Breger postulates a micro-organic ooze or slime, composed mainly of animal remains rather than of plants and possibly composed entirely of soft protoplasmic material which would leave no skeletal or fossil remains. It is clear from the great body of phosphate contained in the oolitic beds and from the fossils in the accompanying beds of limestone, which may represent times when the phosphatic solutions were more dilute, that animal life throughout the epoch of deposition of the phosphatic shales was abundant. From the considerations already set forth regarding the destruction and decay of animal life it seems hardly necessary to postulate special types of animals to furnish the bitumen and the phosphate, if sufficient time is allowed for the accumulation of the débris.

Cayeux [61] believes that the phosphate beds of the Upper Cretaceous in Europe have been formed as a result of great disturbances of the equilibrium of the sea. These disturbances bring in their train changes in ocean currents and in the depth of the sea. Such changes cause the destruction of great numbers of organisms, which furnish in abundance the phosphoric acid that passes into the sediments. This view places phosphate beds in close relationship with unconformities or with other stratigraphic breaks. It has already been noted that the phosphate beds in Idaho lie immediately above an unconformity and that the planes of separation between individual beds in a series such as the phosphatic shales represent interruptions in sedimentation of greater or less magnitude. Similar relationships of glauconite with unconformities are noted by Goldman,[62] who cites earlier writers.

OUTLINE OF ORIGIN

The phosphatic oolites, which constitute so large a proportion of the phosphate beds, were probably formed directly by biochemical and physical agencies from phosphatic solutions or colloids on the sea bottom. This material may have been supplied by some accidental wholesale destruction of animal life, but more probably it represents a slow gathering and concentration of phosphatic débris under conditions which largely excluded oxygen from the deeper waters and were thus unfavorable for forms of life that ordinarily inhabit the sea bottom and prevent the accumulation of organic débris. These conditions were induced by the considerable separation of the waters of the Phosphoria sea from the ocean and by the restriction in the circulation of its waters caused by this separation and by the supposedly smaller temperature differences which then existed between high and low latitudes. Generally cool temperatures with some climatic oscillations prevailed during the time of deposition of the phosphate. These conditions tended to favor the growth of plant and animal life in the shallower waters, while at the same time they reduced the activities of denitrifying bacteria, which curtail plant life and thus hinder the growth of animals dependent upon plants. Reduction of the activities of denitrifying bacteria may also have curtailed the precipitation of calcium carbonate, thus favoring the concentration of phosphatic solutions from which oolites might be formed. There was sufficient time for the postulated slow formation of the extensive phosphate deposits now found.

The above account, which has been prepared with special reference to the Permian phosphates, probably applies, with some modifications, to the Mississippian phosphates as well.

MINERALOGIC CONSIDERATIONS

An account of the general mineralogic composition of the phosphate rock is given on page 213. It had been hoped that more extended mineralogic study of selected hand specimens and thin sections of western

[61] Cited by Collet, L. W., Les dépôts marins: Encyclopédie scientifique, pp. 212-213, Paris, 1908.

[62] Goldman, M. I., Basal glauconite and phosphate beds: Science, new ser., vol. 56, No. 1441, pp. 171-173, 1922

phosphate rock would throw additional light upon the question of its origin. W. T. Schaller, who was kind enough to make this examination, reports that the available material is not suitable for a definite determination of its mineralogic composition. Most of the slides are nearly opaque, owing to the inclusion of very abundant brownish foreign material, probably organic. Much calcite and fluorite is closely associated with the phosphatic material, so that chemical tests would be of no value, for the presence of the groups $CaCO_3$ and CaF_2 is the characteristic, diagnostic feature of some of the phosphate minerals.

According to Schaller, the best that can be said now is that the phosphate rock is composed of oolites of an amorphous mineral, probably collophanite, and some of the oolites are surrounded by a narrow rim composed of a crystallized mineral (probably a metacolloidal form of the isotropic collophanite). This crystallized material may be one or more of the following minerals, whose exact composition and optical properties are not definitely or accurately known: Dahllite, podolite, francolite, staffelite, hydroapatite, β-quercyite, phosphorite, voelckerite, wilkerite, and perhaps others.[63]

The chief difficulty in such a mineralogic investigation is to obtain pure material. If pure homogeneous material were available for the study of the individual minerals it would then be a relatively simple matter to unravel the mixtures or "solid solutions," which exist in ordinary phosphate rock. Plates 64–66, 69, and 70 illustrate some of the phosphatic oolites as seen in thin section, magnified 50 diameters. (See also pl. 63.) Similarly Plates 67 and 68 show in magnified form the type of rock, less common in the Idaho field, composed chiefly of phosphatized fragments of shell. In Plate 64 the oolites are closely appressed and appear to have a very fine granular structure with only slight suggestions of concentric arrangement. Comparatively few of the grains are well rounded. The matrix is nearly as conspicuous as the grains and is of similar constitution.

In Plate 65 the oolitic grains are generally well rounded and show a conspicuous zoned or concentric structure, especially in the outer portion. Both the oolitic grains and the matrix have a finely granular structure, but the matrix is relatively inconspicuous. One of the grains near the center suggests foraminiferal origin. The dark spots in the rock are due to organic matter. In Plate 66, which represents rock from the same locality as Plate 65, the concentric structure of some of the grains is very clear, but, like those shown in Plate 65, most of them have no distinct nucleus. Grains of quartz are distributed irregularly through some of the oolites.

Plates 67 and 68 show a few scattering oolites so dark with organic matter that little can be told of their structure, though this appears to be irregularly granular rather than concentric or radial. The bulk of the material represented in both plates is composed of phosphatized bits of shell or possibly fragments of bone. One such fragment in the center of Plate 67 has been incorporated in a small nodule, and a large fragment near by is suggestive of a jaw or of the toothed hinge line of a shell. This fragment and others have curious wormlike markings. The phosphatic matrix, like the oolites, is dark with organic matter. In Plate 68 the rock has been fractured and recemented with phosphatic material.

In Plates 69 and 70 the oolites and organic fragmental material are mingled in more even proportions, and the oolites, though dark with organic matter, show concentric structure. Some small angular grains, as well as larger, more rounded grains of quartz are present. The phosphatic matrix is dark with organic matter.

DIRECTION OF FURTHER STUDIES

As wider areas of the basin formerly occupied by the Phosphoria sea are explored and the available stratigraphic sections are studied and correlated, much more may be learned about the paleogeographic conditions of Phosphoria time. Such data are needed for a fuller understanding of the problem of the origin of the phosphates. On the experimental side bacteriologic and chemical investigations, under conditions that approximate as closely as possible those existing on the sea floor, afford the greatest promise of definite information. Mineralogic investigations offer little hope of satisfactory results until pure materials can be obtained, perhaps synthetically, for use as standards of comparison.

ORIGIN OF THE REX CHERT

The Rex chert has already been considered to some extent in the descriptions of the Phosphoria formation, of which it constitutes the upper member, and of the Phosphoria sea. Additional details are here presented, and some features already mentioned or implied are further emphasized. The outstanding characteristics of the Rex are its regular bedding, its generally fine texture and apparently uniform composition, the scarcity of its fossils, its remarkable thickness, and its great extent, which represents an original area of deposition to be measured in thousands of square miles. It thus takes rank among the great chert-bearing formations of the world, the origin of which has been a matter of some controversy among geologists for many years.

In the present study no systematic suites of specimens have been collected. Such field studies as have been undertaken have been incidental to work on other problems that for the time were of more pressing importance. No experimental work has been conducted, and no attempt at complete bibliographic study has been made, though some of the more recent articles have been examined and a few of the more pertinent older papers have been consulted.

[63] For a description of some of these minerals see Schaller, W. T., Mineralogical notes, series 2; U.S. Geol. Survey Bull. 509, pp. 89–100, 1912.

BEDDING

In the description cited above two principal types of bedding have been noted—the massively bedded facies and the flinty-shale facies. The massively bedded chert is usually the conspicuous part of the member. These beds commonly form rocky ledges or points along the mountain sides or in canyons, as in Tps. 9 and 10 S., R. 44 E., or fine dip slopes, as in T. 8 S., R. 44 E. (pl. 29, *A*), or impressive gateways, as in the Sublette Ridge (pl. 54). Individual beds range from a few inches to nearly a foot in thickness. No beds of shale have been observed among them. Bedding planes, however, are well developed and are characteristically marked by surfaces with low humps and hollows suggestive of nodular structure. The nodules are usually indistinguishable from their cherty matrix, but locally they become conspicuous by weathering (pl. 50, *A*).

The minor irregularities in the bedding planes noted above tend to produce minor variations in the thickness of a given bed, but no tendency of the beds to become lenticular or to terminate among other beds, such as Davis [64] describes in the California radiolarian cherts, has been observed among the massive beds of the Rex. Although individual beds doubtless are broadly lenticular and wedge out somewhere, the effect at any given locality is that of a series of roughly parallel beds which form a thick layer of chert. Deformation and erosion have caused this layer of chert to become discontinuous, but it can be easily reconstructed in imagination, and in all probability it was formerly continuous over a vast area.

The flinty-shale facies of the Rex is seldom well exposed, for the thin beds are so thoroughly jointed that the rock ordinarily breaks into small chippy fragments, which form rounded knolls or smooth slopes rather than massive ledges. Where beds are actually exposed, as in road or stream cuts, the individual beds range in thickness from perhaps a sixteenth to a quarter of an inch. No intervening beds of shale of other types have been recognized among them and no lenticular development in them has been noticed.

Banding is not a common feature of the Rex chert, but it has been observed at a few places, notably in the SW. ¼ sec. 14, T. 33 N., R. 119 W., in Wyoming and in the SE. ¼ sec. 3, T. 15 S., R. 43 E., in Idaho. At the first-named locality the chert forms a massive ledge, is light colored, and finely and regularly banded. At the second locality the rock is darker, massively bedded, and banded. Each of these occurrences is near a fault along which hydrothermal action has occurred, so that the banding may be in some way connected with that action.

[64] Davis, E. F., The radiolarian cherts of the Franciscan group: California Univ. Dept. Geology Bu "|vol. 11, No. 3, pp. 248-252, 282-288, 1918.

In the area included within the seven quadrangles here described limestone in even beds occurs at places previously noted in some parts of the interval occupied by the Rex chert and may grade into or interfinger laterally with the chert, though such changes have not been observed, probably because of the discontinuity of the areas in which the Rex is exposed. In the Uinta Mountains, as described by Schultz,[65] the portion of the Park City formation which corresponds to the Rex chert of southeastern Idaho contains a much larger proportion of limestone, and the associated chert is there reported as lenticular or nodular in occurrence.

TEXTURE AND COMPOSITION

The texture of the massively bedded chert is usually very fine and even, almost waxy in appearance, and the rock breaks with a conchoidal fracture into sharp angular blocks or fragments. At some places where the chert, which is very brittle, is traversed by a multitude of fine cracks, the rock breaks irregularly across these cracks with an uneven or rough surface. At such a place the weathered surface is covered with small sharp, angular projections. Locally it has a pseudocolumnar structure. (See pl. 61, *C*.) Elsewhere it is usually smooth except for the nodular appearance already mentioned.

Near the base at some localities lies a coarser-textured and more porous bed which at first sight resembles a quartzite but which on closer inspection is seen to be largely composed of the spicules of siliceous sponges. In thin section under the microscope these spicules are seen to lie in different positions, so that all gradations from cross sections to longitudinal sections may be observed. Although no extended search for this bed has been made, it has been encountered in a number of trenches that were dug for sampling and measurement of the underlying phosphatic shales, and it appears to be widespread.

The texture of the flinty-shale facies is not so fine and the freshly fractured surface is more earthy in appearance and is slightly porous.

Thus far thin sections of only the most massive beds have been examined and not many of these. In the ordinary chert the slides show feebly polarizing cryptocrystalline quartz throughout without chalcedony or amorphous material. Slides of the basal bed, in which the sponge spicules are so numerous, contain chalcedony, chiefly in the walls of the spicules, and some streaks of apparently amorphous material that is discolored by organic matter or by iron oxide. Tiny purplish specks and interstitial fillings in some of the slides suggest the presence of fluorite. In the slides thus far examined little or no inorganic detrital material has been recognized.

[65] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, p. 47, 1919.

Although within the area here described little variation in the composition of the chert has been noticed, in the broader area occupied by the chert formation as a whole considerable differences in composition could probably be observed. Thus, in the Montpelier district and in areas farther south and southeast the Rex chert interval contains more or less limestone. On the other hand, the Rex chert on the west side of the Teton Basin, 40 to 50 miles north of the Freedom quadrangle, contains quartzite in its upper part. In Montana the Rex chert is not differentiated from the Phosphoria, but this formation is described by Condit[66] as "being either cherty or quartzitic almost throughout."

FOSSIL CONTENT

A number of fossils have been found in the limestone beds of the Rex, but in the chert itself fossils are relatively rare except in the bed that contains sponge spicules as mentioned above. It is noteworthy that at one locality abundant casts of crinoid stems were found in the chert.

THICKNESS

Although the thickness of the Rex chert is variable when the region as a whole is considered, ranging from about 110 to 550 feet, the thickness in any given district is fairly constant and does not give the impression of excessive local accumulation. In the section on page 78 the massively bedded chert is 60 feet thick. At Raymond Canyon in the Sublette Ridge it is about 80 feet thick and at Hot Springs near Bear Lake it is about 110 feet thick. The thickness at some places is doubtless affected by the strong folding to which the beds have been subjected; the flinty-shale beds at least would be incompetent under such conditions.

DISTRIBUTION

The Phosphoria formation or its equivalent members in the Park City or Embar formations are known to extend, save for interruptions due to deformation and erosion, from the south side of the Uinta Mountains in northeastern Utah northward through eastern Idaho into west-central Montana (Elliston field) and eastward into Wyoming to points east of Big Horn River. About 350 miles north of the Elliston locality phosphate is reported by Adams and Dick[67] in Alberta under conditions of occurrence so similar to those in Montana that probably here, too, the separation of the preserved masses of phosphate from those farther south has been produced by deformation and erosion.

In all these localities the phosphate-bearing beds are overlain by more or less massive beds of chert. Although it is not possible now to trace individual beds of chert from one locality to another it is reasonably certain that chert was in process of formation more or less simultaneously throughout this area and probably in areas as yet unexplored still farther north. It seems, however, to have reached its maximum development in eastern Idaho and in some adjacent parts of western Wyoming.

COMPARISON WITH OTHER CHERTS

The nearest analogs of the Rex chert in this country seem to be the radiolarian cherts of the Franciscan rocks in California. These cherts have been studied by numerous geologists and have been made the subject of a special monograph by Davis.[68] The cherts of the Monterey group, which contain no radiolarian remains but in many respects are much like the radiolarian cherts, are discussed in the same monograph. The Monterey and Franciscan cherts both form lenticular masses of considerable areal extent that have massively bedded and thin-bedded facies. Two series of chert beds in the Franciscan are sufficiently thick (500 and 900 feet, respectively) and are extensive enough to justify their designation as formations. The radiolarian cherts, as the name implies, contain large numbers of radiolarian remains, but these are probably insufficient in quantity to account for the silica of the cherts. A distinctive feature is the rhythmic interbedding of the chert with beds of shale. Individual beds are usually lenticular and wedge in and out among other beds. Many of the layers of chert are very finely laminated, but the laminae are not uncommonly at variance with the bedding. The Franciscan cherts are usually red and the matrix of the rock consists of a microgranular aggregate of chalcedonic silica. Here and there the matrix consists of quartz grains without fibrous crystallization and in some localities it is not crystalline but amorphous. The Monterey cherts are not ordinarily so brightly colored as the Franciscan cherts and they contain a larger proportion of amorphous silica. The more massive beds of both groups of chert form bold outcrops which, to judge from illustrations presented, are similar in many ways to those of the Rex.

According to Lawson[69] radiolarian cherts occur sporadically throughout the Coast Ranges. Although in some occurrences they are many hundreds of feet thick they appear to thin within short distances and do not form extensive sheets. Most of the occurrences are of small extent. Palache[70] notes the occurence of rocks similar to the Franciscan cherts and accompanying rocks as far north as Alaska. Davis cites and describes many occurrences of chert throughout the world, but space does not permit further reference to his summary here.

[66] Condit, D. D., Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U. S. Geol. Survey Prof. Paper 120, p. 113, 1918.

[67] Adams, F. D., and Dick, W. J., Discovery of phosphate of lime in the Rocky Mountains: Canada Comm. Conservation, Ottawa, 1915 (reprint).

[68] Davis, E. F., The radiolarian cherts of the Franciscan group: California Univ Dept. Geology Bull., vol. 2, No. 3, pp. 235–432, 1918.

[69] Cited by Davis, E. F., op. cit., p. 352.

[70] Davis, E. F., op. cit., p. 316.

The cherts of Missouri and adjacent regions have been the subject of much geologic discussion. The Boone formation, as described by Purdue and Miser,[71] is a calcareous and cherty deposit in which nodules of chert occur in layers of limestone. In some layers the nodules are widely separated; in others the nodules are united in part; in still others the chert is sufficiently abundant to form a sheet or lens in the middle of the layer. At many places a succession of layers forms sections 100 feet or more thick. Some of these sections exposed in bluffs along streams are composed wholly of chert. The chert when fresh is dense and brittle. It breaks with a conchoidal fracture, varies in color from white or light gray to nearly black, and has the waxy luster of chalcedony. At some places it contains many fossils as siliceous casts.

The cherts of the Burlington limestone as described by Tarr [72] have somewhat the same arrangement and appearance as those of the Boone formation. Tarr notes that microscopically they show opaline or amorphous silica, chalcedony, and quartz, but the quantity of amorphous silica is small. Lenticular and nodular forms are the rule in the Burlington cherts rather than beds. The cherts of Missouri do not contain the remains of siliceous organisms.

Hinde [73] has described cherts from Ireland, Wales, Yorkshire, and Spitzbergen. The Irish chert occurs in nodular masses and bands in limestone that has an aggregate thickness of 600 to 800 feet, of which the chert is estimated to comprise 150 feet. Microscopically the chert is composed of chalcedony and quartz. It contains poorly preserved sponge remains and siliceous casts of crinoid stems and polyzoa. In Yorkshire the chert beds have an estimated thickness of 90 feet and in North Wales of 350 feet. On Axels Island in Spitzbergen, the accumulation of chert reaches a thickness of 870 feet. These cherts are all said to be similar in lithology and are ascribed by Hinde to an organic origin.

HYPOTHESES OF ORIGIN OF CHERT

Sampson [74] notes the association of cherts with pillow lavas at Notre Dame Bay, Newfoundland. There are three types of this chert—first, that in the interstices of the lavas; second, heavy beds of jasper found with acid tuffs; and third, thin beds interbedded with acid tuffs. He thinks that the source of the chert is magmatic emanations from submarine vents or fissures, and that precipitation of colloidal silica by oppositely charged ions of sea water is the most noteworthy process of its accumulation.

Barton,[75] in referring to the Mississippian chert in the vicinity of St. Louis, states that the theories suggested for the formation of chert are essentially six, of which three ascribe the chert to organic sources and three to inorganic sources. These theories are stated as follows:

1. The chert is composed of formerly colloidal silica that was derived from the decomposition of siliceous sponges and other siliceous organisms that collected in depressions on the ocean floor. The bands of chert represent former sponge beds where the sponges remained in place and accumulated over a considerable area.

2. The chert was formed before the consolidation of limestone through the solution of scattered siliceous spicules and the almost immediate replacement of parts of the limestone.

3. The chert was formed after the consolidation of limestone through the solution by percolating waters of siliceous spicules and the replacement of part of the limestone by this dissolved silica.

4. The chert was formed by the precipitation of silica and the replacement of limestone in the presence of circulating waters which have passed through sandstone, arenaceous rocks, or rocks containing silicates.

5. The formation of the chert was due to the reaction of dissolved silica in sea water with limestone with the consequent precipitation and possible later concentration of the silica.

6. With the diffusion of silica in solution through limestone, concentratration will vary in the direction of diffusion, and deposition, which results when concentration is sufficient, will be in zones perpendicular to the direction of diffusion. As the conditions of diffusion were more favorable in the early days of consolidation, and as the most likely direction is upward toward the surface or downward from it, deposition will be parallel to the stratification, although independent of it. The development of chert in successive zones is due to the lowering of concentration immediately around the first started zone or zones of crystallizing material. The silica may be derived from organic or inorganic sources.

Barton inclines toward the last-mentioned theory but thinks that the presence of argillaceous beds, which would tend to interfere with diffusion, is a serious difficulty.

Tarr,[76] who reviews briefly earlier opinions on the origin of chert, presents evidence in support of the following theory with reference to the cherts of Missouri: The silica is derived from the land by chemical weathering and is transported to the sea by streams in the form of a colloid. Areas of low-lying or peneplained

[71] Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (No. 202), 1916.

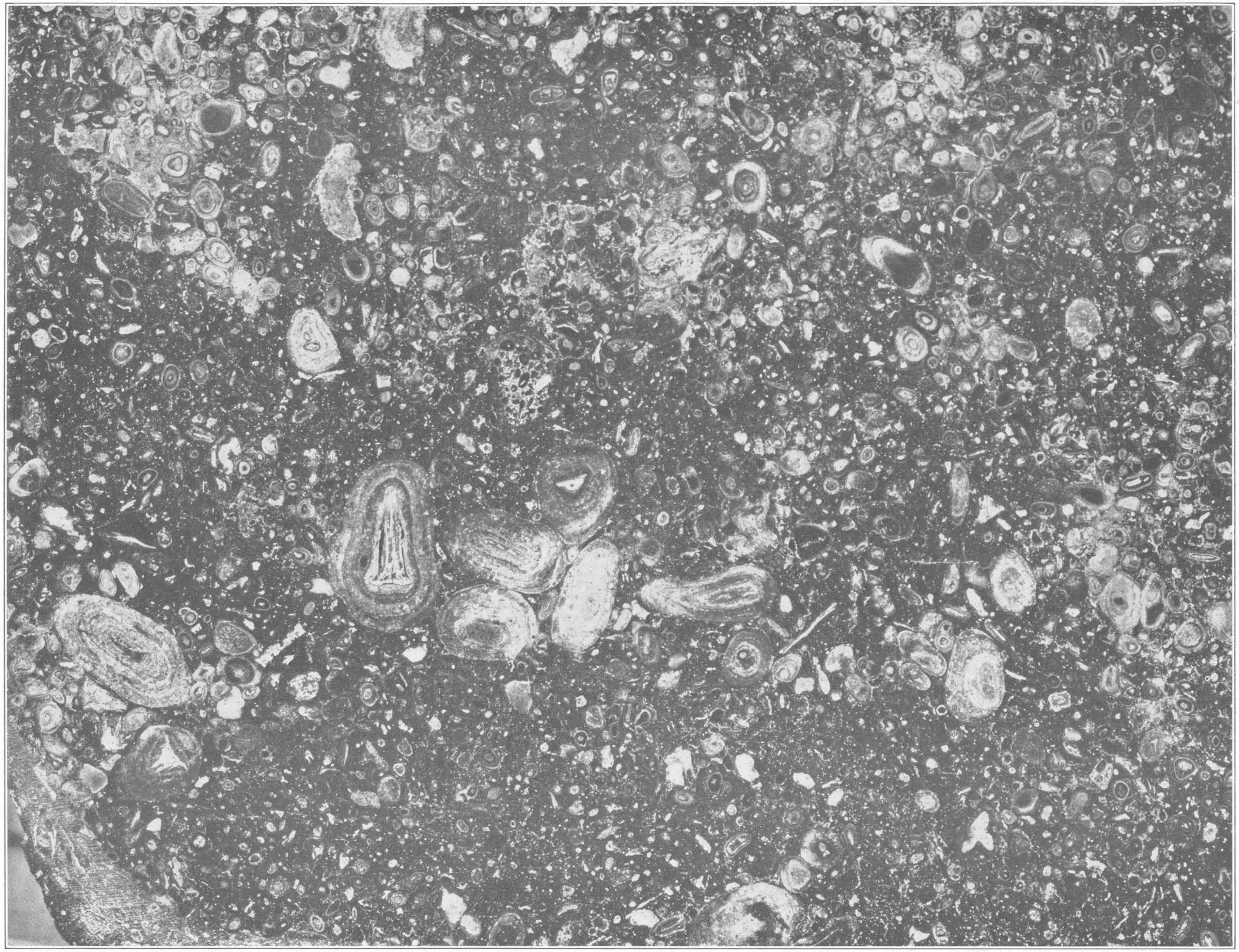
[72] Tarr, W. A., Origin of the chert in the Burlington limestone: Am. Jour. Sci., 4th ser., vol. 44, pp. 409–451, 1917.

[73] Hinde, G. J., On the organic origin of the chert in the Carboniferous limestone series of Ireland and its similarity to that in the corresponding strata in North Wales and Yorkshire: Geol. Mag., new ser., decade 3, vol. 4, pp. 435–446, 1887; On the chert and siliceous schists of the Permo-Carboniferous strata of Spitzbergen and on the characters of the sponges therefrom, which have been described by Dr. E. von Dunikowski: Geol. Mag., new ser., decade 3, vol. 5, No. 6, pp. 241–251, 1888.

[74] Sampson, Edward, The ferruginous chert formations of Notre Dame Bay, Newfoundland: Jour. Geology, vol. 31, pp. 571–598, 1923.

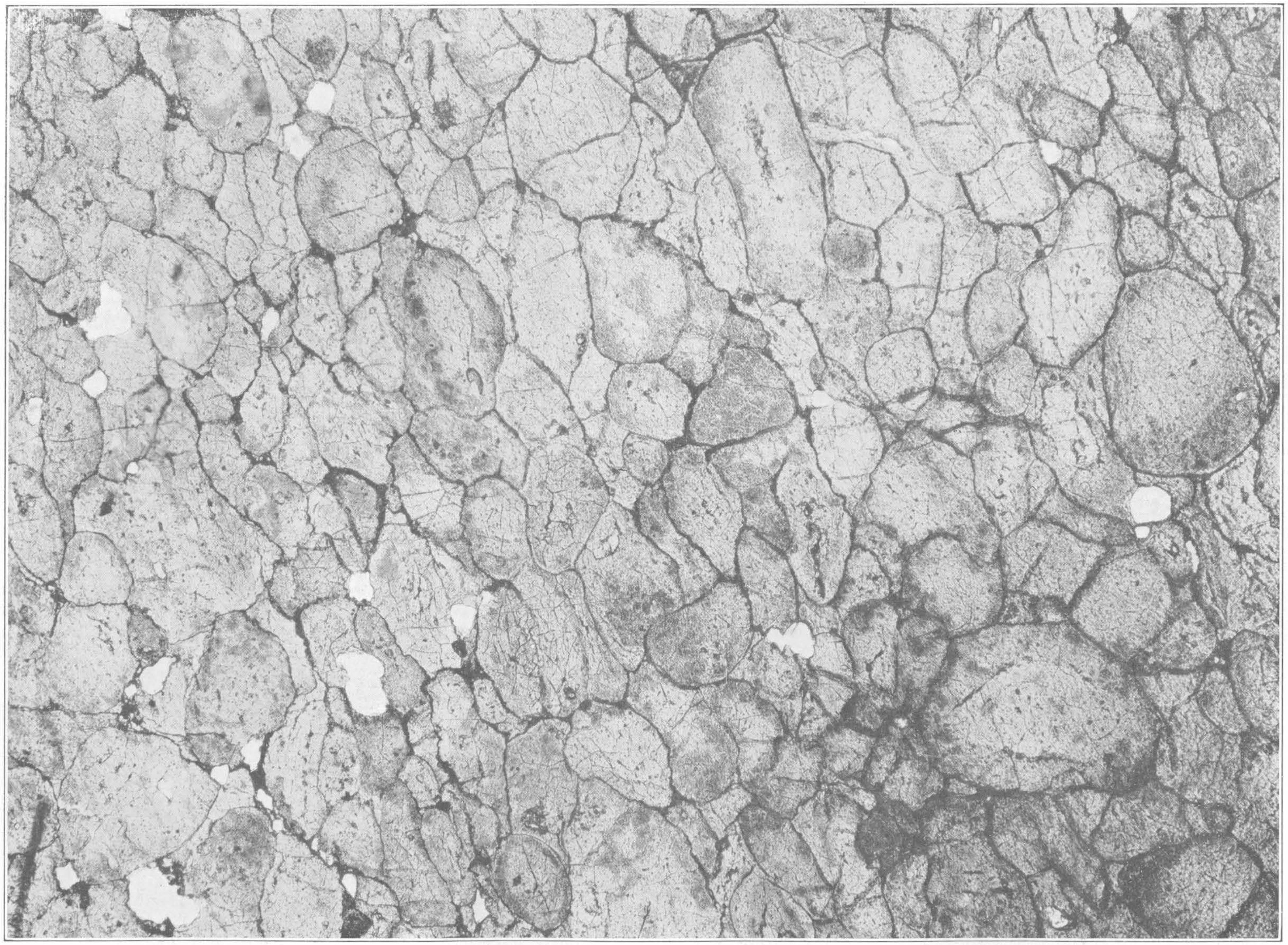
[75] Barton, D. C., Notes on the Mississippian chert of the St. Louis area: Jour. Geology, vol. 26, pp. 361–374, 1918.

[76] Tarr, W. A., op., cit., pp. 427–428.



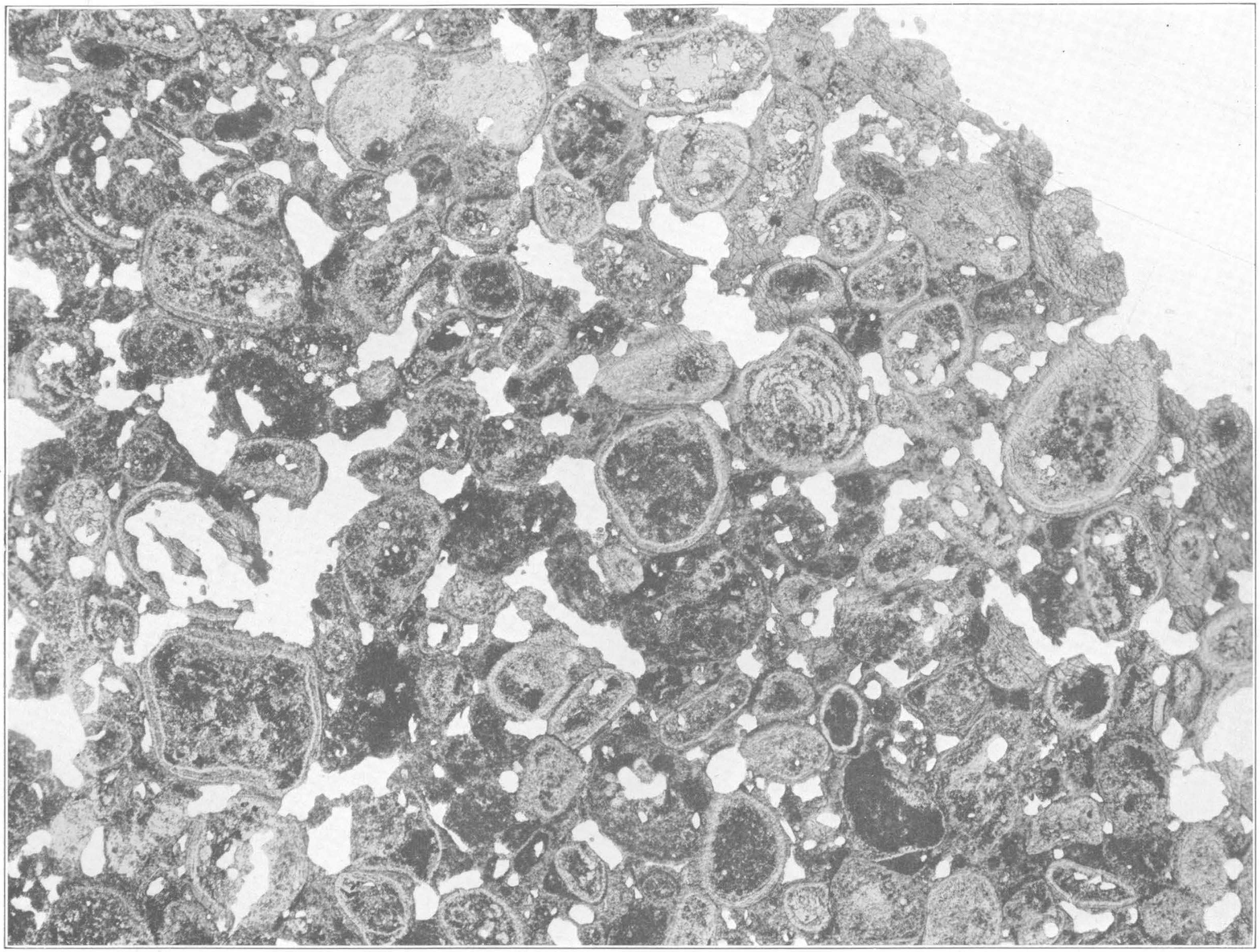
POLISHED SURFACE OF PHOSPHATE ROCK FROM McDOUGALS PASS, SALT RIVER RANGE, WYO., SHOWING BOTH NODULAR AND OOLITIC STRUCTURE

Note tooth in one of the nodules. Enlarged 3⅓ diameters



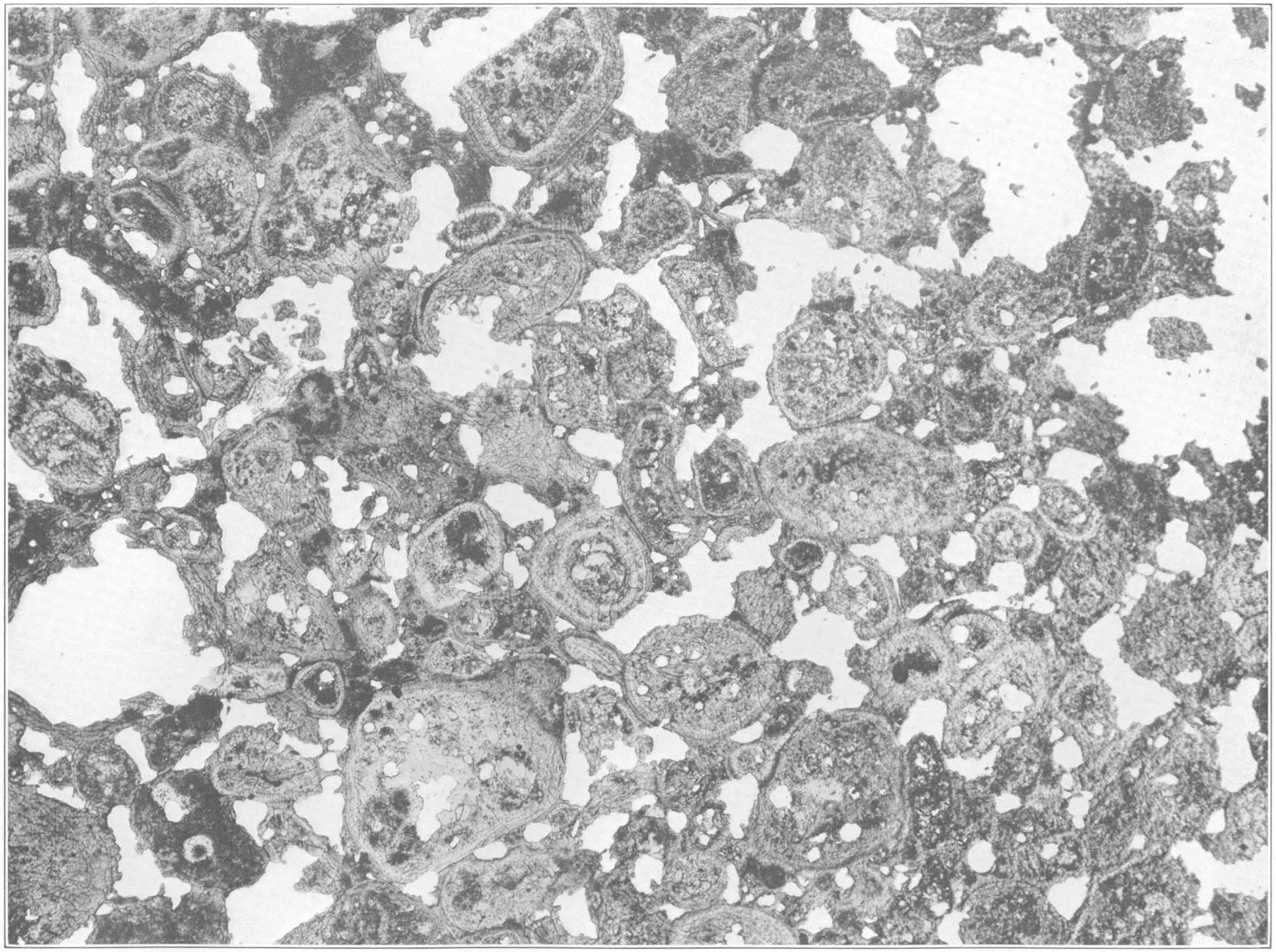
PHOTOMICROGRAPH OF OOLITIC PHOSPHATE FROM ANACONDA COPPER MINING CO.'S TUNNEL IN WARM SPRING CANYON, NEAR GARRISON, MONT.

Enlarged 50 diameters



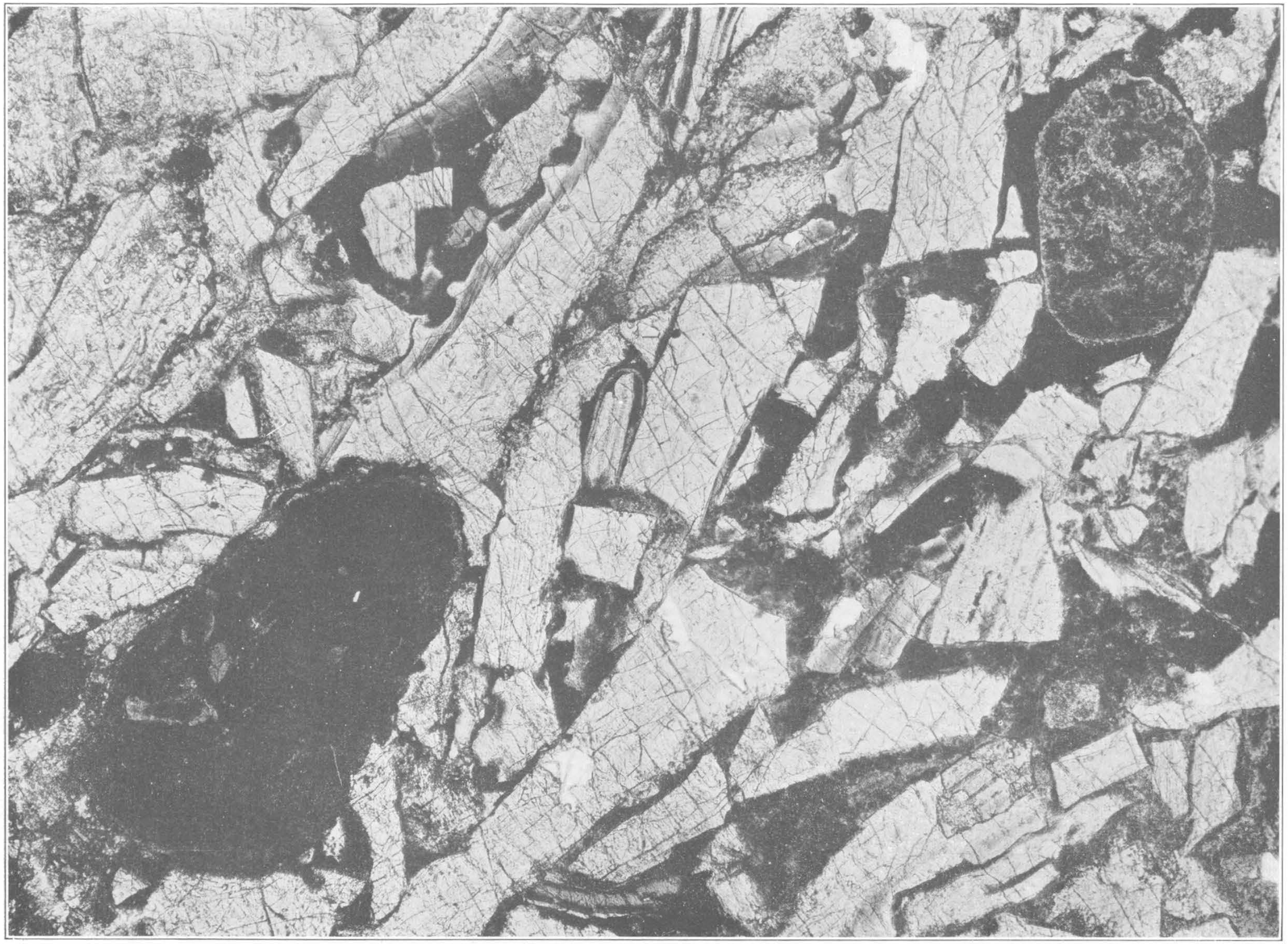
PHOTOMICROGRAPH OF OOLITIC PHOSPHATE FROM SEC. 7, T. 7 S., R. 43 E., LANES CREEK QUADRANGLE

Enlarged 50 diameters



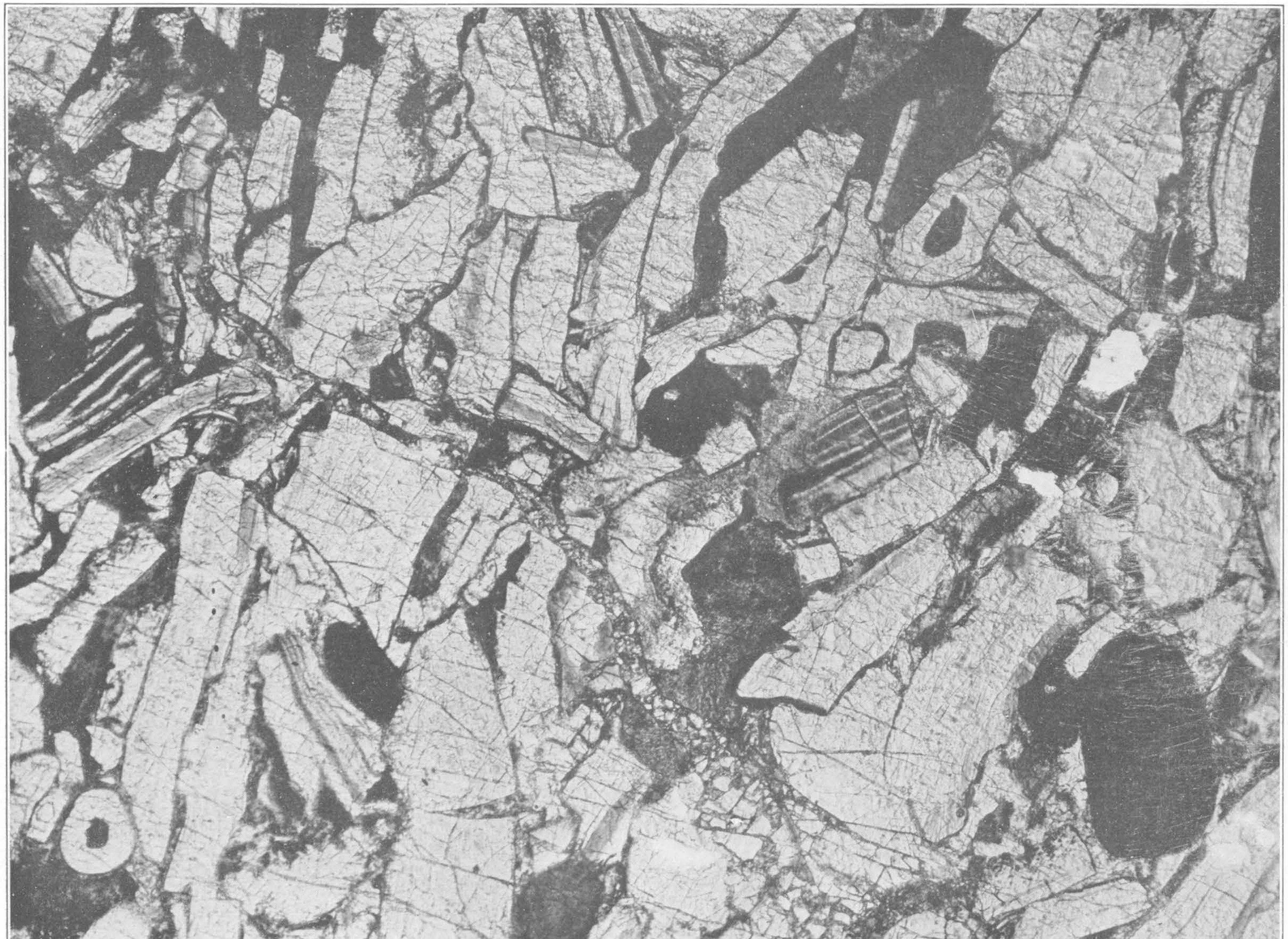
PHOTOMICROGRAPH OF OOLITIC PHOSPHATE FROM SEC. 7, T. 7 S., R. 43 E., LANES CREEK QUADRANGLE

Enlarged 50 diameters



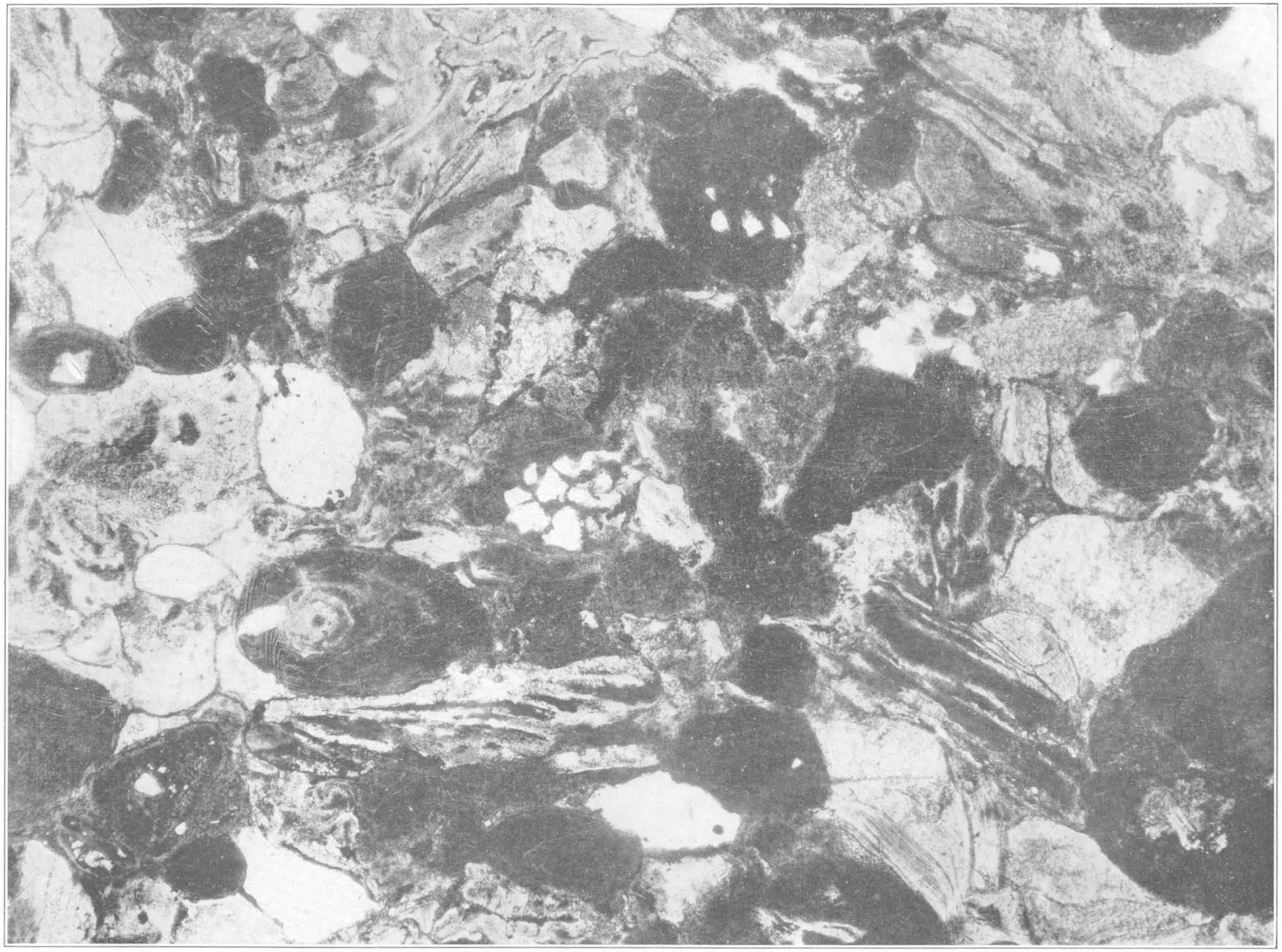
PHOTOMICROGRAPH OF PHOSPHATE ROCK COMPOSED CHIEFLY OF PHOSPHATIZED FRAGMENTS OF SHELL FROM NW. ¼ NW. ¼ SEC. 2, T. 8 S., R. 42 E.

Enlarged 50 diameters



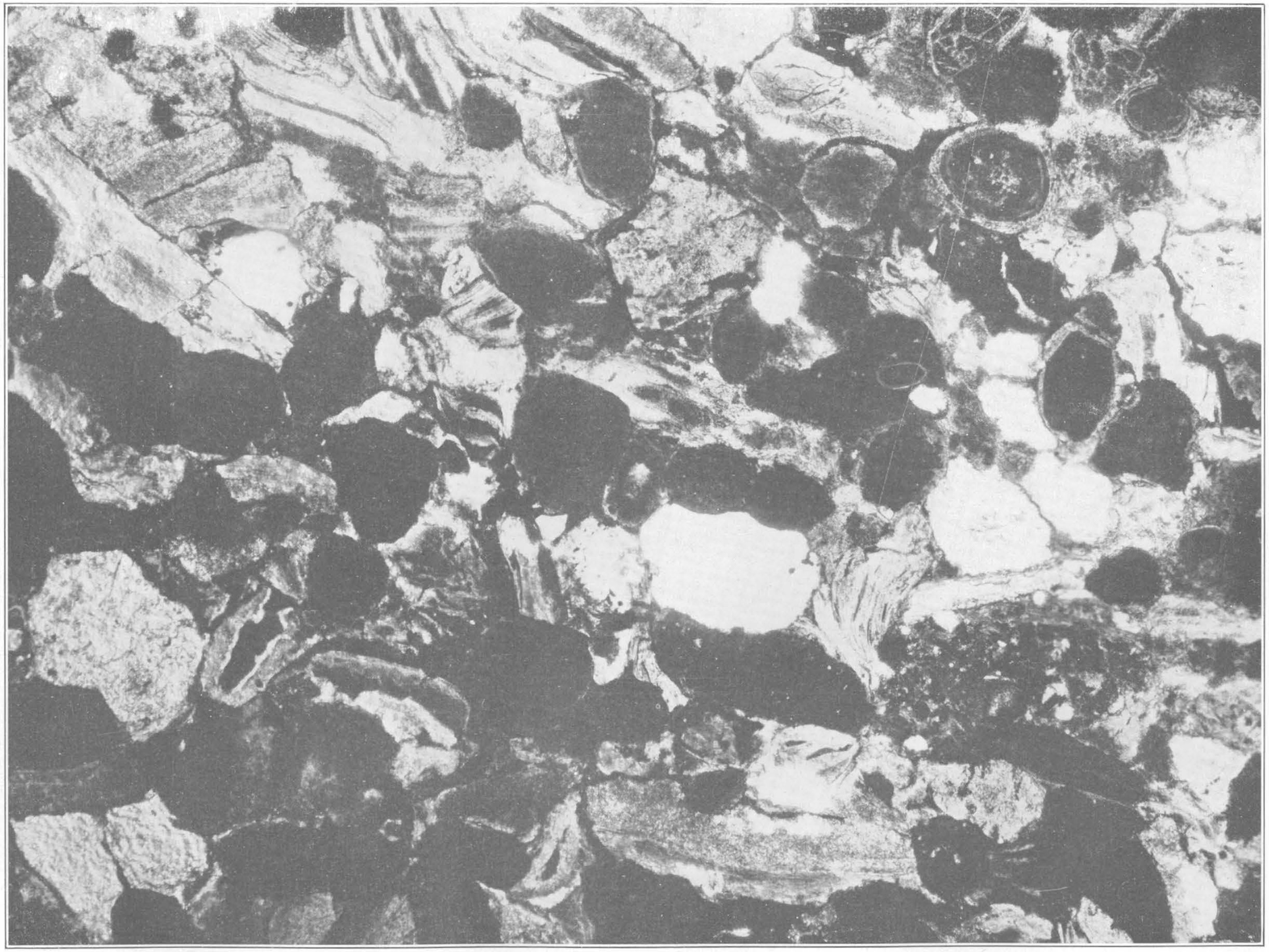
PHOTOMICROGRAPH OF PHOSPHATIZED SHELL FRAGMENTS FROM NW. ¼ NW. ¼ SEC. 2, T. 8 S., R. 42 E.

Enlarged 50 diameters



PHOTOMICROGRAPH OF PHOSPHATE ROCK COMPOSED OF BOTH OOLITES AND PHOSPHATIZED ORGANIC REMAINS FROM PARK CITY, UTAH

Enlarged 50 diameters



PHOTOMICROGRAPH OF PHOSPHATE ROCK FROM PARK CITY, UTAH

Enlarged 50 diameters

land and wide areas of igneous or metamorphic rocks would be favorable for supplying increased amounts of colloidal silica. The present streams supply large amounts of silica to the sea, where it is being dispersed by currents. Colloidal silica is precipitated in the sea by the action of the alkaline salts in the sea water. Fossils that fell into the colloidal silica would be perfectly preserved. As it is the tendency of colloids to aggregate in globular masses, the silica precipitated on the sea bottom would tend to assume globular or ellipsoidal forms. As these become buried under accumulating sediments they would be compressed to elliptical or lenticular form.

Tarr's views are opposed by Van Tuyl,[77] who cites evidence in support of the idea of replacement of carbonate of lime by silica. He attributes the molds or casts in the chert to partial replacement and states that if chert is formed by primary deposition it should be expected to appear at the same horizon over a considerable area. He thinks that replacement proceeded on the bed of the sea possibly contemporaneously with the deposition of limestone, the silica of inorganic origin having been deposited in a colloidal condition on the bed of the sea while the limestone was being formed.

After a most thorough discussion of the radiolarian cherts Davis[78] concludes that there are serious objections to any hypothesis which regards all the silica of the cherts as due to radiolaria or other organisms. The addition of inorganic silica is regarded as highly probable. The idea that the dilute silica in river waters could furnish the additional silica is considered an impossible explanation. Two other possibilities remain—emanations from igneous rocks and deposits from submarine siliceous springs. Davis calls attention to the association with the Franciscan cherts of pillow lavas (basalts), both extrusive and intrusive, and notes that their contact zones are characterized by the addition of soda, probably in the form of sodium silicate, to the altered rocks. He points out similar relationships in other parts of the world, though he notes that at some places cherts occur without basalts and at others basalts without cherts. The activities of springs and basalt are interdependent. It is not necessary, he thinks, that extrusive lava should occur in immediate association with the cherts. If a magma reservoir beneath the surface was slowly cooling it would give rise to siliceous springs. The fact that nothing which corresponds to the radiolarian cherts is now forming points to unusual conditions of accumulation. He points out that Van Hise and Leith consider the ellipsoidal basalts to be abnormal factors in the formation of the cherts of the Lake Superior region.

The rhythmic bedding is believed by Davis to be best explained by colloidal segregation, an idea supported by experimental evidence. Radiolaria would thrive in siliceous waters, but the conditions would be unfavorable for calcareous organisms. The shale partings are explained as mechanical sediments of unusually fine grain.

Gruner[79] considers that the precipitation of silica, iron, and part of the organic colloids of the Biwabik formation of the Lake Superior district was caused chiefly by algae and bacteria. The iron and silica were derived from fresh extrusive rocks and volcanic tuffs that were rapidly decomposed under conditions of humid, tropical, or subtropical climate.

Leith[80] has called attention to the widespread occurrence of cherty materials in connection with old erosion surfaces. These occurrences, however, would seem to have little in common with bedded cherts, such as those of the Rex chert member of the Phosphoria formation.

APPLICATION OF HYPOTHESES TO ORIGIN OF REX CHERT

The Rex chert does not appear to fit very well into any of the hypotheses above outlined. It is true that a sponge spicule bed of probably wide extent has been recognized in its lower part, but so much of the chert is without evidence of siliceous organisms that some other source for much of the silica seems highly probable. Little evidence has been found to support the ideas of replacement or diffusion. The occurrence of perfectly preserved casts of crinoid stems, previously mentioned, appears to indicate that the crinoid remains became entombed in gelatinous silica and were subsequently dissolved away. Van Tuyl's suggestion of partial replacement does not seem very convincing.

The idea of chemical precipitation might apply very well, if an adequate source for the silica could be found. The objection on the part of Van Tuyl and others that such precipitation would imply the formation of broad sheets at definite horizons is apparently met, for, as already shown, it is highly probable that the Rex was formed as a continuous layer of chert and cherty shale over an area of thousands of square miles and at a definite geologic horizon. In these respects the explanation of Tarr is applicable. Davis, however, points out that if the silica was derived from river water siliceous organisms should flourish near the mouths of rivers and that this would tend to localize the deposition of the silica. It may be questioned, too, whether silica that was coagulated under the action of electrolytes in sea water, as postulated by Tarr, would be disperesd by currents rather than localized near the mouths of rivers, where the waters bearing silica would first encounter the sea water. A further objection as pointed out by Davis is the absence of any known

[77] Van Tuyl, F. M., The origin of chert: Am. Jour. Sci., 4th ser., vol. 45, pp. 449–456, 1918.

[78] Davis, E. F., op. cit., pp. 402–408.

[79] Gruner, J. W., The origin of sedimentary iron formations: The Biwabik formation of the Mesabi Range: Econ. Geology, vol. 17, pp. 407–460, 1922.

[80] Leith, C. K., Silicification of erosion surfaces: Econ. Geology, vol. 20, pp. 513–523, 1925.

deposits of gelatinous silica among the sediments that have been brought to light by oceanic investigations.

Davis's idea that unusual conditions of deposition are necessary for the accumulation of great bodies of chert is quite possibly applicable to the Rex chert, but there is as yet little or no evidence to support the view that the silica came from siliceous springs or from emanations that accompanied igneous rocks. The localization of the deposits of radiolarian chert, cited by Lawson,[81] in favor of the siliceous spring hypothesis becomes an objection in considering the Rex on account of the more uniform distribution of that member. Basaltic eruptions in southeastern Idaho are numerous and conspicuous, but these are of a much later geologic age than the Rex chert. Moreover, with the exception of the single occurrence noted on page 125, the basalts are not unusually rich in soda. So far as eastern Idaho is concerned—and there, perhaps, the Rex has its best development—no evidence has been obtained of igneous activity in Permian time, either of a submarine or of a subcrustal nature. In western Idaho, however, as noted in Chapter VI, fossiliferous tuffs and igneous rocks of Permian age accumulated in considerable thickness. Possibly volcanic emanations connected with these tuffs or their erosion may have supplied siliceous solutions in considerable quantity to the Phosphoria sea.

The physiographic conditions of Phosphoria time were unusual. Lowlands or peneplained lands adjacent to the sea are suggested and also the abundance of sandy and quartzitic material in Pennsylvanian terranes, possibly exposed to erosion, is indicated. These conditions fit in well with Tarr's hypothesis. The relative absence of deposits of calcium carbonate in the Phosphoria sea has already been discussed in connection with the origin of the phosphate deposits. It is sufficient here to suggest that bacterial activities and temperature conditions may have some bearing upon the question. The time element may also enter into the problem. With conditions unfavorable for the deposition of calcium carbonate or phosphate, though some of the Rex is slightly phosphatic, and with mechanical sediments largely excluded, possibly because of lowlands and low stream grades, chemical precipitation, probably a slow process, would in time cause considerable accumulations of silica. Data at hand indicate that the time available for such accumulations was ample.

If, as Tarr contends, the silica brought in by rivers is probably not precipitated immediately but accumulates in the form of a colloid until it is of sufficiently high concentration to be coagulated, precipitation near the mouths of rivers would not be necessary and there would be opportunity for its dissemination by currents and its accumulation in a fairly uniform layer in the quieter parts of the sea at or near wave base. In Tarr's experiments,[82] however, in which artificially prepared "sea water" and a solution of sodium silicate were used, precipitation of gelatinous silica was immediate whether stronger or weaker solutions of the sodium silicate were used, and there was no observed change on standing.

The objection that no deposits of gelatinous silica have been recognized in modern oceanic sediments may lose some of its force when it is remembered that the present is a time of unusual continental elevation, and that there is probably nowhere upon the land surface bordering the oceans a condition of lowlands or of a peneplain that approaches quite the condition postulated by Tarr's theory or suggested for the lands surrounding the Phosphoria sea.

The bedding of the Rex corresponds with the diastems discussed on page 178. No further explanation seems to be required than that the accumulation of gelatinous silica at or near wave base was interrupted by the more or less rhythmical minor climatic oscillations to which reference is made at the place cited. The term wave base as here used corresponds approximately to the term mud line, which, according to Murray and Renard,[83] marks the lower limits of wave, tidal, and current action and lies at a depth of about 200 to 3,000 fathoms. The nodular phases of the beds seem to be satisfactorily explained by the tendency of colloids to aggregate in globular form, as explained by Tarr. The flinty-shale facies would be explained by oscillations of the sea floor or of the adjacent land area by which an admixture of terrigenous material with the colloidal silica would be permitted.

The occurrence at some places of limestone within the Rex chert member and at other places of quartzite indicates that in spite of the uniformity of conditions that prevailed over wide areas of the Phosphoria sea, there were some differences, possibly of a diastrophic nature, that permitted the accumulation of these rocks.

THE PERMIAN-TRIASSIC INTERVAL

The pronounced faunal break between the Phosphoria and Woodside formations, which are respectively of Permian and Lower Triassic age, has already been pointed out in Chapters III and VI. The occurrence of the *Ambocoelia*-bearing bed in the Fort Hall Indian Reservation suggests the former wide occurrence of a group of strata of which this bed may be a remnant.

The Phosphoria formation is here correlated with part of the Embar of Wyoming, as originally described

[81] Davis, E. F., op. cit., p. 352.

[82] Tarr, W. A., op. cit., pp. 434–436.

[83] Murray, John, and Renard, S. F., *Challenger* Rept., Deep-sea deposits, p. 383, diagram 2, 1891.

by Darton, in the Owl Creek Mountains. Although named from Embar post office and ranch on Owl Creek, the full thickness of the formation as described by him for the region does not appear to be present there. At this locality the highest exposed beds of the Embar are composed of a massive limestone which contains among other fossils, the brachiopod *Spiriferina pulchra*. This fossil is characteristic of the Rex chert, the upper member of the Phosphoria formation. In the same general region, 6 miles west of Holland's ranch,[84] this limestone bed is overlain by 50 feet of sandstone, which is compact and gray above but weathers brown and merges downward into yellowish soft sandstone. South of Thermopolis it is overlain by 50 to 60 feet of yellowish sandy beds with a few thin layers of impure limestone. On North Fork of Muddy Creek this massive member of the Embar is overlain by 100 feet of the sandy yellow beds; near Anchor post office it is overlain by 20 feet of soft buff sandstone; and on Dry Creek it is overlain by 200 feet of slabby brown sandstones with layers of soft buff sandstone. The massive limestone and the overlying sandy beds compose the upper part of the Embar as defined by Darton.

In Dinwoody Canyon in the Wind River Mountains, Blackwelder [85] measured a section of the Embar, in which he included above the massive limestone member about 250 feet of shales and sandstones that carry obscure pelecypods, which he correlated with the 200 feet of yellow sandy beds included in the top of the Embar by Darton. These upper beds he subsequently named the Dinwoody formation,[86] and they were correlated by Condit[87] with the Woodside shale and Thaynes group of southeastern Idaho.

In the Fort Hall Indian Reservation the *Ambocoelia*-bearing beds above mentioned consist of yellow sandstone and earthy limestone and lie above the usual cherty beds of the Rex. The genus *Ambocoelia* gives to these beds a distinctly Paleozoic aspect, and they have hitherto been included with the Rex in the Permian, but Girty is now inclined to consider them Triassic. They apparently correspond in position and lithologic relationships with Blackwelder's typical Dinwoody and with the yellow sandy beds in Darton's sections at Holland's ranch and many other places in the Owl Creek Mountains.

In the Uinta Mountains Schultz reports that a thin-bedded gray limestone series forms the uppermost member of the Park City formation. These beds may prove to correspond stratigraphically with the *Ambocoelia*-bearing beds of the Fort Hall Indian Reservation, with the uppermost beds of Darton's Embar, and with the Dinwoody formation, though no such correlation is at present practicable.

Recent work[88] in central Wyoming tends to show that beds that correspond to the Phosphoria formation were greatly eroded and in places completely removed before the deposition of the Chugwater formation. The faunal break ordinarily noted between the Rex and the Woodside in southeastern Idaho would seem to correspond with this unconformity.

The relationship of the Idaho section to sections in western and central Wyoming is not well understood, though some work on the Wyoming sections has been done by both Blackwelder and Condit as above stated. Condit thinks that the Embar formation of Darton, which, according to his interpretation, includes beds that range in age from Pennsylvanian to Lower Triassic, grades and interfingers eastward into the lower part of the Chugwater formation of red beds. If this view is correct the above-mentioned unconformity must die out eastward.

A detailed study of the stratigraphic sections exposed in the different mountain ranges westward from the Big Horn Mountains of Wyoming into Idaho is needed to reveal the changes in conditions of deposition and erosion of sediments both in the areas of open seas in Permian and Triassic time and in the transitional and marginal areas of the marine waters of those periods.

An erosion interval between the Permian and Triassic has been noted by Gregory[89] in the Plateau province. He says:

> The plane of separation in most places is a maturely eroded surface that represents in the time scale a long period during which vast amounts of material were weathered, corroded, and redistributed. * * * Neither the duration of the period of erosion nor the place of deposition of the transported sediments is known. The field evidence merely shows that the conditions of sedimentation were markedly dissimilar before and after the erosion interval.

The erosion interval, as represented in the Plateau province, was probably of considerably longer duration than that in southeastern Idaho, for in the latter region more than 4,500 feet of marine Lower Triassic sediments were laid down before the Higham grit, which presumably corresponds with the Shinarump conglomerate of the Plateau province, the lowest Triassic formation in that region.

TRIASSIC AND JURASSIC PHYSIOGRAPHY AND SEDIMENTATION

The Triassic and Jurassic rocks of southeastern Idaho constitute an unusually full and complete series, comprising 12 formations and an aggregate thickness of nearly 12,000 feet, of which more than two-thirds is of marine origin. These formations may therefore

[84] Darton, N. H., Geology of the Owl Creek Mountains: 59th Cong., 1st sess., S. Doc. 219, p. 18, 1906.
[85] Blackwelder, Eliot, A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 476, 477, 1911.
[86] Blackwelder, Eliot, New geological formations in western Wyoming: Washington Acad. Sci. Jour., vol. 8, pp. 417-426, 1918.
[87] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 263, 264, 1916.
[88] Lee, W. T., personal communication.
[89] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 34, 35, 1917.

serve as guides in working out the history of other areas in the Rocky Mountain region in which the record of these periods is less well preserved. Some attempt has already been made to compare the Triassic and Jurassic stratigraphic records of southeastern Idaho with those of southwestern Wyoming and of the Park City district of Utah and to picture the physiographic conditions of the general region at these times.

The relations of the marine Lower Triassic in southeastern Idaho to the Triassic formations of Wyoming, Utah, and regions farther south can not be well understood without further regional studies. The comparisons already made indicate in a broad way that in Lower Triassic time southeastern Idaho and its adjacent territory comprised a region of dominant marine deposition, which underwent diastrophic oscillations of sufficient intensity to cause variations in conditions of deposition, so that there was some alternation of more calcareous and more shaly or arenaceous sediments. At times the oscillations were sufficient to exclude normal marine deposition and to favor either nonmarine or various types of littoral sedimentation.

In general the marine beds appear to thin out eastward and possibly southward, whereas the other types, chiefly red beds, thicken or increase in number in those directions. There is thus an interfingering of true marine beds and of red beds, but it is as yet impossible to correlate individual sets of beds in Idaho with similar beds in Wyoming or Utah. In the Park City district, Utah,[90] the Woodside shale consists of red beds, but it is not known if it corresponds with part or all of the Woodside interval in Idaho. In the same district Boutwell describes a "mid-red" shale in the Thaynes formation that has not been identified in the Idaho section. These beds probably wedge out northwestward before reaching Idaho, but they may be represented by the red beds of the Portneuf limestone member of the Thaynes. The Park City section needs to be reviewed in comparison with the Idaho section to establish relationships and adjust differences.

With regard to southwestern Wyoming it appears probable that the Timothy sandstone and the successive beds of the Portneuf limestone member of the Thaynes are cut out by the extension of the unconformity at the base of the Higham grit in Idaho and that the beds ascribed to the Thaynes in southwestern Wyoming represent the middle and lower portions of this formation as exposed in southeastern Idaho.

In Veatch's[91] description of the region the Thaynes is said to be overlain by what he calls the red-bed member of the Nugget, 600 feet thick. Schultz[92] correlates these red beds with the Ankareh of the Rock Springs uplift, Wyo., and with red beds that he assigns to the Ankareh at different places in Wyoming, Utah, and northwestern Colorado, at all of which he finds the Ankareh resting unconformably on the underlying Thaynes. He also correlates the Ankareh of the Rock Springs uplift with the upper part of Powell's "Shinarump group" in the Uinta Mountains, with which the Higham grit, Deadman limestone, and Wood shale of southeastern Idaho are also tentatively correlated. The unconformity at the base of the Shinarump conglomerate has been recognized by Gilbert,[93] Gregory,[94] Emery,[95] Moore,[96] and others and is a widespread stratigraphic feature in Utah and northeastern Arizona as well as in Wyoming. From its field relationships there seems little doubt of its equivalence in position with the unconformity at the base of the Higham grit in southeastern Idaho. (See Table 101.)

Although conditions of deposition in Middle and Upper Triassic time appear to have been similar throughout much of the Rocky Mountain geosyncline southward and southeastward from Montana, where erosion was in progress, they were not identical, as is indicated by lithologic differences. The Shinarump conglomerate contains pebbles of limestone and chert in addition to quartzite, together with abundant remains of fossilized wood and fragments of bone.[97] It is a source of radium and vanadium ores,[98] which occur in pockets associated with fossil wood in different parts of Utah. None of these features have yet been recognized in the Higham grit, which consists almost exclusively of quartzitic débris, though limestone pebbles and bits of fossil wood have been found in beds assigned to the Timothy sandstone. These occurrences, however, are all in the Montpelier quadrangle where the Higham grit and Timothy sandstone are less distinctively developed than they are in the Freedom quadrangle or in the Fort Hall Indian Reservation and where these formations have not been so well differentiated.

Gregory has designated as the Chinle formation[99] the varicolored beds which in northeastern Arizona constitute the portion of Powell's "Shinarump group" above the Shinarump conglomerate. The Idaho representatives of this interval, the Deadman limestone and Wood shale, are neither so variegated in color and composition nor so well developed as are the corresponding beds in Arizona and adjoining regions, though they are strongly colored and are in general topographically weak.

[90] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 52-59 and pl. 5, 1912.

[91] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 50-52, 1907.

[92] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pp. 24, 36 (tables), 1920.

[93] Gilbert, G. K., Geology of the Henry Mountains: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 2d ed., pp. 6-10, 1880.

[94] Gregory, H. E., op. cit., p. 16.

[95] Emery, W. B., The Green River desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, p. 561, 1918.

[96] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol 6, No. 3, p. 216, 1922.

[97] Gregory, H. E., op. cit., pp. 37-41.

[98] Emery, W. B., op. cit., p. 561. Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 608, 1920.

[99] Gregory, H. E., op. cit., pp. 37, 42-48.

Table 101.—*Tentative correlation of Triassic and Jurassic formations in southeastern Idaho and parts of Wyoming and Utah*

Age		Southeastern Idaho [a]	Southwestern Wyoming [b]	Rock Springs uplift, Wyo. [c]	Vermilion Creek, northwestern Colorado [c]	Henrys Fork field, Wyo.-Utah [c]	Uinta Mountains, Utah [d]		Henry Mountains, Utah [e]		Navajo country, Arizona, New Mexico, and Utah [f]		Green River Desert, Utah [g]		Circle Cliffs, Utah [h]
Cretaceous?		Gannett group, 3,200 feet.	Beckwith formation, 3,800–5,500 feet.	Beckwith, 1,000 feet.	Beckwith, 840 feet.	Beckwith, 1,500 feet.	Flaming Gorge group, 0–1,200 feet.		Flaming Gorge group, 1,200 feet.		McElmo, 400–700 feet. (?)		McElmo formation, 600 feet. Salt Wash sandstone member at base, 198 feet.		McElmo formation, 197–565 feet.
Jurassic.		Stump sandstone, 200–600 feet.									La Plata group.	[Absent.]	Navajo sandstone, 724 feet. (?)		Upper Jurassic sandstone, 973–1,430 feet.
		Preuss sandstone, 1,300 feet.													
		Twin Creek limestone, 3,500 feet.	Twin Creek, 3,500–3,800 feet.	Twin Creek, 140 feet.	Twin Creek, 140 feet.	Twin Creek, 140 feet.		White Cliff limestone.					Todilto (?) formation, 100–300 feet. (?)		Gypsiferous zone, 100–450? feet. Marine Jurassic (?), 45 feet.
		Nugget sandstone, 1,350 feet.	Nugget 1,900 feet.	Nugget, 1,000 feet.	Nugget, 1,000 feet.	Nugget, 1,600 feet.	White Cliff group, 0–1,100 feet.	[Same beds.]	Gray Cliff group, 500 feet.			Navajo, 400–1,000 feet.	Wingate sandstone.	Upper sandstone, 550 feet.	Navajo sandstone, 1,260–1,400 feet.
							Vermilion Cliff group, 0–1,100 feet.		Vermilion Cliff group, 500 feet.			Todilto, 3–200 feet.		Weaker zone, 200–250 feet.	Todilto formation, 125–215 feet.
												Wingate, 30–450 feet. (?)		Lower sandstone, 150–375 feet. (?)	Wingate sandstone, 250–400 feet.
Triassic.	Upper and Middle (?)	Wood shale, [i] 150 feet.		Ankareh, [i] 300 feet.	Ankareh, [i] 300 feet.	Ankareh, [i] 300 feet.	Shinarump group, 0–1,800 feet.	Badland sandstones with gypsum.	Shinarump group.	Variegated beds, 300 feet.	Chinle formation, 1,182 feet. (?)		Chinle formation, 210–300 feet. (?)		Chinle formation, 475–500 feet.
		Deadman limestone, [i] 200 feet.													
		Higham grit, [i] 200 feet.						Shinarump conglomerate, 20–200 feet.		Shinarump conglomerate, 30 feet.	Shinarump conglomerate, 20–100 feet.		Shinarump conglomerate, 80–100 feet.		Shinarump sandstone, 10–125 feet.
	Lower.	Timothy sandstone, 250 feet.	(?)	(?)	(?)	(?)		[?]		[?]	[Absent.]		[?] De Chelly sandstone, absent.		[Absent.]
		Thaynes group, 3,100 feet.	Thaynes, 2,400–2,600 feet.	Thaynes (?), 0–200 feet. (?)	Thaynes (?), 200 feet. (?)	Thaynes (?), 290 feet. (?)		Badland sandstones with gypsum.		Chocolate-colored shale, in part sandy, 400 feet.					
		Woodside shale, 2,000 feet.	Woodside, 500 feet.	Woodside, 300 feet.	Woodside, 556 feet.	Woodside, 500 feet.							Moenkopi formation, 356–586 feet. (?)		Moenkopi formation, 304–480 feet.
Carboniferous.	Permian.	Phosphoria, 450 feet.	Park City, 700+ feet.	Park City, 200 feet.	Park City, 186 feet.	Park City, 450 feet.	Upper Aubrey group, 0–1,400 feet.		Aubrey group.		De Chelly sandstone, 0–585 feet. Moenkopi, 300–500 feet.		Pennsylvanian (?).		Kaibab limestone, 125–165 feet.
	Pennsylvanian.	Wells, 2,400 feet.									Aubrey group.				Coconino sandstone and Supai (?) formation, 1,630(?) feet.

[a] This report.
[b] Veatch, A. C., U. S. Geol. Survey Prof. Paper 56, 1907.
[c] Schultz, A. R., U. S. Geol. Survey Bull. 702, 1920.
[d] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto and atlas, 1876.
[e] Gilbert, G. K., Report on the geology of the Henry Mountains, 1877.
[f] Gregory, H. E., U. S. Geol. Survey Prof. Paper 93, 1917.
[g] Emery, W. B., Am. Jour. Sci., 4th ser., vol. 46, pp. 551–577, 1918.
[h] Moore, R. C., Am. Assoc. Petroleum Geologists Bull., vol. 6, pp. 199–227, 1922.
[i] These formations are classified as Triassic (?), because of the lack of Paleontologic evidence of age.

Another unconformity of wide extent occurs at the top of the Triassic section in parts of southwestern Colorado, Utah, and Arizona and has been recognized by Gilbert[1] and others. Lee[2] notes that it transgresses rocks that range in age from Archean to Triassic and forms an old erosion surface to which he gives the name La Plata peneplain. This unconformity, if it exists in southeastern Idaho, is much less pronounced and has not yet been recognized. Its position would be the base of the Nugget sandstone. Its absence or poor development there is in keeping with the fact that sedimentation in southeastern Idaho was on the whole more continuous than in the southern Rocky Mountain and adjacent plateau regions.

The Jurassic formations of southeastern Idaho point to desert conditions of long duration in the earlier part of the period, followed by an invasion of the sea, which also lasted a long time. The sea then withdrew and there was prolonged erosion followed by a renewal of continental, probably desert, conditions with an ensuing second encroachment of the sea. The last two epochs of sedimentation were shorter than the first two. This fourfold subdivision of the Jurassic has a notable bearing upon the interpretation of the physiography of that time throughout the region of the Rocky Mountains and the adjacent plateaus. A suggestion of separate marine invasions for Montana and Wyoming is given by Reeside,[3] who notes that the Ellis formation (Montana) is older than the Sundance (Wyoming), the Ellis corresponding to the lower Oxfordian and the Sundance to the upper Oxfordian of Haug. The Idaho faunas have not been studied in sufficient detail to make explicit comparisons with the European faunas. The Twin Creek has been correlated by Schultz and others[4] with the Sundance as belonging to the lower part of the Upper Jurassic, but it is now thought that at least part of the Twin Creek may be of Middle Jurassic age. The question is therefore raised whether the Ellis formation of Montana may correspond with the Twin Creek and the Sundance of Wyoming with the Stump, or whether the Ellis and the Sundance, which have ordinarily been considered single units, may be divisible into two or more units which correspond with earlier and later invasions of the sea and each of which contain equivalents of the Twin Creek and Stump of southeastern Idaho.

The Twin Creek has also been correlated with the La Plata group of parts of Utah.[5] Lee[6] considers it the equivalent of the middle part of the La Plata group, which he has studied in Wyoming, Utah, Colorado, and New Mexico. In some places this horizon is occupied only by gypsiferous beds, but at others marine fossils of Jurassic age have been obtained from it. In the Green River[7] and Castle Valley[8] districts of Utah a second and higher horizon of gypsiferous beds occurs, which Lee is at loss to explain without recourse to marine invasion. These gypsum beds are situated with reference to other beds in the section much as is the Stump sandstone of southeastern Idaho. (See fig. 43.) Possibly these gypsum beds represent marginal phases of the sea which deposited the Stump sandstone. There seems little doubt that the horizon where marine Jurassic fossils have been found in these districts and the corresponding horizon in the Circle Cliffs district of Utah[9] represent the Twin Creek

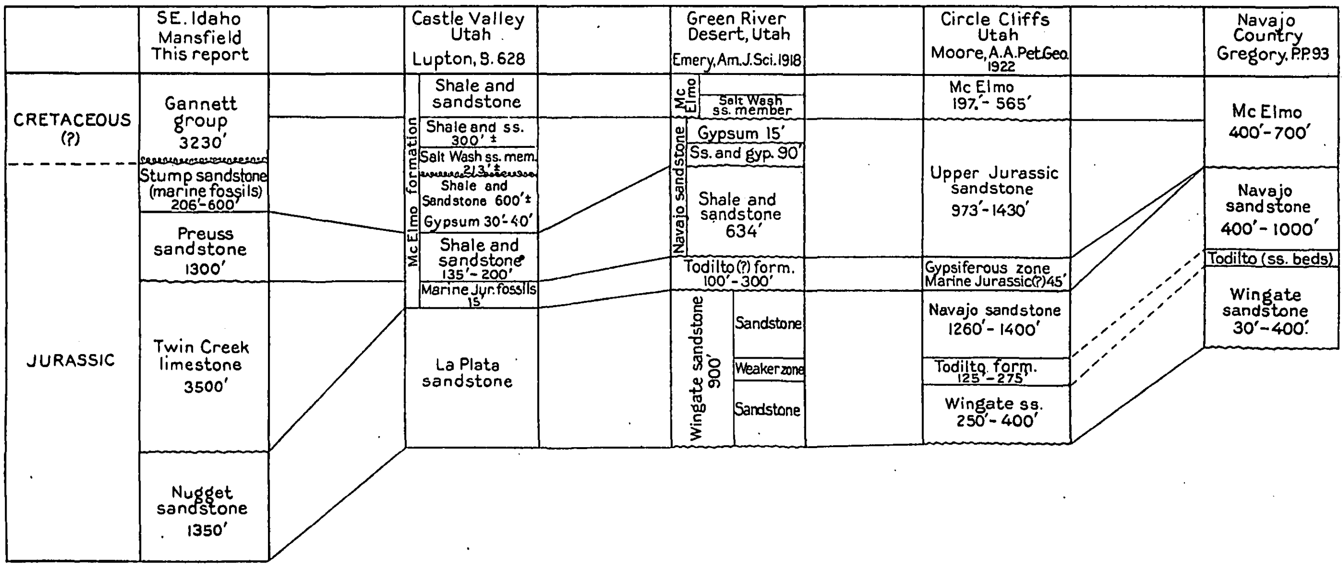


FIGURE 43.—Diagram showing the comparative sequence of Jurassic formations in southeastern Idaho and at places in Utah and Arizona

[1] Gilbert, G. K., op. cit.; Gregory, H. E., op. cit., pp. 16, 48; Emery, W. B., op. cit. p. 563; Moore, R. C., op. cit.

[2] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, pp. 25, 28-29, 1918.

[3] Reeside, J. B., Some American Jurassic ammonites: U. S. Geol. Survey Prof. Paper 118, pp. 10-11, 1919.

[4] Schultz, A. R., U. S. Geol. Survey Bull. 702, 1920. (Cites numerous papers.)

[5] Schultz, A. R., op. cit.

[6] Lee, W. T., op. cit., p. 13.

[7] Emery, W. B., op. cit., p. 571.

[8] Lupton, C. T., Geology and coal resources of Castle Valley: U. S. Geol. Survey Bull. 628, pp. 23-26, 1916.

[9] Moore, R. C. op. cit.

rather than the Stump epoch in southeastern Idaho, for the Twin Creek epoch was of much greater duration and its sea may be presumed to have been more widespread.

The La Plata group at its type locality[10] consists of two massive and cross-bedded sandstones separated by a relatively thin limestone member. This arrangement of beds has been traced southwestward into northeastern Arizona, where Gregory[11] named the lower sandstone the Wingate, the upper sandstone the Navajo, and the intervening beds the Todilto formation. It later developed that Gregory's section in northeastern Arizona was incomplete[12] and that his three divisions really corresponded with the lower part of the La Plata. This fact has introduced confusion into the Jurassic terminology of the plateau region. However, the original arrangement of the La Plata group agrees well, so far as it goes, with the arrangement of the Jurassic formations in southeastern Idaho, for there the marine Twin Creek limestone lies between the Nugget and Preuss sandstones which are probably nonmarine. If the gypsum in the Castle Valley and Green River desert sections is correlated with the Stump sandstone, as above suggested, the agreement is practically complete, for in the Stump sandstone the fossiliferous portion is at the base. The agreement is further emphasized by the fact that in all the localities named the Jurassic beds are overlain unconformably by more or less conglomeratic and variegated beds of supposed Cretaceous age. (See fig. 43.)

CRETACEOUS FORMATIONS AND THEIR INTERPRETATION

The Cretaceous formations of southeastern Idaho have been described in Chapter III (pp. 101 to 108), and their interpretation has been attempted in Chapter VI (pp. 194 to 199). They comprise the Gannett group and Wayan formation and have an assigned aggregate thickness of about 15,000 feet. Their relations to other Cretaceous formations, so far as the writer has been able to ascertain them, have already been stated. The thickness of these formations, even after allowing for reduplications or errors in measurement, is enormous and is probably greater in southeastern Idaho than elsewhere.

Cretaceous beds as continued northward from the Freedom, Lanes Creek, and Cranes Flat quadrangles constitute much of the Caribou Range and its adjacent foothills to the southwest. Poorly preserved forms suggestive of Bear River age have been collected from these beds, but no characteristic Bear River fossils have been found. The plant-bearing beds described on page 108 appear to represent a higher horizon than any that is exposed in the quadrangles here described. The thickness of the Wayan formation and its associated rocks in this region has not been determined, but hasty inspection seems to indicate that it is less than the thickness farther south. Although it has not thus far been practicable to subdivide the Wayan formation, more intensive study of the districts underlain by it in the quadrangles named, together with a critical examination of the unmapped portion of the Caribou district, will probably make necessary its subdivision and may solve the problem of the stratigraphic relationship of the Wayan to the Bear River or to later formations.

In the Big Hole Mountains, west of the Teton Basin, the Gannett group and Wayan formation together comprise only about 1,300 feet of beds, and there is a similar though less marked reduction in thickness in the Jurassic and Triassic formations exposed in that region as compared with southeastern Idaho. The writer has published elsewhere[13] a brief description with maps of this district.

The base of the Cretaceous in the Big Hole Mountains is the bottom of a prominent conglomerate bed, 15 to 25 feet thick, in which the pebbles are composed largely of chert. This conglomerate appears to be lithologically identical with the chert pebble beds near the base of the Ephraim conglomerate of the Gannett group farther south. In southeastern Idaho the Ephraim conglomerate is more than 1,000 feet thick and consists largely of deeply colored and massively bedded red conglomerates. Here the chert conglomerate is the sole representative of the conglomerate series and is succeeded by reddish or purplish sandy, shaly, and calcareous beds with nodules of limestone that resemble pebbles, the whole being much like the nonconglomeratic portions of the Ephraim. The limestones, which here lie perhaps 200 feet above the conglomerate and are 200 feet or more thick, may correspond with the Peterson limestone of the Gannett group, but more probably much of the Gannett group and some of the lower beds of the Wayan formation may be cut out by the unconformity between the two groups. A rather pronounced difference in strike between the limestone and the underlying beds noted in the southwest corner of sec. 8, T. 4 N., R. 44 E., favors such a view. The limestone is interbedded with purplish or dark shales and the upper beds are crowded with poorly preserved gastropods much like the limestone at Sugar Loaf Mountain in T. 2 S., R. 41 E., which is considered Wayan. Above the limestones come yellowish-gray or buff quartzites or sandstones which weather reddish or pinkish and which are much broken and slickensided locally and are estimated to be about 800 feet thick. These beds also correspond in position and lithology to beds of the Wayan formation.

Above the beds assigned to the Wayan in this locality lies a series of rather dark grayish sandstones

[10] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), 1890.
[11] Gregory, H. E., op. cit.
[12] Emery, W. B., op. cit., and Moore, R. C., op. cit.

[13] Mansfield, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716, pp. 123-153, 1920.

with interbedded dark-gray or almost black shales. These beds are unlike the Wayan beds that should follow in sequence according to the section exposed in southeastern Idaho. At several places they are accompanied by thin beds of dark limestone and siliceous shale or gray sandstone which contain typical Bear River fossils. Whether the Bear River beds are here unconformable upon the Wayan or follow in natural sequence was not determined. No noteworthy discordance of strike and dip between the two formations was observed. In view of the great body of Wayan beds that apparently should be represented here the suggestion of unconformity appears the more probable, though possibly some lateral gradation or interfingering of Bear River and Wayan beds may be recognized when the Cretaceous formations of the region have been more intensively studied. The Bear River beds of the Big Hole Mountains are overlain by higher Cretaceous beds, locally coal-bearing, and of supposed Colorado age. The relationship of these beds to the Bear River has not been determined, though probably they are unconformable.

Southeast of Pine Creek Pass, which separates the Big Hole Mountains from the Snake River Range, beds of the Gannett and Wayan formations have been recognized as far as Fogg Hill, which appears to mark the tip of a northwestward-pitching syncline. Bear River beds are exposed in the vicinity of the pass and may include the coal prospects on Rainy Creek to the southeast, though no characteristic Bear River fossils were found at the last-named locality.

Gannett and Wayan beds, together with beds of supposed Colorado age, have been recognized on the Continental Divide in Clark County, Idaho, and Beaverhead County, Mont., near Sheridan and Cottonwood Creeks. There the Bear River formation is absent, but the other formations appear to have thicknesses comparable to those indicated for the Big Hole Mountains.

The Beckwith and Bear River formations as mapped by Veatch [14] and Schultz [15] have a wide distribution in southwestern Wyoming. The terms Beckwith and Bear River, as formerly employed in southeastern Idaho, were applied in part to beds now included respectively in the Gannett group and Wayan formation.[16] According to the authors cited, beds of Gannett age and of the true Bear River are certainly present in southwestern Wyoming, but whether representatives of the Wayan are present is not known.

In Warm Springs Canyon near Garrison, Mont., beds of the Kootenai, as hastily examined by the writer, have many lithologic resemblances to beds of the Gannett and Wayan in southeastern Idaho. A fragment of chert pebble conglomerate, presumably from the Kootenai, is identical in appearance with the corresponding bed in the Gannett. The limestones and sandstones of the Kootenai correspond closely in appearance with those of the Wayan.

Since the preceding discussion was written the author has collected shells from a limestone bed in the Wayan at two localities in the Ammon quadrangle, Idaho. These shells have been identified by Mr. Stanton as belonging apparently " to the fauna of the Kootenai formation, which as recognized in Montana probably includes the equivalent of the Blairmore formation of Alberta." The relationship of at least part of the Wayan to the Kootenai seems therefore at last to be definitely established. Much, however, remains to be learned about the stratigraphy of the Wayan and its relations to the other formations named. The localities from which the collections were taken are respectively the east side of Mud Creek in the NE. ¼ SW. ¼ sec. 6, T. 2 S., R. 40 E., and the west side of Willow Creek in the NE. ¼ SE. ¼ sec. 6, T. 1 N., R. 40 E.

From the above review it appears that in southeastern Idaho the nonmarine Cretaceous beds have great thickness and represent at least two epochs of abundant sedimentation, separated by an epoch of deformation and erosion. Some of the beds have persistent lithologic characteristics by which they can be traced long distances northward and eastward. Apparently some of the beds that pass northward become parts of the Kootenai of Montana and some of those that pass eastward become the Beckwith of Wyoming. Possibly some of the beds mapped as Bear River in Wyoming may contain representatives of the Wayan, though in eastern Idaho the two formations are thought to be unconformable. Regional studies of the nonmarine Cretaceous in the three States named are needed to test the relationships suggested, to explain the great variations in thickness noted, and to determine the physiographic relations of the areas of nonmarine and marine deposition in those regions in Cretaceous time.

TERTIARY FORMATIONS AND THEIR RELATIONSHIPS

As intimated in Chapters III and VI the Tertiary record of southeastern Idaho is fragmentary and some of the evidence regarding it is of a conflicting nature. Broader field studies are needed to correlate more accurately the Wasatch and Salt Lake formations with the other Tertiary formations of the region. For example, there is an extraordinary development of Wasatch beds throughout the Bear Lake and Bear River plateaus. These beds require intensive study to determine if the threefold subdivision of the Wasatch, as advocated by Veatch, with its implication of unconformity between the two upper members, is in fact justifiable. Should this arrangement be

[14] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, 1907.

[15] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, 1914.

[16] Mansfield, G. R., and Roundy, P. V., Revision of the Beckwith and Bear River formations of southeastern Idaho: U. S. Geol. Survey Prof. Paper 98, pp. 75-85, 1916.

sustained, the correlation of the Wasatch of southeastern Idaho with the Almy or the Knight formation of Veatch would still remain in question. Much would depend upon fossil evidence, which is as yet very meager. A systematic search for fossils, especially vertebrates, is needed to solve the problem.

Aside from the doubts already expressed in earlier pages regarding the assignment of the Salt Lake formation to the Pliocene there is the question of the relationship of this formation to the Idaho and Payette formations of southwestern Idaho. Certain similarities of appearance suggest the possible correlation of the Salt Lake formation with one or the other of these formations, but the Salt Lake formation is dominantly coarser textured and of fluviatile origin, whereas the other two formations are described as dominantly lacustrine and of finer texture.[17] The fossils thus far obtained from the Salt Lake formation do not afford any satisfactory basis for such a correlation. Vertebrates are reported by Lindgren from both the Payette and Idaho formations, and more recent similar finds are recorded by Buwalda. The Salt Lake formation has not yet furnished any vertebrate remains, perhaps because it has not been systematically explored for such fossils. The fossil content and the stratigraphic relationships of the Salt Lake formation constitute an attractive problem for regional study.

IGNEOUS PROBLEMS

RELATION OF THE LAVAS OF SOUTHEASTERN IDAHO TO THOSE OF OTHER ERUPTIVE CENTERS

The igneous record of southeastern Idaho has been set forth in Chapters IV and VI. This region constitutes one of the tributary areas that supplied basalts to the Snake River lava plains, but its igneous activities were in large part local and its eruptive products included other types of rock than basalt. The order of its eruptive activity has been fairly well determined, so that it should be possible to make comparisons with other volcanic centers and perhaps to indicate some synchronism of events.

The nearest locality for which the sequence of volcanic events has been worked out on any considerable scale is the Yellowstone National Park. There a long series of volcanic episodes, beginning as far back as the Eocene, is recorded.[18] Some comparison of the records of the Fort Hall Indian Reservation and of the quadrangles here described with that of the Yellowstone Park has already been made. Probably the major igneous activity in southeastern Idaho did not begin until that of Yellowstone Park had been largely completed. The mountainous areas between the Cranes Flat quadrangle and the Yellowstone Park are bordered by rhyolites and basalts that may perhaps correspond with the later rhyolitic and basaltic flows of the Yellowstone. Similar rhyolites and basalts occur along the Continental Divide in Clark County, Idaho.

In the correlation of these lavas the key is probably found in the sediments that underlie or accompany them. In the Yellowstone Park fossil evidence is available. In the Idaho areas, however, no fossils of determinative value have been found in the Tertiary rocks. The discovery of fossil vertebrates would be particularly helpful for such a correlation, and systematic search for them should be made.

In southwestern Idaho lavas occur in association with the Payette and Idaho formations.[19] Definite correlation of these with the lavas of southeastern Idaho must await the discovery in the last-named region of distinctive fossils.

VOLCANISM AND DEFORMATION

The general absence of volcanic activity in association with the major deformation of southeastern Idaho is a noteworthy feature. Of the igneous rocks previously described only the hornblende andesite porphyry could have participated in the diastrophic disturbances which produced the great folds and overthrusts of the region, and even this may have been intruded at a later epoch.

R. T. Chamberlin,[20] in a study of the Colorado Rockies, has pointed out that volcanic activity is usually rare in mountains where intense folding and overthrusting have occurred. He distinguishes as "thin-shelled" those mountains in which the intensely compressed outer portion of the earth's shell has sheared upon a less yielding base beneath, without disturbing the earth's crust to any great depth. In this class he includes the Appalachians, Alps, Jura, the Scottish Highlands, the Scandinavian chain, and others. In all these mountains deformation has been accomplished with little concomitant volcanic activity. In contrast to these thin-shelled mountains are the "thick-shelled" mountains, which show open folding, but are without thrust faults or evidences of intense horizontal compression. In these mountains the depths affected by the compressive forces are far greater than those in the preceding type. Representatives of the thick-shelled type are the Cascade, Andes, and Abyssinian Mountains. Vast floods of lava marked the growth of these ranges.

In a later paper Chamberlin adds[21] that in thick-shelled mountains igneous intrusion may have a close relation to mountain-making stresses. Little igneous

[17] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Boise folio (No. 45), 1898; Lindgren, Waldemar, and Drake, N. F., U. S. Geol. Survey Geol. Atlas, Nampa folio (No. 103), 1904.

[18] Hague, Arnold, Weed, W. H., and Iddings, J. P., U. S. Geol. Survey Geol. Atlas, Yellowstone National Park folio (No. 30), 1896.

[19] Lindgren, Waldemar, and Drake, N. F., U. S. Geol. Survey Geol. Atlas, Nampa folio (No. 103), 1904.

[20] Chamberlin, R. T., The building of the Colorado Rockies: Jour. Geology, vol. 27, pp. 248–251, 1919.

[21] Chamberlin, R. T., Volcanism and mountain-making: Jour. Geology, vol. 29 pp. 166–172, 1921.

activity of any sort is manifested in the marginal and most strongly overthrust portions of the thin-shelled ranges; but in the heart of the deformed belts, where there has been more uplifting and the affected zone goes deeper, granitic and other intrusions are a common and probably characteristic feature.

According to Chamberlin's view great overthrusts are indicative of the thin-shelled type of deformation and are marginal features of the mountain-forming area. The last appears to be the relation in some areas, as in the Lewis overthrust in the Glacier National Park, but in other places the relation is not so clear. Thus the Bannock overthrust in southeastern Idaho, with its accompanying folds, is well within the Idaho-Wyoming Chain. Other notable thrusts, such as the Absaroka and Darby faults described by Schultz,[22] lie farther east, and the mountain-built area itself extends many miles farther in that direction. In southeastern Idaho also the Rocky Mountain geosyncline appears to have reached approximately its maximum depth for the latitude, to judge by the thickness of the sedimentary rocks still preserved there, though these rocks probably constitute only a small proportion of the earth shell in that region. Whether the geosyncline lies in the deeper rooted part of the mountain-built area or in front of it can not be told until observations are extended clear across that area. The roots of the lower Cretaceous and post-Jurassic mountains lie west of the geosyncline in the Pacific element, which supplied the sediments of the portion of the geosyncline comprised in southeastern Idaho.

With reference to intrusions it may be observed that the Idaho batholith as described by Umpleby[23] is probably of late Cretaceous or Eocene age and should thus be contemporaneous with the period of diastrophism that formed the mountains of southeastern Idaho. This batholith lies in the general strike of these mountains but is separated from them by the broad depression of the Snake River Plains and by other ranges which involve older rocks than any that are exposed in southeastern Idaho. To what extent it may have been a cause of uplift or mountain building in central Idaho or how far it may have influenced diastrophism in southeastern Idaho are unknown.

The rhyolitic and basaltic extrusions, which occurred later, may have originated from a concealed batholith. They appear to be connected with epochs of normal faulting, produced either by subsidence and readjustment of older folded terranes or by corresponding readjustments that occurred after the later epoch of broad uplift and gentle folding.

[22] Schultz, A. R., op. cit., pp. 84, 87.

[23] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pp. 42, 43, 1913.

STRUCTURAL PROBLEMS

OVERTHRUST FAULTING

GENERAL OCCURRENCE

The Bannock and Star Valley overthrusts are probably the most interesting structural features of southeastern Idaho. The length of the Bannock overthrust, 270 miles or more, and the breadth of its area of maximum horizontal displacement, estimated at more than 35 miles, indicate disturbances of the earth's crust with far-reaching effects. It is incredible that these disturbances could have no relation to the other similar disturbances that are recorded in scattered areas in the Northern Rocky Mountain province and in regions farther south. Detailed observations in these regions are few, but evidence of the occurrence of overthrusting on a large scale is accumulating. The principal great overthrusts thus far recognized are briefly described below. Their distribution is shown in Figure 44.

LEWIS OVERTHRUST

In northwestern Montana, along the eastern border of the Glacier National Park, Algonkian rocks are made to overlie Cretaceous strata in a great overthrust fault, which was named by Willis[24] the Lewis overthrust. As mapped by Campbell[25] the distance in a straight line between the two ends of the fault, as exposed in Glacier National Park, is about 53 miles, but its actual length in a sinuous course is much greater. Its minimum horizontal displacement is 15 miles. This fault, which has been studied by Daly[26] at the forty-ninth parallel, has been traced northward into Canada by Mackenzie,[27] and at the fifty-first parallel a similar if not identical fault in the Front Range has been described by McConnell.[28] Dowling[29] also records overthrust faulting in the Mackenzie and Franklin Mountains, farther north in Canada.

PHILIPSBURG THRUST FAULTS

Near Philipsburg, Mont., a thrust zone that comprises two principal and several minor faults has been described by Calkins,[30] who considers it probable that this zone is a southerly continuation of the Lewis

[24] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston Ranges, Mont.: Geol. Soc. America Bull., vol. 13, pp. 331-336, 1902.

[25] Campbell, M. R., The Glacier National Park: U. S. Geol. Survey Bull. 600, pl. 13, 1914.

[26] Daly, R. A., Geology of the Northern American Cordillera at the forty-ninth parallel: Canada Dept. Mines Geol. Survey Mem. 38, pp. 55, 90-95, 1912.

[27] Mackenzie, J. D., The historical and structural geology of the southernmost Rocky Mountains of Canada: Roy. Soc. Canada Trans., vol. 16, ser. 3, sec. 4 pp. 97-132, 1922.

[28] McConnell, R. G., Report on the geological structure of a portion of the Rocky Mountains: Canada Geol. and Nat. Hist. Survey Rept., 1886, Part D, 1887.

[29] Dowling, D. B., Geological structure of the Mackenzie River region: Canada Geol. Survey Summary Rept., 1921, Part B, pp. 79-90, 1922.

[30] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, pp. 146-150, 1913.

overthrust. Algonkian rocks are here brought into contact with rocks of Carboniferous and Jurassic ages. Calkins says:

> This zone of faulting offers a striking exception to the general rule that the faults are subsequent to the folds, for it has been folded and has been dislocated by normal faults to nearly the same extent as the rock strata, and is therefore one of the oldest tectonic features of the quadrangle.

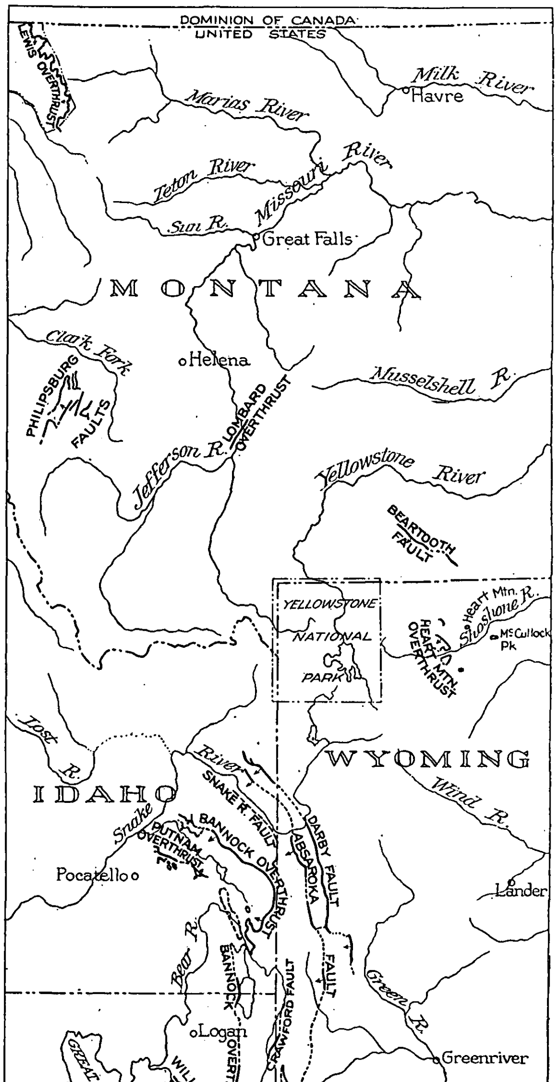


FIGURE 44.—Map showing the distribution of overthrust faults in the northern Rocky Mountains. Arrow shows dip of overthrust plane and direction from which thrust comes

BITTERROOT FAULT

Lindgren [31] has described a great fault with easterly dip ranging from 15° to 26° along the east flank of the Bitterroot Mountains in Montana. The minimum actual movement along the fault plane is 2 or 3 miles. The minimum vertical component of this movement is 4,000 to 6,000 feet. He first interpreted this fault as normal, but he now believes it to be a thrust fault with eastward movement of the upper block but with the fault plane bent down eastward.

LOMBARD OVERTHRUST

Haynes [32] has given the name Lombard overthrust to a great fault studied by him near Lombard, Mont., where strata of the Belt series (Algonkian) overlie Cretaceous rocks. The length of the fault as mapped is about 13 miles and its maximum displacement along the fault plane is about 2 miles.

BEARTOOTH FAULT

Woodruff,[33] and later Calvert,[34] has reported faulting along the northeastern border of the Beartooth Mountains. As mapped by Calvert this fault has a length of about 35 miles. Calvert gives no geologic structure section, but Woodruff shows the fault as vertical, presumably normal. Toward the south Paleozoic limestones are brought into contact with beds of Fort Union age. Toward the northwest, however, Jurassic beds appear in the upper fault block.

Dake [35] records a zone of thrust faults along the eastern edge of the Beartooth Plateau which extends from Clark Fork to the Montana line and which he thinks is related to the forces that produced the Heart Mountain overthrust described by him a few miles to the south in Wyoming; pre-Cambrian granite is carried out over "Red Beds." The fault planes could not be actually observed but are undoubtedly much steeper than the plane of the Heart Mountain thrust. In view of these evidences of overthrusting and of the fact that the Beartooth fault receives little more than mention from either Woodruff or Calvert, this fault seems very likely to be a thrust rather than a normal fault.

Bevan,[36] whose work in this region was published since the above was written, has reached a similar conclusion.

HEART MOUNTAIN OVERTHRUST

Later study of the Heart Mountain overthrust by Hewett [37] shows that this great thrust fault is much more extensive than was at first suspected. Hewett says:

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[31] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol Survey Prof. Paper 27, pp. 47-51, 1904, and recent personal communication

[32] Haynes, W. P., The Lombard overthrust and related geological features: Jour. Geology, vol. 24, pp. 269-290, 1916.

[33] Woodruff, E. G., The Red Lodge coal field, Mont., U. S. Geol. Survey Bull. 341, pp. 92-107, 1909.

[34] Calvert, W. R., Geology of the upper Stillwater basin, Stillwater and Carbon Counties, Mont., with special reference to coal and oil: U. S. Geol. Survey Bull. 641, pp. 199-214, 1917.

[35] Dake, C. L., The Hart Mountain overthrust and associated structures in Park County, Wyo.: Jour. Geology, vol. 26, pp. 52-53, 1918.

[36] Bevan, Arthur, Summary of the geology of the Beartooth Mountains, Mont Jour. Geology, vol. 31, pp. 441-465, 1923.

[37] Hewett, D. F., The Heart Mountain overthrust, Wyo.: Jour. Geology, vol. 28, pp. 536-556, 1920

The residuals on McCulloch Peak show that the extent of overthrust is at least 28 miles and indicate that the fault should be traceable over the entire eastern edge of Absaroka Range perhaps for 125 or 150 miles.

Masses of Ordovician or Carboniferous limestone rest upon beds of the Bridger formation.

DARBY FAULT

The Darby fault, which was recognized by Peale [38] but named by Schultz,[39] extends from Teton County, Idaho, where it has been observed by the writer, southeastward into Wyoming, a distance of approximately 125 miles. At several places along the fault line Mississippian rocks are brought into contact with the Frontier formation, indicating a throw (stratigraphic?) of 20,000 feet. On the basis of Schultz's mapping the horizontal displacement may exceed 15 miles.

ABSAROKA FAULT

The Absaroka fault, which was recognized by Peale [40] and named by Veatch,[41] in southwestern Wyoming, has been followed by Schultz [42] into Idaho, where it has been observed by the writer. Its known length is approximately 200 miles, and on the basis of the combined mapping of Veatch and Schultz its zone of displacement may exceed 25 miles in breadth. Its throw (stratigraphic?) is said to exceed 20,000 feet.

MEDICINE BUTTE AND CRAWFORD FAULTS

Two other thrust faults, namely, the Medicine Butte and Crawford faults, have been mapped by Veatch [43] in southwestern Wyoming, and the Crawford fault has been recognized by Gale and Richards [44] in Utah. According to Veatch's mapping, the Medicine Butte fault exceeds 30 miles in length and the breadth of its zone of dislocation may be greater than 5 miles. It brings beds of the Beckwith and Bear River formations into contact with formations of the Wasatch group.

The Crawford fault appears to be on approximately the same scale, but Carboniferous beds are exposed in the upper block and Cretaceous or Tertiary beds in the lower.

FAULTS ALONG SNAKE AND SALT RIVERS

Schultz and Richards [45] have mapped a thrust fault that has a length of nearly 30 miles on the east side of the Caribou Range along Snake River. According to their mapping, beds that range in age from Carboniferous to early Jurassic are brought into contact with beds of later Jurassic and Cretaceous age.

Several faults along the west side of Star (Salt River) Valley have already been described. The east wall of Star Valley, which constitutes in part the west border of the Salt River Range, is for much of its course relatively straight and truncates obliquely the successive formations and structural features of the west flank of that range. This line is with little doubt a fault, which is considered normal on the basis of a hasty reconnaissance.[46] More detailed study may show this fault to be likewise a thrust.

BANNOCK AND PUTNAM OVERTHRUSTS

The possibility of the connection of the Bannock and Putnam overthrusts has already been suggested. The Putnam overthrust has a known length of about 20 miles. It brings rocks of Cambrian and Ordovician age into contact with Pennsylvanian or Triassic rocks. It is accompanied by or associated with other thrusts that can not be well shown on the scale of the accompanying map but that produce zones of highly shattered material.

WILLARD OVERTHRUST

Near Willard, Utah, Blackwelder [47] has described and named a great thrust fault, with associated or subsidiary thrusts, which brings lower Algonkian formations over Paleozoic rocks. The maximum horizontal displacement, so far as exposed, is about 4 miles, but this is probably only a small fraction of its total displacement. The fault, which has a sinuous course, has been traced, according to Blackwelder's map, about 22 miles but is thought to be much longer. It is cut off on the west by the great normal fault which there marks the west front of the Wasatch Mountains. The inclination of the fault plane averages 15° but locally is as great as 50°. Contrary to the usual rule of Rocky Mountain thrusts thus far investigated the inclination of the fault plane is apparently eastward.

THRUSTS OF COTTONWOOD AND PARK CITY DISTRICTS, UTAH

Numerous overthrusts have been recognized in the Cottonwood and Park City districts of Utah, together with normal faults. So far as mapped these are mostly on too small a scale to be represented on Figure 44. They deserve mention, however, because of the intensity and complexity of the forces by which they were produced.

According to F. C. Calkins,[48] who has made an intensive study of some of these faults, the lowest and

[38] Peale, A. C., Report on the geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., p. 630, pls. 49, 53, and 54, 1879.

[39] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 84–85, 1914.

[40] Peale, A. C., op. cit., p. 543.

[41] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 109–110, 1907.

[42] Schultz, A. R., op. cit., p. 87, and U. S. Geol. Survey Bull. 680, 1918.

[43] Veatch, A. C., op. cit., pp. 111–112.

[44] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, p. 515, 1910.

[45] Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, p. 277, pl. 6, 1913.

[46] Mansfield, G. R., A reconnaissance for phosphate in the Salt River Range, Wyo.: U. S. Geol. Survey Bull. 620, pp. 331–349, 1916.

[47] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 517–542, 1910.

[48] Calkins, F. C., personal communication.

greatest overthrust in the Cottonwood district, was named by F. F. Hintze the Alta overthrust, although it was recognized independently in 1912 by Hintze and by Butler and Loughlin. It causes Middle Cambrian quartzite to rest on lower Mississippian limestone. Other overthrusts of less throw lie above the Alta and roughly parallel to it. This fault dips eastward in general, and its dip steepens downward and probably passes the vertical in places. Calkins believes, mainly from the relations of drag folds, that the upper block moved eastward and that the original dip of the thrust plane was westward.

The Alta overthrust is cut off by the great Silver Fork fault, a normal fault of northward trend and low westward dip about half a mile east of Alta. Farther east there are other overthrusts, the lowest of which may be the continuation of the Alta, brought up by the Silver Fork fault. If this interpretation is correct, the thrust moved at least 3 miles; but the movement was in all probability much greater.

The overthrusts east of the Silver Fork fault are slightly folded, and in places they dip westward.

The structure in the Park City district has been discussed by Boutwell.[49] The principal overthrust, which he calls the Frog Valley fault, has a northward trend and has been mapped for only about 2 miles. Pennsylvanian quartzite is brought into contact with the Thaynes group. The inclination of the fault plane is about 45° W.; the displacement along the fault plane is probably greater than 2,000 feet.

THRUSTS IN THE UINTA MOUNTAINS

Along the north base of the Uinta Mountains two noteworthy zones of thrusting have been observed. The eastern zone at least was noted by members of the King and Powell surveys. As described by Schultz,[50] the first of these zones is a fault zone that extends generally eastward from the vicinity of Rockport, in Summit County, a distance of about 20 miles before it disappears beneath Tertiary sediments. The fault zone is accompanied by steeply inclined or overturned strata and seems to lie approximately along the strike of Jurassic and Cretaceous rocks. The forces which produced the dislocation appear to have acted from the south or southeast.

The second zone of thrusting is the great Uinta fault, also described by Schultz.[51] It is the largest in the region and has been traced across the northern part of Uintah County into northwestern Colorado, a distance of about 80 miles, but neither end of it has been found. In northeastern Uintah County the fault lies entirely in the red quartzite series that makes up the main part of the anticlinal crest of the range. The fault is a thrust caused by pressure from the south or southeast. Farther east the red quartzites rest against sharply upturned and overturned Cretaceous formations. According to Irwin, the displacement involves a stratigraphic interval of more than 30,000 feet. The dip is about 45° and the horizontal movement appears to have been 4 or 5 miles.

RELATIVE MAGNITUDE AND IMPORTANCE OF OVERTHRUSTS

The overthrusts above described range in length from a few miles to nearly 300 miles. The breadth of their areas of dislocation ranges from 2 or 3 miles to nearly 40 miles. They differ also in the stratigraphic intervals which they produce. Some of these apparent differences are probably due to lack of present knowledge, but without doubt some of the faults, such as the Lewis, Bannock, and Absaroka overthrusts, are displacements of a larger order than some of the others, such as the Medicine Butte fault. Large and small, however, they are features of prime significance in the interpretation of the geologic history of the region, and they testify to the activity of tremendous compressive forces in the outer shell of the earth's crust.

RELATIVE AGE OF OVERTHRUSTS

The age of an overthrust is ordinarily determined by its relationship to adjacent strata. It is obviously younger than any formation that it cuts and older than any formation that overlies it and is unaffected by it. Commonly the time interval between these two limits is so great that no very close approximation of age may be made. On the other hand, it is possible in this way to determine broadly the relative ages of many structural features.

It has not been possible thus far to fix the geologic age of many of the overthrusts mentioned above more closely than to state that they are pre-Tertiary (Philipsburg district), late Cretaceous or early Tertiary, or post-Cretaceous. For a few the information is a little more definite. For example, Willis, on the basis of both structural and physiographic evidence, ascribes mid-Tertiary age to the Lewis overthrust. Later work, mostly unpublished, by geologists of the Federal Survey, in regions east of the mountains not visited by Willis, shows that this fault is either of late Eocene or early Oligocene age. Mackenzie states that it is not earlier than the latest Cretaceous nor later than the latest Eocene. The Beartooth fault is indicated in Woodruff's structure section as of post-Fort Union age. Bevan states that it took place long after the deposition of the Fort Union in the Beartooth Range and long prior to the accumulation of the widespread "early basic breccias" in the Absaroka Range. Hewett shows that the Heart Mountain overthrust is

[49] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 94–98, 1912.

[50] Schultz, A. R., A geological reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pp. 69–74, 1919.

[51] Idem. See also U. S. Geol. Survey Bull. 702, pp. 43, 46, pl. 1, 1920, and Irwin, J. S., Faulting in the Rocky Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 108–109, 1926.

of later age than horizon A of the Bridger formation and is therefore not older than middle Eocene nor younger than early Oligocene age. The Uinta fault is stated by Schultz to be older than the Bishop conglomerate, which is regarded as of Tertiary (Miocene?) age.

One fact that appears to be established by reviewing the age relationships of the different thrust faults is that these faults were in all probability not synchronous but that some occurred later than others. This fact indicates that the compressive stresses that produced the overthrusts were maintained over a considerable period and that they found relief at more or less distinct successive intervals—a conclusion that should naturally be expected in view of the greatness of the region affected and of the tremendous stresses involved.

POSSIBLE RELATIONSHIPS

It is easy to believe that the great overthrust blocks, whether they are connected at the surface or not, are parts of a greater mass of the outer shell of the earth's crust driven forward more or less rhythmically at times when the shell was ruptured by the well-nigh irresistible force of accumulating stresses.

Thom [52] mentions briefly most of the overthrusts above reviewed and notes that their relationships are not established but he thinks that the continuity of the mountain ranges, the relative topographic position of the terranes involved, and the observed magnitude of the horizontal displacements indicate that these faults have a common origin and are parts of a continuous major fracture. He depicts central Montana as a region where the simple overthrust, as seen in the Canadian Front Range, gives place to more complex structural conditions probably because the edges of the overthrust sheet there impinged upon older eastward-trending uplifts and was disrupted by them. These older structural features appear to have been absent from the region of eastern Colorado, for the Front Range in that State resumes its simple wall-like aspect. Thom pictures waves of deformation and intrusion, which began on the Pacific coast in Upper Jurassic time, as affecting progressively areas farther east. These influences were not vigorously active in areas along the Front Range until the Upper Cretaceous.

Kober [53] regards the eastern ranges of the Rocky Mountains northward from the Yellowstone National Park as border chains of a great geosyncline, which have been thrust forward upon a foreland of older and more rigid rocks. The foreland for the Rocky Mountains is the so-called Canadian shield of older rocks in the vicinity of Lake Superior, which he would extend westward beneath the cover of later sedimentary rocks. His idea of the structure of border chains, which is derived from a study of the Alps,[54] is that of a highly folded and faulted mass, parts of which have been torn from their foundations, piled upon each other to a greater or less extent, and moved bodily forward toward or upon the foreland. He accounts for the difference in the aspect of the eastern chains in Montana and Colorado by assuming that the mountains in Colorado east of the Wasatch Range, which he calls the Colorado Plateaus and pre-Cordillera, represent earlier folded and eroded mountains, which had become incorporated in the foreland and were little, if any, affected by the supposedly later orogenic forces that produced the mountains farther north.

As noted in Chapter V, certain Alpine characteristics have been observed in the mountains of southeastern Idaho. The discovery of great overthrusts in the Rocky Mountain region points to additional similarities of structure, but thus far nothing comparable in complexity with the more highly developed structural features of the Alps has there been recognized.

Thom in his consideration of conditions in central Montana seems to assume that the movement of the disturbed parts of the outer shell has all been eastward but that some parts were more retarded than others. The evidence presented on Figure 44 shows that there were apparently at least two well-defined directions of movement—an easterly movement, which obtained as far south as the southwest corner of Wyoming and parts of Utah immediately to the west, and a northerly movement, which is represented by the zones of thrusting and faulting along the north border of the Uinta Mountains. The change of direction of movement is very abrupt, forming nearly a right angle. The faults of the Cottonwood district, which are highly complex, appear to occupy a strategic position at the apex of the angle. Possibly the direction of faulting along the Uintas may be due merely to the resolution of the generally eastward-acting forces which there impinged on the earlier opposing structure. On the other hand, it may indicate that the orogenic forces which built the southern Rockies were differently oriented from those which built the northern Rockies and may have originated under different conditions.

DEFICIENCY OF KNOWLEDGE

In considering the data on Figure 44 it is apparent that great gaps interrupt the continuity of the areas examined. The geology of thousands of square miles in the northern Rocky Mountain region has either not been studied at all or has received only cursory study. No odium need be attached to work of this type, for its purpose has ordinarily been purely economic and the conditions under which it has been done have been such as to preclude much opportunity for extraneous observations.

[52] Thom, W. T., jr., The relation of deep-seated faults to the surface structural features of central Montana: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 1, pp. 1-13, 1923.

[53] Kober, Leopold, Der Bau der Erde, pp. 160-161, Berlin, 1921.

[54] Idem, pp. 86-89.

This deficiency of knowledge, however, makes it obvious that generalizations regarding overthrusts and other crustal disturbances in the northern Rocky Mountains should be tentative. Generalizations such as those cited above are valuable as working hypotheses. More numerous and more extended regional studies are needed in order that conclusions, which from the very nature of the problems may never be final, may be more firmly grounded.

OVERTHRUSTING VERSUS UNDERTHRUSTING

It has been customary to consider the underlying block in an overthrust as relatively passive and to ascribe all the movement in such dislocations to the upper block, which at many localities may actually be seen resting upon or overriding the lower. In this conception the upper block is presumed to have moved forward along the fault plane in the direction toward which the driving pressure was exerted. This view is now being challenged.

Some years ago Hobbs[55] argued that

> the active force which produces rock folds, instead of operating from behind and above the anticline, as so generally supposed, is applied below and in front. Continuation of the process yields, therefore, not "overturned" and "overthrust" but underturned and underthrust flexures. * * * Anticlines rise first upon that side of the folding area which is toward the direction from which the force comes; * * * the folds (anticlines) within any arc are developed in order of age from without inward.

More recently Lawson[56] has undertaken to show by simple mathematical treatment what are the limits of length and limits of movement of overthrust blocks. His results indicate that, although upon the given assumptions an overthrust wedge of rock may under nearly horizontal pressure have a length as great as 32 miles, frictional resistance to movement in excess of the strength of the rocks will in all probability be developed, so that it would seem

> mechanically impossible, a priori, that a single intact prism of the earth's crust could move more than a small fraction of a mile by real overthrusting as a mobile block past a passive underlying block.

Continuation of the pressure, according to his argument, will cause the wedge to break up into smaller thrust blocks by successive minor thrusts whose planes will have a steep inclination and a surface that is concave upward. These blocks will develop from the surface downward, and some of them may be deep enough to join the main overthrust. On the other hand, he shows that if the upper block is considered passive and the lower block mobile the limitations on length and movement previously mentioned do not hold. Friction along the fault plane between the two blocks may cause successive ruptures in the upper block, which may develop into thrust faults that originate at the main thrust plane, extend upward toward the surface, and are concave downward.

The phenomena ascribed to overthrusting are widespread. A classic example is the northwest highlands of Scotland, the structure of which has been carefully studied and described by members of the Geological Survey of Great Britain.[57] There a succession of thrust planes has been recognized on which movements of 6 to 10 miles, which are considered as minimum movements, have taken place. Many complexities of structure accompany these thrusts. One of the most striking is the so-called imbricated structure, in which strata above the thrust planes are repeated and heaped up in successive blocks by a series of minor thrusts or reversed faults that lie at oblique angles to the major thrust planes. The blocks appear to have been moved bodily forward along these planes.

Great thrust faults in the Appalachian Mountains have been studied by Willis,[58] Keith,[59] and others.

Another classic examp e is furnished by the Alps, whose difficult geology has been studied by many European and other geologists but by none more brilliantly or carefully than by Heim, whose recent publication[60] summarizes a lifetime of Alpine studies. Heim notes[61] that in the Jura Mountains masses of folded rock have been pushed forward 3 to 8 kilometers and that parts of these displaced blocks have been separated from each other by erosion. In the Alps great mountain masses of folded rocks have been torn bodily from their foundations, overturned, piled upon each other, and displaced, so that they now lie upon younger rocks far removed from their place of origin. This is the so-called "decke" or "nappe" structure, which has become familiar to students of Alpine geology. By means of openings carved by erosion in the upper blocks, by which the underlying rocks have been exposed, it has been possible, as in the Canton of Wallis, to draw profiles of the surfaces of dislocation extending 10 to 20 kilometers underneath the ground. Observations in the mountains and valleys have been checked and corrected by studies of exposures in railway tunnels, so that many of the structural features have been determined with a high degree of accuracy.

Mathematical studies of such problems as overthrusting, however logical, are not always convincing, as the results obtained must depend upon the validity, comprehensiveness, and accuracy of the assumptions upon which the calculations are based. In the Scot-

[55] Hobbs, W. H., Mechanics of formation of arcuate mountains: Jour. Geology, vol. 22, p. 206, 1914.

[56] Lawson, A. C., Isostatic compensation considered as a cause of thrusting: Geol. Soc. America Bull., vol. 33, pp. 337-352, 1922.

[57] Peach, B. N., and others, The geological structure of the northwest Highlands of Scotland: Great Britain Geol. Survey Mem., pp. 463-593, 1907.

[58] Willis, Bailey, The mechanics of Appalachian structure: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 211-281, 1893.

[59] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Roan Mountain folio (No. 151), 1907.

[60] Heim, Albert, Geologie der Schweiz, Band 1 (Molasseland und Juragebirge) 704 pp., 31 colored pls., Leipzig, 1919; Band 2, 1te. Hälfte, 476 pp., 27 colored pls., Leipzig, 1921.

[61] Idem, Band 1, p. 597, and Band 2, pp. 20-21.

tish Highlands the imbricated structure appears to bear out Lawson's view that a great wedge of the superficial crust will break up under powerful tangential pressure into smaller blocks that will stand at high angles with regard to the original thrust plane. It shows further, however, that these smaller blocks, when in this position, develop resistances that accumulate in such manner that the blocks may act as a single unit, which, under sufficient tangential pressure, is moved forward with reference to underlying structural features.

The facts determined by Lawson, that with overthrusting the subsidiary faults would have surfaces concave upward, whereas with underthrusting these faults would curve in the opposite direction, seem to afford a partial basis for checking his results in the field. But when it is remembered that in many places the thrust planes are concealed or poorly exposed and are also perhaps folded or faulted, the problem remains complex.

In most so-called overthrusts the upper block consists of older rocks, more massive and rigid than those that underlie them. It is easier to think of these older rocks, under tangential pressures such as produce these great dislocations, as moving upward and outward toward the surface, where resistance is less, than to suppose that weak, incompetent formations are forced inward and downward into zones of increasing resistance.

With the supposition of underthrusting it is presumed that the greatest effects would be felt near the zone of application of the tangential forces or, in the northern Rockies, along the eastern border of the mountains. If it is further presumed that the zone of application of effective forces should migrate inward; that is, westward, relatively younger dislocations might possibly be discovered in that direction. So far as the facts are known, there seems to be no greater intensity of mountain building along the eastern border of the Rockies than farther west. Moreover, the Heart Mountain overthrust and possibly the Lewis overthrust, which mark the outer border of the known great overthrusts, are later than the Bannock overthrust, and this in turn is probably somewhat later than the Philipsburg faults. Thus it seems that the zone of thrusting has moved progressively eastward rather than westward. These facts accord better with the idea of overthrusting and a westerly source for the tangential pressures than with the reverse supposition.

The load due to the mass of the rocks above the incipient fault plane is without doubt a notable factor in the development of overthrusts. In Cadell's experiments, which were conducted with reference to conditions in the Scottish Highlands,[62] it was found that the compressed mass tends first to seek relief along a series of greatly inclined thrust planes, which dip toward the side from which the pressure was exerted. After a certain amount of piling up has taken place along these minor thrust planes the whole heaped-up mass tends to rise and ride forward bodily along the major thrust planes. These results correspond with actual conditions in the Scottish Highlands. The Bannock overthrust in Idaho is marked at several places along its course by a fault zone of heaped-up rock slices that consist of more or less broken rock folds.

The rock prisms now represented by the Rocky Mountain overthrusts are unquestionably too thin and attenuated to have reached their present positions without breaking to pieces and losing their identity under the tremendous pressures involved in the process of overthrusting. If they may be considered as parts of a great heaped-up mass that moved forward, now here, now there, under accumulating stresses, their origin is more readily comprehensible. This conception carries with it as a corollary the idea of tremendous erosion since the time of faulting. Since Powell published his account of the Uinta Mountains,[63] in which he showed that a maximum thickness of nearly 6 miles of rock had been eroded from those mountains, there has been something of a reaction on the part of American geologists against the idea of such prodigious erosion. Probably, however, for mountain regions at least, the view of great erosion is well supported. For the Alps Heim [64] shows that peaks which now have altitudes of 3,000 to 4,500 meters should have, without allowing for erosion, altitudes of 5,000 to 20,000 meters. It is not supposed that the Alps ever actually attained such altitudes, but their heaping up was obviously at a greater rate than their erosion, and the load thus accumulated would favor the development of the great overthrusts that are such a remarkable feature of Alpine structure.

Thus far the discussion has assumed that one or the other of the two blocks in an overthrust remains passive. As gravity plays a predominant part among the forces which produce the tangential pressure, the probabilities are that both blocks are subject to movement and that the motion of either block with respect to the other is purely relative. This idea has been well expressed by Heim,[65] whose remarks may be freely translated and abridged as follows:

> As the pressure and resistance in a tangential movement of the earth's crust are alike and the direction of movement in great displacements is only relative, the direction in which the heaped-up folds become overturned is not directly dependent upon the direction of movement. It is more often determined by other causes. In fact, we find in the Jura Mountains, near many northward overturned folds, individual folds whose crests are bent back southward. The following causes unite in

[62] Peach, B. N., and others, op. cit., p. 475.

[63] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, p. 181, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

[64] Heim, Albert, op. cit., Band 2, p. 71.

[65] Idem, Band, 1 pp. 647-649.

producing such a result: The relative heights of the bases of the limbs of the respective folds, more free space toward one side, the harmonic compression of folds already present, varying differences in rigidity, and the direction of the chord of the arc produced by the bending chains. Nevertheless it appears, and the Jura gives direct evidence for it, that apart from these causes of direction of overturning there is a one-sided direction of thrust, especially in heaped-up folds. A dominance of overlying in the direction of one-sided movement is plainly present in many mountain chains, and if, as in the Jura, Alps, and Himalayas, the direction of overthrusting shows the same direction of movement as the arc form, we can be sure in our conclusion that there has been a one-sided direction of movement. * * * Careful reflection shows that much more mechanical work would be necessary to produce overthrusting toward the direction of thrust, which corresponds to the underthrusting of a trough. * * * Every tangential movement in the earth's crust has a purely relative direction, and every tangential pressure operates through the entire circle of the earth's crust in which pressure and resistance are always striving to produce equilibrium. There are, however, a thousand irregularities in tangential movements which do not affect the entire earth's crust at the same time but which continually tend to restore the locally disturbed equilibrium. A broad span of the earth's crust is set free only gradually, piece by piece, and it is dismembered by local movements. Thus it often happens that a relatively small fragment as regards size and depth is driven against a larger and more deeply extending mass, which on its side remains in relatively rigid connection with the broader neighboring masses. We do not then say that the entire earth's crust has moved toward this smaller fragment, but we can speak of the direction of movement of this fragment in distinction from that of the neighboring widely extended masses, and this one-sidedness of motion will express itself in mountain building. * * *

The bending of the lines of folds is the single means free from objection for determining the direction of motion of one-sided folding. The thrust is always directed from the inside toward the outside of the bow in the same way as the thrust of the bow is directed toward an arrow. The general outward bending of the folds and fold groups of the Jura chains shows that a one-sided movement proceeded from the southeast. The arch is clearly overthrust, not the trough underthrust. The last interpretation would here be very difficult, for we may not admit that the older, rigid Schwarzwald has been underthrust toward the south beneath the Jura.

CIRCUMFERENTIAL SHORTENING

EFFECTS OF COMPRESSION

When the earth's shell is compressed and folded the affected portions are necessarily shortened along the circumference and thickened in proportion to the intensity of the deformation. Thus Heim [66] estimates that the folding of the Alps, where the geologic structure is very complex, was 20 to 50 times stronger than that of the Jura, where the folding is relatively more open. One of the attractive problems of mountain structure is to determine if possible the amounts of crustal shortening and thickening which the region experienced in mountain-building and to find the bearing of these factors on the mechanics of the process.

[66] Heim, Albert, op. cit., p. 651.

Some years ago Chamberlin [67] made a study of the amount of shortening and the depth of folding of the Appalachians from Tyrone to Harrisburg, Pa.; more recently he has made a similar study of the Rocky Mountains in Colorado. Following generally the same method as that employed by Chamberlin, the writer has undertaken to measure the shortening and thickening of the earth's crust that was produced by the formation of the Peale Mountains and Caribou Range in southeastern Idaho. These mountains constitute but a small portion of the northern Rocky Mountains as a whole, but they serve to illustrate the intensity of the compression of that region.

LINE MEASURED

The line of direction selected for measurement is that of geologic structure section K–K'''. (See pl. 11.) This structure section begins in the southeastern part of the Henry quadrangle, where it crosses the northern part of the Aspen Range in a direction nearly due east, and then bends northeastward across the Lanes Creek and Freedom quadrangles. It cuts the trend of the successive ranges at approximately right angles and thus affords a general view of the geologic structure from the Blackfoot lava field on the west to Star Valley on the east. In Chamberlin's studies the lines of the cross sections were selected and the field measurements made with the definite objective of using the data for the determination of the amounts of crustal shortening and thickening. In the present study, however, the field work was conducted on a more general plan and without the specific intention of using the measurements thus obtained for the determination of crustal shortening. Fortunately the observations applicable to the line K–K''' are fairly numerous, and the geologic structure as portrayed is probably correct in its broader outlines, though more detailed investigation might necessitate minor changes.

CONDITIONS AFFECTING MEASUREMENT

The presence of great overthrust faults in the section measured makes the final result uncertain, because it is impossible to tell how much shortening to allow for these faults. An idea of the shortening produced by the folding alone may be gained, however, and this result may then be modified by an allowance for the overthrusts. Several normal faults, which tend to counteract the compression, appear in the structure section, but their effects are doubtless relatively negligible.

In general the measurements were made upon fairly competent strata that come to the surface here and there. For the western half the Rex chert was selected. For the eastern half the Stump sandstone was chiefly employed, but the Higham grit, Peterson

[67] Chamberlin, R. T., The Appalachian folds of central Pennsylvania: Jour. Geology, vol. 18, pp. 228-251, 1910; The building of the Colorado Rockies: Jour. Geology, vol. 27, pp. 145-164, 225-251, 1919.

limestone, and beds of the Wayan formation were used in some places. There was no road or railroad to which the measurements could be referred, so that it was thought best to use sea level as the reference plane, although this lies generally 6,000 feet or more below the present surface. Chamberlin, following Van Hise,[68] considers various conditions that affect measurements of this sort. In view of the uncertainties introduced by the thrust faulting and the complexities of the structure in the eastern part of the section, it has not seemed worth while to consider any further refinements beyond the measurements themselves and the simple computations based upon them.

THE MEASUREMENTS AND THEIR INTERPRETATION

By means of a fine, soft wire, applied directly to the middle portion of the formation measured, the lengths of the respective portions of the section before folding were obtained. As the western part of the section, nearly half the total length, was measured in the Rex chert, the computations for this part were made separately from those of the rest of the section.

For measuring the crustal thickening produced by the folding it was necessary to restore the structure as it might have been had no erosion occurred. This restoration has been done in a tentative way as shown in Figure 45. One of the questions to be considered in this restoration was the former areal extent of the Jurassic and Cretaceous strata. The Jurassic beds, up to and including a great thickness of the Twin Creek, are exposed in the Fort Hall Indian Reservation to the west, so there is little doubt that at least these formations formerly extended completely over the folded area to be measured. The Preuss and Stump sandstones and the Cretaceous formations, however, have not been recognized west of the limits indicated upon the maps that accompany this paper. The great thickness of these formations, especially those of the Cretaceous, makes it probable that they formerly continued farther west, though the Cretaceous area of deposition may not have extended very far in that direction. The preserved Cretaceous beds are intensely folded and faulted and lie in front of the Bannock overthrust, which has a postulated minimum horizontal displacement of 12 miles. These beds may therefore be reasonably expected to have once covered the area measured. The restoration of the structure is based on this assumption.

The portion of the section marked "AB" in Figure 45 has a dip length of 17.9 miles and an actual length of 14 miles. Hence the shortening of this part produced by folding alone is 3.9 miles. The remainder of the section, marked "BC," has a dip length of

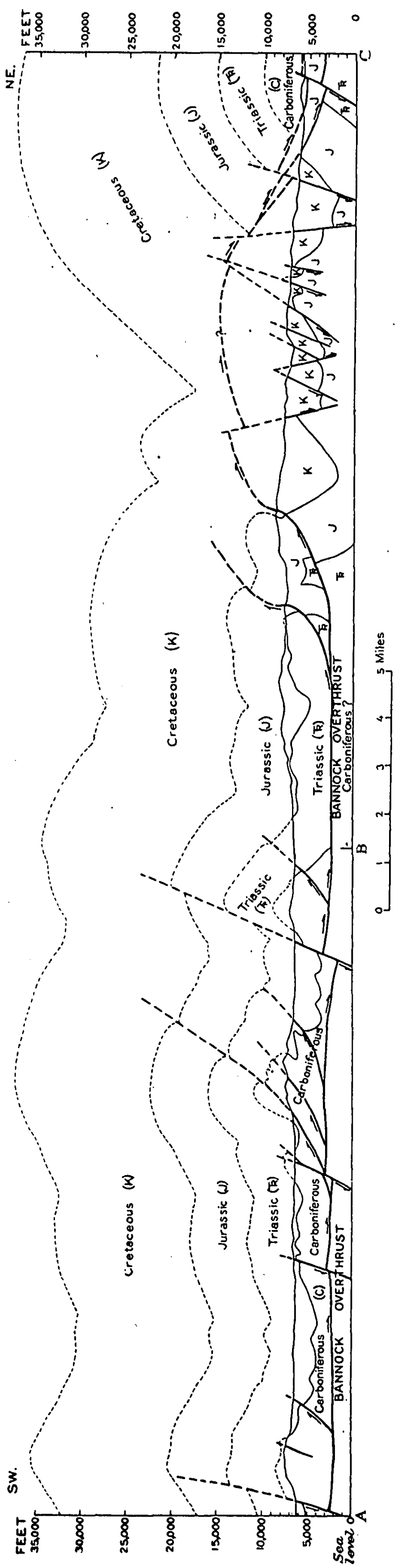

FIGURE 45.—Diagram showing a restoration of structure along the line K-K‴. (See pl. 11)

[68] Van Hise, C. R., Estimates and causes of crustal shortening: Jour. Geology vol. 6, pp. 10–64, 1898.

21.1 miles and an actual length of 16.6 miles, a shortening of 4.5 miles. The entire section, 39 miles long, has been compressed by folding to 30.6 miles. The actual shortening by this process is 8.4 miles or 21.5 per cent of the original length. If the minimum horizontal displacement produced by the Bannock overthrust be added to this shortening the total shortening by both folding and overthrusting, disregarding the minor breaks, would be 20.4 miles or 52.3 per cent of the original length.

The average restored height of the top of the Cretaceous beds above sea level is 6.7 miles for the western part and 5.7 miles for the remainder of the section; the average height for the entire section is 6.1 miles. By using the formula $\frac{c}{l}=\frac{h}{d}$, where c represents the amount of linear compression, l the actual length, h the height of the folded mass above the reference plane, and d the depth of the folded mass below the reference plane, we derive the following equations:

$$\frac{3.9}{14.0}=\frac{6.7}{d}, \text{ where } d=24.1;$$

$$\frac{4.5}{16.6}=\frac{5.7}{d}, \text{ where } d=21.1;$$

$$\frac{8.4}{30.6}=\frac{6.1}{d}, \text{ where } d=22.2.$$

These results represent respectively the depths below sea level of the folded mass for the western part, the eastern part, and the measured area as a whole.

If the minimum displacement produced by the Bannock overthrust is added to the effect of folding the value of d for the entire area measured would be 9.1 miles instead of 22.2 miles.

Van Hise [69] places the maximum depth of the zone of flowage for the strongest rocks at 10,000 to 12,000 meters, equivalent to 6.2 to 7.4 miles. Willis,[70] on the basis of experiments by Adams and Bancroft, thinks that this depth may be as great as 40 miles, but the smaller figure seems to accord better with geologic evidence. The average altitude of the present surface in the western part of the section is 1.3 miles; the average for the eastern part is 1.35 miles and for the whole section 1.33 miles. If these figures are subtracted from the restored heights given above, the results are 5.4 miles for the western half, 4.35 miles for the eastern half, and 4.8 miles for the whole section. These figures, which represent the depth of the present surface below the restored surface, fall well above the depth of the zone of flowage as given by Van Hise and indicate that the visible structures were developed considerably above that zone. That this is true is attested by the general absence of regional metamorphism throughout the district.

[69] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, pp. 189–190, 1904.
[70] Willis, Bailey, Discoidal structure in the lithosphere: Geol. Soc. America Bull., vol. 31, pp. 247–302, 1920.

If the average altitude of the present surface is added to the figures obtained above for the depth of folding and compression below sea level, the average results are 23.53 miles, if only folding is considered, or 10.43 miles if both folding and overthrusting are taken into account. In either event the lower part of the compressed mass should fall within the zone of flowage and the deeper structures should be metamorphosed. On the basis of the figures given above, further erosion amounting to 0.8 mile or more will be necessary before the average depth of the metamorphosed portions is reached.

The restoration indicates that the western part of the area has anticlinorial structure, whereas the eastern part has synclinorial structure. On the basis of the above computations the depth affected beneath the anticlinorium is a little greater than that beneath the synclinorium. The foregoing considerations tend to show that, according to Chamberlin's classification, the mountains in southeastern Idaho, as well as those in northwestern Montana and Alberta, belong to the thin-shelled type.

The principal folding, as previously explained, occurred before the overthrust faulting. The folding, if considered alone, seems to have affected deeper portions of the crust than it did if both folding and overthrusting are taken into account. These data suggest that in the earlier stages of compression the earth's crust was more deeply affected than at later stages. In other words, the zone of compression as it became more intense migrated outward toward the surface.

MAJOR AND MINOR FOLDS

In Chapter V the successive mountain ranges in southeastern Idaho are named and described and some of the folds are shown to exceed 55 miles in length and 3 miles in breadth. Each fold as viewed in the field seems to be a relatively large and independent structural feature, though many smaller folds are present. The restoration given in Figure 45 shows that the large folds in turn are members of still larger structural features and that the region traversed by the structure section K–K''' contains the greater part of two such folds, an anticline and a syncline, each of which is approximately 15 miles wide. The size of these major folds affords another means of comparison of the intensity of compression in different regions where mountain building has occurred. Thus in the island of Anglesea, whose highly complex geology has been studied in great detail by Greenly,[71] the accessible part of the Holyhead recumbent fold is said to have a real horizontal amplitude of about 60 miles. Great thrust faults are also present. It is apparent that in Anglesea the compressive forces were more intense than in southeastern Idaho.

[71] Greenly, Edward, The geology of Anglesea: Geol. Survey Great Britain Mem., p. 181, 1919.

COMPARISON WITH THE ALPS

For the Alps Heim [72] shows that the entire crustal shortening is between 200 and 300 kilometers. As the Alps are now only 120 to 150 kilometers wide, their entire breadth before folding must have been two or three times greater. He estimates the depth of folding beneath the highest Alpine anticline as between 35 and 40 kilometers, equivalent to 22 to 25 miles. This is somewhat more than twice the figure given above for southeastern Idaho, when both folding and overthrusting are considered. Igneous and metamorphic rocks are found at many places in the Alps. This is in accord with the relatively greater depth affected by the folding. Heim notes that in the Alps the depth of folding of any particular layer reaches many more than tenfold the altitude of its highest point.

MAXIMUM FORMER ELEVATION OF MOUNTAINS

The restoration given in Figure 45 shows that theoretically the altitudes attained by the arched Cretaceous beds may have exceeded 35,000 feet or 6.6 miles. Practically such altitudes were in all probability never reached, for erosion went hand in hand with mountain building, though at a slower rate. When deformation ceased erosion continued its destructive work and has never stopped entirely, though its rate of activity has varied from time to time. In Chapter II it is shown that, since the major disturbances that produced the complex structures now seen in the mountains, several other disturbances which have affected the rate of erosion have occurred. The erosional history of the region is therefore complex. There is little reason to doubt that the mountains in southeastern Idaho may once have been considerably higher than now. The coarseness of the Eocene conglomerates bears witness to the existence of steep grades after the post-Cretaceous epoch of mountain building. The breadth of the zone of overthrusting produced by the Bannock overthrust and the general apparent continuity of the upper block suggest that at the time this great fracture occurred the load above the thrust plane was considerably greater than now and that the mountains were correspondingly higher. There seems, however, to be at present no measure by which any accurate idea of the former altitude of the mountains may be obtained.

On the other hand, some measure of the amount of erosion might be gained by considering the volume and distribution of the Tertiary and Quaternary sediments. The quantity of these sediments is known to be large and they are widely distributed, but no adequate study of the problem from this viewpoint has yet been made.

[72] Heim, Albert, op. cit., Band 2, pp. 51-52.

TENSION FAULTING

GENERAL FEATURES

The occurrence of normal faulting in the region here discussed with the production of horst and graben structure has been described in Chapter V. Normal faulting, which is characterized by the fact that the affected strata occupy more space than they did before the faulting, has been widely recognized throughout the world and has been generally ascribed to tensional stresses within the earth's crust. When it occurs in regions that have undergone folding it commonly marks a late stage of that deformation or perhaps an altogether later structural epoch. The folded rocks have in large measure been compressed beyond the limits of their elasticity, but some elasticity remains, which tends to make the rocks resume their former positions and thus creates a strain, which, in turn, is relieved by normal faulting. Similarly rocks that lie behind regions where folding has taken place have been stretched, so that they too seek relief from tension in the same manner. Such in general are the current views regarding the origin of normal faults in relation to folded chains.

NORMAL FAULTS ASCRIBED TO COMPRESSION

Normal faults, as commonly illustrated in text books, have relatively steep inclination and reverse faults a more gentle dip, but studies such as those of Peach, Horne, and others in the northwest highlands of Scotland, have shown that reverse faults may be nearly vertical. Years ago Suess [73] recognized a type of thrust fault in which horizontal thrusts take place on vertical or nearly vertical planes and approximately at right angles with the strike of the folds. These he calls "flaws" or "blätter." He notes that such faults may be metalliferous at some places, whereas overthrusts are more rarely so. The discovery in increasing numbers of thrust faults with steeply inclined planes and of normal faults with gentler dips has made the distinction between the two types of faults more and more difficult. Some geologists have even gone so far as practically to deny the existence of normal faults and to ascribe all such fractures to compression. Thus Hobbs [74] ascribes the block mountain structure of the West, which has been a classic example of normal faulting, to compressional rather than tensional conditions. Kober and Heim also consider such features as the result of compression rather than of tension.

HORST AND GRABEN STRUCTURE

The terms horst and graben were employed by Suess [75] to designate blocks of the earth's crust which had become separated from each other by deep ten-

[73] Suess, Eduard, The face of the earth, translated by H. B. C. Sollas, vol. 1, pp. 120-121, Oxford, 1904.
[74] Hobbs, W. H., Earth evolution and its facial expression, pp. 105-107, 177, 1921.
[75] Suess, Eduard, op. cit., pp. 126-133.

sional fractures and which had subsided unevenly, the horsts representing the relatively higher blocks and the grabens the lower blocks. The classic example has been the Rhine Valley graben with the Vosges Mountains and the Schwarzwald as adjacent horsts. More recently Kober,[76] who cites Suess's interpretation, has undertaken to show that these are compressional features. He finds overthrust faulting in the vicinity of the graben and an actual overriding of the horsts upon the graben. He regards the Rhine graben as a summit break in a great anticline and suggests a similar origin for the well-known rift valley in Africa. Kober ascribes the horst and graben structure, which predominates in Germany, to the irregular elevation of an old peneplained mountain chain, which, by renewed undulation, due to contraction of the earth's crust, has been broken into blocks. The height of the blocks is not equal and not very great; their borders are broken and overthrust; and the higher uprising blocks tend to overspring the deeper-lying basins and troughs. Kober points out that these structural features are very young, that the movements are still in progress, and that the superficial shoving together of the horsts may in time go so far as to lead to the overriding of one by another. Thus the intervening graben break might become an overthrust.

DISCUSSION OF THE DIFFERENT THEORIES

The activity of tremendous compressive forces in the earth's crust is unquestioned, but it does not follow that all fault phenomena should be ascribed directly to this cause, although compression may indeed account for more of them than was formerly supposed. In many faults the relationships of the adjacent blocks are such that they are more reasonably explained by tension than by compression. Faults are favorite places for the migration of mineralizing solutions and vapors, and they are closely related to ore deposition. Compression, which tends to close and seal such fractures, is less favorable for these activities than tension. The deformative movements in the earth's crust are periodic and rhythmical rather than continuous, and the deformation takes place only after the slow accumulation of compressive stress. When the crust yields, as previously explained, the resulting reduction in volume may be greater than is needed to restore equilibrium, so that the strained mass will tend to recover its equilibrium by tension faulting. This explanation seems particularly well adapted to account for the great outpourings of basalt in the region of Snake and Columbia Rivers. Compressional fractures would appear to offer less favorable channels for the extrusion of basalt than tensional fractures. Kober notes the association of igneous extrusions with horst and graben structures, but considers it as confirmatory evidence for his hypothesis. Willis[77] in his discussion of discoidal structure shows that the zones of foliation produced in conjunction with this structure would be favorable places for the migration or extrusion of igneous rocks.

No extended discussion of Kober's view may be undertaken here, but the studies thus far made in southeastern Idaho seem to have brought out definite evidence unfavorable to it. The Meadow Creek graben is bounded by horsts that contain folded structures, but no tendency of either horst to override the graben has been recognized. Both the horsts and the intervening graben have been cut by transverse faults in such manner that in the area between these faults the distance between the horsts has been increased. (See fig. 20.) Had these faults and the boundary faults of the horsts been overthrusts this distance should have been diminished rather than increased.

In general there seems no good reason for abandoning the idea that tension faults do exist and that they may play a notable part in mountain structure. The current view that tensional faulting serves as a method of relief for overstrained or overcompressed structural features is believed to be well founded.

BUILDING OF THE NORTHERN ROCKY MOUNTAINS

GENERAL ASPECTS OF THE PROBLEM

Any intimate study of a mountain region leads inevitably to the consideration of the mode of origin of the mountains. It is evident from the folding and overthrusting of the strata that tremendous tangential pressures have been active. The general elevation also of the mountains, as compared with neighboring regions, and the common presence among the mountains of sedimentary rocks that were obviously formed beneath the sea together indicate that extensive vertical movements of some sort have taken place. However, when inquiry is made regarding the nature and mode of operation of the forces that have produced the observed results, the student is confronted at every turn with problems that fascinate him the more they baffle his attempts at solution.

The mountains of southeastern Idaho are a part of the northern as distinguished from the southern Rocky Mountains (in Colorado and the region to the south), which appear to have been formed in a somewhat different manner. The more local conditions attending their origin have been mentioned in the Chapter V. It is proposed to consider here some of the broader phases of mountain building and their bearing on the origin of the northern Rockies.

The problems regarding the origin of mountains have attracted the attention of students of geology since the early days of the science and an extensive literature has accumulated on the subject. Con-

[76] Kober, Leopold, Der Bau der Erde, pp. 50-56, Berlin, 1921.

[77] Willis, Bailey, op. cit.

tributions have been made both by American and by foreign (chiefly European) geologists, but the work of the European geologists has been more voluminous, partly because the Alps, with their wonderful structure and scenery, not to mention other mountains, have been relatively more accessible to Europeans than the mountains of America, particularly the Rocky Mountains, have been to American geologists. In the present study it has not been practicable to make a comprehensive review of this literature, but enough has probably been done to bring out modern trends of thought on the problems of mountain building and on the still broader problems of the formation of continents and of ocean basins.

CONTRASTED VIEWS ON CRUSTAL MOVEMENTS

American and European ideas regarding the greater movements of the earth's crust may be considered as separate schools of thought. One of the generally accepted tenets of American geology is the idea of the relative permanence of the continental masses and of the ocean basins. Some modifications of the existing outlines of these features are conceded to account for structural or faunal relationships that seem to require the former extension or connection of continental masses, but these concessions are limited to the barest minimum requirements. Two other tenets of American geology that have a bearing upon the one just mentioned and upon mountain building are that the ocean basins are generally underlain by heavier rocks than those which underlie the continents and that with rare exceptions rocks that correspond with those that make up the present abyssal deposits of the oceans are absent from the lands.

European geologists, on the other hand, are inclining more and more to conceptions of paleogeography that involve radical departures from the present conditions. For example, Kober [78] cites Haug as postulating a great continental land mass for the Pacific in Mesozoic time, a postulate which he accepts himself in modified form. He thinks that it is not proved that the oceans are really underlain by heavier parts of the earth's crust than are the continental masses. He believes that there is no positive value in measurements of gravity; that these are controlled by local conditions. He considers it a fundamental proposition that the floor of the oceans is composed of the same materials as the continental masses and that the earth's crust is a unit. With regard to abyssal deposits Kober [79] states that radiolarian ooze is a type of such rocks. Radiolarian cherts, which are known at many places on the continents and may be presumed to correspond with radiolarian oozes, have not been considered by American geologists as representative of marine abyssal deposits.

[78] Kober, Leopold, Der Bau der Erde, pp. 225-226, 245, Berlin, 1921.
[79] Idem, p. 34.

Kober [80] believes that the Mediterranean region, with the Alps on the north and the mountains of Africa on the south, represents a sea underlain by a geosyncline once as wide as the present north Atlantic Ocean, which by contraction of the earth has been compressed to its present relatively narrow breadth. Wegener, who is cited by Kober,[81] believes that continental masses have become separated and driven apart and that rifts like that of eastern Africa are early stages in the process. Similar ideas were advanced some years ago by Taylor,[82] and more recently by Daly,[82a] but few American geologists are inclined to attribute to the earth's crust so high a degree of mobility. In general, American geologists are far more conservative than European geologists in their views relating to the earlier arrangements of continents and oceans and to the mobility of the earth's crust.

ISOSTASY AND ITS BEARING

The crust of the earth has long been recognized as in a state of approximate equilibrium with respect to gravity.[83] Although earlier suggestions and statements of this principle had been made, Dutton [84] in 1889 applied to it the name isostasy, and it is with his name that the principle has become chiefly associated. According to isostatic theory the mountains and other more elevated portions of the earth's crust, which have relatively less density, and the ocean basins and lower portions of the crust, which have relatively greater density, are supported and kept in approximate balance by a yielding mass below, much as blocks of unequal weight and size may be floated in a basin of water. Transfer of material from higher to lower areas on the surface by erosion or otherwise is compensated below by transfer of material in the opposite direction. The depth at which this compensation takes place has been variously estimated by geodesists, but recent figures by Bowie, which have been independently confirmed by Washington,[85] indicate that it is about 60 kilometers (37.28 miles). Still more recent figures by Bowie,[86] however, place this depth at 96 kilometers (60 miles). Earlier work by Hayford had placed this depth at 122 kilometers (75.64 miles).[87]

[80] Idem, pp. 143, 144.
[81] Idem, p. 55. See also Wegener, A., Die Entstehung der Kontinente und Ozeane, 3d ed., Braunschweig, 1922. Translated by J. G. A. Skerl (The origin of continents and oceans), London, 1924.
[82] Taylor, F. B., The bearing of the Tertiary mountain belt on the origin of the earth's plan: Geol. Soc. America Bull., vol. 21, pp. 179-226, 1910.
[82a] Daly, R. A., Our mobile earth, 322 pp., 187 ills., New York, Scribners, 1926.
[83] Putnam, G. R., Condition of the earth's crust and the earlier American gravity observations: Geol. Soc. America Bull., vol. 33, pp. 287-302, 1922.
[84] Dutton, C. E., On some of the greater problems of physical geology: Philos. Soc. Washington Bull., vol. 11, pp. 51-64, 1889.
[85] Washington, H. S., Isostasy and rock density: Geol. Soc. America Bull., vol. 33, pp. 403-409, 1922.
[86] Bowie, William, Isostatic investigations and data for gravity stations in the United States established since 1915: U. S. Coast and Geodetic Survey Special Pub. 99, p. 22, 1924.
[87] Cited by Gilbert, G. K., Interpretation of anomalies of gravity: U. S. Geol. Survey Prof. Paper 85, p. 29, 1914.

Geodesists have investigated the anomalies or departures from normal gravity at many places in the United States and in some other parts of the world and have come to the conclusion, as stated by Bowie,[88] that isostatic compensation may take place for areas as small as 1 square degree at the Equator, or about 70 miles square. This idea involves a relatively high degree of mobility in the outer portion of the earth's shell, as well as a condition at the depth of isostatic compensation akin to that of hydrostatic balance.

Geologists, on the other hand, are inclined to favor a much higher degree of rigidity for the outer part of the earth's shell, though they admit the validity of the principle of isostasy and agree in general that a less rigid zone, corresponding with the zone of compensation, is necessitated by the distribution of the continental masses and ocean basins and of some of the smaller earth features. Thus Gilbert[89] in 1890 stated, as a result of his studies on Lake Bonneville, that

> Mountains, mountain ranges, and valleys * * * exist generally in virtue of the rigidity of the earth's crust; continents * * * and ocean basins exist in virtue of isostatic equilibrium in a crust heterogeneous as to density.

Barrell[90] in 1914, after an exhaustive study of both geologic and geodetic evidence, concluded that certain parts of the earth's outer crust can resist for considerable periods vertical stresses at least equivalent to the weight in air of 10,000 to 25,000 cubic miles of rock in lenslike forms spread over areas of 40,000 to 75,000 square miles and reaching thicknesses in air of 4,000 to 5,000 feet over considerable areas. He did, however, recognize the existence beneath the outer shell of a zone of weakness, to which he gave the name "asthenosphere," and cited Schweydar, who showed from mathematical analysis of the measurements of tides in the crust that they are in accord with the assumption of the existence of a slightly plastic zone about 600 kilometers thick beneath a more rigid crust 120 kilometers thick. This assumption is in general accord with geodetic evidence. Barrell's conception of isostatic balance was that of a more or less approximate "flotational equilibrium."

On the basis of experiments by Adams and Bancroft with rocks under confining pressures, which demonstrate that pressure increases the internal friction and consequently the absolute strength of rocks, Willis[91] more recently concludes that pressure alone can not promote the mobility of rocks. High temperature in excess of the normal is required. Rocks are potentially crushed at a depth of about 40 miles, that is, the zone of flowage lies much deeper than was estimated by Van Hise. Willis emphasizes the fact that "the flow of solid rocks takes place either by recrystallization or by shearing and thus differs markedly from liquid flow." He shows that heat and pressure, "in constant and unrelaxing opposition, maintain the rock in a sensitive elastic state, such that it responds instantly by change of volume to any variation of pressure or temperature." He follows Gilbert's view, which "postulates isostatic equilibrium among large masses, but recognizes effective rigidity of the crust as the condition of support of smaller irregularities of the earth's surface."

On the other hand, Daly[92] argues plausibly for a substratum of basaltic glass at a depth of about 40 miles below the surface. This "substratum is slippery" and thus readily adapts itself to isostatic readjustments or even to the sliding of continents.

Geodesists have gone so far as to consider isostasy a sufficient and satisfactory cause of mountain-building. Thus Hayford[93] in 1911 concluded that the idrag produced by subcrustal flow during isostatic readjustments was sufficient to produce the folded structure observed in mountains. This opinion has been shown by Barrell[94] to be untenable. More recently Bowie[95] has argued that horizontal movements, such as those which result in folding and overthrusting, may be the accompaniment of vertical uplifts caused by isostatic readjustments. Much stress is laid upon changes in temperature and density induced in the rocks by these readjustments and upon the expansional and contractional effects of these agencies in relation to the elevation or subsidence of the affected areas.

Geologists, however, have generally been unwilling to accord a primary place in mountain building to isostasy although they admit that it may play a notable part and that it may, as shown by Willis,[96] exert a directive influence, when some other sufficiently powerful cause becomes operative.

The function of isostasy in earth movements has been well stated by Reid[97] as follows:

> The principle of isostasy is of great value. It bears some analogy to the principle of the conservation of energy in the physical sciences. It does not always tell us what earth movements will take place, but it tells us that these movements must be of such a character that the amount of matter underlying a given area of the earth's surface is never materially increased or decreased; and if there be a transfer of matter at the surface by erosion and deposition, by folding of the strata or by any other means, then there must be a corresponding subterranean transfer in the opposite direction.

[88] Bowie, William, Theory of isostasy—a geological problem: Geol. Soc. America Bull., vol. 33, p. 279, 1922.

[89] Gilbert, G. K., Strength of the earth's crust: Geol. Soc. America Bull., vol. 1, p. 25, 1890.

[90] Barrell, Joseph, The strength of the earth's crust: Jour. Geology, vol. 22, pp., 45-46, 655-683, 1914.

[91] Willis, Bailey, Discoidal structure of the lithosphere: Geol. Soc. America Bull. vol. 31, pp. 247-302, 1920.

[92] Daly, R. A., Our mobile earth, pp. 92, 100, 269, New York, 1926.

[93] Hayford, J. F., The relations of isostasy to geodesy, geophysics, and geology: Science, new ser., vol. 33, pp. 199-208, 1911.

[94] Barrell, Joseph, op. cit., pp. 674-680.

[95] Bowie, William, The relation of isostasy to uplift and subsidence: Am. Jour. Sci., 5th ser., vol. 2, pp. 1-20, 1921: Theory of isostasy; a geological problem: Geol. Soc. America Bull., vol. 33, pp. 280-286, 1922; Isostatic investigations and data for gravity stations in the United States established since 1915: U. S. Coast and Geodetic Survey Special Pub. 99, 1924.

[96] Willis, Bailey, op. cit.; see also The mechanics of Appalachian structure: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 280, 1893.

[97] Reid, H. F., Isostasy and earth movements: Geol. Soc. America Bull., vol. 33, p. 318, 1922.

PRIMARY CAUSE OF MOUNTAIN BUILDING UNKNOWN

The primary cause of mountain building is unknown. The hypothesis that underlies most geologic reasoning on mountain building is that of the contraction of the outer crustal portion of the earth by gravity to fit a cooling and consequently shrinking interior. The mountain chains and irregularities of the earth's surface have not inaptly been compared to the wrinkles in the skin of a drying apple. This hypothesis has been attacked on many sides by geologists and others, but it has never been successfully set aside, although it is recognized that cooling alone is probably inadequate to produce the required shrinkage, and that other causes such as crystallization, progressive condensation under gravitative influences; molecular and subatomic changes, redistribution of internal heat, and other agencies may contribute to produce the observed results. Gravitative readjustments take place periodically as a result of accumulating stresses rather than continuously. The origin of igneous magmas is closely interwoven with these readjustments and the movements or intrusions of these magmas play a significant part in the distribution of temperatures and in the application or localization of stresses within the earth's crust. The net result of these agencies, so far as mountain building is concerned, is to produce the compressive stresses that in turn produce the folding and overthrusting.

Objections to the hypothesis of contraction based upon the view that the earth solidified from a gaseous or liquid body have been ably stated by Chamberlin,[98] Adams,[99] however, shows that cooling of the earth under such circumstances is not controlled by convection, as stated by Chamberlin, and that temperatures at moderate depths are much lower than have often been supposed. This fact is favorable to the hypothesis of contraction. Adams[1] has kindly supplied the following statement on the matter:

> On the basis of the older notion of the age of the earth and of the amount of cooling it has undergone since solidification, the thermal contraction of the surface layers was clearly inadequate to account for mountain building. The newer developments, however, allow a different conclusion to be drawn. The age of the earth (about 2,000,000,000 years) is much greater than was previously thought. The temperature gradient at the surface has been maintained, in spite of the earth's age, by the heat given off by radioactive materials in the crust. The cooling has extended to much greater depth; the total integrated cooling in the outer layers is many times greater than it would be on the basis of the older (Kelvin) theory of cooling; and the resultant thermal contraction is sufficient, or nearly sufficient, to account for the observed crumpling of the earth's crust.

[98] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, 2d ed., pp. 559–562, 1905.

[99] Adams, L. H., Temperatures at moderate depths within the earth: Washington Acad. Sci. Jour., vol. 14, pp. 459–472, 1924.

[1] Adams, L. H., personal communication.

HYPOTHESES OF MOUNTAIN BUILDING

Suess years ago, in his great work entitled "The face of the earth," laid emphasis on the idea of the earth as a failing structure, in which large parts of the crust collapsed or subsided from time to time, causing movements of the strand line, with submergence or emergence of land areas, and incidentally giving rise to mountains. Although the dominant movements were those of subsidence, some of their components were tangential, producing folded mountain chains. The general direction of the folding was toward the greater areas of subsidence. As applied to North America this view would mean that the mountains of the West were folded toward the Pacific, but this proved not to agree with the geologic evidence, and Taylor's explanation[2] that the great eastward and northeastward overthrusts of the Rocky Mountain region are really underthrusts or reflex overthrusts, directed backward over the southwestern general crustal movement, was not convincing. In the last volume of his work, which appeared considerably later than the others, Suess made an exception of that part of the great Cordillera that lies south of British America and admitted that the direction of overthrusting in that region was away from the Pacific.

Chamberlin[3] has suggested a modified form of Suess's view in which the earth's crust may be regarded as composed of major and minor segments whose differential movements may give rise to movements that form continents, plateaus, or mountains. The great master segments are those beneath the oceans. He writes:

> If these segments be regarded as the great integers of body movement, two-thirds of them taking precedence in sinking and the other third in suffering distortion, it is easy to pass to the conception of subsegments, moving somewhat differently from the main segments, so as to aid in their adjustment to one another, and thus to the conception of plateaus and deeps. It is easy also to pass to the conception of mutual crowding and crumpling at the edges of these segments, accompanied by fracture and slipping. These conceptions perhaps represent the true relations between the massive movements of the abysmal and continental segments, as well as the less massive plateau-forming movements and the mountain-forming distortions. The mountains and plateaus are probably the incidental results of the great abysmal and continental readjustments.

This view has the advantage that it does not require the transmission of thrusts for great distances, as from the Pacific Ocean to the eastern ranges of the Rocky Mountains, but permits more local readjustments.

[2] Taylor, F. B., op. cit.

[3] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, 2d ed., pp. 542–549, New York, 1905.

Heim [4] divides the movements of the earth's crust into primary and secondary dislocations. The first are created by the weight of the entire earth's crust, which must adapt itself to the cooling and shrinking interior. These dislocations are divided into two broad groups—those which reduce the earth's circumference through horizontal, tangential pressure and those which produce a shortening of the earth's radius by down sinking. Secondary dislocations are produced by the weight of individual mountains, whether already formed or in the course of development. These dislocations are chiefly regional. Both primary and secondary types of dislocation are operative in the building of a great mountain range. Heim thinks that no tension is involved in the process but only compression. He thinks that the tangential pressure is 1,000 times as great as the crushing strength of granite and is thus strong enough to crush every rock, or at depth to render all rocks plastic to deformation. This plasticity has a notable bearing on isostasy.

According to Heim, the gravity defect in the Alps is at a maximum under the line where the "decke" folds of relatively lighter rocks were originally piled highest. It is normal at the south foot of the Schwarzwald to the north and in excess at the top of the Schwarzwald. Similarly near Locarno, at the south, there is another area where gravity is in excess. This is the belt where the roots of the folds that now form the "decke" are supposed to lie and where basic eruptives are now heaped up. The surface of normal gravity lies unsymmetrically beneath the Alps, its gentler and longer slope passing upward toward the north. The folded complex of the Alps is thus believed to float with its deeper parts concealed in the earth's crust much as an iceberg floats in the sea. This attitude is produced by sinking in consequence of the overload due to the compression of the crustal mass. So it happens that the Alps are not five to ten times higher than their present altitude.

Kober [5] declares that all manifestations of earth structure indicate the contraction of the earth. With Suess he ascribes all tectonic activity to gravitative forces. He distinguishes two main types of tectonic features, the old rigid table-lands—so rigid that they are not overcome by later mountain-building processes—and orogenetic zones, in which mountain chains have been formed. The orogenetic zones, which have developed from geosynclines, pass as relatively narrower bands between the rigid masses, or mobile zones, comparable to hinges, on which the rigid masses shove against each other. The great orogenetic zones of the earth are sharply distinguished from each other—the Mesozoic from the Paleozoic, and these from the Proterozoic, especially from the Archean. Within the same orogenetic zone the different parts are not of the same age. Thus mountain building in any orogenetic zone is not accomplished by a single act but is a continuous process, especially within a given period, such as the Paleozoic or Cenozoic. Kober pictures the geosynclines not as narrow, flat, sea canals, as suggested by Haug's maps, but as great, roomy seas, actual oceans, in which regional phenomena represented by all types of sedimentation from shallow water to deep-sea deposits may take place.

From a study of the region about the Mediterranean Kober works out a plan of mountain building that he applies to other parts of the world, including western North America, which he considers a typical illustration. Briefly his idea is that under gravitative influences the rigid masses on either side of a geosyncline approach each other, thereby compressing the geosyncline. The relatively weak rocks of the geosyncline are gradually squeezed out in a mass that is roughly fan-shaped in cross section, so that they tend, to overthrust the rigid masses. The movement begins in the center of the geosyncline and works progressively outward toward each side, so that border chains, in which the directions of overfolding and overthrusting are outward, are formed on either side of the central mass. These border chains constitute separate major subdivisions or "stems." The outward development of the stems involves successively younger rocks. If the compression is very intense the central mass may be squeezed to a very narrow area or even faulted out, and the two stems may be distinguished only by their respective attitudes, but if the compression is not so great there may be a zone of varying width with intermediate mountains between the stems. These intermediate mountains include the roots from which the piled-up folds, which now constitute the "decke," have been torn. They also include igneous intrusive or extrusive rocks which have been forced up during isostatic readjustments. When the folding in a geosyncline has ceased the resulting mass may be so rigid that it may become incorporated in the original rigid masses, which are thereby enlarged, or it may be involved in geosynclines that were formed later, with their subsequent mountain-building disturbances.

According to Kober's hypothesis,[6] the continental masses have grown by the joining together of the old Archean masses and, to a certain extent, of later tectonic units by mountain building. From the geosynclines orogenetic zones are developed. A great mass accumulates in the mountain chains, which overloads the orogenetic zones. These zones sink into the depths, carrying with them parts of the continental masses. Thus new geosynclines and new ocean floors originate. The present oceans lie over Mesozoic geosynclines, only small portions of which have become

[4] Heim, Albert, Geologie der Schweiz, Band 2, 1te. Hälfte, pp. 52–56, Leipzig, 1921.

[5] Kober, Leopold, Der Bau der Erde, pp. 8, 9, 20–22, 45, 140–170, Berlin, 1921.

[6] Kober, Leopold, op. cit., pp. 297–298.

incorporated as land with their accompanying tablelands. Few also of the Paleozoic zones have been preserved. Most of them began new geosynclinal cycles in the Mesozoic. The constancy of an ocean is doubtless great. It can be said for all oceans to a certain degree that they have become geosynclines again upon a floor of older geosynclines, which were once squeezed out. They are thus permanent as geosynclines but not directly so as oceans.

In applying his hypothesis to North America Kober [7] thinks that the Rocky Mountains, the Pacific coast ranges, and the interior plateaus correspond respectively with the two stems and intermediate mountains of an orogenetic zone. He considers, however, that the Rocky Mountains east of the Wasatch Range and south of the Yellowstone Park belong to a tectonic cycle that is earlier than that of the Mesozoic-Tertiary, and he calls them the pre-Cordillera. These mountains, with the Colorado plateaus, he thinks served as part of the foreland upon which the Rocky Mountain stem of the Mesozoic-Tertiary geosyncline impinged. The Pacific stem, the present Coast Ranges, was formed supposedly against a foreland that is now sunken beneath the Pacific Ocean. Kober, however, thinks that the mechanics of mountain building demands the presence of forelands of approximately equal elevation on both sides of a developing orogenetic zone. He therefore believes that during the building of the mountains a land mass was present where the Pacific now lies; that this Pacific foreland has sunk in comparatively recent times; and that the Pacific Ocean is therefore young.

Hobbs [8] has formulated a hypothesis of mountain building that bears some superficial resemblance to Kober's, though the two differ fundamentally. According to Hobbs, the pressures that produce mountains are developed by the settling of great areas, chiefly the ocean basins. The intervening lands become compressed and underthrust with the development of underturned folds, whose shorter limbs face the depressed areas, and of underthrust faults whose planes dip away from these areas. With regard to the western mountainous highlands of the United States Hobbs postulates that the "Laramide Ocean" on the east side and the Pacific Ocean on the west settled at the time of the great Cretaceous-Tertiary deformation. The intervening lands became underthrust with the development of mountain ranges, which face respectively the Pacific and the site of the former "Laramide Ocean." In Quaternary time, he thinks, the area now represented by the Great Basin sank, causing additional underthrusts, which produced the Sierra Nevada on the west and the Wasatch Mountains on the east. The hypotheses of Kober and of Hobbs are illustrated in Figure 46.

[7] Kober, Leopold, op. cit., pp. 160-169.

[8] Hobbs, W. H., Earth evolution and its facial expression, pp. 119-134, New York, 1921.

Willis [9] has advanced a hypothesis of crustal deformation on the basis of a certain discoidal structure that he deduces from a study of the conditions of temperature and pressure within the earth's crust. He denies the possibility of anything like flotational isostatic equilibrium but thinks that deep-seated foliation oriented by isostatic stress may be developed. The readjustments of the heavier and lighter masses in the earth's crust under gravitative control are effected by rotational shearing movements along these planes of foliation, which also serve to direct the escape of lavas. He has made a plausibly favorable application of this hypothesis to the building of the Sierra Nevada and Coast Ranges.

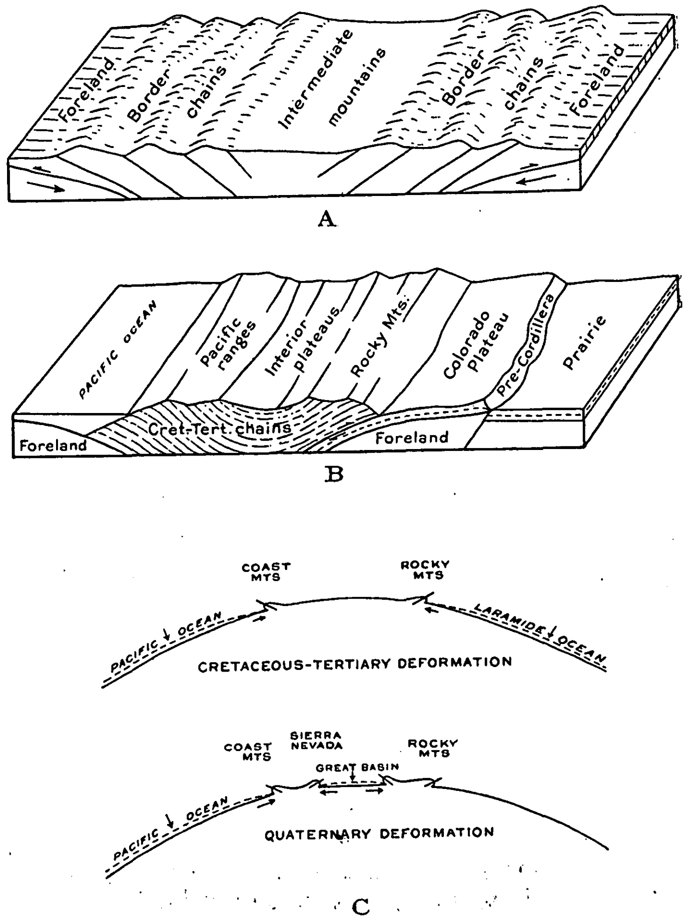

FIGURE 46.—Diagram illustrating hypotheses of mountain building by Kober (A, B) and by Hobbs (C)

Although Bowie [10] states that "the processes involved in the establishment or maintenance of isostatic equilibrium can not explain the formation of a mountain system or, in fact, any major change in elevation of the earth's crust," he does in effect argue that mountains are formed by the expansion of the material in the isostatic column of rock below through changes in density and temperature.

[9] Willis, Bailey, Discoidal structure in the lithosphere: Geol. Soc. America Bull., vol. 31, pp. 247-302, 1920.

[10] U. S. Coast and Geodetic Survey Special Pub. 99, pp. 1, 40-47, 1924.

Briefly stated Bowie's theory is that erosion of an elevated area disturbs isostatic equilibrium, which tends to be restored by the inflow of heavier material into the lower part of the isostatic column beneath. The additional heat brought into this column by the inflow of this deep-seated rock tends to make the column expand, thereby reducing its density, and thus produces elevation of the mountain mass together with such internal compression as is necessary to account for the obvious folding and overthrusting in the mountain mass. Subsequently, as the heat produced by the underflow and the internal crushing is dissipated, the mountain mass gradually contracts and subsides and may descend low enough to become a site of deposition Similarly the area that is receiving sediments from an eroded upland sinks, in part from loading and in part from other causes (possibly the contraction just alluded to), and experiences a rise in temperature as the isogeotherms gradually rise within the subsiding mass. With increasing temperature and decreasing density this mass gradually reverses its motion and begins to rise and in its turn is internally folded, crushed, or overthrust. It, too, would suffer erosion with elevation, would receive inflow in the lower part of its isostatic column, and would undergo the changes outlined above for an elevated mass. Thus the cycle of interchange of isostatic relationship might proceed indefinitely.

This process has recently been invoked by Lee [11] to explain the origin of the southern Rocky Mountains, where according to his view the mountains have been formed chiefly by vertical uplift.

The origin of folded and overthrust structures by internal compression resulting from changes in temperature and density in their relation to isogeotherms was suggested many years ago by Reade,[12] who used a different mechanism from that of isostatic adjustment. Although the importance of this process has been recognized as a contributing cause it has not hitherto been considered adequate to account for such intensely compressed regions as the Alps and Appalachians. It is not at all clear that the process in its current form of statement as an adjunct to isostatic adjustment can be made to account satisfactorily for these areas, especially as later studies of these regions indicate that earlier estimates of the degree of compression were far too small. For example Keith,[13] who cites numerous objections to isostatic adjustments as a primary cause of mountain building, remarks:

If, therefore, the Appalachians as a whole were shortened 40 per cent in a northwest-southeast direction, it is evident that the present width of 270 miles, plus 30 miles for probable extension under the Cretaceous, represents an original width of 500 miles and that the amount of shortening of the crust is thus 200 miles. This amount is more than three times as great as any previously stated, but it is believed by the author to be a conservative measure.

Keith favors batholithic intrusion as a cause for the folding of the Appalachians. Thus he states:

In summing up, the theory of batholithic intrusion seeks to explain the formation of the folded Appalachians by pressure from intrusions of magma. These furnished the heat and force required, were of adequate power and bulk, and accord remarkably with the varied phenomena of the system, both in space and in kind. * * * This theory relies only on natural processes whose effects are open to observation, and it calls for few conditions that are not known to have existed and on none that are unreasonable. [The driving force of this mechanism, as he conceives it, is gravity.] An excess pressure of gravity was transformed into lateral pressure through batholiths, whose magmas were practically in a hydrostatic condition; * * * this pressure built the mountains.

Reid [14] states that we do not know the cause of these great mountain-making movements, but he presents the following picture of the course of events leading to a folded mountain range, where geologic observations are combined with the principle of isostasy.

After the accumulation of sediments to a considerable thickness, forces compress and fold the strata. This necessarily increases the amount of matter in the compressed region and would naturally cause some elevation of the surface. On account of the disturbance of the isostatic equilibrium, forces are brought into play which cause the region to sink and drive out matter from below. When the equilibrium is reestablished the region would be slightly higher than before on account of the accumulation of the lighter surface rock, which lowers the average density of the mass. How great the actual elevation, due to compression, may be depends on the amount of compression and on the relation between the rates of compression and of readjustment of equilibrium. We do not know this relation, and, in the absence of observations of deflection and gravity during the time of compression, we can gain an idea of it only through geological observations which distinguish between folding and uplift. Finally, the uplift of the underlying mass raises the region into a true mountain range.

There is nothing in the principle of isostasy that militates against the coexistence of the expansion and consequent elevation and the folding, but geological observations show that the elevation, now existing in the cases cited above, has occurred at a distinctly later date than the folding. The interval between them has been long enough, in some cases, to allow a peneplanation of the surface; in the other cases depression to well below sea level has occurred and considerable thicknesses of sediments have been deposited in this interval.

What may be called the Taylor-Wegener hypothesis of continental drift has been receiving considerable attention from both European and American geologists in recent years, though American geologists have generally regarded it unfavorably. Briefly it provides for the formation of the present continents by assuming that large masses of the earth's crust composed of acidic rocks ("sial") have separated from a former larger mass of similar composition by drifting over a

[11] Lee, W. T., Building of the southern Rocky Mountains: Geol. Soc. America Bull., vol. 34, pp. 285–308, 1923.

[12] Reade, T. M., The origin of mountain ranges, 359 pp., 42 pls., London, 1886.

[13] Keith, Arthur, Outlines of Appalachian structure: Geol. Soc. America Bull., vol. 34, pp. 309–380, 1923.

[14] Reid, H. F., op. cit., pp. 318, 323–324.

solid, basic substratum ("sima").[15] But there is no sufficient explanation of the mechanism by which a drift of such proportions could be brought about. Joly [16] has contributed the idea of generation of heat through radioactive changes in the atoms by which the basic substratum (sima) becomes fluid at intervals of about thirty million years, thus greatly increasing the forces which tend to cause a locally differentiated westward drift of the outer crust. According to Joly alternations of fusion and resolidification are causally connected with the main world-wide epochs of diastrophism—"revolutions." Daly,[17] who has long argued for the existence of a substratum of basaltic glass, finds in this hypothesis an explanation for the origin both of continents and of mountain ranges, and he provides a mechanism for the process. He thinks that the continents have slid downhill by gravity like huge landslides. Each mountain chain represents a geosynclinal prism caught and folded at the foot of the slope down which the continental mass moved. The principal mechanism is continental doming on the one hand and geosynclinal accumulation and subsidence on the other. When

> horizontal pressure reaches a certain intensity and the geosynclinal prism of sediments has reached sufficient thickness the crust will break at the geosyncline. The dome is no longer firmly supported from the sides. Tension pulls are generated at and near the center of the dome. There the crust becomes torn apart. The crust of the dome is torn into blocks or plates of the sizes of the existing continents. These blocks tend to slide slowly toward the geosynclinal.

On the basis of field measurements in the Appalachians of Pennsylvania some years ago R. T. Chamberlin [18] has propounded a wedge theory for the formation of mountain ranges and of continents. The deformed mountain mass is found to have the shape of a triangular prism or wedge apexing downward beneath the middle portion of the folded belt. This idea he finds is supported both by experiment and by study of mountain ranges of the globe. The continental and suboceanic masses are treated as segments, the suboceanic masses being the larger and heavier. The principal source of the deforming forces is the rearrangement of material in the interior of the globe in favor of greater compactness and higher density. This should cause general shrinkage with resulting circumferential compressive stresses beneath both continental and oceanic areas. In the shrinking process all segments would sink. The master oceanic segments would squeeze the smaller and lighter continental segments between, so that they would be wedged upward. This theory has much in common with the segmental hypothesis of T. C. Chamberlin, to which reference has already been made. As applied to mountain chains it tends to produce symmetrical, marginal folded areas bounded by exterior, inward-dipping shear zones and a relatively undeformed intermediate area. A special application is made to those mountains, which seem to be unsymmetrical, in which the greatest effects of overthrusting appear on the inland side of the range. This result is attributed by R. T. Chamberlin to the fact that the mountain-built area is caught between an oceanic segment on one side and a continental segment on the other, and that the pressure of the oceanic segment tends to overbalance that of the other.

Willis [19] points out that in the course of geologic time the forces of compression would accumulate gradually and would have opportunity to be well distributed. Displacement would be only in the direction of least resistance. The underbody of the continent would be divided by shearing planes into rhomboidal prisms, which would override each other as the mass shortened horizontally. The direction of least resistance would be upward, and the effect would be to elevate a prism, producing at the surface a plateau or mountain range. He continues:

> The superficial effect of shearing in the deeper masses appears at the sides of the upthrust wedge in outward overthrusts. Since action and reaction are equal, such thrusts may develop symmetrically on both sides of a wedge-bottomed range, but in general, since notable horizontal displacement characterizes them, the overthrusts will exhibit the greater horizontal shift away from the active source. The downward extension of the plane of the overthrust would in such a case pass into the plane of the original shear, and the wedge-bottomed range would slide forward as a part of the overthrust block. This means that flat-lying thrusts of this type curve downward to a dip of about 50° and pass into the fundamental planes of dislocation. In applying the idea to Rocky Mountain structure and to other great horizontal displacements we fail, however, to get a sufficient horizontal component of movement from the possible vertical component. This difficulty has led me to incline to the view that the mechanics of shear and of intrusion of molten masses may have cooperated in producing the horizontal shifts, the former having divided the masses into blocks which could be displaced and the intrusions having shoved them aside.

In Thom's paper[20] on the structure in central Montana the suggestion is advanced that local buttresses caused by relatively minor structural features, developed as far back as Mesozoic or even Paleozoic time, may have influenced the nature of the Rocky Mountain front in that region. He thinks that the great thrust faults dissipated the intense compression, which would otherwise have affected the outer part of the earth's shell, but that the deeper part of the

[15] Wegener, A., Die Entstehung der Kontinente und Ozeane, Braunschweig 1922. Translation by J. G. A. Skerl, The origin of continents and oceans, London 1924. Discussion: Waterschoot van der Gracht, W. A. J. M. van, The problem of continental drift: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 1002–1003 1926.

[16] Joly, John, The surface history of the earth, Oxford, 1925.

[17] Daly, R. A., Our mobile earth, p. 268, New York, 1926.

[18] Chamberlin, R. T., The wedge theory of diastrophism; Jour. Geology, vol. 33 pp. 755–792, 1925.

[19] Willis, Bailey, Rocky Mountain structure: Jour. Geology, vol. 33, pp. 272–277, 1925.

[20] Thom, W. T., jr., The relation of deep-seated faults to the surface structural features of central Montana: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 1, pp. 1–13, 1923.

crust was subjected to sufficient stresses to produce differential movement of great blocks of the basement complex, which may or may not have been previously outlined by deep-seated faults. Faults below are shown to pass into folds above and to serve as channels for the upward passage of magma to form laccoliths.

DISCUSSION

The views outlined above deal with questions that are world-wide in their application, but they involve a vast amount of extrapolation and speculation, for detailed observations are confined to relatively few areas, and these are of no great size. Laboratory experiments, such as those of Willis, Cadell, Adams, and Van Ostrand (see Lee's paper cited above), shed much light on the mechanics of mountain building, but it may be questioned how far they are directly applicable to the earth. At least not too much significance should be attached to them. Their chief function should be to stimulate and direct geologic observation rather than to serve as proof for geologic theories.

It may be argued that if the structural details of a single group of mountains can be successfully worked out, a feat that seems to have been well-nigh accomplished for the Alps and the Jura Mountains, thanks to the long and arduous labors of the European geologists, the principles developed by such studies may be successfully applied throughout the world. There is no doubt much truth in such an argument, but caution is needed lest the application of the principle to distant fields should be made too confidently and lest the principles themselves become distorted in the using. Mountain building is a complex process that involves numerous variable features, many of which are known but some of which doubtless are as yet not even suspected; and it is closely linked with the problem of the formation of continents and of ocean basins.

The isostatic theories of Hayford and Bowie, the discoidal theory of Willis, and the tectonic theories of Suess, the Chamberlins, Kober, Hobbs, Daly, and others should be regarded merely as working hypotheses. The present task is to see how far they may be supported by geologic evidence and particularly how the evidence available for southeastern Idaho may bear upon them.

With regard to mountain building by isostasy alone Woodward [21] long ago pointed out that this is "an efficient cause if once set in motion, but how it is started and to what extent it is adequate remain to be determined." Subsequent studies by Hayford and others, supplemented by precise methematical deductions, have served only to confirm this conclusion.

The application of the principle of isostasy and of gravity measurements to the study of the Alps, as shown by Heim, has confirmed in a striking manner the conclusions of European geologists regarding the structure of the "decke" and has accounted in considerable measure for the distribution of igneous and metamorphic rocks. The distribution of anomalies of gravity and the down sinking of the folded mass of the Alps appear to be well explained by the conception of flotational isostasy. The discoidal hypothesis has not been tested upon these mountains as yet. The contraction of the earth is the assigned cause of the folding.

The work of Gilbert, Barrell, and others has established to the satisfaction of many geologists that the rigidity of the earth's crust is sufficient to sustain loads of considerable weight. With so minute a degree of compensation as postulated by Hayford and Bowie it is difficult to see how existing mountain ranges and continental masses could retain their form without overspreading adjacent lower areas.

On the other hand, it seems to the writer that Willis, though at the outset he disclaims any such intention, attaches too great significance to the experiments of Adams and Bancroft on the crushing strength of rock under confining pressures. These results are certainly conclusive so far as they go, but can they be fairly applied directly to the earth? These experiments are necessarily conducted with relatively small masses of rock that are essentially homogeneous, of uniform texture, and at ordinary temperatures. Practically none of these conditions hold for masses of rock in the earth's crust miles in thickness and of indefinite extent. The question arises, too, how rock under such conditions that it could respond "instantly by change of volume to any variation of pressure or temperature" could be distinguished in its practical behavior from rock in the "plastic" condition induced by heat and pressure, as postulated by Heim or Van Hise. Willis's figure, 40 miles for the depth of the zone of flowage, is based largely upon considerations of pressure alone. He makes some allowance for temperature by introducing after the figures the words "or less." Here again computations of the effects of pressure and of heat, on account of extrapolation, are suggestive rather than compelling. Possibly the effects of heat may be sufficient to offset the effects of pressure to a greater degree than the computations show, and the depth of the zone of flowage may not be much greater than the figures given by Van Hise. Under Willis's hypothesis metamorphic rocks would be formed at much greater depth than is customarily supposed and their exposure at the surface otherwise than by direct dislocation would require erosion far more prodigious than seems warranted by stratigraphic evidence.

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[21] Woodward, R. S., Mathematical theories of the earth; vice-presidential address to mathematical section of the American Association for the Advancement of Science: August, 1889; Smithsonian Ann. Rept., 1890, p. 196.

The ideas of Suess and of T. C. and R. T. Chamberlin seem to furnish a fairly satisfactory basis for the consideration of earth structure. There seems little reason to doubt that earth movements are relative but that their net result is to make the earth occupy smaller volume and that the major movements are downward with respect to the surface. With regard to the mobility of large areas of the earth's crust, probably a middle ground should be chosen between the more radical European and the more conservative American views. When world-wide relationships are studied with respect to the forms of continents, the distribution of floras and faunas, the development of great mountain systems, or of other features, alluring hypotheses present themselves. These hypotheses are useful as targets. They serve to develop criticism, to stimulate investigation, and to bring out facts which might otherwise lie hidden.

Such a hypothesis is Kober's structure of the earth. Few American geologists will agree with his broader conclusions regarding the structure of western North America or the former distribution of land areas in the Pacific, but he presents his arguments in a very interesting and plausible way. The general arrangement of western and eastern mountain chains with intervening plateaus and ranges presents a superficial agreement with his plan. Similarly Daly's version of the Wegener hypothesis is fascinating, but numerous objections to this hypothesis have been raised.[22]

The geologic history of southeastern Idaho shows tectonic disturbances at the close of the Mississippian and again at the close of the Pennsylvanian. In the southern Rocky Mountains there appears to have been actual mountain building during the Pennsylvanian epoch, followed by erosion, continental deposition, and peneplanation. This cycle of events would seem to be the justification for Kober's designation of the southern Rockies as the "pre-Cordillera." They were later covered by Cretaceous beds and involved in the Laramide revolution and subsequent crustal disturbances. Kober regards them as part of a "Paleozoic geosyncline," on which mountains were built and eroded and which subsequently was involved with the "Mesozoic geosyncline" in mountain-building activities. This picture is in a measure true, though on the whole this region has been more of a positive than a negative element. American geologists, though they recognize differences in mountain structure between the southern Rockies and other parts of the system, would hardly go so far as to exclude these mountains from the Rocky Mountain system and to assign them a different name.

The Rocky Mountains in Idaho and northward show eastward overturning and overthrusting, which accords with Kober's hypothesis, but the attitude of the folds in the Coast Ranges, which by hypothesis should be overturned westward, is not so clear. The structure sections studied by the writer, though they show intense folding and faulting, do not indicate a predominant direction of overturning or overthrusting. Moreover, the distribution of great igneous intrusions in the Coast Ranges is not very favorable for the hypothesis. It may be questioned, too, how far the interior plateaus and ranges accord with the conditions of his plan. A further objection is the disparity in age of folding in the two mountain systems.

With regard to former land areas in the Pacific the hypothesis is on very insecure ground. However, if the present height and extent of the continents is wholly exceptional in geologic history the present depth of the oceans may be also exceptional. Possibly the failure to find on the continents deposits now characteristic of the oceanic abysses may be due to the absence of such abysses in earlier geologic periods. After all, the hypothesis that the types of rock that underlie the ocean basins differ from those of the continents and are heavier rests on comparatively few actual data, aside from the obvious fact of the lower position of these areas with respect to sea level. The samples of rock collected and analyzed and the available measurements of gravity have been necessarily taken at scattered localities, largely volcanic islands, where the evidence gathered would be favorable to the hypothesis. Much information will doubtless ultimately be gained by gravity measurements at sea, such as those recently made by Dr. F. A. Veming Meinesz, of the Dutch Geodetic Commission. On the other hand, for the Atlantic and Indian Oceans at least, there is much evidence of the former greater extension of continental areas. For the Pacific Ocean this type of evidence is largely wanting.

The remarks about the Coast Ranges apply equally well to the hypothesis of Hobbs. Although the sea extended in Cretaceous time along the eastern front of the Rocky Mountains and even covered areas that are now included in the mountainous belt, this sea (the "Laramide Ocean" of Hobbs) was in no sense an ocean as the term is now understood. It was rather an epicontinental sea of relatively shallow water. This condition is clearly indicated by the nature of the deposits. The hypothesis that the Wasatch and Sierra Nevada are bounded by thrust faults inclined respectively east and west requires demonstration before it can be accepted.

Willis's discoidal hypothesis, though based on careful computations and plausibly presented, is dependent upon the validity of its fundamental assumptions. These assumptions have been shown to be extrapolations on a large scale from the results of experiments which may not be directly applicable to the earth. Although the preliminary test of this hypothesis with the Sierra Nevada and Coast Ranges

[22] See discussion, Continental drift meeting: Am. Assoc. Petroleum Geologists Bull. (to be published).

appears to Willis to have been successful, the conditions in the northern Rocky Mountains may prove less favorable to it and it may not be widely applicable.

Lee's idea of mountain formation seems to apply well to the southern Rockies, where overturned folds and overthrusting on a large scale seem to be absent, but it does not adequately explain the regions farther north where these tectonic features dominate the structure.

Keith's view of batholithic intrusion has much in its favor as far as such intrusion might act as an agent for localizing and applying mountain-building forces, though there is no direct evidence of the presence of such batholiths in southeastern Idaho during the Laramide epoch of mountain building. Farther northwest, however, in central Idaho, granitic batholiths have been recognized and assigned to this epoch.[23]

Reid makes a distinct separation between the folding of mountain ranges and their uplift to their present altitudes. He admits that some elevation may be produced by the folding, but he implies that because of the sinking of the folded mass required by isostatic compensation this elevation may have been comparatively little. Bowie, on the other hand, thinks that material supplied to growing mountains by isostatic transfer will, by its change in density, as the pressures under which it originally lay are gradually relieved by the erosion of overlying rock, maintain these mountains at a considerable height.

The Snowdrift peneplain (p. 14) may be taken to represent the surface to which the mountains of southeastern Idaho were reduced by erosion after the Laramide folding and after the sinking of the folded mass under isostatic conditions. This peneplain, which now stands 9,000 feet or 1.7 miles above sea level, probably affords a maximum measure of the amount of uplift which the folded area experienced in being elevated to its present position. If this amount is subtracted from the theoretical elevation, 6. 1 miles, as suggested by the restoration of the upper beds of the Cretaceous, there still remains a difference of 4.4 miles, which may be accorded to the folding alone. How much of this difference should be allowed for the erosion that prevented the mountains from attaining the full height to which the folding might otherwise have raised them can not be determined from present data. If it is assumed that this erosion consumed half or two-thirds of the folded mass the mountains might have reached altitudes from 1.5 to 2.2 miles. It therefore appears that folding of the strata, with due allowance for isostatic sinking, may produce mountains comparable in height to those of to-day. The later uplifts, which most of the higher ranges have experienced, represent separate mountain-building activities of perhaps another sort, but it is not necessary to infer from their presence that high mountains may not be formed by folding alone.

Under the Wegener hypothesis, as outlined by Daly, the continental mass of North America east of the Rocky Mountains is supposed to have slid westward against the Rocky Mountain geosyncline, which in turn must have been supported at the west by the Pacific element or Cascadia. In view of the general instability of the crust under the conditions of rupture postulated by the hypothesis it is a question how far the relatively small Pacific element could withstand the impact of the sliding continent, especially if the momentum of that mass was acquired by motion from an area of rupture so far away as the mid-Atlantic ridge, which is the site proposed by Daly. It may be further questioned if the intensity of deformation in the geosyncline is sufficient to meet expectations under the assumed conditions. Other objections have already been cited and need not be detailed here.[24]

The segmental hypothesis of T. C. Chamberlin and the wedge hypothesis of R. T. Chamberlin seem to explain the facts better. The conception of larger and smaller segments of the earth's crust settling unevenly under the force of gravity seems to provide a satisfactory mechanism for the distribution of compressive stresses within the earth's crust and for the localization of the observed folding and overthrusting. Willis's comments with respect to igneous rocks may be significant. There is at present no means of telling whether the big thrust planes which, like the Bannock overthrust, are so nearly flat, do eventually steepen to 50° or more and pass into fundamental planes of dislocation. It is interesting to note, however, that in the Cranes Flat quadrangle, in secs. 16 and 21, T. 3 S., R. 41 E., basalt is extruded along a thrust plane regarded as a branch of the Bannock overthrust. There the basalt probably rose along a deep fracture (normal fault?) plane from which it escaped to the thrust plane, so that the association of the basalt with the thrust plane is perhaps fortuitous. (See p. 135.)

Thom's hypothesis postulates that compressive movements are active in the deeper and more rigid parts of the shell beneath the overlying sedimentary beds and that the deformation of these overlying beds is directed or controlled in part by the deformation of the deeper parts of the shell. This view appears to be well founded. Thom's statement, however, that the intense compression in the outer portions of the crust was dissipated by overthrusts but that the deeper part continued to be deformed suggests that the structural features which he describes are younger than the overthrusts. The development of over-

[23] See papers by Umpleby cited on pp. 354 and 358.

[24] See discussion, Continental drift meeting: Am. Assoc. Petroleum Geologists Bull. (to be published).

thrusts was probably progressive both in space and in time, and the easterly overthrusts were probably the latest formed. It is also suggested on the basis of the apparent depth of the folds that the zone of compression, as it became more intense, may have migrated outward toward the surface. If these suggestions are well founded the structural features described by Thom, both the deep-seated and the more superficial ones, may have been formed before the overthrusts occurred, and they may have played a notable part in localizing the overthrusts.

On the map showing anomalies of gravity, which was published in Gilbert's paper,[25] and on a similar more recent map by Bowie[26] southeastern Idaho is shown to possess an excess of gravity, whereas central and northern Idaho and adjacent parts of Montana are deficient. These last-named regions are areas of batholithic intrusion. Under the isostatic theory batholithic intrusions might normally be expected to occur in regions adjacent to areas of intense folding and overthrusting. Such intrusions apparently have occurred in the Alps. As folded sedimentary rocks are relatively lighter and intrusive rocks are supposedly heavier, the plus anomalies, which represent excess of gravity, should under the hypothesis lie in the batholithic areas and the minus anomalies in the sedimentary areas. White[27] in a detailed study of the relation of local geologic conditions to anomalies of gravity mentions the fact that

> deep but relatively narrow synclines, or fault blocks, of light rock close beneath the instrument should and, other things being equal, do give large minus anomalies, while conversely, bosses, fault blocks, great intrusive masses or axial mountain cores of matter heavier than the average, or of rock under which heavy mineral matter is comparatively shallowly buried, should and do cause plus anomalies.

White notes that in the Appalachian Valley trough, a region analogous to the Rocky Mountain geosyncline, all the anomalies in the deep-valley synclines have minus signs and that in most places the anomaly is large. The expected relation apparently exists in the Alps, but the reverse relation actually exists in southeastern Idaho, so far as available records show. The Snake River lava plains lie in the area of excess gravity and the weight of the basalts that underlie these plains may have a bearing on the problem. On the other hand, the Columbia River basalts lie in an area in which there is a gravity defect. Extensive areas of sedimentary beds occur in Colorado, Utah, Wyoming, Montana, and farther eastward. These areas have plus anomalies, which seem to indicate that much of the mountain-built area is not fully compensated and that the batholiths of central Idaho and Montana may not have a close isostatic relationship to the folded rocks of the northern Rocky Mountains. It should be noted, however, that the batholithic intrusions of central Idaho and Montana are of relatively acidic types of rock and are thus lighter than they would be if of more basic composition. As anomalies of gravity are usually expressed in thousandths of a dyne the differences noted in the character and distribution of the anomalies do not imply any marked departure from isostatic equilibrium in the regions named. When more detailed observations of gravity in the Rocky Mountain region are available, it is possible that the conditions cited relating to anomalies may be modified or even reversed. So far as southeastern Idaho is concerned, its proximity to the basaltic extrusions of Snake River may mean that unextruded masses of basic rock now lie at no great distance beneath the surface in much of that area and that these may account for the presence of the plus anomalies. The few basic dikes, the basaltic cones, and the single occurrence of what is probably contact metamorphism, previously cited, lend support to this view. Thom associates the Boulder batholith with the convergence of two sets of mountain trends. Such a region would in all probability be a place of crustal weakness, in which intrusive rocks might be expected.

The uplift that raised the Snowdrift peneplain to its present elevation and that affected a large part of the Rocky Mountain system was not of the intensely compressive type, though in southeastern Idaho it probably caused the folding of the plane of the Bannock overthrust and other gentle open folds. Whether the movement was essentially different from that which produced the close folds is not definitely known. Kober's idea is that a geosyncline which has once been squeezed out and eroded may become so rigid that it behaves toward later compressive stresses much as the old rigid table-lands behaved and that these subsequent movements break the region into blocks that are unevenly elevated. Thus he explains features like the Rhine Valley graben and the African rift valley. It is not clear, however, that horsts and grabens are correctly interpreted in this way. The writer has considered this movement as essentially compressive but as broadly distributed rather than localized and hence not expressed in close folds. Perhaps Kober's idea of rigidity enters into the conception slightly.

On the other hand, Reid ascribes this uplift and others like it to changes in density in the underlying material, though he does not commit himself as to the

[25] Gilbert, G. K., Interpretation of anomalies of gravity: U. S. Geol. Survey Prof. Paper 85, pp. 29-37, 1914.

[26] Bowie, William, Isostatic investigations and data for gravity stations in the United States established since 1915: U. S. Coast and Geodetic Survey Special Pub. 99, 1924.

[27] White, David, Gravity observations from the standpoint of the local geology: Geol. Soc. America Bull., vol. 35, pp. 207-278, 1924.

cause of this change. Bowie thinks it due to changes in temperature in an isostatic column that is rising under the influence of erosion. Under the segmental and wedge hypotheses this movement need not be different from that which gave rise to the Laramide folding.

SUMMARY

The writer believes that no better cause for the building of the northern Rocky Mountains has been found than the periodic contraction of the earth as a result of various causes that have been mentioned. This contraction set in motion gravitative readjustments and magmatic movements, which expressed themselves tangentially in compressive stresses that resulted in folding and overthrusting in the general manner noted in the citation from Ransome (p. 182). The compressive stresses were at first most effective in the lower, better-consolidated sedimentary rocks and in their underlying basement, but gradually they migrated outward, perhaps because of the unloading of the disturbed region by erosion.

Two phases of this compressive activity are illustrated in southeastern Idaho. The earlier phase was that in which the folded and overthrust structure, which forms so conspicuous a feature of the mountains, was developed. The compression at this time was localized by a deeply loaded geosyncline. The mountains formed are believed to have been comparable in height to those of to-day or even higher. They were reduced, however, to a peneplain or were at least greatly worn down. The second phase was begun by a renewal of the periodic contractional disturbances of the earth. This time the effects were not so definitely localized as before, probably because no accumulation of sediments comparable to those of the former geosyncline had taken place, and the rigid crust was therefore not weighted down as before. The result was a broad uplift with only gentle foldings or warpings. The mountains in their present form do not seem to have been completely compensated isostatically, through departures from equilibrium are manifestly slight.

ECONOMIC PROBLEMS

Aside from water resources, which seem ample for the region described in this report, the principal mineral resources are the phosphate beds, though others are discussed in the chapter on mineral resources. The phosphate occurs chiefly in great synclines that are included in the upper fault block of the Bannock overthrust, but some phosphate occurs also in folds of the lower block. Estimates of reserves in the ground have been made in accordance with regulations formulated in conformity with the several acts of withdrawal and with the provisions of the leasing law. As yet little commercial development of these beds has taken place.

In some other phosphate fields, notably in the brown phosphate field in Tennessee, the phosphate is a surface concentration and rock at a distance from the outcrop is lean. For the reasons stated on pages 213 and 214 this condition is believed not to exist in the Idaho field. Nevertheless in that field only surface croppings and shallow workings are available for direct observation, and the quality of the rock at depth is a matter of inference. The estimates of reserves, which are based upon sound geologic observations, have nevertheless an element of uncertainty in consequence of this lack of knowledge of conditions at depth. Another uncertainty is introduced by the relationship of the phosphate-bearing synclines to the Bannock overthrust. The depth of this overthrust is not definitely known, although its inferred position is shown in the structure sections. Probably many of the synclines are not deep enough to be seriously affected by this fault, but in others the fault may cut out a considerable portion of the phosphate. The estimates of tonnage in reserve must therefore be considered as purely tentative until the region is explored more thoroughly by mining. Much could be learned from a few well-placed drill holes, but the urgency of the situation is probably not great enough to justify the necessary expenditure for such work at this time.

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APPENDIX

DESCRIPTIONS OF NEW SPECIES OF CARBONIFEROUS AND TRIASSIC FOSSILS

By George H. Girty

When the plans for this report on the geology of southeastern Idaho were first sketched, many years ago, they called for a section devoted to paleontology, in which I proposed to describe in detail the faunas of the Carboniferous and Lower Triassic formations. This project has been abandoned in all but a mere gesture. The growing size of other chapters made a lengthy discussion of the fossils inadvisable, while preoccupation with other studies made it difficult for me to prepare such a discussion in time to go to press with the rest of the report.

The subject itself, however, holds much that is of interest. The upper Mississippian faunas of the West are but little known and that of the Brazer limestone consequently merits detailed presentation. This statement is true of the Lower Triassic formations also, for, though the rich ammonite fauna of the Thaynes sediments has been described, there remains an almost equally varied fauna of pelecypods and gastropods about which little has been written. Even to our knowledge of the Phosphoria much might have been added. The fossils of the phosphatic shale have received description, but the scattered accounts of the *Spiriferina pulchra* fauna might have been brought together and enlarged.

When it was decided to reduce the paleontologic section to skeletal proportions, I was still in doubt as to which of several purposes it should be made to serve. The plates might be composed with a view to aiding the field geologist to identify formations in a region where the rocks are at the same time greatly disturbed and not greatly dissimilar. They might, on the other hand, be assembled as evidence for the geologic age to which the formations were assigned. Or again, the record might be prepared with a view to contribute somewhat to our still meager knowledge of these western faunas. Unfortunately only an essay in descriptive paleontology, the very thing that it was decided to abandon or postpone, would serve all three purposes. Broadly speaking, only figures of perfect specimens would aid in identifying formations in the field, but the specimens need not have come from the formations themselves. On the other hand, only specimens from the formations themselves would constitute evidence in the determination of geologic age, but (in this field) many of the specimens would of necessity be fragmentary or ill preserved. Finally, though this statement is especially liable to qualification, only the description of new species would add to our knowledge of these faunas, but the new species might neither aid in identifying the formations (if they were rare or not readily recognizable) nor, obviously, serve as evidence for the age of the formation from which they came. The course actually pursued has varied with the conditions. The evidence for geologic age has been vested largely in the faunal lists and discussions that accompany the description of each formation. Some of the plates have been prepared chiefly to aid in identifying the formations; others chiefly to contribute to the sum of paleontologic knowledge, though in some degree they may serve a double purpose. The illustration of new species almost necessarily entails a description of them, and these descriptions constitute the text that follows.

NEW SPECIES OF CARBONIFEROUS FOSSILS FROM THE MADISON LIMESTONE

Schizophoria compacta Girty, n. sp.

Plate 22, Figures 1–5

Shell rather large, transverse, subelliptical to subquadrate in outline. Hinge line more than half the width—two-thirds or less.

Pedicle valve moderately convex, most elevated somewhat in front of the beak but depressed farther forward into a broad, shallow, undefined sinus. Cardinal area approximately perpendicular to the plane of the valves but distinctly inclined backward from the hinge line. Delthyrium slightly higher than wide. Internally the muscular imprints are sharply defined. They are somewhat elongate and generally ovate in shape, deeply indented at the anterior end. The muscular area is divided by a stout but not very high septum, which diminishes backward and disappears toward the beak. Each half is again subdivided by three or four radial ridges, very obscure for the most part but all having marked effect on the outline, the median ridge or septum causing the outline to be sharply emarginate in front, the lateral ridges causing it to be faintly scalloped at the sides. The imprint varies somewhat in different specimens, but it is usually broadest anterior to the middle and it usually extends one-third the shell length. It may extend more than one-third, though it is invariably less than half the shell length, and it may be broadest posterior to the middle.

The brachial valve varies from moderately to strongly convex. It is more or less gibbous in the umbonal region, depressed toward the cardinal angles, and in many specimens inflected into an obscure sinus, which is at best narrow and ill defined. The cardinal area is rather low and directed in the plane of the shell margin. It is lower than that of the pedicle valve and the beak is less prominent, but the difference is not great. On the inside the muscular imprints are relatively large but undefined. For a short distance they are included between the high socket plates, which meet at an angle of somewhat less than 90°. Anterior to the socket plates the outline is indistinct. It reaches halfway to the anterior margin, is somewhat longer than broad, and is multilobate. A faint ridge or septum divides it into two equal parts. This scar is somewhat larger in every way than that of the pedicle valve. The cardinal process usually consists of three small but pronounced ridges or denticles, the central one being much the largest.

The surface is marked by fine sharp subequal radii on which are developed the openings commonly ascribed to hollow spines that have been broken away.

In size and general appearance this shell suggests *S. poststriatula*, and its validity as a distinct species is not beyond question. The preservation of my specimens is such as to show internal characters rather than external, whereas the specimens from the Fern Glen limestone are preserved so as to show external characters rather than internal. In general the present form appears to be relatively broader. *S. poststriatula* is described as having a faint fold in the brachial valve, whereas this species commonly has a faint sinus. The surface of *S. poststriatula* is crossed by numerous varices of growth. That of *S. compacta* appears to be less commonly so marked, though as above noted, but few of my specimens show external characters. This difference consequently may be only apparent, and it is known to be inconstant because some of these specimens also are equally marked by growth lines.

The foregoing description is based on specimens from the Boone limestone of Missouri that are supposed to be of Keokuk age. The specimens from the Madison limestone appear to agree more satisfactorily with *S. compacta* than with other described species. The specimen figured, however, shows the septum of the pedicle valve to have extended beyond the muscular area, much as it does in *S. sedaliensis*. The Madison form apparently does not belong under *S. sedaliensis*, however, and other pedicle valves from the same locality do not have the muscular area shaped in this way, but agree with *S. compacta*.

Horizon and locality: Boone limestone; Webb City, Mo. Madison limestone; Slug Creek quadrangle, about 6 miles north of Georgetown, Idaho (station 1667).

Productus galeanus Girty, n. sp.

Plate 22, Figures 27–32

Pedicle valve subquadrate in outline, wider than long, moderately convex. The outline is nearly straight at the sides above and also across the front, passing around the anterolateral angles in broad, strong curves. The hinge projects but little, and the cardinal angles are approximately right angles. The convexity from front to back is strong and regular. Transversely the vault is rather narrow in the umbonal region, but it broadens rapidly toward the front, where it is distinctly flattened, or possibly faintly depressed. The auricles are undefined, oblique, and arched—scarcely more than a descent to the cardinal and lateral margins.

The surface is marked by radial costae and concentric wrinkles. The costae are rather fine and rather strong but also rather irregular. The wrinkles are fine, irregular, and not at all conspicuous across the vault, but they become fasciculate on the sides, where they are fine but fairly strong and fairly regular. There are also fine crenulations, which might also be described as minute wrinkles or as coarse, regular sinuous growth lines. In addition, the valve is strewn with numerous fine spines, which slightly enlarge the costae and combine with the wrinkles to lend them their somewhat irregular or wavy outline. The costae are not interrupted by the spines, except possibly in the umbonal region, but toward the sides they become weak and discontinuous in proportion as the concentric wrinkles become large and strong and the spines large and provided with nodose bases.

The associated brachial valves that probably belong to this species are mostly preserved in the form of external molds, to which more or less of the shell adheres. They are thus convex objects instead of concave, which is their true shape, but as most specimens have this preservation it will be convenient to frame a description to meet this condition. The brachial valve then is (as an external mold) moderately convex, but irregularly curved, being almost planate over the visceral disk and strongly, though not abruptly arched around its margin. In side view the outline is straight across the visceral disk, and straight down the trail. The two outlines are about equal in length and would meet approximately in a right angle, but they are joined together by a broad regular curve. Transversely the arch is low, oblique at each side, and more or less straight across the top, where, indeed, it is slightly indented by a faint narrow sinus, the three parts of the outline being of approximately equal extent, dependent more or less upon the position of the section.

The surface is marked by rather fine regular costae, which as they are traced backward become gradually finer and then indistinct not far from the beak (7 millimeters, more or less). The visceral disk is crossed by concentric wrinkles, which are fine, strong, and regular—distinctly more so than those of the pedicle valve. As the wrinkles pass from the visceral disk on to the trail they gradually become finer and fainter and are transformed into or replaced by fine, faint striae of growth. This valve develops spines like the pedicle valve. Those observed occur chiefly on the trail, where they are numerous. On the visceral disk the spines are smaller, but they may have been just as numerous. Like those of the pedicle valve they tend to be arranged in concentric rows, and like them, also, they occur on the costae, which are slightly enlarged at the point of origin. On the external mold, of course, the spines occur in grooves between the costae and in little depressions in the groove.

This form is probably the same *Productus* that I called *P. semireticulatus* in describing the fauna of the Madison limestone of Yellowstone National Park. The specimens covered under that term may belong to several distinct species or varieties, though but few are really in an identifiable condition. The figured specimen, however, and others from the same locality represent a species very similar to this one, though perhaps not quite identical in character. The pedicle valve figured as *P. semireticulatus* has somewhat coarser and more rigid and more regular costae and apparently much less numerous spines. Another pedicle valve from the same locality, however, has costae no coarser and but little more regular than those of *P. galeanus.* Here also the spines appear to be less numerous, but near the anterior margin nearly every one of the slender costae has a spine so placed that a continuous row is formed almost across the shell. Indeed, where the spines are small and give rise to small spine bases or none at all, it is rarely safe to infer anything definite about them in specimens from which they have been denuded, except that they are probably more numerous than they appear to be. With this fact in mind and the variation actually shown by specimens from Yellowstone National Park, it is entirely possible that many of the specimens broadly identified as *P. semireticulatus* really belong to the present species. In general appearance the species is not far from *P. sedaliensis* and others of the early semireticulate Producti. From most of them, and from *P. sedaliensis* in particular, it is distinguished, besides other less conspicuous differences, by the abundance of spines, which are said to be sparsely developed in *P. sedaliensis*.

Horizon and locality: Madison limestone; Montpelier quadrangle, Idaho, top of signal station at elevation B. M. 8231 (station 7419).

Bellerophon mansfieldianus Girty, n. sp.

Plate 22, Figures 40, 41

Shell of moderate size, with large umbilici, narrow prominent slit band, and fine lamellose (?) transverse costae. Aperture but little expanded.

The curvature is regular and gentle across the dorsum but is rather abruptly reversed at the sides as it passes into the wide, open umbilici. The slit band is uncommonly narrow and persistently prominent. The transverse costae consist of slender subangular ridges separated by relatively wide interspaces. They were probably somewhat lamellose and have an imbricating effect. The spacing of the costae is not entirely regular nor is their size entirely uniform. They diminish in strength after passing the umbilical shoulder, and upon the inner side of the whorls, where exposed, they are little more than pronounced growth lines. Much smaller secondary costae (or lirae) occur in the interspaces and are especially distinct near the slit band, for as the larger costae converge toward the umbilici the intermediate ones decrease and possibly disappear altogether. In direction the transverse lines are slightly recurved near the slit band, which they cross with crenulating effect, and are gently arched but at the same time strongly oblique from above forward. The plane of the aperture is thus oblique, the margin of the thin inner lip being considerably anterior to that of the equally thin outer lip.

The distinguishing characters of this species are its narrow elevated band, its large umbilici, and its subangular spaced transverse costae. These characters appear separately in other early Mississippian Bellerophons. Thus *B. blairi* has smaller umbilici, a broader band, and finer transverse markings. *B. helena*, which, though a Hamilton species, has been cited from the Waverly group of Ohio, has a wide band, and probably shows other differences. *B. ulrichi* and *B. jeffersonensis* have pronounced transverse markings that are more or less comparable to those of *B. mansfieldianus;* on the other hand, the size is much smaller, the slit band is not elevated—in fact, is scarcely distinguishable in most specimens—and the outer lip has peculiar features which have not been observed in *B. mansfieldianus* and probably were never developed. *B. vinculatus* has a broad band defined by raised lines in marked contrast to *B. mansfieldianus*. More closely related than any of these is *B. panneus* White. Some doubt, however, surrounds the character of that species. The type specimens are not very instructive, owing to their poor condition. According to Weller, who has examined them, the fine specimen figured by Keyes as *B. panneus* is something wholly different and probably represents a new species. On the other hand, the fine specimen which Keyes figured as *B. bilabiatus* is probably *B. panneus*. It is this specimen that *B.*

mansfieldianus resembles, though it appears to be intermediate in character between Keyes's two specimens. The slit band is more like that of "*B. bilabiatus,*" for it does not rise into a pronounced carina like that of "*B. panneus.*" On the other hand, the transverse costae are stronger and more closely arranged than those of "*B. bilabiatus*" and more like those of "*B. panneus.*"

Horizon and locality: Madison limestone; Slug Creek quadrangle, Idaho, eastern edge SE. ¼ sec. 12, T. 10 S., R. 43 E. (station 1441).

NEW SPECIES OF CARBONIFEROUS FOSSILS FROM THE BRAZER LIMESTONE

Pugnoides parvulus Girty, n. sp.

Plate 23, Figures 34–44

Shell small, rarely exceeding 5 millimeters in length. Proportions variable, the length being the greater dimension in some specimens, the width in others. Outline varying from ovate to somewhat triangular or somewhat pentagonal. Convexity strong, especially in the narrow varieties. Fold and sinus well developed but only toward the front. Plications varying in shape from rather high and subangular to rather low and rounded. In number and distribution they are fairly constant. Three to five occur on the fold, four being the most common number and three much more common than five. The lateral slopes commonly bear three, the last one more or less obscure. They may bear three distinct plications with a fourth that is very faint or, on the other hand, though rarely, two plications only that are recognizable.

An almost necessary relation seems to exist between the shape of the shell and the number and size of the plications. In *P. parvulus* the narrow shells are almost globular, the broader ones more triangular and relatively compressed; at the same time the narrow shells commonly have small or slender plications and the broad shells large ones. Selected specimens therefore differ greatly in appearance, but they have been included in a single species both because there seems to be a gradual transition between contrasting forms and because in number and arrangement the costae remain practically constant, their variation in size and other variations in appearance being merely the sequelae of variation in the rate of expansion of the shells themselves. The more slender and globular varieties of *P. parvulus* bring to mind the Spergen form *Camarotoechia grosvenori* just as the broad, more compressed varieties bring to mind *Camarotoechia mutata* of the same fauna. In *P. parvulus,* however, I do not find the same difference that caused those Spergen species to be distinguished. Furthermore, no matter which of the varieties of *P. parvulus* is compared with the Spergen species this difference is found—the Spergen shells have more numerous plications. This is especially true of *C. grosvenori,* which, though smaller than *C. mutata,* is more numerously plicated. Professor Weller gives the total number in *C. grosvenori* as varying from 18 to 22, of which 4 to 7 occupy the fold. *P. parvulus* rarely develops more than 11 or 12 plications and rarely has more than 4 on the fold. Thus *C. grosvenori* commonly has one or two more plications on the fold and still more on the lateral slopes. To *C. mutata* Weller gives 14 to 20 plications, with 4 to 7 on the fold. Thus it has one or two extra plications on the fold and one or two also on the lateral slopes.

I have not touched upon the fact that the present form is referred under *Pugnoides* and the two Spergen species under *Camarotoechia.* The distinction between *Pugnoides* and *Camarotoechia* seems to be of doubtful value, for it is little more than a difference in the strength of the plications, which in the one genus are strong and persistent, whereas in the other they are weak and more or less marginal. The most typical representatives of the two genera do indeed present a marked contrast, but other species are intermediate in character. Most specimens of *P. parvulus* are rather feebly plicated, the plications becoming obsolete in the umbonal region. In this species have also been included a few specimens with somewhat stronger more persistent plications, which if found alone might be regarded as not very characteristic representatives of *Camarotoechia.* The plications of *P. parvulus* are therefore not merely fewer and larger but also weaker and less persistent than those of the Spergen species. The internal characters, though not determined in detail, are essentially the same. They consist of two dental plates in the pedicle valve and a median septum in the brachial valve.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, slide above phosphate ground, Swan Lake Gulch (station 975), and Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Productus richardsi Girty, n. sp.

Plate 23, Figures 7–19

A small, strongly arched, coarsely costate *Productus* of the *semireticulatus* group.

Pedicle valve subquadrate in transverse section, with a shallow undefined mesial sinus, which begins near the margin of the visceral disk and extends to the anterior rim. Longitudinally the curvature is strong, and in mature specimens the anterior slope is prolonged, so that when the shell rests on its aperture the umbonal part projects far beyond the hinge line. The auricles are large, the hinge being the widest part of the shell, and rather well defined, for the vault is gibbous with steeply rising sides and the jutting auricles have somewhat the appearance of being defined by distinct grooves.

The costae are relatively coarse for such a small shell, somewhat widely spaced and more or less irregular. Here and there one of the costae may be observed to bifurcate, or, on the other hand, it may die down and disappear. The costae are as a rule feebly developed over the visceral disk, which is also crossed by rather regular concentric wrinkles, likewise feeble, which render the costae nodose. Altogether, however, in most specimens the visceral disk is but obscurely marked. The spines are fairly numerous and relatively large, but as the costae are also large the spines do not produce conspicuous nodes. Three or four range themselves in an oblique row on the auricles, dividing each about midway; of these spines some are relatively very large.

The brachial valve, when viewed as an external mold, is moderately but irregularly arched, the marginal parts being connected with the visceral disk by a somewhat abrupt curve. The auricles are defined by distinct grooves, from which they spread obliquely upward. Between the grooves the vault also rises rather strongly, so that the brachial valve has a configuration not very unlike the pedicle valve of certain other species. The convexity and anterior prolongation are much less than those of the proper pedicle valve, so that the living chamber was large.

The costae are coarse, as in the pedicle valve, but they are strong for a much shorter distance, inasmuch as here the visceral disk comprises a much larger proportion of the entire shell. The concentric wrinkles on the other hand, are a little more pronounced and take the form of angular grooves that separate rounded ridges. This valve appears to have a few spines of its own, which spring from little dimples between the costae, and it also has nodes on the costae, which correspond to spines of the pedicle valve. Of course on the shell itself (a condition which is rarely seen) all of these characters are reversed. Especially what here appear as costae and nodes are really grooves dotted by dimples, and what appear as grooves are costae which support apparently a few small spines.

These shells vary among themselves, especially in the costae, which in some are very coarse and in others much finer. In certain of its phases *Productus richardsi* recalls *Diaphragmus* and in certain others *Marginifera.* The more finely striated specimens especially resemble the associated *Diaphragmus elegans* and in fact, some imperfect specimens of that genus may in the separation have been unintentionally included here. The more typical specimens, however, are not so spreading as *Diaphragmus* and have a few large spines upon the auricles instead of a large number of small ones just above the auricles on the sides of the vault. On the other hand the pedicle valve is much more elongated than the pedicle valve of most Marginiferas. There is no doubt that *Diaphragmus* and *Marginifera* may have produced species that agree very closely with this one, but no specimen of *P. richardsi,* and a rather large number have been observed, shows evidence of having had the structure distinctive of either of those genera. There is little doubt, consequently, that all the more characteristic specimens belong under *Productus. P. scitulus* and *P. parvus* of the typical Mississippian may be mentioned as species related to *P. richardsi.* From them *P. richardsi* is readily distinguished by its shape, which is more elongated and more highly arched, and by its costae, which are coarser. Two of our western species also resemble *P. richardsi,* namely *P. gallatinensis* and *P. parviformis,* both of which, however, are more finely striated.

Horizon and locality: Brazer limestone; Crow Creek quadrangle, sec. 10, T. 10 S., R. 45 E. (stations 44, 101), and Cranes Flat quadrangle, sec. 33, T. 4 S., R. 41 E. (station 3034a), Idaho.

Cranaena occidentalis Girty, n. sp.

Plate 25, Figures 92–95

Shell of moderate size, elongate, pentagonal in outline.

Pedicle valve considerably longer than wide; greatest width somewhat above the middle, with the outline flattened above, below, and in front, so as to have the pentagonal shape mentioned. Convexity strong, much more so in this than in the brachial valve, flattened or faintly sinuate down the middle and strongly incurved at the sides. Umbonal region broad and somewhat inflated, strongly incurved, projecting far beyond the brachial valve and truncated by a rather small round foramen, which is inclosed at the sides and below by marginal parts of the rostrum that are abruptly inflected and defined almost as if by angles. Interior with two strong dental plates.

Brachial valve distinctly longer than wide, and widest considerably above the middle. Margins straightened so as to produce a pentagonal outline, in which the two opposite lower sides are much the longest, the three others being much shorter and about equal to each other. Convexity rather low, somewhat beveled toward the sides and beveled or faintly sinuate toward the front.

The internal structures have not been ascertained in detail, but they appear to consist of two not very long socket plates connected by a rather small hinge plate from which the crura project as if they formed part of the same structure. No median septum is developed as in *Girtyella,* least of all the more elaborate plate structure of *Dielasma.* These common Mississippian terebratuloid genera seem to be eliminated as receptacles for this species, leaving *Cranaena* as the most probable genus, though the reference to *Cranaena* is somewhat liable to revision.

In its specific relations this form is comparable, though rather remotely, to *C. sulcata* of the Spergen limestone but differs in its larger size and much more faintly developed plications. Indeed, the type specimen, on which the foregoing description is based, is more pronounced in this configuration than some of the associated specimens. In proportion as the valves are more regularly arched the outline is less distinctly pentagonal and more regularly oval, and some of the specimens are more expanded than the typical one, as well as more oval in outline. The internal structure as described is not shown by the typical specimen; for this feature a second specimen was drawn upon, one from the same locality and probably belonging to the same species but less pentagonal.

Horizon and locality: Brazer limestone; Portneuf quadrangle, Idaho, NW. ¼ NW. ¼ sec. 32, T. 5 S., R. 39 E. (station 5925).

Spirifer brazerianus Girty, n. sp.

Plate 24, Figures 12–17

Shell rather large, some specimens as much as 80 millimeters in width though most are less than 65 millimeters. Outline generally subovate, with the width considerably greater than the height. The outlines contract more or less as they near the hinge, but the cardinal angles are nevertheless distinct.

The pedicle valve is strongly arched especially in the umbonal region and the beak is high, prominent, and incurved. In the typical specimen the cardinal area is high and in the lower part directed to the plane of the valves at an angle of about 135°. It is curved above, so that the point of the beak lies in that plane. The sinus for the most part is broad, shallow, and undefined. Toward the beak, however, it is narrower and deeper, and in some young specimens referred here it is narrow, deep, and subangular. It is much less pronounced as a depression than the fold is as an elevation, and in compensation this part of the shell makes a conspicuous linguiform projection in front.

The brachial valve is strongly convex but less so than the pedicle valve, the umbonal region being especially gibbous, though the beak is depressed and inconspicuous. The fold begins as a rather low elevation that has distinct boundaries; at the anterior margin, however, it is broad and very high but not well defined. More rarely the fold is lower and broadly rounded.

The costae are numerous, slender, and sharply defined. They increase by bifurcation and bifurcate more frequently on the median than on the lateral parts of the surface. Thus in many specimens the fold and sinus are more finely costate than the lateral slopes. The tendency of the costae to subdivide is also more pronounced in some specimens than in others; consequently we may distinguish finely and coarsely costate varieties of this species. Before the subdivision is complete the costae appear to be arranged in pairs, and this appearance can be observed on almost any part of the surface, but it is rarely conspicuous and never suggests a grouping in fascicles. As to number, 15 costae or even more may occur in the sinus and 25 on each side.

The finer surface markings are not adequately shown by any of my specimens. The only hint as to this character consists of very fine concentric wrinkles, which can be made out here and there on exfoliated surfaces and which probably represent delicate concentric lamellae in the original shell. *S. brazerianus*, however, undoubtedly belongs to a group of Spirifers that had a finely cancellated surface, the radial lines predominating in some species, the concentric ones in others. The concentric lines would here seem to be the prevailing element.

Spirifer brazerianus is a type of *Spirifer* represented in Europe by *S. striatus* and in the Mississippian faunas of the Mississippi Valley by *S. logani* and *S. grimesi*. Somewhat special interest attached to *S. brazerianus* in that it occurs in rocks of Chester age, whereas in the typical Missisippian section shells of this type are not known above the Keokuk. So close a resemblance to the Burlington and Keokuk species can be traced, however, that *S. brazerianus* might almost be denominated a small variety of one or the other of them. It is a matter of common knowledge that the original specimens of *S. grimesi* and *S. logani* are somewhat extreme in their types. Of *S. grimesi* especially, few specimens have the greatly elongated shape shown by Hall's figures. The more transverse specimens of *S. brazerianus* have the general configuration of *S. logani*, but the more elongate ones that of *S. grimesi*, as *S. grimesi* is commonly seen. So far as observed, however, the western form lacks the fine radial striation that is commonly shown by *S. logani* and *S. grimesi*, though I can scarcely doubt that it originally had fine radial striae of some sort. In marked contrast to those species, however, the radial striae, which are merely assumed, appear to be subordinate to the concentric ones, which are actually indicated, though I hesitate to trust implicitly to the somewhat indistinct markings observed on the Brazer specimens. I can not, on the other hand, name any peculiarities of form that definitely distinguish *S. brazerianus*. The high cardinal area and incurved beak of the typical specimen mark a difference from many shells coming from the Burlington or Keokuk, but one need not look far before finding others in which this feature is essentially duplicated. This statement is equally true of other characters.

Horizon and locality: Brazer limestone; Crow Creek quadrangle, Idaho, sec. 10, T. 10 S., R. 45 E. (station 101). Top of Brazer.

Spirifer haydenianus Girty, n. sp.

Plate 24, Figures 18–21

Shell large, very transverse, widest at the hinge line.

Pedicle valve rather highly convex but compressed in the alar regions, strongly arched from back to front, with a rather small, pointed beak, sharply incurved over a low cardinal area. Umbonal parts prominent but not projecting far beyond the cardinal outline. Cardinal area very broad and narrow, nearly flat except for a short distance under the beak, and nearly erect. Sinus a rather broad, shallow deflection, faintly angulated on the median line.

Brachial valve very transverse, moderately convex, compressed toward the cardinal angles. Beak small, strongly incurved and inconspicuous. The fold is a broad gentle arch, without any definite boundaries in the anterior part. Toward the beak, to be sure, though scarcely elevated above the adjacent surface, it is distinctly defined by striae of somewhat superior strength, and these striae can be traced forward with a certain amount of confidence to the anterior margin, where, however, they occur on the sides of the gentle arch that constitutes the fold.

Surface marked by slender rounded radial costae that are distinct but not very strong. The costae increase by bifurcation and occur in rather conspicuous groups of two or three according as division takes place one or more times. The total number of costae can not be given. At least 60 can be counted on the type specimen, but there is a broad area on each cardinal angle where the markings are too faint to be distinguished. The total number must have been at least 100 and may have been much more. Neither can the exact number on the fold be stated, because the boundaries of the fold are indefinite. If the boundaries as determined near the beak are used, the fold has about 12 costae. If the indefinite boundaries determined by the arch near the front are used, it has about 20. No fine surface markings are shown by the type specimen, though undoubtedly fine superficial lirae, both radiating and concentric, were originally present.

The only specimen referred to the species is the one described; consequently *S. haydenianus* may prove to be more closely connected with *S. brazerianus* than now appears. Nevertheless we have a number of specimens of *S. brazerianus* (all imperfect), and these do not indicate any appreciable intergrading. *S. haydenianus* is an unusual type of *Spirifer* to occur in what appears to be its actual horizon and faunal association, at least if judged by the standards set up by our typical Mississippian section. The Chester faunas there have as yet furnished nothing with which to compare it. The species nearest in geologic time and in its proper characters seems to be *S. subequalis*, though of course the faunal associations of the two species are widely different. As compared with *S. subequalis*, *S. haydenianus* is not so slender and transversely elongate and has a broader, less pronounced fold and sinus.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, sec. 18, T. 10 S., R. 44 E. (station 7609).

Martinia lata Girty, n. sp.

Plate 24, Figures 1–7

Shell rather large, though most specimens are under 40 millimeters in width. Shape subrhomboidal and transverse, the width always equal to or greater than the length. The convexity is high.

The pedicle valve is strongly convex, even inflated in the umbonal region, which is high and full. The beak projects considerably beyond and, though much incurved, is raised high above that of the brachial valve. The sinus is represented by a narrow, more or less shallow, ill-defined sulcus. The cardinal area is defined from the vault by distinct angles. It is strongly concave but is nearly complanate with the shell margin. The delthyrium is about as wide at the base as it is high, and each side is about as long as the part of the cardinal line adjacent. However, I am including in *Martinia lata* two varieties, together with intermediate forms. One variety has a narrow shape and a narrow high area and delthyrium; the other has a more transverse shape and a low broad area and delthyrium. In the latter form, of course, the lateral segments of the cardinal line are longer than the sides of the delthyrium.

The brachial valve is much more transverse than the pedicle valve and also much less inflated. It is rather strongly convex in a longitudinal direction, more or less flexed inward along the posterior margin. Transversely the valve is rather flat, and it is impressed along the middle into a narrow, shallow sulcus similar to that of the pedicle valve but less strong. All the specimens seen are more or less broken in the forward part, but my observations indicate that there is no distinct fold and sinus and that the two valves meet practically in a plane without an appreciable flexure in front. The double sulcus, one in each valve, must produce a short emargination in the outline there.

The surface appears to be essentially smooth, marked only by fine incremental lines or by concentric striae due to intermittent growth.

On the interior some of these shells present a structure faintly suggestive of the genus *Reticularia*, for they develop a low dental ridge on each side of the delthyrium and in old age a faint ridge down the middle of the same valve, like an incipient median septum. These three ridges, however, are not at all comparable to the dental and septal plates of *Reticularia*, for the two dental ridges in these shells bear about the same relationship to the dental plates in those that the dental ridges in *Schuchertella* bear to the dental plates of *Meekella*.

Martinia lata in some ways closely resembles *M. rostrata* of the Madison limestone, and pedicle valves of the two species are distinguished with difficulty. The brachial valves of the two species differ markedly. The brachial valve of *M. lata* is flattened along the middle and traversed by a distinct mesial sulcus, whereas that of *M. rostrata* not only lacks a corresponding sulcus but is raised up into a subangular fold. I have, however, examined only a few brachial valves of *M. rostrata*, and it is entirely possible, so far as this feature alone is concerned, that some of the pedicle valves referred to that species may really belong to this one, or that the brachial valves seen may not really be typical. *M. lata* is distinguished from *M. contracta* and *M. sulcata*, the two eastern species, by its broad shape and by the lack, so far as known, of any distinct fold and sinus.

Horizon and locality: Brazer limestone; Crow Creek quadrangle, Idaho, sec. 11, T. 10 S., R. 45 E. (stations 108 and 108a).

Edmondia brazeriana Girty, n. sp.

Plate 25, Figure 45

Shell small, transverse, subelliptical, widest back of the middle. Hinge line straight, about half the greatest width. Lower margin nearly straight in the median part, rounding upward strongly in front, and then slightly inward under the small incurved and nearly terminal beak. At the posterior end the outline passes upward in a more gradual curve and merges with the posterior outline. The posterior outline is gently convex and very oblique in the upper part, more strongly arched below, and broadly rounding the posterior extremity, which is most prominent somewhat below the middle of the shell. Convexity rather low and evenly distributed, the highest part of the shell anterior to the middle. The descent to the anterior extremity is strong and that to the cardinal border stronger yet. A constriction of scarcely appreciable depth seems to occur a little anterior to the median line.

Surface essentially smooth.

As the dental armature of this shell is unknown, its generic position must be determined on characters much less secure. Very similar species have been described under *Edmondia*, but similar ones are found also under other genera. *E. brazeriana* resembles certain Pennsylvanian and Permian forms, such as *E. bellula*, more closely than those that are comparable in geologic age. It is related to *E. fountainensis* but is a much smaller shell and is broader back of the middle, whereas *E. fountainensis* is broader in front of the middle. This difference gives rise to pronounced differences in the shape of the posterior outline. The anterior end likewise is not quite so prominent. Another closely related species is *E. equilateralis*. Besides being several times as large, *E. equilateralis* lacks the faint though appreciable constriction of the present form and is more regularly rounded in outline at the posterior end, the outline of *E. brazeriana* having a long oblique part above and its most prominent point below the median line. Some of the species referred under *Spathella* are in a general way comparable to *E. brazeriana*, but none is sufficiently similar to require discussion.

Horizon and locality: Brazer limestone; Montpelier quadrangle, 2½ miles south of Dingle, Idaho (station 1446).

Leptodesma occidentale Girty, n. sp.

Plate 25, Figures 42–44

Shell small, strongly oblique, with a rather small anterior lobe and a rather large but not greatly extended posterior wing.

The left valve is rather highly convex, with a pronounced rounded umbonal ridge, from which the descent above to the depressed wing is abrupt but that below is more gradual and more arched. The outline behind the wing is gently concave, and the hinge is not appreciably extended; the body of the shell projects backward far beyond. The anterior lobe is small and the constriction back of it is more or less indistinct.

The surface is marked by relatively strong, widely spaced, lamellose concentric lirae.

The right valve is less convex than the left and its markings are much more subdued. As so often happens in these shells the anterior lobe of the right valve appears considerably larger than that of the left valve.

The most conspicuous difference between this species and *L. spergenense*, with which one would naturally compare it, is in the surface markings. The shells that I refer under *L. occidentale* vary considerably in this character, but even those that are most finely striated are scarcely to be compared to that species, while those that are most coarsely striated are in striking contrast to it. The lirae in *L. spergenense* are very fine and closely arranged; the specimens that I have seen vary but slightly in this regard, whereas those of *L. occidentale* vary greatly in their spacing and in their strength. In their extreme development they are very strong and very far apart for so small a shell and are more or less irregular and inosculating and in that degree discrepant with the outline of the margin. In addition to this difference the anterior lobe is broader than that of *L. spergenense* and not so prominent and the posterior projection likewise is not so slender.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, north side of south fork of Swan Lake Gulch, upper part of formation (station 7606a).

Schizodus semistriatus Girty, n. sp.

Plate 25, Figures 46–49

Shell small, more or less triangular in outline. Greatest width not far above the lower margin, somewhat exceeding the height. Basal outline nearly straight in the posterior part but more and more curved toward the front, where it merges with the broadly rounded anterior outline. Posterior outline nearly straight and strongly oblique, joining the ventral outline in an acute angle that is sharply rounded, and joining the hinge line in an obtuse angle that is distinct. Hinge line short, straight, slightly oblique. Beak small, pointed, incurved, subcentral but distinctly anterior. Convexity rather high, reaching its maximum in a conspicuous subangular umbonal ridge. From the umbonal ridge the shell falls away steeply on the posterior side with a beveled effect, the ridge being emphasized by a faint groove, so that the post-umbonal slope has the appearance of the lunule in some other pelecypod types. The shell is somewhat flattened over the median part anterior to the umbonal ridge, but it rounds downward more strongly to the anterior margin.

The surface is marked by strong regular concentric striae that are rather coarse for the size of the shell. These markings become obsolete near or upon the umbonal ridge, so that the post-umbonal slope is smooth.

This species, which is distinguished by its small size, compact outline, and striated surface, resembles certain Pennsylvanian types more than any that are yet known from our Mississippian faunas. All those shells that have a smooth surface are at once excluded from our consideration and also those large species that are also mostly smooth, found in the early Mississippian, in which period shells of this type seemed especially to thrive. The species that were more or less contemporaneous, such as *S. arkansanus*, *S. batesvillensis*, *S. brannerianus*, *S. chesterensis*, *S. circulus*, *S. depressus*, *S. magnus*, *S. randolphensis*, and *S. varsoviensis*, all differ in their large size, or their configuration, or their lack of sculpture, and most of them differ in all three. *S. depressus* perhaps resembles this species the most closely, but *S. depressus* differs appreciably in shape and has a smooth surface. In the Pennsylvanian there are several species of similar outline but of larger size such as *S. affinis*, *S. ovatus*, and *S. symmetricus*, and the same fauna has furnished several minature species that are comparable not only in shape but in size as well, none so much as *S. curtus* and the form that Meek and Worthen identified as *S. rossicus*. Those species, however, seem to be smooth.

Horizon and locality: Brazer limestone; Montpelier quadrangle, 2½ miles south of Dingle, Idaho (station 1446).

Streblopteria simpliciformis Girty, n. sp.

Plate 25, Figures 51–55

Left valve small and in outline broadly ovate except for the small auricles. The anterior side is a little more prominent than the posterior side, which causes the axis to have a slight forward inclination. It projects far beyond the anterior wing, which is somewhat subquadrate and abruptly depressed, almost as if defined by a groove, and almost horizontal. The posterior wing is smaller than the anterior and undefined, scarcely more than a rather short, steep slope to the shell margin. Hinge line short, half the width of the shell, or less. Convexity rather high and regular.

Surface practically smooth or showing a few faint irregularities of growth. Some specimens, however, are marked by very fine radial striae that bend strongly outward, so that they are more or less perpendicular to the outline where they meet it. These lines have the appearance of very fine fibers and suggest structure rather than sculpture.

The right valve is in general like the left but is less convex, and the anterior wing is defined by a more pronounced groove which meets and gives rise to a deep byssal notch in the outline.

Shells of this type are not uncommon in our Carboniferous faunas and some of them have been referred to the genus *Streblopteria*. They seem to be especially common in the lower Mississippian, for a number of species have been described from the Waverly group of Ohio. They also occur in the Permian, where one of them was described as *Aviculipecten montpelierensis*. In some of these species, though the body of the shell is smooth, the auricles are marked by radial striae. To these species consideration need hardly be given. The Waverly species also, by reason of their remote occurrence and very different geologic age, may well be disregarded, as may the Permian *Aviculipecten* (?) *montpelierensis* because of its geologic age, though it was found in the same general locality as *S. simpliciformis*. From the the upper Mississippian faunas very few smooth pectinoids comparable to this one have been described, though we have *Aviculipecten keoughensis* and *A. simplex*. *A. simplex* was described from a region very remote from this, Windsor, Nova Scotia, and is distinguished from *S. simpliciformis* by its longer hinge line and larger wings. It is also said to have in the right valve a cardinal area of appreciable height, though the present species may have the same structure too, so far as known. *A. keoughensis* is noteworthy in that the description lacks entirely any reference to what is probably the most significant character in pectinoid shells—the surface ornamentation. The surface appears, however, to be devoid of any sculpture, if the figure is to be trusted. Except for its much smaller size and its smaller posterior wing, very few differences can be named as distinguishing this species from that, but these differences, in view of its geographic occurrence, seem to make an identification undesirable.

The generic position of *S. simpliciformis* calls for some discussion. As already noted, certain American species that resemble it have been referred under *Streblopteria* McCoy. The generic characters of *Streblopteria* as given by McCoy are these: (1) The shell is obliquely extended toward the anterior side. (2) The posterior wing is broad and undefined, the anterior wing small and deeply defined. (3) The surface is smooth (as in the type species, *S. laevigata*), or marked by radiating ridges. (4) The hinge bears one long linear slightly divergent posterior tooth, and a narrow simple ligamental facet. (5) The muscular impression is large, faintly defined, and situated a little behind the middle. As compared with *Aviculipecten*, *Streblopteria* scarcely deserves the name allotted to it, inasmuch as the relative size and definition of the wings are the same in both genera, the anterior wing being the smaller and the more sharply defined. In the direction of the axis, which is not so much inclined as curved toward the anterior side, *Streblopteria*, at least as typified by *S. laevigata*, is markedly unlike most species of *Aviculipecten*, and of course it differs also from that genus in its hinge characters. The hinge characters of the American Streblopterias are almost unknown and the generic assignment appears to have been influenced by the shape of the shell, by a larger development of the anterior part, which creates the appearance of slight forward inclination of the axis, though none of our species has anything that approaches the peculiar configuration of *S. laevigata*. On the other hand, nearly all the American species, and among them *S. simpliciformis* here described, agree in possessing a character that is distinctly at variance both with *Streblopteria* of McCoy and also with *Aviculipecten*, to which they would otherwise naturally be referred. The anterior wing is large and well defined, but the posterior wing is small and ill defined, a relationship, at least as to size, which is just the reverse of that found in the most characteristic species of *Aviculipecten* and *Streblopteria*. Whether the American shells ought to be included in either genus is doubtful, but without a better understanding of their hinge characters it would scarcely be advantageous to transfer them to some other group, especially under a new name. It is in obedience to this practice and precedent that I am describing the present species under *Streblopteria*, it may well prove to have the characters of a new genus.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho slide above phosphate ground, Swan Lake Gulch (station 975). Montpelier quadrangle, 2½ miles south of Dingle, Idaho (station 1446).

Streblopteria simpliciformis Girty var. marginata, Girty, n. var.

Plate 25, Figures 56–59

In this place are included four specimens, all from station 3023, which are evidently related to *S. simpliciformis* but which are sharply distinguished by certain characters. The most striking difference is that the shell is abruptly inflected around its free margins, with the result that the valves are for their size unusually capacious and the wings very sharply defined. The posterior one is small and narrow; the anterior one is much larger, spreading out almost horizontally from an almost vertical lateral slope.

The surface is essentially smooth, save for fine fiber-like lines that curve outward toward the margin, which they meet everywhere at approximately a right angle. In this they completely duplicate the character of *S. simpliciformis* itself, from which they differ in their more elongate shape, in the inflected margin, and in the more distinctly defined wings.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Genus CYPRICARDELLA Hall

Among the pelecypods of the Brazer fauna the shells of *Cypricardella* are conspicuous for their abundance and variety. No other group approaches this genus in either respect. The generic reference, however, rests upon their general expression, supported by their geologic age and faunal association. The characters that would definitely establish the generic position, namely, those of the dental armature, are wholly unknown. The generic evidence, such as it is, however, is much more convincing in some forms than in others, and in a few it may be thought less favorable to this generic assignment than to some other. The variation among the shells here assembled under *Cypricardella*, though so great is at the same time so gradual that some connection can be traced from even the most dubious forms to the most authentic.

Variation manifests itself along two lines—configuration and sculpture. The variation in shape both in outline and in configuration, which of course are intimately connected with one another, could be predicted in quality if not in degree from what is already known of other species. In this category these shells seem to run the entire gamut. The variation in sculpture, however, was scarcely to be expected. Typically the Cypricardellas are marked by relatively slender, sharply expressed concentric lirae and many of these Brazer shells are of this type, though the markings vary to an extraordinary degree in scale. Others, however, have sculpture of a somewhat different character, consisting of concentric lamellae, which are apparently not erect and which are very widely spaced. Possibly this form of sculpture should be regarded as only a modification of the other, but the raised lines are more conspicuously lamellose, and their spacing is much wider. There are still other specimens in which, though the markings are almost equally coarse, the lamellae are replaced by somewhat obscure angular ridges more like fasciculate growth lines, and their arrangement and size are less regular. This appearance may be accidental, though I believe it is not, and I have hesitated to use it as a distinguishing character. Even so, the material presents a large and perplexing variety of forms, for the two categories of variation do not show any correlation; shells that are similar in shape differ in the scale of their sculpture, and shells that are similar in sculpture differ in shape, though in either regard what they show is essential agreement rather than exact identity. Under the conditions that I have described it has been difficult if not impossible to discriminate species that have any clear-cut identity, that do not merge, or tend to merge, with some other species. To group this assemblage as a single species was out of the question, to subdivide it meant describing conspicuous varieties and distributing among them what was left over, for many specimens in a manner far from satisfactory. This course virtually consists of describing single specimens of marked individuality rather than groups of specimens that are in mutual agreement, and the specimens serviceable for description are as a rule those that are perfectly preserved. The classification employed has thus in some degree been controlled by chance; that it will stand the test of time in every part is scarcely to be hoped, although it has seemed the best under existing conditions.

It will be remarked that in all this variety of forms none has been found that could be safely identified with species described from the Spergen limestone, where also Cypricardellas occur in considerable numbers. The Cypricardellas of the Spergen, however, are in a state far from satisfactory as regards classification, and, considered as a whole, their range of variation in shape and especially in sculpture is far less wide. Many of the western forms therefore have no parallel in the Spergen. Hall, it will be recalled, describes three species of *Cypricardella* from that fauna, and a fourth was subsequently added by Whitfield. Hall did not publish figures with his original descriptions, but later illustrated two of his species in another connection—*C. nucleata* and *C. subelliptica*. Excellent figures of all four species were, however, given by Whitfield, the specimens used to illustrate Hall's species being taken from Hall's original material and bearing his original identifications. Somewhat to the confusion of anyone attempting to identify these species, Hall's figures and Whitfield's figures do not agree at all well. In fact, according to Whitfield, Hall's figures of *C. nucleata* (as subsequently identified) are based on the typical specimen of *C. oblonga* and even so Hall's figures and Whitfield's figures, though they are supposed to represent the same specimen, are in some respects widely dissimilar. Less confusing, though by no means fortunate, is the fact that Whitfield proposes in his plates a new name for a certain form that he says in the text does not deserve such recognition.

It seems necessary to use Whitfield's figures as truthfully representing Hall's species, even though they differ materially from Hall's own figures and in some details from Hall's original descriptions. As I interpret Hall's three species—and they are by no means easy to interpret—they form two groups. In the one group is *C. oblonga*, transversely elongate, with a prominent anterior extremity; in the other *C. subelliptica* and *C. nucleata*, more compact or less transverse. In discussing *C. nucleata* Hall remarks that "the posterior end is abruptly truncate; the truncation slopes upward and outward from the base. In this respect it is the reverse of *C. subelliptica*, which is more elliptical and obliquely truncated, the truncation not reaching to the base." My first understanding of this quotation was that *C. nucleata* was the reverse of *C. subelliptica* in the slope of the truncation, or to be more specific, that in *C. subelliptica* the truncation slopes upward and inward from the base instead of upward and outward. A comparison of Whitfield's figures, however, shows that the nub of the suggested contrast is to be found in the words "from the base," for in both species the truncation slopes inward from above, but in *C. nucleata* it is continued to the base, meeting the ventral outline in a pronounced angle, whereas in *C. subelliptica* it sweeps forward in an oblique curve without any appreciable posterior inferior angle. There could scarcely have been an appreciable umbonal ridge in *C. subelliptica*, as there must have been in *C. nucleata*, and in addition the anterior end is much more prominent. Both species then differ in truncation from *C. oblonga* in which the truncation is oblique from above backward, as well as in the transverse proportions, and *C. nucleata* differs from it also in the slight prominence of the anterior extremity. The anterior extremity of *C. subelliptica*, on the other hand, is fashioned much as it is in *C. oblonga*. Under *C. oblonga* consequently Hall must have grouped all the Spergen forms which came under his purview that were obliquely truncated from above backward, and the Spergen shells that have this configuration vary considerably in the prominence of the anterior extremity and in the prolongation of the posterior side. In general the Cypricardellas of the Brazer are distinguished even from *C. oblonga* by being rather prominent at the anterior end and by having rather coarse strong sculpture, though some, on the other hand, have sculpture that though sharp is very fine in proportion to their size. Few have the characters combined as they are in Hall's species; least of all do they show a development comparable to *C. nucleata*, with its forward-sloping truncation and its repressed anterior end. One outstanding form, *C. sectoralis*, does closely parallel *C. subelliptica* in shape, but with this shape is combined a sculpture so coarse and strong that no *Cypricardella* of Spergen origin offers anything to compare with it. Most of the Brazer shells are more of the type of *C. oblonga*, but most of them have a more prominent anterior extremity and of those that agree more or less in this regard most are sculptured on a distinctly coarser scale. It is not improbable that specimens will be found in the Brazer that agree very closely with typical *C. oblonga* and even of those that I have examined, a few, if considered apart from their associates, might with some allowances be referred to Hall's species. They appeared, however, to be linked with other and more abundant specimens that could scarcely be so identified, and it seemed the better course to exclude *C. oblonga* from the western fauna except on evidence that was more satisfactory than this.

Cypricardella brazeriana Girty, n. sp.

Plate 25, Figures 68–71

Shell small, strongly transverse, irregularly five-sided in outline. Cardinal margin half the total width or less, slightly arched and slightly declining backward. Lower margin broadly and regularly arched. Posterior outline truncate and very slightly oblique, joining the hinge line above in a strong curve and joining the inferior outline in a curve that is abrupt. Anterior outline faintly concave and strongly oblique. Toward the base the direction changes so as to pass around the anterior lobe, which is rather narrowly rounded and is most prominent well below the middle of the shell. The convexity is moderate. The shell is more or less flattened but rounds downward strongly to the anterior margin. The postumbonal slopes are compressed, so that the umbonal ridge, though broadly rounded, is rather conspicuous.

The surface is marked by slender concentric lirae regularly arranged and considerably more than their own diameter apart.

This species is closely allied to *C. oblonga* and should perhaps not be described as distinct. It appears to differ in having the anterior extremity more prominent, the posterior extremity more contracted, and the sculpture more widely spaced and more sharply defined. It is, however, very difficult to understand the four species described from the Spergen fauna or to recognize them even amongst material from the very localities whence they were described. The difficulty of understanding the original descriptions is not eased by subsequent interpretations by the author who wrote them, or by apparent conflict between the descriptions of the species and their figures. Thus the figures of *C. nucleata* and *C. subelliptica* which Hall gives in his Iowa report show scarcely any similarity to Whitfield's figures of the same species, based upon the original specimens labeled by Hall himself. This is scarcely to be wondered at, however, if, as Whitfield says, the specimen figured as *C. nucleata* in Hall's Iowa report was one of those which he originally identified as *C. oblonga,* in fact the very one used by Whitfield as the typical specimen. As regards the other matter, Hall in his description of *C. nucleata* says: "The posterior end is abruptly truncate; the truncation slopes upward and outward from the base." Hall's figure, however, certainly does not represent the truncation as sloping outward from the base; as just pointed out, that figure really pertains to an altogether different species, though one wonders whether it can possibly have been drawn from the specimen that Whitfield figures as *C. oblonga.*

Among the specimens from the Spergen limestone that I would be inclined to identify as *C. oblonga,* the outline rather characteristically diverges so that the posterior end is somewhat expanded. *C. brazeriana* is described as somewhat contracted at the posterior end, which is actually the condition of some specimens. In this character, as in the prominence of the anterior end, considerable variation is shown by the specimens admitted under *C. brazeriana,* but although some have the dorsal and ventral outlines parallel, few if any have them divergent, whereas in *C. oblonga,* although some specimens have the outlines parallel and others divergent, few if any have them convergent.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, north side of south fork of Swan Lake Gulch, upper part of formation (station 7606a).

Cypricardella dubia Girty, n. sp.

Plate 25, Figure 60

Shell small, subelliptical, moderately transverse. Beak small, not very prominent, directed downward but not appreciably toward either end; situated distinctly to one side of the middle, though not far from it. Ventral outline regularly rounded, more gently across the median part and more strongly at the ends, which are nearly symmetrical. Anterior outline very faintly convex and rather oblique from the beak to the ventral outline, which it joins in a somewhat abrupt curve slightly below the mid height. Posterior superior outline oblique and almost straight, becoming more strongly curved as it passes backward and making a rather broad, almost symmetrical arc around the posterior end. The posterior end is therefore broader and more regularly rounded than the anterior end, which is faintly angular where the upper anterior and ventral margins join. The convexity is fairly regular but not very strong. It is somewhat greater on the anterior side, and a very faint "umbonal ridge" can be traced from the beak to the basal margin of that side. The shell is rather strongly beveled along the upper part of the anterior border, which lends the outline its straight truncated appearance. It is more faintly beveled along the dorsal outline.

The surface is marked by fine sharp concentric lirae, which are closely and regularly arranged.

The specific relations of this shell depend naturally upon its generic position, and its generic position is uncertain. Its association with so many and such varied forms of *Cypricardella* may have led me to a wrong assignment. and in fact the shell itself shows characters which are scarcely compatible with that genus. The position of the beak is taken as determining the orientation, the short end of the valve being anterior, but the beak is not appreciably directed forward. In fact, a very faint deflection of the cardinal outline leaves the impression that the beak may point toward the longer side. The upper part of the anterior outline is not concave, as in typical *Cypricardella*, but gently convex (this departure perhaps being the determining factor in the apparent direction of the beak); at the same time, the anterior extremity is faintly angular. The posterior outline is rather regularly rounded and not truncated, as it commonly is in *Cypricardella*. The "umbonal ridge," if I am not mistaken in detecting a line of maximum curvature nearer to the short than to the long end, is also anomalous. If a *Cypricardella* at all, this shell possesses features that distinguish it radically from the other more typical members of the genus. It is also, however, reminiscent of a quite different group of shells, for the position of the beak, its apparent direction toward the long side of the valve, and certain other characters, recall forms that have been referred under *Yoldia*. The Carboniferous Yoldias are rare, and most of the species are imperfectly known. With the more typical Yoldias, however, this shell is at variance in having the short end narrow and pointed but the long end broad and rounded, and if the short, pointed end is taken as posterior, the beak at least does not point toward it but rather points away from it. The well-marked bevel along the upper part of the short end seems to be a character not found in *Yoldia*.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, slide above phosphate ground, Swan Lake Gulch (station 975).

Cypricardella gibbosa Girty, n. sp.

Plate 25, Figures 72–75

Shell small, transversely subquadrate. Dorsal and ventral margins nearly parallel, sometimes slightly divergent posteriorly. Posterior outline truncating that end almost at right angles to the two intersected margins, which it meets in abrupt curves, the upper curve being more abrupt than the lower. Beak at about the anterior third. The upper part of the anterior outline is gently concave and oblique; the lower part is regularly rounded, meeting the upper at about the mid height in an obscure angle. The convexity is strong, partly produced by an abrupt inflection around the free margins. The umbonal ridge is distinct but rounded. The postumbonal slope is more or less flat, compressed if at all near the posterior superior angle. Some specimens show a faint constriction in the lower part and about midway between the two ends.

Surface marked by relatively strong, coarse concentric striae. Close to the margin there are developed one or two striae of exceptional strength, the shell at the same time being conspicuously inflected.

This species is distinguished by its small size, by its posterior truncation, which is almost perpendicular to the upper and lower margins, and by its strong convexity, enhanced by the rather abrupt marginal flexure. It does not appear to be closely allied to any of the Spergen forms at present known, and the chief uncertainty that can be advanced with regard to these shells is whether they are not abnormal. On this head it can be stated that the specimens are fairly numerous (seven being referred here), fairly constant, and fairly conspicuous among the other Cypricardellas. They seem, indeed, to form a group more compact and natural than some of the others here established in this genus.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, slide above phosphate ground, Swan Lake Gulch (station 975). North side of south fork of Swan Lake Gulch (station 7606a).

Cypricardella occidentalis Girty, n. sp.

Plate 25, Figure 61

Shell rather small, transverse, irregularly elliptical in outline. Lower margin long and gently curved, rounding upward somewhat more strongly at the ends. Anterior outline oblique and sigmoidally curved, concave above and for an equal distance convex below where it joins the inferior outline without a break, so that the anterior end projects strongly and is regularly rounded. Cardinal border straight and oblique, though not so oblique as the outline in front. Posterior outline short and truncated with a slight obliquity, meeting the connecting outlines in a rounded angle above and a pronounced curve below. Convexity moderate, reaching its maximum in the region of the umbonal ridge, which, though rounded, is a conspicuous feature. Postumbonal slope somewhat concave, especially in the more marginal parts. Along the cardinal border the shell is sharply reflexed, so that a narrow strip is vertically directed and is not seen in the side view. The shell is rather strongly inflected along the anterior margin above but much less abruptly.

Surface marked by slender concentric lirae separated by rounded striae of greater width. The markings are more or less irregular and some of the lirae (every alternate one, as a rule) become obsolete at the umbonal ridge.

C. occidentalis appears to be most nearly related to *C. elliptica* (if that is a valid species), but the beaks are more nearly central and the upper and lower outlines contract more strongly toward the posterior end. Though Whitfield himself says that *C. elliptica* is not sufficiently distinct from *C. oblonga* and *C. subelliptica* to be a good species, yet he gives it a new name, and though he introduces it as a new species, he gives no description and only one unsatisfactory figure. As compared with *C. oblonga*, the beaks in the present species are more central and the posterior end more contracted.

Horizon and locality: Brazer limestone; Henry quadrangle, $6\frac{3}{4}$ miles northwest of Henry, Idaho (station 3023); Slug Creek quadrangle, Idaho, north side of south fork of Swan Lake Gulch, upper part of formation (station 7606a).

Cypricardella occidentalis Girty var. lacus-cygni Girty, n. var.

Plate 25, Figure 62

This shell in many respects agrees with *C. occidentalis*, with which it was found associated at station 7606a; the anterior extremity is, however, more produced and pointed, the posterior extremity broader, and the striation finer.

Cypricardella sectoralis Girty, n. sp.

Plate 25, Figures 65, 66

Shell small, somewhat triangular in outline, the long side being formed by a fairly strong, fairly regular curve. Dorsal margin gently convex and rather long; anterior margin rather strongly concave and short. The parts of the outline that remain, including the posterior margin, the ventral margin, and to some extent the anterior margin, are strongly and rather regularly arched, with a mere suggestion of an angle where the ventral part meets the posterior part. This broad curve, on the other hand, meets the cardinal margin and the anterior margin in conspicuous angles, the anterior angle being somewhat rounded. The convexity is moderate with only a suggestion of an umbonal ridge corresponding to the suggestion of a posterior inferior angle. Cardinal and anterior (upper part) margins sharply inflected to form a broad escutcheon and lunule.

Surface marked by strong and somewhat elevated concentric lamellae spaced at wide intervals.

The foregoing description is based upon the type specimen, but a number of other specimens have been assembled here, all apparently possessing essentially the same characters. This is one of the most striking species in the *Cypricardella* fauna of the Brazer, and I know of no other that compares with it in our Carboniferous rocks. In shape it is almost the counterpart of *C. subelliptica*, but in sculpture it is decisively different. If, however, we pass from *Cypricardella* to another group of shells of very similar appearance, *C. sectoralis* strongly recalls the Pennsylvanian *Astartella varica*. Furthermore, there is little if any evidence that *C. sectoralis*, or indeed any of the Cypricardellas here considered do not actually belong to the other genus. If the facts are closely looked into, it is far from certain that some of the more authentic Cypricardellas of the Mississippian, such as the Spergen forms, are not also Astartellas. For the present, however, both questions must be left in abeyance, and in that state *Cypricardella sectoralis* stands out as a striking and very distinct species.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, slide above phosphate ground, Swan Lake Gulch (station 975); Henry quadrangle, $6\frac{3}{4}$ miles northwest of Henry, Idaho (station 3023).

Cypricardella sublevis Girty, n. sp.

Plate 25, Figure 64

Shell small, subovate, or somewhat triangular in outline. Beak situated at or a little posterior to the anterior third, incurved, and directed forward. Ventral outline gently and regularly convex across the median part but curved upward rather sharply close to the ends, the anterior curve being stronger than the posterior. Cardinal outline faintly convex and rather strongly oblique. Posterior outline subtruncate, nearly straight in the upper part and meeting the cardinal border in an angle much more distinct but nevertheless rounded, but curved below around the broad indistinct posterior inferior angle. The anterior outline is strongly oblique and nearly straight though emarginate below the beak and gently convex in the lower part so as to form a broad arc around the anterior extremity, whose most prominent point is not far above the base. Convexity moderate, strongest on the umbonal ridge, which is broadly rounded and indistinct. Postumbonal slope somewhat compressed toward the upper margin. Cardinal border decisively rounded inward for a considerable distance without being sharply beveled.

Surface nearly smooth, marked by a few rounded grooves and subangular ridges, all rather fine, indistinct, and irregularly spaced.

This shell is like *C. dubia* in being a doubtful member of the genus *Cypricardella*, though it is doubtful because of very different characters, and I may have been led in this instance, as in that, to cite the species under *Cypricardella* by reason of its association with those shells which are so numerous and so varied, and of which some, though not the most typical, possess characters more or less similar. The genus under which *C. sublevis* might perhaps more reasonably be included is *Edmondia*. The typical Edmondias are more sharply and regularly striated, but so are the more typical Cypricardellas. The Edmondias (here again we are dealing with a genus whose characters are not well known, or at least have been often misconceived) probably do not have the strongly inflected, almost beveled cardinal margin that is a feature of *C. sublevis* and that is comparable to the more sharply defined escutcheon of *Cypricardella*. If a member of that genus at all, *Cypricardella sublevis* is abnormal in its sculpture, as already mentioned, and in the obscure truncation of its ends. The truncation at the posterior end is short and inconspicuous, whereas that at the anterior end, because it is long, very oblique, and straight instead of concave, produces an outline markedly different from that commonly found in *Cypricardella*. The inconspicuous umbonal ridge, the character of which controls the shape of the posterior end, is also somewhat at variance with *Cypricardella* in its typical expression. These features, which call into question the generic reference in its entirety, are distinguishing characters from the Cypricardellas severally.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, north side of south fork of Swan Lake Gulch, upper part of formation (station 7606a).

Cypricardella subquadrata Girty, n. sp.

Plate 25, Figures 76–78

Shell small, subquadrate, distinctly wider than long. Dorsal margin faintly arched and almost horizontal. Ventral margin approximately parallel to the dorsal, slightly converging with it posteriorly, rounding upward more strongly at either end, especially at the posterior end, where it makes a rather abrupt turn in joining the posterior outline. Posterior outline essentially vertical and essentially straight, consequently meeting the dorsal and ventral margins in an angle of nearly 90°. The junction above is subangular; that below more gradual but still abrupt. The anterior outline above is rather long, rather strongly oblique and gently concave. Below, it is but a continuation of the upward curve of the ventral margin, which takes on a slight backward direction as it meets the concave upper segment of the outline. The point of junction is marked by an obscure angle somewhat below the mid-height. The beak is subcentral though distinctly anterior. The convexity is rather strong. The valves are flattened on the sides and strongly incurved at the anterior margin. The umbonal ridge is conspicuous, especially in the upper part, where it is subangular; in the lower part it is broader and less distinct. The postumbonal slope is rather abruptly depressed, especially toward the umbo, where it is defined as if by a groove, an arrangement that lends the umbonal ridge its compressed almost angular appearance there. The shell is inflected strongly and abruptly along the cardinal border and along the upper part of the anterior border.

The surface is marked by fine, sharp, regularly arranged concentric lirae, which become indistinct on the postumbonal slope and also near the anterior margin, though this may be an accidental character.

The foregoing description is formulated entirely from the type specimen. Other specimens from the same locality referred to the species show certain variations. In several the dorsal and ventral margins diverge slightly toward the posterior extremity. In one specimen the ventral border is more than commonly arched; in consequence the shell is correspondingly narrow at the posterior extremity and the margins appear to contract more decisively than they do in the typical specimen. The beak may be even more nearly central than described. On one specimen the concentric markings are considerably stronger and coarser than those of the type, and on several others they are more or less obsolete, appearing as obscure irregular ridges like fasciculate growth lines that are not so sharp as the lirae of the type specimen and are more widely spaced. The main features that these shells have in common are the subquadrate shape, as expressed in the rather exceptional height and in the almost vertically truncated posterior outline, combined with the almost central umbones and long prominent anterior extremity. They would, if their surface markings were taken more into account, be divisible into at least two groups of possibly specific value, but the distinctive character of one group, the weakened sculpture, can not at present be said to be natural or authentic, though in my judgment it is so.

The validity of *C. subquadrata* in its relationship to certain of the Spergen species may fairly be questioned. In its proportions it is comparable to *C. nucleata*, but the prominent anterior extremity and subcentral umbones discountenance any close relationship. Its relations are really more close to *C. oblonga*, and if the type specimen of *C. oblonga* were curtailed on the posterior side without any change in other respects, a fairly close resemblance to *C. subquadrata* would result. But most specimens of *C. oblonga* have the elongated shape of the typical one, and most specimens of *C. subquadrata* have the compact shape of its type. If the species are interpreted on a broader basis, *C. oblonga* shows nothing to compare with *C. subquadrata* in the way of sculptural variation, most of the specimens being more finely striated and none marked with obscure ridges regularly and widely spaced.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, north side of South Fork of Swan Lake Gulch, upper part of formation (station 7606a); NW. ¼ SW. ¼ sec. 13, T. 10 S., R. 43 E. (station 7607a).

Cypricardella tenuilineata Girty, n. sp.

Plate 25, Figure 67

Shell small, transverse, irregularly elliptical or somewhat pentagonal in outline. The cardinal border and the upper part of the anterior border are nearly straight and nearly equal in length. They are oblique, declining from the umbo, where they meet in an angle of about 120°. The remainder of the outline, comprising the posterior margin, the ventral margin, and the lower part of the anterior margin, forms a broad, nearly symmetrical curve, somewhat straightened on all three sides. The curve still has an outward direction where it meets the cardinal outline and the upper part of the anterior outline, with each of which it makes an angle. The posterior part of the curve is a little straighter and more erect than the anterior part, and the angle there is accordingly somewhat more distinct than that at the anterior end. In fact, the outline below this angle is in the type specimen slightly emarginate. The convexity is moderate and regular, without a well defined umbonal ridge; the cardinal border and the anterior border in the upper part are rather abruptly inflected and angulated. The beak is small and pointed and apparently directed toward the long side.

Surface very finely and regularly striated.

The type specimen is taken to be a left valve, although this orientation causes the beak to be situated posterior to the middle of the transverse diameter. This orientation is adopted partly because the beak appears to point toward one side, even though it be the long side of the shell, and partly because the configuration otherwise correlates more satisfactorily with *Cypricardella*, inasmuch as the one side, though short, is broader and more distinctly truncated, while the other side, though long, is more pointed. Of course, if the shell is not a *Cypricardella*, neither argument would hold. The absence of a distinct umbonal ridge, which is a feature of most Cypricardellas and which would also aid in orienting the shell, together with other abnormal features, suggest that the species is not of this genus at all, but possibly a *Yoldia* or some other genus not common or even not yet known in the Paleozoic. The fact of the beak pointing to the long side of the shell (if it does so point, which is not entirely clear), the fine striation, and the absence of an umbonal ridge would agree with at least some of the Paleozoic shells referred to *Yoldia*, but the shape otherwise seems to belie this relation.

From the discussion of its generic relationships just preceding, it will be obvious that *C. tenuilineata* differs markedly from any of the Cypricardellas known from our American Carboniferous. It is most aptly comparable to *C. subelliptica*, from which it differs in its finer sculpture, in the absence of an umbonal ridge, in the slightly posterior instead of slightly anterior position of the umbo, and in the narrower as well as shorter posterior extremity. It should be remarked that I here refer to *C. subelliptica* as figured by Whitfield from the original specimens. Hall, although this is his own species, figures a shell which is so much unlike Whitfield's that it can scarcely be thought to belong to the same species, and one is led to inquire whether Hall had forgotten what *C. subelliptica* was like after his specimens had passed into the possession of the American Museum of Natural History or whether Whitfield, who had the illustrations prepared a long time subsequently, got hold of the wrong specimens. Whitfield says, however, that all the specimens illustrated were attached to cards bearing Hall's original labels.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Cypricardella varicosa Girty, n. sp.

Plate 25, Figure 63

Shell small, transverse, subquadrate. Cardinal margin straight, about three-fourths the entire width. Ventral margin nearly parallel to the hinge and for most of its extent but slightly arched, bending upward rather strongly toward the front and joining the anterior outline without break. Posterior outline truncating the entire shell and but slightly oblique from above backward. Anterior outline gently concave and strongly oblique in the upper half but at about the mid-height turning rather abruptly backward and then in a convex curve joining the inferior outline in a regular curve. The posterior inferior angle occurs just above the basal outline, but the angular extremity of the anterior lobe occupies a median position. The convexity is rather strong, and a conspicuous subangular umbonal ridge passes from the beak to the lower posterior angle.

The surface is marked in the umbonal region by very fine concentric striae. These striae shortly give place to regularly arranged, widely spaced lamellose ridges, with fine growth lines in the interspace.

In configuration this shell closely resembles *C. oblonga*, but the two species differ decisively in their surface markings, *C. oblonga* having regularly arranged fine striae all over, whereas this form has still finer striae in the younger stages but heavy concentric ridges upon most of its surface.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, north side of south fork of Swan Lake Gulch, upper part of formation (station 7606a).

Sphenotus meekianus Girty, n. sp.

Plate 25, Figure 50

Shell small, transversely subovate. Upper and lower margins gently convex and almost parallel. Posterior outline a broken curve, nearly straight above and oblique but more strongly rounded below. Thus it passes into the ventral outline in a broad curve, whereas it makes a more or less distinct angle with the hinge above. Anterior margin truncate and emarginate. The large strongly incurved umbo is slightly posterior to the extremity of a small subangular lobe below it. The convexity is high. A very distinct umbonal ridge passes from the beak to the posterior inferior angle, near which it becomes sharply angular. The side of the shell below the umbonal ridge is considerably flattened. The postumbonal slope is divided by a thin angular rib situated slightly nearer to the umbonal ridge than to the hinge line; the two elongated areas into which the postumbonal slope is thus divided are gently concave. In addition, the cardinal margin is abruptly inflected to form a broad escutcheon, which is defined above by an angle as sharp as the two other plications. This angle, in appearance forms the cardinal margin, for the inflected border does not show in the side view. Surface marked by fine striae of growth.

This species is related to *S. monroensis* and to *S. plicatus*. It is much smaller than *S. monroensis*, more convex, less prominent at the anterior end, and furnished with an angular rib that divides the postumbonal slope. However, some specimens of *S. monroensis* have the umbo much less prominent than others and some show traces of a radial plication on the umbonal slope. In fact this species appears to be intermediate between *S. monroensis* and *S. plicatus*. As compared with *S. plicatus* it is considerably more elongated transversely and has a smaller anterior lobe.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Pleurotomaria aspeniana Girty, n. sp.

Plate 25, Figures 1–7

Shell rather small, subglobose, composed of about six rounded volutions. The final volution, and to a varying extent the others also, is somewhat flattened on three external surfaces, so that a cross section is as much quadrate as circular. Below the suture the shell juts horizontally for a considerable distance, this zone being flat or faintly concave and in some specimens declining slightly inward. The shell then curves rather abruptly to a direction downward and outward but within a short distance is withdrawn into a deep sulcus. In this manner there is defined or created a narrowly rounded ridge or carina, which occurs near the top of the volution yet because of the flattened lateral surface is not far within the peripheral line. The remainder of the exposed surface, though it forms an irregular curve as above described, presents no features of note except that in many specimens a narrow faint groove a little lower down marks off a second revolving ridge, which, however, is a much less pronounced feature than the other. Owing to the flattened and horizontal zone at the top of the whorls the suture is deeply indented and the spire has a decidedly turreted shape.

The surface is marked by very fine and very faint revolving lines which vary greatly as observed on different specimens. At best however, they are so obscure as to create the impression that the variation is partly illusory and is of little moment. In the largest of my specimens these lines are fairly distinct on the upper part of the whorl down to the sulcus below the carina, which they almost cover. They can not be seen below this indefinite boundary for a considerable distance, but they come in again as very fine, very faint incised lines, which are relatively far apart. These faint lines can be recognized by traces down to the axial region. Thus a relatively broad zone is found just below the sulcus that forms the lower boundary of the carina where no revolving lirae can be seen. In other smaller specimens this zone is marked by revolving lirae like the rest of the surface and the striae are much closer together. Transverse markings are all but absent and are restricted to striae of growth which are very obscure, even where they can be seen at all. The rather broad zone defined above by the pronounced sulcus and below by the very faint one is without much question the site of the slit band, if such a structure is really present. The lines of growth below the zone, and presumably above it, are bent strongly backward, indicating, if not a slit, at least a sinus in the outline. Not far below this band the growth lines make a rather broad turn and pass backward with strong obliquity, but are deflected into a gently concave curve on the lower surface and a gently convex curve near the axis. In several specimens the outer lip is apparently almost unbroken and shows a short but very pronounced notch, which at its inner end conforms closely with the slit band in width and position but widens considerably outward. The lower part of the inner lip appears as if thickened and folded back on itself to form a solid axis.

This species appears to be more closely related to *P. subglobosa* Hall than to any other *Pleurotomaria* of the American Carboniferous, but it is a little uncertain what *P. subglobosa* really is. Either the specimens from the Spergen limestone which I refer to Hall's species are wrongly identified or his description is incomplete as well as inaccurate. My interpretation of the species seems to be along the same lines as that of Cummins, who also animadverts upon this fact, and my specimens agree fairly well with Whitfield's figures of an authentic specimen, though the figures are seemingly at variance with Hall's description. The description represents the shell as being obscurely biangular upon the upper side of the volution, with one depression between the two angles and another toward the suture; the specimens, on the contrary, show grooves where the description calls for angles. The grooves define low ridges of which the upper rounds into the suture above and into the stronger of the two grooves below. The lower ridge is narrower than the upper and less sharply outlined. Its upper boundary, to be sure, is the same groove that makes the lower boundary of the other but its lower boundary is very faint. The configuration consequently is somewhat comparable to that of *P. aspeniana*, though the upper ridge is much less prominent owing to its rounded shape. Thus in its characterization of the shape the original description appears to be misleading, and in its characterization of the sculpture it is equally incomplete. The sculpture is said to consist merely of fine, closely arranged revolving lirae. There are, in fact, fine sharp revolving lirae on the upper of the two ridges and somewhat finer, fainter revolving lirae on the lower. A sharp change occurs below the lower ridge, however, for at that boundary the markings abruptly become much finer and take the form of incised lines with relatively broad, flat interspaces. These markings are more or less wavy, and they are not parallel to the band but run off from it with distinct obliquity. Hall observed no cross striae, but in some specimens the strong and regular revolving lirae on the upper part of the volutions are distinctly cancellated by them. Hall also said that there are some indications of a spiral band on the periphery. The band, I am entirely satisfied, is represented by the lower of the two revolving ridges and consequently in position is well above the periphery. This interpretation is supported by the abrupt change in sculpture below the ridge and its uniform character over the rest of the surface and also by the growth lines which cross the periphery in a broad convex curve and bend backward to the lower boundary of the lower ridge. In this character also there is a close correspondence between *P. subglobosa* and *P. aspeniana*. As thus redefined, *P. subglobosa* differs from *P. aspeniana* in its smaller size, in its less prominent ridges below the suture, and in its sculpture, the lirae being coarser and much sharper over the upper part of the volution and sharper, oblique, and irregular over the lower part.

I might mention in connection with *P. subglobosa* that some of my specimens retain traces of coloration, the most conspicuous being rounded blotches of darker tint at regular intervals along the slit band, the darker spots appearing also to be slightly raised. Narrow, irregular incomplete dashes of darker color cross the lateral surface.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, slide above phosphate ground, Swan Lake Gulch (station 975).

Pleurotomaria brazeriana Girty, n. sp.

Plate 25, Figures 8–12

Shell of medium size, conical, somewhat turreted. Proportions of height and width variable, sometimes one dimension, sometimes the other being the greater.

Final volution rhombic in cross section. The lateral surface is gently concave (gradually transformed from convex in the immature stages) and slopes steeply downward and outward so as to make an angle of 45° or less with the axis. The periphery is rather distinctly truncated by the slit band, which is defined by two slender carinae, the upper carina being a little larger and more prominent than the lower. From the lower carina the shell does not immediately pass inward to the axis but drops a short distance, curves strongly to a direction nearly horizontal, and then passes upward into the very deep umbilicus. The volutions embrace up to the lower margin of the slit band, so that the rather broad band and the rather prominent carina above it conspire to produce the turreted appearance above alluded to.

The upper surface is marked by 7 to 10 sharp, slender revolving lirae, separated by striae of about the same width or slightly wider. These lirae are crossed by slender transverse lirae somewhat smaller than the revolving ones and not so far apart, the two sets of lines producing a conspicuously cancellated appearance. The transverse lirae are slightly curved, with the convex side toward the aperture, and have a strong backward swing. They cross the slit band in a series of strong, rather widely spaced lunettes.

The lower surface is marked by revolving lirae, 10 to 13 in number, generally similar to those on the upper surface, though somewhat more closely arranged. The transverse lines are also finer and much more closely arranged, and on some specimens they are rather obscure. They can usually be seen sharply expressed in the striae between the lirae and as fine crenulations on the revolving lirae themselves.

Although *P. brazeriana* is a simple type of *Pleurotomaria*, I have found no species which, with a certain regard to geologic time and geographic location, closely resembles it. Some species differ so markedly in general form that they are eliminated upon that consideration; others upon consideration of sculpture. The absence of an angular carina, other than the slit band, where the lower and lateral surfaces meet, together with the peripheral position of the band, which is contingent upon this relation, the oblique, steeply descending, and gently concave character of the lateral surface, the absence of distinct nodes upon any part and especially their absence from a zone below the suture—all are more or less distinctive.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Pleurotomaria dinglensis Girty, n. sp.

Plate 25, Figures 21–24

Shell very small, composed of about four rapidly enlarging volutions, compressed, spheroidal, wider than high. Spire low. Suture indented, distinct. The final volution is ovate in section and subangular at the periphery, which is situated a little below the middle. Upper surface moderately convex and oblique. Lower surface moderately convex and almost horizontal. Umbilical region deeply excavated.

Upper surface marked by four slender revolving lirae separated by relatively wide interspaces. The periphery is occupied by a revolving lira larger and thicker than the rest, which with a stronger curvature developed at that locus gives the whorls a somewhat carinated appearance. The lowest of the revolving liræ on the upper surface is finer than the others and is situated close to the large peripheral lira. The narrow groove between them probably represents the slit band. The lower surface is marked by six or seven revolving lirae about their own diameter apart. They are thicker than the lirae upon the upper surface, because of which character and because of their number they are much closer together. They are, however, not so large as the peripheral lira. In addition, the upper surface is marked traversely by minute but sharp raised lines, which die down at or a little above the spiral lira that forms the upper boundary of the slit band but reappear as very fine lunettes, which were observed only as traces, in the narrow groove that is provisionally identified as the band. On the lower surface the transverse markings are again appreciable and are apparently of much the same character as those above though on the type specimen they are by no means as sharp and strong. Those of the upper surface are more slender and much more closely arranged and although fairly regular increase by bifurcation or intercalation in spreading out between the short arc of the suture and the long arc of the periphery.

As above intimated, the slit band can not be identified with complete certainty. If the shell is considered as a whole the irregularly rounded volutions and the inequality of the revolving lirae in size and spacing seem to indicate that it is not one of the Cyclonemas but that some one of the specialized features is the site of the slit band. The most specialized features occur on the periphery, and even if this were not so, the sharp and undeviating transverse lines that pass across most of the upper surface show clearly that no slit band need be looked for there. The most probable locus for such a structure is either the exceptionally heavy peripheral lira or the exceptionally narrow groove just above it. The slit band is commonly a zone of depression, though it may be a depressed part of an elevation. The groove then is more probably the slit band than the peripheral lira, and this probability is enhanced by the presence there, though it can not be vouched for, of traces of lunettes.

P. dinglensis may be said to combine the shape of *P. humilis* or *P. piasaensis* with the surface markings of *P. nodulistriata*, for though the sculpture on the upper surface is altogether different from that of *P. nodulistriata*, the characters of the periphery and of the lower surface, without being identical, are distinctly comparable. On the other hand, the shape, though comparable to that of *P. humilis* and *P. piasaensis*, is not without its differences, and the sculpture is unlike in many particulars. Of the two, the resemblance to *P. humilis* is greater, but even young specimens of *P. humilis*, which are more like this shell than old ones, differ somewhat both in shape and sculpture. The shape is more discoidal and the volutions less angular at the periphery. The revolving lirae on the upper surface are more numerous and necessarily more crowded, but the transverse lirae are coarser and more widely spaced. The slit band is conspicuous and peripheral in position, whereas in this species the periphery is occupied by a ridge or costa and the slit band occurs just above.

Horizon and locality: Brazer limestone; Montpelier quadrangle, 2½ miles south of Dingle, Idaho (station 1446).

Pleurotomaria pealeana Girty, n. sp.

Plate 25, Figures 13–18

Shell small, depressed, almost discoidal. Volutions about four, rapidly enlarging. Spire low; suture indented, distinct. Final volution elliptical in section, its longer axis declining, though not strongly from the horizontal. Upper and lower surfaces gently convex. Periphery narrowly rounded.

Upper surface marked by rather coarse revolving costae, each of which bears a row of beadlike nodes. The costae, which in the type specimen are nine in number, are separated by striae of about the same size or slightly larger. The nodes are very sharply defined and stand about their own diameter apart. They are not apparently arranged in distinct transverse rows, and no transverse cancellating lines have been observed. The periphery is occupied by the slit band, which is of moderate size, defined by strongly elevated lines, and crossed by delicate lunettes, which are rather difficult to make out. The lower surface is marked spirally by raised lines which are very similar to those that bound the slit band but are in strong contrast with those found upon the upper surface, as they are much more slender, are separated by broad, shallow interspaces, and are not nodose. There are eight of these revolving lines, a considerable space in the umbilical region being without them. The umbilicus appears to be open. The type specimen has the appearance of being but little broken; if so, the plane of the aperture is very oblique, the upper margin projecting far beyond the lower, and the slit is a shallow notch.

This species appears to be distinct from any of the Spergen Pleurotomarias, but it may be said to combine the shape of *P. piasaensis* or of *P. humilis* with the sculpture of *P. nodulistriata*, though the nodes of the latter are much more clearly produced by the impact of sharp transverse lirae upon revolving ones. No other Carboniferous species of *Pleurotomaria* of which I have record resembles this one at all closely.

The specimen which furnished the foregoing description is only about half grown, if a second and much larger one from another locality is rightly referred to the same species. This specimen has a diameter of not less than 15 millimeters, but as the rate of enlargement is very high it seems to have only one more volution than the other. Unfortunately it is broken in the apical part, so that a comparison with the type specimen on equal terms as to size can be made only partially. In this partial way the two specimens seem to agree. The larger one, however, in the mature whorl shows some marked changes. The long axis has become relatively much longer, so that the volution is greatly compressed. The sculpture also has undergone a slight transformation. The revolving lirae have increased to the number of 16 on the upper side, not including the slender one that bounds the slit band, and they are distinctly though not strongly alternate in size. They are also conspicuously nodose, but the nodes are connected across the interspaces so as to form a series of transverse lines, which are weaker than the revolving ones and are in the nature of low, stout lamellae. There is strong indication that the difference between the two specimens in this regard is due partly to age and partly to condition of preservation.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, slide above phosphate ground, Swan Lake Gulch (station 975); NW. ¼ SW. ¼ sec. 13, T. 10 S., R. 43 E. (station 7607a).

Phanerotrema brazerianum Girty, n. sp.

Plate 25, Figures 25–27

Shell very small, turbinate, composed of four or five volutions. Spire moderately high. Suture indented, distinct. Final volution somewhat flattened and oblique from the suture downward, strongly rounded across the periphery and moderately convex below. The periphery occurs at about the mid height, and is the site of the slit band, which is rather broad and is sharply defined by raised lines. The upper surface, which is faintly convex above and faintly concave below, is marked by six or seven slightly raised lines, the lowest of which forms the boundary of the slit band. These lines are irregularly spaced, but in general they are not so wide as the intervals between. The lower surface is marked by 12 or 13 fine regular revolving lirae about their own diameter apart, the markings here being very sharp and very regular. The transverse markings on the upper side consist of slender, sharply raised lines, about like the revolving ones but more closely arranged. They produce a cancellate sculpture over most of the upper surface but become fainter in the region of the slit band. On the band itself they form very fine but distinct lunettes, but below it they are scarcely appreciable. They are there extremely fine but regular and are best shown in the narrow striae between the lirae.

This species is obviously related to the common Pennsylvanian *P. grayvillense*, and some of the differences in sculpture might fairly be ascribed to the very great difference in size of the shells themselves. Most obvious of the differences in sculpture are the absence of a swollen and nodose zone below the suture and the subdued character of the transverse markings on the under side of the final whorl, where the spiral lirae are not nodose as on the Pennsylvanian form. Comparisons with other species of *Pleurotomaria* (or *Phanerotrema*) are scarcely necessary. Those which are not obviously different in other ways differ in having the revolving lirae wholly or in part conspicuously nodose. I here have regard, however, only to species recognized in our American Carboniferous faunas. The Spergen fauna especially shows no really comparable species. *P. nodulistriata* is similar in shape, but the upper side is strongly nodulose, and the slit band is entirely different in character. *P. wortheni* is more nearly allied at first glance than on closer inspection. It is impossible, indeed, to bring the description of *P. wortheni* and the figures into reasonable harmony. In the description *P. wortheni* is compared to *Trepospira sphaerulata*, a species which is distinguished among other characters by being wholly without revolving lirae either on the upper surface or on the lower. *P. wortheni*, however, is described as having revolving lirae on its under side, a vital difference which is not mentioned in comparing it with *T. sphaerulata*. Again, the description does not mention revolving lirae as occurring on the upper side, though they are said to be a character of the lower side. The figure, on the other hand, clearly shows fine revolving lirae on the upper surface. An intelligent comparison with *P. wortheni* is thus impossible.

Horizon and locality: Brazer limestone; Montpelier quadrangle, 2½ miles south of Dingle, Idaho (station 1446).

Capulus striatulus Girty, n. sp.

Plate 25, Figures 33–38

Shell rather small and rather broadly conical. Axis slightly curved and slightly oblique, so that the apex projects beyond the posterior margin of the aperture, though not far. The profile of the anterior side is gently convex; that of the posterior side is even more gently concave. The aperture is triangular in outline, one of the angles being anterior and the side opposite posterior. The sides, however, are gentle curves and the angles abrupt ones, the difference being that of degree. The shape of the aperture is indicative of that of the whole shell, or most of it, the anterior surface being obscurely carinate and the posterior surface being flattened.

The surface is variously marked. Most conspicuous are longitudinal costae which are as a rule irregular in size and spacing and not very sharply defined by subangular striae. These costae die out before reaching the apex. Transversely the shell is crossed by distinct growth lines and at intervals by more or less strong striae, which give it a faintly undulating appearance. Here and there, but especially on the posterior face, small roundish depressions can be observed.

There exists considerable confusion with regard to the validity and application of the generic names that have been introduced for the *Platyceras* type of gastropod. The present species has been referred under the genus *Capulus*, but it is not far removed in character from some of the shells that presumably belong under *Orthonychia*. Some of the American species at present resting under *Capulus* resemble this one in being regularly plicated, but even these differ in having the plications larger and less numerous as well as considerably more pronounced. The most closely comparable species in many ways is *C. fissurella,* if the striated shells figured by Meek and Worthen really belong to Hall's species. *C. subelegans* also resembles *C. striatulus* in general appearance, but though the typical specimens agree in having an aperture more or less triangular in shape, in this species the posterior side of the shell is flattened; in that, the anterior. In shells as variable as these, however, especially if their shape is in large measure determined by the object upon which they fixed themselves, as is commonly thought, this difference is minimized. So, indeed, are most of the differences between species in this great group of shells.

Some of the shells referred to *Orthonychia* are in the character of their plications more aptly comparable to *C. striatulus* than the Capuli, but on the other hand they are more slender and elongated in shape. *O. formosa* and *O. jeffersonensis* are perhaps more nearly allied than the other species.

The species of *Platyceras* are, with but few exceptions, which probably should be removed to *Orthonychia,* more strongly involute than *Capulus striatulus.* Some of them are more or less similarly plicated, but those that resemble the present form in that character differ in the other, and those that are especially erect are not only unplicated but more slender; thus if species are to be discriminated among these shells by the only characters with which they come down to us, *Capulus striatulus* can not be closely identified with any yet described, at least with any described from the Carboniferous faunas of North America.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Capulus striatulus var. gracilis Girty, n. var.

Plate 25, Figures 39–41

This variety, as exemplified by the type specimen, is much smaller than *C. striatulus* itself, more slender, less oblique, and possibly more closely coiled at the apex, though the parts involved are so small that it is difficult to tell whether the shells are whole or broken and whether the apical coil is open or closed.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

Phymatifer? tricarinatus Girty, n. sp.

Plate 25, Figures 28–30

Shell, small, discoidal, composed of three or four rapidly enlarging volutions. Spire flat, scarcely rising above the last whorl. Final volution somewhat carinated above, below, and on the periphery. The upper carina finds expression in a row of large rounded nodes not far from the suture. It begins as a faint angulation faintly enlarged at regular intervals. The enlargements rapidly become more pronounced and involve the whole carina, which would otherwise be scarcely appreciable. The peripheral carina is a blunt angulation that is probably not nodose or at least is doubtfully nodose. The lower carina at its maximum is a rather strong angular ridge that is situated nearer to the axial than to the peripheral side of the whorl. It begins as a scarcely appreciable angulation but develops rapidly, so that at the aperture the peripheral carina, instead of occurring midway on the whorl, comes to be situated distinctly above the middle, owing to the increased projection of the lower side. As the lower carina increases in height it becomes also nodose, but the nodes are not as strong as the nodes of the upper carina, and are spirally elongated. There the nodes form the carina; here they are undulations along its crest. In other respects also the two carinae are in contrast, for the upper one is distinguishable along almost the whole of the last volution; the lower one along only about half. Though the upper carina lies almost directly above the lower, their characters and their rate of development are such that the descent to the suture is short and gentle, but the ascent into the umbilical cavity is long and steep. The umbilical excavation is therefore large and deep. The surface is smooth or marked only by faint incremental lines.

The generic position of this shell is problematic, for I recall none quite like it in our Carboniferous, especially in our Mississippian faunas. A certain resemblance to the species referred under *Porcellia* is obvious, but *Porcellia* should be almost complanate, which this shell is not, and especially it should have a slit and a conspicuous slit band on the periphery, of which this shell has no trace. Neither *Porcellia* nor any of the Pleurotomarias consequently need be considered further. The relation next suggested by its general configuration is with the euomphaloids, a relationship which apparently has more in its favor than the other. Certainly some analogies can be drawn between this form and the group of euomphaloids for which the term *Phymatifer* was introduced, but the Phymatifers are commonly very large shells that pass through a rather conspicuous *Euomphalus* stage and they make their appearance late in the Carboniferous. In all respects *P. tricarinatus* is out of the ordinary, and its relation to *Phymatifer* is open to grave doubt.

Horizon and locality: Brazer limestone; Slug Creek quadrangle, Idaho, slide above phosphate ground, Swan Lake Gulch (station 975).

Bulimorpha elegans Girty, n. sp.

Plate 25, Figures 31–32

This is a slender shell that consists of perhaps eight volutions. The last volution comprises considerably more than half the entire height, the length of the aperture considerably less. The final volution is rather strongly convex; the greatest curvature occurs near the middle and the upper half is the most feebly arched. Consequently as the volutions overlap to about the middle the exposed parts that together constitute the spire are rather flat, and the suture, though conspicuous, is not deeply indented. *B. elegans* has much the same shape as *B. bulimiformis,* but it is larger and is composed of more numerous and rounder volutions. As the species of *Bulimorpha* have a strong general resemblance, this Mississippian shell does not differ greatly from certain Pennsylvanian ones, though appreciable differences are more or less obvious as between the type specimens at least. *B. elegans* is, for instance, scarcely more than a miniature replica of *B. nitidula.* It is more slender than *B. whitfieldi,* and the last volution is correspondingly narrower.

Horizon and locality: Brazer limestone; Henry quadrangle, 6¾ miles northwest of Henry, Idaho (station 3023).

NEW SPECIES OF CARBONIFEROUS FOSSILS FROM THE WELLS FORMATION

Schizophoria texana Girty, n. sp.

Plate 27, Figures 1–8

Shell rather small, transversely subelliptical, inflated. The lateral outlines are nearly straight in the upper part but round inward rather strongly to the long hinge line, which they meet at an obtuse but distinct angle. The anterior outline is long, gently emarginate, strongly curved at the sides.

Pedicle valve rather shallow, highest at the posterior end. Cardinal area well defined, about one-fourth to one-third of the greatest width; rather high and nearly flat in the lower part, which is almost perpendicular to the plane of the shell margin but more arched above, so that the inclination of the area as a whole is about 45° backward. Foramen higher than wide, occupying one-fifth or more of the hinge line. Beak narrow and pointed, not strongly incurved, rather prominent as a topographic feature, and projecting distinctly beyond the hinge line. The anterior part of the valve is depressed into a broad undefined but rather deep sinus, which begins well up in the umbonal region as a flattening and becomes deeper and broader as it passes forward.

On the inside the valve shows two narrow elongated muscle scars divided by a septumlike ridge. The dental plates are high and thin, but they abruptly pass into low, rounded ridges that define the muscular area. In some specimens the ridges are distinctly continued around the anterior end of the scars. In others the scars have no distinct anterior boundary. The septum has its origin in the umbonal cavity, a short distance in front of the beak, and steadily rises to its maximum not far from the anterior end of the muscle scars, gradually becoming thicker as it becomes higher. It there abruptly subsides, and in such a manner that in many specimens the septum, which is thin on top and broad below, appears to be obliquely truncated at the anterior end by a plane surface, angular in outline, whose spreading sides form the recurved boundary of the muscular imprints. The muscular area as a whole is conspicuously longer than wide, and it extends about halfway or less down the valve.

The brachial valve is highly arched, more or less inflated in the umbonal region, with a small, pointed, rather prominent and strongly incurved beak. The median part of the shell is flattened lengthwise or in most specimens appreciably depressed into a rather narrow sinus. The cardinal area is narrow, slightly arched above, very sharply defined and situated almost in the plane of the shell margin. The crural plates, which diverge rather strongly, are thin and high but not very long. They project at the anterior end as short but very conspicuous crura, immediately behind which they are expanded to form the dental sockets. A small but well-defined cardinal process is found in the umbonal cavity just anterior to the beak. The muscle scars are rounded and more or less flabelliform, but they are very faintly outlined. They are separated from one another by a low median septum, which is short and dies down rather rapidly in both directions.

The surface is marked by very fine regular lirae, of which certain ones stand up above the rest. These elevated lirae, though they may be rather long, are not continuous but end abruptly in a tiny aperture, as if they were themselves hollow or else ended in a hollow spine. They occur at rather regular intervals and are most strongly developed on the marginal parts of the shell, especially, it would appear, on the mesial part of the pedicle valve and on the sides of the brachial valve.

In their relation to each other the brachial valve is more convex than the pedicle valve, but the brachial valve is highest about midway, whereas the pedicle valve is most elevated close to the posterior end. The beak of the pedicle valve is much more elevated; that of the brachial valve much more incurved. Although the cardinal area of the pedicle valve is much higher than that of the brachial valve it is also more oblique, so that the two beaks project about equally.

The types of *S. texana,* two of which are figured here, come from the Marble Falls limestone of Texas, of Pottsville age. The specimens from Idaho appear to belong to the same species, and the shell from New

Mexico identified by White as *Orthis resupinoides?* should also be compared with it. There seems to have been a marked efflorescence of the *Schizophoria* type in the early part of Pennsylvanian time, of which this occurrence in the Wells may be an instance. This generalization, however, needs to be tested, and it remains to be shown to what extent these various occurrences of *Schizophoria* in the Pennsylvanian, of which others could be mentioned, are really of the same or of about the same geologic age.

Horizon and locality: Marble Falls limestone; San Saba quadrangle, bed of Cherokee Creek, half a mile northeast of Bend, Tex. (station 2417), and about 3 miles south of San Saba on road to Llano (station 2607).

Wells formation; numerous localities in southeastern Idaho, mostly in the basal part of the formation.

Orthotetes mutabilis Girty, n. sp.

Plate 27, Figures 9–15

These shells vary so greatly that what is said of them must be either very general or very individual. The pedicle valve is as a rule very elongate and in some specimens very attenuate, and it has an extraordinarily high and somewhat backward-sloping cardinal area. The cardinal area may, however, be low and but slightly inclined. The growth is strongly irregular, some specimens being undulated transversely, others twisted, and others variously contorted. The high cardinal area is divided midway by a relatively narrow pseudodeltidium, which in turn bears a distinct median groove. On the interior the septum, which is very long, unites with the short converging dental lamellae so as conspicuously to exemplify the camerate type of structure characteristic of *Orthotetes* s. s.

The brachial valve is moderately gibbous, somewhat inflated in the umbonal region. The outlines contract rather strongly as they near the hinge, as of course do those of the pedicle valve.

The surface is marked by the characteristic slender more or less alternating radial lirae, here developed on an unusually small scale.

As the height of the cardinal area varies with age, and as its apparent inclination is affected by breakage at either end of the shell, variation in these characters is apt to be more apparent than real. In these shells the area has a distinct though not very strong backward inclination from the hinge line, varying somewhat toward either extreme. It may be gently convex, and the upper part of the valve may be gently concave, so that but a narrow space is left between. A number of pedicle valves in the collection have this configuration. On the other hand, the area may be flat and the upper part of the valve convex, when a very different appearing and a much more capacious shell results. My specimens suggest that in this form the cardinal area is somewhat lower than in the other. The brachial valve is as usual less variable than the pedicle valve. However, some specimens have the umbonal region flattened, though seemingly in most it is rather gibbous. This valve, like the other is of irregular growth, but from its general plan it can not be so much contorted.

In the greatly elevated pedicle valve, extremely variable shape, and very fine striation, this species suggests *Derbya multistriata*. In *D. multistriata*, however, the median septum does not unite with the dental plates but passes between them, attaching itself to the pseudodeltidium. It thus exemplifies the septate as this species exemplifies the camerate type structure. Even if this were not so, *D. mutabilis* belongs in an earlier and different fauna and has some distinctive characters of its own. For instance, in *D. multistriata*, variable as it is, we rarely find the compressed attenuate shape which here seems to be so common.

Horizon and locality: Wells formation; Slug Creek quadrangle, Idaho, ridge east of Cranes Reservoir (station 7608).

Chonetes mesolobus Norwood and Pratten var. inflexus Girty, n. var.

Plate 27, Figure 16

It is perhaps not entirely safe to take any of the prevalent forms of *C. mesolobus* as the typical one, but from any of those that are commonly seen the present variety differs in the strength of the median lobe and in its depressed position between the two very prominent lateral lobes. The median lobe is also rather narrow for the size of the shell as a whole, which is considerably above the average in *C. mesolobus*. In the more typical varieties of *C. mesolobus*, if one may use that expression, even when the median lobe is well developed, its crest is almost if not quite in the plane of curvature of the upper surface, not deeply depressed below it. In regard to the more minute characters of the shell, it has fine, not very sharply expressed radial lirae and appears to agree with typical *C. mesolobus* rather than with the smooth variety known as *decipiens*.

Horizon and locality: Wells formation; Slug Creek quadrangle, Idaho, ridge east of Cranes reservoir (station 7608).

Spirifer opimus Hall var. occidentalis Girty, n. var.

Plate 27, Figures 28–31

This is a rather large shell, considerably wider than long, and widest at the hinge, which is extended. The convexity of the two valves is rather strong and equal; that of the pedicle valve is greatest in the umbonal region, with a much reduced curvature toward the front. The cardinal area of the pedicle valve is rather low, and the median sinus broad and shallow. In the brachial valve the fold, though similar in width, is rather high and sharply defined. It has flattened sides and would be subangular on top, which is, however, traversed by a rather strong median groove. The plications are rounded but strong; about 12 occur on each of the lateral slopes, 5 in the sinus and 6 or 8 on the fold. The median rib in the sinus is distinctly larger than the others, and correspondingly the median sulcus of the fold is larger than the grooves that separate the costae upon its sides. The plications nearest the fold and sinus may be bifurcated, as many as three on each side.

The surface is cancellated in the usual manner by longitudinal and transverse lirae.

Shells of this type are nearly everywhere present in Pennsylvanian rocks of the Rocky Mountain region, and they have commonly been referred under *S. rockymontanus*. Very few of them, however, agree very well with the small, finely costate form so named by Marcou, least of all this large species with its coarse ribs and extended hinge line. Accordingly I at one time referred a form that is probably specifically identical with this one to *S. boonensis* Swallow. Hardly less distinct is the form that Hall described as *S. opimus*, though *S. opimus* is widely regarded as a synonym of *S. rockymontanus*. I scarcely doubt, however, that close study of these abundant and variable shells will establish them as belonging to several species. The present form I recognize as distinct from *S. rockymontanus* by reason of its large size, extended shape, and coarse heavy costae. It is less sharply distinct from *S. opimus*. The differences are obvious, their importance more a matter of opinion. This variety is larger, is more extended at the hinge line, and has a lower cardinal area in the pedicle valve. Corresponding to its larger size it has more numerous costae, several of which are invariably bifurcated. If these differences are constant the present form deserves to rank as a distinct species. Authentic *S. rockymontanus* and authentic *S. opimus*, as distinguished from varieties that have been cited under those species, are but little known, and the variation shown by shells rightly referred to them may partially obliterate the differences or, on the other hand, establish others.

Although I had at one time referred to *S. boonensis*, a shell which is probably identical with this one, the identification now seems undesirable. The significance of *S. boonensis* is even more a matter of doubt than that of *S. rockymontanus* or *S. opimus*, for of these species we have figures, but of *S. boonensis* we have none. Swallow does not mention bifurcation as taking place on any of the lateral costae of *S. boonensis*, though he describes the development of the costae on the fold and sinus with care and accuracy. Furthermore, he describes the sculpture as consisting of fine concentric imbricating lamellae without any fine radiating striae, this being one of the characters that differentiate this species from *S. opimus*. Certain Mississippian Spirifers are marked in this way, as is well known, but of the Pennsylvanian Spirifers from the Interior Basin I do not recall one that has the concentric lamellae without the radial striae. In *S. cameratus*, to be sure, both markings are very fine and very faint. In *S. opimus* both are present and both are obvious, as mentioned by Hall, and both are found in the form under consideration. Swallow may have had in *S. boonensis* a species of a type entirely new to the Pennsylvanian or he may have had one in which the development of the two sets of markings was extremely disproportionate, or his observations may have been faulty. If his observations were faulty, his description can not at present be corrected, for in my studies of the Pennsylvanian faunas of Missouri I found this type of *Spirifer* extremely rare, only three or four having been observed in several hundred collections. At all events, though the present form may ultimately prove to be the same as *S. boonensis* it appears to show several important differences, which as long as they remain disproved cast doubt on the identification.

Horizon and locality: Wells formation; Crow Creek quadrangle, Idaho, sec. 35, T. 9 S., R. 45 E. (station 32).

NEW SPECIES OF LOWER TRIASSIC FOSSILS FROM THE WOODSIDE AND THAYNES FORMATIONS

Pugnoides triassicus Girty, n. sp.

Plate 30, Figures 1–41

Shell of medium size, rarely much more than 10 millimeters in length. Length and breadth about equal, the length generally the greater. Outline variable; subovate, subtriangular, or subpentagonal in different specimens. Convexity rather high in mature shells, extremely high in some but only moderately so in others.

The pedicle valve has a sharply defined median sinus, which occupies considerably more than one-third the width. It may be very deep or only moderately deep but in either case is practically restricted to the anterior two-thirds of the valve. In the posterior one-third the transverse curvature is rather strong, but by degrees the median part becomes depressed, while the sides remain nearly straight; thus a line down the middle of the sinus is strongly arched, while a line from the beak to one of the angles bounding the sinus is approximately a right line. The beak is small, pointed, and suberect. The lateral margins are folded inward for some distance below the beak, so as to create a sort of false cardinal area, which is rather sharply defined if the shell is not exfoliated. A narrow, open triangular foramen divides the "area," but the structure in this part is not well shown.

The brachial valve is more or less extremely convex and in some respects is the opposite of the pedicle valve in its configuration. The posterior part in the umbonal region commonly appears flattened. The fold is strongly developed and sharply defined, owing to the deeply deflected sides, though the lateral flexures are not sufficiently pronounced to make it a distinguishable feature back of the middle of the shell. The curvature lengthwise along the crest of the fold is but gentle; the sides, though strongly oblique, are not strongly arched lengthwise.

The plications are strong and as a rule angular, though they may be somewhat rounded. Two or three occur on the fold indifferently. The number on the lateral slopes is also variable. We may find one distinct and one obscure plication, two fairly distinct, or two fairly distinct followed by a third that is faint. If the fold bears only two plications it is narrow and occupies on top about one-fourth the width; if it bears three plications it occupies about one-third the width. The sides of the fold diverge considerably, so that the top, which is the most conspicuous part of the fold, and the bottom, which is the most conspicuous part of the sinus, occupy very different proportions of the respective valves.

On the interior the pedicle develops two distinct dental plates and the brachial valve a fairly long, high, thin median septum. The septum connects at the posterior end with the hinge plate, which is divided down the middle by a groove and is flexed at the sides to form the dental sockets.

The internal structures of the brachial valve are not so certainly determined in detail as to be beyond the range of correction, but apparently they are in every essential those of *Camarotoechia* or of *Pugnoides*, though the more or less marginally developed plications definitely indicate *Pugnoides* for the proper generic reference as between these two. Indeed, it is not quite certain that this shell can be adequately distinguished from the common Pennsylvanian *Pugnoides osagensis* Swallow. On the one hand there is an intrinsic improbability that this Triassic shell was really the same species as the Carboniferous one, however difficult it may be to find distinguishing characters in them in their fossil form, and on the other hand not a little uncertainty surrounds the question which of the several rhynchonelloid species that occur in our Pennsylvanian faunas should really be covered under Swallow's loosely drawn description. On both heads an argument might be framed for considering the present form to be a new species. In its proper characters this shell appears to be marked by fewer plications, if we may provisionally employ Meek's interpretation of *Pugnoides osagensis*, for he describes that species as having three or sometimes four plications on the fold and three or four on each side. In comparison with specimens which I would identify with Meek's form the plications are more angular and the sides of the fold and sinus longer, so that there are fewer and also weaker plications on the lateral slopes of the valves.

The question might properly be raised also whether this shell is not the authentic *Pugnoides utah* of Marcou. Unfortunately but little confidence can be accorded to Marcou's description or to his figures, or even to his citation of locality. His description contains too little detail; his figures, one might think, too much. He gives Salt Lake City as the locality and Carboniferous as the geologic age, but a certain latitude must probably be allowed to that statement. His specimens of *Pugnoides utah* may have been received from friends, as were some of his other specimens. Both Lower Triassic and Permian (*Spiriferina pulchra* horizon) rocks occur close to Salt Lake City, but from neither have I seen specimens of *Pugnoides*. Indeed, *P. utah* is said by Marcou to be associated with *Hustedia mormoni*, *Cliothyridina roissyi*, *Composita subtilita*, and *Productus semireticulatus*, and not only is this a distinctly Carboniferous fauna but one probably older than the *Spiriferina pulchra* horizon.

Pugnoides utah, then, must be regarded as a Carboniferous species, and Marcou's figures, though they are not to be trusted implicitly, indicate that the present species is not *P. utah*, which has more numerous and stronger plications on the lateral slopes.

Horizon and locality: Thaynes group; Montpelier quadrangle, 1¾ miles west of Paris, Idaho (station 7631).

Terebratula thaynesiana Girty, n. sp.

Plate 30, Figures 5–7

Shell rather small, rarely more than 13 millimeters in length. Shape generally ovate but varying greatly in the proportion of length to width. The length appears to be invariably greater than the width, but it may be much greater or only slightly greater. The extreme width is situated at about the middle or slightly anterior to the middle, and the outline below tends to be somewhat straightened instead of regularly curved. The convexity is not very high, but the pedicle valve is much more convex than the brachial. The umbonal parts of the pedicle valve above the hinge line are somewhat inflated and obliquely flattened on either hand, the shell being abruptly inflected so as to form almost an angle at the sides and a sort of cardinal area on the dorsal surface.

The fold and sinus bear a reversed position on the valves in comparison with the normal brachiopod, the fold being developed on the pedicle valve and the sinus on the brachial. To this arrangement may be ascribed the marked disparity between the two valves in convexity. The pedicle valve tends to be somewhat flattened down the median portion, from which the descent to the sides is rather strong. Toward the front this flattened portion is defined by faint broad sulci, which give it the appearance of an elevation or fold. The brachial valve is very shallow and is depressed toward the front into a rather broad, shallow sinus, which projects beyond the sides in a linguiform manner. In some specimens an incipient plication of the fold and sinus can be observed, the fold being broadly depressed in the anterior part and bounded at the sides by distinct angles, so that if the specimen is held in the usual position, with the brachial valve uppermost, the brachial valve in anterior view bears a low fold but a fold sunk in a much deeper sinus.

The internal characters are as yet imperfectly known. Dental plates seem to be developed somewhat as in *Dielasma* and other Paleozoic terebratuloids, but the plates are short and oblique and they are situated close to the sides of the rostral part of the shell. My observations on the brachial valve are even less satisfactory than those on the pedicle valve. The length of the loop has not been ascertained. It appears to proceed from the thickened dental sockets without being connected with any internal plates, either horizontal or vertical. As I am thus hardly in a position to place *T. thaynesiana* in the complicated classification of the Terebratulidae, I am including it under the genus *Terebratula* used in its broad sense.

Horizon and locality: Thaynes group; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7406).

Spiriferina mansfieldi Girty, n. sp.

Plate 30, Figures 17–19

A species belonging to the *spinosa* group, of medium size, generally wider than long.

Pedicle valve very variable in shape, correponding to variation in the height, curvature, and inclination of the cardinal area. In a general way the shape is conical, with a broad, abrupt, and somewhat oblique truncation on the posterior side. The area ranges from moderately to very high. Though invariably arched, especially in the upper part, it may be nearly flat or, on the other hand, gently concave. It may make a very obtuse angle with the plane of the shell margin, so as to be somewhat erect in the side view, or it may be more nearly perpendicular to that plane. In the majority of specimens, however, the area is rather high, is only slightly curved and is rather strongly inclined backward from the cardinal line. It is defined from the parts in front by sharp angles. The delthyrium is large, and it may be considerably higher than wide, its proportions tending to vary with those of the area itself. The widest part of the shell occurs at the hinge line. Owing to the great variation in the height and direction of the cardinal area, the width varies in different specimens from considerably greater to considerably less than the length measured from the point of the beak to the anterior margin.

The surface is marked by strong, simple, subangular plications of which the median sulcus, or sinus, is more or less conspicuously larger than the others. Both plications and sulci gradually diminish in size and intensity toward the sides. There are four plications on each of the lateral slopes and also four sulci, the last one being very faint. Somewhat rarely five plications and five sulci can be counted.

The brachial valve is far more constant in character than the pedicle valve. It has a semicircular shape, widest at the hinge, and although its proportions vary to some extent, the width invariably exceeds the length. The convexity is moderate. The plications correspond to those of the pedicle valve. The fold is large, though not greatly larger than the lateral plications. These number four on each side, the final one being obscure in some specimens but distinct in others. The plications are strong and mostly sharply angular, except the mesial one, or fold, which is commonly less angular than the others, and may, in fact, be distinctly rounded.

The surface markings, except for varices of growth, are shown by only a few specimens. These specimens, however, are seen to be covered by rather small, closely arranged pustules, somewhat as in *Spiriferina spinosa*. The varices of growth are rarely numerous and may be wanting altogether. They are apt to occur close together near the margin. The shell substance is coarsely punctate.

On the inside the pedicle valve bears a high thin septal plate and two high thin dental plates in the manner characteristic of the genus.

Horizon and locality: Thaynes group (Ross Fork limestone); Portneuf quadrangle, Idaho, SE. ¼ sec. 9, T. 4 S., R. 40 E. (station 7879).

Spiriferina roundyi Girty, n. sp.

Plate 30, Figures 12–16

Shell of medium size belonging in the group of *S. spinosa*. A width of 17 millimeters is about the maximum observed.

Pedicle valve lozenge-shaped in general outline. Cardinal angles more or less rounded, so that the greatest width occurs a short distance in front of the hinge line. The width is invariably greater than the length measured from the tip of the beak to the anterior border, but the ratio varies greatly, some shells being much wider than others. The cardinal area, which is defined at the sides by angles, is gently concave, commonly nearly planate in the lower part, and is rather strongly inclined backward from the cardinal line. The delthyrium is higher than wide; it occupies about one-third of the hinge line in the narrow forms, and considerably less than one-third in the broader ones.

The surface is marked by rather fine, strong subangular costae, of which in the larger shells about six occur on each of the lateral slopes. The sinus is much larger than any of the grooves that separate the costae, and it bears a strong median rib, which is, however, distinctly lower than the plications that border it.

On the inside the pedicle valve bears the usual median septum, which is here very high and thin and passes down the groove that on the interior of the shell corresponds to the median rib of the sinus on the exterior. The strong dental plates in a similar manner are supported upon the ridges that on the inside correspond to the first groove on either side of the median sinus on the exterior.

The brachial valve is much more transverse than the pedicle valve and has a generally semicircular shape. The convexity, though fairly strong, is much lower than that of the pedicle valve. The plications correspond to those of the pedicle valve, there being about five on each of the lateral slopes. The fold as such is not conspicuous, for it is subdivided by a median groove which is so strong that the two halves are but little larger than the lateral plications adjacent to it. As a result the curvature is fairly regular from side to side, but it appears to be interrupted by a median groove from which the costae graduate in size laterally. The fold then scarcely projects above the general curvature; each of its halves, however, is somewhat larger than the costae adjacent, and, of course, as a whole it is much wider than any of the costae. The cardinal area is narrow. The dental sockets are large and without distinct socket plates.

The surface is marked by very numerous, very fine pustules that are somewhat elongated radially and are so arranged that in one light they form radial rows and in another concentric ones.

This species is readily distinguished from *S. mansfieldi*, especially by its finer plications and the fact that the fold and sinus are so completely divided by a median groove and a median ridge, respectively. The pustulose surface markings are also much finer and the shell as a whole is somewhat smaller and more transverse.

Horizon and locality: Thaynes group; Cranes Flat quadrangle, Idaho, sec. 2, T. 4 S., R. 41 E. (station 7813a).

Aviculipecten disjunctus Girty, n. sp.

Plate 30, Figures 22–24

Species known only from one valve, supposed to be the left.

Shell of medium size; some specimens referred here are as long as 35 millimeters or more, but the usual length is 25 millimeters or less. Shape, except for the auricles, subcircular or ovate. The proportions vary considerably. The width may be as great as the length, but in the more slender specimens the length is considerably greater. In some specimens the axis appears to be essentially perpendicular to the cardinal line; in others it has a conspicuous slant forward or, more accurately, it appears to be curved so that a forward inclination is produced. The hinge line is rather short, but its relation to the width below varies somewhat, the width of the shell being commonly from one and one-fourth to one and one-half times the length of the hinge. The beak is conspicuously anterior and sometimes divides the hinge line in the proportions of 1 to 2. The umbonal angle is rather narrow. The convexity is rather low, but it is strongest in the upper part of the shell, where, as the auricles are likely to be compressed, especially on the anterior side, the umbonal parts are correspondingly elevated. In consequence of this configuration, the small anterior wing is rather abruptly depressed and auriculate, whereas the posterior wing is more spreading and alate. In the outline the anterior auricle has a quadrate shape, although the cardinal angle is commonly more or less obtuse. It is not so much defined by a sinus as by the abrupt swelling of the outline below it. On the posterior side a sinus is more distinct, and in some specimens the cardinal angle is acute and salient.

The surface is devoid of sculpture except for fine incremental lines, which on some specimens have the appearance of being slightly lamellose.

These shells occur in considerable abundance and have been found at a number of localities, but apparently all are left valves, and up to the present time no right valves have been found with which they could be matched. It is true that a costate shell is commonly associated with this smooth one, but the costate shell can hardly be the companion valve because it is far less abundant, is considerably larger, and in many respects is differently shaped. It does not have the configuration of a right valve of the Pectinidae, nor, of course, does *A. disjunctus*, though this fact need imply no more than that the combined valves (if they actually belong together) are a species of some other family. On the hypothesis that they are one and the same species, the shells under consideration would presumably be right valves, as the right valve is apt to be less strongly sculptured than the left. Another point in evidence is that the costate shell which accompanies this one at many localities, though not certainly identified, appears to belong to *Aviculipecten utahensis* Meek. It is a rather singular fact that with the costate shells which are typical of that species Meek found some smooth ones that he regarded as belonging with them and that are at first glance very like the form that I am calling *A. disjunctus*. A more careful comparison with the type specimens of the smooth valve, however, shows that *A. disjunctus* can not possibly be the same species, at least unless the species varies in a most extraordinary manner, because although the posterior auricle (the terms anterior and posterior are here used as if both shells were right valves) is similarly shaped, the anterior auricle in Meek's form is not larger than the posterior and is defined in the outline by a deep notch, whereas in my shell the "anterior" auricle is much larger than the "posterior," is alate, and, in short, has the shape of the posterior auricle of a left valve rather than the anterior auricle of a right valve. My shell is, then, quite distinct from the supposed right valve of *A. utahensis*, so that if *A. disjunctus* is the right valve of the costate shell which occurs at some localities, the costate shell is not really *A. utahensis*, as I wish to identify it, but belongs in a different species and in a different genus. On the other hand, the smooth shell supposed by Meek to be the right valve of *A. utahensis* may not be properly included in that species. It has the configuration of a normal right valve, just as this form has the configuration of a normal left valve, and may possibly belong with *A. disjunctus* in that relation, both being smooth.

I might note that although for some reason the species was named by Meek *A. utahensis*, the original specimens were found not in Utah but in Nevada, if one may rely on the latitude and longitude cited. It should furthermore be noted that Meek originally gave three figures of *A. utahensis* illustrating two specimens, but in a later report he added two more figures, each of a different specimen.[1] In this report the figures on Plate 9 are not correctly numbered with reference to the plate description. Figure 7, B, should be Figure 7, D, and vice versa. Although the reader might readily ascertain that fact for himself, it is pertinent to remark upon it here because I wish to record that of the two specimens originally figured the one represented by Figure 7 appears to be lost and of the specimens subsequently figured the one represented by Figure 7, D (as corrected), is also lost. On the other hand, the original of Figure 7, B (as corrected), occurs on the same slab as the original of Figure 7, C, so that though not one of the type specimens it came from the type lot. The specimen shown in Figure 7, B, appears to be much restored in the region of the anterior auricle. The true outline is not altogether clear, but I should say that either the whole of the auricle was added or that it had a different shape from that shown by the figure. As to geologic age, Meek cites *A. utahensis* as probably "upper Carboniferous," but I feel rather certain that it belongs in the Triassic fauna of this region.

A. disjunctus may prove to belong to the group of pectinoid shells that I am here referring to the genus *Monotis*. The fact that only one valve is known, apparently the left, is significant, but so also is the strong obliquity. Most of the Lower Triassic shells that I would include under *Monotis* are more nearly bilaterally symmetrical than this and most of them also are striated. Amongst those shells, therefore, *A. disjunctus* would appear out of place, and it is accordingly described under the genus *Aviculipecten*, following, in fact, an invariable though misguided precedent.

[1] Meek, F. B., Paleontology: U. S. Geol. Expl. 40th Par., vol. 4, pt. 1, 1877.

Horizon and locality: Thaynes limestone; Cokeville quadrangle, 1 mile northeast of phosphate mine at Cokeville Butte, Wyo. (station 7306 i).

Genus MONOTIS Bronn

Shells that have the general appearance of *Pecten* or *Aviculipecten* are perhaps more abundant in the Lower Triassic beds of Idaho and adjoining States than any other type of fossil—certainly than any other type of pelecypod. A number of species have already been described from this group and many others probably are undescribed. It is not without significance that all the species described, with possibly one exception, are based on left valves, no right valves of any of them being known. In *Pecten*, *Aviculipecten*, *Deltopecten*, and related genera the right valve, in contrast with its mate, has a deep byssal notch under the anterior auricle, and in many species it is also less convex and marked by fainter and somewhat different sculpture. If we turn to the collections themselves a hundred or perhaps a thousand specimens may be observed in a single lot, all having essentially the same shape, which is that characteristic of left valves of *Pecten* and its allies. Specimens that have the characteristic shape of right valves of *Pecten* are extremely rare, and for the most part they can be definitely matched with their proper left valves and do not belong to the group of which I am speaking. Some shells that I would now include in this group may later be found to have been supplied with pectinoid right valves, but it seems almost certain that there are in this Lower Triassic fauna an extensive series of forms in which the right and left valves are not distinguished as they are in the Pectinidae and in fact are scarcely distinguished at all. It is of interest to note in this connection that Meek also was perplexed in the orientation of these shells. Writing of *Aviculipecten occidaneus*, which certainly appears to be one of them, he says:

> I am not sure that I have seen any right valves of this species. There are among the specimens some imperfect examples that would seem from the direction of the very slight obliquity to be right valves. But owing to the fact that they are quite as convex as the others which are certainly left valves and have exactly the same surface markings, while the ears, as nearly as their form can be made out, would also indicate that they are left valves somewhat distorted so as to change their slight obliquity, I am led to regard them as such.

When viewed in a very broad way these Triassic shells are not as a rule very unsymmetrical. The axis shows only a slight inclination and may slope in either direction. The beak is almost central on the hinge line, and the auricles do not differ markedly in size or definition.

If we conclude, as seems almost necessary, in the all but complete absence here of valves comparable to right valves of *Pecten* and its allies, that among these almost uniform shells some are right valves and some lefts, it becomes necessary to test this conclusion by finding some other way of identifying the valves and in addition to showing that right valves of the pectinoid type are absent, to show that right valves of a different type are present. This has been found very difficult. Among thousands of specimens I do not recall one instance in which the two valves are retained in conjunction. It might seem in advance that the inclination of the axis would serve, or the relative size and definition of the auricles, or to some extent the sculpture on the surface. But the inclination of the axis and the differentiation of the auricles are commonly so slight that this evidence has no certain trend—in some instances it even seems to be contradictory. At present I am inclined to believe that in the same species the axis may slope in either direction but that its inclination is rarely strong and may not be appreciable and that the two valves can sometimes be distinguished by one means or another but that they can not be identified as right or left valves. In spite of uncertainty upon this point I feel compelled to believe that most of these pectinoid shells are essentially equivalve. If this is true, they can not be referred under *Aviculipecten*, where all the described species have been placed and where any new species would otherwise naturally be assigned.

No structures of the hinge or of the interior are known for any of these shells, and with our imperfect knowledge it is more clear where they do not belong than where they do. *Monotis* seems on the whole to be the genus best fitted to receive them, in spite of the fact that *Monotis* is included in a family typified by a genus in which, equally with *Pecten* and its allies, the right valve possesses a byssal notch and a special configuration. It would almost seem as if such equivalve genera as *Monotis*, *Halobia*, and *Posidonomya* should be removed from the Pteriidae and, if necessary, placed in a family especially erected to receive them.

Ordinarily it seems to me to be bad in principle to change the status quo in any classification unless the change is either a certainty or a great betterment. To shift an object from a category that is only probably wrong to one that is only probably right is as a rule unwise. In this instance, however, the inclusion of these shells under *Aviculipecten* seems with such high probability to be erroneous and the need of calling attention to that fact seems so great, that I propose to change their generic reference to *Monotis*, even though I am not certain that *Monotis* will prove to be their final resting place. The species that would naturally be considered in this reclassification are *Aviculipecten altus*, *A. boutwelli*, *A. curticardinalis*, *A. idahoensis*, *A. occidaneus*, *A. parvulus*, *A. pealei*, *A. superstrictus*, *A. thaynesianus*, *A. utahensis*, *A. wasatchensis*, and *A. weberensis*. Every one of these species was described under *Aviculipecten*, though several of them with an expression of doubt, and with one exception every one of them was based on the left valve, no right valves being known. With the exception, then, of *Aviculipecten utahensis* I propose to transfer these species to *Monotis*. As concerns *A. utahensis*, smooth shells having a byssal sinus under the anterior auricle, and consequently formed like right valves of the Pectinidae, were found closely associated with the plicated shells that typify *A. utahensis*, and the two valves agreed so well with one another, except in the characters that would distinguish them as right and left, that Meek regarded them as belonging to the same species, though he expressed himself as not absolutely certain of the fact. *A. utahensis* then must be left under *Aviculipecten*. In respects other than the right valve also that species is not characteristic of the shells that I am discussing.

Monotis bregeri Girty, n. sp.

Plate 30, Figure 29

Shell rather small, oblique, broadly subovate, equivalve. Few of the specimens exceed 20 millimeters in length. In the broader ones the length and width are about equal, but in many the length is somewhat greater. The outlines slope backward on the anterior and on the posterior sides, coming together in a broad curve around the ventral margin. They contract somewhat toward the hinge, near which they become slightly divergent, producing little sinuses, that on the anterior side being rather more persistent than the other. The beak is subcentral on the hinge line, probably a little anterior. The convexity is rather strong; the umbonal swell is somewhat narrow and high, descending to small oblique depressed auricles. The anterior auricle is smaller and more abruptly depressed than the posterior auricle.

The surface is marked by slender radial lirae separated by rounded striae of about the same size. The lirae vary considerably in size and arrangement. A few through failure of bifurcation, or even through coalesence of several small ones, are conspicuously large. Others remain conspicuously small, so that in places we find the lirae alternate in size, in places we find several small ones between two large ones, or in places we find them obscurely grouped in fascicles of two or three. Nevertheless these departures from regularity are mostly inconspicuous, so that the surface markings are not ordinarily noticeably irregular. The bifurcation and other factors governing inequalities in size and arrangement, are quite capricious in their appearance, so that every specimen differs in detail from every other. Toward the sides the lirae become more and more slender, but they are quite distinct, even upon the auricles. The concentric markings comprise irregular fine obscure striae and fine growth lines of not very constant size or strength. Toward the sides the growth lines become stronger and more regular, and on the auricles as well as upon the sides adjacent they strongly crenulate the very fine costae.

Many of these specimens apparently retain traces of their original coloration in the form of concentrically distributed shades of a brownish color. The bands are not as a rule sharply outlined or sharply contrasted, but of their existence as well as of their origin there is scarcely reason to doubt.

It is possible that this species is the same as that which Meek described as *Aviculipecten occidaneus*, and certainly the two have much in common. Meek's species, as he described it, and as I have seen it represented in specimens from Weber Canyon, has more numerous costae of the larger size and has them more regularly distributed. In my species they appear to be quite casual.

Monotis bregeri is apparently an equivalve shell, and the foregoing description is framed on that understanding. The assumption is also made that the axis has a backward obliquity, as, indeed, it should have if the generic assignment is correct. The generic relations of *M. bregeri* are, however, more or less open to question. This subject is discussed at some length under the generic caption, but as the generic relations are closely wrapped up in the condition of the shell as equivalve or inequivalve, the description of a specific occurrence typical of a number of species will not be out of place.

Shells that have the general appearence of *Pecten* or *Aviculipecten* are very abundant at station 7485, but nearly all of them have the configuration and sculpture of left valves. Only a very few of those observed possess the specialized characters of the right valve in those genera—the depressed convexity, the subdued sculpture, and the deep byssal sinus beneath the anterior auricle. Now all but a very few of the left valves appear to belong under *Monotis bregeri*, and these few appear to belong more or less probably with the rare specimens that possess the distinctive characters of right valves. If these things are so, we may fairly expect that among the numerous and more or less uniform shells possessing the characters of *M. bregeri* both valves are represented. We might also expect that the two valves would be distinguishable from one another by reason ot a slope in opposite directions, by having the peculiarities of the auricles, such as size and configuration, developed on opposite sides and by some difference in sculpture or in convexity.

Some of the specimens have been compressed, modifying their convexity; some have been distorted, modifying the obliquity of the axis, but with these and other accidents discounted, the specimens apparently show original variation in all these characters. The sculpture varies, but it is not of a definite type in one set of specimens and of a different type in another set. The convexity varies also but not in a decisive manner. The size of the auricles (which is a concomitant of the position of the beak on the hinge line) and their shape, differ appreciably in some specimens, but in others the difference is so slight that neither auricle can confidently be called the larger or the more abruptly depressed. In a similar manner the axis in some specimens slopes distinctly in one direction, but in others it slopes as distinctly in the opposite direction, and in still others the slope is too slight to be appreciable. The inclination of the axis would be the readiest way of distinguishing the valves if it were appreciable and constant, but in these shells, even when the axis slopes in opposite directions, the peculiarities distinctive of the two auricles, where any appreciable distinction is to be observed, do not vary to correspond.

The most satisfactory explanation of the facts presented appears to be that the two valves were essentially alike but that the shell as a whole was inconstant, varying even in the inclination of the axis. The same conclusion, that the shell was equivalve, is also suggested in a few occurences by the attitude of certain specimens to one another in the rock. The two valves have not been observed strictly in apposition, but here and there two have been observed in such a relative position and so complementary in character as to suggest that they belonged originally to the same individual slightly displaced. If such is their relation, the two valves had essentially the same characters.

I do not propose to discuss at any length the generic position of *Monotis bregeri*. If it is an equivalve shell any relation to the Pectinidae may be dismissed forthwith. So far as its more weighty characters are known it might belong among the Limidae. It may have had a byssal opening between the valves along what I have called the posterior auricle, for the shell margin in some specimens is faintly arched in that plane; the general expression, however, is not that of the more typical Limas, at least. The abundant and characteristic Triassic genus *Monotis* offers on the whole the most suitable refuge.

Horizon and locality: Thaynes group; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7485).

Monotis bregeri Girty var. laticostata Girty, n. var.

Plate 30, Figures 30, 31

In the collection in which *Monotis bregeri* is so abundant a few specimens have an unusual number of unusually large flat lirae, apparently because certain of the lirae failed to bifurcate and kept on increasing in size. The more strongly characterized of these specimens are in marked contrast to typical *Monotis bregeri*, and yet a more or less gradual transition can be traced from one to the other, so that certain specimens can not be placed without hesitation in one group rather than in the other. For the more highly characterized shells a varietal name seems desirable.

Horizon and locality: Thaynes group; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7485).

Monotis thaynesiana Girty

Plate 30, Figures 27, 28

This species has been identified at a number of localities, but is especially abundant at station 7878 in the Crow Creek quadrangle. The specimens collected there are especially well preserved and characteristic, and one of them is illustrated on Plate 35.

Though specimens that have the characters of "*Aviculipecten thaynesianus*" are here numerous, all of those examined have the configuration of the left valve of the genus under which the species was originally cited; not a single specimen having the characteristic configuration of the right valve of the Pectinidae was found associated with them. Furthermore, among the shells that have the general configuration of left valves, some lean slightly in one direction and some in the other, while some have the beak a little to one side of the center of the hinge line and others to the other side. The auricles are depressed and distinct from the body of the shell without being sharply defined. The sculpture consists of fine radial lirae separated by striae of about the same size. The lirae are in general straight but may be slightly sinuous. They are also slightly alternate in size, though this is not conspicuous. They become finer and fainter toward the auricles, where they may to all intents be obsolete. Toward the umbo also they may become for a considerable distance indistinguishable, nor can their absence with much probability be attributed to accidental causes. Well-preserved surfaces show also minute cancellating concentric lirae, much finer than the radiating ones and not easily seen in many specimens except upon the auricles, where, owing to the more or less complete absence of the radiating lirae, they are the more conspicuous feature.

Appreciable though not striking variation is shown by these shells. That which relates to the configuration has already been indicated. In sculpture, the markings are a little finer on some specimens than on others; on some they are relatively faint, on others relatively strong. In some the lirae are relatively large and the striae relatively slender; in others these relations are reversed. In some specimens again, the inequality in size of the radiating lirae is more pronounced and regular than in others, and this differentiation may even be so pronounced as to suggest that the species might intergrade with *A. occidaneus*. On the other hand, the more typical variety is likely to prove the same species as *A. curticardinalis*.

In fact the opportunity to examine additiona material, together with the experience acquired during a number of years, has led me to doubt both the validity of the species and of the original generic reference to *Aviculipecten* as well. *A. thaynesianus* is in the main so similar to *A. curticardinalis* that unless some differences are found more significant than those at present known, the two species will probably have to be united. *A. thaynesianus* has a somewhat different outline in the lower part, and especially much larger auricles in the upper, but in these characters shells of the same species may vary materially. In sculpture, its character as well as its scale, the two species appear to be in close agreement. The specimens in lot 7878 have more the shape of *thaynesianus* than of *curticardinalis;* therefore they have been cited under that name, which is retained until the relation between the species is definitely settled.

Horizon and locality: Thaynes group (Ross Fork limestone); Crow Creek quadrangle, Idaho, half a mile north of highway on Crow Creek up Sage Creek (station 7878).

Monotis superstricta (White) var. parksi Girty, n. var.

Plate 30, Figures 20, 21

The form here distinguished as a variety differs from typical *Aviculipecten superstrictus* apparently both in sculpture and in shape, but some of the differences are of minor importance and some may prove to be spurious when more is known about White's species. The specimen which I am using as the type of this variety has its axis distinctly oblique, and if it is a left valve, as it appears to be, and as it certainly is if the shell is one of the Pectinidae, the inclination is backward. Typical *A. superstrictus* is represented as essentially symmetrical, and the absence of any distinct inclination of its axis is regarded by White as one of its essential characters. The difference here, though appreciable, is not pronounced and probably is not important. In my specimen, and the same seems to be true of White's figure, the posterior sinus is very small, and it occurs not where one would be inclined to place the boundary of the posterior auricle as defined by the shell's topography, although it is very ill defined in that way, but well above that boundary.

The sculpture in my shell begins in the umbonal region as very fine closely arranged lirae of almost equal size. Even there, however, certain lirae are slightly larger than the rest, usually about every fourth one. As the shell grew larger the lirae grew larger too, but not sufficiently to make up for their divergence, and new ones were introduced, so that at almost any stage they appear to be so arranged that between each two of the larger lirae there are three small ones, of which the second is conspicuously larger than the first and third and conspicuously smaller than the bounding ones. In places also there may be only one intermediate lira, the two additional ones, the first and third, coming in just below. Some of the secondary lirae may, toward the front, reach a size equal to that of the primary ones, or at least the difference may be scarcely appreciable. The differentiation of the lirae becomes less and less marked toward the sides. First only two orders and then only one is distinguishable, though even on the auricles, especially on the posterior one, a few lirae here and there are slightly larger than the rest. Fine though conspicuous regular lamellose crenulations cross the radial lirae.

White does not describe *A. superstrictus* as being marked by any concentric crenulations at all, although his specimen is not preserved in a way favorable to showing them. Nor does he describe the intermediate lirae as conspicuously alternating in size, merely saying that each space is occupied by five to seven radiating threadlike raised lines. The common number in my form is three in each interspace, and, considered in a broad way, three orders can ordinarily be distinguished, as already described, the first and fifth lirae being of the first order, the third of the second order, and the second and fourth of the third order, though all the lirae of one order are not exactly of the same size and though with the growth of the shell the lirae of the second order become indistinguishable from those of the first, and as new lirae are introduced the tertiary lirae become secondary. This does not seem to accord with White's description, from which one would infer that there were from 12 to 15 primary lirae, which were always primary, separated by five to seven secondary lirae, which were of equal size and which were always secondary. These differences would be important should they prove to be real and persistent, but it seems likely to me that additional knowledge will minimize them.

Aviculipecten superstrictus was founded upon what was thought to be the left valve. No right valves belonging to the species were at that time known nor has any subsequently been recognized. I am speaking, however, of right valves such as are found in the Pectinidae. From the fact just noted, from the general character of the shell itself, and from its geologic age, *A. superstrictus* is thought to belong to a group of Lower Triassic shells that appear to be equivalve and not strongly inequilateral, or if distinctly inequilateral, with anterior and posterior inequalities in the same species. If these shells are actually equivalve, they can no longer be tolerated in *Aviculipecten* under which genus all of them were originally described, and accordingly I have transferred them to *Monotis*, where they may, though it is not certain that they do, belong. *Aviculipecten superstrictus* is one of the species thus reclassified. That some of these Lower Triassic "Aviculipectens" are really equivalve is in the highest degree probable, but certain ones here cited under *Monotis* may, through the discovery of characteristic right valves, revert to the Pectinidae.

Horizon and locality: Thaynes group (Ross Fork limestone); Crow Creek quadrangle, Idaho, NW. ¼ NE. ¼ sec. 20 (unsurveyed), T. 9 S., R. 45 E. (station 7877).

Myalina postcarbonica Girty, n. sp.

Plate 30, Figures 34, 35

Shell small, narrowly ovate in outline, obliquely subtruncate on the posterior side. Oblique diameter rarely more than 15 millimeters. Hinge line straight, distinct, half the width or less. Anterior end narrowly and abruptly rounded. Anterior outline straight or slightly sinuous, making an angle of 45°, sometimes more, sometimes less, with the hinge line. Posterior outline oblique and almost parallel with the anterior outline. It merges with the cardinal margin above but becomes more and more strongly curved below, passing in a broad curve around the lower end and into the oblique inferior margin without a break. Thus from the almost pointed beak the shape widens rather rapidly between the anterior outline and the hinge; it widens also for a distance, though less rapidly, between the anterior outline and the posterior outline, the broadest part lying in the posterior two-thirds or three-fourths of the shell, but behind this it contracts rather strongly.

The convexity is high and the umbonal ridge distinct. Beginning at the beak, which sets a little back from the anterior extremity, the umbonal ridge passes backward and terminates at the posterior inferior angle, or possibly a little in front of it, flattening out as it goes. It may be nearly straight or it may curve in the anterior part so as to point more directly forward. It descends rather abruptly at the anterior end but more gradually in the opposite direction, the highest point being about midway or a little anterior. The umbo is rather inflated, though small and undefined, and it has a small lobe below and partly in front of it. The lobe produces a slight outward deflection in the anterior outline, below which a faint cincture produces a slight deflection inward.

Various modifications in shape are produced, according to whether the umbonal ridge makes a rather more or rather less acute angle with the hinge than usual and also according to whether it is curved for a longer or shorter distance in the anterior part or is practically straight. The umbonal ridge and the ventral margin maintain a close and fairly constant relation, though they converge somewhat as they pass backward and downward. The ventral margin may also swerve away from the umbonal ridge in the anterior region, so as to produce a lobelike expansion; in this way, too, distinct modifications of shape are produced. These variations, however, are too slight and too closely connected to be practicable for smaller subdivisions.

The surface appears to have been marked by lamellose lirae arranged at rather close and regular intervals, though this can not be stated definitely. A number of specimens show radiating lines, apparently due to shell structure, which arch gracefully away from the umbonal ridge in a pinnate manner.

Very little can be seen of the internal structure. Apparently there was not present a broad striated hinge plate like that of many typical species of *Myalina*, but a hinge plate would ordinarily be proportional to the size of the shell and that of a small form like the present species would naturally be narrow. In fact, the shell along the hinge line is flattened out or thickened, and it appears to have held (in the left valve at least) a narrow groove, which may be correlated with one of the numerous grooves that traverse the hinge plates of larger and more massive Myalinas. On the other hand, it may be a distinct structure.

Even if this species is a *Myalina*, it is not, of course, related to the group of large, more or less quadrate forms but rather to the small modioliform ones like *Myalina swallowi*. It also resembles, though less strongly, *Modiola subelliptica*, both species being interpreted according to Meek's figures.[2] If *M. subelliptica* is in fact a *Modiola*, the present species could equally well be cited under the same genus. On the other hand, even *Myalina swallowi*, as interpreted by Meek, has the hinge plate so reduced in width as compared with large species like *Myalina subquadrata*, that this still smaller form might also be referred to *Myalina* with the same propriety, in so far as that character is determinative and in so far as it is shown in my specimens. No matter which genus it belongs to, *M. postcarbonica* is rather clearly distinct from either *Myalina swallowi* or *Modiola subelliptica*.

Horizon and locality: Woodside shale; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7380).

Pleuromya haydeniana Girty, n. sp.

Plate 30, Figure 36

Shell rather large, gibbous, and, except for the prominent umbo, subelliptical in outline. The type specimen has a width of 40 millimeters and a height to the cardinal line of 23 millimeters. The height to the most prominent point of the umbo is 29 millimeters. The hinge line is straight, about half the width of the shell in length. The basal outline is parallel to the hinge and rounds upward almost equally at both ends, a little more strongly at the anterior end than at the posterior, which is somewhat straightened and truncated above. At the anterior end the outline is symmetrical, rounding inward in its upper part slightly below the level of the hinge line. The beak is distinctly anterior but far from terminal, lying about in the anterior third of the shell. The convexity is strong. The maximum height occurs in the anterior fourth and from there the shell rounds downward strongly to the anterior end and descends gradually to the posterior end, but the curvature is interrupted by a distinct rather broad constriction anterior to the middle, chiefly distinguishable in the lower part. The surface is marked by fine growth lines and by faint concentric folds, which seem to play out in the constriction and alternate there, the anterior series with the posterior series. They also become obsolete toward the hinge line.

The muscle scars are not shown, and of the hinge structure also but little can be said. Cardinal teeth may be present, but no lateral teeth either anterior or posterior. The hinge margin behind the beak seems to be thickened without, however, developing any structure sufficiently distinct to be called a posterior tooth. In the lack of definite knowledge of these characters, the generic reference is in doubt, but the general appearance is suggestive of *Pleuromya*, with which the characters that can be definitely determined are not at variance.

This species somewhat resembles the one described by Meek as *Myacites* (*Pleuromya*) *subcompressus*. One of the most obvious differences is found in the regular concentric undulations of Meek's species, which is also less elongated transversely and lacks as well a constriction. In addition to these and other proper differences, Meek cites *P. subcompressa* from strata of Jurassic age, but the present species certainly is not Jurassic.

White[3] figures a number of shells as belonging to Meek's species, all apparently from Jurassic rocks. They differ considerably from one another, and one of them especially resembles the form here described. White's comments on these figures, which should be enlightening, are really perplexing, for his Figure 5a, which he seems to think especially resembles Meek's original figure, appears to me to be most unlike it, whereas his Figure 5e, which he thinks may prove to be a distinct species, appears to me especially to resemble it.

Horizon and locality: Thaynes limestone; Cokeville quadrangle, 1 mile northeast of phosphate mine at Cokeville Butte, Wyo. (station 7306i).

Genus PLEUROPHORUS King

The small group of species here subsumed under the generic name *Pleurophorus* present problems as to their mutual relationship, their generic position, their habitat, and their geologic age.

The generic position of these shells is in a measure involved with the facts of their habitat and geologic horizon, as will appear farther on. The generic characters that belong to them have been incompletely determined and are shown at all by only a few specimens; as is not uncommon, the specimens that yield some knowledge of generic characters are mostly too imperfect to be satisfactorily referred to a definite species. As the different groups appear to be so closely related in their specific characters, however, it seems fair to assume that they all belong to the same

[2] Meek, F. B., Report on the paleontology of eastern Nebraska, in Hayden, F. V., Final report of the United States geological survey of Nebraska, pt. 2, 1872.

[3] White, C. A., Contributions to invertebrate paleontology, No. 7; Jurassic fossils from the western territories: U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pl. 38, figs. 5a–e, 1883.

genus, and my observations go far to justify this assumption. Aside from the configuration and surface markings, which it is not necessary to describe in this place further than to state that the shape varies from transversely subquadrate to subelliptical or subovate with strongly anterior umbones, that the umbonal ridge is more or less pronounced, and that one or two delicate costae are sporadically developed on the post-umbonal slope, the generic characters ascertained are as follows:

The shell substance is in most specimens thick, and in its present condition apparently composed of crystalline calcite, a fact that renders it extremely difficult to procure perfect specimens, as the material neither adheres to the enveloping rock nor coheres to contiguous parts of the fossil itself. The cardinal margin bears a narrow, concave bevel, which appears to have formed the seat of an external ligament, though it may possibly have been only a narrow escutcheon. This ligamental groove extends the entire length of the hinge behind the umbones and reappears for a short distance in front of them. The left valve bears a long posterior lamina close to and parallel with the hinge margin, with which it seems to form a groovelike socket for the reception of a corresponding though less distinct linear tooth in the opposite valve. So far as my observations go it might be inferred that no cardinal teeth were developed; nevertheless it seems probable that cardinal teeth were actually present, though it seems probable also that they were small and feeble. The anterior muscle scar is large, deep, and strongly defined about the posterior side as if by a ridge. A few specimens show what I can not doubt is a large posterior scar, though it is but faintly outlined. The two scars are connected by a pallial line, which is commonly distinct, at least anteriorly, and which appears to be without a sinus.

This assemblage of characters accords best with two families, the Cardiniidae and the Pleurophoridae, recalling in the former especially the genera *Naiadites* and *Carbonicola*, and in the latter the genus *Pleurophorus*. Cardinal teeth are so rarely to be observed anyway, and their character in these forms is so little known, that no inference can be drawn along this line. If as my observations suggest, the cardinal teeth are small and obscure, this fact would tend to place these Triassic shells in the Cardiniidae. My observations, however, are not convincing. If the groove that traverses the thickened cardinal margin and that is visible both anterior and posterior to the beak is ligamental in its character, as I have little doubt, these forms would not accord perfectly with the definition of either family (better, however, with that of the Pleurophoridae), because the Cardiniidae are described as having the ligament opisthodetic, whereas the ligament of the Pleurophoridae is parvincular, ligaments of that type being also usually opisthodetic. In the arrangement of the lateral teeth there seems to be little choice, at least as between *Carbonicola* and *Pleurophorus*, the preference tending to *Pleurophorus*.

As to habitat the Pleurophoridae are marine, but the Cardiniidae inhabit either marine or brackish waters. Hence, if these shells from the Woodside shale are of brackish-water origin, they could not belong to the Pleurophoridae, but if they were of marine origin this fact would not exclude them from the Cardiniidae. It would, however, exclude them from those cardinian genera *Carbonicola*, *Naiadites*, and *Anthracomya*, to which I would conceive them to be most closely allied.

The shells from the Woodside occur in a limestone, a fact which would tend to fix, though not definitely, their station as marine. The fauna associated with them is rich in individuals but poor in variety. Besides these *Pleurophorus*-like forms it contains shells which have the configuration of *Mytilus* and *Modiola*—indeed, which probably belong to those genera—but as quite similar shells are included under *Naiadites*, and as I can not state positively that the Woodside forms are of one family rather than of the other, the evidence afforded by these species can not be pressed. Much rarer than the forms already mentioned are some large pectinoid shells, and those, whether they come under *Aviculipecten* or (more probably) under *Pseudomonotis* seem definitely to determine the associated fauna as marine. The only other types worth mentioning are some nondescript gastropods whose generic position I am unable to fix and whose evidence therefore can not be predicated. If we go outside of the fauna that is associated with these supposed Pleurophori at the same locality and in the same ledge of rocks, the fauna of the Woodside formation as a whole is undoubtedly marine. It therefore seems probable in the highest degree that this fauna is a marine fauna, and that the *Pleurophorus*-like shells can not belong to at least any of the brackish-water genera of the Cardiniidae; specifically they can not belong to *Carbonicola*, *Anthracomya* or *Naiadites*.

In this connection mention may be made of the circumstances that most of the specimens are colored a dark brown or gray, commonly in striking contrast to the tint of the surrounding matrix. This discoloration may be interpreted as indicating the presence originally of a thick periostracum, and this, in connection with the configuration, brings to mind the fresh-water Naiads. Neither a thick periostracum nor the somewhat commonplace configuration of these Triassic shells, is peculiar to the Naiads, and that relationship for the reasons given is not regarded as probable.

On the score of geologic age, whatever evidence could be adduced would be reciprocal. As the age of the Woodside shale and the generic position of this group of shells are equally matters to be determined, if the Woodside could be shown to be of Triassic age then the shells could not belong to any strictly Paleozoic genus, or if the shells could be definitely assigned to some strictly Paleozoic genus then the age of the Woodside could not be Triassic, and so on. This line of argument should not be pushed too vigorously, however—too much is still unknown about the range of genera and species in the geologic column.

A strong probability can be shown on other grounds, however, that the Woodside is in fact Triassic and not Permian in age. A profound change in fauna occurs in passing from the underlying Phosphoria formation to the Woodside. Not a single species appears to be common to the two faunas, and even most of the Phosphoria genera, especially the characteristic genera of brachiopods and Bryozoa, become extinct at the fatal line that divides one formation from the other. The Phosphoria fauna itself is of Permian age, and it seems little likely that another Permian fauna, especially one so different in every way, would immediately follow it in the same section. Furthermore, though proof can not be presented at this time, I believe that the evidence needs only to be formulated to prove that the Woodside is closely allied in its fauna to the Thaynes group above, whose age, as Lower Triassic, is generally recognized. Finally, in its lithologic and stratigraphic relations the Woodside appears to belong conspicuously with the overlying rather than with the underlying beds. If the Thaynes is Triassic there seems little reason to doubt that the Woodside is Triassic also. On this ground it would be unsafe, in default of conclusive biologic evidence, to refer any of the Woodside forms to genera at present believed to be restricted to the Paleozoic.

The several lines of evidence considered agree in indicating that as between *Pleurophorus* on the one side and *Carbonicola* and its allies on the other these shells from the Woodside shale belong with *Pleurophorus*. The genus *Pleurophorus*, though it reaches its greatest development in the Permian (fide Zittel), ranges also into the Triassic. These Triassic Pleurophori, if I may call them so, have a slightly different expression from their Carboniferous congeners, though the difference is so subtle that it would be hard to say just wherein it lies. At least, of these Triassic shells it may be said that they are characterized by their extreme abundance. In Carboniferous collections the Pleurophori are more apt to occur one or two at a time, though even in these collections they may be abundant. These Triassic shells also impress one as being more plastic. No two of them seem to be exactly alike, and they seem to pass by small gradations into extremes that are wide apart. The separation of such a series of forms into groups, be they species or varieties, is more or less arbitrary. This particular series I have separated into three groups, but the groups are not sharply defined. Some specimens seem balanced between two species; others seem out of place in any of the species recognized and apparently might be made starting points for still other species.

Some of the lines of variation observed may briefly be mentioned. It is to be expected that shells such as these would vary considerably in the proportions of height and length and so they were found to do. The upper and lower margins vary in direction from parallelism to strong convergence toward the anterior end. The anterior end itself varies in prominence or projection beyond the beaks, not greatly perhaps in actual measurement but conspicuously in modifying the shape of the shell. The posterior outline also varies from obliquely subtruncate to somewhat regularly rounded. Variation here is closely connected with the strength of the umbonal ridge, which may be distinct and subangular or rounded and obscure. Strength and angularity in the umbonal ridge naturally tend to produce a truncated outline at the posterior end, which then is sharply rounded about the posterior inferior angle and correspondingly straight above. In some specimens one or two faint angles or costae are developed on the postumbonal slope (never on the umbonal ridge or anterior to it), but in others no such features are discernible. The presence of these costae, the angularity of the umbonal ridge (directly), and the prominence of the anterior lobe have not proved very satisfactory differentiating characters, and the three species or varieties which have after careful study been distinguished depend largely upon configuration especially upon outline. Each of these species as here constituted contains specimens that have costae as well as those that are without, specimens that have a more as well as those that have a less prominent anterior lobe, and to a certain extent specimens that have an angular as well as those that have a rounded umbonal ridge. These characters also might have been employed in classification, and other more numerous subdivisions recognized, but no matter what line of separation I sought to follow no sharp distinction was found.

Pleurophorus bregeri Girty, n. sp.

Plate 30, Figure 40

Shell rather small, subovate, wider than long; umbones not very prominent. The cardinal outline is gently arched and extends about two-thirds the entire width. The ventral outline is straight or slightly emarginate along the median portion but curves upward toward the ends. The two outlines converge strongly toward the front of the shell, which is narrow and sharply rounded. The posterior end is strongly oblique and somewhat truncated. The outline is nearly straight above, meeting the cardinal line in an angle which, though obtuse, is distinct. It is increasingly curved below and joins the upturned ventral outline without a break. The beak is small, strongly anterior (though with a more or less prominent lobe in front of it), strongly incurved, and strongly bent forward. The convexity is rather high, chiefly localized along the umbonal ridge, which may be broadly rounded or subangular. The postumbonal region is more or less compressed. A faint constriction passes across the anterior third of the shell, which is slightly inflated just in front.

The surface is nearly smooth and is crossed only by fine unequal striae of growth, some of which, distinctly stronger than others, mark periods of increase.

The specimens included here vary in all the characters shown. In some of them the umbonal ridge is distinct and subangular, though normally it is rounded. In some of them one and in others two delicate angles or plications are developed on the postumbonal slope. Variation is also shown in the width relative to the height, in the prominence of the anterior extremity and in the convergence of the upper and lower outlines. In general I have sought to include here rather high shells whose upper and lower outlines contract rather strongly, whose anterior end is moderately prominent, and whose posterior end is more or less distinctly truncated. Shells that have this configuration are especially abundant at station 7382; those that have the typical configuration of *P. rotundus* and *P. similis* are relatively rare. Passage forms which do not agree satisfactorily with either species are, however, not hard to find. *P. bregeri*, on the other hand, is rare at station 7380, where *P. rotundus* and *P. similis* are abundant and typical.

Horizon and locality: Woodside shale; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7382).

Pleurophorus similis Girty, n. sp.

Plate 30, Figures 38, 39

Shell rather strongly transverse. Upper and lower margins nearly straight and nearly parallel or but slightly converging toward the anterior end. The anterior end is prominent, regularly rounding under the strongly anterior umbones, which are rather small and are curved forward and inward. The posterior end is truncated, the outline being nearly straight and strongly oblique in the upper part, so that it makes an obtuse angle with the hinge line, but rounding with a sharp curve into the ventral outline. The convexity is commonly high. The umbonal ridge is pronounced and subangular, and a plication is commonly developed about midway on the postumbonal slope, producing a slight change of direction in the truncating posterior outline. A constriction, faint but distinct, commonly crosses the shell in front of the umbonal ridge and produces a corresponding emargination in the ventral outline.

The surface is smooth crossed only by fine incremental lines, among which a few of greater intensity mark periods of intermittent shell deposition.

This form may be thought of as derived from *P. bregeri* by a reduction in height, so that the shape is proportionally wider, and by a reduction in the divergence of the dorsal and ventral outlines, so that they are essentially parallel with one another. On the other hand, it may be thought of as being derived from *P. rotundus* by a reduction in the height and by a strengthening of the umbonal ridge, accompanied by a tendency to develop a distinct posterior-inferior angle and a straight oblique posterior outline. Passage forms connect all three species into a more or less unbroken series. *P. similis* may be compared with *P. subcostatus* of the Pennsylvanian, and *P. bregeri* with *P. tropidophorus* and *P. oblongus*, though distinguishing characters are easily found. This species also recalls the genus *Carbonicola* of the Cardiniidae, just as some of the varieties of *P. bregeri* recall the genus *Naiadites* of the same family, and some of the varieties of *P. rotundus* recall the genus *Edmondia* of quite different affinities.

Horizon and locality: Woodside shale; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7380).

Pleurophorus rotundus Girty, n. sp.

Plate 30, Figures 41, 42

Shell small, generally elliptical in outline, and rather high for a representative of this genus.

The ventral outline is nearly parallel to that of the cardinal border. The anterior end is rather prominent, its greatest projection occurring at the mid-height or somewhat above. It is regularly rounded in the lower half but deeply emarginate in the upper, where it is withdrawn under the strongly anterior umbones. The posterior outline is more or less regularly rounded, tending to be somewhat straighter and more oblique in the upper part than in the lower. The convexity is moderate, the umbonal ridge rarely distinct. The postumbonal slope may show one or two delicate radial plications.

The surface is smooth or marked only by concentric striae, punctuated by varices of growth.

P. rotundus graduates into *P. bregeri* and may be regarded as a modification of that species in which the upper and lower margins are parallel, instead of strongly convergent, and in which the posterior outline is more broadly and regularly rounded, probably less oblique in the upper part, so that a truncated appearance is not so conspicuous. Specimens occur which can not be placed satisfactorily in either group but appear to be intermediate between them. Some of the more strongly characterized specimens suggest the genus *Edmondia*, though of course they lack the strong concentric furrows found in so many of the Edmondias. Indeed, it is just possible that *P.? rotundus* has been made to include more than a single generic type, for several specimens do not show, or at least do not show clearly, the linear cardinal tooth that has been observed in *P. bregeri*. Others have all the characters which in *P. bregeri* led me to refer that species to *Pleurophorus*. *P. rotundus* and *P.? similis* are best developed at station 7380, where really typical specimens of *P. bregeri* are relatively scarce.

Horizon and locality: Woodside shale; Montpelier quadrangle, Montpelier Canyon, Idaho (station 7380).

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