PHOSPHATES.

PRELIMINARY REPORT ON A PORTION OF THE IDAHO PHOSPHATE RESERVE.

By R. W. Richards and G. R. Mansfield.

INTRODUCTION.

OUTLINE OF INVESTIGATION.

The examination of the phosphate fields in Idaho, Wyoming, and Utah by the United States Geological Survey begun in 1909[1] was continued in 1910 by three parties, two of which were engaged in geologic work and one in topographic mapping. The investigation comprised a detailed study of a portion of the lands within the phosphate reserve created by the withdrawals of December, 1908, and December, 1909, by the Secretary of the Interior, which were ratified, confirmed, and continued by the President under the act of June 25, 1910, and also a reconnaissance examination of lands possibly phosphate bearing outside of the reserve. The geologic parties in charge of Eliot Blackwelder and R. W. Richards were detailed to Wyoming and Idaho, respectively, and Albert Pike was assigned to undertake topographic work in Idaho. A portion of the reserve in Idaho known to contain extensive deposits situated near the Oregon Short Line Railroad was selected for the detailed examination. Base maps of the townships containing the largest areas of phosphate lands were made by the topographic party on a scale of 1 : 31,680, or 2 miles to the inch, this being the scale in common use by the General Land Office for surveys of the public lands. A 50-foot contour interval was used, and special care was observed in the location of the land corners and in the collection of data for the classification of the forest and agricultural lands. The country surveyed was in part rough and difficult of access, but the cost of the excellent topographic data obtained was about $15 a square mile, or about $500 to a township. The detailed maps of the present report are taken in part from the township sheets made by Mr. Pike, but it is necessary, owing to the

[1] Gale, H. S., and Richards, R. W., Phosphate deposits in Idaho, Wyoming, and Utah: Bull. U. S. Geol. Survey No. 430, 1910, pp. 457–535. Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: Idem, pp. 536–557.

method of publication, to use a smaller scale and therefore to omit much of the topographic detail.

This paper is a progress report of the detailed geologic work for the year in southeastern Idaho. The authors were assisted in the field by J. H. Bridges and E. C. Ragar. Paleontologists G. H. Girty, J. P. Smith, and T. W. Stanton visited the party in the field season and spent some time in the study of the stratigraphic problems.

LOCATION.

The accompanying map of the phosphate reserves of Idaho (fig. 46) shows the area examined during the summer of 1910 and its relation to the areas surveyed in 1909 and described in Bulletin 430.

The area (covered in this report) comprises portions of Bear Lake and Bannock counties, in southeastern Idaho, and includes the phosphate deposits near Bloomington, Paris, Liberty, and Soda Springs.

GEOGRAPHY OF AREA EXAMINED IN 1910.

Bear Lake Valley is the most important topographic feature of the area examined and extends from the south end of Bear Lake nearly due north as far as Bennington. Thence it turns about 15° west of north and continues through the rest of the district under discussion. The southern portion of the valley in this district is 6 to 8 miles wide, but north of Bennington it narrows to about 4 miles and is interrupted by low hills. The altitude of the valley as a whole is nearly 6,000 feet. The mean surface elevation of Bear Lake, as determined by recent level work, is 5,924 feet above the sea; the elevation of Bear River south of Soda Springs is about 5,750 feet.

Bear Lake occupies the south end of Bear Lake Valley. Only the north end of the lake lies in the district covered by this report. East of St. Charles a long, low sand bar constitutes the north end of the lake. North of this bar lies a detached body of water that merges northward into an extensive marsh. This is called North Lake and it varies in volume and extent with the season. On the east side of the lake the land rises abruptly almost from the water's edge to the Bear Lake Plateau, which has an average elevation of 7,250 feet; on the west side it rises somewhat less abruptly to the Bear River Range.

Bear River does not enter Bear Lake but breaks through the east wall of the valley some 6 miles north of the lake, where it enters a great marsh. Thence it continues northward to the vicinity of Soda Springs, where it turns west, and it swings southward at Alexander.

The northern part of the Bear River valley has been overflowed by basalt as far south as a point 4 or 5 miles south of Soda Springs. The basalt has crowded Bear River against the north end of the Bear River Range and has caused the remarkable bend that the river makes at that point. The river here flows in a canyon, the north side of which is basalt and the south side is formed of the limestones of the Bear River Range.

The Bear River Range extends along the west side of the valley with no break until the transverse canyon of Bear River is reached. Beyond that point the range is continued with decreasing altitude in the Soda Springs Hills. The range as a whole stands about 2,500 feet above Bear Lake Valley. The culminating points are Paris and Soda peaks, with altitudes of about 9,500 and 9,660 feet, respectively. The east front of the range has a rather steep descent near Bear Lake, where the Cambrian quartzites approach the western border of the valley. Farther north younger rocks intervene and the slopes descend with longer, gentler grades. Near Liberty an important embayment in the range is made by the valley of Mill Creek, and farther north an outlying portion of the foothills is nearly isolated from the main range by the broad Nounan Valley.

The east side of Bear Lake Valley is occupied successively by the Bear Lake Plateau, a portion of

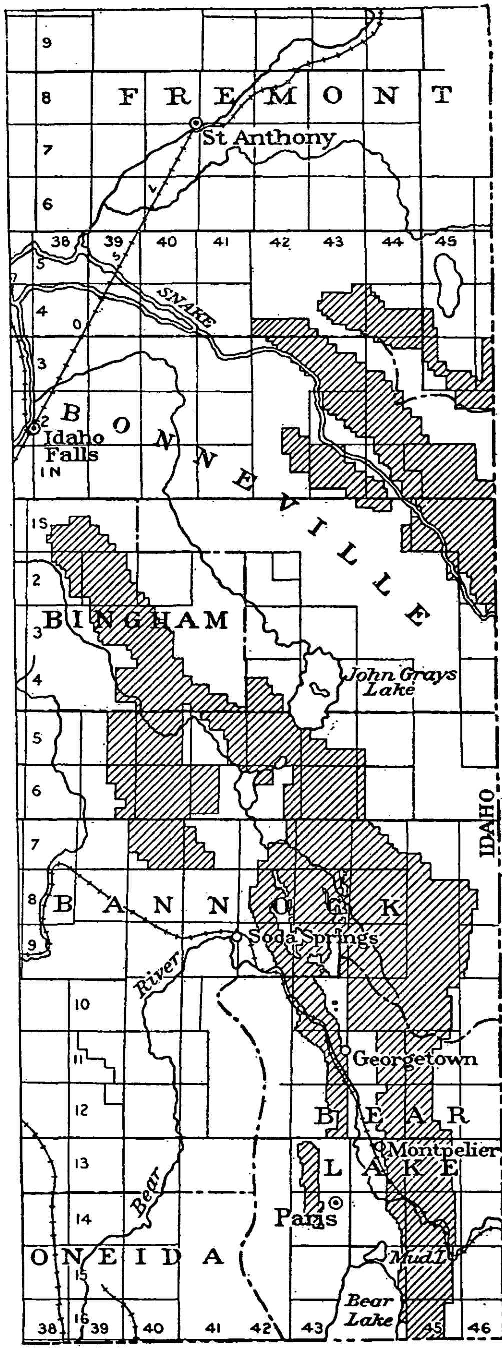


FIGURE 46.—Map showing phosphate reserves in Idaho on June 30, 1911.

the Preuss Range, and the Aspen Range. The general altitude of these eastern uplands is 7,000 to 9,000 feet. The culminating point is Mead or Preuss Peak, which has an altitude of 9,952 feet. Thus the maximum relief in this district is about 4,000 feet. There are three important interruptions in the east border of the valley, produced by the canyons of Bear River, Montpelier Creek, and Georgetown Creek. The west front of the Bear Lake Plateau descends steeply to the lake and forms an almost straight line that cuts obliquely across the strike of the upturned beds. Farther north this line is continued with a considerable degree of regularity by the ranges above mentioned. Thermal and mineral springs occur at intervals along this line and at some places, especially in Tps. 10 and 9 S., R. 43 E., and Tps. 9 and 8 S., R. 42 E., there are extensive deposits of travertine that appear to be associated with this feature and to indicate the presence of a profound fracture.

The topography of the uplands on both sides of the valley indicates a long erosion history. The rocks are complexly folded and faulted and yet the upper slopes have been subdued to the smooth and rounded outlines indicative of late maturity or early old age. Beneath these well-worn slopes the present sharp-featured canyons have been cut to depths of 500 feet or more. The rainfall of the region amounts approximately to 10 inches annually,[1] so that only the larger streams have sufficient drainage areas to supply a permanent flow. The main streams have been able to cut their valleys deeply, but many of their tributaries, with smaller and infrequent flow, have not cut down rapidly enough to enter the main streams at grade. Tributary valleys may therefore be seen hanging at varying heights above the floors of the main canyons. A particularly fine example of this type of hanging valley occurs on the north side of Middle Sulphur Canyon near its mouth, in sec. 7, T. 9 S., R. 43 E. Here the little tributary hangs about 450 feet above the floor of the main canyon.

TRANSPORTATION AND INDUSTRIES.

The Oregon Short Line Railroad, the only transportation line of this district, follows Bear River. A branch line has recently been constructed from Montpelier to Paris, the county seat of Bear Lake County. Montpelier, Paris, and Soda Springs are the largest towns of the district, Montpelier having a population of about 2,000.

The interests of the region are chiefly agricultural. Bear Lake Valley and the adjoining bench lands are fertile and occupied by many ranches and farms.

The higher, open ground is utilized for sheep ranges. Soda Springs and Montpelier are important shipping points.

[1] Henry, A. J., Climatology of the United States: Bull. Weather Bureau No. 361, U. S. Dept. Agr., 1906, pp. 822, 823.

The phosphate industry is represented in this district by the San Francisco Chemical Co., the Utah Fertilizer & Chemical Manufacturing Co., Brown, Perkins & Co., and Duffield & Jeffs. Thus far shipments have been made only from the Waterloo mine, at Montpelier, by the San Francisco Chemical Co., and a single shipment from one of the claims held by Brown, Perkins & Co., at Soda Springs, in the SE. ¼ SW. ¼ sec. 23, T. 8 S., R. 42 E.

EARLIER GEOLOGIC WORK IN THIS AREA.

The springs and their extensive deposits near the present town of Soda Springs figure in the narratives of the early explorers Bonneville[1] and Frémont,[2] but no other account of the geology is known previous to the reports of the Hayden Survey[3] for the years 1871 and 1877.

Weeks and Ferrier[4] published in 1908 a general account of the western phosphate fields with brief descriptions of several localities, including the Swan Lake district (T. 9 S., R. 43 E.).

NATURE AND ORIGIN OF THE ROCK PHOSPHATE.

GENERAL 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 built up in roughly concentric structure and ranging in size from extremely minute specks to bodies half an inch or more in diameter. Many of these oolitic bodies are irregularly flattened, suggesting that they may have actually existed as pebbles and been worn by attrition upon one another. The ovules are in general of a darker color than the matrix and a few of them possess a black shiny coating which is similar in appearance to desert varnish. In the one quantitative comparison that has been made the ovules were found to be 3 per cent higher in content of phosphoric acid than the matrix.

The freshly mined rock usually possesses a dark-brown color, but the weathered material found on the outcrop is predominatingly a light bluish gray. The rock that has lost its oolitic texture through pressure metamorphism appears to retain the darker original color even after long exposure. The bluish-gray coating (somewhat like chalcedony in appearance) has a tendency to concentrate along lines in a netlike pattern. These lines are very apparent upon the darker-

[1] Irving, Washington, The Rocky Mountains, etc., from the journal of Capt. B. L. E. Bonneville, 1873.

[2] Frémont, J. C., Report on the exploring expedition to the Rocky Mountains in 1842: Senate Doc. 174, House Doc. 166, 28th Cong., 2d sess., 1845, p. 693.

[3] Hayden, F. V., Fifth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1871; idem, Eleventh Ann. Rept., 1877.

[4] Weeks, F. B., and Ferrier, W. F., Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 340, 1908, pp. 441–447.

colored rock and are of assistance in following scattered float along the concealed outcrop of the phosphate beds.

The phosphate rock and the limestone closely associated with it when struck yield a characteristic fetid odor which is described by some as bituminous and by others as more nearly sulphurous. One feature on which all agree is that the odor, though not particularly disagreeable, is exceedingly penetrating. The intensity of the odor given off by any portion of the rock when struck is by no means an indication of its phosphatic content.

SPECIFIC GRAVITY.

A series of experimental determinations of the density of the rock phosphate was made in the laboratory of the United States Geological Survey and is described in detail in the report for 1909. The average specific gravity for rock containing 70 per cent of tricalcium phosphate was found to be about 2.9. No further data on this subject have been collected and the above figure has been used in the tonnage calculations of the present report.

ORIGINAL SEDIMENTARY DEPOSITS—SOURCES OF PHOSPHORIC ACID.

The rock phosphates of the western fields occur as deposits interbedded in strata of undoubted sedimentary origin and according to the interpretation of fossil data are regarded of Pennsylvanian age. They were deposited at about the same time geologically as the extensive coal deposits of the Appalachian region. Like the coal deposits, they have been subject to deformation by folding and faulting, but they have suffered less from metamorphic changes, which are indicated only by a loss of the original oolitic texture, the chief microscopic characteristic of the phosphate rock. This oolitic texture is undoubtedly significant as to the origin of these deposits and is regarded by the writers as original rather than secondary.

If the oolitic bodies were secondary or produced subsequent to the deposition of the beds the bedding planes might appear in at least the larger oolites, but such traces of bedding are wholly absent. An unusual facies of the phosphate was collected from the base of the high-grade bed in sec. 2, T. 8 S., R. 42 E., which consists of shell fragments that G. H. Girty [1] is inclined to regard as derived from pelecypods. The phosphoric acid content of this specimen (33.8 per cent P_2O_5) is that of a high-grade rock.

The shells of pelecypods, so far as known, are composed of practically pure lime carbonate, and it seems more reasonable to assume that this deposit is due to the phosphatization of lime carbonate shells rather than to the existence of an unusual phosphate-secreting

[1] Personal communication.

form. Girty, however, states that *Lingula discina*, a phosphate-secreting brachiopod, is prominent and abundant in the Embar formation of Wyoming, which in the area recently examined by Woodruff[1] may prove equivalent to the Park City formation, and a few specimens were found by Gale[2] in the main phosphate bed at Cokeville, Wyo. The question is raised whether or not the evidence indicates that such forms predominated sufficiently over the lime carbonate secreting forms to account for the immense accumulation of phosphoric acid represented by the contents of the western fields.

George A. Koenig[3] has advanced a hypothesis that the lime phosphate was secreted by a protozoan of unknown type, which was extremely prolific and accumulated a great bulk of material in a short time. The writers regard this suggestion as improbable but can not in the present report enter into a detailed discussion of the data and inferences involved. It may be said, however, that a hypothesis adequate for the explanation of the extensive phosphate deposits of the western fields, must consider: (1) The source of the phosphoric acid; (2) the conditions that resulted in the abnormal enrichment of the sea water in the acid or its salts; and (3) a cause for the abstraction of the acid in the form of lime phosphate and its deposition in oolitic bodies.

The formulation of such a hypothesis requires the assembling of further data concerning the geologic constitution of the land areas bordering the epicontinental sea in which the phosphates were deposited. The writers hope to advance, after such data are collected, a scheme of origin in which the constitution of the land areas immediately adjoining the sea, the chemical constitution of the atmosphere (which contained CO_2 in greater abundance than at present), and the character of the basin or basins in which the deposits were formed will all be considered. It is thought that the hypothesis will suggest a direct chemical and physical origin rather than one in which organisms play a prominent part.

MINERAL AND CHEMICAL 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 having the same average index of refraction (about 1.60) and apparently representing the same substance—the phosphatic mineral. In some places the

[1] Woodruff, E. G., The Lander oil field, Wyoming: Bull. U. S. Geol. Survey No. 452, 1911.
[2] Personal communication.
[3] Quoted by M. S. Duffield in Mines and Methods, vol. 2, No. 1, 1910, p. 12.

interstices are filled with calcite and in others with an isotropic material which appears to be identical with the substance forming the cores of the concretions. The ovules include minute curly, hairlike, and branching plant fragments whose appearance strongly suggests that they represent fungi. 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.

Additional mineralogical data have been obtained from the unusual facies of phosphate rock collected from the base of the main bed in sec. 2, T. 8 S., R. 42 E., which is regarded as composed of fragments of pelecypod shells. An examination of a thin section of this rock (R 307) and others of the oolitic variety was made by W. T. Schaller, of the United States Geological Survey, who regards the isotropic substance as probably representing collophanite, $x(Ca_3(PO_4)_2)$ or $x((CaF_2)Ca_3PO_4)_6+yCaCO_3+zH_2O$ and the double refracting substance as possibly quercyite. Quercyite comprises a variable mixture of the series of lime-phosphate minerals, including collophanite described by Lacroix [1] from the French phosphorites.

Chemical analyses of the rock phosphate of the western field are published on page 465 of the 1909 report. No additional complete analyses have been made, and no reason has appeared for modifying the 1909 statement that the calcium phosphate mineral closely approximates in composition a basic calcium phosphate.

DETERMINATION OF PHOSPHORIC ACID.

The field quantitative determination of phosphoric acid was abandoned in 1910, and the determinations published in this report were made by Henry A. Lepper and John G. Fairchild in the chemical laboratory of the United States Geological Survey.

A number of the field determinations published in the 1909 report have been reviewed and found to run from 1 to 2 per cent high.

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 mineralogical composition of this material, no extensive examination has been undertaken to verify this conclusion. In the 1909 work at Montpelier an average sample of the main bed taken at the surface ran 4 per cent higher in phosphoric acid than the average samples taken in the Waterloo mine, and J. J. Taylor, the superintendent of the property, reports that a still lower content was found in the bed as cut by

[1] Lacroix, A., Sur la constitution minéralogique des phosphorites français: Compt. Rend., vol. 150, 1910, p. 1213; Minéralogie de la France, vol. 4, pt. 2, 1910, p. 555.

a bore hole at comparatively shallow depth. This evidence is probably insufficient on which to base general conclusions, but the mining operations in other parts of the field seem to demonstrate that fresh, clean rock from the thicker workable beds usually maintains an average content exceeding 32 per cent of phosphoric acid in the area examined during 1909. The average for the area described in the present report, however, would probably be slightly lower.

Positive information about the character of these deposits at greater depth is needed, as it must be admitted that 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 importance of the phosphate deposits still in public ownership is greatly enhanced if only the outcrop of these deposits is of present commercial value, and it is therefore imperative that a study of the quality of these deposits under cover should be conducted by systematic drilling prior to their disposal and development.

IRON AND ALUMINA.

Iron and alumina in phosphate rock in excess of 3 to 4.5 per cent in the eastern fields are considered as placing the ore below foreign contract standards. These substances are supposed to produce in the present process of superphosphate manufacture deliquescent salts which render the drying and shipment of the product difficult. The several ultimate analyses of samples of rock phosphate from the western fields by George Steiger[1] published in the 1909 report give both iron and alumina determinations. A number of additional iron determinations made recently by Steiger on samples of phosphate from the vicinity of Bloomington, Idaho, range from 0.30 to 0.45 per cent. In all samples from these fields that have been tested in the laboratory of the Geological Survey less than 1 per cent of either radicle computed in the oxide form was found. The manufacturers of superphosphate using the rock from the western field all agree that the amounts of these substances present are too small to be considered objectionable.

METAMORPHISM.

Metamorphic changes are effected in the rock phosphate by pressure and also by solution. The loss of oolitic texture and an apparent slight increase in density has been noted in places where the phosphate has been subjected to excessive compression in the deformation of the inclosing strata. A somewhat porous facies has been found which indicates that partial solution of the rock has been accomplished, probably by the carbonated water with which the springs of the northern part of the area abound.

[1] Bull. U. S. Geol. Survey No. 430, 1910, p. 465.

GEOLOGY.

GENERAL STATEMENT.

The rocks of the area surveyed in 1910 (see Pl. IX) are mainly sedimentary, with a stratigraphic range from Middle Cambrian to Quaternary, but in the extreme northwestern part there occur basaltic flows which have generally been regarded as of the same age as the flows of the Snake River lava plains.[1] Late Tertiary beds cover an area of about 50 square miles. An overlap with Tertiary beds lying on Triassic or Carboniferous rocks, thousands of feet of beds which are prominent in the areas to the south and east being absent, is the most significant stratigraphic feature of the region. The most prominent structural feature consists of a great easterly overthrust which crosses the area from north to south and causes rocks of Middle Cambrian to Mississippian age to overlie Triassic(?) sediments.

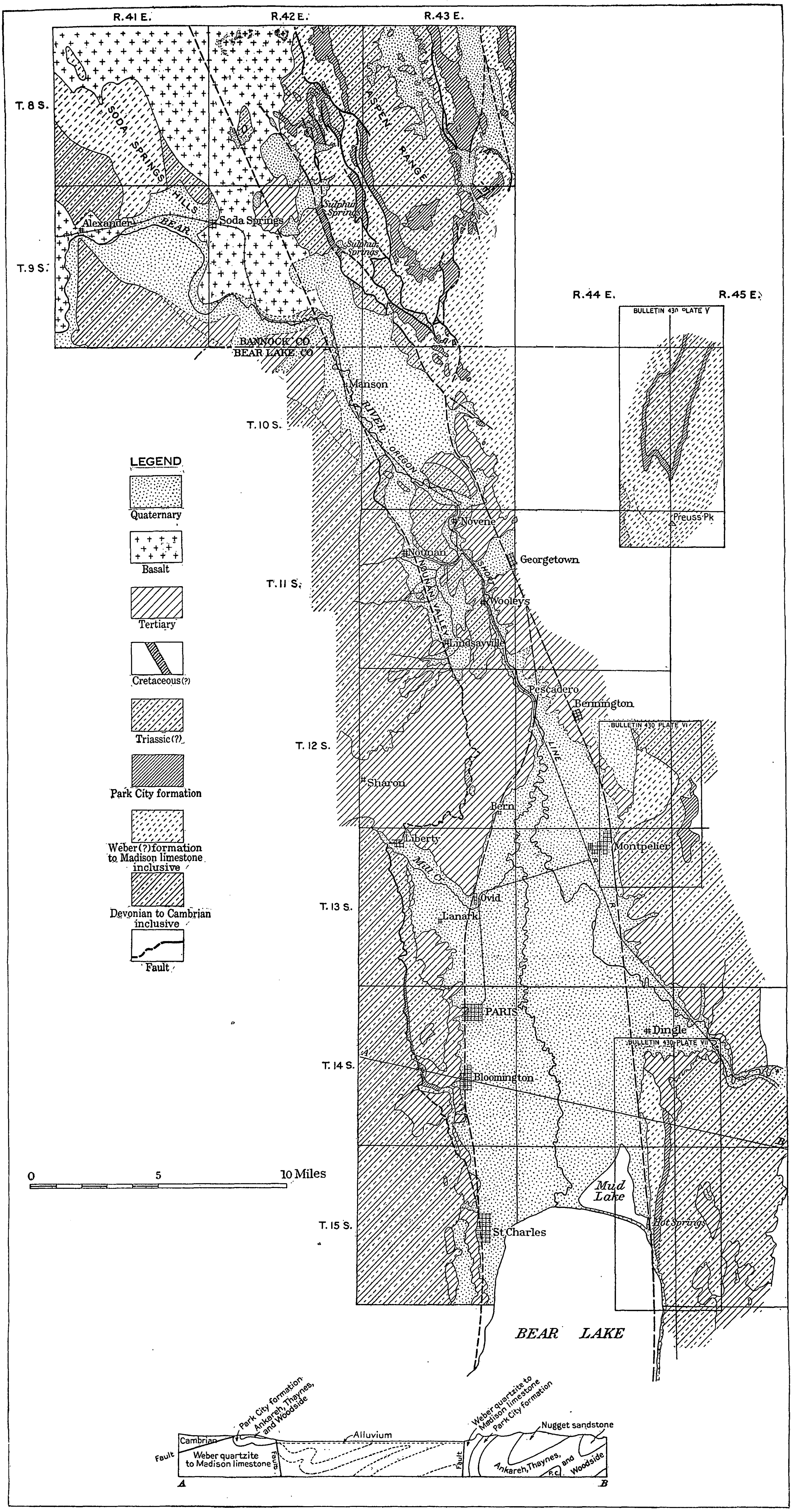
A compiled tabular summary of the stratigraphy of the area is given below. The several formations are described in greater detail in the pages following the table.

General section of phosphate area in Idaho.

Geologic age.		Formation.	Thickness.	Description.
Quaternary.			Not measured.	Alluvium, travertine, basalt flows.
Tertiary.	Pliocene(?)		Not measured.	White marls, marly limestones, calcareous conglomerates; dense, nearly lithographic limestones near Soda Springs; pea-green grits.
	Eocene.	——Unconformity——	Not measured.	Roughly bedded coarse sandstones and coarse conglomerates or bowlder beds, in places of a deep red color.
Cretaceous(?).		——Unconformity——	Not measured.	Agglomerate (of fault origin?) composed of fragments and masses of volcanic ash (white tuff) and Triassic and Carboniferous rocks.
Triassic or Carboniferous (including the Middle and Lower Triassic of Hyatt and Smith).[a]		Ankareh shale.	670 feet near Montpelier.	Consists essentially of red shale and mottled red and greenish clay and shales, with some sandstone and some limestone.
		Thaynes limestone.	About 2,000 feet or less.	The main body of the formation consists of dark-blue limestone, in many places fossiliferous, weathering to a brown muddy color, also including sandy and calcareous shale.
		Woodside limestone.	1,000 feet in the Preuss Range.	Thin-bedded platy limestones, somewhat shaly and sandy.

[a] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

[1] Russell, I. C., Bull. U. S. Geol. Survey No. 199, 1893.



GENERAL GEOLOGIC MAP OF A PORTION OF SOUTHWESTERN IDAHO.

General section of phosphate area in Idaho—Continued.

Geologic age.		Formation.	Thickness.	Description.
Carboniferous.	Pennsylvanian.	Park City formation.	600 to 850 feet.	A formation including three members as follows: (*a*) One or more massive strata of cherty limestone or chert, prominent as a ledge maker, grading in part to a purplish cherty or flinty shale. (*b*) Rock phosphate, phosphatic shale and minor limestone bands. (*c*) Limestone, massive white to light bluish, granular, weathering with projecting fossil fragments, usually with bluish chert bands and in some localities black chert in rounded nodules in the lower portion.
		Weber (?) formation.	1,000 ± feet.	White sandstone and quartzite, calcareous sandstones, and light-colored limestones, with variable amounts of interbedded quartzites.
		Morgan (?) formation.	500 ± feet.	Light-colored limestone with interbedded sandstones.
	Upper Mississippian.		1,200 ± feet.	Bluish-gray limestones with spherical nodules of black chert; gray sandy limestone streaked with calcite and specked with siderite; locally marked by fossil corals and crinoid stems.
	Lower Mississippian.	Madison limestone.	Not measured.	Massive blue to gray limestone, a thick formation usually making high mountainous country where brought to the surface in mass.
Devonian.		Jefferson (?) limestone.	Not measured.	Dark-gray to black limestone.
Silurian.			Not measured.	Dark cherty limestone; thin-bedded and light-gray sandy limestone.
Ordovician.			Not measured.	Limestone, cherty limestone, quartzite with some shale, and gray limestone.
Cambrian.		Divided into six formations by Walcott.	5,000 + feet.	Limestones and quartzites with a few beds of shale.

CAMBRIAN ROCKS.

The rocks of the western portion of the area comprise a series of limestones and quartzites which have been studied in detail by Walcott[1] and referred on abundant fossil evidence to the Cambrian. The following section is compiled from his publications.

[1] Walcott, C. D., Nomenclature of some Cambrian Cordilleran formations: Smithsonian Inst. Misc. Coll., vol. 53, 1908, pp. 1-12; Cambrian sections of the Cordilleran area: Idem, pp. 167-230.

Geologic section on Mill Creek west of Liberty, Idaho.

	Feet.
Upper Cambrian:	
St. Charles limestone: Bluish-gray to gray arenaceous limestones, with some cherty and concretionary layers, passing at the base into thin-bedded gray to brown sandstones....	1,197
Middle Cambrian:	
Nounan limestone: Light-gray to dark lead-colored arenaceous limestones....	814
Bloomington formation: Bluish-gray, more or less thin-bedded limestones and argillaceous shales. Small rounded nodules of calcite are scattered irregularly through many of the layers of limestone....	1,162
Blacksmith limestone: Gray arenaceous limestone in massive layers....	23
Ute limestone: Blue to bluish-gray thin-bedded fine-grained limestones and shales, with some oolitic, concretionary, and interformational conglomerate layers....	731
Spence shale member: Argillaceous shales....	30
Langston limestone: Massive-bedded bluish-gray limestone with many round concretions....	30
Brigham quartzite: Massive quartzitic sandstones....	1,000+

These formations outcrop along the east side of the Bear River Range, and in all places where it was examined the margin of the overthrust consists of the Ute and Langston limestones or the Brigham quartzite. Spence Gulch, the type locality for the Spence shale member of the Ute limestone, was visited, but no attempt was made to map the several formational units as laid down by Walcott.

ORDOVICIAN ROCKS.

Limestones and quartzites of Ordovician age were found west of St. Charles and north and west of Soda Springs but were not studied in detail. The fossils collected from the limestones at this point are referred by E. O. Ulrich[1] mainly to the Beekmantown horizon of the East. The most extensive fauna collected is identical with a fauna from Malade, Idaho,[2] and a fauna collected by Sidney Paige[1] near Silver City, Grant County, New Mex.

SILURIAN ROCKS.

Limestones containing fossils which are identified by E. O. Ulrich as basal Silurian were collected in the southwest corner of T. 8 S., R. 41 E. Lithologically this portion of the section is characterized by gray and black limestones, more or less brecciated and cut by streaks of calcite, associated with rough-weathering sandy limestones, which are reddened by limonite stains.

[1] Personal communication.

[2] Meek, F. B., Sixth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1872, p. 469.

DEVONIAN ROCKS.

A dark, nearly black, magnesian limestone has been found in T. 10 S., R. 43 E., which contains fossils identified by Kindle as *Atrypa reticularis*, *Productella* close to *subaculeata*, *Favosites* cf. *limitaris* (most abundant), *Diphyphyllum* sp. undet., and *Cystiphyllum* sp. undet. *Favosites* cf. *limitaris* is one of the characteristic species of the Jefferson limestone of Montana, and its presence in the fauna, together with the resemblance of the dark magnesian limestone holding the fauna to that of the Jefferson, suggests that the collection represents that formation.

Another collection made in T. 8 S., R. 41 E., from a magnesian limestone that contained numerous specimens, is said by Kindle to be comparable to *Favosites digitatus*, which is provisionally referred to the Devonian.

CARBONIFEROUS ROCKS.

LOWER MISSISSIPPIAN.

MADISON LIMESTONE.

The basal Carboniferous sediments of the area are heavy beds of light-gray limestones, which where favorably situated resist erosion effectively and make rugged topographic features. The fauna collected from these beds is referred by G. H. Girty to the Madison limestone, which according to Girty corresponds to the basal portion of the "Wasatch limestone" of the Wasatch Mountains of Utah as described by the early writers.

UPPER MISSISSIPPIAN.

Above the Madison limestone, apparently in conformable succession, there is in this region about 1,200 feet of limestones, including clear bluish-gray limestones with spherical nodules of black chert and gray sandy limestones streaked with calcite and speckled with siderite and locally marked by layers in which zaphrentoid corals are abundant. This interval includes the Ross Fork-Lincoln Creek (Idaho) fauna of Meek,[1] which is comparable to that of the Spergen limestone of the central basin region of the United States.

The following section shows in detail the upper 435 feet of the upper Mississippian and the lower 560 feet of the overlying Pennsylvanian, which is tentatively correlated with the Morgan formation.

[1] Meek, F. B., Sixth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1872, pp. 470-471.

Section measured in sec. 29, T. 9 S., R. 43 E., in Swan Lake Gulch.

	Feet.
Pennsylvanian:	
Morgan (?) formation—	
Concealed.	
Limestones, light colored, with chert nodules and intercalated quartzitic layers. Bryozoa and *Syringopora* abundant at the top but not found in place; *Chonetes* and *Stenopora* 100 feet from the top, also in float	375
Sandstones, gray, interbedded with gray limestones and light-colored chert; *Schizophora* abundant near top	150
Limestone, light blue, fine grained; a ledge maker; *Chonetes?*	35
Upper Mississippian:	
Limestone, dark gray, pure, in part oolitic, and some light blue or lavender lithographic limestone with the Ross Fork-Lincoln Creek (Idaho) fauna of Meek[1] abundant at top, and corals abundant toward the base	65
Limestone, dark gray, pure, in part streaked with calcite and specked with siderite; full of rather small zaphrentoid corals	150
Limestone, quartzitic; fenestelloid Bryozoa and zaphrentoid corals	225
Limestone, gray, siliceous, more or less cross-bedded with thin shaly bands; some chert	
Concealed.	

PENNSYLVANIAN.

MORGAN (?) FORMATION.

The upper Mississippian limestones are succeeded, with apparent conformity, by about 500 feet of soft sandy limestones of reddish and yellow tints intercalated with a minor amount of clear blue-gray fossiliferous limestones from which many collections have been made. Concerning these fossils, Girty says:

> In general these Idaho faunas have a facies closely similar to the Morgan fauna as represented in Mr. Blackwelder's collections from Weber Canyon, and they therefore indicate a correlation with the Morgan. As many of the species had a long range in other areas and as the fauna of the Weber quartzite in Weber Canyon is practically unknown and may prove to be the same as the Morgan fauna, a certain element of doubt still remains. On the other hand, these Idaho faunas succeed others of upper Mississippian age, just as the Morgan faunas do in Utah, and there is an interval between them and the Park City formation which has thus far furnished no fossils corresponding to the Weber quartzite in Utah, though not very similar to it lithologically. The Idaho faunas are especially characterized by an abundance of branching Bryozoa, belonging chiefly to the family Batostemellidæ, a feature which is not found in the typical Morgan.

No attempt has been made to differentiate the beds which may subsequently be referred to this formation on the preliminary maps that accompany this report.

[1] Meek, F. B., loc. cit.

WEBER (?) FORMATION.

The Weber quartzite in the area examined in 1909 consists chiefly of massive white quartzite with subordinate amounts of shale and calcareous sandstone or limestone. In the region studied during the present year the conditions are practically reversed, and the true quartzite is subordinate to calcareous sandstone and limestones. The character and position of the small amount of quartzite present are extremely variable. It was found so impracticable to locate the exact top, and especially the bottom of the quartzite, that attempts to map it were abandoned. The beds that are present in this interval, which has been mapped as Weber quartzite elsewhere, merge so gradually into the underlying sediments that they have not been differentiated from the Morgan (?) formation and the underlying Mississippian limestones on the maps that accompany this report.

PARK CITY FORMATION.

The Park City formation was named for the Park City mining district, Utah,[1] where it is said to have contained the principal bonanzas for which that district is known. The correlation of corresponding strata in southern Idaho and northeastern Utah with the Park City formation of the central and southern Wasatch regions is based on faunal and lithologic correspondence between the sections of the two regions; this similarity is indeed remarkable considering the distance by which the areas are separated. In the recent study of the phosphate beds, however, much more complete evidence of the continuity, especially of the beds associated with the phosphate, has been found, and the phosphate has been identified in the corresponding position in the Park City section. So exact is the lithologic correspondence that the thicknesses and descriptions given for the Park City district [1] are almost directly applicable to the Idaho sections.

The Park City formation is divisible into three parts—(1) an upper cherty limestone; (2) an interval of phosphatic shales, phosphate rock, and limestone bands; and (3) an underlying limestone, usually massive and commonly containing much chert.

The massive ledge-forming stratum of chert or cherty limestone immediately overlying the phosphate-bearing shales is distinguished as a separate member, on account of its prominence and its value as a horizon marker from which to trace the outcrops of the phosphate beds themselves where they are not continuously exposed. This member has been referred to locally as "the cherty lime," "the *Productus* limestone," or "the overlying limestone." In the districts examined in 1909, except in the Montpelier district, it consists of

[1] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434-458.

black chert, dark cherty limestones, and a minor amount of bluish-gray limestone and is quite distinct from the brown shaly limestones of the lower part of the Woodside shale, overlying the Park City formation. North and west of these districts the member has undergone considerable modification, both in thickness and lithologic character, and dark-colored siliceous or cherty shale which weathers pink to brown is the most prominent characteristic of the member. The cherty shale attains a maximum thickness of about 450 feet. Locally, however, heavy beds of chert vary from cream, pink, yellow, brown, or dark blue to nearly black in color. Another variation observed in Wood Canyon, in T. 8 S., R. 42 E., consists in the presence near the base of a coarsely granular gray limestone crowded with large crinoid stems, with minor thin intercalated beds of bluish-black chert.

A review of the Montpelier district during the summer of 1910 shows that a shaly bed is present within the chert and that a small amount of prospecting had been done on it in the search for phosphate. This occurrence is interesting for comparison with the rather extensive shaly strata which are developed to the north, in the Aspen Range, and with the discovery of a phosphatic stratum within the chert member of corresponding beds in Wyoming, as described by Blackwelder on pages 452–481 of this bulletin.

The "*Productus* limestone" contains some characteristic fossils, in the main species of *Productus*. These are as a rule limited in occurrence to the chert and the clear blue-gray limestones, the shaly portions of the member being practically barren. Girty calls attention to the fact that only three collections were obtained from this limestone in 1910 and lists the forms *Productus semireticulatus*, *P.* aff. *subhorridus*, *Marginifera splendens?*, and *Spirifer* aff. *nikitini*.

The areas examined in 1909 contain *Productus semireticulatus*, *P. humboldti*, and *P. subhorridus?*, and in some beds *Spiriferina pulchra* and *Stenopora* are found in relatively greater abundance than *Productus*, being commonest in zones near the top of the cherty limestones. Locally in portions of the area studied in 1910 numerous crinoid stems are found both in chert and in coarse gray limestone near the base of the member.

The phosphate-bearing member of the Park City formation, including all the main phosphate beds, consists of 77 to 140 feet of massive brown to gray phosphatic sandy shales and beds of rock phosphate, with some limestone and in places cherty bands in the upper part.

The occurrence of rounded or oval limestone nodules, ranging from a few inches to several feet in diameter, is a characteristic feature in the phosphatic shales. The nodules consist of very dense, compact fine-grained limestone, having a fetid odor when struck with a hammer, but showing a low percentage of phosphoric acid wherever tested.

Many detailed sections were measured in the phosphatic shales, especially in those immediately associated with the main phosphate beds. By reason of the weaker constitution of these shaly rocks they commonly give way to weathering and decay at the surface, and the outcrop is usually concealed as a whole or in greater part. Float of the harder rock phosphate remains in the soil and is very readily detected by one who has become familiar with the peculiar appearance which is due to its oolitic texture and the characteristic bluish-gray bloom, concentrated in reticulated pattern upon the exposed surfaces.

A complete section of the phosphate shales was measured under particularly favorable conditions in Georgetown Canyon in 1909, and as the section is situated only a few miles east of the middle of the region discussed in the present report, it is repeated for comparison.

Complete section of the phosphate-bearing strata in Georgetown Canyon, Idaho.

Field No. of specimen.		P_2O_5.[a]	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		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; lower 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	82.3	2 11
144-E	Shale, brownish, earthy, containing 6 inches of phosphate; effervesces considerably	10.0	21.9	1
144-F	Phosphate rock, including— *Ft. in.* (*a*) Phosphate rock, oolitic, hard, gray, calcareous 7 (*b*) Phosphate rock, medium, gray, oolitic 6 (*c*) Shale, phosphatic, light brown 4 (Sample shows considerable effervescence.)	21.9	48.0	1 5
144-G	Phosphate rock, including— (*a*) Phosphate rock, coarsely oolitic, gray, brittle 1 2 (*b*) Phosphate rock, finely oolitic, brownish gray 4 (*c*) Phosphate rock, coarsely oolitic, dark gray 2 (*d*) Phosphate rock, finely oolitic, brownish gray 4 (*e*) Phosphate rock, coarsely oolitic, gray 7 (*f*) Phosphate rock, finely oolitic, thin bedded 3 (*g*) Phosphate rock, coarsely oolitic, gray 1 4 (Sample effervesces slightly.)	33.3	72.9	4 2
144-H	Phosphate rock, including— (*a*) Phosphate rock, medium to finely oolitic, brownish gray 7 (*b*) Shale, phosphatic, brownish, somewhat oolitic 10 (*c*) Phosphate rock, coarsely oolitic 2 (*d*) Phosphate rock, shaly, brown 3	29.3	64.1	1 10
144-I	Phosphate rock, including— (*a*) Phosphate rock, coarsely oolitic, brownish-black streaks 1 1 (*b*) Phosphate rock, shale, brown, thin bedded 5 (*c*) Phosphate rock, coarsely oolitic, crumbly 4 (*d*) Phosphate rock, medium to coarsely oolitic 3 (Sample effervesces considerably.)	34.7	76.0	4 10
144-K	Shale, brownish to black, earthy composition, thin bedded, with a few limestone lenses; effervesces slightly	24.2	53.0	8 9
	Limestone, dark, compact, fetid			1 9
144-L	Shale, brownish to black, earthy; effervesces slightly	11.7	25.6	12

[a] Phosphoric acid determinations by W. H. Waggaman, Bureau of Soils, U. S. Dept. Agr., 1909.

Complete section of the phosphate-bearing strata in Georgetown Canyon, Idaho—Contd.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
144-M	Shale, including— *Ft. in.* (*a*) Shale, brownish black, earthy.................... 7 (*b*) Concealed, not included in sample (probably same as *a* and *c*).................... 4 7 (*c*) Shale, brownish black, earthy.................... 5 5	15.1	33.1	17	
144-N	Shale, black, earthy; effervesces slightly....................	19.9	43.6	12	
144-O	1. Shale, brownish black, earthy.................... 4 2. Limestone, single stratum (not sampled).................... 2 3. Shale, brownish black, earthy.................... 4 4. Limestone, single stratum (not sampled).................... 2	21.2	46.4	12	
144-P	Shale, black and dark brown, calcareous, earthy; effervesces considerably....................	25.8	56.5	6	
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	39.0	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, gray, contains two or three minor streaks of shaly material; effervesces slightly....................	36.8	80.6	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 partial section of the phosphatic beds was measured in 1910 in a prospect opening in Diamond Gulch, on the west side of the Aspen Range. This locality is about 12 miles from the Georgetown Canyon section.

Partial section of the phosphate-bearing strata in Diamond Gulch, in the NW. ¼ NW. ¼ sec. 33, T. 9 S., R. 43 E.

Field No. of specimen.		P_2O_5.	$Ca_3(PO_4)_2$.	Thickness.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
M 316a	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 shale....................	28.3	62.1		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 phosphatic 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.

The main bed of rock phosphate is exposed and is 1 foot thinner than in the Georgetown Canyon section. The quality of the rock is equally good. In Georgetown Canyon the main bed is only 9 inches above the underlying limestone, but in Diamond Gulch the interval between the limestone and the main phosphate bed is about 6 feet. Another difference consists in the presence of 17 inches of phosphatic shale between the phosphate bed and the cap limestone.

A complete section was measured on a small tributary of Slug Creek just east of the east boundary of T. 8 S., R. 43 E., about 26 miles north-northwest of the Georgetown Canyon locality. The section which follows is the leanest in phosphate material yet obtained and only a small portion of the series was regarded as phosphatic. The beds that were sampled are indicated by numbers.

Complete section of the phosphate-bearing strata in the SW. ¼ SW. ¼ sec. 7, T. 8 S., R. 44 E. of the Boise meridian, Idaho.

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	Phosphatic 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	Phosphatic 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

A comparison of this section with the Georgetown Canyon section shows its striking inferiority both in the quantity and in the quality of the phosphate. That this variation is a local one rather than a general change in the character of the deposits is shown by the Diamond Gulch section and also by the following partial section of the lower part of the phosphate shales measured near the west border of the township, in Trail Canyon. At this place there is 7 feet of phosphate rock containing over 70 per cent of tricalcium phosphate and about 5 feet more which ranges from 65 to 68 per cent. The section as exposed in Trail Canyon shows relatively a greater amount of high-grade phosphate rock than that present in the similar portion of the Georgetown Canyon section.

Section of the Park City formation 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 cherty talus			71 6
379-10	Phosphatic rock, brown, medium to finely oolitic	28.5	62.3	4
	Limestone, gray, shaly in middle			7 6
	Shale, brown rock			1
379-9	Phosphatic rock, brown, medium oolitic	31.3	68.3	2 8
379-8	Shale, brown	20.7	45.2	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	Phosphate rock, brown, medium oolitic	38.3	72.7	3
379-1	Phosphatic rock, brown, finely oolitic	33.5	73.2	3
	Shale, brown			7
	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

Unfortunately in this locality the upper portion of the phosphatic shales is so covered with heavy talus derived from the overlying limestone or chert that no prospecting has been done and the character of that portion is undetermined. Phosphatic beds are found, as in the Georgetown and Montpelier districts, near the underlying limestone which forms the basal member of the Park City formation. The cap limestone with its characteristic fossils of the same districts is, however, either entirely lacking or much thicker and higher in the section, consisting of two phosphate beds separated by phosphatic shales. The persistency of the shaly partings over large areas is considered doubtful, and development will undoubtedly show faces of phosphate beds which are as clean and as suitable for mining as those at Montpelier and Georgetown.

About a mile west of Bloomington the following nearly complete section of the phosphate shales was measured. There is much local disturbance in the section, owing to the proximity of the margin of the thrust block, and it is highly probable that the section is somewhat compressed and that the measurements may be less than would be found in an undisturbed section of the beds, such as might be encountered by drilling a mile or so to the east.

Section of phosphatic shales exposed in Spomberg's tunnel, in sec. 21, T. 14 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.*
	Limestone, dark, with seams of gypsum	2.5	5.5	....	
	Shale, dark, carbonaceous?	8.4	18.3	80	
	Clay, yellow to gray, sandy at west	18.5	40.4	15	
M. 185 n	Phosphate rock, gray and brown, finely oolitic	31.3	65.4		6
185 m	Phosphate rock, gray, coarsely oolitic	30.6	66.8		1¾
185 l	Phosphate rock, gray, medium oolitic	33.6	73.4		8
185 k	Phosphate rock, gray, finely oolitic	31.9	69.7		1½
185 j	Phosphate rock, gray, medium oolitic	33.7	73.6		4
185 i	Phosphate rock, gray and brown, finely oolitic	34.0	74.3		9
185 h	Phosphate rock, gray, finely oolitic	34.1	74.5		10
185 g	Phosphate rock, gray, coarsely oolitic, weathered	33.2	72.5		1½
185 f	Phosphate rock, gray, finely oolitic, much jointed, weathered	33.1	72.4	1	11
·	Shattered zone	....	....		1
185 d	Shale, gray, finely oolitic and sandy, much jointed and weathered	29.9	65.4		9
		....	....	101	2¾

Fossils occur at many horizons in the phosphate-bearing member of the Park City formation and have been described by Girty[1] in a separate bulletin.

The distinction between the phosphate-bearing strata and the underlying limestone is clear, but at its base the Park City formation consists of calcareous sandstone and bands of quartzite alternating with limestone, so that it shows but slight difference from the calcareous sandstones and sandy limestones which are believed to represent the Weber quartzite. The under limestone in the northern part of the area possesses a fauna consisting, according to Girty,[2] mainly of *Chonetes ostiolatus*, *Productus* aff. *cancrini*, *P.* aff. *porrectus*, *P.* aff. *ivesi*, *Rhynchopora taylori*, *Composita subtilita*, and *Squamularia* sp. This member in the other districts has been found barren of fossils, and the presence here of a fauna so similar to that generally found in the overlying cherty limestone naturally led to the supposition that the section was overturned, but the normal character of the sequence was soon clearly proved and the variation in abundance of fossils and difference in faunal character were determined. Owing to the local change in the character of the chert overlying the phosphate shales, both lithologically and by the decrease in abundance of fossils, the lower limestone becomes an important marker in the prospecting of the phosphate beds. Where favorably situated it weathers into conspicuous white cliffs, and as it practically forms the floor on which the lower high-grade bed was deposited, the location of that particular phosphate bed is very easily found.

[1] Girty, G. H., Fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: Bull. U. S. Geol. Survey No. 436, 1910.

[2] Personal communication.

TRIASSIC OR CARBONIFEROUS ROCKS.

WOODSIDE LIMESTONE.

The Woodside limestone immediately overlies the Park City formation and is so called by correlation with the section in the Park City mining district, Utah. It is composed mainly of thin-bedded, platy, somewhat shaly or sandy limestones. In the southern part of the area visited in 1910, including the Paris-Bloomington district, the upper portion of the Woodside formation includes "red beds" similar to those of the area farther south and east, examined in 1909. In the greater part of the region discussed in this report the "red beds" are absent, but some of the more massive beds in the upper part of the formation weather with a slightly reddish or purplish tint. The great mass of the formation consists of the thin beds above mentioned, which have a yellowish to olive-greenish tint and are firm textured and hard enough, when fresh, to ring under the hammer. They weather to yellowish or brownish colors, usually retaining the slightly greenish tint.

The base of the Woodside is quite distinct, for the upper cherty limestone of the Park City is usually well defined, in contrast with the overlying platy or muddy limestones. Even where the flinty-shale facies of the upper part of the Park City formation is present, the distinction between the float fragments of the two formations is usually so clear that the position of the stratigraphic boundary can be determined with little difficulty.

The upper limit of the Woodside is not so clear. As this formation was originally defined in the Park City district it was intended to include the reddish shaly beds and to be limited by the more massive limestones of the overlying Thaynes. The distinction is perhaps not so clear in this field, but a more or less arbitrary limit may be drawn, which corresponds closely with the descriptions and thicknesses given for the typical sections. Where it has been recognized the *Meekoceras* zone has been adopted as a paleontologic definition of the base of the Thaynes.

In the Paris-Bloomington district the upper Woodside consists of heavy limestones that weather reddish. The actual transition into the beds that carry *Meekoceras* is not exposed, but the *Meekoceras* zone outcrops on the south side of the mouth of Paris Canyon in sec. 10, T. 14 S., R. 43 E. This zone here consists of white, somewhat sandy limestones, weathering with a yellowish tinge.

In sec. 5, T. 9 S., R. 43 E., and the adjoining township on the north a complete section of the Woodside is exposed. The lower and middle portions consist of thin-bedded platy and sandy limestone, of a yellowish to olive-green color, weathering brown. Alternating with this, especially in the middle portion, are somewhat thicker bedded purplish-gray, yellowish, or greenish limestones. The upper portion of the formation consists of heavy-bedded, dense purplish-gray limestones that in some zones are crowded with fossils, principally species of *Myalina.* The uppermost members of the heavy-bedded limestones pass into those containing *Meekoceras* with no perceptible lithologic or stratigraphic break.

THAYNES LIMESTONE.

The Thaynes limestone, overlying the Woodside shale in normal sequence, was named from its occurrence in Thaynes Canyon, near Park City, Utah. It contains marine fossil shells at many horizons, and from the occurrence of certain ammonoids (*Meekoceras*) at its base it has been assigned by Hyatt and Smith to the Lower Triassic.[1] The Woodside shale, Thaynes limestone, and Ankareh shale were referred to the "Permo-Carboniferous" by the Fortieth Parallel Survey. The "*Meekoceras* beds," where recognized by the Hayden Survey, were referred to the Triassic.

The Thaynes is distinguished chiefly by massive ledge-forming limestones which are in places abundantly fossiliferous. It also includes many shaly intervals and, to a minor extent, some brown-weathering calcareous sandstones that pass by gradations into the limestone. The limestone itself commonly contains a considerable percentage of clay and sand, so that on weathering it assumes a sandy or muddy aspect, making much of it difficult to distinguish from sandstone except on fresh fractures. The thickness of the Thaynes limestone is somewhat less than 2,000 feet as measured in Raymond Canyon, and the measurement obtained in Montpelier Canyon shows at least that thickness, but it is doubtless several hundred feet thinner at other localities from which measurements have been recorded.

ANKAREH SHALE.

The Ankareh shale of the Park City section was originally described from the exposures in Big Cottonwood Canyon, near Salt Lake City. It consists chiefly of clay shale of deep maroon and chocolate colors, massive where fresh, though commonly breaking down with exposure into thinner-bedded shaly material. It includes also some pale-greenish clayey and sandy strata, beds of mottled green and maroon shale, and harder layers of red or greenish sandstone and limy strata, and in the Montpelier district is defined at the top and bottom by massive limestones. The limestone or calcareous shale at the top distinguishes the Ankareh to the south from the massive sandstones and red sandy shales of the Nugget sandstone. The limestone at the base of this "red bed" formation is the uppermost of the massive beds that con-

[1] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

stitute the more prominent part of the Thaynes limestone. The total thickness of the Ankareh as measured in the Montpelier district is about 670 feet, including the limestone at the top, but excluding the massive underlying sandstone strata more properly classed with the main body of the Thaynes. The thickness in this area is about the same as in the Montpelier district.

CRETACEOUS (?) ROCKS.

Associated with the sulphur deposits in T. 9 S., R. 42 E., there is a white rock which resembles a fine-grained sandstone but under the microscope is found to consist of angular particles of glass. This rock is apparently sedimentary. The fault agglomerate in which the sulphur is deposited includes fragments of this tuff associated with fragments of Carboniferous quartzite and limestone and Triassic (?) limestone. It is older than Cretaceous, the supposed age of the faulting. W. R. Calvert,[1] of the United States Geological Survey, suggests that this tuff may have been deposited during the same period of volcanic activity as the Livingston formation of Montana, which Stone and Calvert [2] have shown to range in age from lower Montana to Fort Union, inclusive.

TERTIARY ROCKS.

EOCENE LAKE BEDS.

The beds of the region which are younger than those of Triassic (?) age lie unconformably upon the older strata. The unconformity is great, for the oldest rocks above the Triassic (?), with the exception of the volcanic tuff, which because of its relations to the faults of the area is regarded as possibly of Cretaceous age, are lake beds not older than Eocene. These lake beds are conglomeratic and are best exposed on the hills forming the east flank of the Bear River Range in the vicinity of Bloomington and to the south. In places they are dark red, unevenly bedded, and made up mainly of bowlders derived from the Paleozoic quartzites. They are lithologically and stratigraphically equivalent to the lower portion of the Eocene beds south and east of Bear Lake and undoubtedly correspond to the Almy conglomerate of Veatch.[3] In the northern part of the area they are not present in sufficient amount to warrant mapping. Small patches of conglomerates which may represent them were seen about 2 miles north of Liberty, in T. 12 S., R. 43 E.

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[1] Personal communication.

[2] Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingston formation of Montana: Econ. Geology, vol. 5, No. 6, pp. 551; No. 7, pp. 652-669; No. 8, pp. 741-764.

[3] Veatch, A. C., Geography and geology of a portion of southeastern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907, p. 89.

PLIOCENE (?) LIMESTONES AND CONGLOMERATES.

Marls, marly limestones, calcareous grits, and calcareous conglomerates, of probable Pliocene age, which were included in the Salt Lake group of Hayden[1] and Peale,[2] fringe Bear Lake Valley on its west side, forming a terrace-like border about the Paleozoic and Mesozoic sediments. Farther north, in the region between Bern and Nounan, the deposits run up to the tops of the high hills, and the deformation of the beds is made very apparent by the presence of dips as high as 50°. In the middle of the area in the vicinity of Georgetown similar deposits lie near the present valley level in nearly horizontal position. But on the hill immediately east of Novene station the same beds have been so folded that they rise with the eastern slope and cap the hilltop. The extensive travertine deposits which extend from this vicinity northward to Sulphur Canyon appear to dovetail with the lake deposits, and their close lithologic resemblances render the areal distinctions difficult. These supposed Pliocene deposits may be in part fluviatile, and the apparent deformation may be due in part to inclined deposition.

QUATERNARY DEPOSITS.

BASALT FLOWS.

The four townships in the northwestern portion of the area are covered in part by flows of dark-colored igneous rocks, which represent the southern lobes of the outpourings of the craters situated between Soda Springs Hills and Blackfoot Marsh, 3 to 6 miles north of the area shown on Plate IX. The rocks of these flows are called basalts throughout this report. They have been so described in the earlier papers on this region,[3] and their mineralogical constitution and dark color warrant the determination. Examination with the naked eye shows the presence of phenocrysts of yellowish-brown glassy olivine and areas of transparent cleavable calcite, which is undoubtedly secondary, inclosed in a dark aphanitic groundmass.

The greater part of the basalt is dense, and in cliffs shows the development of irregular columnar jointing, but minor scoriaceous and cellular facies are found, especially near the margins of the flows. The surface of the basalt has a comparatively fresh and recent appearance, and the soil cover is thin except where it has been augmented by alluvial agencies. The number of flows has not yet been worked out in detail. It is evident that there are several, because of the intercalation of scoriaceous and tuffaceous lentils. The exact geologic range of the flows has not been determined, but it appears that some at least, from their relation to the deformed limestones of probable Pliocene age, are as late as early Quaternary.

[1] Hayden, F. V., Fifth Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1871, 1872, pp. 154, 155.
[2] Peale, A. C., Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1877, 1879, pp. 588 640.
[3] Fifth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1872.

SPRING DEPOSITS.

The portion of the area described in this report from the vicinity of the south boundary of T. 10 S., R. 43 E., to the northern margin is characterized by the presence of extensive deposits of travertine and numerous springs, many of which are depositing tufa at the present time. The largest group of springs, in the neighborhood of Soda Springs, afforded a rendezvous for the Indians and the early voyagers and trappers. Washington Irving's accounts of the gatherings at the "Beer Springs"[1] are vivid and clearly present the fascination which the natural effervescing waters possess. Frémont[2] described the springs in considerable detail and prepared the first map of the locality. Hayden[3] visited the springs in 1871 and Peale[4] in 1877. Peale gave an excellent account containing a large amount of new data which he compared with the earlier records. The prophecy that the springs would become one of the great pleasure resorts and watering places of the country has not yet been fulfilled, probably because of their proximity to the Yellowstone National Park with its greater variety of natural wonders, and because of the fact that a community in which sheep grazing is the principal industry is not particularly agreeable to the seeker of pleasure or health.

The natural carbonated water is exploited commercially under the trade name Idanha and the water is sold extensively through the Northwest, occasional shipments being made as far east as Chicago and Milwaukee. The water has an agreeable taste and pungency, and the content of mineral matter averages 152 grains to the United States wine gallon (2,599 parts per million).

The other springs of the vicinity are said to vary in character and amount of salts from the spring which yields the Idanha water. The water from certain of the springs is higher in magnesium salts; in others the iron salts are especially abundant. Mammoth Spring, in T. 8 S., R. 41 E., is one of the springs discharging a large amount of carbon dioxide. Its daily discharge is reported to average 2,000,000 cubic feet.

The extensive travertine deposits in the vicinity of Formation Spring and Swan Lake Gulch are especially remarkable and represent remnants of spring basins which during the period of maximum spring activity exceeded in size the present basins of the Yellowstone National Park. The deposition of the calcium carbonate is clearly due to the loss of carbon dioxide, for as a general rule the waters do not deposit at the point of emergence, but after running a distance, which appears to vary with the declivity. The faster flowing waters lose their gas more rapidly and deposit nearer the springs.

[1] Adventures of Capt. Bonneville, or Scenes beyond the Rocky Mountains of the Far West, Philadelphia, 1837; London, 1850.

[2] Frémont, J. C., Report of the exploring expedition to the Rocky Mountains in the year 1842, and to Oregon and California in the years 1843-44: Senate Doc. 179, House Doc. 166, 28th Cong., 2d sess., 1845.

[3] Hayden, F. V., Fifth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1872, p. 154.

[4] Peale, A. C., Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1879, pp. 590-596.

STRUCTURE.

The major structural features of the region are the broad synclinal troughs and broken intervening anticlinal ridges of the Aspen Range and the great folded and overthrust mass of the Bear River Range. In Bear Lake Valley the structure is problematical, being concealed by alluvium.

The details of the structure of the Aspen Range are included in the portions of the report dealing with Tps. 8 and 9 S., Rs. 42 and 43 E.

The great overthrust from the west, the trace of which runs through the area from north to south, is a striking example of the overriding of younger sediments by older and harder formations which takes place when the shortening of the strata accomplished by folding is not sufficient to relieve the compressive strain. The force apparently originated to the west of this area and acted toward the east. The overthrust is similar to and probably a direct continuation of the thrust fault observed in the Woodruff Creek area, Utah,[1] in 1909. If the structures in the two areas are really continuous, the fault has a known length of about 100 miles and an apparent horizontal displacement of about 10 miles.

The origin of Bear Lake Valley is a problem both structurally and physiographically. The length of the valley from Bennington, Idaho, to Laketown, Utah, is about 36 miles, and the width at the Idaho-Utah line is a little over 7½ miles. The valley includes an area of about 180 square miles, two-thirds of which is in Idaho. It is shut in on both sides by mountains. The direction of outflow in earlier times is unknown, but was presumably northward, as at present.

The valley wall, especially along the east side of Bear Lake, is strikingly scarplike when viewed from the opposite side of the lake. This, together with the occurrence of several thermal springs on the margin of the alluvial plain near the base of the mountains at Hot Springs, Idaho, suggest that this side of the valley is determined by the presence of a fault extending to considerable depth. The west side of the valley has also, to a lesser extent, a scarplike appearance, although the structure of the exposed rocks permits also the postulation of a down folding of the beds below the present valley level.

A brief summary of the geologic conditions existing in the areas adjoining the valley may be given as an introduction to a discussion of the inferences concerning the conditions existing under the alluvial valley cover.

The area directly west of the valley is occupied by a rock series ranging from Madison limestone to Thaynes limestone, Mississippian, and Triassic (?), respectively, emerging from under an overthrust block of sediments that are mainly of Cambrian age but include in the vicinity of St. Charles rocks of a somewhat more recent aspect. The

[1] Gale, H. S., and Richards, R. W., Bull. U. S. Geol. Survey No. 430, 1910, p. 527.

east edge of the overthrust block lies at a maximum 4 miles back from the valley margin toward the north end of the valley, but so far as is known practically coincides with it in the vicinity of St. Charles and to the south of that point.

The geologic structure on the east side of Bear Lake Valley [1] is that of a series of large easterly overturned anticlines and synclines. The valley margin cuts somewhat obliquely across the axis of an overturned anticlinal fold from the vicinity of Dingle to the Utah line.

The geologic structure in the northern part of the valley is best exposed east of Novene station, where a portion of the Thaynes limestone lies close by an area of Madison limestone. The exact nature of the relation between the two is obscured by a cover of Tertiary lake beds, but it is supposed to be a fault contact along the line of disturbance of a fault zone which may form the eastern boundary of the valley. It is probable that this same line of dislocation extends to the north along the line of extensive spring deposits near Swan Lakes, Sulphur Springs, and Formation Spring.

A geologic section across the south end of Bear Lake Valley, in Utah,[2] involves a folded series of Cambrian to Mississippian sediments on the west overthrust on a block of Mississippian to Jurassic folded rocks on the east.

The above review of the geologic conditions existing in the areas surrounding Bear Lake Valley suggests the following conclusions:

1. A fault or a series of nearly parallel faults, probably normal because of the presence of hot and depositing springs and possibly of considerable length, extends along the west front of the Aspen range and southward into and along the east side of Bear Lake Valley, possibly passing out of this valley to the south along the same line as the thrust found between the Cambrian and Mississippian and the block including the later sediments. The downthrow is everywhere on the west side of the fault, and the amount of displacement is greater toward the north than in the southern part of the area.

2. A displacement has occurred along the west side of Bear Lake Valley, either by downfolding or by faulting, the effect being in both cases practically the same—viz, to place postphosphate rocks in unknown distribution and at unknown depths below the valley floor.

3. A fault of less throw than that of the one supposed to bound the valley on the east may be regarded as branching from the major fault in the vicinity of Wooleys and extending along the western margin of the valley, as indicated on Plate IX. This may, perhaps,

[1] Gale, H. S., and Richards, R. W., Bull. U. S. Geol. Survey No. 430, 1910, p. 496.
[2] Idem, p. 522.

be considered as offering the simplest explanation of the observed conditions. Whether or not such a fault passes through the rock series in the southwest corner of the valley is unknown.

Bear Lake Valley, therefore, probably constitutes a true graben, or downthrown fault block. The north end of the graben tapers; the nature of the south end is obscure, and no attempt is made to explain it at this time.

Peale [1] suggested that Bear Lake Valley is probably underlain by at least one anticlinal fold. The recent work in the region between Bloomington and Liberty has disclosed evidence of an anticlinal axis east of the syncline involving Triassic (?) rocks which comes out from under the overthrust block of Cambrian quartzites and limestones. This fold lies a little to the east of the present west border of the valley. The existence of another anticlinal axis along the eastern margin of the valley has already been mentioned. A parallel intervening syncline probably intervenes between these anticlines. It appears rather unlikely that this syncline is of a sufficiently greater order than the exposed folds to occupy the entire valley. More probably the valley area was originally spanned by a series of anticlines and synclines, in part at least overturned toward the east in a manner similar to that of the exposed lower anticlinal limb of the east side of the valley in the vicinity of Hot Springs.

A diagrammatic cross section across the valley is shown on Plate IX. The portion of the section based on information derived from the outcrop is shown in solid line; the inferred portions are indicated by broken lines. In the construction of this section the intervening unknown folds were assumed to be approximately of the same order as the known folds, and it was assumed that the eastern part of the intervening folded series is overturned like the folds observed farther east. One of the folds of this valley area was probably of sufficient magnitude to afford an origin for the overthrust of Madison limestone in the vicinity of Montpelier.

The period of overturning and overthrusting was succeeded by a period of relaxation and settling in which adjustment took place mainly by normal faulting. The evidence of such faulting in the immediate vicinity of Bear Lake Valley has been presented in the foregoing discussion. The fault of the greatest moment extends along a line connecting Formation Spring and Hot Springs, forming the eastern margin of the valley. The downthrow in all places is on the west and the fault plane dips in that direction. The Aspen Range contains abundant normal faults which presumably came into existence during the same period of structural readjustment that to a large extent determined the shape and size of Bear Lake Valley.

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[1] Peale, A. C., Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr. for 1877, 1879, p. 588.

DETAILED DESCRIPTION OF AREA.

TOWNSHIPS EXAMINED.

The area examined in 1910 comprised 15 townships in Rs. 41, 42, and 43 E. of the Boise meridian. These townships were included either in whole or in part in the phosphate reserves as originally constituted by the withdrawals of December, 1908, and December, 1909.

Reconnaissance examinations were found sufficient for nine of these townships, in which large areas of prephosphate rocks existed and the phosphate deposits were indicated mainly by the normally overlying formations. The remaining six townships contained the phosphate deposits and the rocks immediately associated with them, both normally above and below. The areas of these rocks were complicated by both folding and faulting, so that detailed geologic mapping was essential in the study of the deposits.

T. 8 S., R. 41 E.

A reconnaissance of T. 8 S., R. 41 E., demonstrated the absence of the phosphate-bearing strata, at least in outcrop, and accordingly the geology was not mapped in detail. The location of the places at which information was collected was determined by means of the map made by the Hayden Survey in 1877, and the geologic mapping of the township on Plate IX is a compilation of the new data and those of the earlier survey.

The sedimentary rocks range in age from Cambrian to upper Mississippian and outcrop only in the southwestern half of the township, and the series is in ascending order from southwest to northeast. Basaltic flows cover the northern and eastern portions of the township and entirely conceal the underlying sediments.

The strike and dip of the rocks, so far as observed, together with the distribution of the several formations and the supposed Cambrian outlier on Threemile Hill in T. 8 S., R. 42 E., suggest that the main structural feature is a rather open syncline with a northwest-southeast axis. The great easterly overthrust of the Bear River Range is projected west of the exposure on Threemile Hill across the northeast corner of the township under the basaltic cover along the general line of strike of its trace. More detailed work will doubtless show many minor faults within the area.

The limestones in the southwest corner of the township are dark gray or bluish gray in color, are dense, and contain fragments of trilobites. These, together with the associated sandy limestones, are considered of Cambrian age. The overlying beds, comprising a series of gray limestones, contain fossils which are pronounced by E. O. Ulrich to be of Beekmantown (Lower Ordovician) age and the fauna is similar to that collected by the geologists of the Hayden Survey at

Malade, Idaho, about 33 miles southwest of this locality. Near the top the limestone includes a small amount of yellow-banded chert, and it is overlain by a glassy white quartzite which should probably also be included in the Ordovician. Fossils collected from a series of darker and more or less brecciated limestones which may lie conformably above the quartzite have been identified by Ulrich as representing the basal portion of the Silurian system. About 600 feet higher corals were found which are regarded by E. M. Kindle as probably representing the fauna of the Jefferson limestone (Devonian).

The Carboniferous system is represented by limestones outcropping in the higher of the Soda Springs Hills, which lie in a northwest-southeast diagonal across the township. These rocks are referred by G. H. Girty to the Madison limestone (lower Mississippian) and the upper Mississippian.

It is doubtful if sediments later than these are exposed with the exception of Tertiary lake beds. The basaltic flows are at least in part Pleistocene, but possibly in part older.

The portion of the township in which the sediments outcrop does not contain rocks as young as the phosphate-bearing Park City formation, and if this formation is present it is concealed by the basaltic cover. The general character of the syncline suggests that phosphate deposits are not included in the central portion of the township. It is possible, however, that such deposits exist in the northeast corner to the east of the great thrust fault.

T. 9 S., R. 41 E.

T. 9 S., R. 41 E., was not mapped in detail in the present work, but a reconnaissance examination was made along the southern and northern boundaries and neither the Park City formation nor the normally overlying formations outcrop. The general geology of the township as shown on Plate IX is compiled from the data recently collected and from the work of the Hayden Survey.

The geologic structure has not been worked out in detail, but it may be stated broadly that the strata are deformed in large folds and that the structure is further complicated by faults.

The geologic sequence so far as studied includes formations of Cambrian to Mississippian age overlapped by much later rocks—Tertiary lake beds, basalt flows, travertine, and alluvium.

The details of the Paleozoic section, as exposed in the northern part of the township, are as follows: Light yellowish-gray sandy limestone outcropping in the sides of an irrigation ditch on the point directly west of Alexander apparently represents the oldest sediment. Above it is an iron-stained limestone with a few beds of soft hematitic shale, succeeded by clear bluish-gray limestones whose Cambrian age is indicated by abundant fragments of trilobites. These in turn give way to sandy limestones and breccias of similar lithologic character, which in places show clear evidence of a later period of movement, probably normal faulting. One especially interesting fissure tapered upward and held a calcareous filling. The amount of displacement could not be ascertained and no metalliferous values were apparent. Still higher in the section, provided that the displacements have not been great in amount, clearer limestones again predominate and in this part of the section they carry a fairly abundant Ordovician fauna. They are succeeded by a dense white quartzite, to the east of which is found a series of limestones apparently ranging from Silurian to Mississippian in age.

The eastern and western portions of the township are covered by basalt flows which apparently cross the township along the valley of Bear River. The lava was supplied from two sources—the group of craters in T. 7 N., R. 41 E., and the craters in Basalt Valley immediately west of the township.

In the vicinity of Soda Springs and to the west, in Spring Basin, varicolored travertine is the most conspicuous surficial deposit. This is the product of the many springs which yield carbonated waters. In those places where the travertine is white it somewhat resembles an alkali flat in appearance, but it supports a heavy growth of cedar or, where cultivated, fair crops. Near the place where Soda Springs Creek enters Bear River, Steamboat Spring, a thermal spring, still appears as active as when described by Bonneville, Frémont, and Peale.

The Park City formation is not found in the township, and as commercially available phosphates are not known in any other formation of the region, such deposits are inferred to be absent.

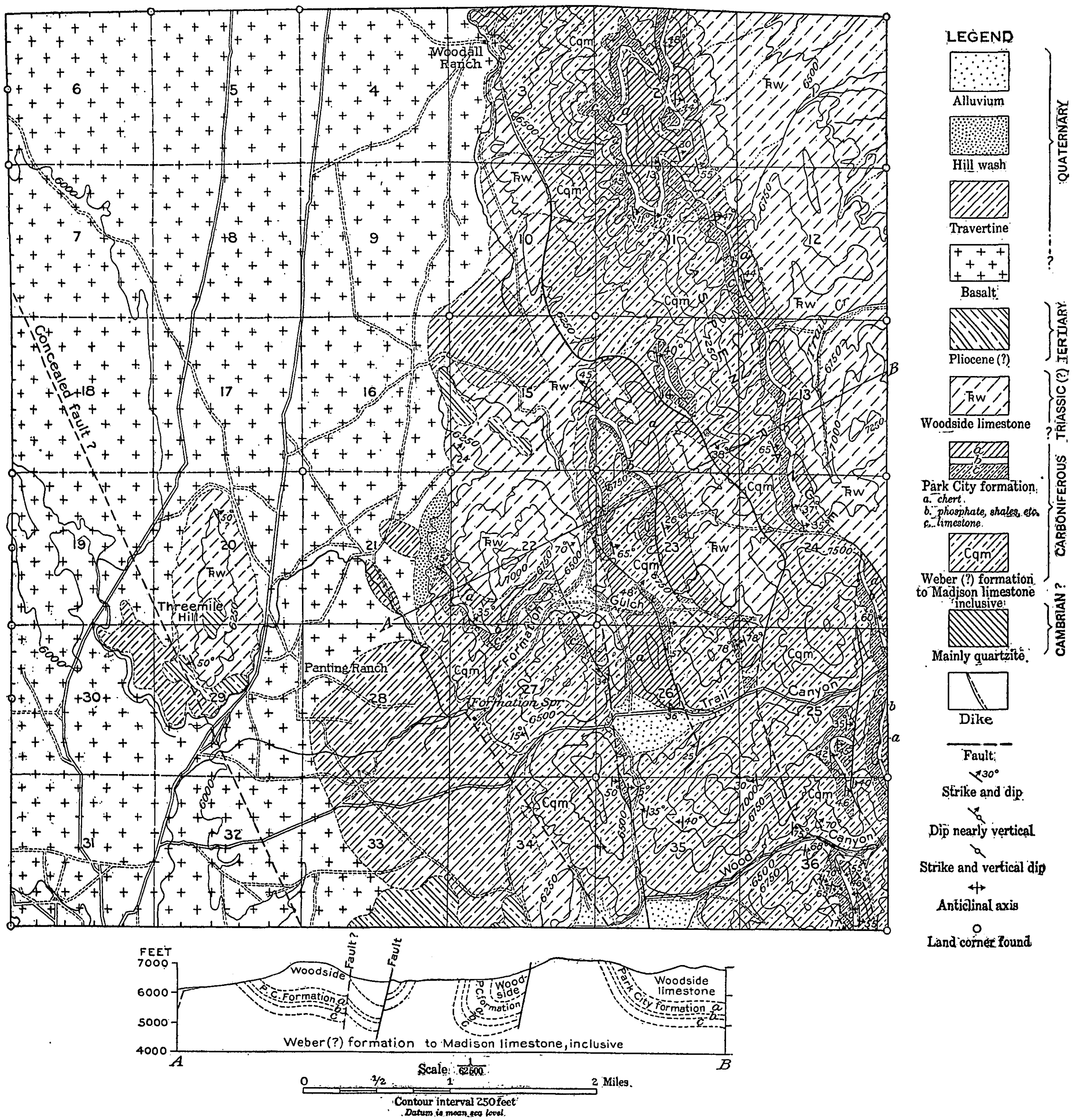
T. 8 S., R. 42 E.

SURVEY AND MAP.

A detailed geologic survey of the eastern half of T. 8 S., R. 42 E., was made with a Johnson plane table and Gale telescopic alidade, the locations being found on the base map, which had been prepared in advance by Albert Pike, by either the station method or stadia traverse. The location of the outcrops of the base of the phosphate series was determined with as high a degree of accuracy as the conditions of exposure and the field mapping scale of 1:31,680 would permit. The map of the township (Pl. X) accompanying this report is a reduction from the field map.

GEOLOGY.

The entire western half of the township with the exception of Threemile Hill is covered by basaltic flows which were poured out by the group of craters 3 to 6 miles north of the township. Evidence



PRELIMINARY GEOLOGIC MAP OF T. 8 S., R. 42 E.

of the existence of several flows was noted, but sufficient data have not been collected for a statement of the number or of the variation in lithologic character of the different sheets. Scoriaceous agglomerates and beds of tuff are included in the volcanic series. The age of the flows was not definitely ascertained, but limestones in sec. 33 which are regarded as Pliocene were clearly deformed prior to the extrusion of the lava, which embayed their outcrops, establishing the probability that at least this particular flow is Pleistocene.

The spring deposits are calcareous travertines and are mainly later in age than the basaltic flows, although minor exceptions were noted. Formation Spring is the largest of the springs in this portion of the area and is named from its extensive travertine deposits, which form an elaborate set of basins.

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. The fossils found are few in number of species and unfortunately have a wide geologic range, and for the present the Pliocene classification of these beds by the Hayden Survey is accepted.

The Woodside as exposed in this township consists of rusty brown shales, shaly limestones, and a minor amount of clear bluish limestone which is with difficulty distinguished on purely lithologic evidence from the older limestones of the early Pennsylvanian or the late Mississippian. Fossils are so abundant, however, that doubt as to the identification of a particular outcrop can usually be cleared.

The presence of a heavy talus effectually conceals the upper part of the phosphate shales in this township and no prospecting has yet been done upon that portion of the beds, so that it is impossible to compare the entire section with the complete section measured in Georgetown Canyon. All that may be said in this respect is that the partial section measured in Trail Canyon (p. 390), though not showing so high grade a bed at its base, yet contains for the proportion of the series exposed a relatively greater amount of commercially available phosphate.

The sediments underlying the Park City formation consist of a series of gray limestones much seamed with calcite, sandy limestones, and calcareous quartzites, with locally brecciated zones containing angular ashy-gray chert fragments, which when weathered out into brownish nubs are conspicuous, and in most places still higher in the series a geodal limestone spotted with small quartz-lined cavities. Heavy massive beds of quartzite such as characterize the Weber quartzite in the areas examined by Gale and Richards in 1909 are absent, and approximately the 1,000 feet of beds occupying the same position in the section consist of poorly exposed soft sandstones and earthy limestones, which locally have reddish tints. The limestones immediately underlying these beds for a stratigraphic interval of about 500 feet are considered of Pennsylvanian age by Girty,[1] on faunal evidence, and are provisionally correlated with the Morgan formation of Utah. The remaining series to the exposed base includes both upper Mississippian and a portion of the true Madison limestone (lower Mississippian).

The township includes along its eastern border a portion of the west flank of the Trail Creek syncline and to the west at least two other synclinal folds with the broken remnants of intervening anticlines. The fracturing of the anticlinal structures has given rise to a complicated set of faults, both thrust and normal. Evidence of a major thrust fault bringing supposed Cambrian rocks over Triassic rocks is found on Threemile Hill, in sec. 29, and this identical relation is produced by the thrust that is found to the south. A line drawn a short distance west of this outlier to the last exposure of the fault in T. 10 S., R. 43 E., is the only suggestion that can be given of the position of the trace of the fault under the cover of basalt and lake beds. The extension of the same line to the northwest indicates a theoretical position for the fault under the basaltic cover in that direction. The known stratigraphic magnitude and linear extent of this fault to the south warrants such a northwestward extension. The uneroded phosphate deposits occur in synclines, with the exception of the deposit in sec. 2, where the highest mountain in the township is capped by an anticlinal arch of the chert which immediately overlies the phosphate-bearing portion of the Park City formation.

PHOSPHATE DEPOSITS.

The prospecting in this township has been carried on mainly by open cuts, and most of these are in the basal portion of the phosphatic shales. The beds in many places are nearly horizontal and the rock is very much broken and jointed, so that the information gathered is for the most part limited to the basal bed. The most complete section obtained was measured in sec. 25 on the north side of Trail Canyon and is given on page 390 of this report. It shows that 7 to 10 feet of high-grade phosphate rock is included in the lower portion of the phosphatic shales. A comparison of this section with some which have been made by L. P. Brown in other parts of the township shows that it can be regarded as typical.

Many of the sections measured by the survey were partial 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 which would undoubtedly not exist where mining had been done more recently. The details of these

[1] Girty, G. H., Fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: Bull. U. S. Geol. Survey No. 436, 1910, p. 7.

sections and the analyses are therefore omitted from the present report.

The only shipment of phosphate rock which has been reported from this township was made early in the summer of 1910, from a prospect in the SE. ¼ SW. ¼ sec. 23, by Brown, Perkins & Co. The shipment, which is said to have consisted of 40 tons, is reported to have contained 34.14 per cent of phosphoric acid, 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 phosphoric acid. The prospect from which the shipment was made was examined and the following section measured:

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 $Ca_3(P_4O)_2$	Thickness.
		Per ct.	*Per ct.*	*Ft. in.*
M 536-4	Phosphatic rock, brownish gray, medium oolitic	28.5	62.3	2 1
3	Phosphatic rock, brown to gray, fine to medium oolitic	33.5	73.9	2 1
2	Phosphatic rock, brown, finely oolitic, slightly sandy	33.0	72.1	2 1
1	Phosphatic rock, brown, fine to medium oolitic	33.4	73.9	2 1
				8 4

The prospect is located on the axis of a small westerly overturned syncline, and the apparent thickness of phosphate rock exposed in the prospect is nearly twice that of the above section.

The portion of the township covered with basalt may contain extensive areas of phosphates and postphosphate rocks, but it is excluded from consideration in the following estimate of acreage. Approximately 5,000 acres of land is clearly underlain by the phosphatic shales of the Park City formation and for purposes of estimate the thickness of the minable 70 per cent rock is taken as 7 feet. The computation is most readily made by regarding the deposits as lying horizontally throughout the area. Such an assumption takes into account less than the actual content of the deformed beds and may be accepted as conservative. On the assumption stated the phosphate lands contain in round numbers 122,500,000 long tons of rock phosphate. The thickness of the cover over these deposits does not exceed a maximum of 1,000 feet, and a large portion of the phosphate is probably above the ground-water level, as indicated by the elevation of the springs.

T. 9 S., R. 42 E.

SURVEY.

The partial topographic and geologic survey of T. 9 S., R. 42 E., necessary for the investigation of the phosphate deposits was made by J. H. Bridges. The work was done with a plane table and mainly by the station or triangulation method of location.

GEOLOGY.

A more complete discussion of the several formations present in this township will be found on pages 380–396, but a brief statement concerning each of the formations is included here. (See Pl. XI.)

The obviously alluvial deposits are limited to the muds, sands, and gravels of the Bear River valley and the similar deposits in and about the openings of the several canyons upon the plain which makes up the northwestern and central parts of the township.

Calcareous spring deposits occupy extensive areas within this township and locally are distinguished with difficulty from the softer limestones of the Pliocene (?) beds. They are also associated with the finely comminuted deposit of white volcanic glass in the fault agglomerate or breccia near the sulphur deposits. A series of basaltic flows entered the township from the craters to the northwest and extended as far south as the river. The surface of the basalt is still unweathered, in places, and several cliffs along the margin afford examples of columnar jointing. The thickness of the several flows as reported in wells drilled by A. G. Kugler is as follows:

Section of well in the NE. ¼ NW. ¼ sec. 22, T. 9 S., R. 42 E.

	Feet.
Alluvium, light-colored soil, sand and gravel	45
Basalt	17
Alluvium, light colored	48
Basalt	65
	175

Section of well in sec. 20, T. 9 S., R. 42 E.

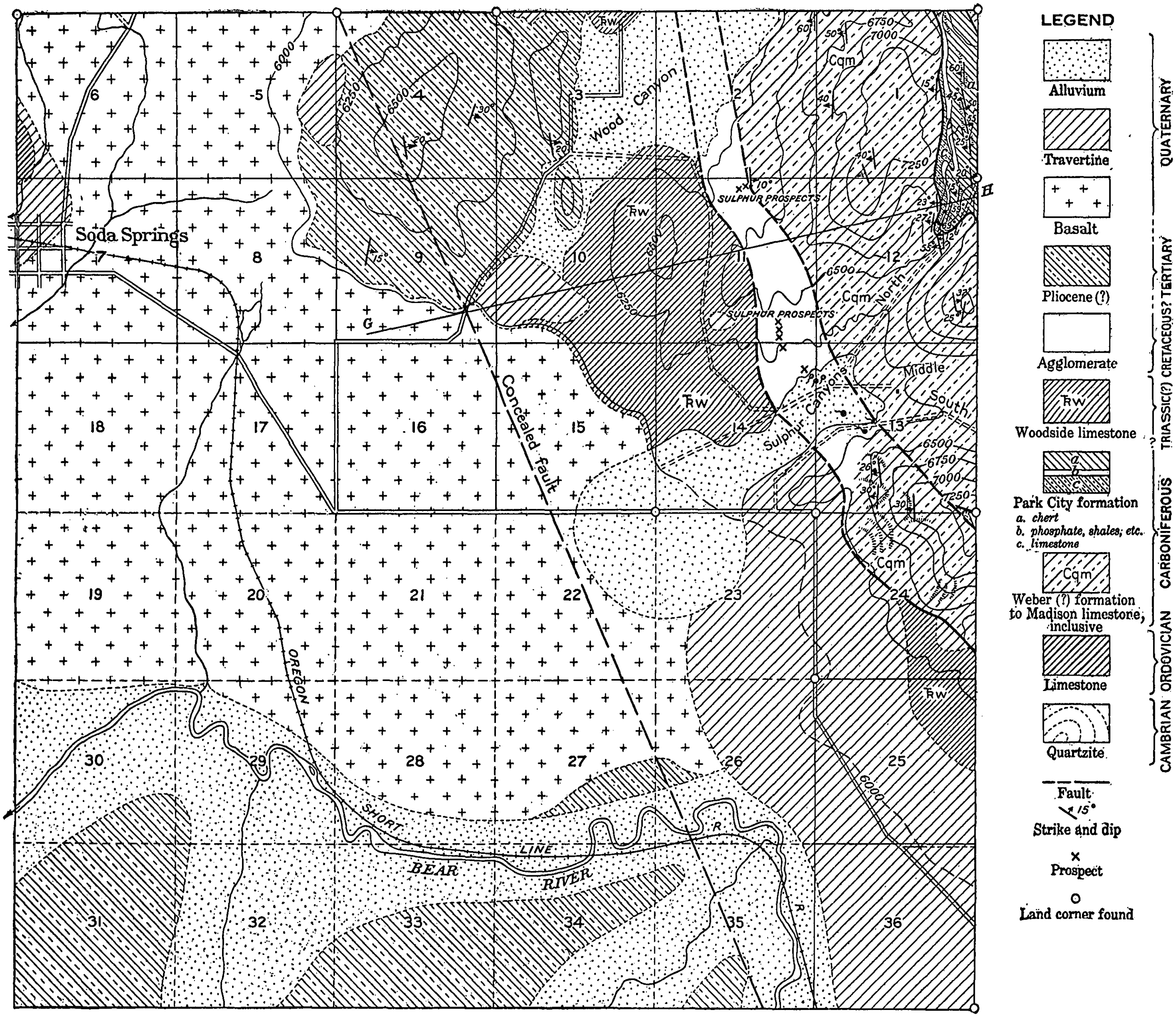
	Feet.
Basalt	110
Shale, carbonaceous	4
Clay, white (travertine ?)	10
Basalt	4
Sand, yellow	16
	144

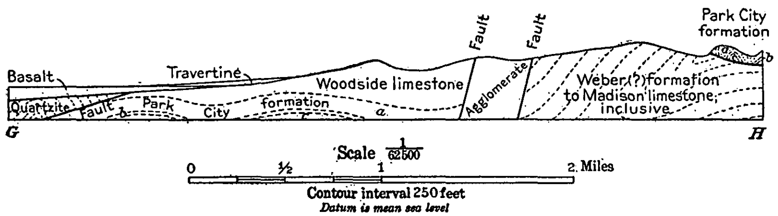
No attempt is made to correlate the several flows or to estimate their number, but their age, if the interpretation assigned by Peale [1] to the fossils collected by Hayden [2] is correct, is later than early Quaternary.

The area intervening between the faults in secs. 2, 11, 13, and 15 is occupied by an agglomerate composed of angular fragments of Triassic (?) limestones, Carboniferous limestones and quartzites, and a volcanic tuff or ash. The tuff is snow white, fine grained, and composed of minute angular glass fragments. In sec. 11,

[1] Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1877, 1879, p. 589.

[2] Fifth Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1871, 1872, p. 154.





PRELIMINARY GEOLOGIC MAP OF T. 9 S., R. 42 E.

near the northernmost of the sulphur prospects, the tuff is the country rock for an area of approximately half an acre. It is, however, much broken, and is regarded as lying within the fault zone. The relation of the ash to the other rocks is not clear, but the presence of angular masses of it within the agglomerate indicates that it was deposited prior to the faulting. The age of the faulting is not locally determinable more closely than that it is post-Triassic, but comparison with other parallel faults, of which the Cokeville (Wyo.) fault described in the 1909 report[1] may be taken as a type, it is probably late Cretaceous. The age of the tuff, then, is Cretaceous or earlier. The sulphur deposits are described in a separate chapter of this bulletin.

The deposits which were considered of Pliocene age by Peale consist of close-grained, nearly lithographic limestones, which are best seen in secs. 3 and 4, and soft marly limestones and calcareous conglomerates, which are best exposed on the south side of Bear River. No additional data relative to the age of these rocks have been collected. The only fossils found have a wide stratigraphic range.

The portions of the township mapped as Triassic (?) were so determined by the presence in the float of predominating amounts of fragments of the rusty bronze-brown shales and shaly limestone carrying fossils characteristic of the Woodside limestone. So far as is known the only outcrops of the formation clearly in place protrude through the loose weathered material which covers the surface in secs. 24 and 25, and most of the area shown as Triassic (?) might equally well be designated Quaternary hill wash.

The Park City formation outcrops over only a small area in secs. 1 and 12 and is represented mainly by the black chert which overlies the phosphatic shales and phosphate beds of the section.

The formation is bent up in a sharp syncline with minor folds on its western limb. The phosphatic shales are exposed and an abundance of high-grade float was found along the west side of the fold, except where the beds are cut out by the thrust fault. This fault appears to pass under the syncline and into the normal fault to the east.

The portion of the western front of the Aspen Range which occupies the northeast corner of this township is composed mainly of massive gray limestones, yellowish and reddish sandy limestones, and calcareous quartzites. These beds are deformed in large folds which are apparently overturned toward the east. The rocks range in age from early Pennsylvanian to late Mississippian, and comprise the Weber (?) formation, the Morgan (?) formation, an unnamed

[1] Bull. U. S. Geol. Survey No. 430, 1910, p. 506.

interval of upper Mississippian strata, and the Madison limestone.

The area west of the concealed fault which crosses the township in a northwest-southeast direction is underlain by early Paleozoic sediments, probably Cambrian. A small outcrop of rocks, presumably of Cambrian age, was noted by Mr. Bridges as protruding through the alluvium in sec. 32 about 400 feet northwest of T. J. Hopkins's house.

The major fault of the area is the overthrust concealed by the cover of basalt and lake beds which to the north and south is known to cause sediments of Cambrian age to override rocks as late as Triassic (?). The position of the fault as indicated is, of course, approximate and its presence is hypothetical.

This thrust is roughly paralleled by a series of branching normal faults which intersect in the vicinity of the sulphur springs and the sulphur deposits in the eastern part of the township. A minor thrust underlies the area of Park City chert in the northeast corner of the township.

PHOSPHATE DEPOSITS.

No prospects were found in the township showing oolitic phosphatic rock, but one or two shallow openings have been made in the phosphatic shales. Abundant float of the high-grade rock phosphate afforded evidence of the presence of the richer beds. The area west of the normal fault series and east of the great thrust presumably contains the phosphate deposits at depth.

The quality of the rock phosphate as inferred from the adjoining townships is on the average equivalent to 70 per cent tricalcium phosphate, although the float rock would probably run above that figure. An average of 70 per cent would doubtless be fair for these deposits, and it is reasonable to assume the presence of 6 feet of such rock in the section. The area in which the portion of the Park City formation overlying the phosphate beds actually outcrops comprises about 200 acres, and about 3,200 acres may conservatively be regarded as representing the outcrop area of the Woodside limestone, the formation next overlying the Park City formation.

The assumption that 3,200 acres of land in the township is underlain by a 6-foot bed of phosphatic rock running 70 per cent in tricalcium phosphate which weighs 180 pounds to the cubic foot indicates a total of about 67,200,000 long tons of rock. This estimate might be increased if more of the concealed area between the thrust and the normal fault were included.

The phosphate deposits included in the tonnage estimate lie at a maximum depth probably not in excess of 1,000 feet, and roughly two-thirds of the tonnage lies within 500 feet of the surface.

T. 10 S., R. 42 E.

A portion of T. 10 S., R. 42 E., was included in the phosphate reserve on the basis of the Hayden mapping of these areas as Carboniferous. A reconnaissance examination of this township was made by the senior author in company with Prof. J. P. Smith on a horseback trip along its southern border, and another trip near the northern border. Locations of observation were determined by the Hayden map, and the geology of the portion of the township originally included in the reserve is shown in a general way on Plate IX (p. 380).

The southwest half of the township so far as examined is made up of early Paleozoic rocks, as early as Ordovician and possibly Cambrian; the remainder of the township is covered with the marly limestones and calcareous deposits called Salt Lake group by the Hayden Survey and regarded as of Pliocene age.

It is doubtful if any recoverable phosphate deposits exist in the township, although the extreme northeast corner may include, under the Quaternary cover of travertine and alluvium, rocks younger than the phosphate-bearing strata. The deposits if present lie to the east of the great overthrust fault whose trace is projected across the corner of the township.

T. 11 S., R. 42 E.

The eastern part of T. 11 S., R. 42 E., was included in the phosphate reserve on the basis of the geologic mapping by the Hayden Survey.

A reconnaissance examination of the northeast corner of the township was made by a horseback trip in company with Prof. J. P. Smith. The route traveled was from the east boundary along the northern border to about the middle of the township and southward to the vicinity of Soda Peak. The rocks, so far as observed, were all of early Paleozoic age (Cambrian and Ordovician?), the Hayden mapping as Carboniferous being clearly incorrect.

T. 12 S., R. 42 E.

A portion of T. 12 S., R. 42 E., was originally included in the phosphate reserve on the basis of the mapping of the Hayden Survey, which indicated that the area is made up of Carboniferous rocks.

The Spence shale member occurs near the eastern boundary of this township, and the type locality from which this member of the Ute limestone was described[1] is about 2 miles south of the township boundary on Spence Gulch. Walcott's Cambrian section is measured westward from this point and includes a stratigraphic interval of 3,000 feet. Since the dips at the base of the section are only 30°

[1] Walcott, C. D., Nomenclature of some Cambrian Cordilleran formations: Smithsonian Inst. Misc. Coll., vol. 53, 1905.

and flattened toward the west, presumably nearly all the sedimentary rocks present in the township are Cambrian and there is slight chance of the presence of beds as late as the phosphate-bearing Park City formation.

T. 8 S., R. 43 E.

A detailed geologic examination of T. 8 S., R. 43 E., was made prior to the preparation of the topographic base map. The survey was carried on with Johnson plane table and Gale telescopic alidade by triangulation and stadia traverse methods. The control points established for the geologic work were used by Mr. Pike in the subsequent topographic mapping, and the two resulting maps were combined in the office by means of these common points.

GEOLOGY.

The stratigraphic sequence ranges from the Madison limestone to the Thaynes limestone in conformable series, with minor areas of Tertiary beds, probably Pliocene, and extensive valley areas of alluvial deposits. The several formations are described on pages 12–28.

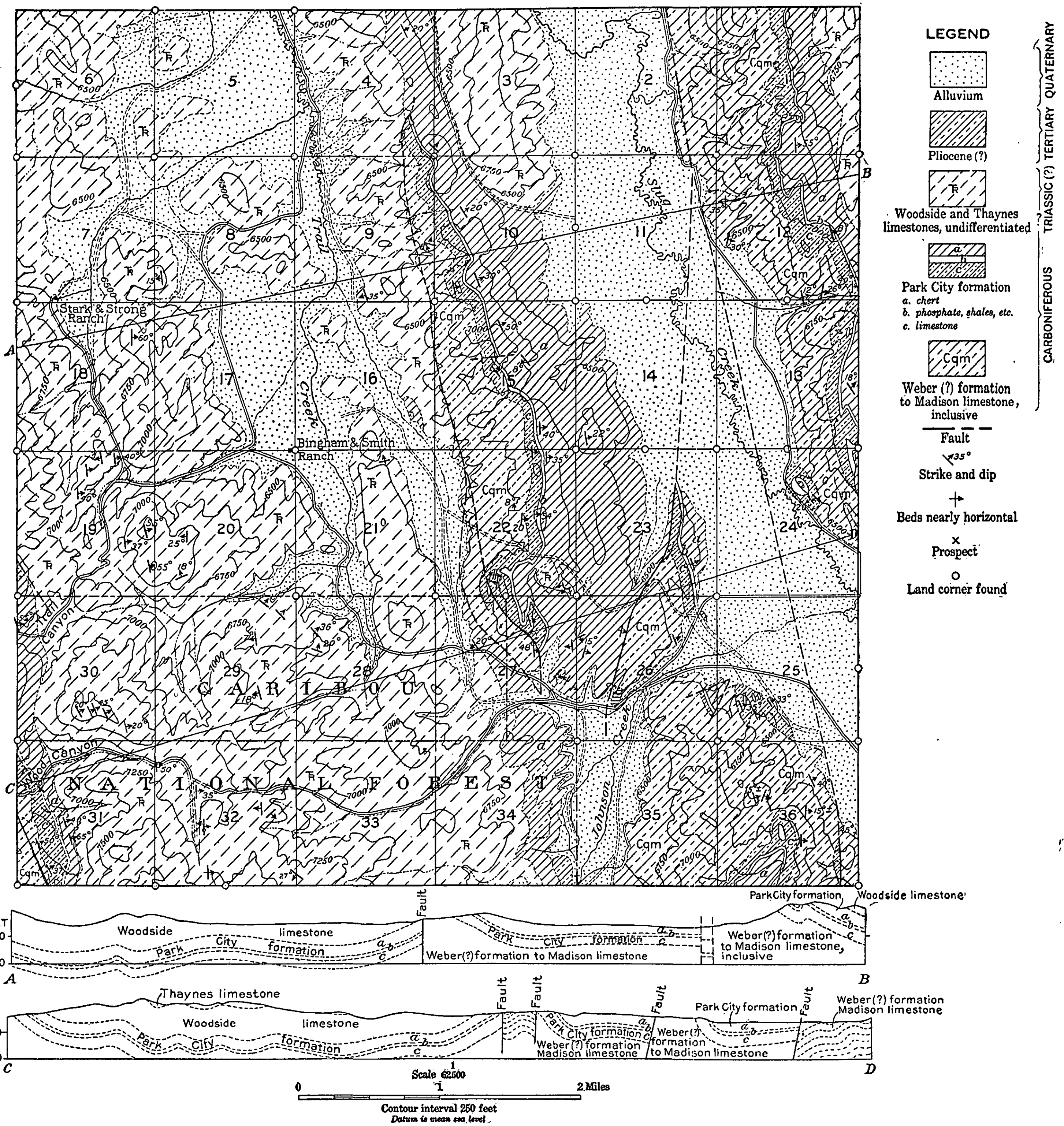
The structural features comprise a series of folds with axes a little west of north, the large Trail Creek syncline, the Slug Creek syncline, a portion of the western limb of a third syncline whose axis lies nearly parallel with Middle Creek or Dry Valley in T. 8 S., R. 44 E.,[1] and the intervening parallel and faulted anticlines. The character of the folds and faults will be best understood by reference to the structure sections which accompany the map of the township, Plate XII.

The synclines include the phosphate-bearing Park City formation, which erosion has removed for the most part from the anticlines. Trail Creek lies in the largest synclinal trough and to the east of the main axis. The fold is complicated by plications of a smaller order, and here and there the axes of these minor folds are almost at right angles to that of the main synclines.

The Trail Creek syncline includes along its axis in secs. 7, 17, 18, 19, 20, 29, 30, and 32 small areas of the basal portion of the Thaynes limestone. These areas are not differentiated on the accompanying map (Pl. XII).

The anticline lying to the east of the broad Trail Creek trough is apparently intact only in sec. 4, and a fault is present along the axis to the south. The displacement reaches its maximum in a short distance and the throw is probably 800 to 1,000 feet. The fault is less prominent in the southern part of the township, so that the displacement, if any, is within the members of the Park City formation—the cherty limestone and shale overlying the phosphate member. Except in secs. 4 and 10 erosion has cut back the outcrop

[1] Peale, A. C., op. cit., Pl. LXII, facing p. 560.



PRELIMINARY GEOLOGIC MAP OF T. 8 S., R. 43 E.

of the underlying limestone and the phosphate shales to the crest of the ridge and in a few places a short distance down the east side. The limestone overlying the phosphate shales in this township has more true chert than cherty shale and forms a cover which resists erosion effectively and outcrops over large areas where the dips are low. A diagonal offset with the northern and western block moved in a southwesterly direction relative to the southern and eastern block is held to explain the counter position of the Weber (?) formation and Mississippian limestone area in secs. 26 and 35 relative to the chert of the Park City formation to the west. A number of small and rather sharp minor folds within this member in secs. 22, 23, and 27 include small patches of the Woodside limestone.

Slug Creek valley is a syncline and is underlain by the chert or "upper *Productus* limestone" of the Park City formation. The fault lines shown on the map as extending through the valley along its eastern margin are based on abundant outcrop evidence in the southern part of the township, but toward the north are located by the line of springs. It is possible that the alluvial cover conceals the eroded rather than the faulted edges of the Park City formation, but the fault hypothesis is regarded as more in keeping with the conditions found on the east side of Trail Creek, where better opportunity for observation exists, and it is thought that the conditions on Slug Creek are similar.

A portion of the west flank of the parallel anticline to the east persists in sec. 24, but elsewhere the Park City formation has been practically eroded from this flank of the fold. The outcrop of the phosphate shales has in general been cut back over the crest of this ridge and now lies on the Middle Creek side of the divide.

PHOSPHATE DEPOSITS.

The quality of the phosphate rock in this township is indicated by analyses of a rather unsatisfactory series of samples. The detailed section of the phosphatic member of the Park City formation given on page 389 indicates that both in amount and in quality the rock is inferior to that of the Georgetown section (pp. 387–388). These beds were measured in a shallow trench dug by the Survey party practically on the east line of sec. 12, and it is suspected that 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 general section of the lower part of the phosphate shales was measured in Trail Canyon in sec. 25, T. 8 S., R. 42 E., close to the west line of the township under discussion. This section is given on page 390, and although the analytical results may be somewhat low, owing to the inclusion of soil with the samples, the rock analyzed is superior in amount and quality of phosphate to that in the first section and compares well with the similar portion of the Georgetown Canyon section.

Brown, Perkins & Co. have located ground in unsurveyed sec. 31 and samples were taken by the Survey party from three of their openings, immediately north of the Wood Canyon road. The sections of the beds sampled and the analytical results are given below:

Section of beds exposed in prospects north of Wood Canyon road, in hypothetical lot 2, sec. 31, T. 8 S., R. 43 E.

Fourth prospect north of road.

Field No. of specimen.		P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.
		Per cent.	*Per cent.*	*Ft. in.*
	Soil			1
	Soil and broken phosphate rock			1
	Phosphate rock, brown, medium oolitic, broken			1
R 276-1	Phosphatic rock, brownish black, medium oolitic, broken	28.8	63.0	1
	Shale, phosphatic, oolitic in streaks			3
R 276-2	Phosphatic 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

All these prospects are located a few feet back from the outcrop of the top of the gray limestone underlying the phosphate shales, and none of them are on high-grade phosphate rock. It appears that they are in the interval corresponding to the 7 feet of brown shale measured at the base of the phosphatic member in the Trail Canyon section.

Mr. L. P. Brown,[1] of Brown, Perkins & Co., reports that the upper part of a bed exposed in an opening on the Esmeralda claim, on the south side of the road, yielded 34.7 per cent of phosphoric acid, equivalent to 75.8 per cent of tricalcium phosphate. At the time of the examination by the authors the pits on this claim were so filled that no measurements were made or samples collected.

The data at hand appear to indicate that the presence of high-grade phosphate rock in this township will be more clearly demonstrated when the deposits are thoroughly prospected and developed.

[1] Personal communication.

It is regarded as conservative to base the tonnage estimate on the presence of at least 5 feet of high-grade rock in the section, as it is thought that a greater thickness will be found upon thorough prospecting. An attempt to estimate the area of the portion of the township occupied by phosphate raises a question whether the northern portions of Trail Creek and Slug Creek valleys have been so incised prior to the present filling of the valleys that some portion of the Park City formation has been removed. It is considered more probable that a portion of the phosphate deposits may have been eroded in the valley of Slug Creek than in this part of the Trail Creek valley, which is relatively nearer its head, and in the computation allowance is made for such erosion by regarding the strata in the area underlain by the phosphate beds as horizontal, no addition being made for the increased surface area of the bed as compressed in the folds.

The area containing phosphate includes all of the land on which the phosphate shales, the overlying chert, and the Triassic (?) formations outcrop or are concealed either by the Pliocene (?) beds or by alluvium. This area is estimated to contain 16,750 acres. The phosphate deposits are all regarded as ultimately available, as the greatest depth from favorable points of entry is not more than 1,200 feet. The presence of artesian basins, however, will increase the cost of mining in a large portion of the area.

The assumption that a 5-foot bed of phosphate extends under 16,750 acres gives somewhat more than 293,150,000 long tons as an estimate of the amount of high-grade rock present. The complete section doubtless contains at least this quantity, as well as a much greater amount of low-grade material. More accurate estimates of the phosphate contained in this township would require additional prospecting, preferably by tunneling or drilling, in order to determine the character of the entire phosphatic portion of the section at a distance back from the outcrop in the deepest portions of the synclines.

T. 9 S., R. 43 E.

SURVEY.

A detailed geologic survey of all but the eastern tier of sections of T. 9 S., R. 43 E., was made mainly by plane-table triangulation on the topographic base prepared by Albert Pike.

The field work was done on a scale of 1:31,680, but for this report the map has been reduced to a scale of 1:62,500 and reproduced in Plate XIII.

The subdivision of the township by the General Land Office survey is only partial, but for convenience of reference in the following discussion a hypothetical net has been indicated for the remainder of the township.

STRATIGRAPHY.

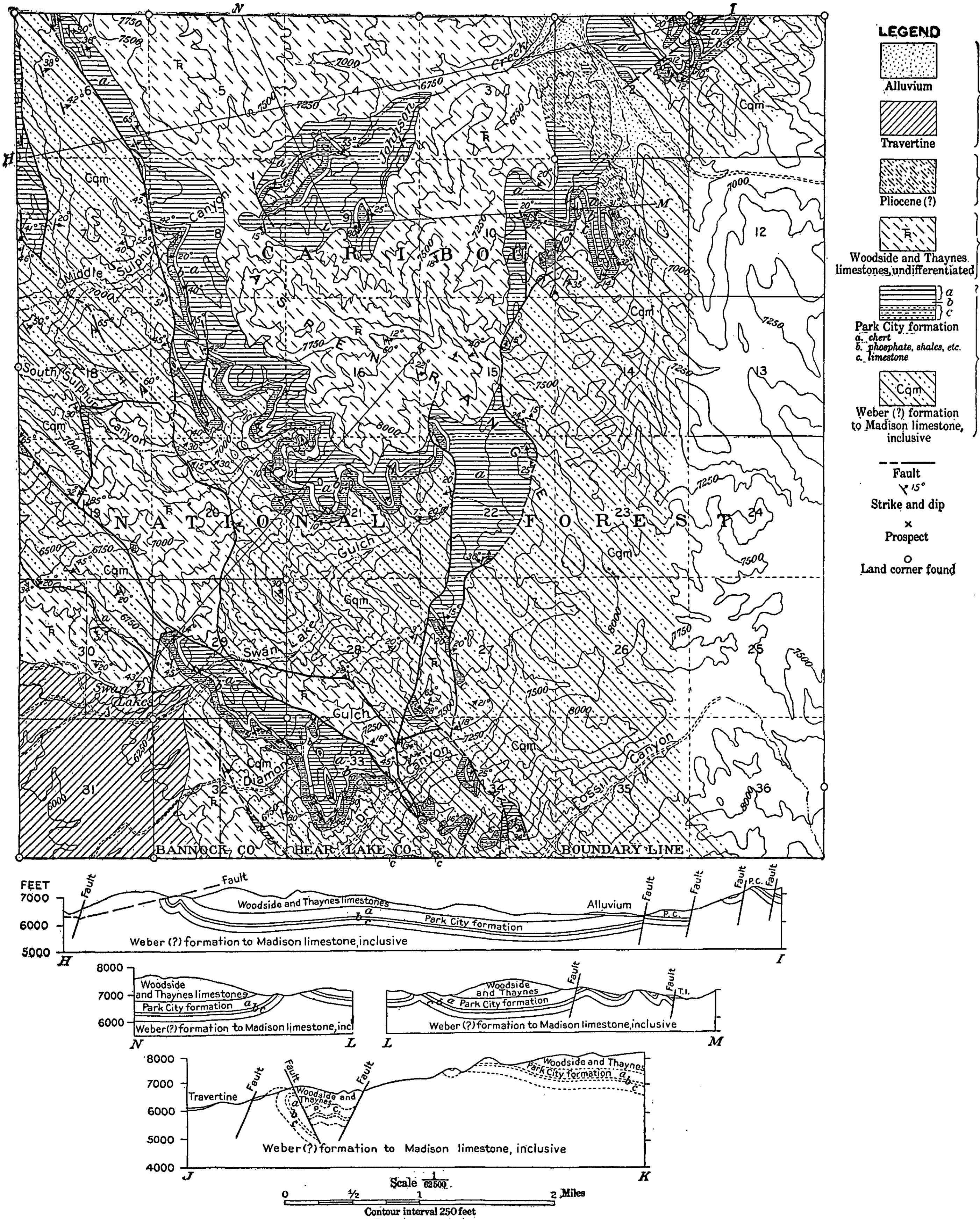
The rocks of the area are mainly of Carboniferous and Triassic (?) age. The Carboniferous rocks include the upper Mississippian limestone, in heavy beds, typically exposed in the lower portions of Middle and South Sulphur canyons. They also include a thick series of sandy and calcareous beds, tentatively correlated with the Morgan formation. Perhaps, too, the Weber quartzite is represented, though the lithology of the rocks occupying the interval of that formation is somewhat different from that at Weber Canyon in Utah. These formations were not differentiated in the field, and attention was devoted mainly to the phosphate series, which here attains great importance.

The Park City formation is well developed in this township. It consists of three members. The lowest member is a white and massive limestone, somewhat siliceous and containing near the top bands of bluish chert from 1 inch to 8 inches thick. The color of this chert is a distinctive lithologic feature, for it is different from that of the other cherts in this district. The limestone carries an abundance of poorly preserved silicified fossils. These resist weathering and stand out in little crescents from their more easily weathered limestone matrix; this feature serves as a valuable guide to the member. Girty[1] states that among these fossils are species of *Spirifer*, *Squamularia*, and probably *Composita*, and that in the upper portion of the rock a large semireticulate *Productus* is found. The rock itself is also a prominent topographic feature, and in many places forms cliffs 30 to 50 feet high.

The second member of the Park City formation consists of phosphatic shales, phosphate beds, and impure limestones. No complete section of these beds has been found exposed in this township. The main phosphate bed lies just above the "underlying limestone." It maintains a remarkable uniformity of thickness and character throughout the township. The principal features of the phosphate beds are given in detail on pages 386–387.

The third member of the Park City formation in this township consists mainly of a heavy chert that appears in two general facies. The more common facies is that of a black to dark-gray and purplish flinty shale, apparently nonfossiliferous. The other facies is that of beds of solid chert from 1 or 2 inches to 1 or 2 feet in thickness. The color is prevailingly dark—black, dark gray, or bluish black. Here and there lighter colors are seen, and in the southeast extension of the big syncline shown on the map (Pl. XIII) the color is buff to nearly white, or even pinkish. This facies is nonfossiliferous in this

[1] Girty, G. H., The fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: Bull. U. S. Geol. Survey No. 436, 1910, p. 6.



PRELIMINARY GEOLOGIC MAP OF T. 9 S., R. 43 E.

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 region, however, the chert is accompanied by some limestone, whereas none has been observed in connection with these cherts in the township under discussion. The cherty character of the rocks that overlie and underlie the phosphate beds, together with their rather distinctive color tints, has led to the use of the convenient field terms "upper chert" and "lower chert," and the lower limestone, on account of the presence of the large *Productus*, is sometimes conveniently called the "lower *Productus* limestone" or the "underlying limestone."

The Woodside formation, which represents the Triassic(?) in this township, exhibits the same uniform characteristics that accompany it in other parts of this field and that are described on pages 392–393. In the northern part of the township, in secs. 5 and 6, the entire thickness of the Woodside is present and the "*Meekoceras* beds," which constitute the basal portion of the Thaynes limestone, are also found. In sec. 30 the massive limestones near the top of the Woodside are exposed, and in other parts of the township the formation is present in considerable thickness.

Beds assigned tentatively to the Pliocene occur in secs. 11 and 2 and in the eastern portion of sec. 3. They consist of weak calcareous conglomerates, containing pebbles of local material ranging from a fraction of an inch to a foot or more in diameter. The larger pebbles are not very numerous. The average diameter of the coarser material would be from 2 to 5 inches. The pebbles are apparently waterworn and are generally subangular or poorly rounded. In the largest area mapped the rock is badly weathered and most of the calcareous matrix has disappeared, thus making it difficult to distinguish the weathered Pliocene (?) from float fragments of the local formations. From evidence obtained in areas closely adjoining the Pliocene (?) beds it seems probable that these beds conceal the upper cherty beds of the Park City formation and, near its eastern margin, overlie an important fault.

Travertine constitutes the entire surface formation in sec. 31, and extends into adjacent portions of secs. 30, 29, and 32. This is a part of a much larger travertine area that occupies much of T. 10 S., R. 43 E., and extends into the southeastern sections of T. 9 S., R. 42 E. The structural relations immediately to the east indicate that the travertine in this township overlies rocks of post-phosphate age.

The township as a whole is so rugged that there are few alluvial deposits within its limits of sufficient extent to warrant mapping. The largest area lies in the valley of Johnson Creek and its tributaries, in secs. 11, 2, and 3. The structural relations of that portion of the township indicate that the alluvial deposits probably conceal rocks of postphosphate age only in the NW. ¼ sec. 2 and the NE. ¼ sec. 3.

STRUCTURE.

The rocks of the township have been folded and faulted on both a large and a small scale. Some of the larger structural features are relatively simple, but in places the lesser structures present a high degree of complexity.

FOLDING.

Big syncline.—The largest and most important fold is a great open trough or syncline which is a southern extension of the Trail Creek syncline of T. 8 S., R. 43 E. In this township the fold pitches gently northward and its south end emerges in sec. 21 and adjoining portions of secs. 20 and 22. The area occupied by this syncline is shown on the map of the township (Pl. XIII). From the N. ½ sec. 21 its boundaries extend northeastward to the E. ½ sec. 2 and northwestward to the W. ½ sec. 6, so that along the north boundary of the township this trough is approximately 4¾ miles wide. Most of this trough is underlain by valuable deposits of phosphate. A broad cross buckle in the floor of the syncline brings the phosphate beds to the surface over small areas in secs. 4, 5, 8, and 9, as shown on Plate XIII. Johnson Creek and its branches give access at an easy grade to this portion of the syncline and thus allow exceptional opportunity for reaching a large quantity of high-grade phosphate.

The south margin of the syncline, in secs. 17, 20, 21, and 22, is simple but is cut back by several canyons, so that the outcrop of the phosphate beds lies in a succession of points and coves. The underlying limestone here forms prominent cliffs 500 feet or more above the valley bottom. From sec. 15 a narrow projection of the syncline, bounded on the east and west by two apparently normal faults, extends to the NW. ¼ sec. 27.

The west margin in sec. 17 is broken by a subordinate syncline, with axis about N. 18° W., which is inclined eastward and is accompanied by a small anticline on the west. Both are cut on the west by a fault that is described in a later paragraph. On the east side this minor syncline is cut by a fault that may be traced northward for about half a mile. The fault plane itself is concealed by float and vegetation, but, for reasons stated below, it is interpreted as representing a minor thrust from the west. Southeastward traces of what appears to be the same syncline are found in two patches of the underlying limestone on the ridge in the NE. ¼ sec. 20, and also in the synclinal patch of underlying limestone and phosphate that occurs on another ridge about half a mile farther southeast.

In the NW. ¼ sec. 17 and the SW. ¼ sec. 8 the big syncline is bordered by a minor anticline commensurate with the minor syncline just described and with the same axial direction. This anticline also is cut off on the west by the above-mentioned fault, which continues northwestward and strikes the north line of the township about a quarter of a mile east of the northwest corner.

The east border of the big syncline is rather complex, including both subordinate folding, as seen in secs. 10 and 11, and faulting, interpreted as normal, although the evidence is not decisive. The folds in sec. 11 appear to be inclined westward instead of eastward like the minor folds on the west side of the syncline. This inclination may be due to proximity to the fault that extends along the dry branch of Johnson Creek through the center of sec. 11 and probably through the NW. ¼ sec. 2.

The sections on Plate XIII show most of the structural relations of the big syncline as above outlined.

Swan Lake district.—A second important folded area extends from the SW. ¼ sec. 29 to the east side of sec. 33. The main feature here is a syncline, with axis running approximately N. 50° W., cut off along its entire length on the northeast flank by a normal fault with downthrow to the northeast. On the northwest side of Swan Lake Gulch this syncline is so far overturned that the underlying limestone and phosphate shales become completely inverted about 150 yards from the point where they are cut off by the normal fault. In the same region the inverted underlying limestone is truncated by a thrust fault from the west that brings in rock assigned in the field by Girty to the upper Mississippian. The structural relations here are shown in the geologic section drawn along the line J–K (Pl. XIII).

The main syncline is complicated by the presence of subordinate anticlines and synclines and, in sec. 33, bifurcates southeastward because of a broad, flat anticline that pitches northwestward in the direction of the main axis. In Diamond Gulch a subordinate anticline brings the phosphate beds to the surface and also exposes a patch of the underlying limestone, which constitutes a knoll, cut by the stream. To the southeast, along the axis of this same anticline, occur several other similar patches of the underlying limestone.

Minor folded areas.—In sec. 34, on the ridges between Dry Canyon and Fossil Canyon, are several patches of the underlying limestone, some of which are accompanied by phosphate shales or by phosphate shales and small areas of the overlying limestone. These beds are in places associated with minor faults. Three of these areas are large enough to deserve mention. The first lies in the NE. ¼ sec. 33 and extends for a few hundred feet into secs. 28 and 34. It extends from the ridge between Dry Canyon and Diamond Gulch down into the bottom of the gulch and about 150 feet up its north side. The second area lies on the ridge southeast of Dry Canyon, in the SE. ¼ NW. ¼ sec. 34. The third lies on the ridge northwest of Fossil Canyon, in the NW. ¼ SE. ¼ sec. 34.

FAULTING.

At least eight important faults and a still greater number of minor ones have been recognized in the township and are indicated on the map (Pl. XIII).

Overthrust.—Perhaps the earliest of the important faults, if the present interpretation is correct, is that which has already been mentioned as constituting the west border of the big syncline in secs. 17, 8, and 6. This fault is interpreted as a reverse fault with thrust from the west-southwest. The interpretation rests on the following data. In the southwestern part of sec. 17 this fault appears either to pass into or to be cut by another fault that passes southeastward through sec. 20. This second fault is clearly a normal fault with downthrow on the southwest. Now, if the supposed reverse fault were really normal the downthrow must be on the east, for the stratigraphically higher beds lie on that side. If the fault plane is normal, it appears to have been rotated from a pronounced westerly hade in the southern portion to an easterly hade farther north. This, though possible, seems unlikely. The eastward inclination of the axial plane of the border syncline in sec. 17 indicates that there has been thrusting from the west or west-southwest, so that reverse faults, like the one under discussion, might well be expected. The minor fault on the east side of the border syncline appears to have developed from that syncline and may well have been associated in occurrence with the larger fault.

If the west border fault of the big syncline is interpreted as a reverse fault, it may be associated with and may perhaps be considered as identical with the reverse fault that causes the Mississippian limestones to overlie the "upper *Productus* limestone" and the Woodside limestone in South Sulphur Canyon in secs. 19 and 18. This fault appears to be cut both on the northeast and southwest by the normal faults that extend northwestward from sec. 29 and can be seen very distinctly on the ridge north of Swan Lake Gulch and at several other places. It is probable that the thrust fault already described as truncating the overturned syncline on the north side of Swan Lake Gulch in sec. 29 may be associated with the thrust fault above described, and that the Mississippian limestones, extending nortwestward from the NE. ¼ sec. 30, may be associated with the other blocks of similar rock mentioned above as parts of one great overthrust block, now broken by normal faults.

Under the interpretation here suggested a great block of Mississippian limestone, with a greater or less burden of overlying strata, was thrust from the west-southwest in such a way as to overlie the west border of the big syncline in the northern part of the township. This block was subsequently broken by normal faults that let down the Mississippian area, which now constitutes the region about the mouths of South and Middle Sulphur canyons. The ridge of upper limestone, here entirely a chert, that extends along the western border in secs. 6 and 7 is interpreted as an overthrust slice, associated with another subordinate reverse fault, cut by one of the extended normal faults already described. An alternative view would assign the chert to the lower rock mass, overridden by the great thrust block above described but uncovered in this area by the erosion of the overthrust strata. This would make the faults on the east and west of the chert ridge simply a part of the great overthrust. The fault along the west side of the chert ridge is in all probability a thrust fault, but that along the east side seems to be the continuation of one of the normal faults already described in connection with Swan Lake Gulch. It can be seen to cut the ridge between South and Middle Sulphur canyons, just east of the high summit.

The idea of a subordinate upper block, produced perhaps by a second less important overthrust fault, is supported by the fact that just beyond the west border of this township, in the NE. ¼ sec. 12, T. 9 S., R. 42 E., the plane of a reverse fault, with gentle westerly dip, may be seen on the north side of North Sulphur Canyon. Above the fault plane is a syncline overturned toward the east and containing the three members of the Park City formation. Each member is truncated in succession by the fault plane and rests on folded beds of upper Mississippian limestone. That this fault is not the big thrust fault above described is indicated by the fact that it lies above upper Mississippian limestone that appears to be continuous with the big block extending to the southeast and south.

Other faults.—The most important fault in this district is probably the one that is represented on Plate XIII as entering the township in the SE. ¼ sec. 32 and passing out from the SW. ¼ sec. 19. This fault is believed to be the northern extension of the great fault that bounds Bear Lake Valley on the east. Near the north end of Bear Lake it is marked by the occurrence of hot springs, and at several points along its course northward there are extensive deposits of travertine. In this township the head of the large travertine area associated with Swan Lake and the vents that emit sulphide of hydrogen and possibly sulphur dioxide in considerable quantities, located in the NE. ¼ NW. ¼ sec. 30 and the SW. ¼ sec. 19, lie upon the line of this fault. In T. 9 S., R. 42 E., the sulphur springs in Sulphur Canyon and vicinity are believed to lie on this line, as is also the great Formation Spring in T. 8 S., R. 42 E. The occurrence of so much thermal action along this fault line would seem to indicate profound fracture, and the fault is interpreted as a normal fault with downthrow on the west, for the higher beds (Woodside limestone) lie on that side.

This fault appears to truncate on the southwest the great overthrust block above described, from the point where it first encounters the block near the mouth of Swan Lake Gulch northwestward to the SW. ¼ sec. 19, where it leaves the township. The structural relations near the mouth of Swan Lake Gulch are shown in the geologic section along the line J–K (Pl. XIII).

The faults in and north of secs. 33 and 34 are apparently of less magnitude and importance than those described in the preceding paragraphs. The fault planes themselves are concealed and the interpretations here given are based on the character and distribution of the rocks. These faults all appear to be normal. Three are sufficiently important to receive mention. The first of these appears to branch off in the NE. ¼ sec. 33 from one of the long northwestward faults previously described. From this point it extends northward into the western portion of sec. 15 and forms the western boundary of the southeast extension of the big syncline. The second fault begins in sec. 34, about half a mile to the east of the one just described, and extends northward along the east side of the southeast prolongation of the big syncline. It probably terminates in the southwestern part of sec. 11. The third fault originates in the great limestone area east of the big syncline and follows approximately the line of the large dry arm of Johnson Creek that extends to the south. It is clearly recognized in the SE. ¼ sec. 11. Thence it proceeds along the general course of the same valley about N. 15° W. and leaves the township in the NW. ¼ sec. 2, about midway between the section and quarter-section corners. Much of its course is concealed by beds provisionally assigned to the Pliocene and by alluvial deposits, hence only small portions of it are represented on the map.

The rock formations associated with the several faults are indicated on the map. The fossil data are not sufficient for the accurate determination of the actual horizons involved. The two normal faults that extend northwest from sec. 34 bring the lower or middle portions of the Woodside limestone against rocks of early Pennsylvanian age on the southwest and of late Mississippian age on the northeast. They thus involve displacements amounting vertically to about 2,000 to 2,500 feet. The normal fault that passes from the SE. ¼ sec. 32 northwestward to the SW. ¼ sec. 19 involves the heavy limestones that occur near the top of the Woodside formation and rocks of lower Pennsylvanian age, and thus represents a vertical displacement of about 2,500 to 2,800 feet. The broken thrust block that laps upon the west side of the big syncline appears to have a somewhat variable thickness and to involve rocks ranging from those of early Mississippian to early Pennsylvanian age on the one hand to those of the Park City formation on the other. Thus the vertical displacement in South Sulphur Canyon, where the upper Mississippian limestones and the Park City formation are involved, amounts probably to more than 3,000 feet, while north of Middle Sulphur Canyon, along the west side of the syncline, where the beds tentatively correlated with the Morgan formation rest against the upper part of the Park City formation, the vertical displacement probably does not exceed 1,800 feet.

The vertical displacements of the other faults mapped are probably less than those of the faults above described.

PHOSPHATE DEPOSITS.

The phosphate beds of the folded area from Swan Lake Gulch in sec. 29 southeastward to sec. 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 somewhat weathered and caving has occurred in several of the pits. During the season of 1910 development work 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. Opportunity was thus afforded for procuring material from a fresh face of a portion of the beds.

In Diamond Gulch, at a point near the valley floor, almost on the line of sec. 28 and in the NW. ¼ sec. 33, 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 any complete section of the phosphate shales.

Other phosphate pits were seen in the NW. ¼ sec. 6, the NW. ¼ sec. 17, the SE. ¼ sec. 17, and the SW. ¼ sec. 21 near the north line. In most of these pits sufficient opening had been made to develop the presence of apparently high-grade rock, but beyond that little development work has been done.

Along the south border of the big syncline phosphatic float is abundant and samples of float for analysis were collected in a small gulch in the NW. ¼ sec. 21, where a small anticline has caused the phosphate beds to become exposed in the midst of the surrounding upper chert member of the Park City formation, here represented by the flinty shale facies.

In the upper part of Diamond Gulch, in the SE. ¼ sec. 28, is 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 in the SW. ¼ sec. 27 and for about

160 feet down the slope to the west, but there appears to be no actual deposit of the phosphate 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 big syncline. This is probably the only considerable body of phosphate in Diamond Gulch, aside from that in secs. 33 and 32. The deposits just referred to in sec. 27, however, are apparently continuous through sec. 22 with the big syncline itself and appear to be of more importance than those of other areas in Diamond Gulch. The head of this gulch has not been prospected. Samples of the phosphate float were collected for analysis.

On the northeast side of the dry branch of Johnson Creek, 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 rock phosphate. This section has not been prospected. Samples of the float were taken for analysis. So far as observed in this township, the main bed lies near the base of the phosphate shales, with a variable thickness (6 inches to 3 or 4 feet) of brown to black shales, more or less phosphatic, between it and the underlying limestone.

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.	
		Per cent.	*Per cent.*	*Ft.*	*in.*
R. 388	Phosphatic rock, broken and folded against the main part of the bed			1	6
2	Phosphate rock, black and soft, but in place	33.0	72.0	2	5
3a	Phosphate rock, black, hard, and medium oolitic	32.0	69.9	2	0
3b	Phosphatic rock, black, hard, and medium oolitic	28.5	62.3	2	0
	Shale, brown			0	6
4	Lower 3 feet of above exposure, fresh face	29.5	64.5		
				8	5

The samples indicated in the above table were taken from the prospecting tunnel of the San Francisco Chemical Co., which was cleared out and extended in 1910. The tunnel runs nearly due north for about 70 feet. The strike of the phosphate beds is nearly north and south, and the dip, which is somewhat wavy, averages about 45° E. Neither the top nor the base of the main bed is exposed in this section.

Other pits are located on the same hillside along the strike of the phosphate shales, but they are not so well opened and no measurements were taken from them.

The "cap lime" of the Georgetown and Montpelier sections [1] does not appear in the above section, though it is probably present in the

[1] Gale, H. S., Richards, R. W., and Blackwelder, Eliot, Bull. U. S. Geol. Survey No. 430, 1910, pp. 477, 493.

district, for a dark fossiliferous limestone, slightly phosphatic and occupying a somewhat similar position with respect to the higher-grade phosphate beds, has been recognized in Diamond Gulch in the NW. ¼ NW. ¼ sec. 33 and in pits in secs. 17 and 21. 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, amounting 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, while in the Georgetown and Montpelier districts it does not exceed 6 or 7 feet.

The greater thickness of this portion of the phosphate series in this township seems to be due to an increase in the thickness of the accompanying lower-grade phosphatic shales. This is, however, accompanied by a slight decrease in the thickness of the main bed itself. In the Swan Lake Gulch district some thickening is probably to be ascribed also to the folding that has occurred there. The syncline that extends northwestward from sec. 33 into sec. 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. 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, as shown in Plate XIII, structure section J–K. The tunnel of the San Francisco Chemical Co. lies southwest of the axial plane of the syncline but probably near enough to it to include a portion of the thickened area.

The section described on page 388 in the general discussion of the Park City formation was taken at the mouth of a partly caved tunnel in the NW. ¼ NW. ¼ sec. 33, near the floor of Diamond Gulch, on the north side, some 250 feet northeast of the cut made by the gulch, in a low arch of the underlying limestone. The available exposures were somewhat weathered. The phosphate shales are nearly horizontal. The tunnel appears to run approximately north and south. The beds on the west side are much more broken than those on the east side, where the measurements were made. This is the only section in the township, so far as observed, that shows both the top and the bottom of the main bed. The layer marked "e" in the table apparently corresponds to the "cap lime" of the Georgetown and Montpelier districts, and above that are included some 6½ feet of the overlying shales and limestones. The highest-grade bed of rock phosphate here 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 of the measured section are practically horizontal, several broken and sheared beds indicate some disturbance of the rocks. The presence of the small anticline to the west points to the probability of a corresponding minor synclinal axis east of the anticline and possibly passing through the area occupied by the tunnel. On the slope north of the tunnel a normal fault cuts off the phosphate beds, and the proximity of this fault has doubtless caused some disturbance of the strata at the tunnel.

About 1,200 to 1,300 feet southwest of the tunnel there is a series of pits running up the northwest side of the gulch. These indicate the presence of the main phosphate bed but do not afford good opportunities for measurement. A tunnel near the top of the slope has caved very badly.

At the head of Diamond Gulch there are no prospect pits, but samples of the float (specimen M 339a) were collected for analysis in the NW. ¼ sec. 27, and gave 31.9 per cent of phosphoric acid, equivalent to 69.67 per cent of tricalcium phosphate.

In the NE. ¼ NW. ¼ sec. 6 there are several pits in a saddle west of the high chert ridge. These were mostly filled with brush and gave no good opportunities for measurement. The great thrust fault along the west side of the big syncline passes just west of this group of pits and cuts out the phosphate for about a mile and a half to the southeast. The general structural relations here are shown on Plate XIII, structure section H–I.

Several pits in the SW. ¼ NW. ¼ sec. 17 show fragments of phosphatic shales and indicate the presence of the main bed, but there were no good opportunities for measurement here. The rocks are much disturbed both by folding and by proximity to the great thrust fault along the west side of the big syncline.

In the SE. ¼ SE. ¼ sec. 17 there are several pits 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 to the interior of the big syncline. 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 are three phosphate pits. The deepest pit was measured and samples were collected in it for analysis. The results are shown in the following table:

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.
		Per cent.	*Per cent.*	*Ft. in.*
	Dark, fossiliferous limestone ("cap lime"), broken			10
M 377a	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 passes with gentle dip into the big syncline and that the beds are present in their usual thickness and in a relatively undisturbed condition.

In the SW. ¼ sec. 21, near the north line, several phosphate pits occur above the high cliffs of underlying limestone that stand nearly a thousand 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 phosphate shales is not exposed. About 1,000 to 1,200 feet northwest of this area, in the SE. ¼ NW. ¼ sec. 21, is the small gulch previously mentioned, where phosphate float occurs in the midst of an area of upper chert. Samples from this locality (specimen M 337a) gave 26.2 per cent of phosphoric acid, equivalent to 57.3 per cent of tricalcium phosphate.

An estimate of the area underlain by the phosphate-bearing member of the Park City formation in this township gives 8,865 acres.

In secs. 18 and 19 where the structure is interpreted as an overthrust block of upper Mississippian limestone, the suggestion from the map is that phosphate beds underlie the thrust block. The upper chert member of the Park City formation is, however, seen to lie around the end of the Woodside limestone on the northeast, and hence, in estimating the acreage underlain by the phosphate, only enough space has been assumed to permit the phosphate to follow the upper chert around the Woodside. It is assumed that the structure is similar to that of the west border of the big syncline farther north. (See Pl. XIII, structure section H–I.)

The entire area of sec. 31 is covered by travertine. From the structures to the northeast it would seem that this section is underlain by the Woodside and lower formations, including the phosphate. It is true, however, that the structure of this section is completely concealed, and the assumption that the entire section is underlain by phosphate may be hazardous. For the sake of conservatism only half of this section is included in the computation of phosphate area.

The quantity of high-grade phosphate rock present in this township is estimated at about 155,150,000 long tons. In this estimate the thickness of the main phosphate bed has been assumed to be 5 feet, which is a fair average according to observations throughout the general district. The weight of the rock phosphate has been regarded as being 180 pounds to the cubic foot.

Practically the entire amount may be considered as available and 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 sections the most accessible, though those in sec.

31 are probably near the maximum depth. The most extensive deposits appear to lie in the big syncline in the northern part of the township. This occupies high ground in the main and is rather 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 cross buckle in the floor of the syncline. 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.

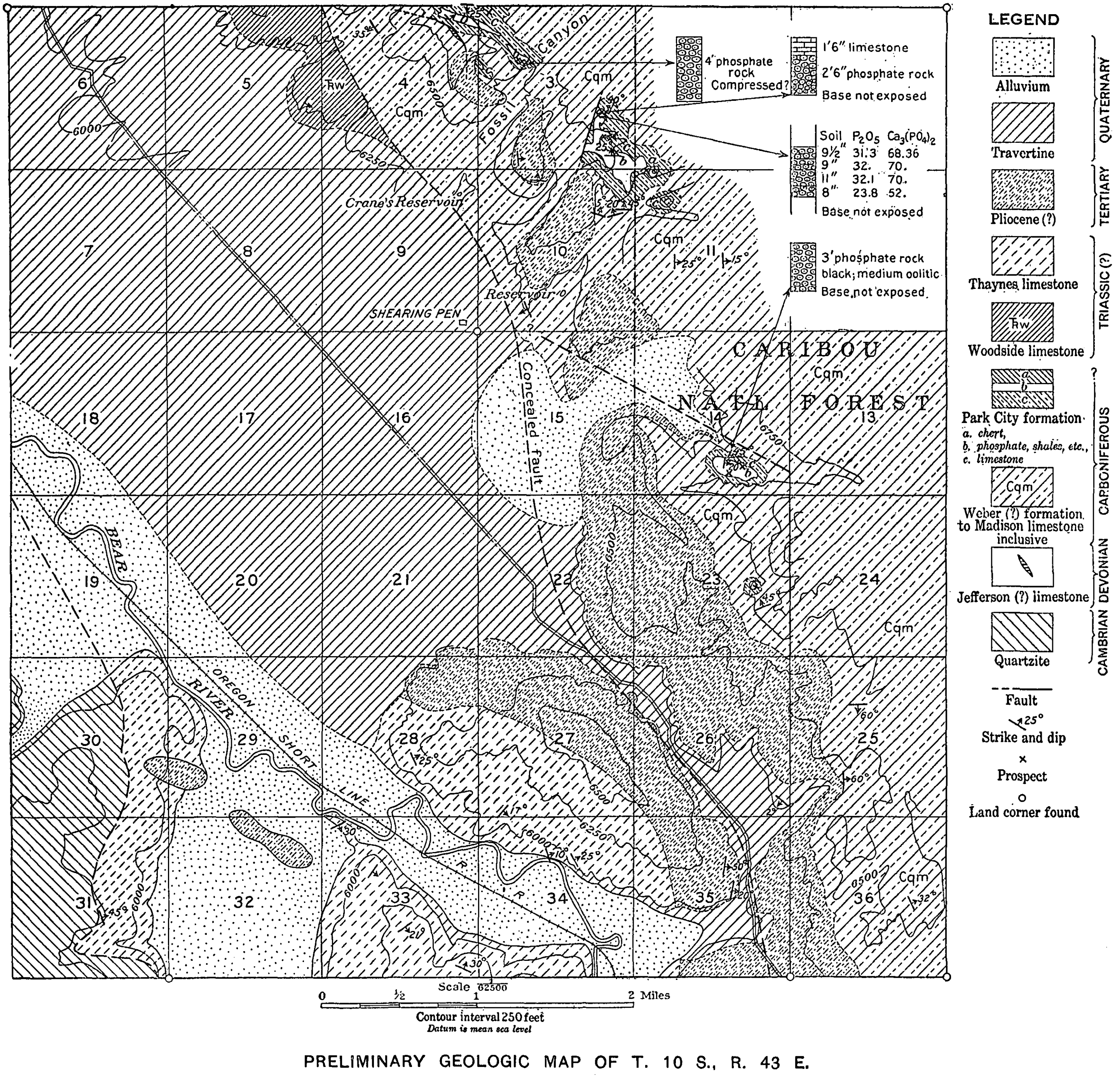
The topographic and geologic map of the portion of T. 10 S., R. 43 E., shown on Plate XIV was prepared by J. H. Bridges with a plane table, by combination of the triangulation location and stadia traverse methods.

GEOLOGY.

The geologic sequence in this township includes Cambrian, Devonian, Carboniferous, Triassic (?), Tertiary, and Quaternary strata. The Cambrian is represented by quartzite, probably the Brigham quartzite, on the margin of the overthrust block which enters the township in the southwest corner. The interval from Cambrian to Mississippian is represented only by a small patch of limestone of Devonian age, which is included along a fault margin in sec. 4. Lithologically this rock is a light to dark gray limestone, and the fossils collected from it have been identified by E. M. Kindle as those of the Jefferson limestone. The Carboniferous sediments range in age from the Madison limestone through the upper Mississippian into the Pennsylvanian, including the supposed Morgan formation and the Weber (?) formation. Light-gray limestone, sandy limestones with yellowish and reddish tints, yellow calcareous sandstones which weather red, and a small amount of quartzite are among the sediments included in this portion of the Carboniferous underlying the Park City formation. An abundant fauna has been collected from these rocks and studied by G. H. Girty. (See pp. 383–384.)

The phosphate-bearing Park City formation outcrops in this township only in small patches which have resisted erosion in small synclines, and the principal area underlain by this formation is completely concealed by the overlying Triassic (?) sediments, including the Woodside limestone and the Thaynes limestone, and by later overlapping Tertiary and Quaternary deposits.

The Park City formation is made up of three members, as elsewhere—the phosphate shales overlain by a cherty limestone member and bedded on an underlying light-colored limestone which in this



PRELIMINARY GEOLOGIC MAP OF T. 10 S., R. 43 E.

district constitutes the principal marker in tracing the outcrop of the main phosphate bed.

The Tertiary beds consist of marls, calcareous conglomerates, and white marly limestones which are with difficulty distinguished from the more or less interlocked travertine deposits. The conglomerates have locally a brecciated facies and occur in rather isolated patches upon the hills on the front of the range.

The spring deposits cover the northwestern to central open, plain-like portion of the township and range in age from Tertiary to Recent. Thin patches of alluvium, talus, or wash locally obscure the distribution of all the geologic formations and necessitate the location of many of the geologic boundaries mainly by inference.

A synclinal block of rocks as high in the stratigraphic section as the Thaynes limestone lies in a northwest-southeast, nearly central diagonal across the township. This block is overthrust on the west by a block of Cambrian quartzite and lies on the east against a block of mainly Mississippian and lower Pennsylvanian rocks, presumably as a result of faulting. A fault producing this relation is found in sec. 4 and has been mapped as extending to the south on the same general strike, with slight modifications suggested by the topography. The presence of a fault extending diagonally across sec. 14 is suggested by the finding of upper Mississippian fossils abnormally close to the outcrop of the Park City formation, and the direction of the fault is suggested by the topography. The Carboniferous rocks in the eastern part of the township are folded into a complex which is in part isoclinal. The details of structure have been worked out only in the places involving members of the Park City formation.

PHOSPHATE DEPOSITS.

The largest area in this township in which the phosphate deposits can be studied in outcrop is in sec. 3, and here considerable prospecting has been 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 phosphate 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 and found as given in the table following.

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.*
B 88	Soil.			
a	Phosphatic 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	Phosphatic 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. The other prospects in this section afforded poorer exposures of the phosphate bed and no other measurements were obtained. A caved prospect in the NW. ¼ NW. ¼ sec. 11 showed indications of phosphate rock of a fair quality on its dump, but the face of the bed was inaccessible.

The mode of occurrence of the phosphate in sec. 14 appears to be similar to that in sec. 3, namely, in an isolated patch in the trough of a secondary fold, but the conditions of exposure are not as good as could be desired, and it is possible that the concealed area to the south may be partly underlain by the Park City formation instead of by the earlier Carboniferous formations, as mapped from the indications obtained from float fragments.

The best exposure of the bed showed 3 feet of black phosphate rock with a 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 limestone of the Georgetown and Montpelier districts, bearing *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 limestone lenses.

Another small area of the phosphatic shales is found in sec. 23 on the end of a northwesterly ridge, and the following partial section was measured at that point by Mr. Bridges:

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.		

The dip of the underlying limestone is about 50° W., while that of the phosphate bed is reported as low as 4°. The bed has a lower dip than the hill slope and must therefore come to the surface within a short distance, although no evidence was noted of its outcrop. It seems probable, however, that the dip of the underlying limestone is a better indication of the general structure and that a larger body of the Park City formation may lie to the west of this outcrop, although the evidence gathered in the float appears to indicate its absence.

The main area of phosphatic deposits is in that portion of the township underlain by Triassic (?) rocks, either outcropping or concealed by the overlapping lake beds and travertine. It is probable that a less disturbed section showing a series of beds comparable to those of Georgetown Canyon would be encountered on drilling to the west near the Cambrian overthrust and to the east near the block of earlier Carboniferous sediments. The arbitrary assumption of the presence of a 5-foot bed of high-grade rock phosphate is regarded as conservative, for the measured sections, which were only partial, average about 4 feet, and the main bed in the computations for the Georgetown district was found to be 6 feet thick.

An estimate of the area of the lands in this township underlain by the phosphatic member of the Park City formation gives over 12,000 acres. The structure of a large part of this area, however, is concealed by the overlapping Tertiary and later rocks, and in order to make the basis for tonnage computation clearly conservative only one-half of this area is taken. The assumption that 6,000 acres is underlain by a 5-foot bed of phosphate rock weighing 180 pounds to the cubic foot leads to an estimate of over 105,000,000 long tons for the township. The entire amount is considered ultimately available and its value is enhanced by the fact that it is immediately along the Oregon Short Line Railroad. It is undoubtedly possible to cut this deposit by shafts at depths which range from a few feet to a maximum of 1,500 feet or thereabouts.

T. 11 S., R. 43 E.

A thorough reconnaissance of T. 11 S., R. 43 E., demonstrated the presence of a large area of Triassic (?) rocks (Pl. IX), which are undoubtedly underlain by the phosphate-bearing Park City formation. This formation, however, does not outcrop, and the character of the phosphate deposits can only be inferred from the outcrops in the adjoining regions.

STRATIGRAPHY.

The geologic formations present in this township are described in the foregoing pages of this report. Cambrian, possibly Ordovician, Triassic (?), Tertiary, and Quaternary rocks constitute the surficial formations found in the township, and probably Carboniferous rocks older than the phosphate series underlie the Tertiary cover in the northwest corner.

The Triassic (?) rocks are of especial importance in that they directly overlie the phosphate-bearing Park City formation. They comprise grayish-brown muddy and sandy limestones and are correlated with the Thaynes limestone on both lithologic and fossil evidence. These rocks were described by Hayden,[1] who found no fossils in them and believed them, purely on lithologic grounds, to "appear to be of modern Tertiary age."

STRUCTURE.

The Triassic (?) area appears to consist of a broad syncline which may be called the Nounan syncline, as its axis lies a little east of and nearly parallel with the Nounan Valley. Two important faults limit the area underlain by phosphate deposits. The greater of these faults lies to the west and is the great thrust which causes the old Paleozoic rocks to overlie the Triassic (?). On the east a normal fault causes the Triassic (?) block to lie against rocks that range in age from Mississippian limestone to Weber (?) formation, but are covered in this township by an overlap of Tertiary (Pliocene ?) beds.

PHOSPHATE DEPOSITS.

The quality and thickness of the phosphate beds underlying the Thaynes limestone are of necessity matters of inference from the nearest measured exposures—those of the Georgetown district, a detailed section of which is quoted on pages 387–388.

The depth of the phosphate series in this township ranges from 1,300 to possibly 2,700 feet at a maximum. The phosphate will probably be found at maximum depth in secs. 23 and 26, where the hills are capped with a trace of a red-bed formation which is thought to represent the Ankareh shale.

The township is estimated to contain 11,500 acres of lands which are underlain by phosphate at recoverable depth. These rocks are regarded as horizontal for the purpose of estimating the tonnage and only a 5-foot bed of high-grade phosphate is taken into account, although the main bed alone in the Georgetown district averages 6 feet, so that the estimates are amply conservative.

The assumption that the 11,500 acres is underlain by a 5-foot bed of rock phosphate weighing 180 pounds to the cubic foot leads to an estimate of 201,270,000 long tons.

T. 12 S., R. 43 E.

GEOLOGY.

A careful reconnaissance of T. 12 S., R. 43 E., demonstrates that in the greater part of the township the bedrock geology is obscured by Tertiary (Pliocene ?) beds. (See Pl. IX, p. 380.)

[1] Fifth Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1871, 1872, p. 155.

The principal deposits of alluvium are found in secs. 3, 29, 31, 32, and 36. The Tertiary lake beds comprise marly limestones and conglomerates with a calcareous matrix and are probably Pliocene, though possibly some of the coarser conglomerates may be of Eocene age. These Tertiary beds have been subject to deformation and dips as high as 50° were observed in them. They have been crumpled into a series of folds whose axes have a north-south alignment and which are in general parallel to the deformation of the older rocks and may represent a continuation of movement along the same lines.

The Triassic (?) rocks are entirely concealed by the overlap in this township and their existence in the northeast corner is inferred from the outcrops in sec. 35, T. 11 S., R. 43 E. At this place fossils were collected which are characteristic of the Thaynes limestone. The rock is a bluish-gray to brownish muddy limestone. The southern limit of these rocks and the phosphate is unknown, but the point to the southwest of Bern is thought to possess an anticlinal structure which brings up the subphosphate section. The only outcrops are found in sec. 26 and the fossils collected at this point are poorly preserved and not susceptible of positive identification. The limestone is bluish gray and seamed with calcite and siderite. Brecciated sandy limestone of a yellowish tint is also found here, but none of the bluish-black limestone, such as has been removed from the Tiptop, a prospect for metalliferous values in the NW. ¼ NW. ¼ sec. 26. The bluish-black limestone is regarded as representing the Cambrian, while the yellowish limestone is presumed to be Mississippian, although the data at hand are scarcely sufficient to the contention. The lithology is also similar to that of Ordovician limestones in the vicinity of St. Charles, in T. 15 S., R. 43 E., and to the north of Alexander, in T. 9 S., R. 41 E.

The western portion of the township consists of quartzite which should probably be correlated with Walcott's Brigham quartzite (see pp. 381–382), and a small amount of limestone which may represent a portion of the Ute limestone. The only outcrops of this limestone seen are situated near the top of the hills in the western parts of secs. 23 and 26.

STRUCTURE.

The structure of the rocks immediately above and below the Park City formation is obscured by the Tertiary cover, and the conclusions that have been drawn concerning it are purely hypothetical. The evidence on which the ideas of structure are based is gained from the somewhat less hidden geology of the townships adjoining on the north and the south, described on pages 429–430 and 432–434. Most of the western two-thirds of the township may be eliminated from further consideration by stating that it consists of folded Cambrian and possibly Ordovician rocks, overthrust on later sediments. The thickness of the overthrust block is unknown and the character of the rocks overridden by it indeterminable. The position of the margin of the overthrust block is of necessity estimated because of the extensive cover and may be considerably in error. The northern half of the eastern third of the township may be regarded as including post-phosphate rocks as high as the Thaynes limestone in a synclinal trough; the southern half of the same portion of the township is presumed to consist of prephosphate rocks in anticlinal structure between the Paris–Liberty syncline and the Nounan syncline.

PHOSPHATE DEPOSITS.

The character of the phosphate deposits underlying the Triassic (?) rocks is wholly a matter of inference from the nearest measured exposures at Bennington and Montpelier, which are described in last year's report.[1] The character of the deposits at these localities apparently justifies the assumption of a 5-foot bed of high-grade rock as the probable content of the deposits in T. 12 S., R. 43 E. An estimate which is scarcely more than an arbitrary assumption of the area underlain by the deposits gives about six sections, or 3,840 acres, and the resultant tonnage obtained is 67,200,000 long tons. The depth at which this phosphate lies is in excess of 1,200 feet in the northern portion of the area, but probably diminishes toward the south.

T. 13 S., R. 43 E.

SURVEY.

Two methods of field work were employed in mapping T. 13 S., R. 43 E., depending on the absence or the presence of cover. The zone along the thrust fault in secs. 17, 20, 29, and 32 was mapped by a plane-table stadia traverse, and the remainder of the township was examined only in reconnaissance, using the topographic base map prepared by A. E. Murlin. (See Pl. XV.)

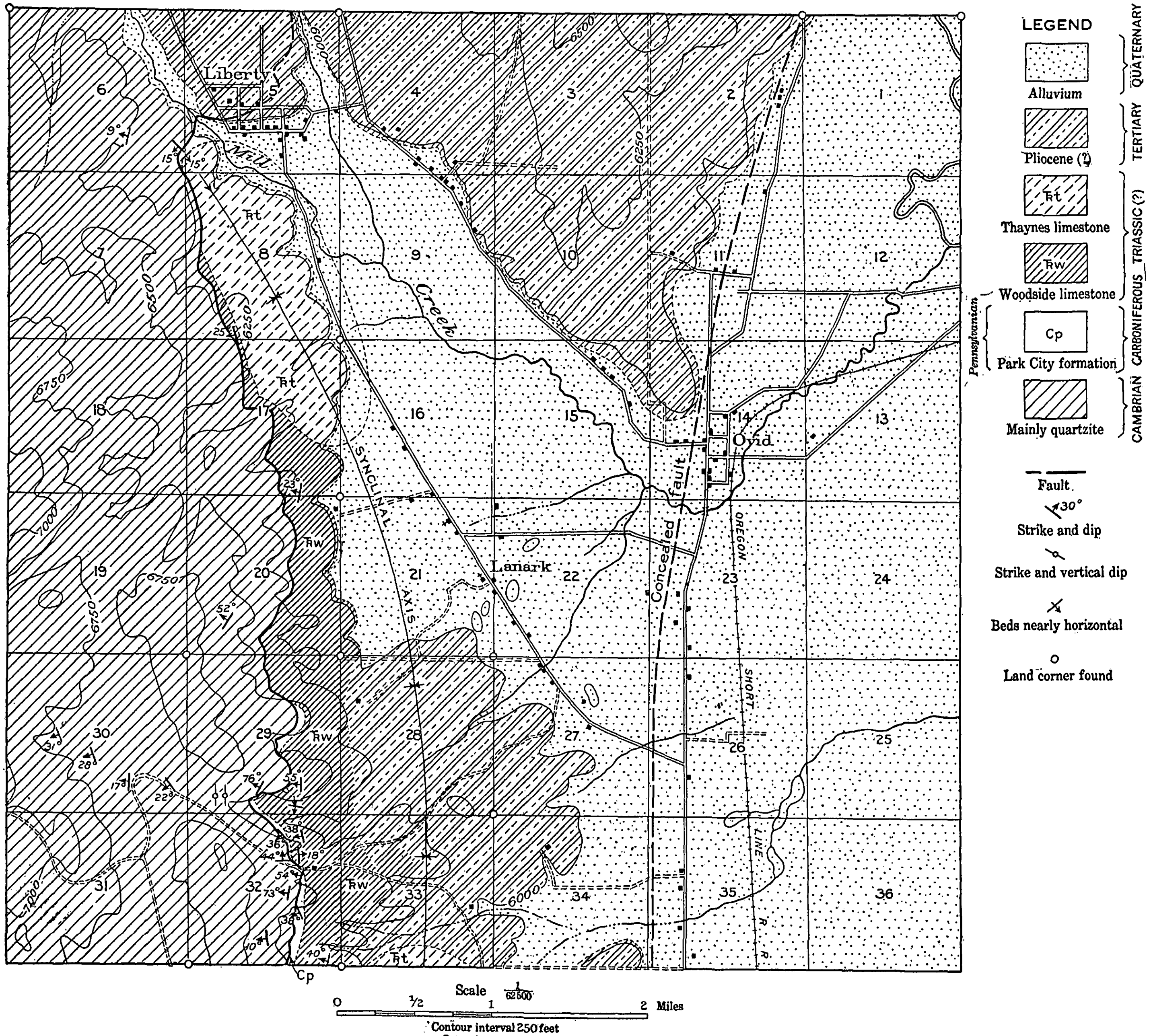
GEOLOGY.

The bedrock geology of the sections east of the second tier from the west boundary is rendered very obscure by the extensive cover of alluvium and Tertiary beds.

The valleys of Bear River, Mill Creek, and the subordinate creeks to the southwest are filled to an unknown depth with alluvium, and the parts that are not swampy constitute good farming land.

The hills in the eastern two-thirds of the township are covered with the white marly limestone and calcareous conglomerates which Hayden and Peale included in their Salt Lake group. These deposits were laid down in Tertiary (Pliocene?) time.

[1] Bull. U. S. Geol. Survey No. 430, 1910, pp. 488–495.



PRELIMINARY GEOLOGIC MAP OF T. 13 S., R. 43 E.

The larger area of Triassic(?) rocks shown on the map is undoubtedly made up of the Woodside limestone, with its characteristic rusty-weathering limestone, but the small oval area in the northern part of the township is known to be higher in the series by the presence of ammonites in the southwest corner of sec. 5 and the NW. ¼ NE. ¼ sec. 8. These *Meekoceras* forms mark the base of the Thaynes limestone. A small area of the same formation is shown at the southern edge of sec. 33. It is possible that patches of the Thaynes limestone are present in other places along the synclinal axis but are obscured by the cover.

The only member of the Park City formation found in outcrop is the upper cherty limestone, which occurs normally under the Woodside limestone and directly above the phosphate series. Small pieces of float phosphate rock were found at a number of places to the west of the chert.

The western portion of the township consists mainly of the quartzite named Brigham quartzite by Walcott (see p. 382) and a small area of his Langston limestone. This is a blue limestone with abundant fossils characteristic of this formation and was found in the SW. ¼ NE. ¼ sec. 32. The type locality of the Spence shale member of the Ute limestone is a little over a mile west of the township line in unsurveyed sec. 12, T. 12 S., R. 42 E.

The structure from west to east involves an overthrust block lying on a folded complex, which is limited on the east by a graben of unknown content but probably containing postphosphate rocks.

The folds, both anticlinal and synclinal, are, in general, overturned toward the east. The axis of a synclinal fold involving the Triassic(?) rocks occupies the central portion of the township, and the point northwest of Ovid is supposed, because of its suggestive topography, to represent the tip of a parallel anticline. It must be noted, however, that in this township the nature of the country rock underlying this hill is entirely concealed by the cover of Tertiary beds. It seems probable that the rocks composing the main mass are prephosphate rather than postphosphate because of the relief of the hill.

Bear Lake Valley is probably underlain by folded strata which, because of the lack of the salient outcrops that are especially characteristic of the prephosphate rocks, are supposed to consist of the softer postphosphate rocks.

The Cambrian overthrust block is made up of quartzites folded into an anticline which is overturned toward the east.

The township is crossed from north to south by two faults, the western one being a thrust of great magnitude and the eastern a normal fault of slight displacement. The facts for which an explanation is sought by assuming a normal fault can also be explained by folding, but the explanation by faulting is simpler.

PHOSPHATE DEPOSITS.

The exposures of the Park City formation in this township are so meager that no detailed information could be obtained concerning the local section of the phosphate shales.

The sections at Montpelier and at Bloomington will be found on page 493 of the 1909 report (Bulletin 430) and page 391 of this report, respectively, and it appears reasonable to assume that the average character of the deposits in this township is at least as good as at those places. As a conservative basis for estimate, a 5-foot bed of high-grade rock may be inferred as present throughout the portion of the township underlain by the Park City formation.

The attempt to make an estimate of the acreage with available phosphate deposits brings up the rather difficult questions whether or not the boundary of the Cambrian thrust block actually limits the workable area on the west and what portion of the phosphate underlying the alluvial bottoms can be profitably recovered. While it may be extremely doubtful that the phosphate can be mined at a profit under adverse conditions, such as are represented by the overthrust and the cover of alluvium, yet in the future the relative accessibility of these deposits to lines of transportation may render them valuable. The estimate is therefore made in round numbers and with regard to the future.

The assumption that 5,000 acres in the township is underlain by a 5-foot bed of phosphate rock, weighing 180 pounds to the cubic foot, gives a total of 87,500,000 long tons.

The depth of the phosphate is nowhere in this township much in excess of 1,200 feet, and undoubtedly decreases at right angles to the synclinal axis, so that comparatively shallow shafts should encounter the deposits west of the margin of the Bear Lake Valley block.

T. 14 S., R. 43 E.

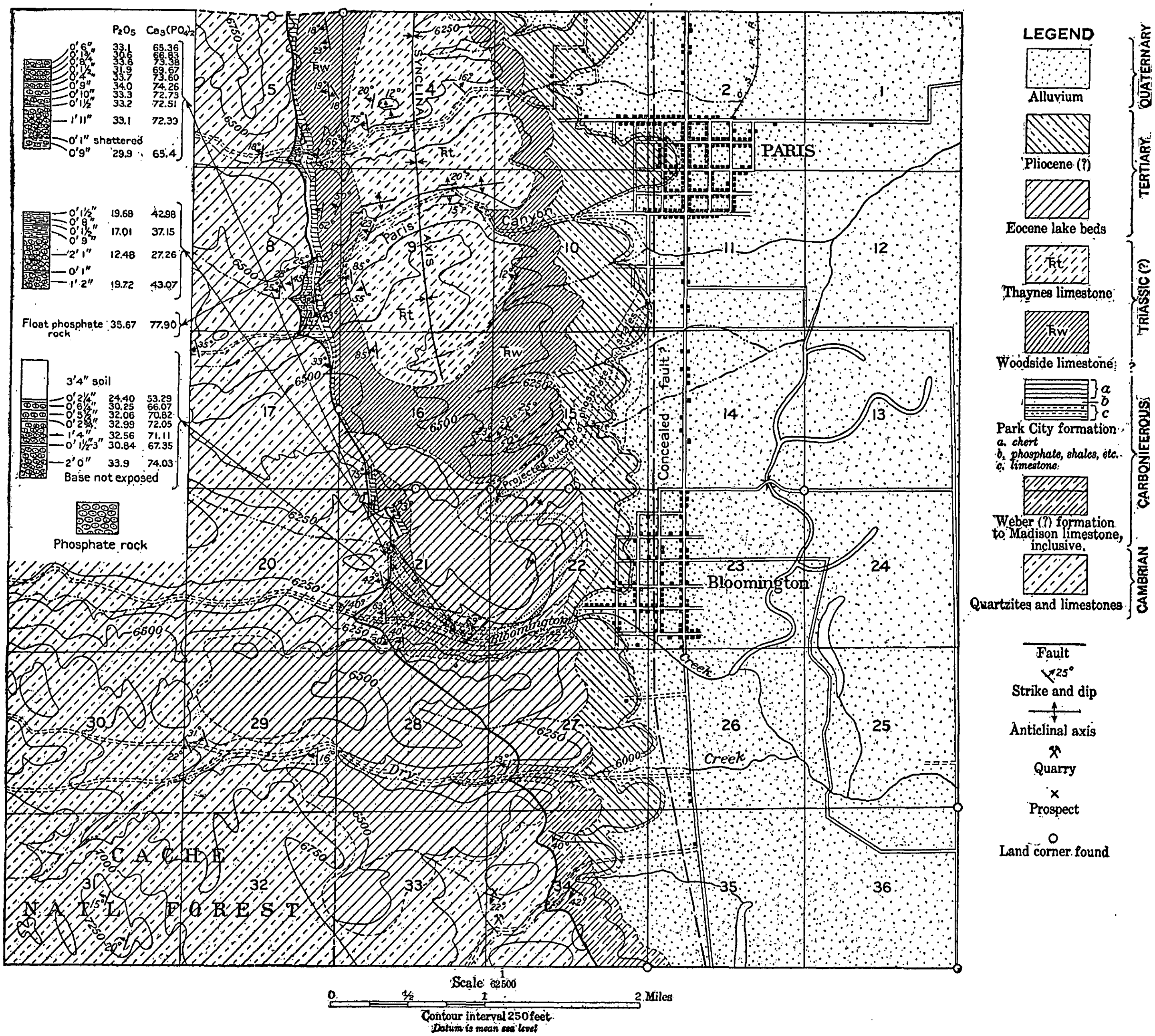
FIELD WORK.

In T. 14 S., R. 43 E., the area including the phosphate shales and Triassic(?) rocks was mapped by plane-table stadia traverses; the remainder of the township was examined by traverses in general at right angles to the strike of the beds, and the locations of observations were determined by plotting pocket-compass sights on the topographic base.

GEOLOGY.

The surficial areal geology is shown on Plate XVI, and the geologic formations present are discussed in detail on pages 380–396.

The white marly limestones and calcareous conglomerates found along the western margin of Bear Lake Valley are regarded as of Pliocene age.



PRELIMINARY GEOLOGIC MAP OF T. 14 S., R. 43 E.

The ferruginous conglomerates capping some of the high hills in the middle of the township are probably of Eocene age and may be the equivalent of Veatch's Almy conglomerate.

That portion of the Triassic(?) rocks lying above the *Meekoceras* zone is mapped as the Thaynes limestone, and these beds are known from the succession of the faunas to lie right side up in Paris Canyon.

The portion of the Triassic(?) section below the *Meekoceras* zone is mapped as Woodside limestone.

The two upper members of the Park City formation—the cherty upper limestone and the phosphate shales—are found in typical form in this township. The underlying limestone, however, is not represented by the clear bluish-gray limestone and occasional beds of chert common elsewhere but by a sandy yellow limestone.

The Weber formation was not noted, but the outcrops of rocks older than Park City are scarce and fossils which were clearly of Mississippian age were collected in sec. 34, so that a portion of the sandy limestone close to the base of the Park City formation may represent the Weber. No data have been found which may be used to determine the upper limit of the Madison limestone, but the sequence of deposition is apparently continuous, as no evidence of an unconformity was seen, and portions of the interval may represent the upper Mississippian and the Morgan formation. The quartzites and limestones of the western part of the township may be correlated with the lower portion of Walcott's Cambrian section measured on Mill Creek near Liberty, and probably comprise the Brigham quartzite, the Langston limestone, and the Ute limestone, including the Spence shale member.

The rocks emerging from under the overthrust block of Cambrian are caught up in the Paris-Liberty syncline, the axis of which lies nearly central in the township, in a north-south direction. The western limb of the fold is overturned toward the east, and minor cross folds cause the marginal outcrops of the several formations to depart from the regular arrangement they would naturally acquire from the major fold.

The location of the margin of the Cambrian overthrust was determined by detailed plane-table mapping in the area north of Bloomington Canyon, but the mapping of its extension to the south from the same place must be regarded as less certain and possibly to some degree in error. This great thrust fault has been described in the general discussion of the structure of the valley (pp. 397–399).

PHOSPHATE DEPOSITS.

The only prospects which had been opened in the phosphate shales were found 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 shown on Plate XVI. The high-grade rock is found near the mouth of Spomberg's tunnel (see section on p. 391), in the dry gulch. The greater part of the tunnel is in a dark-colored shale, containing less than 20 per cent of P_2O_5. The outcrop of the overlying chert is concealed at this place, but it can be seen in the slightly offset block a short distance to the north.

The mapping of the outcrop of the phosphate shales from the mouth of the tunnel to the prospects in the southeast quarter of the section is based on scattered traces of phosphate float mingled with the wash derived from the lake-bed conglomerate which caps the hill. The inferred outcrop from the prospects to the margin of the valley block is based on the projection of the strike of the beds to the east of the prospects and also on the calculated interval from the dip reading obtained at the base of the Thaynes limestone in sec. 10.

Small pieces of float phosphate were found mixed with fragments of chert near the margin of the thrust in the SE. ¼ SW. ¼ sec. 21. These are thought to have been dragged up along the thrust and derived from outcrops which are now concealed by the overlying Cambrian, and no attempt has been made to suggest the nature of the structure of this underlying block.

The supposed recoverable tonnage of phosphate rock is estimated as equivalent to that which would be included in a horizontal series of rocks with a surface area of six sections, or 3,840 acres. This estimate is exclusive of the content of the valley block, which, because it is concealed, can not be estimated.

The sections measured in this township indicate that the bed of high-grade rock is somewhat less than 5 feet in thickness, and 4.5 feet is considered a safer basis for estimate. The assumption that 3,840 acres is underlain by a 4.5-foot bed of phosphate rock weighing 180 pounds to the cubic foot gives a total of over 60,000,000 long tons.

The depth of the phosphate shales varies in the area from the outcrop at the surface to a maximum probably not in excess of 1,500 feet along the axis of the syncline.

T. 15 S., R. 43 E.

A reconnaissance geologic examination of T. 15 S., R. 43 E., determined the absence of the Park City formation. A small amount of prospecting for phosphate was reported in sec. 15 on the north side of St. Charles Creek, but an examination of the rocks in the vicinity of the pit proved them to be older than Carboniferous and probably Ordovician. No indications of phosphatic rock were found. The limestones are slightly fetid and this character doubtless led to the supposed discovery. The areal geology of the township is represented on Plate IX (p. 380).

The mountainous portion, comprising all but the two eastern tiers of sections, is made up of Cambrian and Ordovician sediments in a great overthrust block, with small overlying areas of Tertiary lake beds. Lead deposits are present in this part of the township and are described in a separate chapter of this bulletin. The valley portion of the township is within the Bear Lake Valley region, whose structural and stratigraphic conditions have been discussed on pages 380–399.

GENERAL SUMMARY.

TONNAGE OF AREAS EXAMINED.

The tonnage estimates included with the township descriptions accompanying this report cover only the area examined in detail in 1910 and are additional to the estimates for 1909. These estimates are, of course, approximate at best, but they are derived from the most complete data available at the present time. Emphasis should be placed on the fact that all these estimates, like those of 1909, are based to a considerable extent on arbitrary assumptions, which are, however, carefully explained in the accompanying text. All the estimates made are intended to be amply conservative. They are confined to the content of the main bed, whch is to be found for the entire area near the base of the phosphatic member of the Park City formation, and no attempt is made to estimate the vast tonnage of the intermediate or low-grade rock.

Estimates of phosphate rock available in the townships reviewed in this report.

	Long tons.
T. 8 S., R. 42 E	122,500,000
T. 9 S., R. 42 E	67,200,000
T. 8 S., R. 43 E	293,150,000
T. 9 S., R. 43 E	155,150,000
T. 10 S., R. 43 E	105,000,000
T. 11 S., R. 43 E	201,270,000
T. 12 S., R. 43 E	67,200,000
T. 13 S., R. 43 E	87,500,000
T. 14 S., R. 43 E	60,000,000
	1,158,970,000
Total for area examined in 1909	266,950,000
Total tonnage for area covered with detailed surveys to date	1,425,920,000

The 1910 estimates are more liberal than those of 1909 in that an arbitrary limit of one-half mile from the outcrop has not been used, as in the case of the 1909 estimate for the Montpelier district.

The distribution of the phosphate of the area examined in 1910 is shown graphically by figure 47.

RELATIONS OF THE IDAHO, MONTANA, AND WYOMING AREAS.

The area examined during 1910 owes its greater acreage of phosphate land and consequent greater tonnage to the inclusion of the phosphate-bearing rocks in broader and larger folds. In quality, the deposits appear somewhat inferior to those examined in 1909, but the authors feel confident that this difference is local rather than one applying to the whole area examined and is somewhat accentuated by the uniformly low results obtained by the chemist. The presence of high-grade beds of workable thickness and of the same geologic age in the Wyoming areas described by Blackwelder on pages 452–481, shows that the area of phosphatic deposition was extensive. The discovery of the similar deposits in Montana, described by Gale on pages 440–451, has extended the limit 150 miles beyond the northern boundary of the reserve as originally drawn, and it appears highly probable that additional deposits will be found in the portions of Idaho and Montana intervening between the two fields.

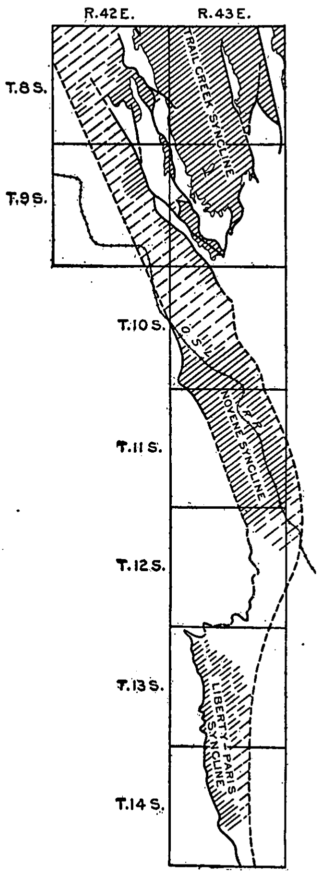


FIGURE 47.—Diagram showing distribution of phosphate in a portion of the Idaho phosphate reserve. Solid-lined areas are regarded as underlain by recoverable phosphate; broken-lined areas probably have phosphate present, but its recovery is doubtful.

SIGNIFICANCE OF WORK DONE AS TO TOTAL EXTENT OF DEPOSITS.

The continuity of the deposits within the area examined in 1909 and 1910 is a good indication that these beds originated under conditions of great uniformity and wide extent, both as to the manner of deposition and as to the character of the material making up the strata. Continuity of the rock formations with which the phosphate is identified throughout the area of lands withdrawn in the phosphate reserve is well established in a general way. The actual commercial availability of phosphate deposits beyond the areas now known can be determined only by examination and study. Such scattering evidence bearing on this subject as has been brought together seems to indicate the great probability that the deposits are more extensive than the first predictions implied, and it is well within the limits of possibility that these western fields are the most extensive phosphate fields of the world.

An estimate of the total tonnage of the probable phosphate lands of the western fields has been prepared by taking the ratio of the content of the areas which have been surveyed in detail to their surface and applying it to the total area of phosphate lands which have been examined only in part by reconnaissance. The result obtained is 2,500,000,000 long tons of rock of 70 per cent tricalcium phosphate grade. It should be understood, however, that this is merely an estimate which may be materially increased or decreased as a result of future work.

ROCK PHOSPHATE NEAR MELROSE, MONTANA.[1]

By Hoyt S. Gale.

INTRODUCTION.

DISCOVERY.

Rock-phosphate deposits of the same type as those of south eastern Idaho and vicinity were found in Montana by the writer, in October, 1910, while engaged in a geologic examination in an area southwest of Butte. It is believed that commercial deposits of phosphate have not heretofore been recognized in Montana, and no sign was observed that these beds had ever been prospected.

LOCATION AND ACCESSIBILITY.

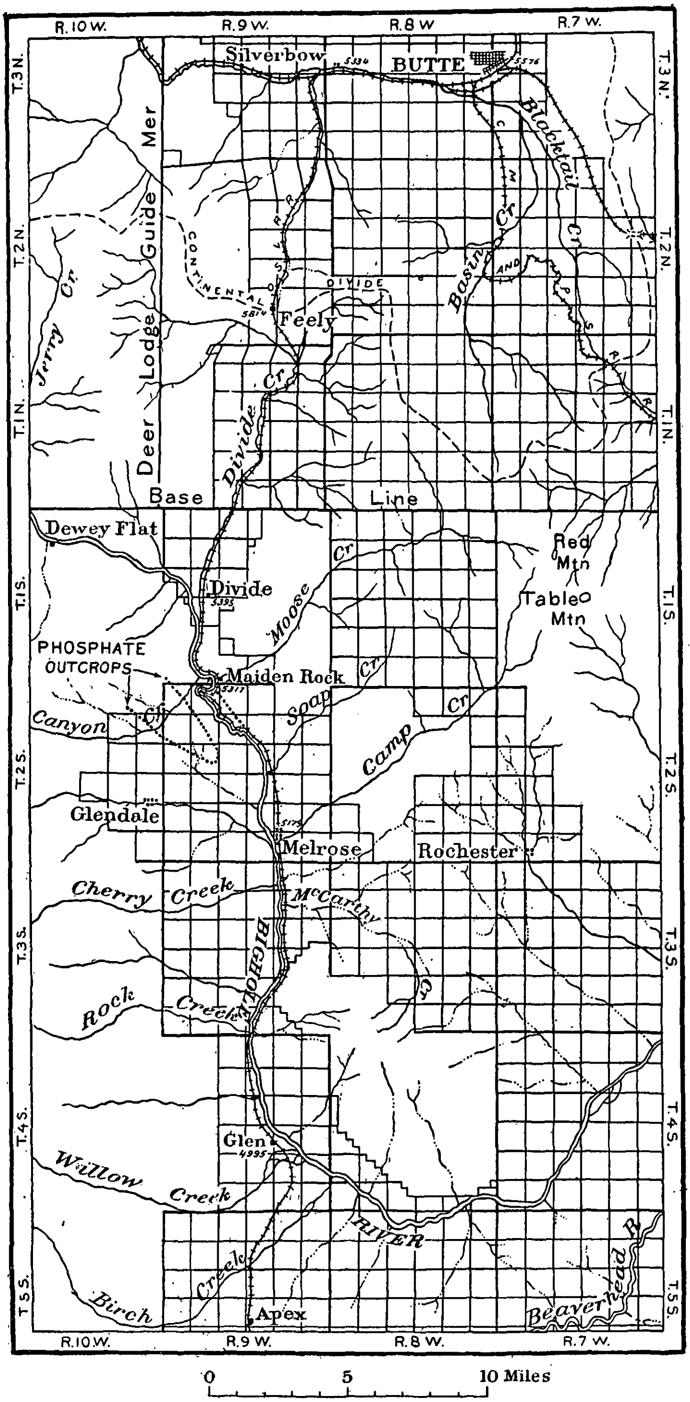
The deposits are situated in the canyon of Bighole River and in the hills northwest of Melrose and south of Divide, both towns on the Oregon Short Line Railroad. (See fig. 48.) Melrose is near the corner of Silver Bow, Madison, and Beaverhead counties and has long been a shipping depot for the surrounding mining camps, Hecla, Rochester, Soap Gulch, Wickeyup, Camp Creek, and numerous other less-extensive workings.

The phosphate deposits are readily accessible and advantageously situated for shipment by rail to the agricultural centers in the northern Middle West. The beds outcrop within about a mile of the railroad, and perhaps considerably nearer to the main right of way of the Oregon Short Line Railroad in the canyon of Bighole River, about 30 miles southwest of Butte. They are therefore readily accessible from Butte or Anaconda and within easy shipping distance of the smelters at Helena and Great Falls.

CHARACTER OF THE PHOSPHATE.

The rock was found as float on the outcrop of the bed and was recognized by its physical character. The more massive part of the bed, which is usually found as float, somewhat resembles a dark, coarse, granular limestone or might even be mistaken, on casual examination, for a dark, fine-grained basalt. It has an oolitic structure, is dark gray to black in color, is noticeably heavy in comparison

[1] Revision of paper published in January, 1911, as an advance chapter (470-A) from Bulletin 470.



0 5 10 Miles

FIGURE 48.—Map showing location of phosphate deposits northwest of Melrose, Mont.

with the sedimentary rocks with which it occurs, and on many of the weathered surfaces has a bluish-white coating, a "phosphate bloom," probably of a secondary phosphate mineral. The oolitic structure, though constituting one of its most distinct features, is in places somewhat obscured, probably by the shearing or other metamorphic influences to which these strata have been subjected.

ANALYSES.

A number of samples were collected, representing float along the outcrop, and these have been analyzed by J. G. Fairchild in the laboratory of the Geological Survey, with the following results:

Tests of phosphate rock from vicinity of Melrose, Mont.

	A.	B.	C.	D.
Insoluble in HNO_3		4.49		3.64
P_2O_5	29.5	35.09	14.1	34.80
Al_2O_3		2.20		.81
Fe_2O_3		.10		.82
CaO		51.15		51.40
Equivalent to bone phosphate	64.5	76.64	30.8	74.43

Of these samples, A, B, and C are from a locality near the east quarter corner of sec. 17, T. 2 S., R. 9 W., and D is from an outcrop in Canyon Creek about 2½ miles southwest of Maiden Rock station on the Oregon Short Line Railroad, in sec. 12, T. 2 S., R. 10 W. Sample A was a very small fragment sent in for preliminary test, picked at random from a sack of the first material collected; B and C were obtained by crushing and averaging individual blocks, each weighing several pounds, each sample thus representing a product of 6 to 8 inches of the original bedding; and D was an average from a considerable collection of small fragments picked up at random. All came from the surface of the ground.

These analyses show considerable variation, but they indicate the presence of some high-grade ore that is approximately equivalent to 75 per cent tricalcium phosphate. An average of ore now being shipped from southeastern Idaho runs about 70 per cent tricalcium or bone phosphate. It may be pointed out, however, that experience has shown that weathered fragments are commonly enriched 3 to 5 per cent or more, owing to the leaching of the more soluble lime carbonate.

LOCATION AND STRUCTURE OF THE DEPOSITS.

The quarter-section stone on the east side of sec. 17, T. 2 S., R. 9 W., consists of a block from the phosphate bed set and marked as a corner and situated practically in the outcrop of the bed. At this point the beds strike N. 10° E. and dip 70° to 80° W., the strata being overturned toward the east. From this corner the phosphate outcrop may be readily traced northward about a quarter of a mile to a point where it crosses the summit of the ridge, and presumably it continues northward beyond that point on the face of the steep slope parallel to and overlooking the canyon of Bighole River and the railroad, which is less than a mile distant. A short distance south of the land corner described above, the outcrop bends sharply westward in conformity with the general structure of the rocks, which is that of a partly overturned anticline whose axis pitches southeastward, in the

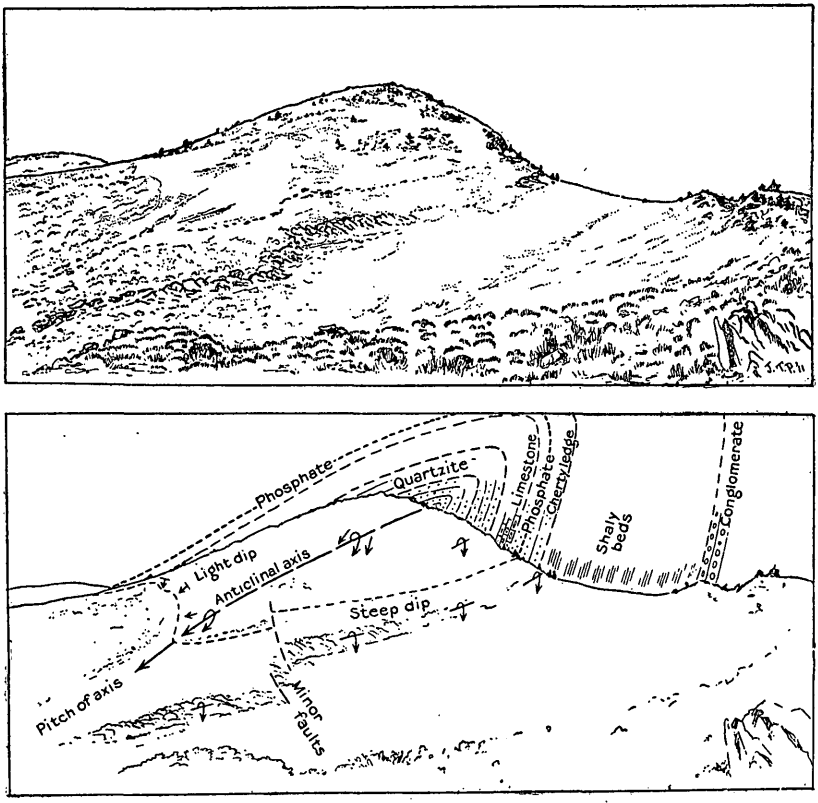


FIGURE 49.—View of the phosphate mountain near Melrose, Mont., looking from the direction of Melrose, with a diagrammatic section showing the geologic structure.

direction of Melrose. This structure is somewhat more clearly brought out in the concentric arrangement of the outcropping harder ledges in the overlying beds where these are bent about the axis of the pitching fold.

The accompanying sketch (fig. 49) is a view of the peak in sec. 17, T. 2 S., R. 9 W., looking from the southeast, showing the position of the phosphate outcrop, with a diagrammatic indication of the structure at this place. This peak is plainly visible from Melrose, from which it shows in about the same perspective.

STRATIGRAPHY OF MONTANA PHOSPHATE DEPOSITS.

This phosphate occurs in rocks of Pennsylvanian (upper Carboniferous) age which overlie the massive quartzite of the Quadrant formation. The Quadrant formation is generally described as composed of an upper more massive portion consisting chiefly of quartzite, forming prominent outcrops of hard, commonly vitreous ledges, including some shaly layers, and a less prominent member in the lower part, consisting of more calcareous beds, including some purplish and reddish strata. This formation overlies a pure, usually bluish limestone known as the Madison, which is of Mississippian (lower Carboniferous) age. The relation of the phosphate bed to these massive strata is the principal clue by which the position of the phosphate horizon may be identified in the field. The quartzite of the Quadrant is overlain by light, sandy-weathering blue limestone, about 130 feet thick in the Melrose section. This limestone contains much black chert in nodular form and in layers. The phosphate bed immediately overlies this sandy blue limestone and is itself overlain by ledges containing much massive chert, so that the stratigraphic section here corresponds remarkably in lithologic character with the sequence of strata typically associated with the phosphate beds in southeastern Idaho.

A measurement of the stratigraphic section obtained by pacing on the outcrops exposed near the northeast corner of sec. 17, T. 2 S., R. 9 W., and combined with further measurements obtained in a similar way in Canyon Creek, is as follows:

Stratigraphic section including the phosphate bed in T. 2 S., R. 9 W., Montana.

[Thicknesses approximate or estimated.]

	Feet.
Cretaceous:	
Shale, black, fissile (probably Colorado, Upper Cretaceous)	
Sandstone, fine grained, brown and rusty weathered (possibly representing the base of the Colorado)	10
Shale, in part varicolored	200
Limestone, dark blue, containing gastropods ("gastropod limestone," supposed to be near the top of the Kootenai formation, Lower Cretaceous)	10
Sandstone, dark greenish and buff, with varicolored shales (red, maroon, greenish, yellow, brown, etc.), including some thin beds of blue limestone	600
Quartzite, or sandstone and massive ledges of coarse-pebble conglomerate. The sandstone is evenly bedded, of greenish and brownish fine-sandy material. (Possibly representing the base of the Kootenai formation, Lower Cretaceous)	100
Triassic (?) or Jurassic (?):	
Shale, with some limestone, showing some decided green and brown colors in upper part	400

Carboniferous:	
Pennsylvanian—	Feet.
Chert (and quartzite?), massive, yellow stained, brecciated	100
Phosphate bed, approximate thickness, estimated	5
Limestone, blue, sandy, containing black chert in nodules and layers	130
Quartzite, very massive, white, vitreous (Quadrant)	400
Sandstone, quartzite and sandy shale, including dark red and purplish bands (Quadrant)	300
Mississippian—	
Limestone, massive blue-weathering ledges (Madison)	1,000+
	3,250+

THICKNESS OF THE PHOSPHATE.

In May, 1911, after the first publication of this paper as an advance chapter of Bulletin 470, the phosphate beds near Melrose, Mont., were prospected by E. L. Jones, jr., of the Geological Survey, and the accompanying chemical tests shown on the diagram (fig. 50) have been made since in the laboratory of the Geological Survey by J. G. Fairchild.

The following is an abstract from Mr. Jones's notes:

The phosphate-bearing section was trenched at a point 430 feet S. 10° W. from the quarter corner on the east side of sec. 17, T. 2 S., R. 9 W. The excavation is 14 feet long, 18 inches wide, and 4 feet deep. It trends N. 85° W., nearly at right angles to the strike of the phosphate beds. The phosphate occupies, together with the shale, a depression between two rather prominent ledges, a chert or quartzite on the east and a light-blue limestone on the west side. The average distance between these outcropping ledges was found to be about 50 feet. The strike of the phosphate bed at the point where the trench was dug is N. 8° E., with a dip of 81° W. The structure is apparently that of an overturned fold, as described in the report of Mr. Gale.

The phosphate beds *f* and *h* are fractured and brecciated, veins of calcite being common, and specimens showing cementation of argillaceous fragments torn from the walls are included in the samples mailed to you. In these beds the phosphate rock is in loose slabs which dip in the same general direction as that of the undisturbed ledge. This evidence, taken together with the similarity of the beds *f* and *h* separated by a thin bed of argillite, suggests a strike fault, and thus bed *h* may be a repetition of bed *f*

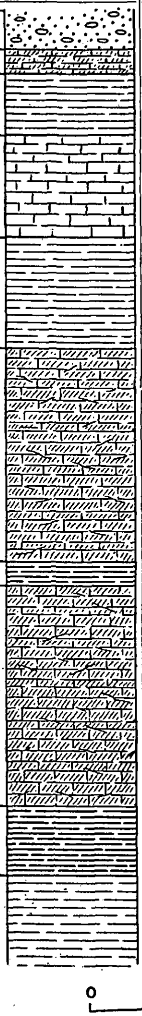
Representative samples of the different beds were taken in the places indicated in the section. From phosphate bed *d* the sample was taken at the surface, but from beds *f* and *h* the samples were taken at depths of 3 to 4 feet.

TYPE AND EXTENT OF DEPOSIT.

Rock phosphate of the type that has been found near Melrose was recognized as such in the western United States only in recent years, and the extensive fields exploited in southeastern Idaho and vicinity have been studied in some detail by the writer.[1] Thus the Montana

[1] Gale, H. S., and Richards, R. W., Phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: Bull. U. S. Geol. Survey No. 430, 1910, pp. 457-535.

deposits indicate a wider extension toward the north of this large field than has ordinarily been assumed. There can be little doubt as to the identity or correlation of these beds in Montana and in southern Idaho, western Wyoming, and Utah. The withdrawals made in the phosphate reserve of December, 1908, covered an area



Specimen.			Thickness.		P_2O_5.
			Ft.	*in.*	*Per cent.*
No. 1	*a*	Chert or vitreous quartzite	....		None.
No. 2	*b*	Brecciated phosphate rock		4	23
	c	Cream-colored argillite		11	
No. 3	*d*	Solid bed of phosphate rock	1	7	24.3
No. 4	*e*	Mottled reddish and cream-colored argillite	1	8	None.
No. 5	*f*	Brecciated phosphate containing veinlets of calcite	3	3	30.6
No. 6	*g*	Dark-colored argillite		4	.7
No. 7	*h*	Brecciated phosphate containing veinlets of calcite	3	4	29.8
	i	Dark-colored argillite	1		

FIGURE 50.—Section across phosphate deposit near Melrose, Mont. Specimens collected and section prepared by E. L. Jones, jr. Determinations of phosphate content by J. G. Fairchild.

extending from a point near the Yellowstone National Park on the north to the vicinity of Morgan, Utah, having a total length from north to south of about 200 miles. The Melrose phosphate deposits are about 160 miles northwest of the northernmost of these former withdrawals.

There is good reason to expect that workable phosphate deposits may be found in many places throughout western Montana or even farther north. The beds now considered workable in the fields of southeastern Idaho and vicinity range from 4½ to 6 feet or more in thickness, and the product now mined is very similar to the material found in the Montana beds.

UTILIZATION OF ROCK PHOSPHATE.

All the phosphate rock now shipped from the phosphate fields of the western United States is sent to the Pacific coast, where it is used in the manufacture of fertilizers. In this practice the rock is finely ground and mixed with sulphuric acid. Nearly equal parts by weight of acid and rock phosphate are used. This forms an acid calcium phosphate, which when dried and pulverized is the substance sold as superphosphate.

The superphosphate obtained by this process includes a considerable proportion of gypsum produced in the chemical reaction by which the superphosphate itself is formed. This gypsum dilutes the acid calcium phosphate in a mixture which can not readily be separated. Therefore these fertilizer products have a considerably lower percentage of phosphoric acid than the rock from which they are made. In the form of superphosphate, however, the phosphoric acid is more readily soluble in the weak acid soil solutions, and it appears to be more "available" as a plant food.

The experience of foreign countries whose soils have become exhausted by long-continued use shows the importance that will some day be attached to our own phosphate resources. For the present our phosphate fields will probably be developed in accordance with the increasing demand, and this growth must depend to a large extent on an intelligent understanding of the value and the proper methods of using such fertilizers.

PRICES OF PHOSPHATE.

The mining of rock phosphate in the western fields is controlled almost entirely by the concerns by whom it is manufactured and sold as fertilizer, so that quotations of market value of the raw rock at the mines are not readily available. Its value is usually estimated as the cost of mining plus that of transportation. The present freight rate to the Pacific coast is about $4 a ton. Similar high-grade rock in the eastern fields is sold at $4 to $5 a ton f. o. b. at the mine, as shown by the values reported.

Superphosphate is usually sold on a guaranty basis of so many per cent available phosphoric acid, recent quotations of wholesale prices showing this to be at a rate of about 60 to 65 cents a unit per cent of available phosphoric acid in both eastern and western markets.

MARKETS FOR PHOSPHATE.

The chief obstacle to the development of the western phosphate fields at the present time is the high cost of transportation of the bulky fertilizer products and the lack of markets sufficiently near to warrant their development. Much of the agricultural land of the Western States is relatively new, and as its original phosphates have not been exhausted by cropping it is less in need of fertilizers than the older farm lands of the East and South. The use of fertilizers is said to be fast increasing on the Pacific coast; also in some other parts of the West where intensive farming is practiced. There will henceforth probably be a rapidly growing market for fertilizer product in the Middle West, and it is to this territory also that the western phosphate producers must look for markets.

FAVORABLE SITUATION OF DEPOSITS IN WESTERN MONTANA.

One of the most important considerations in connection with the discovery of phosphate rock in western Montana is its significance as to the probable extent of the western phosphate fields, for it now appears probable that similar deposits may extend over a large part of western Montana. Their nearness to the large smelters where sulphide ores are reduced is important, for these smelters produce great quantities of sulphuric and sulphurous acid fumes,[1] which are usually allowed to go to waste through the smokestack of the plant. Investigation has shown the effect of these fumes to be detrimental to vegetation and injurious to animal life in the vicinity of the smelters.[2] In recent years efforts have been made to compel the smelter companies to condense or otherwise dispose of the acid fumes, and a number of suits against the companies have been brought in different parts of the United States by the Department of Justice and by local authorities.

Reduction of phosphate rock by means of sulphuric acid appears to offer what is perhaps the largest commercial use for these waste products of the smelters.

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[1] These fumes are reported in certain studies of the smelter smoke at Anaconda, Mont., to average 4,636,000 pounds of SO_2 and 447,600 pounds of SO_3, equivalent to about 3,800 tons of sulphuric acid daily. See Harkins, W. D., and Swain, R. E., The determination of arsenic and other solid constituents of smelter smoke: Jour. Am. Chem. Soc., vol. 29, No. 7, July, 1907, pp. 970–998.

[2] Haywood, J. K., Injury to vegetation by smelter fumes. U. S. Dept. Agr., Bur. Chem. Bull. 89, 1905; Injury to vegetation and animal life by smelter wastes: Idem, Bull. 113, 1908. Formad, R. J., The effect of smelter fumes upon the live-stock industry in the Northwest: Idem, Twenty-fifth Ann. Rept., 1908, pp. 237–268.

SUGGESTED MANUFACTURE OF HIGH-GRADE SUPERPHOSPHATES.

Available supplies of rock phosphate and by-product sulphuric acid in close proximity suggest a strong inducement for the manufacture of high-grade or "double" superphosphates, whose relatively greater value may permit their transportation to distant markets. The subject has been discussed by Wyatt,[1] from whose book the following abstracts are made in order that these processes may be carefully considered in their bearing on the utilization of the Montana deposits.

It is stated in this work that the average superphosphate manufactured in this country contains about 13 to 14 per cent of "available" phosphoric acid, but the rapid development of the industry in the last few years (before 1891) has led to the introduction of what are known as "high-grade supers," containing about 45 per cent of phosphoric acid in a "water" and "citrate" soluble form. The manufacture of this product consists essentially of two steps, the first being the preparation of a commercial grade of free phosphoric acid and the second involving the use of this phosphoric acid as the solvent for more raw phosphate rock.

The theory of the process is described in the following chemical reaction:

$$Ca_3(PO_4)_2+3(H_2SO_4)=3(CaSO_4)+2(H_3PO_4).$$

The further treatment of raw phosphate rock with the commercial phosphoric acid is described as resulting in the following reactions, in which both the acid or "water soluble" and the neutral or "citrate soluble" calcium phosphates are produced:

$$Ca_3(PO_4)_2+4(H_3PO_4)+6(H_2O)=3[CaH_4(PO_4)_2(H_2O)_2]$$

$$2Ca_3(PO_4)_2+2(H_3PO_4)+12(H_2O)=3[Ca_2H_2(PO_4)_2(H_2O)_4].$$

The following estimates are quoted from Wyatt for the purpose of suggesting more directly important economies that may be effected by the special conditions afforded in the Montana smelter regions:

Estimated cost of preparing phosphoric acid.

[By Francis Wyatt.]

1 ton (2,000 pounds) of mineral phosphate, containing 50 to 60 per cent phosphate of lime	$4.00
Grinding same to 70 or 80 mesh	1.50
2,130 pounds chamber sulphuric acid of 50° B., at, say, $7 a ton	7.50
Labor of mixing and filtering, wear and tear, etc., calculated at the rate of, say, $1 a gross ton of raw material handled	2.00
Concentration, labor, wear and tear of plant, calculated at $1 a gross ton of raw material	2.00
Total net cost of producing, say, 1,000 pounds of 45° B. phosphoric acid	17.00
Cost of 45° B. phosphoric acid per ton of 2,000 pounds	34.00

[1] Wyatt, Francis, Phosphates of America, where and how they occur; how they are mined; and what they cost. Scientific Pub. Co., New York, 1891, ch. 7, pp. 106–137.

Passing now to the manufacture of high-grade superphosphate by decomposing the mineral phosphates with this acid instead of with chamber sulphuric acid, we shall find that it works out thus:

Estimated cost of preparing high-grade superphosphate.

[By Francis Wyatt.]

1 ton of mineral phosphate, containing 75 to 80 per cent tribasic phosphate and of about the general composition shown in the examples selected for former calculations	$14.50
Grinding same to 70 or 80 mesh	1.50
1 ton phosphoric acid of 45° B	34.00
Cost of mixing, manipulating, drying, pulverizing, and bagging the finished material, calculated at $2 a ton of material used	5.00
	55.00

The net product of the mixture, after allowing 15 per cent for loss by evaporation and in manufacture, will be, say, 3,400 pounds. It will contain 1,530 pounds of phosphoric anhydride (P_2O_5) and will cost $55. Its cost ready for market and containing 45 per cent of mixed water-soluble and citrate-soluble phosphoric anhydride will therefore be $32.50 a ton.

The practical operator will probably foresee the application of such a process to the use of smelter by-product acid under present industrial conditions. The economies are in part suggested in the following notes:

Mills developed within the last 8 or 10 years have greatly decreased the cost of grinding. Those used in cement manufacture are said to be handling similar material at 25 cents a ton and less.

The estimate above given is for chamber acid manufactured expressly for this purpose from sulphur or pyrite and did not contemplate the use of by-product acid.

Labor will probably cost more than Wyatt estimated, but this factor may be offset by increased efficiency of equipment used in these processes.

A most important consideration is that the cost of the high-grade rock used in the second step of the process (the preparation of superphosphate) need be reckoned at no more than the cost of mining, as in the case of the material used at the start. This item may therefore be reduced from $14.50 a ton to perhaps $4 or less.

Three tons or more of the ordinary superphosphate would be required to equal a ton of the concentrated or high-grade material described above. The latter contains, according to Wyatt, the equivalent of 99 per cent of bone phosphate of lime, or 45 per cent of phosphoric acid, made practically as soluble and equally available, and is therefore especially adapted to the requirements of the middleman. The distributer would pay freight on 1 ton where he now pays it on 3, and could, if he so desired, dilute it to the ordinary commercial strength by the addition of gypsum or any other convenient and low-priced filler.

STATUS OF LANDS.

These deposits of rock phosphate are situated on public lands that have now been withdrawn from entry. The withdrawal of the phosphate lands in Montana officially known as "Phosphate reserve No. 7" was made by an order of the President dated January 12, 1911, and is based on a recommendation submitted by the Director of the Geological Survey. The lands thus withdrawn include about 33,950 acres in Tps. 4 and 5 S., R. 8 W., and Tps. 1 and 2 S., Rs. 9 and 10 W., Montana, which are to be reserved for classification and to await legislative action.

In the mining law at present there appears to be no adequate provision for the disposal of phosphate lands, and it is presumed that Congress will in the near future pass some well-considered measure to cover this need.

A RECONNAISSANCE OF THE PHOSPHATE DEPOSITS IN WESTERN WYOMING.

By Eliot Blackwelder.

INTRODUCTION.

Workable deposits of rock phosphate have been known for some years in northern Utah, southeastern Idaho, and the adjacent part of Wyoming, but the limits of the field are even now imperfectly deter-

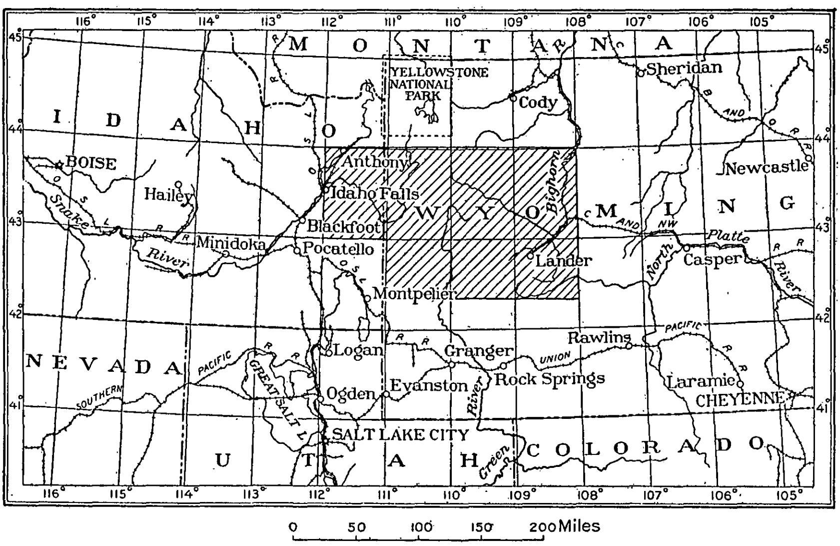
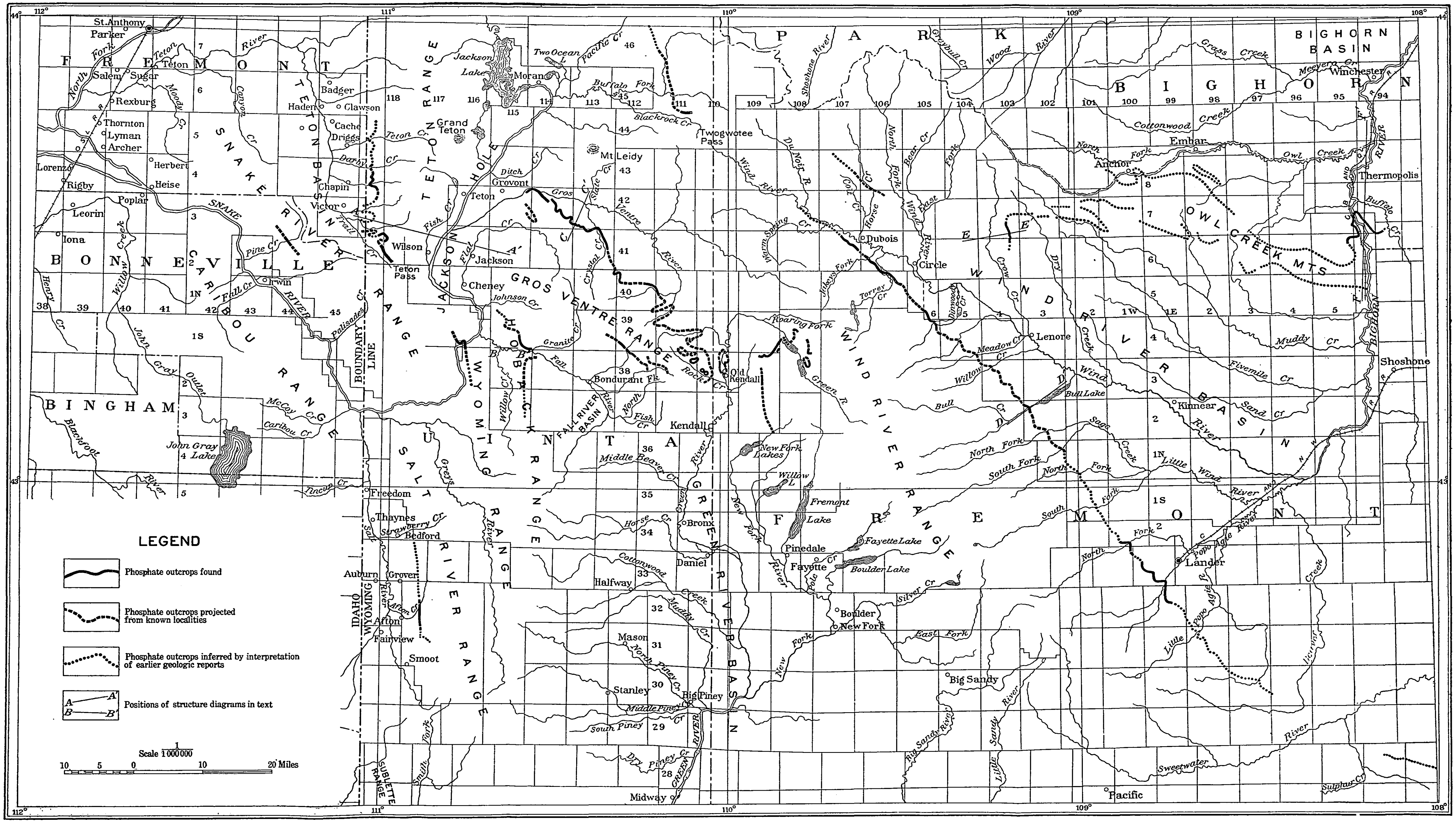


Figure 51.—Index map showing area in western Wyoming containing phosphate deposits.

mined. During the last year or two the existence of rock phosphate has been reported from a number of widely separated localities in Utah, Nevada, Idaho, and Wyoming. For the purpose of ascertaining the limits of this field on the northeast and east, and of finding how the phosphate deposits change from place to place within that region, a party in charge of the writer made a reconnaissance trip through the mountains of western Wyoming from Montpelier, Idaho, northeast and then southeast to Lander, and finally to Thermopolis, Wyo. (See fig. 51 and Pl. XVII.) C. L. Breger was assigned to the party as assistant, and J. M. Jessup and C. W. Tomlinson aided in the collection of fossils and in other ways.


LEGEND
Phosphate outcrops found
Phosphate outcrops projected from known localities
Phosphate outcrops inferred by interpretation of earlier geologic reports
Positions of structure diagrams in text
Scale 1/1000000
10 5 0 10 20 Miles
112°
111°
110°
109°
108°
44°
43°
FREMONT
BONNEVILLE
BINGHAM
CARIBOU RANGE
SNAKE RIVER
TETON BASIN
TETON RANGE
JACKSON HOLE
GROS VENTRE RANGE
WYOMING RANGE
HOBACK RANGE
SALT RIVER RANGE
FALL RIVER BASIN
UINTA
GREEN RIVER BASIN
WIND RIVER RANGE
WIND RIVER BASIN
OWL CREEK MTS
PARK
BIGHORN
BIGHORN BASIN
IDAHO
WYOMING
BOUNDARY LINE
SUBLETTE RANGE
St.Anthony
Parker
Salem
Sugar
Teton
Rexburg
Thornton
Lyman
Archer
Herbert
Heise
Lorenzo
Rigby
Poplar
Leorin
Iona
Irwin
Badger
Haden
Clawson
Cache
Driggs
Chapin
Victor
Wilson
Teton Pass
Jackson
Cheney
Grand Teton
Teton
Grovont
Moran
Jackson Lake
Two Ocean L
Mt Leidy
Twogwotee Pass
Dubois
Circle
Lenore
Bull Lake
Kinnear
Shoshone
Thermopolis
Embar
Anchor
Winchester
Lander
Bondurant
Old Kendall
Kendall
New Fork Lakes
Willow L
Fremont Lake
Fayette Lake
Boulder Lake
Pinedale
Fayette
Boulder
New Fork
Big Sandy
Pacific
Bronx
Daniel
Halfway
Mason
Stanley
Big Piney
Midway
Freedom
Thaynes
Bedford
Auburn
Grover
Afton
Fairview
Smoot
John Gray Lake
OUTLINE MAP OF A PORTION OF WESTERN WYOMING AND ADJACENT PART OF IDAHO.

In accordance with the purpose of the expedition, detailed mapping was not attempted except in a few localities where it could be done without the loss of time. The distribution of the phosphate outcrops was mapped where opportunities permitted and attention was devoted especially to the phosphatic formation—the variations in its thickness, character, richness, and associations. Much information about geologic matters not directly connected with the phosphate deposits—such as structure, stratigraphy, and physiography—was obtained by the party. The more important of these results will be published in the near future in a bulletin of the United States Geological Survey and elsewhere. In the present paper the existing classifications of the different regions will be used, questions of age determination and correlations being left for discussion in the stratigraphic papers which are to follow.

GEOGRAPHY.

ITINERARY.

The party moved by rapid stages from the railway at Montpelier, Idaho, northeast across the Preuss Mountains to Afton, Wyo.; northward along the Salt River valley to Snake River near the State boundary; thence down the Snake to Irwin, Idaho; and across the Snake River Range to Victor, Idaho, in the Teton Basin. Up to this point only cursory observations were made along the route, but on the west side of the Teton Range several days were spent in more systematic geologic work. A similar study was then made of the mountains south and east of Jackson Hole, including the canyon of Snake River in Wyoming, a part of the Hoback Range, and nearly all of the Gros Ventre Range, together with the valley of Buffalo Fork of Snake River farther to the northeast. The remainder of the season was devoted to a somewhat more detailed study of the Wind River Mountains. Of these the north side was reconnoitered from Union Pass to Lander and the southwest side around the headwaters of Green River. At the very end of the season a short trip enabled the writer to examine the canyon of Bighorn River south of Thermopolis, Wyo. Two other side trips to the north side of the Wind River Basin were made by Mr. Breger and the writer.

TOPOGRAPHY AND SETTLEMENT.

With the exception of the eastern part of the Wind River Basin, this region is one of rugged, well-forested mountains. On the west side of the district the ranges trend nearly north and south, but in the central and eastern portions they run northwest and southeast. The ranges are generally separated by narrow valleys, but a few of the intervening spaces are wide, flat-bottomed basins, such as Teton Basin in Idaho, Jackson Hole in western Wyoming, and the upper valleys of Wind River and Green River, farther east. These larger valleys are now fairly well settled with ranchmen, but elsewhere in the district there are few inhabitants and no settlements of importance. The spur of the Chicago & Northwestern Railway which reaches Lander from the east and the Burlington line through Thermopolis are the only railroads in the entire district. A few principal wagon roads serve to give communication between different parts of the region, but there are many valleys of considerable size which are as yet impassable for wagons. The region is, however, a celebrated game country, and therefore trails for pack trains are maintained throughout the mountains, especially in the vicinity of Jackson Hole. In recent years the United States Forest Service has built some excellent roads and many trails in that portion of the region included in the national forests.

GENERAL GEOLOGY.

PREVIOUS REPORTS ON THE DISTRICT.

There is but one comprehensive treatise on the geology of the region covered by the reconnaissance of 1910, namely, that of Orestes H. St. John, of the Hayden Survey.[1] Considering the conditions under which they were made, the maps in this report are remarkably accurate; and in the text the vivid descriptions of the formations and localities constitute a mine of useful information on the geology of the northern part of the Rocky Mountains.

More recently the sedimentary formations which underlie the area described in the present paper have been studied in adjacent districts by Darton, Veatch, Gale, Boutwell, and others. (See list below.)

In central western Wyoming, however, the same formations have received but little attention in late years. Darton [2] and Woodruff [3] have examined the Owl Creek Mountains and also the south side of the Wind River Basin near Lander. Other publications bearing on this and related districts will be found noted in the selected bibliographic list below:

Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: Bull. U. S. Geol. Survey No. 430, 1910, pp. 536–551.

Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434–458.

Darton, N. H., Geology of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51, 1906.

——— Fish remains in Ordovician rocks in the Bighorn Mountains, Wyoming, with a résumé of Ordovician geology of the Northwest: Bull. Geol. Soc. America, vol. 17, 1906, pp. 541–566.

——— Paleozoic and Mesozoic of central Wyoming: Bull. Geol. Soc. America, vol. 19, 1908, pp. 403–470.

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[1] Twelfth Ann. Rept. U. S. Geol. and Geog. Survey Terr., pt. 1, 1878, pp. 173-270.

[2] Darton, N. H., Geology of the Owl Creek Mountains: Senate Doc. 219, 59th Cong., 1st sess., 1906.

[3] Woodruff, E. G., The Lander oil field: Bull. U. S. Geol. Survey No. 452, 1911, pp. 7-36.

Eldridge, G. H., A geological reconnaissance in northwest Wyoming: Bull. U. S. Geol. Survey No. 119, 1894.

Endlich, F. M., Report on the geology of the Sweetwater district: Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1877, pp. 5–158.

Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: Bull. U. S. Geol. Survey No. 430, 1910, pp. 457–535.

Hague, Arnold, Iddings, J. P., and others, Geology of the Yellowstone National Park: Mon. U. S. Geol. Survey, vol. 32, pt. 2, 1899.

Hague, Arnold, Weed, W. H., and Iddings, J. P., Yellowstone National Park folio (No. 30), Geol. Atlas U. S., U. S. Geol. Survey, 1896.

St. John, Orestes H., Report on the geology of the Wind River district: Twelfth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1878, pp. 173–273.

Schultz, A. R., Coal fields in a portion of central Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 316, 1906, pp. 212–241.

Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907.

Weeks, F. B., Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 340, 1907, pp. 441–447.

Weeks, F. B., and Ferrier, W. F., Phosphate deposits in western United States: Bull. U. S. Geol. Survey No. 315, 1906, pp. 449–462.

Woodruff, E. G., The Lander coal field, Wyoming: Bull. U. S. Geol. Survey No. 316, 1907, pp. 242–243.

Woodruff, E. G., and Wegemann, C. H., The Lander and Salt Creek oil fields, Wyoming: Bull. U. S. Geol. Survey No. 452, 1911.

GEOLOGIC FORMATIONS.

The formations in this region represent nearly all the geologic periods from Archean to Quaternary. The accompanying comparative sections will serve to show something of the variations in different parts of the district. In general, the formations are thicker near the Idaho-Wyoming boundary than farther east, and the gaps in the sequence are more numerous in the eastern region. For comparison, sections from three widely separated districts are given below.

Formations in the northwestern part of Yellowstone Park.[1]

	Feet.
Cretaceous:	
Dakota sandstone—sandstone and conglomerate	150
Jurassic:	
Ellis formation—soft gray and green shales with beds of oolitic limestone containing abundant marine fossils. Massive sandstone at the top	550–600
Triassic (?) and Carboniferous (?):	
Teton formation—buff to reddish sandstone and shale resting upon bedded dark limestone with beds of chert containing tubular concretions[2]	270–300

[1] Slightly modified after Hague, Arnold, Iddings, J. P., and others, Geology of the Yellowstone National Park: Mon. U. S. Geol. Survey, vol. 32, pt. 2, 1899.

[2] The lower part of the Teton formation is believed to be equivalent to the Embar formation of north-central Wyoming.

Carboniferous:	
Pennsylvanian:	Feet.
Quadrant quartzite—white quartzite and sandstone with beds of limestone	325
Mississippian:	
Madison limestone—brown to gray fossiliferous limestone	1,300
Devonian:	
Threeforks limestone—dark-brown limestone with thin sandy beds	170
Jefferson limestone—hard gray to yellowish limestone resting upon dense cream-colored to white dolomite	110
Cambrian:	
Gallatin limestone—mottled gray limestone with sandstone, limestone conglomerate, and beds of green shale	110
"Flathead formation"—thin-bedded gray or mottled limestone with several important beds of green shale in the upper part and quartzite with conglomerate (Flathead quartzite) at the base	750
Unconformity.	
Archean:	
Gneiss.	

Formations in southeastern Idaho.[1]

Tertiary.	
Unconformity.	
Cretaceous:	
Bear River formation—dark shale, sandstone, conglomerate, and some limestone. Contains beds of impure coal	(?)
Jurassic and Cretaceous:	
Beckwith formation—coarse conglomerate, white to yellowish calcareous sandstone, and sandy shale	(?)
Jurassic:	
Twin Creek limestone—mainly limestone, mostly thin bedded or shaly, with some massive strata	3,500
Jurassic or Triassic:	
Nugget sandstone—massive red and white sandstone and red sandy shale. In places an upper zone is distinct as a clear white sandstone	1,900
Triassic or Carboniferous:	
Ankareh shale—essentially red shale and mottled red and greenish clay and shale, with some sandstone and limestone	670
Thaynes limestone—mainly dark-blue fossiliferous limestone, weathering to a brown color, also including sandy and calcareous shale	2,000
Woodside shale—chiefly shales; generally red in the upper part, with the base composed of shaly limestone, weathering rusty brown	1,000

[1] Slightly modified, after Gale, H. S., and Richards, R. W., Bull. U. S. Geol. Survey No. 430, 1910, p. 470.

	Feet.
Carboniferous:	
Pennsylvanian:	
Park City formation—(*a*) one or more massive strata of cherty limestone, prominent as a ledge maker; (*b*) rock phosphate, phosphatic shale, and minor limestone bands; (*c*) limestone, massive, usually light bluish, in some localities containing abundant black chert in rounded nodules	±600
Weber quartzite—massive white quartzite, locally rather calcareous, with minor limestone beds and sandy shale forming transition zones near the top and base	±1,000
Mississippian ("Wasatch limestone" of King, in part):	
Limestone with an upper Mississippian fauna Madison limestone—thick massive blue limestone locally marked by fossil corals	3,000+

Formations in the Owl Creek Mountains, Wyoming.[1]

Upper Cretaceous (and Eocene?):	
Laramie (?) formation—gray sandstones and carbonaceous shales, with lignite deposits	2,250+
Upper Cretaceous:	
Fox Hills sandstone (?)—soft massive buff sandstone, with harder, darker concretions	225
Pierre shale—dark-gray shale with concretions	1,000–2,600
Colorado formation—gray shales, thin brown sandstones below; hard fine gray sandstones (Mowry beds) in middle; concretions with *Prinocyclus*, etc., and massive buff sandstone near top	1,000–1,300
Upper and Lower Cretaceous:	
Cloverly formation—coarse massive buff sandstone below; purplish and gray shale and some sandstone above	125
Lower Cretaceous (?):	
Morrison formation—massive shale, greenish gray, buff, and maroon, with thin sandstones	200
Jurassic:	
Sundance formation—soft sandstones, overlain by greenish-gray shales; several hard fossiliferous layers near top and bottom	200
Triassic (?) and Permian:	
Chugwater formation—red shale and soft sandstone; thin limestone layers near top and bottom, and gypsum deposits near top	800
Carboniferous:	
Pennsylvanian:	
Embar formation—gray limestone and shale with cherty beds	250
Tensleep sandstone—massive buff to gray sandstone	200

[1] Darton, N. H., Geology of the Owl Creek Mountains: Senate Doc. 219, 59th Cong., 1st sess., 1906, p. 12.

Carboniferous—Continued.	
Pennsylvanian and Mississippian (?):	Feet.
Amsden formation—red shales at base, overlain by fine-grained white limestone; sandstones and cherty limestone near top	250
Madison limestone—light-colored limestone, very massive near top	550
Ordovician:	
Bighorn limestone—hard massive limestone, with irregular streaks of silica	40–150
Middle Cambrian:	
Deadwood formation:	
Slabby limestones with flat-pebble limestone conglomerates	0–100
Green shale with limestone member near base	400–500
Sandy shales with sandstone member near base	200–300
Massive brown sandstone	50–100
Archean or Algonkian:	
Gray and red granite of several kinds, penetrated by diabase and other dikes.	

The formations which it is especially important to know in mapping the phosphate deposits are those of Carboniferous to Triassic age. One of the most conspicuous formations in the region is the Madison limestone (Mississippian), which is found throughout the district and is as a rule easily recognized by characteristic fossils. It is darker, thicker, and more richly fossiliferous on the west, and lighter colored, somewhat thinner, and poorer in fossils in the Wind River Range and northeastward.

Above this limestone is a sandy series, which is somewhat variable in different parts of the region. The larger part of it comprises the Weber quartzite in southeastern Idaho and Utah and the Tensleep sandstone in central Wyoming. Its basal portion generally contains beds of red shale and purple or gray limestone, and where thus developed in Utah has been called the Morgan formation, while in eastern and north-central Wyoming Darton has named the corresponding beds the Amsden formation. The upper and larger part of the sandy series is generally a massive yellowish or cream-colored sandstone (Tensleep) in the east, or a quartzite (Weber) in the southwest. On account of their resistance to erosion the outcrops of the Weber, Tensleep, and equivalent rocks are almost invariably marked by ridges or peaks, and in canyons by cliffs.

Several hundred feet above the top of the sandstone or quartzite lies the bright red series of shaly sandstone and sandy shale with gypsum beds which in north-central Wyoming is called the Chugwater formation and in southeastern Idaho is probably represented by the Nugget sandstone and Ankareh shale of Boutwell, Gale, and others. These formations have been classified as Triassic (?)—the "Juratrias" red beds of the Hayden Survey.

Between these two conspicuous horizon markers, the yellow sandstone below and the red shales above, lie the less resistant strata which include the phosphate beds. In north-central Wyoming, where these strata are relatively thin, Darton has named them the Embar formation. These beds increase in thickness and change considerably in character in passing westward to the Hoback and Salt River ranges, and there they may be divided into several formations, corresponding probably to those recognized by Gale in southeastern Idaho and Utah, namely, the phosphatic Park City formation below, the Woodside shale in the middle, and the Thaynes limestone at the top. As not all parts of these strata are fossiliferous, the exact equivalence of the divisions in the eastern and western sections has not been established, but it seems to be approximately as stated. The phosphate beds lie near the base of the Embar formation to the east and the Park City formation to the west and are associated with dark shale and fossiliferous limestone. In the Gros Ventre Range the limestone above the phosphate beds is largely replaced by chert and fossils are very scarce.

The individual beds of phosphate rock are subject to much variation in character and richness. In the western sections they are generally considerably thicker than in the east and northeast. The richest variety of phosphate rock is commonly a black oolitic material—firm but not particularly hard. When broken it emits a disagreeable odor of petroleum. From this richer variety there are all gradations, through hard phosphatic limestone and soft phosphatic shale and sandstone down to beds that contain but little phosphoric acid.

In the canyon of Snake River in western Wyoming the total thickness of phosphatic beds, both rich and lean, exceeds 40 feet. Of this about 29 feet contains more than 30 per cent of tricalcium phosphate, and some beds exceed 70 per cent.

On the north side of the Wind River Range the phosphate beds have dwindled to 3 or 4 feet in thickness and consist largely of gray phosphatic sandstone, which contains only 35 to 45 per cent of tricalcium phosphate. Across the Wind River valley, in the Shoshone and Owl Creek mountains, the deterioration of the phosphate deposits is still more marked, for there the beds are but 2 to 4 feet thick and generally contain less than 20 per cent of tricalcium phosphate. It will be noted that even the best phosphate deposits thus far discovered in Wyoming are inferior to the better-known beds in Idaho and Utah.

From the work of other geologists in Wyoming it is believed that phosphate deposits exceeding a few inches in thickness do not occur much north of the Owl Creek Mountains, northeast of the southern part of the Bighorn Range, nor east of the low ranges between Casper and Lander. There is no information as to the southward extension of the material, but it has never been recognized south of the Wind River Range in Wyoming. It is highly probable, however, that lean phosphate beds of some importance stretch north by west across Yellowstone Park into southern Montana, where H. S. Gale in 1910 discovered a deposit of considerable promise. (See pp. 440–451.)

STRUCTURE.

The rocks associated with the phosphate deposits are all folded. In general the folding is mild on the east but is much more intense and accompanied by more faulting farther west. The Owl Creek, Wind River, and Gros Ventre ranges are in general broad anticlines somewhat complicated by faults, among which overthrusts are prominent. In the Hoback, Wyoming, Salt River, and Snake River ranges near the Idaho boundary the rocks are closely folded and apparently considerably faulted, so that in many places the strata stand on end. The Teton Range constitutes an exception among these western mountain units, for it appears to be a fault block upon which the little-disturbed Paleozoic rocks dip gently westward.

Between the ranges in central Wyoming, and to some extent farther west, there are wide basins floored with nearly horizontal Tertiary or later sediments. These beds lie indiscriminately across the beveled edges of the folded Mesozoic and older rocks and are themselves almost horizontal.

DEVELOPMENT OF PHOSPHATE DEPOSITS.

In contrast to the Bear Lake region in Idaho and Utah, the region described in this report has received practically no attention from prospectors in search of phosphate rock. Throughout the district the very existence of phosphate deposits seemed to be unknown to the inhabitants. At the mouth of Coal Creek, near Teton Pass, there is a small excavation in the phosphate beds. (See pp. 463–464.) This tunnel, dug more than 15 years ago, was made, however, on the supposition that the black material was coal. Its real nature apparently remained unknown.

DESCRIPTION OF PHOSPHATE DEPOSITS BY DISTRICTS.

SALT RIVER RANGE, WYOMING.

Only a most cursory examination was made of the Salt River Range. Mr. Breger explored the canyon east of Afton and found that the rocks are strongly folded, although not broken by noteworthy faults. On the west slope of the mountains the succession is overturned, so that the beds dip into the mountain and quartzite (Weber ?) rests upon the phosphatic series (Park City formation ?), which is much like that in the Preuss Range farther west, described by Gale and Richards.[1]

[1] Gale, H. S., and Richards, R. W., Bull. U. S. Geol. Survey No. 430, 1910, pp. 483–488.

Although exposures at that point are imperfect, Mr. Breger was able to recognize at the base about 42 feet of gray limestone, overlain by 40 to 78 feet of soft shaly beds, including phosphate rock, overlain in turn by more than 100 feet of massive to thin-bedded chert. It is believed that there are two phosphate beds in the shaly strata here—the lower one at the base, and the upper one about 40 feet above the base. The thickness of either phosphate bed is still unknown, but pieces of the float from the upper bed, consisting of massive black oolite, yield on analysis 67.4 per cent of tricalcium phosphate.

Inasmuch as the Paleozoic formations run nearly parallel to the range, it is probable that phosphate deposits are found generally along the Salt River Mountains, usually well up toward the crest; and there is some reason to believe that they are not subject to great variations in richness along the outcrop.

SNAKE RIVER RANGE, IDAHO.

The Snake River Range, which is structurally a joint continuation of the Wyoming and Salt River mountains of western Wyoming, lies northeast of Snake River in Idaho. The geology of the range is complex and as yet little known. The rocks are all highly folded and are broken by important faults, the exact positions of which have not been ascertained. The southwest slope seems to consist largely of Paleozoic limestone; the northeast slope is underlain generally by sandy coal-bearing beds, doubtless Cretaceous. In the central part of the range the phosphate series is exposed as a band trending approximately N. 50° W., with the range itself. It was observed in the valley of Pine Creek, 6 or 7 miles north of Irwin post office. Exposures at that point are very poor, but it was possible to recognize a gray quartzite (Weber ?) overlain by gray limestone and about 75 feet of phosphatic shale. A sample of the shale gives on analysis 36.8 per cent of tricalcium phosphate. The expected beds of rich oolitic phosphate rock were not found, but may well be present, although concealed by wash, soil, and turf at the point examined. The phosphatic shale is overlain by the fossiliferous limestone and massive chert beds generally associated in this region with the phosphate beds. On the whole, the general constitution of the phosphatic series (Park City formation ?) in the Pine Creek section is so similar to that in the Preuss Range that it is safe to expect that phosphate deposits of notable value will be found in the Snake River Range when it is adequately explored.

SNAKE RIVER CANYON.

Where Snake River cuts through the mountains in the deep canyon south of Jackson Hole and thus separates the Snake River Range from the Wyoming Mountains, there is an unusually clear exposure of the phosphate beds in the river bluff just opposite the ranch of J. C. Counts, about 3 miles below the mouth of Fall River. The accompanying detailed section shows a greater thickness of phosphatic beds than was observed anywhere else within the district of this survey and compares favorably with the better-known deposits of eastern Idaho. The richer phosphatic beds alternate with black phosphatic shale and limestone containing varying quantities of tricalcium phosphate. The upper portion of the phosphatic series (Park City formation?) is not well exposed there, but it clearly consists in part of massive bedded chert and some quartzite, with another thin bed of hard cherty phosphate rock 1 foot thick, which contains about 23 per cent of tricalcium phosphate. This is succeeded by shaly and calcareous beds which resemble lithologically the Woodside, Thaynes, and Ankareh formations of southeastern Idaho and contain similar fossils, but are very much thinner.

At the Counts ranch locality the phosphate-bearing formation is closely folded and broken by one or more faults; the folds pitch rather steeply northwestward.

Section of phosphatic beds in the northwest bank of Snake River opposite Counts Warm Springs.

	Ft.	in.
Top overlain unconformably by Tertiary conglomerate.		
Shale and limestone, gray-buff to brown, with thin black phosphatic seams here and there	20	
Phosphate rock, brown and nodular (21.2 per cent tricalcium phosphate)	2	6
Phosphate rock, black, soft, and shaly (random sample, 68.5 per cent tricalcium phosphate)	9	
Chert, dark gray	12	
Shale, black and probably phosphatic	4	
Chert and seams of limestone, passing gradually upward into cherty limestone with black shale partings	33	
Limestone, earthy buff to gray, with black chert nodules	20	
Sandstone, soft and white, with thin beds of gray chert	26	
Sandstone, fine, white, and very soft	6	
Limestone, pearl-gray, argillaceous	22	
Phosphate rock, black and oolitic		2½
Chert, massive, gray	6	
Alternating thin beds of soft oolitic phosphate rock and hard black limestone (probably about 20 per cent tricalcium phosphate)	5	10
Massive brown phosphate rock (66.3 per cent tricalcium phosphate)	2	5
Brittle black limestone	1	
Phosphate rock, soft, black, granular (20 to 30 per cent phosphate)	3	
Limestone, brittle, black	2	6
Phosphate rock, soft and shaly (29.6 per cent phosphate)	4	6
Limestone, brittle, black	2	

	Ft.	In.
Phosphate, black, shaly, and granular, with lenses of black limestone (average of entire bed, 20.3 per cent tricalcium phosphate)	12	
Limestone, brittle, black	1	3½
Phosphate rock, soft, shaly, and granular with lenses of black limestone (average of entire bed, 31.2 per cent tricalcium phosphate)	12	
Limestone, hard, dark, gray	9	
Sandstone, soft, argillaceous, gray	8	
Shale and limestone, smoky gray to buff	22	
Quartzite (Weber?), white to buff	47	

TETON RANGE, IDAHO-WYOMING.

The Teton Range (fig. 52) is one of the most imposing in the Rocky Mountain region. It rises with a singularly abrupt slope from the west side of Jackson Hole, culminating in the ragged lofty peaks of Grand Teton and Mount Moran. On the west it slopes off more gently to the broad Teton Basin in Idaho. Along the east slope the rocks seem to be very largely ancient gneiss and schist, intruded by veins of pegmatite and large basic dikes. On the west slope Paleo-

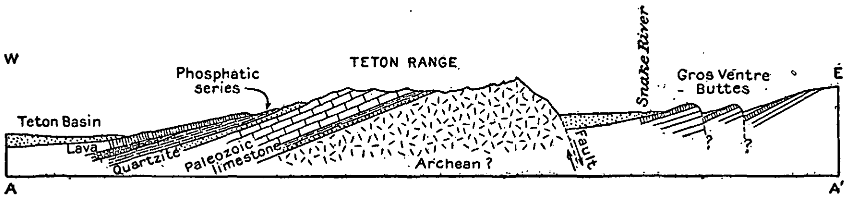

FIGURE 52.—Diagrammatic structure section of the Teton Range and vicinity. (See Pl. XVII.)

zoic rocks overlie the Archean and dip gently westward. Near the south end of the range the Paleozoic beds are somewhat folded, with axial lines trending west by north; but farther north these minor folds seem to disappear.

The phosphatic series is poorly exposed on this slope—partly because it has been very generally removed by erosion, thus leaving only the Mississippian limestone and older beds on the surface, and partly because along the lower slopes of the range it is now covered by gently inclined sheets of Tertiary lava. Near the south end of the Teton Range, where this range articulates with the highly folded Snake River Range, the phosphatic series is pinched down in the several sharp synclines above mentioned, and farther north it appears locally along the western foothills. On account of the dearth of exposures, no satisfactory section of the series in this region was obtained in the brief reconnaissance made in 1910. It is evident, however, that it is much thinner here than along Snake River, farther south.

Just west of Teton Pass, near the mouth of Coal Creek canyon, an old prospect dump shows a soft black material which proved to be phosphate rock. The tunnel was dug 15 or 20 years ago, on the supposition that the black material was coal; but it is now so badly caved in that it can not be explored. The phosphate bed appears to be several feet thick and consists of soft black oolitic to earthy phosphate rock. The oolitic variety yields 52.2 per cent of tricalcium phosphate and a general sample of all the material on the dump shows 20.8 per cent.

Such samples and analyses, although the best at hand, can hardly be considered truly indicative of the character of the material in the undisturbed bed. At this point the phosphate bed stands in vertical attitude and rests against a massive bed of gray chert several feet thick. The red beds outcrop above and the Madison limestone below at a distance of several hundred feet, but the other familiar formations which generally intervene are largely covered and were not definitely recognized.

In the canyon of Darby Creek, between Driggs and Victor, the phosphatic series is almost the youngest Paleozoic formation exposed. It appears to be scarcely more than 100 feet thick and consists of cross-bedded brownish-gray sandstone resting upon a thin shaly series in which there is more or less gray limestone and bedded chert. Immediately above the principal chert band there is evidently a thin bed of phosphate rock, but all the outcrops are so covered with soil that the beds could not be seen at any point. Abundant pieces of weathered phosphate rock strewn along this outcrop show on analysis 78.3 per cent of calcium phosphate. Although this weathered material should be slightly richer than the unaltered portion of the bed, it clearly indicates a rich deposit of phosphate rock. It is the writer's belief, however, that this bed can not be more than 3 or 4 feet in thickness in this locality and may be much less.

Beneath the phosphatic series lies a quartzite, which appears to be highly variable from point to point along the Teton Range. Near the mouth of Darby Creek it consists of alternating soft reddish and yellowish sandy beds, with cream-colored sandstone and limestone near the middle, the whole being less than 200 feet thick. On Coal Creek, near the south end of the range, the body of the formation is buff quartzitic sandstone with beds of gray dolomite near the base.

How far northward along the Teton Range the phosphate beds extend is not yet known, but there is reason to expect that they dwindle rather than increase in the direction of Yellowstone Park.

HOBACK RANGE, WYOMING.

The Hoback Range (fig. 53) is a parallel offshoot from the eastern flank of the Wyoming Range. Like that range, it bends around to the northwest near Jackson Hole. Fall River cuts through it in a deep canyon, but otherwise it is a continuous ridge.

The range consists of Paleozoic and Mesozoic rocks, all closely folded and broken by one or more important faults. Sections examined in the canyons of the north fork of Willow Creek and Fall River show that, even in the short distance between the Hoback and Wyoming ranges, there have been important changes in the character of the strata. The white to cream-colored quartzite with dolomite beds appears to have a thickness of about 1,000 feet, with 600 to 700 feet of shaly beds beneath. Upon this quartzite rests, apparently with a very obscure unconformity, the phosphatic series, here reduced to a thickness of 250 feet and therefore considerably thinner than in southeastern Idaho but thicker than in the Teton Range to the northwest.

The phosphate beds are exposed in the upper slopes of the range in peak after peak as far south, at least, as Hoback Mountain. Northwestward they run along the west slope of the range for several miles, at least beyond the canyon of Johnson Creek. Apparently they may extend even as far as the village of Jackson. As in the Snake River canyon, there are two distinct beds of phosphate—one near the base of the phosphatic series, and the other overlying

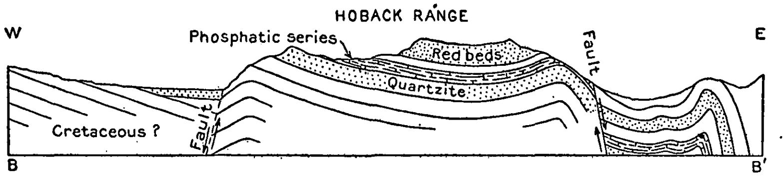

FIGURE 53.—Section showing probable structure and relations of beds in the Hoback Range just south of Fall River. (See Pl. XVII.)

the massive bed of chert in the upper part. Both beds are important, but the lower one is apparently much thicker. The accompanying section shows details and relations.

Partial section of the phosphatic series in the north slope of Fall River canyon.

Argillaceous gray limestone with seams of olive shale and abundant but poorly preserved mollusk shells	350±
Olive-gray and buff shales with bands of impure fossiliferous gray limestone	260±
Dark-gray shale, becoming black and phosphatic at the base. (Representative sample 5 feet above the base gives on analysis 7.7 per cent tricalcium phosphate.)	20±
Hard black, coarsely oolitic phosphate rock (52.9 per cent tricalcium phosphate)	1.5+
Massive gray chert interbedded with gray argillaceous limestone and quartzite	75±
Brownish dark-gray to black shale and phosphate rock, the richest beds being near the top. Owing to the lack of exposures pits were dug at vertical intervals of about 5 feet. The samples thus obtained analyzed as follows: 5 feet up, 54.5 per cent phosphate; 10 feet up, 5.7 per cent; 15 feet up, 17.1 per cent; 20 feet up, 23.8 per cent; 3 feet below the top, 5 per cent	45−

Hard blue-black pisolitic phosphate rock (70.3 per cent phosphate)	1.3

This rests with irregular contact upon beds of gray dolomite which intergrade downward with the quartzite.

OUTLYING BUTTES NEAR JACKSON, WYO.

From the flat alluvial bottom of Jackson Hole rise four isolated hills or buttes, of which three are situated immediately north and west of Jackson and the fourth lies about 10 miles farther up Snake River. Geologically these buttes are much alike, consisting of Paleozoic rocks (including part of the Carboniferous) associated with Tertiary lava flows. In the Gros Ventre Buttes,[1] near Jackson, the strata all dip northwestward at moderate angles and similar strata are repeated in the successive buttes. This suggests that the observed structures are due to normal faulting.

The phosphate beds have not been actually found in any of these buttes, but it is possible that they exist in two or three of them, or, more probably, in the buried portions of the supposed fault blocks beneath the alluvial floor of the valley. The little butte (apparently nameless) northeast of Jackson post office seems to consist entirely of the Mississippian Madison limestone and the overlying quartzite (Weber?) with the intervening red beds. In the two larger buttes, called East and West Gros Ventre buttes, the Paleozoic succession is nearly complete up to and including parts of the quartzite. The quartzite, however, is nearly everywhere, so far as observed, covered unconformably by andesitic flows and breccia. If the eroded surface of unconformity is parallel to the Paleozoic formations, then it is clear that the phosphatic series has not been preserved; but if, on the other hand, the eroded surface bevels the edges of the Paleozoic strata, then the phosphatic and younger beds may occur on the northwest slopes of the buttes beneath the lava caps. Close detailed studies may result in solving this question.

In Blacktail Butte, near Grovont post office, the main ridge is reported by Mr. Breger to consist of the Madison limestone flanked on the southwest by soft Tertiary (Eocene?) sedimentary beds. The Madison limestone of the ridge forms an upright compressed anticline, and along the edge of the butte a syncline is traceable southwest of it. In this syncline the quartzite is exposed, but there is no evidence of the existence of the phosphatic series.

In view of the prevalence of Paleozoic rocks in these buttes in the bottom of Jackson Hole, it may be considered probable that the phosphate beds would be found exposed here and there in the floor of the basin if the more recent alluvial accumulations, together with the Tertiary formations, could be stripped off. A detailed structural study of the surrounding foothills may throw some light on this

[1] "Lower Gros Ventre Buttes" of Hayden Survey.

problem, but apparently deep drilling would be necessary to prove the existence of phosphate deposits in any particular locality in the Hole. Such deposits, if they exist, doubtless lie buried some scores or hundreds of feet beneath the present alluvial floor of the valley.

GROS VENTRE RANGE, WYOMING.

The Gros Ventre Range (fig. 54) is a broad, somewhat complex anticlinal uplift with steep dips and local faults on the southwest side and gently inclined strata interrupted by low asymmetrical folds along the northeast side. Most of the higher peaks consist of carboniferous limestone and quartzite, and the prevailing rocks generally throughout the range are of Paleozoic age. Here and there along the axis of the uplift, however, there are exposures of the Archean gneiss and granite. The thick Mesozoic sequence borders the range on the north, east, and south, the Triassic and Jurassic formations rising locally into the upper slopes. In general the formations are somewhat thinner than in the Hoback and Snake ranges and distinctly thinner than in southeastern Idaho. From the west to the east end of the range there is clear evidence of a transition between

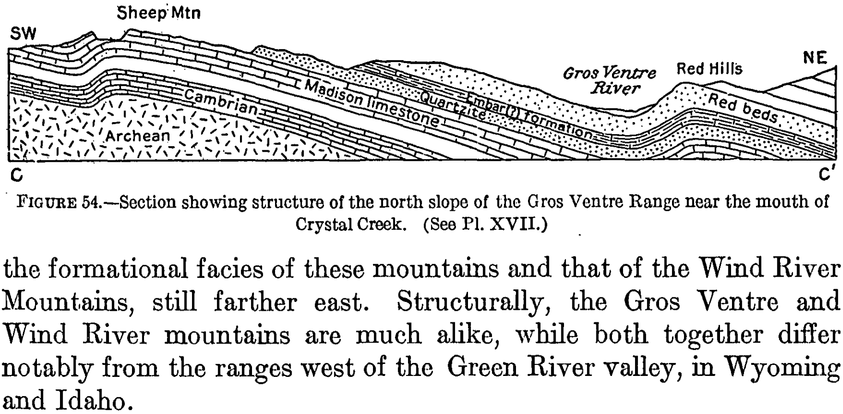

FIGURE 54.—Section showing structure of the north slope of the Gros Ventre Range near the mouth of Crystal Creek. (See Pl. XVII.)

the formational facies of these mountains and that of the Wind River Mountains, still farther east. Structurally, the Gros Ventre and Wind River mountains are much alike, while both together differ notably from the ranges west of the Green River valley, in Wyoming and Idaho.

The phosphatic formation rests directly, without visible interruption, upon white and cream-colored quartzitic sandstone and cherty limestone. From this locality northward and eastward it is scarcely practicable to discriminate the formations known as Park City, Woodside, and Thaynes in southeastern Idaho and northern Utah. The corresponding interval is occupied by a gray or pale buff alternation of shale, limestone, and chert with black layers of shale and phosphate rock, which is believed to represent the Embar formation. This name was applied by Darton in the Owl Creek and Bighorn mountains to all the beds between the top of the Tensleep sandstone (Pennsylvanian) and the base of the red beds (Chugwater formation).

Fossils are rare, except obscure pelecypods in the upper part. Being comparatively soft, these strata generally occupy saddles or ravines between ridges of the underlying sandstone and the harder Triassic red sandstone. Good exposures of them are to be found only in cliffs. The succession of these beds is given in the accompanying stratigraphic section. As usual, the phosphatic portion is near the base and within this portion there are several distinct layers of phosphate rock and phosphatic shale separated by clay shale and limestone. As in the Hoback Range, there are two principal beds of phosphate. The richer bed lies near the base, is between 5 and 7 feet thick, and consists of soft black oolite interspersed with some hard coarse-grained bands and a few seams of brownish phosphatic limestone. In this bed the content of tricalcium phosphate varies between 27 and 80 per cent, and the average content is apparently somewhat more than 50 per cent. The upper phosphate bed lies beneath a massive bed of chert, characterized by peculiar vertical tubular concretions that bear a fancied resemblance to a mass of twisted boiler tubes. This upper phosphatic bed consists largely of black or dark-gray shale with a thin layer of hard pisolitic phosphate rock at the base. The hard layer is less than 6 inches thick, but averages 56 per cent of tricalcium phosphate. The overlying shales are 40 to 45 feet thick, and their phosphate content is but 5 to 15 per cent. The upper shaly zone is therefore much less valuable than the thinner bed first described.

Section of phosphate beds on the south side of Gros Ventre River near the mouth of Crystal Creek.

	Ft.	in.
Gray earthy limestone, shaly sandstone, and shale	150	
Chert, thin bedded, knobby, and smoke-colored	7	9
Limestone, massive, grayish	7	
Shale, blackish gray		5
Chert, thin bedded, gray	3	6
Limestone, massive, grayish, and cherty; upper portion speckled and almost quartzitic	22	
Chert, consisting of gnarled tubular concretions, of blue-black color, variegated with bands of white	11	
Shale, phosphatic below (5 to 10 per cent phosphate), nearly all concealed by soil.		
Phosphate, hard, black, oolitic (55 to 65 per cent phosphate)		5
Limestone, gray to brownish, sandy in lower part	27	
Chert, gray, interbedded with layers of chert breccia	11	6
Phosphatic sandstone, hard, calcareous, black rock with phosphatic nodules and chips of *Lingulodiscina* (10 to 25 per cent phosphate)		6
Gray cherty limestone	2	6
Alternating beds of buff, gray, and brown limestone	27	7
Shale and oolitic phosphate rock, entirely concealed by soil, but shown by débris on outcrop	12	
Chert, pale brown	5	4

Beneath the chert is exposed 83 feet of white to pale brown quartzitic sandstone with a few beds of gray limestone, which is believed to represent the Tensleep sandstone to the east and the Weber quartzite to the southwest.

A detailed section of the lower part of stratum No. 2 in the above section is given below. This section was made by digging a trench along the outcrop about half a mile below the lowest falls on Crystal Creek.

Detail of the lower phosphate beds on Crystal Creek.

[From notes of C. L. Breger.]

	Ft.	In.
Hard gray shale	3	
Dark clay shale, with thin phosphatic laminæ (6.9 per cent tricalcium phosphate)	3	
Lean phosphate rock and buff shale		4
Black oolitic phosphate rock (51.1 per cent phosphate)		8
Black oolitic phosphate rock (33.3 per cent phosphate)		8
Black oolitic phosphate rock (50.4 per cent phosphate)	2	11
Coarse soft black oolitic phosphate rock (70 per cent phosphate)	2	1
Brownish black oolitic phosphate rock (42.1 per cent phosphate)		3
Gray phosphate rock with a little shale (23 per cent phosphate)		1
Hard black oolitic phosphate rock (60.2 per cent phosphate)		6
Hard black oolitic phosphate rock (61 per cent phosphate)		1

The upper part of the Embar(?) formation along the north slope of the Gros Ventre Range consists of alternate shale, shaly sandstone, and limestone, altogether about 200 feet thick. Some of the argillaceous limestone beds bear a distant resemblance to the Thaynes limestone of southeastern Idaho and northeastern Utah, and they contain some similar fossils.

At the southeast end of the Gros Ventre Range the phosphatic series is well exposed in foothills and canyons, and it even makes its appearance in a low anticline crossed by Green River just north of Old Kendall (now a United States Forest Service station). The exposures in the eastern part of the Gros Ventre uplift were explored by Mr. Breger, but with indecisive results. The general succession and character of different members of the Embar (?) formation seem to be much the same as along the lower part of Gros Ventre River. Nevertheless, in specimens from this locality one may find the gray speckled phosphatic sandstone characteristic of the Wind River Range, as well as the soft black oolite found farther west in the Gros Ventre Mountains. Samples from the thin dark oolitic zones give analyses as high as 80 per cent of tricalcium phosphate.

The south side of this range was not visited by the party in 1910, but from views from somewhat distant points both east and west, and from reports of the Hayden Survey, it is evident that the phosphatic series is exposed here and there along this part of the range. From Pass Peak eastward the Pennsylvanian beds are all covered by the early Mesozoic formations, which dip gently eastward. Thence westward the phosphate beds are exposed along the slopes of the range for several miles. In part of this belt the phosphatic series and adjacent formations stand on edge and are doubtless clearly exposed in a series of ridges. Judging from their proximity to the Hoback Range, one may presume that the deposits on the south side of the Gros Ventre Mountains are somewhat richer than those in the Gros Ventre Valley farther north.

BUFFALO FORK ANTICLINE.

The headwaters of Buffalo Fork of Snake River have intrenched an anticline or elongated dome, but the structure has not expressed itself in the topography as a well-defined range of mountains and hence has received no appropriate name, although it may be considered as part of the Absaroka Range in a large sense. The south end of this anticline appears at Black Rock Meadows, on the military road from Wind River to Jackson Lake. Northward the anticline probably extends into the southeastern part of Yellowstone Park, but its course is partly obscured by horizontal beds of Tertiary volcanic tuff and lava.

In this anticline, around a core of Archean gneiss, is exposed the usual sequence of Paleozoic and Mesozoic strata, dipping steeply away on all sides. Across the eroded top of the dome has been laid a thick and nearly horizontal sequence of dark volcanic tuff and lava flows, probably of middle Tertiary age. The lower portions of the valley are further much obscured by widespread deposits of glacial drift, some of which appear to be of comparatively recent age, while other portions are evidently considerably older. On the whole, exposures of the bedrock are not so good in this district as in most of the ranges farther south and southeast.

The Paleozoic formations here differ in important particulars from those in the Gros Ventre Range. Upon the thin-bedded limestone and greenish shales of the Cambrian and Ordovician rests hard gray to ash-white dolomite which is brittle and apparently devoid of fossils. This is about 600 feet thick. It is overlain by yellowish dark-gray to black shales with beds of dark dolomite interleaved, the whole formation being about 350 feet thick. These beds are followed in turn by massive gray to brownish limestone containing typical Madison fossils, having a thickness of a little more than 1,300 feet. Above the Madison limestone is the usual cream-colored to white quartzitic sandstone with interbedded white siliceous dolomites, apparently 300 to 400 feet thick; but at the base this formation intergrades with the Madison limestone through a succession of dolomites, sandstones, and purplish shales in beds 5 to 15 feet thick, so that there is no natural plane of division between the two formations. Possibly more thorough examination of this sequence may show that the transitional shaly portion represents the Amsden formation of central Wyoming and that it may be separated from the Madison limestone by an obscure unconformity as it is in the Wind River Range. Although it was impracticable to make exact measurements, it appears probable that the entire Embar (?) formation here is less than 200 feet thick. It rests upon and seemingly intergrades with the quartzitic sandstone and is overlain as usual by the bright-red shale and sandstone of probable Triassic age. These red beds are apparently about 1,000 feet thick at Black Rock Meadows.

In this locality the Embar (?) formation contains at least one phosphatic bed, as usual, but it is very thin and lean. The upper half of the formation consists almost entirely of buff and gray shale and argillaceous platy limestone containing obscure remains of mollusk shells. Beneath this there are beds of shale, chert, and sandstone, but no exposure was found in which a section could be measured. Small pieces of débris upon the outcrop indicated the presence of a phosphate bed, and by digging a trench across the outcrop it was found that this bed had a thickness of 2 feet 2 inches and consisted of waxy brown to gray oolitic and sandy phosphate rock, which weathers to an ashy-white or light-buff color. Samples of this bed, when analyzed, showed 35 to 45 per cent of tricalcium phosphate. When dissolved in nitric acid the rock leaves a copious residue of gray sand. From its relative position this bed appears to be equivalent to the lower zone in the Gros Ventre Range, but nothing was found here to indicate the presence of the lean, upper zone of black shale and phosphate rock which is so prominent in the region farther south.

Section of phosphate beds in the top of the mountain north of Black Rock Meadows.

	Ft.	in.
Massive brown chert	10+	
Thin-bedded yellowish-brown chert	1	6
Cherty brown shale		8
Nodular and oolitic brown phosphate rock		1
Tough yellowish-brown clay		6
Dark-green to rusty-brown oolitic phosphate rock; crumbles readily (45.6 per cent tricalcium phosphate)	1	2½
Resinous brown phosphate, of fine oolitic texture (35.5 per cent tricalcium phosphate)		5
Thin-bedded wax-brown oolitic phosphate; weathers ashy white on the surface (39.1 per cent tricalcium phosphate)		7
Brown and speckled sandstone with bits of chert, slightly phosphatic (?)	4	
Cream-colored sandstone or quartzite.		

WIND RIVER MOUNTAINS.

CHARACTER AND PHOSPHATE OUTCROPS.

The Wind River Range is a broad, low, somewhat broken anticline with northwest-southeast trend. Along the north slope the general northeasterly dip is interrupted by several low but sharp asymmetrical anticlines which, as in the Gros Ventre Range, are always oversteepened toward the southwest. On the south side the older rocks are said to be largely concealed by Tertiary sediments and thick deposits of glacial drift. Around the head of Green River, in the southwestern part of the range, and perhaps farther southeastward, the ancient metamorphic rocks are overthrust upon the Paleozoic strata, which are there complexly folded and faulted.

The Carboniferous phosphatic beds are continued from the Gros Ventre Range over to the Wind River Mountains and are there both well and widely exposed. In 1910 they were traced almost continuously along the northeast slope of the range; and another much smaller group of outcrops has been found on the southwest side of the mountains. These two occurrences may best be described separately.

GREEN RIVER LAKES DISTRICT.

Green River rises among the lofty and rugged peaks near the west end of the Wind River Range. Deep glacial gorges and lakes hemmed in by somber pines impart a wild grandeur to the scenery surpassed by few, if any, places in the Rocky Mountains.

In this region C. L. Baker in 1909 discovered phosphatic deposits in the Embar formation. As the beds are highly folded, somewhat broken by faults, and locally covered by thick deposits of glacial drift, the determination of the distribution of the phosphatic series necessitates a close study of the geologic structure.

In general, it may be said that the folds trend nearly north and south and pitch northward. The folded beds are cut off on the east by an overthrust which brings the Archean gneisses up over the Carboniferous and even the Mesozoic strata. Another large overthrust along the west base of the higher mountains causes the older Paleozoic and Archean rocks to override the Carboniferous and Mesozoic beds in the foothills bordering the Green River valley.

Most of the high peaks in this region have been carved out of the hard Archean granites, gneisses, and other crystalline rocks. The nearly complete succession of Paleozoic formations which rests upon the Archean is beautifully exposed in the rugged spurs of Sheep Mountain and adjacent peaks near the Green River Lakes. On the whole, these Paleozoic beds resemble those in the Gros Ventre Range, but there are considerable differences in details. The Mesozoic formations which lie north and west of Sheep Mountain are not well exposed and are largely covered with glacial drift. They include the familiar red beds and gypsum of the Chugwater formation, the Jurassic marine shale (Sundance), and Cretaceous yellowish shales and sandstones.

The Carboniferous formations, which contain the phosphate deposits, may be described in somewhat greater detail. The drab to brownish Madison limestone, of Mississippian age, seems to be reduced here to a thickness of but little more than 750 feet. Upon it rests, in unknown but apparently conformable relation, a series of sandy beds. In White Rock Mountain, where these sandy beds are clearly exposed, they are about 400 feet thick and may be divided into three distinct parts—(1) a lower white cross-bedded sandstone, (2) a succession of red shales, with thin beds of purple and gray limestone, overlain by (3) a much thicker white to buff quartzite-sandstone, which is somewhat shaly and calcareous at the base. The last member makes the extreme summit of White Rock Mountain. Nos. 1 and 2 are believed to represent Darton's Amsden formation and No. 3, the upper sandstone, to be equivalent to Darton's Tensleep sandstone farther east. This upper sandstone is overlain by a shaly and calcareous formation, the Embar, which is in turn followed and clearly delimited by the bright-red shale and sandstone of the Chugwater formation. Altogether the Embar formation appears to be 350 to 400 feet thick in this locality. No complete section was measured, but a partial section, which includes the upper phosphate bed, is given below.

Section of the phosphatic portion of the Embar formation on the northeast slope of Sheep Mountain.

	Ft.	in.
Chert and brownish-gray shale interbedded	7	
Dark-gray shale	1	2½
Phosphate rock, massive, black, and oolitic (38.4 per cent tricalcium phosphate)		2½
Dark-gray to brown papery shale	16	
Sepia-brown brittle phosphatic shale (5–8 per cent phosphate)	1	
Blackish to light-gray shale	26	
Smoky-brown phosphatic limestone		6
Blackish-gray papery shale	1	
Phosphate rock, black, finely oolitic, with abundant fossils, chiefly gastropods, pelecypods, etc. (54.7 per cent tricalcium phosphate)	1	
Dark-brown phosphatic limestone		2½
Phosphate rock, black, oolitic, thin bedded (35.4 per cent phosphate)	3	2½
Soft drab phosphatic limestone		4
Dark-gray fetid limestone with abundant fossils (*Spirifer* aff. *cameratus*, *Productus nevadensis*, etc.)	10	
Highly fossiliferous shaly gray limestone	2	8½

The underlying part of the Embar formation here consists of thin-bedded gray limestone with some beds of chert and a thick ledge of drab dolomite, altogether 50 to 60 feet thick. Above the beds represented in the section there is a ledge of nodular chert and highly fossiliferous gray limestone several feet thick. This, in turn, is followed by somewhat sandy shale and argillaceous limestone with poorly preserved pelecypod shells which suggest the Woodside shale of southeastern Idaho. It will be noted that in the vicinity of Green River Lakes the phosphate formation lacks the thick beds of chert with tubular concretions, etc., which are so characteristic of it in the Gros Ventre Valley and regions farther southwest. On the other hand, it contains an abundance of fossils at several different horizons, whereas in the Gros Ventre and adjacent ranges fossils are scarce in this formation. The Sheep Mountain phosphate layer seems to occupy the position of the upper phosphatic bed on Gros Ventre River. If the lower phosphate zone is present near Green River Lakes, it was not observed.

Being relatively soft, the Embar formation has been generally worn off the upper slopes of the mountains, but it is still present in scattered patches lying on dip slopes, as on the north side of White Rock Mountain. It also outcrops here and there along the bases of the steeper slopes, as on the north side of the Sheep Mountain group. Good exposures of the formation are decidedly rare in this locality, because the lower slopes are generally covered with glacial drift or soil. West and southwest of these mountains the formation, including the phosphate bed, is exposed in a steep overturned fold at the mouth of the canyon of the south fork of Gypsum Creek and again at the mouth of the valley known as Upper Boulder Basin. Baker reports it also at the mouth of New Fork Canyon. Its further extent in a southeasterly direction has not been determined. There again thick deposits of glacial drift and a general mantle of soil make the finding of the soft phosphatic formation a difficult task.

NORTH SLOPE OF THE WIND RIVER RANGE.

On the northeast side of the Wind River Range the Paleozoic beds dip gently northeastward and in general are well exposed. They are

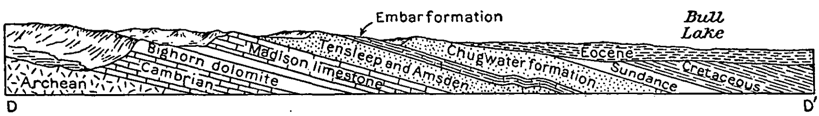

FIGURE 55.—Diagrammatic section of sedimentary beds in the north slope of the Bull Lake Basin, on the north side of the Wind River Range.

not broken by noteworthy faults, but the monocline is interrupted by two low, sharp anticlines near the base of the range. (See fig. 55.)

In general, the formations are similar to those at Green River Lakes, although on the average they are somewhat thicker. The higher parts of the range consist of hard granitic and gneissic rocks, supposedly Archean. Along the flanks the hard limestones of Cambrian to Mississippian age rise in the form of broad triangular dip slopes alternating with narrow canyons. The lowest prominent knobs and dip slopes along the foothills consist of the hard Tensleep sandstone. This generally carries upon its surface more or less of the Embar formation, which consists partly of hard limestone. The upper part of the Embar, however, is so soft that it has been worn down to the base of the range and planed off to the general level of the Wind River Basin, which is underlain largely by the red beds and the overlying Jurassic and Cretaceous rocks. Locally even the harder limestones of the Embar formation have been likewise removed from the foothills. All these tilted Paleozoic and Mesozoic beds are covered in the central part of the Wind River Basin, and in places even up to the very base of the mountains, by the nearly horizontal Eocene clays with their basal conglomerate. Here and there thick deposits of glacial drift from the mountain canyons conceal the underlying formations, including the Eocene.

Partial section of strata on the north slope of the Wind River Mountains, near Circle.

	Feet.
Jurassic:	
Sundance formation—pale-green fossiliferous shale with thin hard limestone at the base, grading upward into green sandy shale and earthy sandstone	200+
Triassic (?):	
Chugwater formation—red sandy shale overlain by alternate layers of red shale and earthy sandstone with thin beds of gypsum; the upper part consists of variegated purple and green shale with conglomerate and limestone layers overlain by massive pink to yellowish sandstone, and then more red shale at the top (no fossils)	1,400
Pennsylvanian and Permian (?):	
Embar formation—gray to blackish dolomite, shale, and phosphate rock, with limestone and chert, overlain by a succession of gray shaly sandstone and limestone, with soft clay and sandstone at the top; all of gray or buffish colors. Fossils abundant in the middle (*Spiriferina pulchra*, *Productus nevadensis*, *Spirifer* aff. *cameratus*, *Derbya* sp., bryozoans, pelecypods, etc.)	300–400
Pennsylvanian:	
Tensleep sandstone—massive cream-white to pink sandstone	250–300
Amsden formation—massive white sandstone at the base, overlain by interbedded light-colored shale, sandstone, and thin beds of limestone. Locally some of these beds are deep red in color	250–275
Mississippian:	
Madison limestone—massive gray and brown limestone and dolomite, with thin beds of chert in the upper part; fossils at scattered horizons (*Spirifer centronatus*, *Chonetes loganensis*, etc.)	650–675
Devonian (?):	
Alternating beds of gray dolomite, dark-brown bituminous dolomite, purple calcareous shale, and white sandstone; fossils very rare	115
Ordovician:	
Bighorn dolomite—cream-colored to buff dolomite, rather thin bedded above but very massive below; fossils rare	160

Ordovician (?):	
Hard striped limestone overlain by mottled gray and ocher crystalline limestone, with beds of chert	200-220
Cambrian:	
Light-brown sandstone at the base, overlain by green shale and limestone, followed in turn by hard flat-pebble limestone, with beds of shale and gray oolite	935
Unconformity.	
Archean:	
Hornblende gneiss and granite with large dikes of diabase.	

In the field the position of the phosphatic Embar formation may be picked out readily by the aid of the prominent outcrop of the brilliant red beds of the Chugwater formation which lie just above it. On the other hand, it rests upon the massive buff Tensleep sandstone which everywhere forms cliffs in the canyons and triangular dip slopes along the base of the range. In the sharp anticlines near Fort Washakie and Lander the Embar formation, with its phosphatic deposits, must be very near the surface along the axes of the folds, for the red beds are well exposed there. On the whole, the phosphatic deposits are to be looked for at or very near the base of the mountains and they will be found well exposed only in the sides of the canyons. There, however, they will be encountered almost invariably just at the mouth of the narrower part of the valley, where it opens out on the plain.

The detailed sections of the Embar formation given below serve to show that it consists of an alternation of limestone with shaly beds, somewhat more sandy and cherty below and more purely argillaceous near the top. The phosphatic beds occur below the middle of the formation. All along this slope of the Wind River Range, particularly from Bull Lake northwestward, several of the limestone and shale beds are wonderfully rich in fossils. Specimens of *Productus nevadensis?* and *Spirifer* cf. *cameratus* may be gathered by the cartload. In the vicinity of Lander, however, these fossiliferous beds have become so changed that the fossils are obscure and in some beds quite unrecognizable.

Complete section of the Embar formation in Dinwoody Canyon.

	Ft.	In.
Pale-green to white clay, with local sandy and calcareous beds, overlain conformably by bright-red sandy shale of the Chugwater formation	130	
Gray shaly limestone, weathering brown	28	
Alternate calcareous and sandy shale and argillaceous sandstone in thin beds	12	
Dark argillaceous limestone with shale partings containing many obscure pelecypod shells	10	
Grayish sandy shale, shaly limestone, and shaly sandstone, in alternate beds	75	
Massive gray crystalline limestone with fossil bryozoans and brachiopods	16	6

	Ft.	In.
Nodular greenish-gray clay, greenish limestone, and chert; *Spiriferina pulchra*, *Hustedia meekana*, *Derbya* sp., crinoids, and bryozoans in abundance	6	
Alternating sepia phosphatic and calcareous shale and shaly limestone with thin beds of chert near the top; abundant *Productus nevadensis*? near the base	35	6
Brown shale and soft nodular black and gray phosphate rock interlaminated (30.5 per cent tricalcium phosphate)	1	8
Dark greenish-gray oolitic and argillaceous phosphate rock (41 per cent phosphate)	1	
Gray to sepia-brown shale, full of oval nodules somewhat more calcareous; abundant *Spirifer*, *Productus*, etc. (average 8.5 per cent phosphate)	12	5
Hard greenish-brown phosphatic limestone, with glauconite grains (23.7 per cent phosphate)		7
Brown argillaceous limestone and calcareous shale, nodular as above; abundant *Productus nevadensis*, *P. cora*, *P. subhorridus*, *Spiriferina pulchra*, *Pugnax utah*, bryozoans, etc. (±8 per cent phosphate)	6	
Dark-drab or brown fetid limestone in massive beds; upper layers crowded with bryozoans	21	
Green clay shale with thin beds of chert and platy gray limestone	43	
Gray speckled phosphatic sandstone	1	
Earthy white sandstone	2	
Greenish-gray speckled phosphatic sandstone containing *Lingulodiscina utahensis*, etc. (27.4 per cent tricalcium phosphate).	2	2½
Light-gray earthy limestone	1	9½
Dark-green shale	1	3½
Pale-gray smoky dolomite with seams of black chert and pores full of black bitumen	25	
White calcareous sandstone and conglomerate of chert pebbles. (This lies with obscure unconformity upon the Tensleep sandstone.)	1	7

Section of phosphate and associated beds 12 miles west of Lander.

Soft whitish clays near the top of the Embar formation.		
Gray to dull-white limestone with calcite geodes, chert nodules, and poorly preserved fossils (*Derbya* sp., *Spiriferina pulchra*, bryozoans, etc.)	42	
Green nodular shale and chert	3	
Shale, smoky brown below to greenish above; contains a 5-inch bed of lean shaly phosphate near the base and a 6-inch bed of speckled gray phosphatic limestone (21.8 per cent tricalcium phosphate) 13 feet below the top	62	7
Brownish-gray oolitic and nodular phosphate rock full of *Productus subhorridus* and other fossils (42.4 per cent tricalcium phosphate)	4	7
Brown phosphatic and glauconitic limestone; passes into shale above; contains *Productus nevadensis*, *Spirifer cameratus* var.	12	
Hard gray siliceous limestone, with large *Productus nevadensis* shells on the weathered surface		11
Soft brown phosphatic limestone (25.5 per cent tricalcium phosphate)		6
Alternating gray limestone and shale, more or less cherty and siliceous, with but few well-preserved fossils	180	
Massive white to buff sandstone (Tensleep)	200+	

The phosphatic beds, being relatively soft and crumbling, are exposed only here and there in sharp arroyos. The presence of the beds may generally be recognized, however, by pieces of the rock mixed with the soil upon the outcrop. This float usually consists of a gray speckled material, which, when broken open, is found to be dark brown inside and emits the odor of petroleum. It is also distinctly granular in texture. In size the individual granules vary from minute pepper-like particles up to nodules a quarter of an inch or more in diameter. The average is about the size of mustard seed or small bird shot.

It will be noted that on the whole the phosphate deposits on the north slope of the Wind River Mountains are leaner than in the districts farther west; and yet there is some improvement in the quality as the series is traced southeastward along the range. Thus the beds near Lander are more than 4 feet thick and average more than 40 per cent of tricalcium phosphate; while near Dubois the thickest bed is less than 3 feet thick and averages but little more than 35 per cent of phosphate.

SOUTH END OF THE SHOSHONE MOUNTAINS, NORTH OF WIND RIVER.

Along the north side of the Wind River Basin, in the vicinity of Dubois and Circle, the Paleozoic strata appear beneath the Eocene

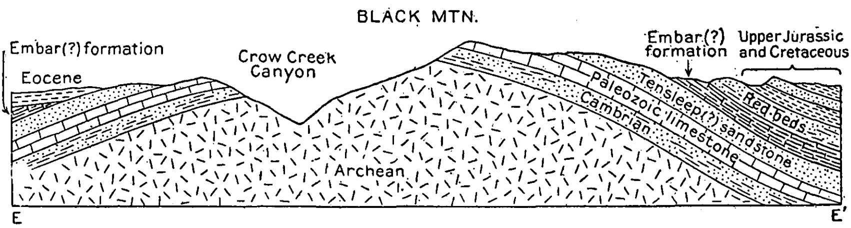

FIGURE 56.—Section showing structure of Black Mountain, northwest of the Wind River Basin. (See Pl. XVII.)

beds in folds which are structurally a part of the Shoshone Range farther north. These were examined by Mr. Breger in the valley of Horse Creek north of Dubois, and by the writer at Black Mountain, on the head of Crow Creek. (See fig. 56.) In both places the Embar formation appears in much the same condition as in the Wind River and Owl Creek mountains; and in both places there are lean phosphatic beds near the middle of the formation. The subjoined section from Black Mountain will serve to illustrate the succession.

Partial section of the Embar formation on the east slope of Black Mountain.

	Ft.	in.
Soft clay or shale concealed	50–100	
Earthy grayish limestone with beds of shale and sandstone partly concealed	31	
Greenish-gray crystalline limestone, with abundant fossils (bryozoans, *Hustedia meekana*, *Derbya* n. sp., *Spiriferina pulchra*, etc.)	14	
Yellowish shaly limestone with many nodules and, in the upper part, continuous beds of chert	40	
Dark-brownish calcareous and phosphatic sandstone, weathering to speckled gray on the surface (average analysis of entire bed 20.2 per cent tricalcium phosphate)	4	1
Dark-gray speckled phosphatic sandstone	2	8
Massive pale gray to thin-bedded limestone, full of large shells (*Productus nevadensis*, *Spirifer* cf. *cameratus*, etc.)	15	6
Gray to yellowish limestone, more or less shaly, with some cherty beds very rich in fossils (*Spirifer cameratus* var., *Productus subhorridus*, *P. nevadensis*, *Spiriferina pulchra*, *Composita subtilita*, bryozoans, etc.)	26	
Alternate beds of gray limestone or dolomite with thinner beds of chert and shale; fossils scarce. (This rests on the massive white to buff quartzitic Tensleep sandstone)	115	

The middle portion of the formation is quite as fossiliferous here as at any point on the north slope of the Wind River Mountains, and the zones identified in Dinwoody Canyon in that range can be recognized at Black Mountain also. On the average there is a little more chert here than in the Wind River Range. There seems to be only a single phosphatic zone, and although that is nearly 7 feet thick, it is very lean as compared with the phosphate beds farther southwest. While thin laminæ may be richer, most of this bed contains less than 20 per cent of tricalcium phosphate. It is therefore too poor to be worthy of much attention at present and does not render the lands it underlies subject to withdrawal from entry.

According to Mr. Breger, who investigated the folded Paleozoic rocks on Horse Creek north of Dubois, the chert overlying the phosphate beds becomes somewhat more massive northwestward. He found there, however, scarcely 2 feet of phosphate rock. Of this, the average phosphate content is less than 20 per cent and the highest analysis of a single lamina 23 per cent. North and northwest of the Horse Creek locality all the older strata are concealed by nearly horizontal beds of Tertiary volcanic ejecta, from which the picturesque crags known as Ramshorn Peak and others adjacent have been carved.

OWL CREEK MOUNTAINS.

As shown by Darton,[1] the Embar formation occurs throughout the Owl Creek Mountains in much the same condition as it does on the north slope of the Wind River Range. (See fig. 57.) In 1910 the formation was examined hurriedly by the writer in the canyon of Bighorn River a few miles south of Thermopolis. The general relations there are similar to those in the Wind River Mountains. As usual, the Embar formation lies directly beneath the red beds (Chugwater formation) and rests upon the massive cliff-making Tensleep sandstone in broad, smooth dip slopes.

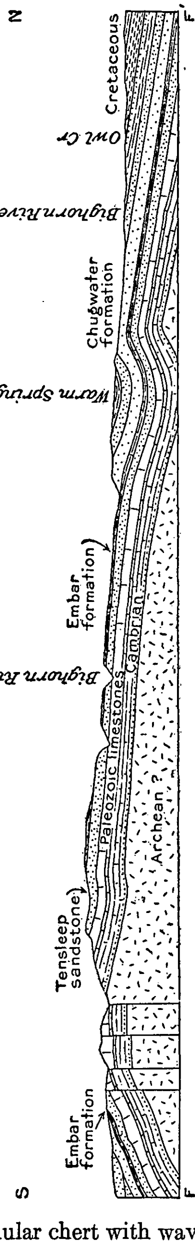

FIGURE 57.—Section showing structure of the Owl Creek Mountains in the longitude of Thermopolis, Wyo. (After N. H. Darton. See Pl. XVII.)

Although much the same as in the Wind River Range, the Embar formation here shows differences, as the accompanying section indicates. The limestones are more impure and cherty and contain very few recognizable fossils. There seems to be but a single phosphatic bed and that is so lean that it is barely good enough to be withdrawn from entry under the current ruling of the Interior Department. The material in this bed is brownish-gray speckled rock like that in the Wind River Mountains, and consists of dark granules and larger nodules embedded in a gray limy matrix. The bed is only 2½ feet thick, and, while the upper portion yields on analysis 34.4 per cent of tricalcium phosphate, the lower and leaner portion shows but 14.9 per cent.

Complete section of Embar formation in Bighorn Canyon, south of Thermopolis, Wyo.

	Ft.	in.
Impure yellowish gypsum lying at the base of the Chugwater formation (red beds)	17	
Buff sandy shale with beds of impure gray limestone	29	
Variable gray to chalky white limestone, partly dolomitic and containing chert nodules and calcite geodes. A few fossils in the lower part, chiefly *Spiriferina pulchra* and bryozoans, with traces of *Derbya* and *Spirifer*	55	
Nodular chert with wavy partings of dark-brown shale	15	
Brown phosphatic shale		3½

[1] Darton, N. H., Geology of the Owl Creek Mountains: Senate Doc. 219, 59th Cong., 1st sess., 1906.

	Ft.	in.
Phosphate rock, massive gray muddy oolitic limestone sprinkled with waxy brown granules; a few *Productus subhorridus* shells (34.4 per cent tricalcium phosphate)	1	5
Brownish-gray hard argillaceous limestone with brown phosphatic granules (14.9 per cent phosphate)		9½
Crystalline cream-colored limestone passing downward into chalky white dolomite, without fossils	52	
Soft yellowish calcareous shale, with beds of argillaceous limestone	40	6
Dense brittle gray limestone	3	6
Gray calcareous shale with thin beds of limestone	32	
Massive chalky white dolomite or limestone (this rests upon the massive cliff-making Tensleep sandstone)	25±	

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SURVEY PUBLICATIONS ON PHOSPHATES AND OTHER MINERAL FERTILIZERS.

The following papers relating to phosphates and other mineral materials used as fertilizers have been published by the United States Geological Survey or by members of its staff. Further references will be found under the head of "Gypsum."

The Government publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The one marked "Exhausted" is not available for distribution, but may be seen at the larger libraries of the country.

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