Geography, Geology, and Mineral Resources of the Ammon and Paradise Valley Quadrangles, Idaho

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Geography, Geology, and Mineral Resources of the Ammon and Paradise Valley Quadrangles, Idaho

By GEORGE R. MANSFIELD

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A supplement to earlier studies, supplying new geologic information and additional data on phosphate reserves

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By George R. Mansfield

ABSTRACT

This report[1] is one of a series by the author dealing with contiguous areas in southeastern Idaho, the others being Professional Paper 152 and Bulletins 713 and 803 of the Geological Survey. The Ammon and Paradise Valley quadrangles constitute the northwestward extension of the general area studied, where the Blackfoot Mountains descend to the Snake River Plain near Idaho Falls.

The history of these quadrangles is briefly outlined, and their geographic features are systematically described. Except for a few square miles in the Snake River Plain to the northwest, the entire area is an upland comprising subdued mountains that trend northwestward, reaching altitudes exceeding 7,400 ft, and relatively broad intermontane valleys. Some sharp-featured canyons are as much as 1,300 ft or more deep. The climate is semiarid, with an average annual rainfall of about 14 in.

The geologic formations include representatives of the Carboniferous and later systems, but parts of the Triassic, Jurassic, Cretaceous, and early and middle Tertiary are either absent or not recognized. The rocks are folded and broken, and the folds have a noticeable tendency toward eastward inclination or overturning, a common structural habit of the general region. Many of the structural features are concealed or obscured by a widespread blanket of Tertiary rocks and of later volcanic products, especially welded rhyolite tuff. Perhaps the most noteworthy structural feature is the Bannock overthrust zone, which comprises three principal branches as well as numerous other faults and includes the Paradise Valley window, where complexly folded and faulted beds of the underlying fault blocks are exposed by the local removal of the upper block by erosion. The horst and graben structure is continued into this area from neighboring areas to the southeast.

The mineral resources of the two quadrangles include phosphate rock, limestone, road metal, building stone, and volcanic ash. Occurrences of coal and nitrate also have been noted. Phosphate is discussed with reference to the individual townships in which it occurs and in some of its broader relations. All these resources are present in sufficient quantity to supply any probable local need over a long period.

INTRODUCTION

PURPOSE AND SCOPE OF WORK

Since December 9, 1908, when the first withdrawals of potential phosphate lands in the Western States were authorized by the Secretary of the Interior, the classification of the public lands in Idaho and adjacent states as to their phosphate content has been in progress more or less continuously. In the early years of this period several field studies were carried on and progress reports were published, centering chiefly on the distribution, thickness, quantity, and amount of phosphate rock present. The areas were studied under conditions prescribed by certain rules of procedure adopted for purposes of land classification.

The work had not progressed very far, however, before the existance of billions of tons of high-grade phosphate reserves was revealed. This allayed the original fear that domestic scources of supply might be depleted by the exportation, then in progress, of Florida hard-rock and pebble phosphates. Furthermore, when fears of a shortage were revived in 1938, a congressional investigating committee reported that the phosphate resources of Florida, Alabama, and Tennessee, as well as of the Western States, were far greater than previously supposed and that no early national shortage was anticipated. Thus the urge for land classification as an immediate end slackened somewhat but meanwhile the geologic and geographic features disclosed during that work had proved to be of great importance to an understanding of Rocky Mountain geology.

A plan was then adopted of combining the classification work with areal and structural studies which could be published on a quadrangle basis similar to that employed in the folios of the Geologic Atlas of the United States but which would be in a more convenient form. Under this plan it has been necessary to coordinate the work on the Ammon and Paradise Valley quadrangles with other projects of the Geological Survey, some of which were regarded as of more immediate importance. As a result, work on these quadrangles was intermittent and progress was retarded.

The first work (Mansfield, 1927) published under this plan covered seven quadrangles—Montpelier, Slug Creek, Crow Creek, Lanes Creek, Freedom, Henry, and Cranes Flat—located in southeastern Idaho with narrow, overlapping strips in Utah and Wyoming. The next (Mansfield, 1929) covered a single quadrangle, the Portneuf, which adjoins the larger area on the west. The two quadrangles discussed in the present report

[1] The prolonged ill health and subsequent death of the author have delayed the publication of this paper.

also adjoin the larger area on the west and northwest; they lie north of the Portneuf. These 10 quadrangles, together with the previously mapped Fort Hall Indian Reservation (Mansfield, 1920a), provide a continuous strip about 100 miles long, extending eastward from the vicinity of American Falls on the Snake River in Idaho to Star Valley in western Wyoming. The width of this strip, which is quite irregular, ranges from 10 to 70 miles.

The geology of the area is known in considerable detail. The present report supplements the author's earlier work in Idaho and provides new geologic information and new mapping for part of this complex region. It also supplies additional data regarding the phosphate reserves and other mineral resources of Idaho.

LOCATION AND EXTENT OF AREA

The Ammon and Paradise Valley quadrangles together occupy an area of about 435 sq mi between parallels 43° and 43°30′ north latitude and between meridians 111°45′ and 112°. (See fig. 1 and pl. 1.)

The northwest corner of the Ammon quadrangle is about a mile east of the city of Idaho Falls, an important agricultural center in the Snake River valley at the junction of the Butte and Yellowstone branches of the Oregon Short Line Railroad. Blackfoot is another important agricultural and railway center in the area. It is 21 miles southwest of Idaho Falls and about 17 miles west of the middle of the west boundary of the Paradise Valley quadrangle. Smaller towns and settlements lie along the railroad between these two cities and along a branch railroad, active only during the potato and sugar-beet harvests, that extends near the eastern margin of the Snake River valley from Firth to Belt and has a main-line connection at Orvin, about 3 miles north of Idaho Falls. This branch road is in general west of the area here described, but it enters the northwestern part of the Ammon quadrangle about 3 miles southwest of the town of Ammon, which is one of the settlements it serves.

The western part of the Paradise Valley quadrangle south of the Blackfoot River includes a strip nearly 3 miles wide belonging to the Fort Hall Indian Reservation. This quadrangle lies immediately west of the Cranes Flat quadrangle, the northwesternmost of those described in Professional Paper 152 (Mansfield, 1927), and adjoins the Portneuf quadrangle on the north.

HISTORICAL NOTES

Earlier reports (Veatch, 1907, pp. 9–32, and Mansfield, 1920a, pp. 12–14, 1927, pp. 2–5, 1929, pp. 3–5) on the general region of which the Ammon and Paradise Valley quadrangles form a part have included accounts of its early history, together with references to original sources. The present paper can add little to what has already been stated.

The area described was formerly roamed by Indians, trappers, explorers, and adventurers. Bonneville, Frémont, Wyeth (the founder of Fort Hall), the Astorians, and others have figured in its past, but it is difficult to tell from the available accounts to what extent these men may have visited the actual ground covered by the Ammon and Paradise Valley quadrangles. The old emigrant route to the coast passes within a short distance to the south, and no doubt some of the emigrants may have strayed far enough north to penetrate parts of the area. The stories of buffalo hunting and Indian fighting and of the hardships and trials experienced by both explorers and emigrants have cast a glamour of romance over the region which still lingers in some of its less-frequented parts. The Ammon and Paradise Valley quadrangles, which, except for a few relatively poor roads, are largely beyond the range of the automobile, have retained a suggestion of this quality.

Prior to 1885, the site of the present city of Blackfoot was little more than a sagebrush desert. Idaho Falls, formerly known as Eagle Rock, is located where the Snake River falls over the edge of a lava flow. The river has cut back the lava to form a narrow canyon about half a mile long. Here, in 1866, a toll bridge was built. The tolls collected from the freight-laden wagon trains passing over the Utah-Montana trail financed a store, and around the store a town grew up. The railroad was built northward from Idaho Falls in 1879 and completed as far as Silverbow, Mont., in 1881, and the Yellowstone branch line was finished in 1906 (Lee, Stone, Gale, and others, 1915, pp. 130–135).

HAYDEN SURVEYS

The survey parties under F. V. Hayden in 1871 and under F. H. Bradley in 1872 made reconnaissance trips through the general region extending from the vicinity of Salt Lake on the south to the Teton Range and Yellowstone country on the north (Hayden, 1872 and 1873). In so doing they traversed areas adjacent to the one here described and may have actually penetrated parts of it. Few of their observations, however, apply directly to these quadrangles.

In 1877 and 1878, the Teton Division of the Hayden Survey, in charge of Orestes St. John, geologist, completed a map that includes all of the Paradise Valley quadrangle and somewhat more than the southeast half of the Ammon quadrangle. The map was published in 1879 on a scale of 1:253,440 (4 miles to the inch). It is much generalized, but it shows some of the principal geologic features of the two quadrangles. For example, St. John noted the main ridge of Carboniferous rocks that extends northwestward through both quadrangles, the secondary ridge of Carboniferous rocks in the Paradise Valley quadrangle, and the general distribution of some areas of Mesozoic and Tertiary rocks and of the

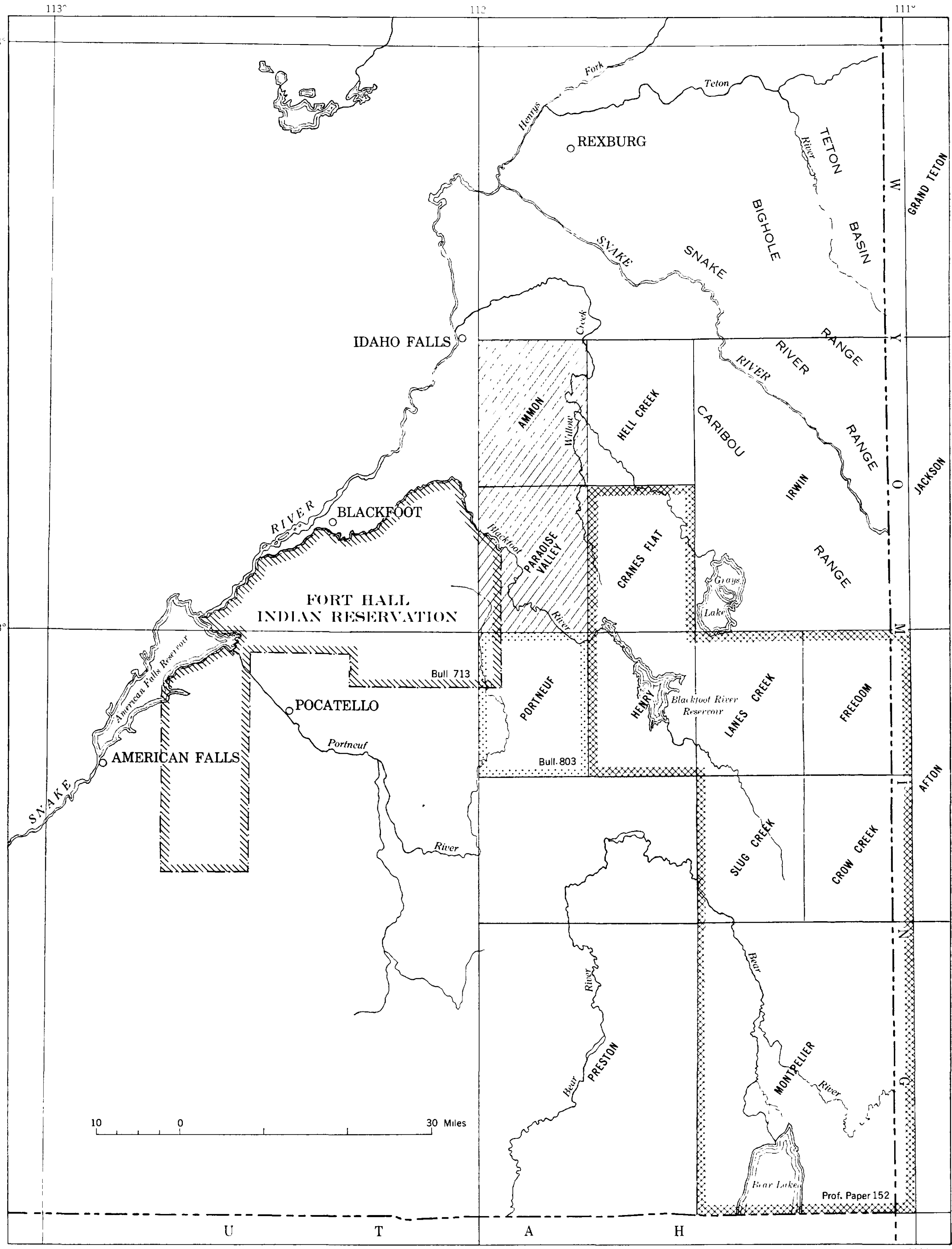


FIGURE 1.—Index map of southeastern Idaho, showing the location of the Ammon and Paradise Valley quadrangles with reference to other mapped quadrangles and to the Fort Hall Indian Reservation

igneous rocks. His report (St. John, 1879, pp. 321–508) gives brief descriptions of some of these features. His broad outlines still stand, but later, more detailed studies have brought out many features that he could not have hoped to see in his rapid reconnaissance and many distinctions that, for the same reason, he could not have made. Some of his work and interpretations will be discussed, but any apparent criticisms offered should not be construed as detracting in any way from his achievement in covering so large an area so well under the difficulties of travel and field work then existent.

LATER GEOLOGIC WORK

In 1911, after the close of the regular field season, Schultz and Richards (1913) spent three weeks in a geologic reconnaissance of a region comprising some 2,000 sq mi lying chiefly between the Blackfoot and Snake Rivers south of the latitude of Idaho Falls. The territory covered by this work included all of the Ammon quadrangle and most of the Paradise Valley, together with considerable country to the east, southeast, and south. During the reconnaissance Schultz and Richards were able to recognize many formations and structures familiar to them from their previous work in the phosphate field farther southeast. They noted the northwestward extension of the Bannock overthrust east of Mount Taylor in the Ammon quadrangle and mapped other faults. Their map, which was published on a scale of nearly 8 miles to the inch, was intended principaly to show the general occurrence and distribution of phosphate and coal beds within the area. The formations indicated on this map, though necessarily very much generalized, represented some advance in knowledge beyond St. John's work.

In 1913 the author and several associates mapped the Fort Hall Indian Reservation (Mansfield, 1920a), which adjoins the Paradise Valley and Portneuf quadrangles on the west and includes part of the Paradise Valley quadrangle. One result of this work was further subdivision of the Triassic formations, and several of the type localities of these subdivisions are in the Paradise Valley quadrangle or adjacent territory.

In 1917, while searching for coal, the author (Mansfield, 1920b) passed down Willow Creek into the northeastern part of the Ammon quadrangle, turned eastward to the Teton Basin, and then traveled northwestward across the Snake River Plain to the Continental Divide. This work disclosed Cretaceous beds in the valley of Willow Creek and threw light on some of the geologic and physiographic features there.

In 1923 Kirkham (1924), then of the Idaho Bureau of Mines and Geology, was studying the geology and oil possiblilties of a sizable tract in three counties of southeastern Idaho lying mostly to the north of the areas studied and mapped by the U. S. Geological Survey. Kirkham's report, which includes geologic maps of six quadrangles, contains many new stratigraphic and structural details in regions covered by St. John's mapping and thus marks a considerable advance over that work. His map of the Cranes Flat quadrangle covers an area previously mapped by the author and P. V. Roundy in 1916 and later included in the author's paper on southeastern Idaho (Mansfield, 1927). Kirkham's work on this quadrangle was done later than the author's, but the results were published earlier, giving it apparent priority. Although Kirkham had access to the author's manuscript map and published papers bearing on the quadrangle, his work nevertheless was largely independent, and it provided general confirmation of the author's interpretations.

Although his report includes no maps of the Ammon and Paradise Valley quadrangles, Kirkham discusses their geology briefly under the caption "The Idaho Falls-Blackfoot Peak area." As his work in that area was entirely of a reconnaissance nature, he could note only a few of the larger features, including the general distribution of the Carboniferous beds, the position of the Bannock overthrust (middle branch), and the general relations of the Tertiary sediments and lavas. The Cretaceous beds east of the Bannock overthrust, which he ascribed to the Wayan formation, are here considered members of the Gannett group, of which three are represented The Wayan formation is present, to be sure, but is farther east than indicated by Kirkham. The beds immediately east of the overthrust in the Mount Taylor area are Jurassic and not Cretaceous.

FIELD WORK LEADING TO PRESENT REPORT

The topographic control of the combined Ammon and Paradise Valley quadrangles was established by H. H. Hodgeson and E. M. Bandli about 1916. The topographic mapping of the Ammon quadrangle was done in part by C. G. Anderson in 1916 and in part by R. T. Evans and W. J. Lloyd in 1924. The topography of the Paradise Valley quadrangle was mapped by C. G. Anderson in 1916. The strip belonging to the Fort Hall Indian Reservation, comprising parts of Tps. 3, 4, and 5 S., R. 38 E., together with other parts of the reservation, was surveyed topographically in 1913 by C. G. Anderson on a field scale of 1:192,000. In the same year the Geological Survey field party in charge of the author made its geological survey of the entire reservation, mostly on a field scale of 1:31,680. The final map resulting from this work, however, was adjusted to Anderson's topographic mapping and published on a scale of 1:125,000.

In 1916 the author, with P. V. Roundy as assistant, mapped the geology of parts of Tps. 2, 3, 4, and 5 S., R. 40 E., in connection with the survey of the Cranes Flat and Henry quadrangles. In 1917 he examined certain coal prospects in eastern Idaho. These were mostly outside the area here described, but some of the prospects examined were in the northeastern part of the Ammon quadrangle and adjacent areas. In 1923 the author mapped the Portneuf quadrangle and extended his work into the southern and southeastern parts of the Paradise Valley quadrangle. W. B. Lang was the assistant that year. In 1925 geologic mapping of the Paradise Valley quadrangle was completed and that of the Ammon quadrangle begun; in 1928 the Ammon quadrangle was essentially completed. The field periods during these 2 years, during which W. B. Lang was again the assistant, were relatively brief. In 1930, 1935, and 1936, in connection with other work, the author revisited the two quadrangles for periods of about 2 weeks each to restudy and recheck certain doubtful areas. In 1935 he was accompanied for part of the time by James Steele Williams and W. D. Keller.

GEOGRAPHY

SUMMARY OF PHYSIOGRAPHIC DEVELOPMENT

In a previous report (Mansfield, 1927, pp. 11–20), the regional physiography of the country adjacent to the Ammon and Paradise Valley quadrangles on the east and southeast has been discussed at some length. Nine episodes in the physiographic development of southeastern Idaho were recognized and tabulated. This tabulation is repeated here for reference. In the author's paper on the Fort Hall Indian Reservation (Mansfield, 1920a), an earlier and less-extended interpretation was presented. This also is given in the table for comparison.

Episodes in the physiographic development of southeastern Idaho

Epoch	Professional Paper 152	Bulletin 713
Recent.	Postglacial.	Spring Creek cycle.
	Blackfoot cycle (St. Charles glacial episode).	Gibson cycle.
Pleistocene.	Dry Fork cycle.	Putnam cycle.
	Elk Valley cycle.	
	Gannett cycle.	
Pliocene.	Deposition of Salt Lake formation.	
Miocene.	Tygee cycle (?). Middle Miocene deformation.	
Eocene.	Snowdrift peneplain.	

Field study of the Ammon and Paradise Valley quadrangles has brought out the fact that, in common with adjacent parts of the region previously studied, these areas have had a complex erosional history. Some of the broader relationships are readily recognizable. For example, there is an old topography that affects the Blackfoot Mountains and some of their adjacent slopes, below which stand several sets of lower ridges and knobs, and these in turn are succeeded at lower altitudes by such broad valleys as those of upper Willow Creek and the upper Blackfoot River and Paradise Valley.

These broad valleys, however, are being further cut by sharp-featured canyons of generally youthful or early mature aspect, such as those of the Blackfoot River, Grays Lake Outlet, and Willow Creek. Other narrow and deep canyons, such as those of Wolverine and Jones Creeks, are not so obviously related to earlier broad valleys as those just mentioned, but here and there along them are remnants of earlier valleys at higher levels which may correspond to these broad valleys or to some of the older stages, though definite correlation with them is difficult.

At least four or five erosional stages are shown by a study of profiles taken at numerous places across the quadrangles, some without regard to topographic features and others principally along divides.

The oldest erosion surface preserved is found in the higher parts of the Blackfoot Mountains throughout much of their length, but it is especially well developed along the divides south of Wolverine Creek canyon in the Ammon quadrangle. A profile drawn from the mouth of Wolverine Creek canyon along these divides is shown on figure 2*A*. Its course is very irregular, because in general it follows the ridges except where it crosses Jones Creek. Its position is indicated by the line *a–b* on plate 1. The broad upland shown in this profile at an altitude of 7,200 to 7,400 ft is here considered to correspond to the Gannett erosion cycle given in the table. It is marked by broad, relatively shallow depressions or parts of former valleys and by intervening low knobs and ridges, and is thus in a stage of late mature development or in early old age. Its relief ranges from 200 to 400 ft or more. It is developed on numerous rock formations differing in hardness and in age. Mount Taylor in the Ammon quadrangle (the Blackfoot Peak of the Hayden Surveys) and the crest of the Blue Ridge in the Paradise Valley quadrangle represent the most conspicuous of the knobs and ridges that rise above this surface.

At least two and possibly more erosion episodes at lower levels seem to be recorded by the succession of lower knobs and ridges developed on older rocks that flank the east side of the Blackfoot Mountains. These lower surfaces may be considered to correspond in a general way to the Elk Valley and Dry Fork cycles mentioned in the table.

Conditions on the west side of these mountains are affected by the great accumulations of younger and weaker rocks along that side, so that comparison with conditions on the east side is uncertain. It might be presumed that, while such erosion surfaces as those of the Gannett, Elk Valley, and Dry Fork cycles were being developed on hard rocks, corresponding surfaces were produced on other areas underlain by weak rocks but at lower levels. Figure 3, which gives a view south-

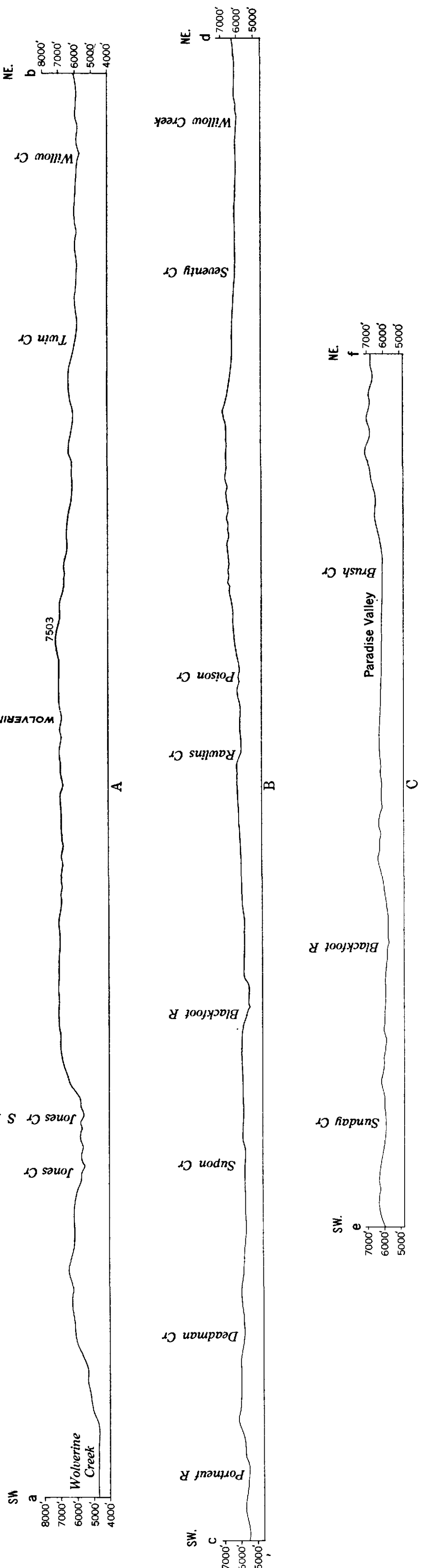


FIGURE 2.—Profiles across the Ammon and Paradise Valley quadrangles. *A*, Along the divides south of Wolverine Creek canyon, Ammon quadrangle (line *a–b*, pl. 1). Supposed erosion cycles: 5, Gannett; 4, Elk Valley; 3, Dry Fork; 2, Blackfoot. *B*, Northeast across the Paradise Valley quadrangle (line *c–d*, pl. 1). Erosion cycles same as for *A* with addition of 1, Spring Creek. *C*, Northeast across the southeastern part of the Paradise Valley quadrangle (line *e–f*, pl. 1). Erosion cycles same as for *B*.

westward down Miner Creek, shows four erosion surfaces developed on the weaker rocks along the west side of the Blackfoot Mountains. If the uppermost is considered the equivalent of the Gannett surface as developed on the weak rocks, the other three might correspond to the Elk Valley, Dry Fork, and Blackfoot cycles.

The Willow Creek lava field, Paradise Valley, and the Blackfoot River valley are believed to be in part at least of structural origin and to represent areas that were depressed with respect to adjoining ridges when the horst and graben structure to be described was developed. Their erosional development, however, apparently falls within the Blackfoot cycle of the table. Probably, too, much of the development of Wolverine Creek and Jones Creek canyons, both of which are 1,000 ft or more deep, falls within this cycle—as is probably true of the canyons of Henry Creek, Willow Creek, and other streams.

During the later stages of deposition of the Salt Lake formation, and after its deposition, volcanic activity in areas bordering the Blackfoot Mountains and some of the mountains farther south led to the emplacement of the earlier basalt flows, now tilted and faulted in places. These flows were more or less localized in areas bordering the larger valleys; for example, the basaltic hills in T. 4 S., R. 39 E., Paradise Valley quadrangle, apparently belong in this group. Later came the widespread deposition of the rhyolitic welded tuffs, erosional remnants of which overlie the older basalts here and there, as in secs. 20 and 21, T. 4 S., R. 39 E. The topographic relations of the welded tuff in the Ammon quadrangle, and especially in sec. 15, T. 3 S., R. 39 E., in the Paradise Valley quadrangle, suggest that the Blackfoot cycle of erosion may have been well advanced at the time this tuff was laid down. Both the earlier basalts and the welded tuffs are hard rocks, the slow removal of which has delayed the erosional development of the region, permitting the widening of valleys, such as Paradise Valley and the valley of Willow Creek, from which the filling composed of the relatively soft Salt Lake formation was being removed.

Then came the widespread outpouring of the flat-lying valley basalts that now occupy the Willow Creek lava field, Paradise Valley, and the Blackfoot lava field southeast of the Paradise Valley quadrangle. Judged from the high-level remnants that lie along the upper valley slopes of the Blackfoot River and Willow Creek, these basalts once extended across both quadrangles to the Snake River Plain, but they have largely been eroded away from the lower courses of both streams. A probable vent for some of this basalt in the valley of Willow Creek is represented by the volcanic plug in sec. 32, T. 1 N., R. 40 E., Ammon quadrangle (fig. 23), but erosion has now reduced this plug in elevation and separated it from any flow to which it may have given rise. Sheep Mountain, in Tps. 2 and 3 S., R. 41 E., Cranes Flat quadrangle, gave rise to much of the basalt in the Willow Creek lava field. Numerous basaltic craters in the Blackfoot lava field are mapped in the Henry quadrangle to the southeast (Mansfield, 1927); Paradise Valley was no doubt supplied in part with basalt from the Willow Creek lava field that entered the southeast end of the valley.

The removal of this basalt from the Blackfoot River valley, except for residual patches, has progressed up the main stream approximately to the site of Blackfoot Dam in the NE¼ sec. 12, T. 5 S., R. 40 E., Cranes Flat quadrangle, and up Brush Creek, a large tributary of the Blackfoot River from the east, as far as the escarpment that truncates Paradise Valley on the northwest in secs. 1 and 12, T. 4 S., R. 39 E., and northward. The transition from broad, open Paradise Valley to Brush Creek canyon, 350 ft deep, takes place within about three-quarters of a mile.

The canyon of Willow Creek begins at about the point where the creek enters the Ammon quadrangle. Although this canyon is mapped as being in basalt as far north as sec. 16, T. 1 S., R. 40 E., this may not be strictly correct. The canyon sides are mostly blocky talus, and there is reason to think that this may conceal beds of the Salt Lake or older formations.

During the period in which these broad valley flows were being removed, later flows coursed down some of the valleys. Remnants of at least one such flow have been found in Willow Creek canyon, as in secs. 8, 17, 20, and 33, T. 1 N., R. 40 E., Ammon quadrangle. Possibly the basalt flow in Taylor Creek, sec. 34, T. 1 N., R. 38 E., and southward, may belong in this episode. In the Blackfoot River canyon the latest flow, which is cut through in secs. 10 and 11, T. 3 S., R. 38 E., extends up the valley, presumably to the base of Blackfoot Dam. It is paralleled in places by remnants of a higher flow, intermediate in position between the present canyon top and the high-level basaltic remnants previously mentioned, as in sec. 14, T. 3 S., R. 38 E., and secs. 19, 30, 29, and 32, T. 3 S., R. 39 E.

Whether all the igneous episodes just described should be included in the Blackfoot cycle is questionable, but they seem to have accompanied the development of the Snake River Plain, which is contiguous with the Gibson terrace as described in the report on the Fort Hall Indian Reservation (Mansfield, 1920a, pp. 16–17), and to be older than the Spring Creek cycle of that report.

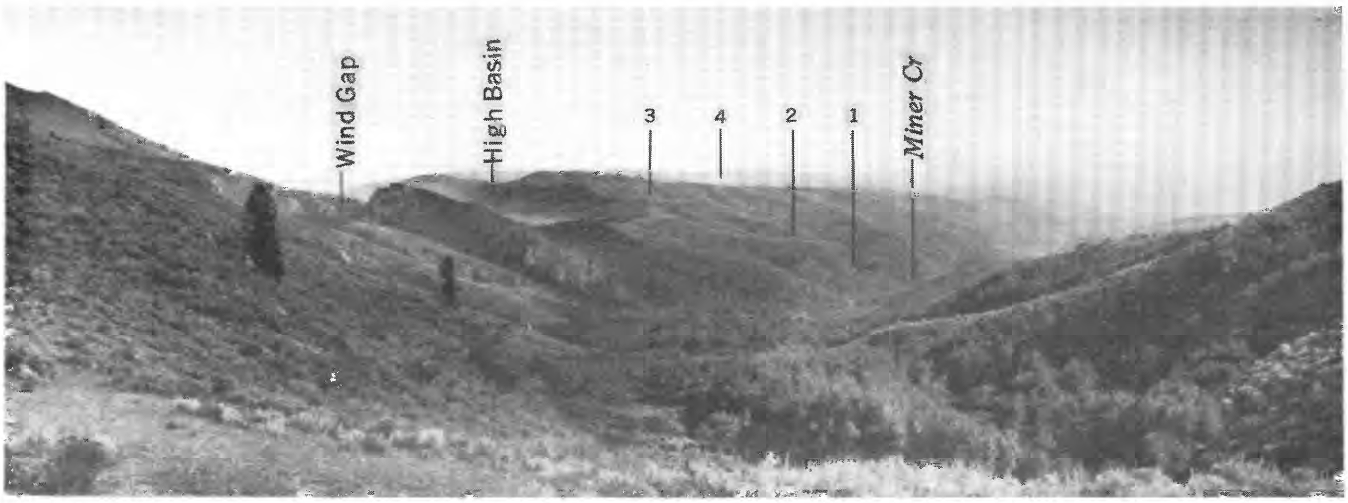


FIGURE 3.—Miner Creek area, looking south from about SE¼SE¼ sec. 28, T. 2 S., R. 39 E., Paradise Valley quadrangle. Supposed erosion cycles: 4, Gannett; 3, Elk Valley; 2, Dry Fork; 1, Blackfoot. Photograph by W. B. Lang.

PRINCIPAL TOPOGRAPHIC FEATURES

The principal topographic features in the two quadrangles from northeast to southwest are the Willow Creek valley, the Blackfoot Mountains, Paradise Valley, the Blackfoot River valley, the Chesterfield Range, the Portneuf Mountains, the Portneuf River valley, and the Snake River valley, which enters the northwest part of the Ammon quadrangle.

WILLOW CREEK VALLEY

The valley of Willow Creek lies along the entire eastern side of the Ammon quadrangle and along about two-thirds of the eastern border of the Paradise Valley quadrangle, in which it descends in altitude from about 6,500 to 6,150 ft. Willow Creek heads in sec. 1, T. 4 S., R. 40 E., only a mile or two east of Paradise Valley, but its valley is continuous southeastward with that of southeastward-flowing Meadow Creek, from which it is separated by only a low divide. The valley of Willow Creek is 4 or 5 miles wide for much of its course and is floored chiefly with basalt, especially in the

Cranes Flat and Paradise Valley quadrangles. This part of the valley has in consequence been called the Willow Creek lava field. Along the east side of the Ammon quadrangle, Willow Creek occupies a canyon. Below sec. 10, T. 1 S., R. 40 E., this canyon assumes an irregularly entrenched meandering course, the radii of the meanders ranging from half a mile to a mile or more in length. Where it leaves the Ammon quadrangle, the valley bottom is at an altitude of somewhat less than 5,100 ft. Willow Creek, therefore, descends more than 1,400 ft in its irregular course through the 24-mile strip along the eastern border of the two quadrangles.

In the Ammon quadrangle considerable basalt and some rhyolitic rocks are exposed in the canyon here and there, but the upland above the canyon is underlain largely by sedimentary rocks, tuffs, volcanic ash, and wind-blown materials. The rhyolitic rocks are largely welded tuffs and beds of volcanic ash of wide extent. It is uncertain how far the basalt extends beneath cover; nevertheless, from the exposures in the Hell Creek quadrangle to the east and in the Willow Creek and Blackfoot River valleys farther south, it is reasonable to assume that it was fairly widespread in the broad, shallow valley existing at the time of its extrusion.

Willow Creek is joined by Grays Lake Outlet near the middle of the east boundary of the Ammon quadrangle. The two creeks have much in common; both have cut entrenched meandering valleys in similar materials, and both have reached the same general late-youthful stage of physiographic development. A general view of the Willow Creek valley showing the canyon stage in relation to the earlier valley floor is given in figure 4. Figure 5 shows how Grays Lake Outlet, in entrenching its meandering course, has cut through the basalt that floored an older valley at the east end of Pine Mountain in the NW¼ sec. 4, T. 2 S., R. 41 E., Hell Creek quadrangle. Part of the basalt has been isolated and now caps a hill about 150 ft high.

BLACKFOOT MOUNTAINS

The Blackfoot Mountains, as defined by the writer (Mansfield, 1927, p. 34), extend northwestward nearly 30 miles from Wilson Creek and the Blackfoot River, in the southwest part of the Cranes Flat quadrangle; they are about 15 miles in greatest width in the southern part of the Ammon quadrangle. Most of their mass is included in the Ammon and Paradise Valley quadrangles, but they overlap slightly on the southeast, west, and north. The group as a whole is relatively low, reaching altitudes not greatly exceeding 7,000 ft. The highest point is an unnamed peak of the Blue Ridge in the SW¼ sec. 34, T. 2 S., R. 39 E., Paradise Valley quadrangle. This peak is shown to have an altitude of slightly more than 7,550 ft. Several other summits in the Blue Ridge are nearly as high, and in secs. 33 and 28, T. 3 S., R. 40 E., several exceed 7,400 ft. In the Ammon quadrangle the highest summit is Mount Taylor (7,414 ft) a well-known landmark in sec. 30, T. 1 S., R. 39 E., and there are summits nearly as high in secs. 9 and 10, T. 2 S., R. 39 E., a few miles farther south. The Blackfoot Mountains rise as much as 2,800 ft above the Snake River Plain on the west, but in the Paradise Valley quadrangle they are only about 600 ft higher than the Willow Creek valley on the east.

The broader physiographic features of the Blackfoot Mountains have been discussed in summarizing the physiographic development of the region. There are, however, two intermontane basins that deserve description—High Basin and Paradise Valley. The latter is large enough to be considered one of the principal topographic features of the area and is described under a separate heading.

FIGURE 4.—Willow Creek canyon southward from its rim in about north-central sec. 5, T. 1 N., R. 40 E., Ammon quadrangle. Two stages of canyon cutting are shown.

High Basin is in the north-central part of T. 3 S., R. 39 E., in the Paradise Valley quadrangle. It is flanked on the east by the Blue Ridge, which is composed of older, well-consolidated sedimentary rocks, and on the west by lower hills composed of younger and generally weaker rocks, including some of volcanic origin.

The basin itself is lined with a series of low slopes or benches which are partly dissected by the headwaters of Rawlins Creek. The surface represented by the benchlands possibly corresponds to the Blackfoot cycle of erosion, although it may correspond instead to the Dry Fork cycle. The younger valleys dissecting it may correspond to a late episode in the Blackfoot cycle induced by the partial removal of lava flows in the main Blackfoot River valley, to which Rawlins Creek is tributary.

FIGURE 5.—Basalt-topped hill partly enclosed by an entrenched meander of Grays Lake Outlet, east of Pine Mountain in the NW¼ sec. 4, T. 2 S., R. 41 E., Hell Creek quadrangle.

The basin has been beheaded at the north by Miner Creek, which provides a more favorable grade to the Blackfoot River. The upper course of Miner Creek seems once to have been continuous with what is now upper Rawlins Creek, but lower Miner Creek, cutting vigorously in weaker rocks on a shorter course, captured it at a point near the center of sec. 33, T. 2 S., R. 39 E. Faulting appears to have had some part in the procedure, for the wind gap in the SE¼ sec. 33 is out of line both with High Basin and with upper Miner Creek.

The east side of High Basin is relatively straight, and the slope upward to the summit of the Blue Ridge is steep. A topographic break between hard and soft rocks occurs along this line. Thus there are physiographic suggestions of a fault along the east side of the basin. Little geologic evidence of a fault here has thus far been recognized, however, and it is not believed that the west side of the Blue Ridge at this locality is a fault scarp.

PARADISE VALLEY

Paradise Valley is a noteworthy intermontane depression in the Blackfoot Mountains, occupying an area of a dozen or more square miles in the southeastern part of the quadrangle to which it gives its name. It heads in the Cranes Flat quadrangle, at an altitude of about 6,500 ft, about a mile southeast of the common quadrangle boundary. It trends northwestward between the higher and narrower ridge of the Blackfoot Mountains on the northeast and the lower and broader mass of the mountains on the southwest. About a mile wide where it enters the quadrangle, it broadens to nearly 3 miles where it is cut by the canyon of Brush Creek near the northwest corner of T. 4 S., R. 40 E. The valley is relatively flat floored and has a general altitude of about 6,300 ft. It is blocked by basalt at the southeast end, and basalt extends along its northeast side for nearly 4 miles, forming a low terrace where it enters the Paradise Valley quadrangle. The valley, about 9 miles long, terminates at the divide between Horse Creek and Brush Creek in about sec. 19, T. 3 S., R. 40 E.

It is perhaps significant that to the southeast the course of the Blackfoot River, as indicated by the linear northwest arm of the Blackfoot River reservoir, mapped in the Henry quadrangle, lies in the same straight line as the axis of Paradise Valley. The southeast end of Paradise Valley now stands 300 ft or more above the level of the reservoir, and the intervening slope is occupied by basalt. The Blackfoot River valley itself, in the Cranes Flat and Henry quadrangles, also has been extensively flooded with basalt. The Blackfoot River near the northwest end of the reservoir makes an abrupt rectangular turn from northwest to southwest, then curves around to the northwest again in the Portneuf and Paradise Valley quadrangles. Conditions here are therefore similar in some respects to those at the head of High Basin, but this comparison should await further field study. Faulting probably has played an important part in the existing relationships.

Brush Creek, after following an irregular course of 5 or 6 miles on the flat floor of Paradise Valley, flows off the floor and down through a canyon 350 to 500 ft deep. The creek thus furnishes the present outlet for the broad, flat valley. It is dissecting a considerable tract that may once have been part of the valley, and the canyon itself marks much of the northwest edge of the present Paradise Valley.

Paradise Valley is presumably in part a product of the Blackfoot cycle of erosion, but it is probably also in part of structural origin, for a concealed normal fault along the east side is believed to separate it from the east ridge of the Blackfoot Mountains, which is here considered a horst (p. 70). Between its broad floor and the summits of the northeast ridge of the Blackfoot Mountains, several sets of knobs and projecting points at different altitudes have developed on rocks of different ages, hardness, and structure. They perhaps represent eroded remnants of early, incomplete erosion surfaces. If the top of the range represents products of the Gannett cycle, as already postulated, the better-defined intermediate surfaces accord fairly well in position with surfaces cut in the intervening Elk Valley and Dry Fork cycles. Brush Creek canyon presumably represents a late episode in the Blackfoot cycle, induced by the erosion of basalt from the Blackfoot River valley.

Paradise Valley is probably underlain by basalt throughout most of its extent, although the basalt is largely concealed by soil and wash. Basalt is exposed in the southeastern part of the valley, at a few places along the southwest margin, in the bed of Brush Creek above its canyon, and along the top of the escarpment above Brush Creek canyon. The presence of this basalt has doubtless retarded the erosion of the valley and prevented Brush Creek from excavating the relatively weak rocks that underlie the basalt cover, as indicated by exposures along the canyon walls.

BLACKFOOT RIVER VALLEY

The Blackfoot River valley winds irregularly northwestward across the Paradise Valley quadrangle and forms the boundary between the Blackfoot Mountains on the northeast and the Chesterfield Range and Portneuf Mountains on the southwest. Its width in the area here described varies from less than half a mile to more than 2 miles. The Blackfoot River occupies a trench in the bottom of the valley, less than 50 ft deep where it enters the quadrangle but 350 ft or more deep where it leaves. The altitude of the valley floor within the quadrangle, exclusive of the canyon, is 300 to 800 ft lower than that of Paradise Valley.

The Blackfoot River valley and its environs exemplify more clearly than most other parts of the area the successive erosion episodes to which the region has been subjected. With the exception of a mile or two in the southeast part of the quadrangle, the valley is carved in weak sedimentary rocks and their accompanying volcanics, both massive and fragmental. The canyon, which is the latest feature, is of course youthful, and its youthful appearance is intensified by the basaltic cliffs and talus slopes that form the canyon walls in many places. The older parts of the valley, having been excavated largely in weak rocks, have relatively gentle slopes, which bring out effectively the relationships of the surfaces corresponding to the different erosion cycles.

Figures 6 and 7 give views northwestward from the junction of Brush Creek with the Blackfoot River and show Blackfoot River canyon with its irregular course incised in the floor of an earlier valley.

The profiles shown in figures 2*B* and 2*C* suggest five erosion episodes within the area. If, as seems probable, the floors of Paradise Valley and the older Blackfoot River valley, designated no. 2 in the profiles named, correspond with the neighboring Willow Creek and Blackfoot lava fields and with the Bear River valley in the Montpelier quadrangle farther south, they would represent the Blackfoot cycle, and no. 1 would represent a substage of that cycle. No. 3 would probably represent the Dry Fork cycle, no. 4 the Elk Valley cycle, and no. 5 the Gannett. The line of profile in figure 2*B* apparently misses any features resulting from the Gannett cycle. The profile, however, shows the slopes of

FIGURE 6.—View northwest down the Blackfoot River valley from a point in the SW¼SE¼ sec. 33, T. 3 S., R. 39 E., Paradise Valley quadrangle, showing remnant wedges of basalt flows (*a* and *b*) that have affected the development of the valley. Photograph by W. B. Lang.

FIGURE 7.—View down the Blackfoot River valley similar to that of figure 6 but taken from the next higher point, in the NW¼NE¼ sec. 4, T. 4 S., R. 39 E. This view shows the later canyon in the earlier valley floor. Photograph by W. B. Lang.

the older surfaces toward the Blackfoot River valley from both sides.

The principal reason for designating the floor of Paradise Valley and the older floor of the Blackfoot River valley as representative of the Blackfoot erosion cycle is that they have been invaded by flat-lying valley basalts, whereas in neighboring uplands there are older, dislocated basalts comparable to those described in the Cranes Flat quadrangle (Mansfield, 1927, pp. 167–168). It is thought that the extensive outpourings of basalt in the broader valleys, such as those cited, were approximately synchronous, geologically speaking, and took place at a late epoch in the Blackfoot cycle of erosion (Mansfield, 1927, pp. 17–19). In the Blackfoot River and Willow Creek valleys, still younger flows have occurred, and these have been trenched by later erosion (figs. 6, 7). That the basalt represented here is truly a late valley flow and not an earlier, widespread layer uncovered by erosion is shown by the relations indicated on figure 8, where the north edge of the flow may be seen wedging out against the side of the former enclosing valley. (See also fig. 6.) Farther down the valley, as shown in figure 9, the weak sediments (Salt Lake formation) on which the basalt was outpoured may be seen in characteristic exposure on the lower valley slopes. The valley into which the basalt flowed was shallower and wider than the present canyon.

CHESTERFIELD RANGE

The northern part of the Chesterfield Range, as previously defined by the author (Mansfield, 1927, p. 35), enters the south-central part of the Paradise Valley quadrangle from the Portneuf quadrangle, where it forms extensive uplands. In the Paradise Valley quadrangle, however, it comprises a group of hills 6,000 to 6,700 ft in altitude, dissected and more or less dismembered by branches of the Blackfoot and Portneuf Rivers. These streams serve as boundaries on the northeast, north, and west, except for the low divide west of Morgan bridge in sec. 19, T. 4 S., R. 39 E. The largest reentrant is the valley of Graves Creek, which, with its tributary Sunday Creek, broadens into a flat occupying 4 or 5 sq mi south of the Blackfoot River in the same township. This flat and its valley extensions presumably correspond in stage of topographic development to the Blackfoot cycle and the late-mature surfaces of the adjoining hills with the Dry Fork cycle.

PORTNEUF MOUNTAINS

The northeast tip of the Portneuf Mountains enters the Paradise Valley quadrangle from the southwest. As defined by the author (Mansfield, 1927, p. 37), these mountains terminate northward at the Blackfoot River. Southward they extend for nearly 70 miles, as far as the north end of Cache Valley, Utah. In the central part of their course they are relatively high and rugged, with summits probably exceeding 9,000 ft in altitude. They have not yet been mapped topographically or geologically except in the Fort Hall Indian Reservation,

FIGURE 8.—View down a small side canyon into the Blackfoot River canyon in sec. 10, T. 3 S., R. 38 E., Paradise Valley quadrangle. The valley flow of basalt (*b*) wedges out against the Salt Lake formation (*Tsl*). Note the bedding and "badland" erosion. Photograph by W. B. Lang.

FIGURE 9.—View down the Blackfoot River canyon from a point in sec. 10, T. 3 S., R. 38 E., Paradise Valley quadrangle. Basalt overlies the Salt Lake formation, which shows (light color) in the middle distance. Photograph by W. B. Lang.

the Portneuf and Paradise Valley quadrangles, and a few local areas. The highest summits in the Fort Hall Reservation are North and South Putnam Mountains, with altitudes, respectively, of 8,837 and 8,989 ft. The mountains are high enough in such places to preserve parts of the Gannett erosion surface. The part of the Portneuf Mountains that falls within the Paradise Valley quadrangle, however, is considerably lower and bears evidence of the lower erosion episodes. The rocks comprising the mountains as exposed in this quadrangle afford some variety, including older sedimentary rocks in the southwestern part with later sediments and volcanics of several kinds farther northeast. The area is being submaturely dissected by branches of the Blackfoot and Portneuf Rivers.

PORTNEUF RIVER VALLEY

The Paradise Valley quadrangle includes parts of the headwaters of the Portneuf River and a corresponding portion of the Portneuf River valley. This valley, though relatively constricted where the river leaves the quadrangle and for about 2 miles to the south, broadens sharply to a width of about 10 miles in the southern part of the Portneuf quadrangle, where it becomes continuous with the extension of the Bear River valley that lies west of the Bear River Range. The Portneuf River itself, however, turns west through a canyon cut in the Portneuf Mountains and joins the Snake River about 15 miles northwest of Pocatello.

The two principal forks of the Portneuf River in the Paradise Valley quadrangle join in sec. 26, T. 4 S., R. 38 E. The northwest fork heads against the divide above Lincoln Creek in the Fort Hall Indian Reservation about 6 miles farther northwest. Along its northeast side, northwest of the center of sec. 23, is a conspicuous row of low points apparently marking a dissected rock terrace. The points rise to altitudes of about 200 to 250 ft above the stream, and the accompanying ridge to the northeast rises about 400 ft higher. As the terrace is carved on rocks little different from those that constitute the ridge above, it doubtless represents a true erosion stage rather than differential erosion in rocks of unequal hardness.

The Portneuf River valley is considered to represent the Blackfoot cycle of erosion and is thus comparable to the Blackfoot River or Willow Creek valleys above their lower canyoned courses. In the Portneuf quadrangle, the Portneuf River valley has been widely flooded by basalt and is there comparable to the Blackfoot and Willow Creek lava fields mapped in the Henry and Cranes Flat quadrangles (Mansfield, 1927, pls. 2 and 3). The rock terrace mentioned may represent the Dry Fork cycle and the accompanying ridge the Elk Valley cycle.

The east fork of the Portneuf River in sec. 19, T. 4 S., R. 39 E., heads against a low divide about half a mile from the Blackfoot River near Morgan bridge. The Portneuf River valley is in general lower than the Blackfoot River valley. Within 1¾ miles from Morgan bridge, the Portneuf River descends 100 ft below the level of the bed of the Blackfoot River at the bridge, whereas the Blackfoot in its own course descends only 50 ft in nearly 2½ miles. Conditions are therefore developing for a capture of the Blackfoot by the Portneuf in the not very distant future, geologically speaking. A proposal has been made to hasten this process for the benefit of agriculture by tunneling through the divide for 3,820 ft, as indicated on the map, and diverting water from the Blackfoot into a ditch that would traverse the east side of the Portneuf River valley and deliver water to some 35,000 to 55,000 acres 30 miles or more away. This suggested improvement was part of a plan to supply water for the proposed Empire irrigation district (Mansfield, 1929, pp. 105–106).

SNAKE RIVER VALLEY

About 25 sq mi in the northwest part of the Ammon quadrangle is occupied by a part of the Snake River valley, one of the major topographic features of the State of Idaho. This valley begins at Henrys Lake in eastern Idaho and makes a broad crescentic sweep across the entire southern part of the State. It is in large part a lava plain, and those parts of it that can be irrigated are highly productive. Its complex history has been described by Stearns (Stearns, Crandall, and Steward, 1938). Within the Ammon quadrangle it is essentially a young lava plain with only minor irregularities of surface, overstrewn with gravels and alluvium. Its altitude is approximately 4,700 ft. A group of sand hills half a mile wide extends into the quadrangle for 1½ miles, occupying parts of secs. 3, 4, and 9, T. 1 N., R. 38 E. (fig. 10 and p. 47).

DRAINAGE

RIVERS

The drainage of the entire Ammon and Paradise Valley quadrangles is tributary to the Snake River, and most of it is delivered by Willow Creek, the Blackfoot River, and the Portneuf River. A few smaller creeks in the Ammon quadrangle are independent of these larger streams and deliver their water to large irrigation ditches.

Willow Creek enters the Paradise Valley quadrangle in sec. 15, T. 3 S., R. 40 E., and continues northward through the remainder of that quadrangle and through the Ammon quadrangle, lying generally within a mile or two of the eastern boundary of the area defined by the two quadrangles. Its larger tributaries from the east are Cranes Creek, which drains Cranes Flat in the adjoining Cranes Flat quadrangle, and Grays Lake Outlet, a stream comparable in size to Willow Creek at the point of junction. Grays Lake Outlet drains Grays Lake and the intervening territory for 30 miles or more to the southeast. Tex Creek, one of the more important eastern affluents, joins Willow Creek in the northeast corner of sec. 10, T. 1 N., R. 40 E., in the Hell Creek quadrangle. On the west, Willow Creek receives practically all the drainage from the east side of the Blackfoot Mountains, including, in the Paradise Valley quadrangle, Seventy and Mills Creeks. In the Ammon quadrangle eight fairly evenly spaced creeks yield permanent flows. From south to north they are Williams, Twin, Canyon, Birch, Squaw, Rock, Hatchery, and Badger Creeks. Squaw Creek joins Birch about three-quarters of a mile above its junction with Willow Creek.

The Blackfoot River drains most of the west side of the Blackfoot Mountains, together with the northeastern part of the Chesterfield Range and some of the northeastern part of the Portneuf Mountains. Its larger tributaries from the east are Brush, Miner, Cedar, and Wolverine Creeks. Brush Creek, with its tributary Rawlins Creek, drains much of the central part of the Paradise Valley quadrangle, including Paradise Valley itself. Rawlins Creek drains High Basin, and its tributaries Poison and Horse Creeks drain some of the higher parts of the main crest of the Blackfoot Mountains. Miner and Cedar Creeks drain the north-central part of the Paradise Valley quadrangle. Wolverine Creek, with its tributary Jones Creek, extends back into the broader and higher part of the Blackfoot Mountains and drains the southwestern part of the Ammon quadrangle. From the south the Blackfoot River receives the water of Graves Creek, which drains the northern part of the Chesterfield Range, and from the west the water of Deadman, Supon, and Beaver Creeks, which originate in the Portneuf Mountains. These streams are all in the Paradise Valley quadrangle.

The Portneuf River, which leaves the Paradise Valley quadrangle less than a mile east of its southwest corner, drains only about a dozen square miles within the quadrangle, an area lying partly in the Chesterfield Range and partly in the Portneuf Mountains. In this upper part of its course the river is a relatively insignificant and sluggish stream, considerably smaller than either the Blackfoot River or Willow Creek. It has no canyon here except for the contraction of its valley near its point of exit from the Paradise Valley quadrangle. In its lower course, in the Portneuf quadrangle, it receives the inflow from numerous large springs and thus becomes one of the most important tributaries of the Snake River within the plains area.

The principal independent streams are Taylor and Henry Creeks, which drain much of the central part of the Ammon quadrangle, reaching back into the northwest flank of the Blackfoot Mountains, and Sand and Little Sand Creeks, which lie entirely in the Snake River Plain and cross the northwest part of the quadrangle.

The Snake River does not enter the area discussed in this paper, but passes through the town of Idaho Falls about 1 mile west of the northwest corner of the area.

SPRINGS

Many springs have been found in the area covered by the two quadrangles or near its borders. As springs play an important part in supplying water for dry farming and for stock, those noted have been listed in the accompanying table. The actual number present is no doubt considerably larger than shown, because no special search for springs was made and in most instances only casual notice was taken of those observed.

FIGURE 10.—Secondary dunes in sec. 9, T. 1 N., R. 38 E., Ammon quadrangle. Note the wind ripples and curved front.

Springs in and near the Ammon and Paradise Valley quadrangles, Idaho

Date observed	Location	Temperature (F)	Remarks
Aug. 15, 1923, and Aug. 2, 1925.	Near SW. cor. sec. 18, T. 4 S., R. 38 E., about 3 miles west of Paradise Valley quadrangle.	44 (in 1925)	Small spring; constant flow; south of road about half a mile below and southeast of Portneuf River-Lincoln Creek divide, Fort Hall Indian Reservation.
Sept. 10, 1923	Secs. 4, 9, and 10, T. 5 S., R. 40 E., Paradise Valley quadrangle.		Several springs noted in straight-sided, southeastward-trending valley.
Sept. 14, 1923	Near center sec. 10, T. 4 S., R. 40 E., Paradise Valley quadrangle.		Springs on fault line.
Sept. 1923	SW¼ sec. 24, T. 4 S., R. 39 E., Paradise Valley quadrangle.		Good water; flow smaller than that of spring in NE¼ sec. 25.
Do	NE¼ sec. 25, T. 4 S., R. 39 E., Paradise Valley quadrangle.		Good flow; clear water.
Aug. 3, 1925	NW¼ sec. 1, T. 5 S., R. 40 E., Cranes Flat quadrangle.	72	In travertine east of road about a mile north of Blackfoot Dam.
Aug. 4, 1925	SW¼ sec. 13, T. 4 S., R. 38 E., Paradise Valley quadrangle.	50	Small spring; constant flow.
Do	NW¼ sec. 19, T. 4 S., R. 39 E., Paradise Valley quadrangle.		Small spring; good water; a few paces south of road.
Aug. 5, 1925	NE¼ sec. 13, T. 4 S., R. 38 F., Paradise Valley quadrangle.	66±	Water emerges from south ledge of outcrop of Timothy sandstone.
Aug. 12, 1925	On line between secs. 8 and 9, T. 4 S., R. 39 E., Paradise Valley quadrangle.		Near house shown on map a short distance north of the quarter corner.
Aug. 1925	NE¼ sec. 3, T. 4 S., R. 39 E., Paradise Valley quadrangle.		Spring deep in canyon; good flow of water.
Sept. 1925 and July 1928.	NE¼ sec. 13, T. 1 S., R. 38 E., Ammon quadrangle.		Heavy flow of water in east fork of Taylor Creek due to two springs, each with large flow.
Do	NE¼ sec. 18, T. 1 S., R. 39 E., Ammon quadrangle.		Small spring; northeast side of road, south of bend in Dry Creek.
Oct. 11, 1925	NE¼ sec. 4, T. 1 S., R. 40 E., Ammon quadrangle.	68	Spring on east bank of Willow Creek; flow about 30 gpm; yields odorless gas. See analysis.
Oct. 1925	SW¼ sec. 21, T. 1 N., R. 39 E., Ammon quadrangle.		In canyon at head of little flat; supplies water for ranch house.
Do	SE¼ sec. 28, T. 1 N., R. 39 E., Ammon quadrangle.		Moderate flow of good, clear water; source of "schoolhouse" fork of Henry Creek.
Do	SW¼ sec. 19, T. 1 N., R. 40 E., Ammon quadrangle.		Good water; strong flow, sufficient to fill 4-in. pipe; south side of Hatchery Creek. Other springs in creek bed for eighth of mile farther upstream (west), so that creek below springs has a large flow (100-200 gpm). Water soft; piped to old hatchery.
July 31, 1928	Secs. 4 and 5, T. 1 S., R. 39 E., Ammon quadrangle.		Springs in straight canyons between rhyolite hills.
Aug. 7, 1928	NW¼ sec. 6, T. 1 N., R. 40 E., Ammon quadrangle.		Small spring; good water; south of forks of road.
Aug. 8, 1928	NE¼ sec. 11, T. 1 N., R. 39 E., Ammon quadrangle.		Spring near house and west of road supplies small stream.
Aug. 1930	SW¼ sec. 14, T. 1 N., R. 39 E., Ammon quadrangle.		Fair flow; good water; in valley bottom about one-eighth mile west of Ozone in creek above schoolhouse.

The relationships of the springs to the terranes in which they occur have not been studied in detail. Many of them seem to be definitely associated with faults. The fact that most of those whose temperatures were measured are warmer than the mean annual temperature of the region (somewhat lower than 44 F) lends support to such a view. Others have no such apparent connection, particularly those that issue from the Salt Lake formation, which in many places occurs as a blanket on the older rocks.

Only two of the springs in the area here described would be classed as mineralized: the spring in sec. 4, T. 1 S., R. 40 E., and another in Miner Creek. A sample of water from the first-mentioned spring was analyzed with the following results:

Analysis of water from spring on east side of Willow Creek in NE¼ sec. 4, T. 1 S., R. 40 E., Ammon quadrangle

[Laboratory number, W. R. 3569. M. D. Foster, analyst]

	Parts per million
SiO_2	34
Fe	.38
Al	----
Ca	92
Mg	23
Na and K, calculated	2,806
CO_3	0
HCO_3	2,406
SO_4	3,045
Cl	910
NO_3	Trace
Total solids	8,246
Total hardness	324

This spring is a mile south of the basalt plug that forms a conspicuous landmark a mile west of the junction of Grays Lake Outlet with Willow Creek. The temperature of the water was 68 F on the day the sample was collected by W. B. Lang (Oct. 11, 1925). The water has a soft sweet taste, contains a gas which is liberated on shaking, and is charged with mineral matter containing a total of 8,246 ppm of dissolved solids (upon conversion of the bicarbonate to carbonate). It is a highly mineralized water with sodium sulfate, sodium bicarbonate, and sodium chloride as the chief constituents. The water is strongly alkaline, and it contained considerable gas (CO_2?) when the sample was collected. It is comparatively low in calcium and magnesium salts.

In sec. 15, T. 5 S., R. 40 E., about a mile south of the Paradise Valley quadrangle, a spring has built a small travertine deposit, and in the southwest part of the adjoining Cranes Flat quadrangle near the lower end of the Blackfoot River reservoir there are numerous thermal springs and considerable areas of travertine. The small travertine area in Miner Creek, in sec. 33, T. 2 S., R. 39 E., doubtless marks a thermal spring, but its location is masked by the creek, which flows in a narrow, brushy canyon at this point and mingles its waters with those of the spring.

SINKHOLES

A few sinkholes, some of which contained water, were noted in some of the areas underlain by the Salt Lake formation—for example, in sec. 9 and vicinity, T. 4 S., R. 39 E. In this locality pieces of rhyolitic welded tuff lie just below the rims of some of the sinks. Possibly calcareous beds of the underlying Salt Lake formation have been leached out beneath such areas. A somewhat similar process may account for the like occurrence in sec. 20, T. 2 S., R. 39 E.

CLIMATE

Climatic data for southeastern Idaho have already been included in published reports (Mansfield, 1921, pp. 75–92, and 1927, pp. 37–44). The pertinent information here given is taken from one of these earlier papers (Mansfield, 1927, pp. 39–41).

The data given, except for the Fort Hall and Blackfoot Dam stations, are based on records covering periods of more than 20 years and are fairly applicable to the Ammon and Paradise Valley quadrangles. However, with the exception of the Snake River Plain, the valleys of the Blackfoot and Portneuf Rivers, and parts of Willow Creek valley, the country covered by the present report is considerably higher than the stations in the table. The maximum difference is represented by the difference in altitude between Blackfoot or Fort Hall and the highest summit of the Blue Ridge, somewhat more than 3,000 ft. Undoubtedly the figures given for precipitation and snowfall are too low, and those for the highest and lowest temperatures, mean annual temperature, and length of growing season are too high.

Climatic data bearing on the Ammon and Paradise Valley quadrangles, Idaho

Station	Precipitation, mean annual (inches)	Average number of days having precipitation [1]	Annual snowfall, unmelted (inches)	Temperature (F)			Direction of prevailing winds	Length of growing season (days) [2]
				Highest average annual	Lowest average annual	Mean annual		
Blackfoot Dam	17.26	66	81.1	96	−42	37.8	SW.	48
Chesterfield	13.74	68	52.8	99	−48	40.0	W.	65
Fort Hall	9.81	76	28.1	100	−28	45.4	SW.	121
Pocatello	13.88	93	45.0	102	−20	47.5	SE.	158
Blackfoot	10.98	55	30.6	108	−32	44.6	SW	116
Idaho Falls	13.69	83	44.0	99	−33	44.5	SW.	118
Region [3]	13.96	77	62.4	99.2	−38.0	41.1	SW.	87

[1] Total of 0.01 in. or more.
[2] Average number of days between last and first killing frosts.
[3] Averages for these and six other stations in southeastern Idaho, plus five in Wyoming, weighted according to the length of record at each station.

For the area here described it is probably safe to assume that the mean annual precipitation is somewhat greater than 14 in., the mean annual temperature somewhat lower than 44 F, and the length of the growing season possibly 100 days or more.

VEGETATION [2]

The western slopes of the Blackfoot and Portneuf Mountains, as viewed from the Snake River Plain, seem relatively free of trees and quite barren. On closer approach, however, the slopes are seen to be largely covered with sagebrush (*Artemesia tridentata*), scattered low shrubs, and grasses. The east sides of the mountains and the northward- and eastward-facing slopes of the canyons, being somewhat more sheltered from the prevailing winds and from direct sunshine, are moister. Snow lingers later in such places, and vegetation is more abundant. Viewed from the east side, the area shows more wooded slopes and brushy areas, especially at higher altitudes. In the valleys the continuity of the sagebrush and associated vegetation is broken by meadows. The drier meadows support grasses, which, with the accompanying weeds, have a high forage value and consequently are utilized for grazing.

Mountain brush occurs along the canyons and on the slopes above the areas chiefly occupied by sagebrush. The most abundant species are buckbrush (*Symphoricarpos*), serviceberry (*Amelanchier* sp.), sagebrush, chokecherry (*Prunus melanocarpa*), and mountain-mahogany (*Cercocarpus parifolius*). With the exception of the sagebrush, all these species have forage value, and with the associated grasses and weeds they are good for grazing. Aspens and conifers are found at the higher altitudes above the mountain brush where more moisture is received and temperatures are lower. The two types may occur in either pure stands or mixed growth, where normally many species of brush are included.

The stands of aspen (*Populus tremuloides*) vary from dense patches of small gnarled trees that resemble brush thickets to more open groves of trees with trunks as much as 12 and 14 in. in diameter. The gnarled and brushy growths are usually found just below divides and and on the lee sides of mountains where they have been deeply covered, weighted down, and deformed by snow. Examples of the more open growths of large aspens are found on branches of Mill Creek, east of the Blue Ridge, in the northern part of the Paradise Valley quadrangle.

[2] This discussion is largely abstracted from a more detailed statement furnished by the Conservation Branch of the Geological Survey and by the Forest Service. See Mansfield, 1927, pp. 44–46.

The conifers are confined chiefly to the higher altitudes, although they are found in many of the canyons. The principal types are the Douglas fir (*Pseudotsuga taxifolia*) and the lodgepole pine (*Pinus contorta*). Associated with them in lesser numbers are the Engelmann spruce (*Picea engelmanni*), the alpine fir (*Abies lasiocarpa*), and the limber pine (*Pinus flexilis*). The Douglas fir, lodgepole pine, and Engelmann spruce attain their best growth and are more evenly distributed between the altitudes of 6,000 and 8,000 ft. The Douglas fir is the most valuable timber tree, but because of fires and for other reasons its numbers have been greatly reduced. The Douglas fir and to a lesser extent the lodgepole pine furnish some saw timber for local use. The lodgepole pine is favored in the construction of log cabins for ranch buildings.

ANIMAL LIFE

Bear, deer, and elk are seen in the mountains occasionally, and a few coyotes and wolves range the countryside. Rabbits and rodents are relatively abundant, and there are beavers in some of the streams, notably upper Miner Creek. Grouse of several species exist in diminishing numbers on the sage-covered slopes and in the wooded areas. Ducks and waterfowl are seen here and there, though their haunts are more remote. The streams have been fairly well depleted of fish; at one time a fish hatchery was maintained in Willow Creek valley, in sec. 19, T. 1 N., R. 40 E., but this has been abandoned for many years.

WATER SUPPLY AND MINERAL RESOURCES

Aside from its other natural resources, the area has water both for power and for irrigation and a considerable number and variety of nonmetallic mineral resources, such as phosphate rock, limestone, building stone, volcanic ash, road metal, sand, and gravel. Coal of poor quality has been found in a few prospects in and near Willow Creek valley in the northeastern part of the Ammon quadrangle.

SETTLEMENTS AND INDUSTRIES

The only settlement within the area described is the village of Ammon, in the northwestern part of the quadrangle of the same name. It had a population of 368 in 1940. In the adjoining Snake River Plain are several thriving towns and cities, of which Idaho Falls, with a population of 15,024 in 1940, and Blackfoot, with a population of 3,681 in 1940, are the nearest and the most closely related to the Ammon and Paradise Valley quadrangles. The principal industries are agriculture and grazing. Irrigated farms are scattered along the northwest base of the mountains, and irrigated fields extend out into the Snake River Plain. Several large ditches supply water from the Snake River, and smaller ditches carry the available runoff from the mountains. Potatoes and sugar beets are the principal crops raised under irrigation. A few ranches in the bottom of Willow Creek valley and in other valleys in the two quadrangles obtain limited supplies of water for irrigable crops, but dry farming is the principal agricultural method used in the area. Wheat is the chief crop raised by this method, though oats and rye also are grown. Before and during World War I, until it proved unprofitable, dry farming was fairly popular in the more open plains and on treeless slopes, especially in the northern part of the Ammon quadrangle. A few of the farms were still active, but most of them had been abandoned, when the area was last visited by the author in 1936. Much of the territory described is not settled, and the country is largely given over to sheep and cattle grazing.

Any industries developed will doubtless center about the nonmetallic mineral resources already listed. Road and structural materials are perhaps the most likely to receive early attention. The volcanic ash is available in large quantities and should be suitable for abrasives, acoustic plasters, cement admixture, cement blocks, and other uses. In addition, the phosphate reserves are an important future resource.

TRANSPORTATION FACILITIES

The Oregon Short Line Railroad, part of the Union Pacific system, utilizes the Snake River Plain for its lines to Butte, Mont., and the Yellowstone National Park. It serves Idaho Falls and other towns in the Snake River valley and passes within a mile of the northern part of the area covered in this report. Temporary local service is furnished during harvest time by the branch line that enters the northwestern part of the Ammon quadrangle.

Though there are roads and trails in most of the canyons, many are practically impassable for automobiles through lack of maintenance. Even the best roads are poor in comparison with modern highway standards. Most of them are not surfaced, and under bad weather conditions they become hazardous. Two roughly parallel routes extend in a general northerly direction in the eastern part of the area. One lies on lower and more open ground within a mile or two of Willow Creek and the other on higher ground in the eastern foothills of the Blackfoot Mountains. These roads connect the country to the southeast with Idaho Falls and points farther north in the Snake River valley. A route extending generally northwestward from Blackfoot Dam and the country to the southeast enters the Paradise Valley quadrangle through the

Blackfoot River valley. One branch turns west, roughly following the boundary line between Bingham and Bannock Counties, and connects through the Ross Fork road with Fort Hall. Another branch follows the northwest fork of the Portneuf River across the divide into Lincoln Creek in the Fort Hall Indian Reservation and connects with the city of Blackfoot. A third branch continues northwestward east of the Blackfoot River canyon and enters the Snake River valley above Blackfoot. Aside from the cross routes mentioned, the only east-west route available is by way of Wolverine Creek canyon and Williams Creek near the boundary between the two quadrangles. A former route by way of Cedar and Mill Creeks in the northern part of the Paradise Valley quadrangle is usable only by sheep outfits. West of the divide it was in fair condition, though steep, when last seen by the author in 1936, but the Mill Creek portion was so badly washed out as to be impassable.

STRATIGRAPHY

GENERAL FEATURES

A detailed description of the stratigraphy of the general area of which the Ammon and Paradise Valley quadrangles form a part has been given in an early report by the author (Mansfield, 1927), so that only brief descriptions of the formations represented and of differences noted in them are needed here. The record of the strata in the region as a whole spans geologic time from early Paleozoic to the present and indicates a total thickness of sediments approximating 46,000 ft. The story here begins with the lower Carboniferous (Madison limestone) and is fairly complete to at least the early part of the Upper Cretaceous. Tertiary formations are represented only by the Salt Lake formation (Pliocene?), which covers probably more than half the combined areas of the two quadrangles and blankets the older rocks to greater or less depths. Some products of volcanism are mapped with this formation, and the volcanic rocks themselves are associated with it. Four Quaternary formations have been differentiated, but with the exception of those in the Snake River Plain to the northwest and the broader parts of such valleys as Paradise Valley and the Blackfoot River valley they are not extensive. Volcanic rocks have played an important part in the story of this period also.

Plate 1 shows the distribution of the geologic formations within the area. The part falling within the Fort Hall Indian Reservation has been revised in the light of the more detailed topography now available and the wider experience and knowledge gained in the general area since the publication of the earlier report (Mansfield, 1920a).

The stratigraphy may be summarized as follows:

Stratigraphy of the Ammon and Paradise Valley quadrangles

	Feet
Quaternary:	
Recent: Alluvium.	
Pleistocene:	
Sand dunes.	
Hill wash and older alluvium.	
Travertine.	
Unconformity.	
Tertiary: Pliocene (?): Salt Lake formation: Chiefly conglomerate	0–800+
Unconformity.	
Cretaceous:	
Upper and Lower (?) Cretaceous: Wayan formation: Sandstone, shale, conglomerate, and limestone; only part of formation present; may include some beds of the Gannett group	1,500–2,000
Unconformity.	
Lower Cretaceous: Gannett group:	
Bechler conglomerate: Sandstone and conglomerate	1,000+
Peterson limestone (fresh-water)	200+
Cretaceous and Jurassic: Lower Cretaceous and Upper Jurassic: Gannett group continued: Ephraim conglomerate: Conglomerate, sandstone, shale, etc.; lower part Upper Jurassic	1,000+
Unconformity (?).	
Jurassic:	
Upper Jurassic:	
Stump sandstone (calcareous)	200–250
Preuss sandstone	500–550
Upper and Middle Jurassic: Twin Creek limestone (partly Middle Jurassic)	1,200–1,500
Unconformity (?).	
Lower Jurassic: Nugget sandstone	1,000–1,500
Triassic (?):	
Wood shale	200–250
Deadman limestone	150±
Higham grit	500±
Unconformity.	
Triassic:	
Upper Triassic: Timothy sandstone	200–800
Unconformity.	
Lower Triassic:	
Thaynes group:	
Portneuf limestone	1,500±
Fort Hall formation: Sandstone, shale, and limestone	1,000±
Ross Fork limestone	1,350±
Woodside shale	2,000±
Unconformity.	
Permian: Phosphoria formation: Chert and phosphatic shale and sandstone	500–650
Unconformity.	
Carboniferous:	
Pennsylvanian: Wells formation: Sandstone and limestone	2,500–3,000
Unconformity.	
Mississippian:	
Brazer limestone	2,000±
Unconformity.	
Madison limestone	1,100±

EARLIER PALEOZOIC FORMATIONS

Although not exposed in the Ammon and Paradise Valley quadrangles, early Paleozoic formations in a fairly complete sequence are present in the Portneuf quadrangle immediately to the south and presumably could be reached in those quadrangles by deep drilling. They are given in the following section, taken from the author's Portneuf report (Mansfield, 1929).

Early Paleozoic formations in the Portneuf quadrangle, Idaho

	Feet
Unconformity.	
Devonian:	
Upper Devonian: Three Forks limestone[3]	180
Middle Devonian: Jefferson limestone	935
Unconformity.	
Silurian: Laketown dolomite	485
Ordovician:	
Upper Ordovician: Fish Haven dolomite	700
Unconformity.	
Lower Ordovician:	
Swan Peak quartzite	700
Garden City limestone	1,130
Unconformity.	
Cambrian:	
Upper Cambrian: St. Charles limestone	1,300
Middle Cambrian:	
Nounan limestone	300±
Bloomington formation: Limestone and shale	400±
Blacksmith limestone	350±
Ute limestone	400±
Langston limestone	450±
Middle and Lower Cambrian: Brigham quartzite	1,000–1,600

CARBONIFEROUS SYSTEM

Carboniferous formations stretch diagonally northwestward through the area, entering the Paradise Valley quadrangle at the southeast and disappearing beneath a cover of Tertiary strata in the southwestern part of the Ammon quadrangle. In general, they form the core and higher part of the Blackfoot Mountains. They consist chiefly of limestones, more or less massively bedded, together with some sandstones and some cherty and shaly beds. Both series, Mississippian and Pennsylvanian, are present in considerable amount. The aggregate exposed thickness of the system is approximately 6,000 ft.

MISSISSIPPIAN SERIES

The Mississippian series includes the Madison limestone below and the Brazer limestone above. Both formations are characterized by rather pure limestone, but both include rock of other types and there are also faunal differences. The Mississippian series is well represented in a section measured north of Monroe Canyon in T. 7 S., R. 40 E., in the Portneuf quadrangle. It is given here because it is the only section available in the general vicinity of the Ammon and Paradise Valley quadrangles which gives both the bottom and the approximate top of the series. This section also contains Devonian and Silurian strata, which, as already stated, presumably underlie parts of these quadrangles at greater or less depth. The section was measured in a direction at right angles to the strike with a 5-ft rule to which a clinometer was attached. Offsets were made here and there along the strike in order to utilize more favorable ground for travel or to visit more favorable exposures.

[3] The change in spelling of "Threeforks" to "Three Forks" reflects a change in the Geological Survey's official usage since the publication of Bulletin 803.

Section of Paleozoic strata north of Monroe Canyon in secs. 32 and 28, T. 7 S., R. 40 E., Idaho

[Adapted from Bull. 803, p. 23]

	Feet
Concealed; top of section.	
[Brazer limestone]:	
36. Limestone float, bluish-gray, with low-lying ledges	5+
35. Limestone, massive, dense, medium-gray, fairly free from chert; corals and brachiopods of Brazer age	425
34. Limestone, dark bluish-gray, with cherty nodules; weathers sandy; strike N. 35° W., dip 45° E	80
33. Limestone, dark bluish-gray, cherty, streaked with calcite; coarser-textured and lighter gray in upper part; fossiliferous; strike N. 35° W., dip 68° E	100
32. Limestone, massive, gray, forming crest of ridge; cherty nodules; fossiliferous	230
31. Limestone float, gray, similar to beds below	160
30. Limestone, massive, bluish-gray; beds as much as 4 ft thick; chert nodules and bands about 20 ft above base	60
29. Limestone, massive, light-gray, relatively pure, fossiliferous	100
28. Limestone, very massive; sandy streaks; cross bedding	75
27. Limestone, light-gray, massive, but with some thin sandy beds; fossiliferous; many shell fragments 15 ft above base	120
26. Sandy and limy beds, yellowish, thin-bedded	58
25. Limestone, light-gray, massive, with chert streaks and nodules in bands at 4- to 6-in. intervals; fossiliferous	40
24. Limestone, dove-colored to drab, massive; beds 1 to 10 ft thick; strike N. 35° W., dip 40° E	42
23. Limestone, light-gray, sandy; weathers into angular blocks; strike N. 35° W., dip 25° E	108
22. Sandstone, weathering yellowish and reddish; thin-bedded; no ledges exposed; float intermingled with chert fragments; more calcareous toward top	405
21. Limestone, platy, sandy and cherty, weathering pink to purplish; indistinct fossils; freshly broken rock has odor of petroleum; no ledges	80
[Madison limestone:]	
20. Limestone, light-gray, thin-bedded; no ledges; weathers drab to pink or reddish	195
19. Limestone, gray, massive, finer and more sandy toward the top, float becoming thin-bedded and weathering drab to pink; Madison fossils	390

Section of Paleozoic strata north of Monroe Canyon in secs. 32 and 28, T. 7 S., R. 40 E., Idaho—Continued

	Feet
[Madison limestone:]—Continued	
18. Limestone, gray, more or less concealed by Salt Lake formation; strike N. 35°–40° W., dip 30° E	25
17. Limestone; massive bed, projecting through cover of Salt Lake formation; base of Madison (?)	2
[Three Forks limestone:]	
16. Debris of Salt Lake formation, covering older beds	10
15. Calcareous beds, reddish and yellowish; rather fine float, pieces usually no larger than 3 or 4 in. across; no ledges; much more reddish yellow near top	140
14. Limestone, gray, weathering pinkish or purplish, in pieces 1 ft or more in diameter; no ledges	30
[Jefferson limestone:]	
13. Limestone; gray ledges; individual beds as much as 1 ft thick; lower beds are limestone breccia; fine banding on weathered surface	70
12. Limestone, light brownish-gray, weathering to thin slabs; no ledges; finer float red, pink, drab, or yellow	295
11. Limestone, grayish-brown; beds 1 ft or more thick; finely banded; strike N. 30° W., dip 30° E	110
10. Limestone, brownish, highly fractured; a few chert nodules as much as 6 in. in diameter; beds as much as 1½ ft thick; finely banded on weathered surface	30
9. Limestone, massive, brownish-gray, much fractured; contains small linear and branching organisms and a few corals of Jefferson age	80
8. Limestone, light grayish-brown, massively but indistinctly bedded and highly fractured; black cherty patches	55
7. Limestone, like beds below but weathering smooth and fractured; fewer ledges	20
6. Limestone, massive; some beds as much as 3½ ft thick	77
5. Limestone, grayish-brown, massive; well-marked ledges	48
4. Limestone, dark brownish-gray, much fractured and seamed with calcite; beds 1 ft or more thick; Jefferson lithology; strike N. 35° W., dip 20° E	150
[Laketown dolomite:]	
3. Dolomite, gray, crystalline; no good ledges; Laketown lithology	120
2. Dolomite, massive, like unit 1; contains many poorly preserved fossils, some silicified, of Laketown age	250
1. Dolomite, gray, finely crystalline, massive; beds as much as 2½ ft thick; strike N. 40° W., dip 21° E	115
Covered area; base of slope and bottom of measured section.	
Total thickness	4,300

MADISON LIMESTONE

Though the base of the Madison limestone is not exposed in the area here discussed, it is known to rest unconformably upon the Devonian (Three Forks limestone) in the Portneuf quadrangle to the south. The eastern or lower parts of the belt are composed of massive bluish-gray fossiliferous beds, which form a series of knobs or knolls subordinate to the main ridge of Brazer limestone. West of these more massive beds are relatively thin platy beds of dark limestone that weather light gray and even pinkish. The thin beds are weaker and form sags and depressions between the knobs and the main ridge of Brazer limestone.

The principal ridge of Carboniferous rocks extending northwestward from sec. 15, T. 4 S., R. 40 E., in the Paradise Valley quadrangle, is mapped as Brazer limestone. However, at several localities the presence of Madison limestone was indicated, and a few poor collections of fossils were obtained here and there at such places. One such collection obtained on a low knoll south of the road and east of the divide in the SE¼ sec. 10, T. 4 S., R 40 E., is probably to be interpreted as of possible Madison age. According to G. H. Girty, it contained cephalopods of a type unknown in the Brazer limestone, but they were so poorly preserved that not even a generic identification could be made. The lithologic character of the fossil zone also was quite different from that of the Brazer. Girty was at first inclined to consider it Triassic, and fault relations observed immediately west of the ridge suggest that it might be the *Meekoceras* zone, exposed in a window on the east side of the ridge comparable to the one on the west side. However, the immediately adjacent rocks carry Brazer fossils, and no other evidence of a window on the east side of the ridge was recognized.

The dip of the Madison limestone ranges from about 38° to 61° W., and the strike is about N. 18° W. The average of two geometrical measurements gives a thickness of about 1,100 ft for the formation at this locality.

BRAZER LIMESTONE

Distribution.—The Brazer limestone plays a conspicuous part in the topography of the Ammon and Paradise Valley quadrangles, for it forms the greater part of the central mass of the Blackfoot Mountains in their diagonal course across the area. It extends without interruption from sec. 22, T. 4 S., R. 40 E., to sec. 21, T. 2 S., R. 39 E.; for about a mile it is concealed by Tertiary sedimentary and volcanic rocks. In the NW¼ sec. 20, T. 2 S., R. 39 E., it reappears and continues with varying width to sec. 34, T. 1 S., R. 38 E., where it again disappears beneath Tertiary cover. Two isolated exposures in the direction of strike in secs. 34 and 27 complete its northwestward extension. Wolverine and Jones Creeks in the Ammon quadrangle and Horse Creek in the Paradise Valley quadrangle cut deep and picturesque canyons in the Brazer limestone (fig. 11). The Blue Ridge, in which are the highest summits

FIGURE 11.—Gateway of Wolverine Creek canyon, in Brazer limestone, from a point on the south side near B. M. 6790, sec. 12, T. 2 S., R. 38 E., Ammon quadrangle.

within the area and the highest summit of the Blackfoot Mountains as a group, is largely composed of Brazer limestone.

In detail the outlines of the areas where the Brazer limestone is exposed are highly irregular. This is due in part to the fact that the outcrop of the Brazer is bordered by the trace of the Bannock fault for considerable distances (p. 67) and in part to its chance exposure through Tertiary cover.

Character.—As is true of the Madison limestone, the best continuous section of the Brazer limestone in the region adjoining the Ammon and Paradise Valley quadrangles is that in the west flank of the Chesterfield Range just north of Monroe Canyon in the Portneuf quadrangle. In the Monroe Canyon section beds here assigned to the Brazer limestone include nos. 21 to 36 and have a total thickness of 2,088 ft, not including the top of the formation, which is not exposed. Exposures in Little Flat Canyon, 2 miles to the northwest, however, indicate that the contact between the Wells formation and Brazer limestone is not far from the southwest edge of the Tertiary cover.

The cherty and phosphatic beds at the base of the Brazer limestone are represented by the 80 ft of beds in no. 21 of the measured section. Above these beds is 405 ft of thin-bedded sandstone, which is better exposed on the slopes southeast of the canyon, where there are well-marked ledges and where the change to the overlying massive limestone is rather abrupt. Although sandy beds have been noted elsewhere in the Brazer limestone, sandstone of this type is unusual in the formation. Possibly its absence in other localities may be due to the same unconformable relations that make the occurrence of the underlying cherty and phosphatic beds somewhat sporadic (Mansfield, 1927, p. 183).

The general lithologic character of the Brazer limestone in the Ammon and Paradise Valley quadrangles is similar to that in the Monroe Canyon section, but the two lower units at whose base the platy cherty beds with the petroleum odor occur, and the overlying 405 ft of thin-bedded sandstone, are absent or poorly developed. Also, near what appears to be the top at several places, as in the NE¼ sec. 33, T. 2 S., R. 39 E., and the NE¼ sec. 10, T. 3 S., R. 39 E., there is a development of green papery shales. In some places, as in the SW¼ sec. 27, T. 2 S., R. 39 E., fossiliferous gray limestone alternates with red sandy beds. Although the Brazer limestone is in general fairly distinctive lithologically and is easily recognized, it contains beds that may be confused with the overlying Pennsylvanian Wells formation or with the underlying Madison limestone. Fossils are rare or absent in large areas, though plentiful at some horizons. It is probable, therefore, that the general area mapped as Brazer limestone may locally contain parts of one or the other of the formations named. The lower part of the Brazer limestone in some areas, as in the Montpelier and Logan quadrangles farther south, is phosphatic. No beds of this type were recognized in the Brazer in the Ammon and Paradise Valley quadrangles.

The Brazer limestone here as elsewhere is characterized chiefly by massive, generally light-gray limestone that is prominent as a ridge and cliff maker (fig. 11) and in certain beds is highly fossiliferous.

Fauna.—According to G. H. Girty, corals play a much more prominent part in the Brazer fauna than in most faunas of Carboniferous age in North America. Especially conspicuous and characteristic are cup or horn corals, distinguished by their large size and numerous slender septa. Some of them have been referred at one time or another to *Cyathophyllum?* and to *Campophyllum*, but under more recent concepts of coral genera they may belong to some other genus. Large specimens attain a length of 8 in. and a diameter of 2½ in. In some beds they are very plentiful and are associated with slender tubular colonies (*Syringopora*) and with colonies of the *Lithostrotion* type, some forming hemispherical masses and others having a bushy habit. The massive forms all appear to belong to the genus *Lithostrotionella*, the others to *Lithostrotion*. Collections from a number of localities studied in 1924–28 are listed in an earlier report (Mansfield, 1929, p. 25).

Thickness.—The structural conditions within the Brazer limestone are in general unfavorable for accurate measurement of its thickness, as it is folded, faulted, or brecciated in many places. On the basis of dip measurements at favorable localities and the structure as worked out in structure sections (pl. 2), the Brazer in the area here considered appears to be about 2,000 ft thick.

PENNSYLVANIAN SERIES: WELLS FORMATION

Distribution.—All the rocks of the Pennsylvanian series as here mapped belong to the Wells formation, which, like the Brazer limestone, is a prominent ridge maker and is well exposed in several parts of the Blackfoot Mountains. It no doubt underlies much larger areas than are represented by the exposures, because much of the terrane in the two quadrangles is covered by Tertiary sedimentary rocks, volcanic materials, and outwash. The principal areas of exposure are two irregular strips in the southwestern part of the Ammon quadrangle, one of which extends into the adjoining north-central part of the Paradise Valley quadrangle; a relatively small area at the south end of the Blue Ridge in T. 3 S., R. 39 E.; two faulted areas that together occupy a narrow strip about 2½ miles long in the foothills of the Blackfoot Mountains east of Paradise Valley; a small area on the east flank of the Blackfoot Mountains at the line between Tps. 3 and 4 S., R. 40 E.; and a strip nearly a mile wide that extends northwestward from secs. 27 and 34 to sec. 20, T. 4 S., R. 40 E. The largest continuous area, however, extends northward from sec. 17, T. 2 S., R. 39 E., to sec. 13, T. 1 S., R. 38 E., and includes the Mount Taylor district, where the belt is nearly 2 miles wide. In the northern part of T. 2 S., R. 39 E., particularly in the Paradise Valley quadrangle, the Wells has become involved in some broken folds and is so much faulted that it forms numerous more or less distinct areas of exposure of different sizes.

Character.—The threefold division of the Wells formation noted in other parts of the region is observed in the Ammon and Paradise Valley quadrangles, but the red beds seen near the base of the Wells in some localities in the region have not been observed here. The lower beds of the Wells are massive limestones, generally more sandy and cherty than the massive beds in the upper part of the Brazer limestone. The cherts are either characteristically ovoid masses, 4 in. or more long and concentrically banded, or are irregular, though some bands and streaks are present. Locally cross-bedded sandy limestones have been silicified and partly replaced by chert. Branching bryozoans and the big brachiopod *Spirifer occidentalis* Girty are distinctive features of the lower part of the Wells.

The middle sandstone unit forms steep slopes strewn with debris but makes few ledges, or only inconspicuous ones, except in the steeper-sided gullies. Some of the beds are hard enough to be quartzites; others are softer and more sugary, and some are red or pink. The float fragments range from white or light gray to yellowish, tan, pinkish, or even red.

The upper siliceous unit forms prominent ledges or knobs along the hillsides. These ledges or knobs are emphasized by the relative weakness of the overlying phosphate shale beds. The unit consists of dense, calcareous, fine-textured sandstone that grades in places into a siliceous limestone. The rock weathers into white massive beds that are topographically conspicuous here and there as cliff makers. Bluish-white chert occurs in it locally in bands a few inches to a foot thick and in nodules. This bluish-chert phase is common in the Georgetown district farther south but has not been observed generally in the intervening region. It was noted, however, in upper Miner Creek in the Paradise Valley quadrangle. There a thin phosphatic bed or lens was observed in heavy chert bands ascribed in the field to the brecciated upper part of the Wells formation, though possibly it belongs to the Phosphoria formation. Toward the base of this division of the Wells the chert becomes more nodular and darker.

The extensive area, mapped as Brazer limestone, that extends northwestward from the eastern border of the Paradise Valley quadrangle into the southwestern part of the Ammon quadrangle includes a strip in T. 4 S., R. 40 E., whose lithologic character strongly suggests that it may belong to the Wells formation. This strip is nearly half a mile wide and 5 miles long, and for much of that distance it is bounded on the west by folded and faulted Triassic beds. Such fossils as have been found in it resemble those of the Brazer limestone. Hence the strip is mapped as part of the Brazer in spite of its lithologic character.

Relation of Wells formation and Brazer limestone.—The Wells formation in the Ammon and Paradise Valley quadrangles is believed to lie unconformably on the Brazer limestone. This belief is based on the fact that here, as in other parts of the region studied by the author, certain beds included in the upper part of the Brazer, such as the greenish shales, are present only locally. In other parts of the region fossiliferous beds, such as the *Martinia* beds mentioned by Girty (Mansfield, 1927, p. 71), have been found in only a few places. Moreover, the lower unit of the Wells formation, which is composed largely of sandy and cherty limestone, varies greatly in thickness from place to place. Contacts between the two formations are generally concealed. In secs. 6 and 7, T. 2 S., R. 39 E., Ammon quadrangle, the contact forms part of the west branch of the Bannock overthrust. In T. 4 S., R. 4 E., the contact is considered unconformable because of the discordance in strike of the two formations. However, local brecciation along this contact suggests that a minor fault may be present. If a fault is present, it may account for the discordance in strike.

Fauna.—In his discussion of the Wells fauna, Girty (Mansfield, 1927, p. 73) writes: "In my own judgment the probabilities are that the Wells covers both Pottsville and post-Pottsville Pennsylvanian, but that, in so far as it is represented by paleontological collections, it does not cover a considerable part of the later Pennsylvanian." Fossil collections made from the Wells formation were identified by Girty in 1924–28 (Mansfield, 1929, p. 27). A list is given in the author's paper on southeastern Idaho (Mansfield, 1927, pp. 73–75).

Thickness.—Although the Wells formation occurs in areas of considerable extent in both the quadrangles here discussed, no place was found where both its top and its bottom were exposed. Moreover, because of folding, faulting, and brecciation, it is not clear how continuous the section at a given place may be. No detailed measurements were made in these quadrangles, but at its type locality at Wells Canyon, T. 10 S., R. 45 E., in the Crow Creek quadrangle, it is 2,400 ft thick. In the general area of the type locality, the lower massive limestone unit ranges in thickness from 100 to 750 ft, the middle sandy unit from 1,700 to 1,800 ft, and the upper siliceous unit from a few feet to about 75 ft. The general arrangement and thickness of these units in the Ammon and Paradise Valley quadrangles are comparable to those in the region of its type locality. On the basis of mapping and of the structure sections made from measurements of available dips and strikes (pl. 2), the general thickness of the Wells formation in these quadrangles is 2,500 to 3,000 ft.

RELATION OF CARBONIFEROUS TO PERMIAN

Prior to 1912, the beds included in the upper division of what is now the Wells formation in southeastern Idaho were considered part of the Park City formation, whose type locality is at Park City, Utah. Girty (1910, pp. 6, 7) refers to them as the "lower *Productus* limestone." However, in that year Richards and Mansfield (1912), following an earlier suggestion by Girty (1910, p. 7), excluded them from the Park City and included them with more than 2,000 ft of underlying beds in the newly named Wells formation because of an unconformity generally recognized in southeastern Idaho at the base of the phosphate shales. The shales and the overlying limestones and cherts of the Park City formation in Idaho were referred to the Phosphoria formation named at the same time.

Recent work by Baker and Williams (1940) in the Wasatch Mountains east of Provo, Utah, has shown that the Permian formations in the Hobble Creek area comprise five units, of which the upper three are thought to correspond with the Park City formation at its type locality; the other two, the Diamond Creek sandstone and the Kirkman limestone, are absent there. The Park City formation in the Hobble Creek area is much thicker than at the type locality. In its lowest unit *Productus* (*Dictyoclostus*) *ivesi* Newberry is abundant. This fossil is regarded as characteristic of the Permian Kaibab limestone of the Colorado Plateau. The Diamond Creek sandstone, which conformably underlies the Park City formation, is thought to be continuous with the Permian Coconino sandstone of the San Rafael Swell, Utah. The Diamond Creek sandstone is conformably underlain by the Kirkman limestone in the Hobble Creek area, but eastward the sandstone seems to grade laterally into the limestone. The Kirkman limestone at many localities contains a breccia at its base, and it also contains oolitic phosphate locally.

In the vicinity of Hobble Creek the Kirkman limestone is underlain by the Oquirrh formation, which consists of interbedded quartzite, limestone, and sandstone, in large part if not entirely of Pennsylvanian age. However, some geologists think that the boundary between Pennsylvanian and Permian lies within the quartzite series of the Oquirrh because the fusulinid *Pseudoschwagerina*, considered by some to be a Permian index fossil, has been found in the upper part of that formation. The thickness of the Permian formations in the Hobble Creek area, not including any of the Oquirrh, apparently exceeds 4,000 ft.

In southeastern Idaho the Phosphora formation in some places lies upon the upper division of the Wells formation, but elsewhere this division is reduced to only a few feet or is entirely lacking. On this basis the Wells and Phosphoria have been considered unconformable.

If the upper division of the Wells is to be correlated with the lower part of the Park City formation of Hobble Creek and considered Permian, the boundary between the Permian and Pennsylvanian in southeastern Idaho might be tentatively placed at the top of the second division of the Wells, which would accord with the top of the Weber quartzite as used in the earlier mapping by Gale and Richards (1910) and by Richards and Mansfield (1911). The supposed unconformity between the Wells and Phosphoria formations would then lie within Permian strata. However, if *Pseudoschwagerina* or some other fossil of Permian aspect should be considered indicative of Permian age and should be found within the middle or lower divisions of the Wells formation, as its occurrence in the Oquirrh formation would suggest that it might, it would be an almost hopeless task to draw a satisfactory geologic boundary between the Pennsylvanian and the Permian. As the Phosphoria formation is easily recognized and lends itself well to geologic mapping, it seems desirable to retain it as a cartographic unit. For the purposes of this report, the term "Wells" also is retained, together with its mapping, with the understanding that the upper division is probably Permian and that some of the underlying beds also may prove to be of that age.

PERMIAN SYSTEM

The Permian system in the United States is considered by many geologists to be best developed in the Glass, Delaware, and Guadalupe Mountains of western Texas, where King (1942) and others have divided it into five series that have at least provincial significance. In Utah, east of Provo, and in the Colorado Plateau, Baker and Williams (1940) also have divided the Permian into five units, but their Utah section has not been definitely correlated thus far with that of King. The principal index fossil of the lowermost of the units of western Texas, the Wolfcamp series, is the fusulinid *Pseudoschwagerina*. The unit is considered Permian by some and Carboniferous by others and is classified as Permian or Carboniferous by the Geological Survey. In the Utah section, *Pseudoschwagerina* is found well within the Oquirrh formation, which underlies the lowermost Permian formation of Baker and Williams, the Kirkman limestone. The Oquirrh formation is not yet divisible on any satisfactory basis. The Utah section of the Permian is thicker than the western Texas section and will probably become the standard for the Rocky Mountain region. Some geologists have advocated making the western Texas section standard for the United States, but the difficulties of correlating this section with that of Utah and both these sections with that of the eastern United States show that the time is not ripe for establishing a standard for the entire country.

In southeastern Idaho, if the upper division of the Wells formation is considered Permian, it would probably be better to abandon the name "Phosphoria formation" and revert to the name "Park City formation." However, for the purposes of this report the name "Phosphoria" is retained because it is not feasible to remap the Ammon and Paradise Valley quadrangles to make the change and because the Permian age of the upper limestone unit of the Wells formation is not definitely established. The Phosphoria formation is readily recognized and easily mapped, and its base serves as a convenient geologic boundary. The upper division of the Wells could probably be mapped separately, mainly on the basis of its lithologic character, and added to the Phosphoria to conform with the needs of a reintroduction of the term "Park City." It would be difficult to do this, because at some places the upper part of the Wells formation is so sandy that it is distinguished with difficulty from the middle division. Furthermore, if a separation were made, some uncertainty would still remain as to whether other beds of Permian age might be present in lower parts of the Wells. On the basis of the evidence in Utah, it is possible that the actual boundary between the Permian and Pennsylvanian may lie at some horizon within the sandstone of the middle division of the Wells and be determinable only on the basis of scarce paleontological data.

PHOSPHORIA FORMATION

The Phosphoria formation, though not of great thickness in southeastern Idaho, maintains a nearly uniform character over wide areas. The rocks are exposed in narrow bands along the flanks of some of the larger, simpler folds in more complex crumplings in smaller folds, and along the borders of faulted areas. The Phosphoria formation is of great economic and scientific interest because it contains the extensive deposits of high-grade phosphate rock that, next to water, perhaps constitute the chief natural resource of the region and because it presents several unusual stratigraphic and chemical problems. In the Ammon and Paradise Valley quadrangles, as in the rest of southeastern Idaho, the formation is divided into the phosphate shale member below and the Rex chert above.

DISTRIBUTION

The Phosphoria formation enters the Paradise Valley quadrangle from the Cranes Flat quadrangle in the southeast corner of sec. 34, T. 4 S., R. 40 E., and extends northwestward in a band about 3 miles long and a quarter of a mile in maximum width. It is bounded on the southwest by a fault. In secs. 32 and 29, T. 3 S., R. 40 E., are several tiny, faulted synclines that contain what might be called "pinches" of the phosphate shale. In sec. 22, T. 2 S., R. 39 E., and extending northwestward into sec. 8 of the same township, the Phosphoria formation is caught in one or more anticlinal folds that have been shattered into relatively small fragments by faults. From sec. 8 the Phosphoria passes northward for about 4 miles in a somewhat irregular band affected by minor folds and faults along the east flank of the anticline that culminates topographically in Mount Taylor in the Ammon quadrangle. Another band about 2½ miles long, mostly north of Wolverine Creek, borders the west flank of the same anticline. A third band about 2 miles long lies along the south border of secs. 33 and 34, T. 1 S., R. 39 E., and overlaps the township line southward.

PHOSPHATE SHALE MEMBER

Though the phosphate shale member of the Phosphoria formation is readily recognized by float fragments in the areas where the formation occurs, no good natural exposures of it are available. However, several openings have been made by Geological Survey personnel in the course of prospecting to obtain samples for analysis. The sections measured at these localities are given in the descriptions of the townships that contain phosphate reserves. The most detailed measurements of the phosphate shale in southeastern Idaho prior to the work on the Ammon and Paradise Valley quadrangles were made from 1909 to 1912, when more prospecting was being done and exposures were better. Many measurements made during this period are given in the author's general report on southeastern Idaho (Mansfield, 1927).

In more recent years Geological Survey parties, first financed by Public Works Administration funds and later carrying on investigations connected with World War II, have done much detailed phosphate prospecting in southeastern Idaho. Since Professional Paper 152 and Bulletin 803, however, only one brief report has appeared (Gardner, 1944); otherwise the results of this work have not been released for publication.[4]

The following measured section is in the NE¼SE¼ sec. 10, T. 6 S., R. 42 E., in the northeastern part of the Henry quadrangle. This locality is the closest to the Ammon and Paradise Valley quadrangles of the three that were prospected by Survey workers in 1912, after special funds had been made available, by means of long trenches made with plow and scraper.

Section across phosphate shale member of Phosphoria formation in NE¼SE¼ sec. 10, T. 6 S., R. 42 E., Henry quadrangle

[Adapted from Professional Paper 152, p. 233. Field no. of specimen, M–355–12]

	Ft.	in.
Chert (base of Rex), oolitic and somewhat sandy, with a few discoid fragments.		
Shale, brown, broken	11	6
Sandstone, brown, broken, and partly covered with calcareous coating	27	0
Phosphatic shales and shales only slightly phosphatic	1	2
Yellow earthy zone		6
Phosphate rock, much broken, in beds half an inch thick, medium to finely oolitic	1	6
Yellow earthy zone		8
Phosphate rock, medium-oolitic, in beds ½ to 1½ in. thick and in fragments coated white; sample 4 contains 32.75 percent P_2O_5, equivalent to 71.50 percent $Ca_3(PO_4)_2$	2	0
Sandstone and shale, brown to black, much broken and coated with calcite near top; nodule 2 ft in diameter noted; fine shale at top	10	6
Covered zone with fragments of brown nodular sandstone	6	6
Shale, chiefly thin-bedded and brown, somewhat nodular, and apparently cherty near base	10	6
Sandstone, broken, with some shale, all in broken pieces	7	6

[4] See also Deiss, Charles, 1949 [1950], Phosphate deposits of the Deer Creek-Wells Canyon area, Caribou County, Idaho: U. S. Geol. Survey Bull. 955–C.

Section across phosphate shale member of Phosphoria formation in NE¼ sec. 10, T. 6 S., R. 42 E., Henry quadrangle—Continued

	Ft.	in.
Earthy zone, consisting chiefly of broken brown shale and some thin fragments of fetid limestone, all streaked and covered with white calcareous coating	7	6
Shale, brown, broken and containing some phosphate, all badly weathered	6	6
Yellow, powdery, earthy zone		8
Shale, black, broken, much iron-stained; beds ⅛ in. thick with 3-in. cherty layer at top	2	3
Limestone, brown, sandy, fetid, and much broken	2	0
Shale and phosphate rock, broken and weathered to black earth with white calcareous streaks; pass upward into broken shale	3	0
Sandstone, brown, calcareous, in broken beds ½ to 3 in. thick and coated with calcite	2	6
Shale, brown, in beds ⅛ to ½ in. thick, much broken	3	0
Limestone, sandy, weathering yellow	1	0
Limestone, brown, fetid		6
Shale, brown, much broken and containing two or three thin beds of dark limestone coated with $CaCO_3$ and $CaCO_3.P_2O_5.n(H_2O)$? (collophanite); gastropods found in one piece of shale	11	0
Earthy black soil, apparently a mixture of weathered phosphate and shale with phosphate predominating	3	0
Limestone, fetid, dark-brown to black; some pieces coated with $CaCO_3$ and collophanite ? and the whole mass partly exposed and broken	19	0
Broken zone, chiefly brown shale, like above	5	0
Shale, brown, somewhat phosphatic and containing at least two beds of phosphate 2 in. thick	3	0
Phosphate rock in beds ⅛ to 2 in. thick; black, weathering brown, with thin shaly seams; finely to medium oolitic. Thicker beds, broken and sprinkled with sandy yellow spots:		
Sample 3 represents lower part; contains 27.21 percent P_2O_5, equivalent to 59.42 percent $Ca_3(PO_4)_2$	2	6
Sample 2 represents middle part; contains 31.21 percent P_2O_5, equivalent to 68.12 percent $Ca_3(PO_4)_2$	2	0
Sample 1 represents upper part; contains 26.84 percent P_2O_5, equivalent to 58.58 percent $Ca_3(PO_4)_2$	2	0
Broken rock, chiefly fragments of brown shale with some pieces of underlying limestone; chert of underlying limestone and soil	20	0
	175	9

The stratigraphic character of the phosphate shale member in the area of the present paper is fairly well indicated by the accompanying section. The "Cap lime" of the Montpelier and Georgetown areas was not identified in any of the openings made, but from the fact of its occurrence in sec. 36, T. 5 S., R. 38 E. (Mansfield, 1920a, p. 40), about 4 miles south of the Paradise Valley quadrangle, it might well be expected here. The phosphate shale member, lying between massive limestone below and massive chert beds above, has served as an adjustment zone. Where the formation has been strongly folded, the movements within the phosphate shale member have in many places sheared and faulted the phosphate beds and made them locally unfit for commercial exploitation.

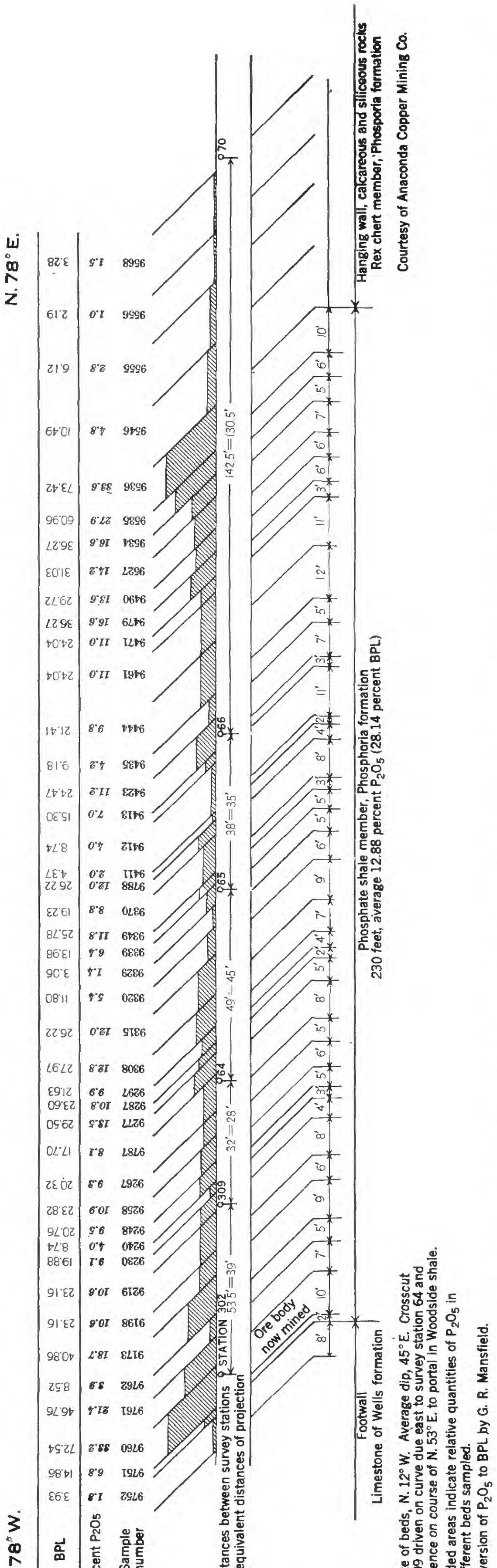


FIGURE 12.—Longitudinal section (vertical projection), showing the phosphate contents of strata penetrated by crosscut 509 of the Anaconda Copper Mining Co.'s mine at Conda, Idaho, in sec. 13, T. 8 S., R. 42 E. Altitude, 6.825 ft.; scale, 1 in.=10 ft.

Fauna.—The characteristic dark phosphate rock itself is practically nonfossiliferous. *Lingulodiscina* is found here and there near the base of the main phosphate bed, as is an occasional fish spine. The principal fossil collections have been made from the "Cap lime" of the Montpelier district. In the author's report on the Portneuf quadrangle (Mansfield, 1929, p. 29), Girty listed the fossils he considered representative. Further discussions of the fauna are given in Girty's own report (1910) on the phosphate beds of the Park City formation and the report on southeastern Idaho by the author (Mansfield, 1927, pp. 78–81).

Thickness.—The thickness of the phosphate shale member is about 145 ft in the southeastern part of the Paradise Valley quadrangle, as shown by the section in the SE¼ sec. 34, T. 4 S., R. 40 E., given on page 86. In the northern part of this quadrangle and in the Ammon quadrangle it is apparently somewhat less. A measurement of 90 ft was obtained in sec 22, T. 2 S., R. 39 E. The greatest thickness of phosphate shale observed by the author in any part of the Idaho phosphate field is in the tunnel of the phosphate mine of the Anaconda Copper Mining Co. at Conda, Idaho. This tunnel cuts 230 ft of beds between the footwall of the Wells formation and the hanging wall of the Rex chert member of the Phosphoria formation (fig. 12).

Analysis.—Analysis of 43 samples by the phosphate laboratory of the Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C., shows an F content ranging from 0.09 to 3.58 and an $F:P_2O_5$ ratio ranging from 0.0709 to 0.1449. The sample with the highest F content was also highest in P_2O_5 (33.98 percent), but the sample with the highest $F:P_2O_5$ ratio was low in P_2O_5 (3.24 percent). Results were calculated on a moisture-free basis at 105 C.

REX CHERT MEMBER

Distribution and character.—As usual in this region, the Rex chert member is the conspicuous unit of the Phosphoria formation topographically. It stands out in cliffs, ledges, and knobs, whereas the softer phosphate shale member is represented by sags, depressions, and gullies. In the Ammon quadrangle some beds of the Rex form walls 10 ft or more thick (figs. 13, 14). The limestone facies present in the Montpelier district is not represented here, though some of the coarser-textured and more quartzitic beds have a tendency to be limy, a feature that locally makes it difficult to distinguish them from beds of the Wells formation. Such, for example, are the beds that constitute the low knoll on the side of Wolverine Creek canyon in the NE¼ NE¼ sec. 32, T. 1 S., R. 39 E. These beds were at first considered Wells but were referred to the Rex after this facies had been more broadly recognized.

In the Miner Creek basin, near the northern boundary of the Paradise Valley quadrangle and northward in the Ammon quadrangle, beds of quartzite form part of the lower part of the Rex. The quartzite here is lighter-colored than the Rex in general and more suggestive lithologically of some beds of the Nugget sandstone or even of the Wayan formation. Nevertheless, its connection with the Rex is clear. Beds of this type were observed by the author in the lower part of the formation in areas adjoining the west side of the Teton Basin, and they constitute much of the Phosphoria formation in the Warm Spring Canyon area near Garrison, Mont. They have not been recognized in the area previously studied in southeastern Idaho, though a quartzite bed bearing sponge spicules has been observed at the very base of the Rex in many places. The beds shown in figures 13 and 14 represent the quartzitic facies. This facies lends itself well to the development of dip slopes, which have been produced in many places in the quadrangles here described. Noteworthy examples may be seen in sec. 16, T. 2 S., R. 39 E., in the Paradise Valley quadrangle, secs. 8 and 17 of the same township in the Ammon quadrangle, and the NW¼ NW¼ sec. 28 and sec. 34, T. 1 S., R. 39 E., in the Ammon quadrangle.

The part that quartzite plays in the composition of the Rex chert member has been emphasized by Keller (1941).

A peculiar thin layer in the Rex at the locality in sec. 16, T. 2 S., R. 39 E., just mentioned, which at first was thought to be phosphatic, proved on microscopic examination by C. S. Ross to contain large vitric tuff fragments in a thoroughly silicified arkosic matrix. This is the first recognition of volcanic material in the Phosphoria formation of southeastern Idaho, but volcanic rocks of similar age are known in northeastern

FIGURE 13.—Wall-like ledges of the Rex chert member of the Phosphoria formation, viewed along the strike, in the NE¼ sec. 6, T. 2 S., R. 39 E., and the adjacent section to the north, Ammon quadrangle.

FIGURE 14.—The same ledges of the Rex chert member of the Phosphoria formation shown in figure 13 viewed across the strike.

Oregon and adjacent parts of Idaho and may be present in central Idaho. Fossils from the Clover Creek greenstone in Oregon were regarded by Girty as of Permian age and "more nearly allied to the Permian faunas of Alaska" than to any that had come under Girty's observation in the United States (Gilluly, 1937, pp. 26–27). The Clover Creek greenstone is reported by Gilluly to extend eastward to the Snake River canyon (Gilluly, 1937, p. 27). F. B. Laney stated in a letter to C. P. Ross dated Oct. 19, 1921, that these rocks near Homestead, Oreg., had yielded fossils determined by Girty to be of the age of the Phosphoria formation in eastern Idaho and Montana, a statement which was confirmed by a conversation between Girty and Ross (Ross, C. P., 1938, p. 26). Ross has mapped volcanic rocks (Casto volcanics) in central Idaho that may be of similar age (Ross, C. P., 1927, p. 7; 1934, pp. 28–35) but have yielded no fossils to confirm this assumption.

Boulders of chert closely resembling the Rex and as large as 15 by 10 by 8 ft have been found here and there. Some of them may represent material nearly in place weathered out from Tertiary beds that are otherwise largely eroded away. Others seem to be definitely associated with traces of thrust faults.

Fauna.—No fossils were seen in the Rex in the Ammon and Paradise Valley quadrangles, but they are relatively abundant in the limestone facies in the Montpelier district. Characteristic fossils from this facies as listed by Girty, are included in a previous publication (Mansfield, 1929, p. 29).

Thickness.—The thickness of the Rex chert member of the Phosphoria formation varies in its different exposures from about 350 to more than 500 ft. This variation may be due partly to the readjustment of the formation as a whole to the squeezing and folding to which it has been subjected. It may also be partly due to the unconformable relations between the Permian and Lower Triassic.

BROADER RELATIONS OF PHOSPHORIA FORMATION

Evidence is accumulating that the seas of Phosphoria time were more widespread than was earlier supposed. Their connections northward and westward were early recognized and have been discussed in reports by Girty (1910) and Mansfield (1927). Later, correlatives of the Phosphoria were found in the Kaibab formation of Arizona and southern Utah and in the Leonard and Word formations of the Glass Mountains of Texas (King, P. B. and R. E., 1929; King, P. B., 1934, pp. 735, 786). More recently their extension into central and southern Wyoming has been traced by Thomas (1934). His study confirms earlier work by Condit (1916 and 1924) and shows that the Phosphoria in the Wind River Mountains of Wyoming interfingers southeastward as well as eastward with beds of the lower part of the Chugwater formation.

The peculiar conditions leading to the deposition of beds of phosphate and of massive chert, though actually extensive, were much more restricted than the area covered by the Phosphoria sea itself. The outlying areas, such as the Glass Mountains (Texas) and central Wyoming, contain rocks more highly fossiliferous than those of southeastern Idaho; hence the corresponding parts of the ancient seas must in general have been subject to more normal marine conditions.

AGE

The age of the Phosphoria formation as discussed in reports of the Geological Survey has been considered Permian. Some years ago E. B. Branson (1916), after a study of the fauna (largely fish) of the lower phosphatic member of the Lower Embar (Phosphoria) in the Wind River Mountains of Wyoming, concluded that the fauna indicated an age for these beds older than Permian. Later C. C. Branson (1930, pp. 20, 21) studied the fauna of the entire Phosphoria formation of the Wind River Mountains. He states that

> * * * the formation through the Lower Phosphate member is late Pennsylvanian in age, and that there is a gradation into beds of Permo-Carboniferous age somewhere between the Lower Phosphate and the *Pustula* member. There is no indication of a stratigraphic break in the lithology. The *Pustula* and *Hustedia* faunules are Permo-Carboniferous with Pennsylvanian holdovers, and the *Aulosteges* fauna is a very different one of distinctly Permian age. From the complete absence of ammonites, however, it must be concluded that the faunule belongs to the lowermost part of the Permian. Here, as in Kansas and Nebraska, is a gradation without a break from Pennsylvanian to Permian.

In more recent articles, C. C. Branson (1933 and 1934) has described a fish fauna from the middle part of the Phosphoria, which, because of the absence of cochliodont sharks common in the lower bed and because of this fauna's association with *Spiriferina pulchra* and *Aulosteges hispidus*, he considers Permian. Still later (1936) he concludes that the entire Phosphoria was of Permian age.

Miller and Cline (1934) have described new species of ammonoids from a zone about 60 ft below the base of the Rex chert member of the Phosphoria formation in western Wyoming. The fauna includes representatives of several nautiloid genera and of the ammonoid genera *Stacheoceras*, *Vidrioceras*, *Gastrioceras*, and *Goniatites*. These genera are represented by species which suggest that the zone is probably correlative with the Word formation of western Texas and may be as old as the Leonard formation.

The evidence thus far seems to show that much of the Phosphoria formation is undoubtedly Permian, but that some of the lower beds may be Pennsylvanian. It has been noted, however, that in the Glass Mountains of Texas, where there is one of the most complete fossiliferous marine Permian sections in the United States, the correlatives of the Phosphoria are well up in the section of beds that have been considered Permian. Likewise, in northern Arizona and southern Utah, the Kaibab limestone, which is in part correlative with the Phosphoria, occupies the upper part of the Permian section there exposed (Baker and Reeside, 1929). McKee (1938, pp. 173–176), who has summarized the relations of the Kaibab and Phosphoria, arrives at the following conclusion: "Evidence based both on its brachiopod and on its cephalopod faunas points strongly toward middle Permian age for at least part of the Phosphoria, and a sea connection across northern Arizona to west Texas; therefore the writer believes that the Kaibab formation must represent the deposits of this connecting sea."

Under the heading "Relation of Carboniferous to Permian" it was stated that the work of Baker and Williams (1940) east of Provo, Utah, disclosed a thick section of the Permian in which the lower limestone of the Park City formation contains Kaibab fossils and some elements of the Phosphoria fauna. The authors state that "there is evidence at this locality [Hobble Creek, Utah] that in general the Phosphoria fauna overlies and is younger than the Kaibab fauna, although some Phosphoria species existed in Kaibab time. Evidently the Phosphoria sea is in part a late stage of part of the Kaibab sea."

James Steele Williams (personal communication) says: "The middle Permian of Miller and many [other geologists] in the southwest United States is lower Permian to me. So far as I know the [Geological] Survey has never adopted a middle Permian."

In southeastern Idaho at least, as has already been pointed out, the Permian probably contains a stratigraphic break between the Phosphoria formation and the upper part of the Wells formation if the latter is to be regarded as the lower unit of the Park City formation. Thus the sequence in Idaho is not entirely gradational, as that in Wyoming is described by Branson.

RELATION OF PERMIAN TO TRIASSIC

In the area east of Provo, Utah, Baker and Williams (1940) refer to a "pre-Triassic" unconformity that cuts out part of the Park City formation in different places. In southeastern Idaho the relations of the Phosphoria formation and the succeeding Woodside shale (Lower Triassic) have been considered as probably unconformable because of the differences in their respective faunas and lithologic character, though little difference in their attitudes has been observed. Ordinarily the contact between the two is concealed. However, some variations in the thickness of the Rex chert member of the Phosphoria have been observed from place to place.

In 1935 the author, in company with James Steele Williams and W. D. Keller, visited the phosphate prospects in a small canyon about half a mile east of the hot springs at the northeast corner of Bear Lake in the Montpelier quadrangle. Keller measured a section of the Phosphoria at this locality. The contact of the Rex chert member of the Phosphoria and Woodside shale was there exposed under overlying ledges, and Keller noted at the base of the Woodside a conglomerate bed, about 8 in. thick, which consisted of chert pebbles. The pebbles were thickly distributed at the base of the bed, but thinned out above. They were indented, doubtless by the pressure to which they had been subjected during their pronounced folding. A similar unconformity was noted by the party on Waterloo Hill, east of Montpelier Creek in the same quadrangle. The discovery of this conglomerate bed lends further support to the theory that the two formations in southeastern Idaho are unconformable.

TRIASSIC SYSTEM

Rocks assigned to the Triassic system are exposed in four principal areas in the two quadrangles. These are in (1) the southwestern and (2) southeastern parts of the Paradise Valley quadrangle, (3) a 4-mile strip with complex structure along the west flank of the Blackfoot Mountains east of Paradise Valley, and (4) a large irregular area in the north-central part of the Paradise Valley quadrangle and the south-central and southeastern parts of the Ammon quadrangle. In addition, there are exposures in several small outlying areas. There is little doubt that Triassic rocks underlie much larger areas within the boundaries of the two quadrangles, but the cover of Tertiary sedimentary rocks and volcanics is so extensive that older rocks are concealed for many square miles.

In the Fort Hall Indian Reservation (Mansfield, 1920a, pp. 42–51), which extends into the Paradise Valley quadrangle for 3 miles along nearly three-quarters of the west boundary, five formations with a maximum thickness of 5,300 ft have been distinguished. Four of these—the Woodside shale, Ross Fork limestone, Fort Hall formation, and Portneuf limestone, the last three comprising the Thaynes group—are definitely assigned to the Lower Triassic series. The fifth, the Timothy sandstone, formerly assigned to the Lower Triassic, is now considered as more probably Upper Triassic.

LOWER TRIASSIC SERIES

In the general region of southeastern Idaho outside the quadrangles considered here, the formations assigned (Mansfield, 1927, pp. 85–94) to the Lower Triassic series include 3,850 to 5,350 ft of shales, calcareous beds, and sandstones grouped in four formations of which the Woodside shale and the three formations of the Thaynes group are fossiliferous at certain horizons. The age determination, as pointed out in the discussion of the Thaynes group, has been based upon ammonite zones occurring 1,000 to 1.250 ft above the top of the Phosphoria formation. The fossils of the overlying 3,300 ft of the sedimentary rocks are less distinctive, and the faunal relations of some of them have not been fully studied. The fifth Triassic formation, the Timothy sandstone, has thus far yielded no identifiable fossils.

WOODSIDE SHALE

Distribution.—The Woodside shale occupies a triangular area in the SE¼ sec. 22 and adjoining parts of sec. 27, T. 4 S., R. 38 E., Paradise Valley quadrangle. It forms a strip a mile wide and 2½ miles long in the northwestern part of T. 5 S., R. 40 E., in the southeastern part of the same quadrangle, and it lies in several faulted and irregular strips on the mountain slopes east of Paradise Valley. In T. 2 S., R. 39 E., it forms an area a mile wide that extends northwestward from the SE¼ sec. 23 and bifurcates to flank both sides of an anticline of Paleozoic rocks that extends northwestward into the Ammon quadrangle. The western strip in this quadrangle is partly cut out by faulting and partly concealed by Tertiary cover, but it extends as far as the NW¼ sec. 25, T. 1 S., R. 38 E. The eastern strip, which is generally wider and reaches a maximum width of about a mile and a half, is continuous, though cut by several faults, as far north as the SE¼ sec. 20, T. 1 S., R. 39 E., in the Ammon quadrangle, where it is cut off by the middle branch of the Bannock overthrust. Another irregular bifurcating area partly encloses the broken anticline that extends about 5 miles in a general northwesterly direction from the SW¼ sec. 11, T. 2 S., R. 39 E. It also is partly faulted out by the middle branch of the Bannock overthrust. Beds assigned to the Woodside extend from the locality just mentioned along the west flank of the anticline as far as the SW¼ sec. 33, T. 1 S., R. 39 E., and those on the east flank as far north as the SE¼ sec. 34 of the same township.

General character.—In his larger work on southeastern Idaho (1927, pp. 81–94) the author has discussed the Lower Triassic formations of the general region of which the Ammon and Paradise Valley quadrangles are a part. The Woodside shale in these quadrangles maintains the general characteristics set forth in the report cited. The red beds which characterize the formation at its type locality in the Park City district, Utah, and in Montpelier Canyon in the Montpelier quadrangle, Idaho, are either entirely absent or only faintly suggested locally by a few beds with reddish tints. Newell (1942, p. 945) reports that the beds were not found in the section that they measured in the Henry quadrangle, Idaho. The beds are generally platy, sandy, and calcareous, many of the plates being thin enough to justify the retention of the term "shales" for the formation as a whole. On the other hand, some of the sandy beds are several inches thick and when weathered are locally difficult to distinguish from some beds of the Wells formation or even of the Nugget sandstone. In the middle and upper parts of the formation, limestone beds, which are usually gray on fresh fracture but which weather to velvety brownish or even chocolate-colored surfaces, are more abundant. Near the top the beds are grayish limestones, lithologically resembling those of the immediately overlying Thaynes and distinguishable from them chiefly by their fossil content. The uppermost beds of the Woodside are crowded with pelecypods but contain no ammonoids, whereas the base of the Thaynes group is a widespread and easily recognized ammonite zone. However, this ammonite zone is locally poorly developed or cut out by faulting, so that the boundary becomes indefinite. In such circumstances the pelecypod zone at the top of the Woodside is a helpful marker, as is also a relatively widespread bed of dark-colored shale in the Thaynes near its base. As in all formations whose boundaries are determined by faunal zones rather than by structural or lithologic differences, the accurate delineation of the upper boundary of the Woodside requires close examination and detailed tracing on the ground.

The beds of the Woodside shale at the type locality in Utah are unfossiliferous, and their red color, mud cracks, and raindrop impressions suggest a continental or perhaps an estuarine origin. The beds of the Woodside formation in the region of southeastern Idaho, on the other hand, are notably fossiliferous at many horizons and are undoubtedly marine. The prevailing color is an olive drab, and many joint cracks and loose fragments are coated to a greater or less extent with dendrites.

The lower boundary of the Woodside usually is readily mapped in the field on the basis of lithologic character and faunal differences between this formation and the underlying Phosphoria. In the preceding discussion of the relations between the Permian and Triassic, evidence of the uncomformable relations between the Woodside and Phosphoria is given.

Age and correlation.—In the northeastern part of T. 4 S., R 37 E., in the Fort Hall Indian Reservation, about 5 miles west of the Paradise Valley quadrangle, a fauna of Paleozoic aspect was found by Girty in beds that resemble the Woodside lithologically and lie above the usual cherty shales of the Rex. This fauna consisted chiefly of the brachiopod *Ambocoelia* in abundance together with pelecypods and gastropods that suggest Paleozoic characteristics, but have not been definitely identified (Mansfield, 1927, p. 85). Girty at first was inclined to consider these beds Permian, which would have necessitated drawing the boundary between the Permian and Triassic within beds of Woodside lithology. Later, however, he concluded that *Ambocoelia* and its accompanying genera of Paleozoic aspect had transgressed the Triassic boundary, as the beds that contain them also contain many Triassic types. Though *Ambocoelia* and its Paleozoic associates thus far have not been found in the Woodside elsewhere in southeastern Idaho, it seems probable that close search might reveal their presence.

Blackwelder (1918, pp. 425, 426) has applied the name "Dinwoody formation" to 250 ft of beds that overlie the Park City formation in Dinwoody Canyon in the Wind River Range, western Wyoming. These two formations correspond to Darton's Embar formation in the Owl Creek Range of Wyoming. Blackwelder noted that the Dinwoody formation increased in thickness westward and graded imperceptibly into the Woodside and Thaynes formations of southeastern Idaho. Although he found no diagnostic fossils in the formation, he inferred that it was of either Permian or Lower Triassic age. Condit (1916, pp. 263, 264) also correlated the Dinwoody with the Woodside and Thaynes of southeastern Idaho.

In the Afton quadrangle, Wyo., Rubey (personal communication) has identified and mapped two units between the Phosphoria and the Thaynes. The lower unit he ascribes to the Dinwoody. It is marine and not unlike the Woodside of Idaho in lithologic appearance. The upper unit he calls Woodside because it is a red-bed formation much like the Woodside of the Park City area, Utah, its type locality. No such red-bed units have been recognized in the Woodside of the Ammon and Paradise Valley quadrangles, but it seems likely that their place is taken by beds of marine facies in those quadrangles, for the total thickness of the Woodside there is comparable to the combined thicknesses of the Dinwoody and Woodside in the Afton quadrangle.

The presence, already noted, of the *Ambocoelia* zone in the Fort Hall Indian Reservation suggests that an undetermined part of the Woodside shale as mapped in the Ammon and Paradise Valley quadrangles may be correlative with the Dinwoody formation. This is confirmed by the work of Newell and Kümmel (Newell and Kümmel, 1941; Newell, 1942), who have collected and examined fossils from sections of the so-called "Woodside" near Melrose in Montana and near Montpelier and Henry in Idaho and from sections of the Dinwoody at several localities in the Wind River Mountains near Lander, Wyo. These sections have yielded cephalopod remains and other fossils ascribed by Newell and Kümmel to the lowest zone of the Triassic, the *Otoceras* zone.

Thickness.—In the general region of southeastern Idaho (Mansfield, 1927, p. 87), the thickness of the Woodside shale ranges from about 1,000 ft in the southern part to 2,000 ft in the northern part. In the Portneuf quadrangle (Mansfield, 1929, p. 31), which adjoins the Ammon and Paradise Valley quadrangles on the south, its thickness is about 2,000 ft. In the Paradise Valley and Ammon quadrangles the Woodside has been involved in much folding and faulting, and no detailed sections were measured. However, the structural relations here indicate that the thickness is approximately 2,000 ft. Westward the formation apparently thins, for in the Fort Hall Indian Reservation (Mansfield, 1920a, p. 46) it is about 900 ft.

THAYNES GROUP

SUBDIVISIONS AND GENERAL DISTRIBUTION

In his report on the Fort Hall Indian Reservation (Mansfield 1920a, pp. 46–50), the author considered the Thaynes a group of three formations—the Ross Fork limestone, Fort Hall formation, and Portneuf limestone—and mapped them separately. That classification is followed in the present report, which concerns an area overlapping and immediately adjoining the eastern part of the reservation. The distribution of the group in the Ammon and Paradise Valley quadrangles follows closely that of the Woodside shale, with which it is intimately associated.

The Thaynes occurs in an area approximately 2 miles wide and 3 miles long in Tps. 4 and 5 S., R. 40 E., in the southeastern part of the Paradise Valley quadrangle. Small strips and areas of it lie along the southwest flank of the Blackfoot Mountains east of Paradise Valley, extending northwestward from sec. 15, T. 4 S., R. 40 E., to the SW¼ sec. 33, T. 3 S., R. 40 E. Two parallel areas separated by younger rocks extend northwestward from secs. 23, 24, 13, T. 4 S., R. 38 E., to the quadrangle boundary and beyond. Irregular areas with a general northwesterly trend are associated with the folds and faults that extend from sec. 1, T. 3 S., R. 39 E., through T. 2 S., R. 39 E., into secs. 31, 32, 33, and 35, T. 1 S., R. 39 E. In addition, small outlying areas have been mapped in secs. 23 and 26, T. 4 S., R. 38 E.; in sec. 25, T. 4 S., R. 39 E.; in secs. 1, 2, 12, and 14, T. 1 N., R. 39 E.; and in sec. 7, T. 1 N., R. 40 E.

ROSS FORK LIMESTONE

Name and character.—The Ross Fork limestone, the lowest formation of the Thaynes group, takes its name from Ross Fork Creek, in the Fort Hall Indian Reservation, in the upper waters of which this limestone is well exposed. The base of the Ross Fork lies conformably on the Woodside shale and is marked by the "*Meekoceras* beds," recognized by the Hayden Survey and referred to the Triassic, and later referred by Hyatt and Smith (1905, pp. 17–19) to the Lower Triassic. The description of the Ross Fork given in the report on the Fort Hall Indian Reservation already cited applies generally in the Ammon and Paradise Valley quadrangles.

The *Meekoceras* zone consists of limestones, generally grayish and about 50 ft thick, which contain numerous ammonites, the chambered shells of which appear on weathered surfaces of the rock. In this region the fossils do not weather out so regularly, and the horizon is not so conspicuous as in the Georgetown district farther southeast. The *Tirolites* and *Columbites* zones, which have been recognized by Smith (1912, p. 17) in the region of Paris, Idaho, 250 and 275 ft, respectively, above the *Meekoceras* zone, have not been definitely recognized in the quadrangles here considered, but in the SW¼SW¼ sec. 3, T. 2 S., R. 39 E., of the Ammon quadrangle, some poorly developed cephalopod fossils were found at about the horizon where the *Tirolites* might be expected. They have not been identified with certainty.

Above the *Meekoceras* zone in the Fort Hall Indian Reservation is about 800 ft of massively bedded and thin-bedded gray to brown limestones, which contain large numbers of small brachiopods, chiefly "*Pugnax*" and terebratuloids, and pelecypods, *Myalina* and others, with intervening calcareous shales. The shales and thinner-bedded limestones are much like those of the Woodside. The limestones have a velvety appearance when weathered and are very fossiliferous. The presence of small brachiopods in the massive limestones near the base is a convenient guide to the Ross Fork limestone where the *Meekoceras* zone is not recognizable. The upper part of the Ross Fork limestone consists of about 500 ft of a dense calcareous gray to olive-green shale that weathers brown to yellow. These shales form conspicuous cliffs and are mainly unfossiliferous.

The fauna of the Ross Fork has been little studied since Girty's contribution to the author's Fort Hall report (Mansfield, 1920a, pp. 47–48) previously cited.

Thickness.—The total thickness of the formation in the Fort Hall Indian Reservation is about 1,350 ft. In the Ammon and Paradise Valley quadrangles the formation is so involved in folds and faults that no satisfactory determination of its thickness was obtained. Graphic measurements suggest that the Ross Fork limestone may be about 2,000 ft thick in secs. 22 and 23, T. 4 S., R. 38 E., Paradise Valley quadrangle. However, the formation here is thought to be involved in an overturned anticline, so that its thickness has locally been increased. Probably the actual thickness is comparable to that in the Fort Hall Indian Reservation.

FORT HALL FORMATION

Name and character.—The Fort Hall formation is named from Fort Hall, which was once situated in the valley of Lincoln Creek (on some maps called Fort Hall Creek), in the northeastern part of the Fort Hall Indian Reservation. The formation occurs as a prominent ridge along the northeast side of the valley, and the rocks lie conformably on the Ross Fork limestone. The boundary is drawn on both lithologic and faunal grounds. In the Fort Hall Indian Reservation four subdivisions were recognized, and they hold for the two quadrangles considered here.

1. The base of the formation is a soft and somewhat sugary yellow calcareous sandstone, about 50 ft thick, which is sparingly fossiliferous. It includes at one locality a bed of yellowish sandy limestone, about 15 ft thick, that contains plicated oysterlike pelecypods, terebratuloids, and other forms. This bed is overlain by white calcareous sandstone that weathers red or pink.

2. Above these sandstones is a gray or yellowish siliceous dense limestone. It contains large pectinoids and irregular cherty nodules and streaks that weather with a rough surface and project along the bedding planes. This limestone forms rough ledges and high knolls. The thickness of this sequence of beds is estimated to be about 100 ft.

3. At two localities, secs. 36 and 26, T. 3 S., R. 37 E., there was observed above subdivision 2 about 50 ft of sandy and shaly gray limestones, including an oolitic bed 6 to 10 ft thick.

4. The remainder of the section, estimated to be about 600 ft thick, consists of yellow to grayish cherty and sandy limestone in beds that are represented chiefly by fairly smooth slopes strewn with yellow and reddish sandy and cherty float fragments.

Fauna.—In his contribution to the Fort Hall report (Mansfield, 1920a, p. 49), Girty writes:

> The Fort Hall formation might approximately be called the *Aviculipecten* [*Aviculopecten*] *idahoensis* zone, for it is particularly characterized by that species, which occurs in most collections and in many of them is very abundant. With *Aviculipecten idahoensis* are associated a few other types of pelecypods, among which a large *Bakewellia* or *Pteria* and two or three species of pectinoid shells are the most common. There is also a form resembling *Myalina* (possibly the *Volselia platynota* of the Ross Fork limestone but smaller and less abundant), and several types which are too poorly preserved to be identified, but in general expression suggest *Myacites*, *Schizodus*, and *Pleurophorus*. A small naticoid (*Natica lelia*?) is rather abundant in places, but otherwise gastropods are practically absent.
>
> In contrast to the preceding formation [Ross Fork], the Fort Hall does not contain any cephalopods nor, with the single exception noted below, any brachiopods. As regards the pelecypods, the pectinoid shells, except *Aviculipecten idahoensis*, are much less abundant in the Fort Hall formation, and some species of the Ross Fork limestone appear not to occur there at all. On the other hand, *Aviculipecten idahoensis* appears to be restricted to the Fort Hall formation.
>
> Our collection shows a remarkable and interesting variant of the Fort Hall fauna. It is distinguished by the absence of most of the pectinoids, even of *Aviculipecten idahoensis*, and by the abundance of terebratulas, of which there are four or five varieties or species. Of the pelecypods the most noteworthy are a large *Lima* (new species) and a sharply plicated oyster, besides which there are two species of *Myacites*?, a large *Bakewellia*?, and one or two other forms. The gastropods are represented by *Natica lelia* and by another species, possibly a *Pleurotomaria*.

In his discussion of new species of Lower Triassic fossils from the Woodside and Thaynes formations, Girty (Mansfield, 1927, p. 439) says that numerous pectinoid shells formerly assigned to the genus *Aviculipecten* have in all probability been wrongly classified. He proposes to assign them instead to the genus *Monotis*. Among these shells he includes *Aviculipecten idahoensis*, but he does not give it a specific name.

In the Ammon and Paradise Valley quadrangles the Fort Hall formation is not so readily distinguished as in the Fort Hall Indian Reservation. The bed with the plicated oyster shells was not found, and the boundary is placed at the base of the more massive beds of relatively soft and reddish-weathering sandstones that succeed the thinner-bedded and more platy and sandy shales of the upper part of the Ross Fork. Above this horizon are more platy and thinner-bedded sandy and calcareous shales that contain large pectinoid shells [*Aviculipecten idahoensis?* (*Monotis?*)]. The upper part of the formation is not easily recognized, as it is either largely concealed by the Salt Lake formation or cut out by faults.

Thickness.—In the belt extending northwestward from the NW¼ sec. 24, T. 4 S., R. 38 E., in the Paradise Valley quadrangle, as shown in structure section *P–P′* on plate 2, the formation apparently is more than 2,000 ft thick, but it thins northwestward. Here it is involved in an overturned fold that is cut along the northeast flank by a fault, interpreted as a thrust, which causes it to override Nugget sandstone. It is thought that the thickness here has been unduly increased by folding and faulting and that it is more likely to be about 1,000 ft, inasmuch as in the area of the type locality it was about 800 ft.

PORTNEUF LIMESTONE

Name and distribution.—The Portneuf limestone is named from the Portneuf River, at the head of which it is well exposed. In the Paradise Valley quadrangle the Portneuf limestone occurs as a band, a half to three-quarters of a mile wide, extending about 3 miles northwest from the SW¼ sec. 13, T. 4 S., R. 38 E., to the boundary of the quadrangle. In the NE¼ sec. 26 and the SE¼ sec. 23 of the same township it forms an isolated hill half a mile long and a quarter of a mile wide. In the north-central part of the quadrangle, extending northward into the Ammon quadrangle, the Portneuf limestone occurs in several more or less distinct areas, chiefly in the E½ T. 2 S., R. 39 E., but overlapping into sec. 1, T. 3 S., R. 39 E., and sec. 19, T. 2 S., R. 40 E. The pre-Tertiary rocks in these townships lie in the zone of the Bannock overthrust, of which there are at least three branches and numerous minor faults and broken folds. These structural features, together with erosion, account for the irregular distribution of the Portneuf. The largest individual area is irregularly triangular and extends northwestward about 3½ miles from the center of sec. 1, T. 3 S., R. 39 E., to the northern part of sec. 26 in the township to the north. It is bounded on all sides by faults and has a maximum width of about 1½ miles. In addition, two small areas have been found in T. 1 N., R. 39 E., in the Ammon quadrangle, one in the north-central part of sec. 14 and the other in the NE¼ sec. 12. A third small area doubtfully assigned to the Portneuf is in the NE¼ sec. 1 of the same township.

Character.—The rock is generally recognizable by its lithologic character. It is chiefly a massive, siliceous and cherty, gray to yellowish limestone. The chert occurs in rounded and elongated nodules and in streaks. Silicified fossils, including *Spiriferina* n. sp.?, *Terebratula semisimplex* and other terebratuloids, and *Myophoria lineata?*, project from weathered surfaces here and there. In the Lanes Creek, Freedom, and Montpelier quadrangles farther east and southeast, the limestone contains a well-developed red-bed unit, which consists of interbedded red sandstones and shales and ranges from 200 to 1,000 ft in thickness. In the Fort Hall Indian Reservation this unit was not recognized and, if present, is much less conspicuous than in the other regions named. In the Ammon and Paradise Valley quadrangles the red-bed unit is present, though apparently it is not so well defined as in the other quadrangles mentioned. The red beds do not seem to be confined to a single unit but recur more or less irregularly. It was not determined whether this is due to repetition by folding or to intertonguing. In his larger work (Mansfield, 1927, p. 374) the author called attention to the tendency of the marine Lower Triassic in southeastern Idaho to interfinger eastward with red beds. It seems likely that there is the same tendency in the Ammon and Paradise Valley quadrangles.

Fauna.—Girty's description of the Portneuf fauna given in the writer's Fort Hall report (Mansfield, 1920a, p. 50) is repeated here for reference.

> The Portneuf fauna is the most varied and interesting of the three Triassic faunas of the Fort Hall Reservation. Echinoid spines occur in a number of localities, but they are not plentiful. On the other hand, segments of the stems of *Pentacrinus* are often found in great abundance. In two localities Bryozoa are abundant—small branching types, which superficially resemble the Carboniferous genus *Batostomella*. Several new genera and species are indicated by thin sections. Brachiopods are abundant but confined to two families. The Portneuf contains the horizon of *Terebratula semisimplex*, and several other terebratuloid types, which are apparently undescribed, are also found in this formation. An undescribed species of *Spiriferina* is present in many of the collections, and there may be a second species.
>
> Pelecypod types are numerous, though many of the specimens are poorly preserved. No species in this fauna is more common than one which was figured by Meek as *Myophoria lineata?* * * *. As compared with their abundance in the two lower formations, pectens are scarce in the Portneuf. A large form with very coarse ribs is present in several collections, and there are other species, both large and small. A large *Pteria* or *Bakewellia* has been found at many localities; also a *Myalina* or *Mytilus*. *Leda* is present, and *Nucula*, together with types suggesting *Pinna*, *Myacites*, *Pleurophorus*, *Astarte*, *Cucullaea*, and other forms. One locality has furnished a few specimens of *Ostrea*, not only a plicated form similar to that of the Fort Hall but also a smooth type.
>
> The scaphopods, too, are represented in this fauna by one or two species of *Dentalium*.
>
> Gastropods are less abundant than pelcypods, the only common type being a small *Natica*, probably *N. lelia*. Several small species of *Pleurotomaria?* have been collected, and also shells suggesting the genera *Holopea*, *Nerita*, and *Macrocheilina*. The most interesting representative of this type, however, is a beautiful little species which apparently belongs to the Carboniferous genus *Schizostoma*, or at all events to the euomphaloid group.
>
> Cephalopods are practically absent in this formation, as they are in the Fort Hall. One specimen only was obtained; it is apparently identical with *Pseudosageceras intermontanum*.

The difficulties of determining silicified fossils in the Portneuf limestone are pointed out in a letter from Girty dated April 9, 1932, relating to the exposures assigned to the Portneuf in the NW¼ sec. 14, T. 1 N., R. 39 E., and in the NE¼ sec. 12 of the same township in the Ammon quadrangle. In both localities the stratigraphic field evidence strongly supports an assignment to the Portneuf. Girty writes:

> The rock, which is an earthy and siliceous limestone, appears on the weathered surface to be full of fossils, many of which are silicified, but when the rock is broken, the break either passes through the fossils or deeply exfoliates them, and when it is dissolved in acid, the fossils that remain prove to be so coarsely silicified that not only is the original structure destroyed but a fictitious structure is created. In addition to these difficulties, which are inherent in the material, we have this other difficulty that the species represented are almost all undescribed, this last statement finding its support in the fact that these species are gastropods and pelecypods, and that the entire gastropod and pelecypod faunas of the Lower Triassic are unworked. The following list represents a conscientious ef-

fort to cite the species in the usual manner, but the generic identifications are entirely untrustworthy, and as for specific identifications few would have been possible even if the species had been described. I can hardly doubt that both collections came from the same horizon, even though one of them (sec. 12 locality) is so very meagre, and they may well have come from the Portneuf limestone as suggested. The field evidence on this point would outweigh the paleontological evidence. The following list will afford some idea of the differentiation of the fauna and in some degree of its general character: *Myalina postcarbonica?*, *Pteria* sp., *Monotis* sp., *Trigonodus* sp., *Pleurophorus* sp., *Levidentalium* sp., *Pleurotomaria?* sp., *Trochus* sp., *Turbo* sp., *Naticopsis* sp., *Sphaerodoma?* sp., *Macrocheilina?* sp.

Thickness.—In the Fort Hall Indian Reservation the thickness of the Portneuf limestone was estimated at 1,500 ft, though there was some uncertainty because of the complexities of structure. In the Ammon and Paradise Valley quadrangles the complexities of structure in the areas where the Portneuf occurs are even greater because of the numerous broken folds and the faulting to which the beds have been subjected. However, the thickness appears to be comparable with that in the reservation.

Later studies.—Since the author's field work on the Ammon and Paradise Valley quadrangles was essentially completed, two studies involving the Thaynes group in other localities in the general region of northeastern Utah and southeastern Idaho have been published. One of these studies, by Mathews, resulted in two publications (Mathews, 1929, 1931). The first is entirely paleontological, but the stratigraphy of the Thaynes is described in the second (Mathews, 1931, pp. 6–36). Mathews found that the tripartite division of the Thaynes was not applicable in the central Wasatch area, and he considered that the Thaynes formation as originally described by Boutwell was Middle Triassic in age. To avoid confusion, he proposed the name "Emigration formation" for these beds, which have a total thickness of about 1,000 ft. For the underlying 600 ft of beds between the base of the "Emigration" and the top of the Woodside shale, he proposed the name "Pinecrest formation."

The other study, by Kümmel (1943), relates to the Thaynes as examined at three localities in the Montpelier quadrangle, Idaho. Kümmel also finds the present author's classification unsatisfactory and instead proposes five subdivisions of his own, but as yet he has not assigned them geographic names. He states that Mathews' conclusions as to a Middle Triassic age for the upper part of the Thaynes cannot be substantiated. However, Reeside (1929, table, p. 50), in a paper roughly contemporaneous with that of Mathews, indicates that the upper part of the Thaynes may be Middle Triassic.

To apply either of the proposed new classifications to the Ammon and Paradise Valley quadrangles would require much new detailed Field work and the remapping of the areas here included in the Thaynes group. As this is impractical at present, it seems better for the purposes of this report to let the present mapping stand, as it is consistent with the mapping of the adjoining Portneuf quadrangle and the Fort Hall Indian Reservation.

UPPER TRIASSIC SERIES: TIMOTHY SANDSTONE

Name and distribution.—The Timothy sandstone is named from Timothy Creek in the Lanes Creek and Freedom quadrangles farther southeast, where it is well developed and is cut by the creek.

In the Ammon and Paradise Valley quadrangles, the Timothy is exposed in a few narrow bands and numerous small disconnected areas associated with broken folds and with faults. The largest band extends northwestward from the NW¼ sec. 13, T. 4 S., R. 38 E., about 2½ miles to the boundary of the Paradise Valley quadrangle and beyond. It is nearly a third of a mile in maximum width but is cut by a strike fault that introduces a narrow and irregular wedge of overlying Higham grit near its northeastern border for a distance of about a mile. A second band, longer but narrower than the first, occurs in the form of a zigzag, partly around two folds that lie chiefly in the northeastern part of T. 2 S., R. 39 E. This band begins in the SW¼ sec. 19, T. 2 S., R. 40 E., and extends northwestward and westward as far as the SW¼ sec. 14, T. 2 S, R. 39 E.; it then swings back northwest and north to the SE¼ sec. 1 in the same township. It is cut twice by transverse faults, and is bordered in part by a bedding fault which cuts out the overlying Higham grit for nearly a mile and probably also part of the Timothy. Its width ranges up to about an eighth of a mile. A third band, smaller than the others, partly encloses a broken anticline in sec. 25, T. 2 S., R. 39 E. In addition, there are numerous faulted masses occupying small areas near these bands and two small outlying areas, one in the NW¼ sec. 14 T. 1 N., R. 39 E., where it forms a narrow band about half a mile long between other formations, and the other in the SW¼ sec. 7, T. 1 N., R. 40 E., where a small area of sandstone of Timothy aspect is doubtfully assigned to that formation.

Character.—The Timothy sandstone is characteristically a somewhat sugary, yellowish to grayish rock in beds 1 to 3 in. thick or locally more massive. Some beds that are gray on fresh surfaces weather reddish or pinkish. At places beds of red and greenish shales are included in the formation.

A bed of dense, whitish to grayish sandstone, exposed in the canyon of Williams Creek in the southeastern part of the Ammon quadrangle, contains obscure plant remains. Plant remains also occur in beds thought to represent the Timothy sandstone in the Montpelier quadrangle. Copper deposits, which have been described by Gale (1910), occur in connection with these plant remains in the Montpelier quadrangle, but in the Ammon and Paradise Valley quadrangles no traces of copper have been seen in the Timothy. No fossils other than plant remains have been found by the author in the formation. Gale in his report assigns the beds here called Timothy to the Ankareh shale, together with the Jurassic (?) formations next to be described, for the Timothy and the other formations mentioned had not been differentiated when he prepared his report. In general, the Timothy sandstone weathers more readily than the Portneuf limestone and exposures are relatively few and poor.

In the Ammon and Paradise Valley quadrangles, the Timothy sandstone appears to be conformable with the underlying Portneuf limestone and overlying Higham grit. However, the broader relations discussed in the author's larger work (Mansfield, 1927, pp. 91–93, 374) suggest that the relations of the Timothy with the formations both above and below are unconformable.

Correlation and age.—Although no marine fossils have been found in the Timothy sandstone, and in spite of its broadly unconformable relations, the author had considered it Lower Triassic because in its lithologic composition it seemed to agree better with the underlying Portneuf limestone than with the overlying Triassic (?) formations. Reeside (1929, p. 55), however, thinks it would be better correlated with the Shinarump conglomerate and Chinle formation of northern Utah and assigned to the Upper Triassic.

Thickness.—The thickness of the Timothy sandstone in the Fort Hall Indian Reservation is about 800 ft, but it thins eastward to about 250 ft in the Lanes Creek and Freedom quadrangles. In the Ammon and Paradise Valley quadrangles it seems to range in places from about 200 to nearly 800 ft. Some of this difference may be due to unconformity; most of it is doubtless due to the fact that wherever exposed it is involved in folding, which may cause thickening or thinning in different parts of a given fold, or in faulting.

TRIASSIC(?) SYSTEM

HIGHAM GRIT

Name and distribution.—The type locality of the Higham grit is Higham Peak in sec. 23, T. 3 S., R. 37 E., about 4 miles west of the Paradise Valley quadrangle.

The distribution of the Higham follows closely that of the Timothy sandstone, as it is in general involved in the same folds and faults affecting that formation. Two noteworthy bands traverse the northeastern part of T. 3 S., R. 38 E., in the Paradise Valley quadrangle, and in addition a narrow irregular fault strip lies within a broad band of the Timothy in the same general area. In T. 2 S., R. 39 E., the Higham parallels the Timothy in many places but is not coextensive with it. The principal outlying areas are in the NW¼ sec. 14 and the NE¼ sec. 12, T. 1 N., R. 39 E.

Character.—The Higham grit is a coarse, white to pinkish, gritty or conglomeratic sandstone, which is distinct lithologically from other rocks of the region and in some places forms prominent topographic features—especially bold strike ridges that are marked by rough craggy ledges in many localities (fig. 15).

The pebbles in the Higham grit are all of quartzite, so far as observed. No material derived from immediately underlying formations has been found in the Higham. Though the formation, in most places in the Ammon and Paradise Valley quadrangles where it is not faulted, appears to be conformable on the underlying Timothy sandstone, the relations between the two formations in secs. 13, 14, and 24, T. 2 S., R. 39 E., and in sec. 19, T. 2 S., R. 40 E., are suggestive of unconformity. These relations, however, may be due to faulting. Moreover, the abrupt change in the lithologic character of the Higham and its apparent gradual transgression of underlying Triassic formations farther east and southeast indicate an unconformity of considerable magnitude and significance. The rocks are much fractured, a feature that causes them to weather in pinnacled and in castellated forms, and in many places they are slickensided as a result of severe deformation.

Thickness.—The thickness of the Higham grit is estimated at about 500 ft, as in the Fort Hall Indian Reservation, but because the formation is everywhere involved in folds or faults, or both, its apparent thickness varies from place to place. As exposed in the Freedom quadrangle farther southeast, it is about 200 ft thick.

DEADMAN LIMESTONE

Name and distribution.—The type locality of the Deadman limestone is Deadman Creek in the north-

FIGURE 15.—Wall of Higham grit, viewed across the strike, in sec. 3, T. 4 S., R. 38 E., Paradise Valley quadrangle.

eastern part of T. 4 S., R 38 E., Paradise Valley quadrangle, where the formation is crossed by the creek and extends northwestward along the ridge parallel to and northeast of a prominent band of Higham grit. Within the quadrangle at this locality, the length of the limestone outcrop is about 3 miles, but it continues northwestward beyond the boundary and along the same strike for about 10 miles. It is involved with associated formations in the folded and faulted area already mentioned in the eastern part of T. 2 S., R. 39 E., and in the extension of the structure into sec. 1, T. 3 S., R. 39 E. In addition, it is well exposed in the NW¼ sec. 14, T. 1 N., R. 39 E., and in the SW¼ sec. 7, T. 1 N., R. 40 E., Ammon quadrangle.

Character.—The Deadman limestone is a peculiar rock of variable character and may be white, pinkish, purplish, grayish, or greenish. In some places it is dense and of almost lithographic quality; elsewhere it is cherty and has an irregular streaky, nodular character and a roughly weathered surface. The bedding is generally indistinct. Where the rock is greenish and cherty it has been prospected locally, presumably for copper. As a whole the rock is resistant to weathering, and in favorable places it forms well-defined ledges.

At many outcrops parts of the rock bear a superficial resemblance to igneous material, which, however, is not supported by available data on its character as seen under the microscope. A thin section of a specimen from an old prospect in the NW¼ sec. 25, T. 2 S., R. 39 E., is described by C. S. Ross (personal communication) as "an arkosic limestone, composed of well-cemented limestone fragments. These contain varying proportions of quartz, feldspar, and other igneous rock minerals." A specimen collected in the NE¼-SW¼ sec. 7, T. 1 N., R. 40 E., has an appearance suggestive of igneous rock and is marked on the surface by cavities that look like vesicles. However, in thin section Ross found it "composed almost exclusively of quartz that was introduced by replacement and fine-grained iron oxide in irregular aggregates. The character of the original rock is not evident, as no recognizable primary rock-minerals or structures are present." Of a second specimen from the same locality but from a different bed, he notes that it is "similar to the other specimen but in addition contains secondary carbonate".

No fossils have been found in the Deadman limestone, but at the locality just mentioned one of the dense purplish-gray limestone beds is marked on its weathered surface by straight and branching linear impressions, some filled with shaly materials, that look as if they might have been made by plant stems.

Thickness.—In general, the formation appears to be about 150 ft thick, undoubtedly varying more or less in faulted or folded sections.

WOOD SHALE

Name and Distribution.—The type locality of the Wood shale is on Wood Creek in T. 3 S., R. 38 E., less than 2 miles west of the Paradise Valley quadrangle. In T. 4 S., R. 38 E., Paradise Valley quadrangle, the Wood shale parallels the Deadman limestone for about 3 miles and extends northwestward beyond the quadrangle. In the eastern part of T. 2 S., R. 39 E., it is involved in the numerous folds and faults that affect that area. Locally it is apparently faulted out where some of the accompanying formations are present. In T. 1 N., R. 40 E., it extends through parts of secs. 18 and 7, where it forms part of the west limb of an eastward-inclined syncline.

Character and thickness.—The rock is primarily a bright-red sandy shale or shaly sandstone that weathers more readily than the formations on either side and therefore tends to occupy topographic depressions. In many places its presence is indicated by a characteristic red soil rather than by exposures, but in secs. 18 and 7, T. 1 N., R. 40 E., Ammon quadrangle, the Wood shale where exposed contains purplish and green shale in addition to the red beds. No fossils have been found in the formation. Locally it contains fragments or lenses of gypsum, but none has been observed in the quadrangles here discussed. The thickness of the formation is estimated at 200 to 250 ft.

JURASSIC SYSTEM

LOWER JURASSIC SERIES: NUGGET SANDSTONE

Name and distribution.—As in his earlier reports, the author restricts Veatch's name "Nugget sandstone" (1907, p. 56) to the upper part of the formation as exposed at the type locality at Nugget station, southwestern Wyoming. The lower "red bed member" there exposed is here considered to be the equivalent of the beds just described as comprising the Higham grit, Deadman limestone, and Wood shale.

In the Paradise Valley quadrangle the Nugget sandstone occurs as a band, nearly half a mile in maximum width, extending about 3½ miles northwestward from the NW¼ sec. 13, T. 4 S., R. 38 E., to the boundary of the quadrangle, beyond which it continues along the same general strike, with some interruptions, for another 10 miles. A second band, nearly parallel but much narrower and faulted on both sides, extends northwestward from the northwest corner of sec. 24 of the same township. This band is about 3 miles long within the quadrangle but extends several miles farther along the strike in the same direction. The Nugget sandstone occupies considerable areas in the northwest part of T. 3 S., R. 40 E., and in adjoining parts of Ts. 2 and 3 S., R. 39 E., and T. 2 S., R. 40 E., where it is involved in a large syncline that lies in front of and is partly overturned eastward by the Bannock overthrust. A somewhat smaller area occupies another syncline farther north, which is partly in T. 2 S., Rs. 39 and 40 E., Paradise Valley quadrangle, and partly in the Ammon quadrangle. Both these synclines are more or less broken by faults. In addition, the Nugget sandstone occupies isolated areas in the Bannock overthrust zone in T. 2 S. Rs. 39 and 40 E., and forms a noteworthy ridge, about a quarter of a mile in maximum width, extending about 2½ miles northward from the SW¼ sec. 19, T. 1 N., R. 40 E., to the center of sec. 7 in the same township. Several minor occurrences have been noted in sec. 6, T. 1 N., R. 40 E., and in secs. 14, 23, and 26, T. 1 N., R. 39 E.

Character.—The Nugget sandstone gives rise to ledgy, rugged, brushy hills and is generally a good ridge maker. It weathers into angular reddish or grayish fragments that form blocky talus piles. The rocks consist chiefly of massive reddish sandstone, deeply colored locally and in places much cross-bedded. The stratification is commonly well developed, here and there producing slabby blocks. The texture is generally fine, the grains subangular, and the matrix siliceous. At some places the rock is sufficiently silicified to be called a quartzite. The formation includes beds of sandy shale, which are generally cut by talus of the more massive strata. Locally the upper part of the formation is composed of several hundred feet of white or yellowish sandstone; however, in the Ammon and Paradise Valley quadrangles no such beds were noted. Their absence may be due to unconformity, or the lighter-colored beds may be merely a local phase of the more prevalent dark-red rock.

Age and correlation.—No fossils have been found in the Nugget sandstone in southeastern Idaho except certain markings, too indistinct for identification, that resemble foot prints and impressions. These the writer collected from the Fort Hall Indian Reservation. Mathews (1913, p. 42) reports finding a *Trigonia* "in sandstones near the base above the conglomerate," but no further details about this find are available. Mathews thinks the Nugget in the central Wasatch Mountains should be considered either Lower or lower Middle Jurassic. He quotes Reeside as having written in a letter dated 1928, "I would say that both Middle and Lower Jurassic [marine] deposits are possible for the central strip of Utah, but that the probabilities against the presence of Lower Jurassic are so high that pretty good evidence is needed to warrant such an assignment; for Middle Jurassic the odds are better but not especially favorable."

Shortly afterward, Reeside (1929, p. 50) published a paper giving a stratigraphic diagram in which the Nugget sandstone of southeastern Idaho, northern Utah, southwestern Wyoming, and northwestern Colorado is shown in the bracket designated "Middle and Lower Jurassic." This reference becomes somewhat more detailed in a later paper written with Baker and Dane (Baker, Dane, and Reeside, 1936, p. 41 and table facing p. 40). Here the sandstone of the eastern Uinta Mountains commonly designated "Nugget" in the literature is considered equivalent to the Entrada sandstone and probably the Carmel and Navajo formations; the beds commonly called "Twin Creek" limestone are here called "Curtis formation." In the table cited, the Navajo is included in the upper part of the Glen Canyon group, partly of Jurassic (?) age and partly Jurassic. The Carmel, Entrada, and Curtis with the overlying Somerville comprise the San Rafael group, assigned to the Jurassic. Concerning the relations of the Entrada and the overlying Curtis formation, the authors (Baker, Dane, and Reeside, 1936, p. 8) state that "the contact * * * in the San Rafael Swell is an erosional unconformity, but elsewhere the upper boundary [of the Entrada] is only moderately sharp and probably not an unconformity. In the eastern Uinta Mountains the boundary between the so-called Nugget sandstone and so-called Twin Creek formation is gradational."

In southeastern Idaho, the present author (Mansfield, 1927, pp. 96, 97) has considered the boundary between the Nugget sandstone and Twin Creek limestone as probably unconformable. However, the time interval, if any, between the two formations cannot be very long.

More recently Imlay (1945) has shown that the Twin Creek limestone of southeastern Idaho contains Bathonian (lower Middle Jurassic) fossils and that Bajocian (upper Middle Jurassic) fossils are widely distributed in the Rocky Mountain region. This would suggest that the typical Nugget sandstone is of lower Jurassic age.

Thickness.—The Nugget sandstone is involved in numerous folds and faults and is so broken that no good places for measurement were found. On the basis of the mapping and the structural relations observed, it is estimated to be 1,000 to 1,500 ft thick in the quadrangles here described.

MIDDLE AND UPPER JURASSIC SERIES: TWIN CREEK LIMESTONE

Name and distribution.—The name "Twin Creek limestone" was applied by Veatch (1907, pp. 56–57) to 3,500 ft or more of marine beds that are well exposed along Twin Creek between Sage and Fossil, two stations on the Oregon Short Line Railroad in southwestern Wyoming. It has been applied by other writers to corresponding beds in southeastern Idaho.

The Twin Creek barely enters sec. 27, T. 3 S., R. 38 E., on the western side of the Paradise Valley quadrangle, but occurs in association with the Nugget in the two large synclines that occupy parts of Tps. 2 and 3 S., Rs. 39 and 40 E., and in several small fault blocks and minor folds in those townships in the northeastern part of the quadrangle.

In the Ammon quadrangle, it underlies a large irregular area in the fault zone of the Bannock overthrust, chiefly in T. 1 S., R. 39 E., but connecting southeastward with the folded and faulted area in secs. 1 and 2 in T. 2 S., R. 39 E., and secs. 6 and 7, T. 2 S., R. 40 E. In the southern part of T. 1 N., R. 39 E., and in sec. 1, T. 1 S., R. 39 E., the Twin Creek is involved in numerous small fault blocks that rim the northern tip of a large syncline containing Cretaceous rocks. In T. 1 N., R. 39 E., also, several isolated areas of Twin Creek appear in the midst of Tertiary volcanic and sedimentary rocks where these have been eroded sufficiently to uncover the underlying rocks locally. In T. 1 N., R. 40 E., the Twin Creek is exposed for about 2 miles along both walls of Willow Creek canyon northward from the pronounced bend of the creek in secs. 19 and 20. It forms the forked ridge north of this bend and continues south on the east side of the canyon for a half a mile.

Character.—The Twin Creek limestone in the area here considered is broadly divisible into three units that are generally recognizable but have not been differentiated on the map. The basal unit ordinarily is a yellowish to grayish calcareous sandstone with interbedded massive gray limestones that contain oyster shells and other fossils in considerable abundance. Farther south and southeast in the region, a relatively thin red-bed horizon was noted locally in the basal unit of the formation, and a bed of greenish silicified, volcanic ash about 5 ft thick is relatively widespread. In the Ammon and Paradise Valley quadrangles this reddish bed has been recognized in a few places, but the bed of volcanic ash has not been seen.

In the W½ sec. 17, T. 1 S., R. 39 E., several occurrences of red sandstone suggest Nugget infolded with the Twin Creek. As this area is only about half a mile in front of the middle branch of the Bannock overthrust and as nearby outliers of overthrust rocks may indicate that the areas containing the red beds were themselves once overridden by rocks of the overthrust block, this suggestion may have merit. The beds of the Twin Creek limestone in this area are considerably folded and faulted. Another reddish bed is exposed south of Wolverine Creek canyon in the SW¼SE¼ sec. 28 of the same township at a comparable distance in front of this same overthrust. Here, however, the rock is an impure limestone that contains sections of crinoid stems (*Pentacrinus*), and the reddish material seems to be interstitial.

The main body of the formation, the middle unit, is composed of grayish-white and bluish shaly limestones that form steep slopes covered by a veneer of chippy and splintery weathered pieces. In places the close jointing of the shales makes the determination of the bedding difficult. The middle shaly unit is on the whole the most characteristic part of the formation lithologically, but it yields few fossils.

The upper unit is more sandy and more massively bedded than the middle unit, though it includes beds of limestone, red shaly sandstone, and greenish shale here and there. In the SE¼SW¼ sec. 35, T. 1 N., R. 39 E., the green shale has been prospected, presumably for copper. In places the upper unit is difficult to distinguish from parts of the overlying Preuss and Stump sandstones, especially when all three formations have become involved in faulting as in secs. 27, 28, 33, 34, 35, and 36, T. 1 N., R. 39 E., and secs. 1, 16, 17, 20 and 21, T. 1 S., R. 39 E. From about the center of sec. 34, T. 1 S., R. 39 E., northwestward into sec. 21, the upper unit parallels the Preuss and Stump and seems to have a thickness of about 750 ft, comparable to that of these two formations combined.

The shaly character of much of the formation produces smooth, rounded hills, many of them relatively high, that break with abrupt, bare slopes to the adjoining valleys. On such slopes massive ledges with steep dips appear at many places. The soil weathered from the formation does not produce abundant vegetation, so that the light color of areas underlain by the Twin Creek limestone is noticeable for considerable distances.

Fossils and age.—Although the formation is fossiliferous in certain localities, there are many places where fossils are scarce or absent and the collections made do not show many types. In many places too, such fossils as are present are fragmentary, and collections yield little that is diagnostic. For example, the hill in the SW¼ sec. 36, T. 1 S., R. 39 E., is considered Twin Creek on the basis of its lithology and a few fragments of fossils. The northern part of the hill, however, and its extension northward across the canyon contain small gastropods characteristic of the Peterson limestone (Lower Cretaceous) and have a somewhat different lithologic character from that of the main hill farther south. The two limestones have certain similarities which make it difficult to draw an exact boundary, but the Twin Creek here has apparently been overthrust on Lower Cretaceous limestones.

The best locality found for collecting fossils is the south end of the forked ridge in secs. 19 and 20, T. 1 N., R. 40 E., at a large bend in Willow Creek canyon. At this locality the following forms, identified by T. W. Stanton, were collected: *Isocrinus* sp. (abundant stem fragments), *Gryphaea nebrascensis* Meek and Hayden, *G. planoconvexa* Whitfield, *Modiolus* sp., *Astarte meeki* Stanton, and *Cyprina?* sp. In collections made at several other localities, Stanton has identified the following forms and contributed the accompanying notes: SW¼SW¼ sec. 27, T. 1 N., R. 39 E., *Nerinea* sp. (probably two or more species). NW¼ sec. 26, T. 1 N., R. 39 E., "contains only a few fragmentary fossils, most of which have been so altered in the process of silicification that they are not identifiable. There are a few specimens of a smooth pectinoid shell which I refer to *Camptonectes* and a smaller thick shelled form which may be an *Astarte*. There is also a fragment of a brachiopod and many cross sections of undetermined pelecypods. The age may well be Twin Creek, though the fossils show nothing really diagnostic." SW¼-SW¼ sec. 23, T. 1 N., R. 39 E., *Camptonectes* sp. (young shells), *Eumicrotis* sp. (very young shells), *Astarte* sp. (young shells). "The horizon is most probably Twin Creek or at least marine Jurassic." SW¼NE¼ sec. 16, T. 1 S., R. 39 E., *Ostrea strigilecula* White.

From the fossils listed and others collected in the type locality, the age of the upper part of the formation has been determined as Upper Jurassic. Possibly the lower part may include Middle Jurassic rocks.

Thickness.—As the Twin Creek limestone in the Ammon and Paradise Valley quadrangles is involved in folds or faults, or both, no place was found where a complete section across the formation could be measured. In the type locality, Veatch reports a thickness of 3,500 to 3,800 ft. However, there seems to be a tendency for the formation to grow thinner northward. On the basis of the structure as worked out for the two quadrangles, the thickness probably does not exceed 1,200 to 1,500 ft. As already noted, in its principal area of exposure in T. 1 S., R. 39 E., the Twin Creek for some miles lies in front of the middle branch of the Bannock overthrust, so that larger or smaller parts of the formation—and locally all of it—are cut out by this fault.

UPPER JURASSIC SERIES

PREUSS SANDSTONE

Name and distribution.—The name "Preuss sandstone" was applied by Mansfield and Roundy (1916, p. 81) to about 1,200 ft of red sandstones exposed in the canyon of Preuss Creek in the northeastern part of the Montpelier quadrangle. It has since been applied by the author (Mansfield, 1927, pp. 98, 99) to corresponding beds farther north in the general region of the Idaho-Wyoming border.

In the Paradise Valley quadrangle, the Preuss sandstone is exposed only in a small wedge along a fault that separates Twin Creek limestone from Stump sandstone in the NW¼ sec. 17, T. 2 S., R. 40 E. In the Ammon quadrangle, the Preuss sandstone is intimately associated with exposures of Twin Creek limestone but does not occur with all of them. The principal exposures are in a northwestward-trending belt that extends from the SE¼ sec. 34, T. 1 S., R. 39 E., to the SE¼ sec. 16 of the same township and in a second belt trending generally northward from the northeast quarter of this same section to the NW¼ sec. 33, T. 1 N., R. 39 E. The limestone also occurs in numerous fault blocks in secs. 33, 34, and 28, T. 1 N., R. 39 E.; in sec. 1, T. 1 S., R. 39 E., and sec. 6, T. 1 S., R. 40 E.; and in several minor belts in the area of faulting included in secs. 16 and 17, 20 and 21, T. 1 S., R. 39 E. Within the areas covered by rhyolitic welded tuff, the Preuss forms isolated exposures in places where the welded tuff has been removed by erosion, as in the SW¼ sec. 21, the NW¼, center, and SE¼ secs. 28, and the SE¼ sec. 32, T. 1 N., R. 39 E.

Character.—The formation consists of very fine, even-grained sandstones that range from pale reddish gray to deep dull red. They are generally calcareous and more or less argillaceous, locally with green partings, and become very shaly in places. In the zone extending northwestward from the NW¼ sec. 34, T. 1 S., R. 39 E., the beds mapped as Preuss sandstone include a massive bed of dark-gray, greenish- and brownish-weathering sandy limestone whose lithologic character resembles that of the Stump sandstone, but with reddish films on bedding planes. Beneath and above it are red beds more characteristic of the Preuss. Moreover, red beds have been observed here and there in the Twin Creek limestone. Thus the boundary between the two formations as here drawn is less distinct than in areas mapped farther south and, in fact, somewhat arbitrary. Farther southeast the relations of the Preuss to the Twin Creek are believed to be unconformable, but no evidence of unconformity between the two formations was observed in the Ammon quadrangle. An 11° difference in dip was noted in the NE. cor. sec. 28, T. 1 S., R. 39 E., but it may not be due necessarily to an unconformity. Also, no evidence of salt beds such as those indicated by salt springs in the Crow Creek and Freedom quadrangles farther southeast was observed in the Ammon quadrangle.

Age and correlation.—No fossils have been found in the Preuss sandstone, but it is regarded as late Jurassic in age because it lies between beds of the Twin Creek below and the Stump sandstone above, both of which contain Upper Jurassic fossils. The Preuss sandstone constitutes the lowest unit (red sandstone) of the Beckwith formation as described by Breger (1910, pp. 562, 563) and by Mansfield and Roundy (1916) in the Crow Creek area in what is now the Crow Creek quadrangle, about 80 miles southeast.

Thickness.—The Preuss sandstone as mapped in the Ammon quadrangle is only about 500 to 550 ft thick, less than half its thickness at its type locality.

STUMP SANDSTONE

Name and distribution.—The Stump sandstone (Mansfield and Roundy, 1916, p. 81) was named from Stump Peak in T. 6 S., R. 45 E. (unsurveyed), in the Freedom quadrangle, about 40 miles southeast of the Ammon quadrangle.

In the Paradise Valley quadrangle, the Stump sandstone is exposed only to the northeast in a small area in the NW¼ sec. 17, T. 2 S., R. 40 E. In the Ammon quadrangle, it is closely associated with the Preuss and Twin Creek formations in the zone extending northwestward and northward through the central part of T. 1 S., R. 39 E., and in faulted areas in the western part of that township. It also has been observed in the faulted areas in the southern part of T. 1 N., R. 39 E., and in the northeast corner of T. 1 S., R. 39 E. Another occurrence is in sec. 32, T. 1 N., R. 40 E., where the Stump sandstone is punctured by an intrusive plug of coarsely porphyritic basalt.

Character.—The Stump sandstone consists mainly of thin-bedded, gray to greenish-gray, fine-grained sandstones that weather into platy fragments about an inch thick. Near the base are some beds of compact calcareous sandstone, locally as much as 6 ft thick. The grains are very fine and chiefly of colorless quartz. The rock tends to break with a conchoidal fracture and to ring under the hammer. Fresh surfaces are steel gray, but weathered surfaces may be velvety brown—a feature less noticeable in the Ammon quadrangle than in areas farther southeast. At the base is a bed of grit, or coarse-grained sandstone, which contains marine fossils of Jurassic age. This bed is calcareous and tends to weather with a pinkish tint. It is practically the only bed in the entire formation from which fossils have been obtained. The Stump sandstone is usually resistant to weathering and forms conspicuous ridges.

Age and correlation.—The only fossils seen or collected from the Stump sandstone in the Ammon quadrangle have been *Ostrea strigilecula* White?, as determined by T. W. Stanton. These might be either Stump or Twin Creek. In areas to the southeast species of "*Rhynchonella*," *Camptonectes*, *Pentacrinus*, *Astarte*, *Trigonia*, and some other forms have been collected, including two or more genera of corals not yet studied. Stanton remarks that these forms might all be considered as Twin Creek, though the corals are a new element. However, the beds containing these fossils in the areas to the southeast are separated from the Twin Creek limestone by an unconformity and more than 1,000 ft of nonfossiliferous sandstones. In the Ammon quadrangle, the intervening sandstones are not so thick as they are in the areas farther southeast, and no very good evidence of unconformity has been observed at the top of the Twin Creek.

Like the Preuss sandstone, the Stump represents a lower part of the Beckwith formation as hitherto described in southeastern Idaho and perhaps a corresponding part of the Beckwith of southwestern Wyoming. It is the "lower gray band" of Breger's section of the Beckwith (1910). On faunal evidence, the Stump sandstone is considered to be of Late Jurassic age.

Thickness.—In the NE¼ sec. 28, T. 1 S., R. 39 E., where the beds are nearly vertical, a paced measurement shows the Stump sandstone to be about 200 to 250 ft thick.

JURASSIC AND CRETACEOUS SYSTEMS: UPPER JURASSIC AND LOWER CRETACEOUS SERIES

BASIS FOR AGE ASSIGNMENT

Above the Stump sandstone lies a group of conglomerates, fresh-water limestones, and sandstones that have been designated the Gannett group and divided into five formations. The limestone formations contain a fresh-water fauna, which, according to Stanton, is of later aspect than Jurassic and has affinities with the faunas of the Kootenai and Bear River formations. On the basis of these fresh-water fossils, the group as a whole has hitherto been tentatively assigned to the Lower Cretaceous (?).

Since the author's field work in the area was completed, new evidence has been obtained, showing that the Ephraim conglomerate, the lowest formation of the Gannett group, is at least in part Upper Jurassic and that the other formations of the group are definitely Lower Cretaceous.

GANNETT GROUP

GENERAL DESCRIPTION

The Gannett group was named from the Gannett Hills, which lie in parts of Bear Lake and Caribou Counties, Idaho, and Lincoln County, Wyo., 50 to 75 miles southeast of the Ammon quadrangle. Here all the formations of the group are well exposed.

The group consists of the Ephraim conglomerate at the base and the Peterson limestone, Bechler conglomerate, Draney limestone, and Tygee sandstone. The maximum thickness is more than 3,200 ft. The Gannett group rests with apparent conformity upon the Stump sandstone and follows the outcrop of that formation with a high degree of conformity for long distances. Nevertheless, the abrupt appearance of massive conglomerates accompanied by fresh-water limestone and the local absence of certain red beds near the contact of the Stump limestone and Ephraim conglomerate may indicate a considerable stratigraphic break.

In the Ammon quadrangle the Draney limestone and Tygee sandstone have not been recognized. The present discussion therefore is confined to the other three formations—the Ephraim conglomerate, Peterson limestone, and Bechler conglomerate. Both the Ephraim and Bechler conglomerates are finer-grained in the Ammon quadrangle than in the areas farther southeast, and the Bechler in some places might better be considered a sandstone.

The following stratigraphic section of the Gannett group as measured at the type locality is given here for reference. The section includes descriptions of the Stump and Preuss sandstones, which underlie the Gannett group at this locality.

Stratigraphic section of the Gannett group, with some underlying beds, in secs. 2 and 3, T. 8 S., R. 46 E., east of Miller ranch, Freedom quadrangle, Idaho

[By P. V. Roundy; adapted from Mansfield, 1927, pp. 101–103]

	Feet
Gannett group, Upper Jurassic and Lower Cretaceous:	
Tygee sandstone: Sandstone, gray to buff, somewhat resembling no. 7 of the lower unit of the Wayan (Mansfield, 1927, p. 106) but not greenish; not exposed in this section but appears above upper limestone in Crow Creek quadrangle 6 miles or more to the south, where about 100 ft of beds is exposed.	
Draney limestone:	
V. Limestone, white, much like the Peterson limestone; dip uncertain; near top of hill a prominent gastropod layer; top of bed not determined	125
Covered; light soil, float composed of light limestone	50
	175
Bechler conglomerate:	
Covered	150
Sandstone, salt-and-pepper-colored	4
Covered; soil reddish; float scarce; a few pebbles, as from conglomerate	60
U. Conglomerate, reddish-gray, heavy-bedded and cross-bedded; some finer conglomerate; a maker of subordinate ridges. Average strike, N. 6° W.; dip, 23° E	100
Covered	60
T. Sandstone, gray, fine-grained; beds 4 in. to 2 ft. If obtainable in good quantity would make good building stone (?); in most places masked by the debris of the conglomerate above	8
Covered; soil reddish; float is from conglomerate and sandstone above	60
S. Sandstone, gray, fine-grained, with purplish patches. Dip uncertain but assumed for purposes of measurement to be 30° E	25
Covered; soil a light reddish gray; abundant float; small pieces of limestone, gray to purplish pieces of fine-grained sandstone, chert pebbles, and some pieces of red sandstone. This division is probably like the overlying division (S)	95
Covered; mostly conglomerate pebbles	200
R. Conglomerate and sandstone like division Q; conglomerate predominates	60
Covered; soil red; float mainly that of a conglomerate and sandstone	225
Q. Sandstone and conglomerate; the sandstone is pepper-and-salt-colored, coarse- to medium-grained, and forms a small, very subordinate ridge in the saddle; the sandstone changes along the strike to a medium-coarse conglomerate. There are some slickensides, the grooves in which correspond to the dip and are probably due to the synclinal folding (slipping along bedding planes). Where measured the lower 45 ft is composed of sandstone overlain by conglomerate; 100 ft north there is not over 20 ft of sandstone. This division makes ridges south and north	75

Stratigraphic section of the Gannett group, with some underlying beds, in secs. 2 and 3, T. 8 S., R. 46 E., east of Miller ranch, Freedom quadrangle, Idaho—Continued

	Feet
Gannett group, Upper Jurassic and Lower Cretaceous—Con.	
Bechler conglomerate—Continued	
P. Conglomerate, medium, with calcareous cement, weathering red; aspect of weathered ledge is red. Strike, N. 12° W.; dip, 45° E. Ledge shows only in few favorable positions; bedding massive; one bed 2 ft 11 in. thick	30
Covered; reddish soil; float small; varied pebbles	70
O. Sandstone, pepper-and-salt-colored, coarse; beds appear to be 1 to 2 ft thick; soil not red but quite gray	40
N. Mostly covered; float composed of pepper-and-salt-colored sandstone like M	115
Covered; soil red; probably this interval and covered interval between K and M both correspond to J; the float is composed of scattered pieces of red sandstone	60
M. Sandstone, coarse; pepper-and-salt-colored like that of L and K; weathers roundish, so that strike and dip are uncertain. Ledges strike N. 10° W.; for purposes of measurement dip assumed to be 45° to correspond with dips above; soil reddish	18
L. Covered; soil reddish; float mainly scattered pieces of red sandstone	65
K. Sandstone, coarse, pepper-and-salt-colored; like I without the hard, fine-grained sandstone at base. Dip, 50° ± E	45
Covered; probably like J	40
J. Sandstone, reddish, rather dull and grayish; seems to weather easily	50
I. Sandstone, coarse, pepper-and-salt-colored, with a small amount of fine-grained sandstone near base; thin-bedded; beds 8 to 10 in. thick. Strike, north; dip, 55° E	70
	1,725
Peterson limestone:	
H. Limestone, fine-grained; weathers white; is slate-colored to light gray inside. Strike, north; dip, 66° E. Considerable calcite in upper part in the form of veins. Most veins are 1/8 in. or less thick; one is 1/2 in. Upper part is the more massive; average bed 1½ ft thick, thickest bed 2 ft 10 in. This limestone is the prominent ridge maker of this region; forms white soil	205
Ephraim conglomerate:	
G. Sandstone, coarse, conglomeratic, grayish to reddish, massive, like division F. Upper 20 ft is mixed float from "lower white limestone" above and coarse reddish sandstone of division G	145
Covered; soil reddish; float composed of small varied pebbles and reddish sandstone	95
F. Sandstone, coarse, conglomeratic, grayish to reddish, heavy-bedded; upper 10 ft somewhat purplish and slightly calcareous. Coarse sandstone predominates with conglomerate in scattered bands; pebbles in conglomerate 1/8 to 1/4 in. in diameter; thickest bed 3½ ft thick. Strike, N. 7° W.; dip, 66° E	355

Stratigraphic section of the Gannett group, with some underlying beds, in secs. 2 and 3, T. 8 S., R. 46 E., east of Miller ranch, Freedom quadrangle, Idaho—Continued

	Feet
Gannett group, Upper Jurassic and Lower Cretaceous—Con.	
Ephraim conglomerate—Continued	
Covered; soil reddish; float composed of different kinds of pebbles less than 1 in. in diameter	65
E. Covered; soil varies from gray to red, mainly reddish gray; float not very abundant but mainly grayish limestone boulders, all containing chert in irregular ornamental forms	75
D. Limestone band forming roughly rounded, fine-grained dense boulders 1 to 14 in. in diameter, close together; color on fresh fracture dull gray to purplish gray; weathered surface white to purplish gray, but white predominates; no ledges exposed in this region, but this band is rather constant; soil a dull gray	25
Covered; soil grayish red; float composed of dull pale-red sandstone with gray limy patches and small gray limestone pebbles. This area and the overlying covered area form a saddle between low peaks	45
Covered; soil dark and rather clayey; float, small angular pieces of indurated sandstone with purplish and grayish colors	90
C. Sandstone and conglomerate, gray, indurated; contains black, gray, and yellowish chert pebbles; this band is rather constant in this region on both sides of the syncline, but it is not present everywhere in the Crow Creek quadrangle; a few beds 2 to 3 ft thick stand out prominently, and the rest of the band is composed of scattered exposures of beds and float of small angular pieces; a bed of this conglomerate east of Peterson's ranch is 7 ft thick	130
	1,025
Total, Gannett group	3,130
Jurassic:	
Stump sandstone: B. At base, steel-gray fine-grained calcareous sandstone, which weathers somewhat like trap; hard, rings under the hammer; is not exposed here as ledges, though commonly does form ledges; is abundant on surface and lies just below the crest; generally this band forms the crest. Above lies a thin-bedded greenish-gray to gray sandstone, mainly with greenish cast in this region; the thickest bed observed is 2 ft 8 in. thick; this bed upon the more weathered portions appears to be composed of distinct beds 1 to 3 in. thick; some cross bedding; float not as angular as red sandstone below and usually roughly platy; few pieces as much as 2 in. thick, generally ¼ to ¾ in.; dip of middle portion, 68° E.; soil grayish; this band makes a series of low subordinate peaks and ridges, elsewhere prominent peaks and ridges, and is much thicker to the south; lower contact not clearly shown, as debris from overlying bed overlaps this bed. This zone in Crow Creek quadrangle and other places contains a reddish-gray grit that carries scattered oyster shells	430

Stratigraphic section of the Gannett group, with some underlying beds, in secs. 2 and 3, T. 8 S., R. 46 E., east of Miller ranch, Freedom quadrangle, Idaho—Continued

	Feet
Jurassic—Continued	
Preuss sandstone:	
A. Sandstone, dull-red, fine, even-grained, somewhat calcareous, also somewhat shaly, thin-bedded; not a ridge maker; occupies slopes that have dull-red soil which contains angular pieces of stone ½ to 8 in. across; small pieces about as thick as broad, larger pieces 1 to 4 in. thick; few ledges exposed, but better ledges occur in southeastern corner of Crow Creek quadrangle	360
Base of formation concealed by Salt Lake formation, which contains well-rounded, assorted pebbles of red and gray sandstone, limestone, quartzite, and chert.	
	3,920

EPHRAIM CONGLOMERATE

Name and distribution.—The Ephraim conglomerate was named from Ephraim Valley in T. 10 S., R. 45 E., Crow Creek quadrangle.

In the Paradise Valley quadrangle the Ephraim conglomerate, which is here the sole representative of the Gannett group, is exposed only in a small area in the NW¼ sec. 17, T. 2 S., R. 40 E. The formation is contained in a small slice of rocks in the zone between the middle and east branches of the Bannock overthrust, which extend northwestward into the Ammon quadrangle.

The main body of the formation occupies a faulted syncline that extends northwestward from Williams Creek in secs. 17 and 18, T. 2 S., R. 40 E., to sec. 33, T. 1 N., R. 39 E., where it ends abruptly at a fault. It also extends northward east of the fault in secs. 25 and 36, T. 1 S., R. 39 E., as far as the diagonal fault in secs. 24 and 26 of the same township. Subordinate faulted masses occur in secs. 1 and 12. Other areas lie along and near Willow Creek from secs. 32 and 33 into sec. 21, T. 1 N., R. 40 E., and from the SW¼ sec. 8 into the NW¼NE¼ sec. 6 of this township.

Character.—At the type locality the rock is a red conglomerate, about 1,000 ft thick, which contains minor amounts of sandstone and some thin bands of gray to purplish limestone, some of which is nodular. The Ephraim differs locally in thickness and character, being much more conglomeratic in some places and more sandy in others. In the type locality, the pebbles or boulders reach a maximum diameter of nearly a foot, but in the Ammon quadrangle such boulders are scarce or absent; the pebbles do not exceed a few inches in diameter, and most of them measure less than an inch. The pebbles represent a wide variety of materials, including quartzite, limestone, and chert—probably derived from Carboniferous or early Paleozoic as well as from later formations. The pebbles are mostly smooth and subangular, and some are even well rounded. Perhaps 100 ft above the base is an olive-yellow band, 25 ft or more thick, which is relatively widespread; in it the pebbles are composed almost exclusively of dark chert, rounded or subangular and generally an inch or less in diameter. The Ephraim conglomerate makes rough, ledgy hills and ridges.

Correlation and age.—The Ephraim conglomerate is equivalent to the upper middle part of the Beckwith formation of southeastern Idaho as described by Breger (1910, pp. 562–563) and perhaps to part of the lower division of the Beckwith formation of southwestern Wyoming as described by Veatch (1907, pp. 57–58).

The only fossil found in the Ephraim conglomerate by the writer's field party was a small fragment of unidentifiable bone from an exposure in Tincup Canyon in the Freedom quadrangle. However, Rubey (personal communication) reports that at a locality along the old Lander trail in the southwestern part of the Afton quadrangle, Wyoming, he found *Belemnites*, *Ostrea strigilecula* White, and other marine Jurassic forms in place in beds of red shale about 50 ft above the base of the Ephraim. These beds overlie red shale, siltstone, and sandstone like that in the Ephraim above, so that the fossiliferous beds are clearly above the Stump sandstone, which is well developed in the sequence below. In higher beds of the Ephraim, saurian (dinosaur) bones were found but were not well enough preserved for identification. These beds were of nonmarine aspect and might represent the Morrison formation, though no recognizable Morrison fossils were found.

In variegated clayey beds in the top of the Ephraim at places in the Afton quadrangle, Rubey found shiny stones ("gastroliths"). These are not distinctive, however, because such stones are widely distributed from Colorado to Wyoming and Montana and may be of either Jurassic or Early Cretaceous age.

More recently Stokes (1944, pp. 968–969), who has visited the type locality of the Ephraim, has concluded that "the evidence, though meager, indicates that all or part of the Morrison and Cedar Mountain is probably equivalent to the Ephraim conglomerate and contiguous formations of the Gannett group." Stokes, who also found "gastroliths" in the Ephraim, considers them as important evidence in favor of Morrison age for the beds that contain them.

The presence of marine Jurassic fossils in the lower part of the Ephraim conglomerate and the absence of any distinctive Morrison fossils in the rest of the formation make any direct reference of the Ephraim to the Morrison inadvisable. It may be said, however, that the lower part of the Ephraim is marine and of Late Jurassic age, whereas higher beds in the formation are nonmarine, some of them in all probability of Late Jurassic age, possibly equivalent to the Morrison, and some perhaps even of Early Cretaceous age.

Thickness.—In the Ammon quadrangle the thickness of the Ephraim conglomerate has not been measured directly, but from the mode of occurrence and structural relations of the formation its thickness appears to be at least 1,000 ft, comparable to that in the type locality.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES: GANNETT GROUP (CONTINUED)

PETERSON LIMESTONE

Name and distribution.—The type locality of the Peterson limestone is east of Peterson's ranch in sec. 34, T. 7 S., R. 46 E., Freedom quadrangle, about 48 miles southeast of the Ammon quadrangle. It is not known to occur in the Paradise Valley quadrangle. In the Ammon quadrangle it forms a Y-shaped area in the southeastern part of T. 1 S., R. 39 E., and halfway up the joint boundary of this township and T. 1 S., R. 40 E., where it forms part of a faulted synclinorium. It forms a narrow faulted band extending along the west limb of this synclinorium from the NW¼ sec. 26, T. 1 S., R. 39 E., to the NE¼ sec. 3 of the same township. It occurs in several faulted areas in secs. 1 and 12 of this township and in minor areas in secs. 3, 4 and 9, T. 1 S., R. 40 E., and in secs. 33, 21, and 6, T. 1 N., R. 40 E., where it is involved in minor folds or faults.

Character.—In the Ammon quadrangle, the Peterson limestone locally contains more or less reddish and purplish material and does not everywhere supply the dead-white flattish pieces of float that are so characteristic of the Peterson generally. At such places, its lithologic character is more suggestive of that of the limestone bands or lenses seen in the Ephraim conglomerate here and there. The limestone in the Ephraim, however, is not persistent like that in the Peterson, and it does not form any noteworthy linear hills and ridges. Locally, too, the Peterson is difficult to distinguish from some beds of the Twin Creek limestone, where they are in juxtaposition, as in sec. 36, T. 1 S., R. 39 E., and in sec. 6, T. 2 S., R. 40 E., unless fossils can be distinguished in each formation.

Correlation and age.—Fossils in the Peterson limestone in the Ammon quadrangle are neither well preserved nor very distinctive. Regarding a collection from the SE¼NE¼ sec. 36, T. 1 S., R. 39 E., T. W. Stanton reported as follows: "The specimen submitted is a fresh-water limestone made up of small gastropods not well enough preserved for generic identification, though several genera may be represented. The fossils suggest the Kootenai fauna of the northwest." From collections from the Peterson in the Freedom and Crow Creek quadrangles farther southeast, Stanton has identified the following fossils: *Unio* sp., *Planorbis* (*Gyraulus*) sp. related to P. *praecursoris* White, *Viviparus* sp., *Goniobasis?* sp., and two distinct species of *Physa*. He states that fossils of similar types occur in the Kootenai, Bear River, and later formations; that the fresh-water gastropods are not distinctive; and that similar forms of *Planorbis* are found in both the Morrison and Bear River formations but no species of *Physa* have been reported from beds older than the Bear River.

More recently, R. E. Peck (1941), who collected microfossils from the type localities of the Peterson and Draney limestones in southeastern Idaho, has identified ostracods and charophytes in these collections. He concludes: "The occurrence of the genera *Clavator*, *Perimneste*, and highly ornamented species of *Cypridea* and *Metacypris* in association with *Atopochara trivolvis* Peck, heretofore known only from the Trinity of Oklahoma and Texas, substantiates the conclusions of most students that the Gannett group and lower part of the Kootenai formation are Lower Cretaceous in age." Peck, however, excluded the Ephraim from his study because of its conglomeratic nature. His statement must therefore be amended accordingly.

The Peterson limestone is the "upper gray band" of the Beckwith formation as described by Breger (1910).

Thickness.—The Peterson limestone in the Ammon quadrangle is so involved in folds and faults that no place was found where the formation was fully exposed. However, its thickness here appears to be about 200 ft, comparable to that given for areas in and near the type locality.

BECHLER CONGLOMERATE

Name and distribution.—The Bechler conglomerate is named from Bechler Creek, a tributary of Stump Creek in the Freedom quadrangle about 45 miles southeast of the Ammon quadrangle.

The principal exposures of the Bechler are in the eastern part of T. 1 S., R. 39 E., where it occupies an area extending northwestward from the diagonal fault in secs. 26 and 24 as far as sec. 34, T. 1 N., R. 39 E. Large parts of it are concealed by welded rhyolitic tuff. A band of Bechler less than half a mile wide extends southward from sec. 19, T. 1 S., R. 40 E., to sec. 6, T. 2 S., R. 40 E. Other areas are mapped in secs. 3, 4, and 10, T. 1 S., R. 40 E., and in secs. 6, 21, 28, and 33, T. 1 N., R. 40 E. The formation is not exposed in the Paradise Valley quadrangle.

Character.—The general character of the Bechler conglomerate in the region near the type locality has been described. In the Ammon quadrangle the formation should perhaps more properly be considered a sandstone, for sandstones predominate even though beds of conglomerate are present here and there. The pebbles in these conglomerates are generally small, ranging from about an eighth of an inch to perhaps an inch in diameter, and consist largely of chert. The sandstone beds are commonly pepper-and-salt-colored or gray on fresh surfaces. They weather reddish, brownish, or locally black, and the finer beds weather to red soil. The general impression given by the formation as a whole is that of red beds. Locally flakes of clay are included in the sandstone, and at one locality impressions resembling casts of saline crystals, possibly glauberite, and fine sandy markings suggestive of former fillings of plant stems were observed.

Correlation and age.—No fossils have been found in the Bechler conglomerate. The formation lies above the Beckwith described by Breger (1910) and probably corresponds to some part of the Beckwith formation of southwestern Wyoming (Veatch, 1907, pp. 57–58). The age of the formation is Early Cretaceous.

Thickness.—The Bechler conglomerate in the Ammon quadrangle is involved in folds and faults, and its full thickness is not exposed. Its structural relations apparently indicate that at least 1,000 ft of the formation must be present.

LOWER (?) AND UPPER CRETACEOUS SERIES: WAYAN FORMATION

In the Freedom quadrangle, 30 miles or more southeast of the Ammon quadrangle, the Gannett group is overlain unconformably by sandstones, shales, carbonaceous shales, limestones, and conglomerates that have an apparent thickness of about 11,800 ft. These beds are grouped in the Wayan formation (Mansfield and Roundy, 1916, pp. 83–84). In the Ammon quadrangle the Wayan succeeds the Bechler conglomerate, the two higher members of the Gannett group, the Draney limestone and Tygee sandstone, being absent.

Name and distribution.—The Wayan formation is named from Wayan Post Office, Caribou County, Idaho, in the Lanes Creek quadrangle, about 25 miles southeast of the Ammon quadrangle, east of which the formation occupies large areas.

As mapped in the Ammon quadrangle, the Wayan formation occupies two general areas: the first extends from parts of secs. 5 to 8, T. 2 S., R. 40 E., northward as far as the SE¼ sec. 19 and the SW¼ sec. 20, T. 1 S., R. 40 E.; the second lies in and near Willow Creek canyon in secs. 4 to 9, T. 1 N., R. 40 E. The eastern third of the quadrangle is extensively covered by igneous rocks or their derivatives and Tertiary sedimentary rocks. It seems probable that the Wayan formation occupies considerable additional areas within the quadrangle beneath the cover of these later rocks.

Character.—The Wayan formation as described at its type locality (Mansfield, 1927, pp. 105–108) is broadly divisible into two units. The lower unit is composed of about eight subdivisions, including sandstones locally conglomeratic; shales, some of them carbonaceous; and several thick beds of fresh-water limestone. The combined thickness of the lower unit in the type locality is estimated at about 2,800 ft. The upper unit, estimated at about 9,000 ft (assuming no duplication), is composed chiefly of red and gray sandstones with intervening shales and some calcareous beds. The sandstones form a series of low ridges and knolls, but the shales are mainly weathered into soil-covered areas. Toward the top, yellowish and brownish sandstones appear, and the uppermost strata are recognized only by fragments of dark-gray, siliceous sandstones, together with fragments of bentonitic tuff and pieces of whitish-weathering, dark-brown material suggestive of silicified wood. This material has since been identified by R. W. Brown as *Tempskya knowltoni* Seward and *Tempskya minor* Read and Brown. It represents the stems and bundled rootlets of two species of fern. Large fragments of this fossil have been found by local people, who have mistaken them for bones of prehistoric animals (dinosaurs) because of their size and shape and because of a superficial resemblance of their weathered surfaces to bone.

Associated with the sandstones of the lower part of the upper unit are calcareous conglomerates and grits that are generally grayish or pepper-and-salt-colored. The darker fragments against the white calcareous matrix produce a curious patchy appearance.

In the Ammon quadrangle only a small part of the Wayan formation is exposed. It would appear that at least the lower half of the lower unit is missing and that only the lower portion of the upper unit, including red and gray sandstones and some of the patchy conglomerate, is present. Fossiliferous limestone beds with intervening black carbonaceous shales have been recognized at three localities, one in sec. 6, T. 2 S., R. 40 E., and two in sec. 6, T. 1 N., R. 40 E. On the evidence of fossils collected, however, these localities apparently represent the same bed. At the localities in sec. 6, T. 1 N., R. 40 E., the shales accompanying the limestone beds are sufficiently carbonaceous to have been prospected for coal (p. 88).

Although the limestone beds and their accompanying carbonaceous shales presumably represent a subdivision of the lower unit of the Wayan, it is not clear which one it is; possibly, however, it is no. 6 (Mansfield, 1927, p. 106).

Some of the beds of the Wayan lithologically resemble those of members of the Gannett group, and it is locally difficult to distinguish the formations. J. B. Reeside, Jr. (personal communication), thinks that the Wayan formation at its type locality probably includes some Gannett beds.

Correlation and age.—Fossils have been collected from the limestone beds of the Wayan at two localities in the Ammon quadrangle. One of these is close to the center of sec. 6, T. 2 S., R. 40 E. Here the fossils came from a bed not definitely in place but represented by blocks of limestone 3 to 6 in. thick that lie at the same level along the hillside together with blocks of sandstone of the Wayan formation. The fossils, as determined by T. W. Stanton, include *Unio* sp. (long slender form), *Unio* sp. (small short form) and *Goniobasis? increbescens* Stanton?. According to Stanton, they "apparently belong to the fauna of the Kootenai formation, which as recognized in Montana probably includes the equivalent of the lower part of the Blairmore formation of Alberta." The other locality is the old Cloward entry in the SE$\frac{1}{4}$ sec. 6, T. 1 N., R. 40 E., and in the draw immediately to the north. Here the fossils were identified as *Unio* sp. (long slender species) and *Goniobasis? increbescens* Stanton? by Stanton, who notes that both species are represented in the collection from the first-named locality and are probably from the same bed.

On the basis of their studies of the *Tempskya* collections from southeastern Idaho Read and Brown (1937, p. 127) conclude:

> Several specimens of *Tempskya minor* were collected by G. R. Mansfield, W. W. Rubey, and J. S. Williams in the Lanes Creek quadrangle, southeast of Grays Lake and 40 miles west of the Horse Creek area, in Idaho. These specimens were found loose on the surface in secs. 17 and 19, T. 5 S., R. 44 E., in an extensive outcrop of the Wayan formation. Other specimens, according to Mansfield, were seen but not collected in the region northwest of Grays Lake. All these specimens were most probably derived from the uppermost beds of the Wayan formation, as these beds occupy the axial region of a broad syncline, and the course of the axis to the northwest in the region of Grays Lake Outlet marks the general line along which the specimens were found. The writers believe that the finding of *Tempskya minor* in the Wayan formation only 40 miles distant from the Aspen localities in Wyoming, in a region of similar lithology, indicates a fairly close correlation in ages, and that the Wayan formation, or a portion of it, may reasonably be regarded as of Colorado age and the time equivalent of the Aspen shale in Wyoming. This conclusion was also independently reached by W. W. Rubey in his field studies of the stratigraphy and lithology of these beds.

The affinities of the fossils from the lower division of the Wayan formation with those of the Kootenai formation of Montana would seem to indicate an Early Cretaceous age for that part of the formation. On the other hand, at least some beds of the upper division of the Wayan appear to be correlatives of the Aspen shale of Wyoming and thus to be of Late Cretaceous age.

Thickness.—No measurements of the thickness of the Wayan have been made in the Ammon quadrangle. It is estimated, however, that 1,500 to 2,000 ft of the formation may be exposed there.

TERTIARY SYSTEM: PLIOCENE(?) SERIES (SALT LAKE FORMATION)

Large areas in the Ammon and Paradise Valley quadrangles are occupied by rocks considered to be of Tertiary age, amounting perhaps to half or even more than half the area of each quadrangle. They lie unconformably upon rocks of all the earlier formations represented and are all included in the Salt Lake formation of Pliocene (?) age.

Name and distribution.—The author has elsewhere (1927, p. 110) discussed the use of the name "Salt Lake formation" as hitherto applied in southeastern Idaho. This usage is retained in the present report.

The extensive development of the Salt Lake formation in the Chesterfield Range in the Portneuf quadrangle to the south continues northward into the Paradise Valley quadrangle, where the formation also occupies extensive areas along the east flank and at the north end of the Portneuf Mountains and in the broad foothill area between the Blackfoot River and the ridges of the Blackfoot Mountains to the northeast. The greater extent of the Salt Lake formation in the southeastern part of T. 4 S., R. 38 E., and in the northeastern part of T. 5 S., R. 38 E., as shown in the present report as compared with the author's earlier report on the Fort Hall Indian Reservation (1920a, map), is due to remapping and reinterpretation on the basis of wider experience in the general area. In the earlier report areas underlain by certain groups of rock fragments were mapped as representing rock in place, whereas in the present report these fragments are considered as material weathered from conglomerate beds of the Salt Lake formation.

In the Ammon quadrangle a broad blanket of the Salt Lake formation laps around the west, north, and northeast flanks of the Blackfoot Mountains and extends into adjoining quadrangles in those directions.

Character.—As mapped in the Ammon and Paradise Valley quadrangles, the Salt Lake formation includes a wide variety of materials, some of which, on further and more detailed field work, may prove to be of later age. This is almost certainly true of fine, powdery, apparently wind-blown material, rather widely distributed but particularly noticeable in Tps. 1 and 2 N., R. 39 E. There also are widely distributed beds of volcanic ash, apparently of different ages, which may or may not be properly included with the Salt Lake formation. Some of these beds undoubtedly should be so included, but others are with little doubt younger. The differentiation and mapping of the Salt Lake formation constitute a regional geologic problem requiring intensive geologic field work which could not be undertaken in the present investigation.

The Salt Lake formation most commonly consists of conglomerate, light gray, buff, or locally pinkish, in which the matrix is white, relatively soft, loose-textured, and calcareous. Most of the pebbles are of local materials, and rather angular, though many are subangular or even rounded. The component materials range widely in size from boulders several feet in diameter to pebbles of less than an inch. The bedding is generally massive and not well defined. Ledges, which are infrequent, weather with rounded surfaces (fig. 16). In the southern part of the Paradise Valley quadrangle, the pebbles are chiefly of Paleozoic rocks with some Triassic material; farther north younger sedimentary rocks, including some of Cretaceous origin, are represented.

FIGURE 16.—Salt Lake formation in the NW¼SE¼ sec. 2, T. 5 S., R. 38 E., Paradise Valley quadrangle.

In addition to the conglomerate there are beds of white marl, or limestones, calcareous clay, sandstone, grit, and volcanic ash. The occurrences of these materials, except the volcanic ash, are sporadic and sparse and not worth mapping on the scale here used. The volcanic ash, though occurring sporadically to some extent, is more widespread and has been mapped in some places; however, much of it is not differentiated from the Salt Lake formation.

Most of the ash is well bedded, water-laid, and sufficiently consolidated to be called a tuff. Some of it contains water-worn pebbles of igneous rock. A spectacular occurrence of this type of material is shown in figure 8. Here the tuff is tilted and contains lenticular pebbly zones with pebbles apparently derived in large part from earlier andesitic tuffs such as those exposed in the southeastern part of T. 3 S., R. 38 E. Elsewhere such material may include pebbles of rhyolite, welded tuff, or basalt.

The fine, white, powdery materials may in part be soil derived from the weathering and decomposition of volcanic ash beds, which in many places lie close to the surface, but where the welded tuffs intervene, as they do in much of the area in Tps. 1 and 2 N., R. 38–40 E., the fine white soil is probably derived from windblown dust. It has not been practicable to map this material separately from the Salt Lake formation.

Correlation and age.—Little further information on the age of the Salt Lake formation in southeastern Idaho has been obtained since the publication of the author's earlier report (1927, pp. 111–112). On the basis of the evidence there stated, the Salt Lake has been considered Pliocene (?). However, some beds here mapped with the Salt Lake are with little doubt to be considered Pleistocene or even Recent. For example, a collection by W. B. Lang of plant remains from carbonaceous beds included in bedded and altered volcanic ash in the NE¼NE¼ sec. 16, T. 1 S., R. 40 E., Ammon quadrangle, was studied by the late F. H. Knowlton. He reported:

> This material—a light, loosely compacted carbonaceous shale—contains only two species of plants, a large grass (*Phragmites* sp.) and the root-stock of a water-lily (*Castalia* sp.). The grass is represented by stems and leaves and makes up the bulk of the material. The water-lily is represented by fragments of the thick root-stock, with characteristic scars.
>
> These plants evidently grew in the shallow water of a lake or pond. The grass was probably at least 10 feet tall and, to judge from the matted mass of stems and leaves, was abundant, probably forming dense masses not unlike the canebrakes of our southern swamps. The water-lily doubtless lived in open but shallow water just outside the grass stand.
>
> Neither of these plants is sufficiently well preserved to admit of specific identification, but from their very modern appearance and the loosely compacted nature of the matrix I incline strongly to the opinion that they are Pleistocene in age. In fact they are more likely to be younger rather than older than Pleistocene.

A later collection by Lang from the same locality yielded a few fish remains in addition to the plants. The fish remains were examined by the late J. W. Gidley, who stated: "The specimen is too fragmentary to be determined further than to say that the two recognizable pieces are opercula of some fresh-water fish about the size of the sucker or a large minnow."

Although the organic remains contained in the beds are comparatively recent, the beds themselves have been subjected to considerable dislocation and erosion. The creek bed at this locality has been cut nearly 200 ft below the overlying welded rhyolitic tuff, and for about 75 ft the rock beds are undercut to a steep slope in part nearly vertical. Here a nearly vertical fault cuts them, bringing the lacustrine beds that contain the fossils into contact with stream-laid, cross-bedded sand and gravels containing pebbles as much as half an inch in diameter. The displacement is 75 ft or more, at least as great as the height of the exposure, which has been produced by the erosion of the tuff and of some overlying basalt. Similar ash beds and welded tuff have been faulted and deformed elsewhere in the region, notably in secs. 8 and 9, T. 1 S., R. 40 E., a mile or more to the northwest. (See also fig. 8.) The ash beds apparently belong to a sequence that has been found underlying the welded tuff at many places. Presumably it overlies the conglomerate of the Salt Lake, but no contact with the conglomerate has been observed and it is not known whether the contact is conformable or not.

Apparently the Salt Lake formation as mapped is not older than Pliocene and some of it is Pleistocene or even younger.

Thickness.—The Salt Lake formation occurs in patches on older rocks at altitudes as great as 7,000 ft and in mounds on the Snake River Plain as low as 4,728 ft. Thus its vertical range in the area here described is more than 2,000 ft. It was laid down on an eroded surface, where it filled valleys and overspread intervening areas. Its thickness is therefore very irregular and varies from almost nothing to hundreds of feet. In the northwestern part of the Paradise Valley quadrangle, canyons nearly 800 ft deep have been cut in its nearly horizontal or only gently inclined beds. The formation as a whole has been extensively eroded; it has undoubtedly been much thicker than it is today.

QUATERNARY SYSTEM

The rocks of the Quaternary system consist mostly of unconsolidated gravel, sand, and mud on the larger valley bottoms and of coarser or finer debris, less well stratified, that has accumulated here and there along the lower slopes above the valley bottoms. Glacial deposits are absent, but there are a few small travertine deposits and some wind-blown material. The Quaternary deposits are all unconformable upon older rocks. For mapping they are divided into four groups.

PLEISTOCENE SERIES

TRAVERTINE

Travertine has been found in three places in the area here described. At each occurrence it is associated with faulting. The first of these occurrences is too small to map; the travertine here lies as float along a small fault in the NE¼ sec. 33, T. 4 S., R. 40 E., in the Paradise Valley quadrangle. The second locality is near the center of sec. 33, T. 2 S., R. 39 E., Paradise Valley quadrangle, where the travertine lies just below the intersection of two faults and forms a group of terraces over which Miner Creek falls as it leaves the Brazer limestone of the Blue Ridge and enters the part of its canyon that is cut in the Salt Lake formation. The rock is a soft, porous limestone, gray when moist but white when dry. The third occurrence is a ledge of travertine at the mouth of a small tributary that enters Wolverine Creek from the south in the NE¼ sec. 32, T. 1 S., R. 39 E., in the Ammon quadrangle. The travertine lies on a small fault that passes southeastward up this tributary and offsets the boundary between the Woodside shale and the Ross Fork limestone.

HILL WASH AND OLDER ALLUVIUM

The lower slopes of many of the hills are covered with rock fragments and soil, which conceal the underlying formations. In many places this material is poorly sorted or without definite arrangement. Elsewhere it merges with fluviatile deposits and forms alluvial fans that have considerable areal extent, as in Paradise Valley and at various places along the east side of the Blackfoot Mountains. The upper limit as mapped is the general line that marks the outcrop of the older, underlying formations, or the line where the debris of these rocks is sufficiently characteristic and abundant to indicate the strong probability of their occurrence beneath. The line is somewhat generalized, especially where it lies between the Salt Lake formation and the hill wash. The bouldery nature of the slopes underlain by the Salt Lake makes any sharp distinction between the two formations difficult or impossible. The lower limit, also somewhat generalized, is the line separating these deposits from those of the valley bottom, which are generally finer and better sorted.

The materials of the hill wash and older alluvium are mostly local, ranging from boulders to fine soil. They are usually not well rounded. The deposit has been cut away to some extent by stream action, so that the present surface is uneven, with low-lying spurs and interfingering depressions. The low-lying spurs and higher slopes of the deposit are generally covered with sagebrush where they have not been cleared for agriculture. Many of the depressions are grass-covered, and those large enough to be separately indicated are mapped with the younger alluvium.

The principal accumulations of hill wash and older alluvium in the Ammon quadrangle are in the Snake River valley. This area is presumably underlain in large part by basalt, which crops out here and there, but it is overspread by gravel and soil, now intensively cultivated. It laps eastward against areas mapped as Salt Lake, though here that formation is largely composed of volcanic debris and fine soil. The boundary is very irregular, and hummocky outliers of the Salt Lake formation, now more or less obscured by cultivation, project above the older alluvium. A few of these are represented in general outline, though no attempt was made to map them accurately.

In the Paradise Valley quadrangle the principal areas of hill wash and older alluvium are in Paradise Valley, along the east flank of the Blackfoot Mountains, in the Blackfoot River and Sunday Creek valleys to the south, and in the valley of the upper Portneuf River to the southwest.

SAND DUNES AND WIND-BLOWN DUST

In secs. 3, 4, and 9, T. 1 N., R. 38 E., Ammon quadrangle, and extending southwestward a short distance beyond the west boundary of the quadrangle, is an area of sand dunes and sand ridges that is mapped as a unit. The sand ridges lie along the northwestern part of the area. They stand 10 ft or more above the level of the surrounding plain and are probably rearranged wind-blown sand, possibly thrown up in connection with excavation for an old canal now filled and abandoned. To the southeast nearby are normal sand dunes 50 ft or more high surmounted by smaller, secondary dunes. These have wind-rippled back slopes and steep, crescentic front slopes (fig. 10). The sand is generally gray or tan, but includes many dark grains of igneous material. The nature of these dark grains was not determined, but they may represent a northeastward diminution of the deposit of volcanic sand mapped and described in the author's report on the Fort Hall Indian Reservation (Mansfield, 1920a, pls. 3, 4, p. 72).

Wind-blown dust, as already noted, is associated with the Salt Lake formation. It is also probably present in the older alluvium in the Snake River Plain, in Paradise Valley, and in the soil which covers much of the Willow Creek lava field in the Paradise Valley quadrangle. This dust has not been differentiated in mapping the associated formations.

The climatic oscillations of the Quaternary period in southeastern Idaho have probably differed in degree rather than in character from those of the Bonneville Basin near Great Salt Lake as described by Gilbert. The epoch of deposition of the hill wash and older alluvium in the Ammon and Paradise Valley quadrangles is believed to correspond with Gilbert's pre-Bonneville epoch (1890, p. 221).

No fossils have been found in the gravel pits of the Snake River Plain in and near the Ammon quadrangle. It may be of interest to note, however, that in gravels near McCammon in the Portneuf River valley, about 60 miles south of Idaho Falls, vertebrate fossils have been found. In 1930, some of them were on display at Lindenschmidt's garage at McCammon. The writer visited the gravel pit, which was located near the 1-mile sign east of McCammon on the Granger division of the Oregon Short Line Railroad. One bone was collected in place, and others were taken from a nearby pile of stones which apparently had come from the pit. These bones were reported by J. W. Gidley as horse (*Equus* sp.), mammoth (? *Elephas*, now *Parelephas columbi* according to Osborn), and bison (*Bison* cf. *alleni*). According to Gidley, they are all Pleistocene.

Some fossil shells preserved in clay and in a limy nodule were taken from the same pit. These were identified as *Limnea* sp., *Planorbis* sp., and *Sphaerium* sp. by W. C. Mansfield, who stated: "All the fossils represent genera that now live in fresh water. The specimens are too poorly preserved to definitely determine the age of the bed in which they occur; however, they do not appear to have been buried for a long period of time."

Although this area was not studied in detail, the gravels near McCammon, which stand above the present valley bottom of the Portneuf River, appear to occupy a position, with reference to the Salt Lake formation of the adjoining hills, similar to that of the Snake River Plain in the Ammon quadrangle with reference to the adjoining hills mapped as Salt Lake.

RECENT SERIES: ALLUVIUM

In the valley bottoms along the courses of many of the streams are narrow bands or broader areas of grassy meadowland or brush-covered areas (willows and the like) with fingerlike extensions up the tributary streams. The materials that underlie these areas are commonly well sorted or locally gravelly. Along the Blackfoot River in the southeastern part of the Paradise Valley quadrangle there are stony flood-plain deposits.

The areas mapped as alluvium in the Ammon and Paradise Valley quadrangles are generally narrow and more or less interrupted, for the valleys in the main are narrow and steep-sided. Where they open out wider here and there, the alluvium also spreads out. The principal areas in the Ammon quadrangle are scattered along Willow Creek in the eastern part of the quadrangle and in the lower courses of some of its larger tributaries—for example, Williams Creek. In the Paradise Valley quadrangle the larger areas are associated with the Blackfoot and Portneuf Rivers.

Between the deposition of the hill wash and older alluvium and that of the alluvium here described, an interval of moister climate interposed. No lacustrine stages such as those in Bear Lake valley described by the writer (Mansfield, 1927, pp. 30–32) have been recognized in the two quadrangles, but it is believed that otherwise the physiographic development of this area is generally parallel to that of the broader area previously described and that the age of the alluvium may be considered Recent.

IGNEOUS ROCKS

GENERAL OCCURRENCE

The author has elsewhere (Mansfield, 1927, pp. 116–130) discussed the igneous rocks of southeastern Idaho at some length. They consist in general of three types—hornblende andesite porphyry, rhyolites, and basalts. In addition, it may be noted that intrusive bodies of unusual character are exposed a short distance east of the area described in the present paper. These are the highly potassic rocks of the so-called "Highwood" type in and near T. 4 S., R. 44 E. (Anderson and Kirkham, 1931). Anderson and Kirkham suggest a possible relationship between these rocks and hornblende andesite on Sugarloaf Mountain in T. 2 S., R. 41 E.

The andesite in southeastern Idaho is sporadic in occurrence and seems to be confined to a few localities. The rhyolites and basalts, however, are widespread and seem to increase in number of occurrences and in areal extent northward and northwestward toward the Snake River valley. Andesite was found as both intrusive and extrusive types, the principal area in which it occurs being underlain by andesitic breccia and tuff. Rhyolite was found in the form of flows, as pumiceous cones, and in beds of volcanic ash. Basalt was found as flows, as ash and scoria, and as ash beds.

In the Ammon and Paradise Valley quadrangles the andesite is confined to a single general area, where it is mapped as andesitic breccia and tuff. The rhyolites occur principally as beds of welded tuffs, which, in some places, are not readily distinguishable in the field from flows of rhyolite. There is also much volcanic ash, closely associated with the Salt Lake formation and generally mapped along with it, although some beds are sufficiently prominent to be mapped separately. Basalts are abundant in both quadrangles. Some forms relatively high hills and has been subjected to faulting and tilting; it is apparently older than other basalts that occupy valleys and are flat lying. However, the valley basalts are themselves of different ages, as some of them were poured out at intervals separated by various stages of physiographic development in certain valleys. Beds of basaltic ash occur chiefly in the south-central part of the Paradise Valley quadrangle, where some of them have been mapped separately from the basalt.

ANDESITIC BRECCIA AND TUFF

DISTRIBUTION

The andesitic breccia and tuff occupy an area of nearly 8 sq mi located chiefly in the southeastern part of T. 3 S., R. 38 E., Paradise Valley quadrangle, but overlapping slightly the townships to the south and east. In addition a few small areas in secs. 1, 11, and 12, T. 4 S., R. 38 E., represent masses of the tuff exposed by the erosion of formerly overlying beds of the Salt Lake formation. A few small areas of rhyolitic material, basalt, and Salt Lake formation are indicated within the general area mapped as andesitic breccia and tuff, but this general area is essentially a unit.

CHARACTER

The andesitic tuff is a breccia composed chiefly of fragments of hornblende andesite porphyry ranging in size from a fraction of an inch to boulders as much as 4 ft in diameter. Locally fragments of basalt are included in the tuff. Locally, too, small flows of basic material resembling basalt are associated with the tuff. At least some of these flows are andesite (see specimen M460–30 in accompanying table). The general color of the material is dark gray, weathering reddish, but some material is lighter. These differences suggest some differences in composition, but thin sections of specimens taken at several localities show little actual variation and any slight variation is due largely to difference in texture and in degree and character of decomposition. C. S. Ross, who examined the thin sections, reports as follows:

The andesitic rocks are all porphyritic in texture and the phenocrysts are andesine plagioclase and brown hornblende or nearly colorless augite. In most specimens containing hornblende that mineral was unstable and has been partly or wholly altered to an aggregate of minute magnetite grains. In a few specimens the hornblende is partly changed over into augite.

The groundmass varies from fairly coarse-grained—in which plagioclase, augite, and minor amounts of magnetite may be recognized—to one so fine-grained that no minerals are recognizable. Thus the variations are largely textural.

In the accompanying table Ross gives brief descriptions of the specimens studied, including a few fragments of basalt that were taken from the tuff.

Descriptions of thin sections of fragments taken from andesitic breccia and tuff, Paradise Valley quadrangle, Idaho

[Descriptions by C. S. Ross. Specimens LX and LY collected by W. B. Lang]

Specimen	Locality	Description
M10–25	Center sec. 1, T. 4 S., R. 38 E.	Andesite. Composed of phenocrysts of plagioclase and brown hornblende in an andesitic groundmass.
LX	NE¼ sec. 34, T. 3 S., R. 38 E.	Andesite. Composed of abundant phenocrysts of plagioclase, augite, and brown hornblende with a small proportion of fine-grained groundmass.
M459–30	SE¼SW¼ sec. 26, T. 3 S., R. 38 E.	[From small flow associated with tuff.] Basalt. Composed of plagioclase and augite phenocrysts in a groundmass that contains a large proportion of iron oxide secondary to ferromagnesian minerals.
M460–30	About 0.15 mile E. of M459.	[From small basic flow.] Andesite. The hornblende has been largely altered to aggregates of iron oxide.
M13–25	SW¼SE¼ sec. 26, T. 3 S., R. 38 E.	Andesite. The hornblende phenocrysts are partly altered to iron oxide aggregates, but the augite is fresh.
LY	Sec. 34, T. 3 S., R. 38 E	Coarse-grained andesite. Contains a large proportion of fresh augite and no hornblende.
M457a–30	SE¼SW¼ sec. 27, T. 3 S., R. 38 E.	[From boulder in fine tuff.] Andesite. Brown hornblende and augite phenocrysts, both fresh.
M456–30	SE¼NW¼ sec 35, T. 3 S., R. 38 E.	[Basaltic fragment in tuff.] Basalt with very abundant iddingsite secondary to olivine.
M454–30	NW¼SW¼ sec. 36, T. 3 S., R. 38 E.	Andesite with very abundant brown hornblende that is perfectly fresh. Groundmass very fine grained.

The general appearance of the andesitic breccia and tuff in some of the coarser facies is shown in figure 17.

STRUCTURE

In sec. 1, T. 4 S., R. 38 E., and sec. 36, T. 3 S., R. 38 E., and farther north near the east side of the area where the andesitic tuffs are exposed, the observed strike ranges from about N. 12° to N. 20° W. and the dip from 13° to 42° NE. Farther west, in the SE¼SW¼ sec. 26, the strike is N. 36° W. and the dip 20° W. The tuff therefore appears to have an anticlinal structure pitching southeast. Locally it weathers with columnar jointing.

SOURCE

Hornblende andesite porphyry is known to be intrusive at several localities in the general region (Mansfield, 1927, p. 116, and 1929, pp. 40, 41). The largest and most prominent of these is in Caribou Mountain in T. 4 S., R. 44 E., about 35 miles east of the area containing andesitic breccia in the Paradise Valley quadrangle. However, if this were the source, it would seem likely that the intervening area between the two localities might furnish other occurrences of the breccia. If any are present, they are buried beneath later formations. More probably the source is local, though nothing corresponding to a volcanic structure has been recognized other than the anticline mentioned. Conceivably, this structure could be an old eroded volcanic vent. Some merit is lent to this suggestion by the occurrence of small flows of dark igneous rock in association with the breccia.

AGE

The andesitic breccia and tuff make up the oldest of the igneous formations mapped in the area, but as it includes some basaltic fragments (see table), at least some basalt is older than the breccia. Patches of the Salt Lake formation (Pliocene ?), of rhyolitic rocks, and of basalt lie here and there on the breccia, which is therefore older than those rocks. On the other hand, the references cited show that hornblende andesite porphyry similar in character to that which forms the breccia is intrusive into the Wayan formation (Lower and Upper Cretaceous).

C. P. Ross (1927, pp. 7–9; 1934 [1935], pp. 45–53; 1937, pp. 49–68; also Ross and Forrester, 1947) has included under the name "Challis volcanics" great quantities of lava and pyroclastic rocks that are dominantly latitic and andesitic, with much rhyolitic material in the upper part. These rocks occur in Custer, Blaine, Valley, Camas, and Lemhi Counties north of the Snake River basin (Ross and Forrester, 1947). Ross states that fossils from beds high in the sequence in Custer

FIGURE 17.—Andesitic breccia and tuff in the NW¼SW¼ sec. 36, T. 3 S., R. 38 E., Paradise Valley quadrangle.

and Lemhi Counties have been studied by R. W. Brown, who thinks they are of late Oligocene or early Miocene age. Though no direct connection between the andesitic breccia of the Paradise Valley quadrangle and the Challis volcanics can be assumed, the assumption of comparable age for the two formations would not contradict any available evidence and seems fair.

THICKNESS

Though no measurements have been made of the thickness of the breccia, the maximum relief in the area mapped as andesitic breccia and tuff is more than 500 ft, and canyons more than 250 ft deep have been cut in it. The beds are not horizontal, but they have not been cut through by any of the canyons. It seems likely that they are at least several hundred feet thick.

RHYOLITIC ROCKS

MODE OF OCCURRENCE

Rhyolitic rocks assume greater areal importance in the Ammon and Paradise Valley quadrangles than in the parts of southeastern Idaho previously studied by the author. Though some of the rhyolite is perhaps in the form of flows or sills, as is true in the areas farther south, most of it is in the form of welded volcanic tuff. There are also extensive accumulations of bedded volcanic ash, most of which is not differentiated from the Salt Lake formation in mapping, though in some places where the bedded ash is well exposed it is mapped separately. No cones such as those in the northern part of the Henry quadrangle were observed.

Much of the welded tuff, especially the more massive and more devitrified material, may readily be mistaken in the field for rhyolite flows or sills. Examination of the rock in thin section under the microscope, however, reveals its true nature. The welded tuff and the flows or sills of rhyolite are not distinguished in the mapping. A single occurrence of rhyolite, represented only by boulders, in the midst of Twin Creek limestone in the SW¼ sec. 8, T. 3 S., R. 40 E., Paradise Valley quadrangle, was interpreted as probably a small dike.

DISTRIBUTION

The welded volcanic tuff in the central part of the Ammon quadrangle forms a great apron that wraps around the northern end of the Blackfoot Mountains and occupies extensive areas on their crest and flanks. T. 1 N., R. 39 E., is in the crest region, where the pre-Tertiary sedimentary rocks plunge in several prongs beneath the cover of welded tuff, which there forms the surface more or less uninterruptedly for several square miles. Farther south the cover of welded tuff has largely been removed by erosion, but numerous patches of it persist at various altitudes and cap some of the higher hills. Thus, in the NW¼ sec. 10, T. 2 S., R. 39 E., the welded tuff forms the summit at an altitude of 7,406 ft.

From the broad area of exposure in T. 1 N., R. 39 E., the welded tuff descends eastward, more or less covered by soil and wind-blown dust, toward Willow Creek. Broad patches and narrower areas of it are exposed here and there on both sides of the creek as far south as sec. 5, T. 2 S., R. 40 E. Similarly, on the west side of the range, the welded tuff descends to the valleys of the Snake and Blackfoot Rivers. On this side the cover of soil and dust is more continuous than on the east and the exposures of tuff are in the form of linear ridges here and there and narrow areas in stream canyons.

The soil and dust cover has not been differentiated from the Salt Lake formation in mapping. It is, however, overlapped by the alluvium of the Snake River Plain, as shown in Tps. 1 and 2 N., R. 38 E. In the NW¼ sec. 25, T. 2 N., R. 38 E., a patch of welded tuff protrudes from this cover at an altitude of about 4,740 ft. This is the lowest recognized altitude of the tuff in the area studied.

In the Paradise Valley quadrangle, the welded tuff appears to have been more extensively eroded than in the Ammon quadrangle, though relatively large areas of exposure still persist. Larger or smaller patches of the tuff are scattered here and there throughout much of the southwest half of the quadrangle. The larger and more continuous areas are in Tps. 3 and 4 S., R. 39 E. Here, as in the Ammon quadrangle, there seems to be a close relationship between the present distribution of the tuff and the topography on which the tuff was deposited. It seems to have been laid down as a blanket over hill and valley alike, a feature well shown in secs. 15, 16, 21, 22, T. 3 S., R. 39 E.

This explanation does not seem to hold for the relation of the rhyolitic rocks to other formations in secs. 1 and 12, T. 5 S., R. 39 E. It is thought that the rhyolite may occur in the form of flows or sills here and in other places in both quadrangles, but the true explanation must await more detailed field study.

WELDED TUFF

CHARACTER

Although the author had recognized the tuffaceous character of the rhyolitic rocks at certain places in the two quadrangles, the varied textures of some of the rocks—glassy, perlitic, massive, platy—led him to interpret them as flows. Not until he had largely completed his field work, and C. S. Ross had studied thin sections of the rocks, were the rocks revealed as welded tuffs. The specimens submitted to Ross are listed and briefly described in the accompanying table, which also includes his comments on each specimen.

Rhyolitic rocks from the Ammon and Paradise Valley quadrangles

[Thin sections described by C. S. Ross. "L" series of specimens collected by W. B. Lang]

Specimen	Location	Field notes	Description of thin sections
L-1-23	NE¼ sec. 20, T. 4 S., R. 39 E., Paradise Valley quadrangle.	Quartz rhyolite at least 50 ft thick	Rhyolitic glassy tuff.
L-2-23	NW¼ sec. 21, T. 4 S., R. 39 E., Paradise Valley quadrangle.	Similar to L-1-23	Rhyolite. Eutaxitic texture, later devitrified.
L-12a-23	NW¼SW¼ sec. 19, T. 4 S., R. 40 E., Paradise Valley quadrangle.	Very light weight whitish rhyolite	Rhyolitic tuff, devitrified and probably silicified.
L-26-23	NE¼ sec. 25, T. 3 S., R. 39 E., Paradise Valley quadrangle.	Rhyolite	Rhyolitic tuff. Much secondary carbonate has been introduced between tuff fragments.
L-43-25	NW¼ sec. 34, T. 1 S., R. 38 E., Ammon quadrangle	do	Rhyolite with glassy eutaxitic texture.
L-53-25	SW¼ sec. 24, T. 1 S., R. 38 E., Ammon quadrangle	Rhyolite (?), heavy black; top 10 ft vesicular.	Rhyolite. Eutaxitic tuffaceous texture, later devitrified.
L-63-25	NW¼ sec. 23, T. 1 S., R. 38 E., Ammon quadrangle	Rhyolite, 10 ft thick; vesicular over more compact.	Rhyolite with glassy eutaxitic texture.
L-86-25	W. center sec. 22, T. 1 S., R. 38 E., Ammon quadrangle	Baked Salt Lake formation ?	Rhyolitic glassy tuff.
L-92-25	NW¼ sec. 9, T. 1 S., R. 40 E., Ammon quadrangle	Basalt ?	Probably originally a rhyolite. Has been silicified and secondary carbonate introduced.
L-96-25	NW¼ sec. 10, T. 1 S., R. 40 E., Ammon quadrangle	Glass of andesitic character; top vesicular.	Rhyolite. Composed of a few phenocrysts in a glassy groundmass with eutaxitic texture.
L-102-25	SW¼ sec. 18, T. 1 S., R. 40 E., Ammon quadrangle	Lava capping. Bottom of flow a black glass with large white phenocrysts.	Rhyolite composed of glassy eutaxitic tuff fragments.
L-127a-25	Ridge from center to south border of sec. 30, T. 1 N., R. 40 E., Ammon quadrangle.	20 ft of rhyolite containing lithophysae	Rhyolitic tuff. Glassy tuff in a partly silicified groundmass.
L-127b-25	do	Rhyolitic glass	Rhyolite with tuffaceous eutaxitic texture. Largely glassy but also has been slightly devitrified.
L-127d-25	do	Black portion of red ash on top of lava. Part of red ash and probably only a variation in color. Lies above L-127a-25 and is 2 to 3 ft thick.	Rhyolite with eutaxitic texture. Similar to M333-28.
L-127e-25	do	Silicified ash 1 to 2 ft thick between beds of lava 5 ft thick above and below.	Rhyolite. Devitrified eutaxitic texture.
L-150b-25	NE¼SW¼ sec. 32, T. 1 N., R. 40 E., Ammon quadrangle	Top of rhyolite flow 30+ ft thick in creek; base not seen. Mostly platy; very little of vesicular type.	Rhyolitic tuff that has undergone devitrification.
L-152-25	SE¼NW¼ sec. 19, T. 1 N., R. 40 E., Ammon quadrangle	Lava 5+ ft thick. Probably base of thin or eroded flow.	Vitric rhyolitic tuff. Contains a little secondary carbonate and a few orthoclase phenocrysts.
L-156-25	Center sec. 30, T. 1 N., R. 40 E., Ammon quadrangle	Rhyolite containing lithophysae	Probably originally a rhyolitic tuff. Now shows traces of spherulitic structure in hand specimen but nothing under the microscope.
M235-23	NE¼NW¼ sec. 33, T. 4 S., R. 40 E., Paradise Valley quadrangle.	Rhyolite (weathered) or tuff. Contains inclusions of quartz porphyry.	Rhyolitic tuff with secondary carbonate.
M301-23	SW¼ sec. 23 (?), T. 4 S., R. 39 E., Paradise Valley quadrangle.	Rhyolite quartz porphyry on top of hill.	Rhyolite. Tuffaceous eutaxitic texture that has undergone devitrification.
M5f-28	NE¼SE¼ sec. 19, T. 2 N., R. 39 E., Ammon quadrangle	Vesicular and massive rhyolite	Rhyolitic flow rock. Shows eutaxitic texture similar to that of M333-28 but has subsequently undergone devitrification with the development of spherulitic structure that is independent of the flow structure.
M5e-28	do	Spherulitic rhyolite	Rhyolite with pumice or eutaxitic texture and large spherulites that have developed subsequent to the eutaxitic texture.
M5c-28	do	Baked ash or glass; top of bed	Glassy rhyolite with perfect eutaxitic texture.
M5b-28	do	Baked ash or glass; bottom of bed	Rhyolitic tuff. Dark-brown glass and a few quartz phenocrysts.
M333-28	SW¼NW¼ sec. 26, T. 1 N., R. 38 E., Ammon quadrangle	Vesicular rhyolite	Vesicular, vitric rhyolite of eutaxitic texture. Very few phenocrysts of quartz and oligoclase.
M333-28	do	Fractured black glass about 2 ft thick	Very coarse grained glassy rhyolite tuff.
M336-28	SE¼SE¼ sec. 12, T. 1 N., R. 38 E., Ammon quadrangle	Rhyolite flow exposed in stream bed; massive, not vesicular.	Rhyolitic tuff. Originally glassy but has been completely devitrified.
M340-28	NE¼NE¼ sec. 19, T. 1 N., R. 39 E., Ammon quadrangle	Dark lava, not a basalt. Cap rock 15 to 20 ft thick.	Rhyolite with eutaxitic texture that has undergone devitrification and the development of spherulitic structure subsequent to the development of the eutaxitic texture.
M352-28	NW¼ sec. 18, T. 1 S., R. 39 E., Ammon quadrangle	White-weathering rhyolite or tuff 15 to 20 ft thick. Seems to be a mass of devitrified bubbles.	Devitrified tuff with secondary carbonate.
M435a-30	NW¼NE¼ sec. 21, T. 2 N., R. 39 E., Ammon quadrangle	Pumice; silky luster where fresh, earthy and bricklike where weathered; 3 ft thick. Top of knoll.	Glassy rhyolite tuff.

Summarizing his study of the specimens, Ross has supplied the following information:

The greatest interest in the rhyolites lies in the pyroclastic textures that have developed. The rhyolitic volcanic materials all appear to be very similar in mineral composition. In general phenocrysts are minor constituents, but in a few specimens quartz and orthoclase are abundant. Albite is present but less abundant than orthoclase. Augite is a rare mineral in a few specimens but is absent in most of them. Both quartz and feldspars show very marked resorption and commonly only a small rounded residual area remains. The groundmass is glass or devitrified glass, and no normally crystallized rhyolites were observed.

Without exception the rhyolitic materials show pyroclastic structures and no normal flow rocks were observed. A few of the specimens examined are normal vitric tuffs. Some appear to be the result of direct ash falls, but a few may be arkosic reworked tuffs with accessory detrital feldspar and quartz grains.

Most of the pyroclastic rhyolitic materials show various degrees of welding and distortion of the tuff fragments, due to various degrees of accommodation of the shape of one grain to another while still in a plastic condition. That is, the rhyolitic materials from the Idaho region show a typical eutaxitic texture as described and pictured by Iddings (1909, vol. 1, pp. 331–333) from the Yellowstone region.

The degree of plasticity of the grains after their fall varied greatly. In many specimens the plasticity was so great that the tuff fragments have become completely welded and very generally elongated in one direction. There is, however, no indication of more than slight flowage after fall and welding. In a few specimens there is welding, but only slight accommodation of the shape of one grain to another. In other specimens the original porosity has been partially eliminated and in many of them it has been almost completely eliminated.

Tuff grains are commonly fragments of broken bubbles and glassy plates; moon-shaped fragments, Y-shapes and occasional hollow spheres are to be observed. One specimen contains an unusual proportion of hollow spheres. The completely collapsed and welded fragments are now in the form of wavy plates or grotesquely distorted forms, but occasionally even these show a typical Y-shaped form. A few grains show a pumice-like structure, but these are commonly larger than the others and appear to have had a slightly different origin. A number of specimens contained glassy fragments that were not of the dominant, slightly welded bubble fragment type of grains, but were themselves composed of numerous, completely welded tuff fragments. These tuffs evidently represented two generations of pyroclastic action. It seems probable that explosive tuffs fell back into the crater vent in such condition that they were completely welded together and were later shattered and blown out together with normal fragmental material composed of broken bubble walls. At this later period the materials were evidently so cool at the time of fall that the grains were only slightly welded together. The variation in size of the individual grains is commonly between 1.0 and 0.1 millimeters.

The groundmass of the tuffaceous fragments, which were completely glassy at the time of fall, has undergone various degrees of subsequent modification. A few are black obsidians, with pronounced perlitic structure, and in the hand specimen show no evidence of pyroclastic origin, but this is beautifully shown on the microscopic examination of thin sections. Abundant perlitic cracks have developed entirely independent of the older pyroclastic structures. Other specimens that are dominantly obsidian contain spherulites up to 1 centimeter in diameter, with marked radial structure that has also developed without being influenced by the pyroclastic structures. One specimen is composed almost wholly of spherulites up to 1.5 centimeters in diameter with only a small amount of glassy material remaining in the angular spaces between the individual spherulites.

Many of the pyroclastic rhyolites with eutaxitic texture have been completely devitrified, through the crystallization of the glass. These show that minute crystals have grown inward from borders of the tuff grains. In many specimens of this type spherulites have also developed. These devitrified rhyolitic tuffs show varying degrees of porosity. A few are highly porous, and others are compact and all porosity has been eliminated by welding. That is, the modification of structure due to the plastic character of the fragments can be duplicated in both the glassy and devitrified types of material.

The only recognizable minerals in the devitrified rhyolitic tuffs are feldspar and tridymite. In many specimens tridymite crystals project into cavities.

The completeness of devitrification, the character of the minerals formed (feldspar and tridymite), and the terminated crystals projecting into cavities, are all phenomena indicative of crystallization in the presence of hot gases. This, however, has occurred in pyroclastic material and not in rhyolitic flows where that type of crystallization commonly occurs. The strong evidence of a gas-phase control of crystallization and heat adequate to maintain the tuff fragments in a plastic condition during wide dispersion from their volcanic vent suggests comminution and distribution under the influence of a blast of hot gases (nuées ardentes) as described by Lacroix (1904), at Pelée, and by Fenner (1923) for the Valley of Ten Thousand Smokes. However, the eutaxitic tuffs of the Idaho region do not show the heterogeneity that is supposed to characterize nuées ardentes deposits. A large proportion of the fragments are fairly well sorted with only an occasional grain or phenocryst markedly exceeding the average size. It therefore seems probable that the eutaxitic material of the Idaho region was distributed by blasts of hot gas, but was blown so high and so far from the vent that a very fair degree of sorting occurred. In much of the material that fell under these conditions, there was welding of the grains, very commonly a complete fusion together of the grains, and elimination of porosity. Commonly enough hot gas was present after the fall and welding of the grains to promote devitrification.

Ross has further described and illustrated specimens of welded tuff in a joint paper with the author (Mansfield and Ross, 1935, pp. 313–321).

Thin sections of welded tuff showing characteristic eutaxitic texture are shown in figures 18 and 19.

SEQUENCE

The general sequence of welded tuff beds is illustrated in the following section (see also fig. 20):

Section of welded tuff in SE¼ sec. 19, T. 2 N., R. 39 E., Ammon quadrangle

	Feet
Tuff, highly vesicular, strongly resembling rhyolite flow	10
Tuff, resembling stony rhyolite flow fairly free from vesicles	1.5
Tuff, glassy, black, like obsidian, spherulitic with spherules 2½ to 3 in. in diameter	2
Tuff, glassy, black, perlitic	1
Volcanic ash, baked black	1
Volcanic ash, whitish, grayish, yellowish with reddish streaks, cross-bedded; contains lumps of grayish-white pumice as much as 1 to 1½ in. in diameter	4
	19.5

The contact of perlitic glassy tuff with the underlying baked ash is generally sharp and somewhat irregular. The contacts between the subdivisions of the tuff are gradational. At the indicated locality the beds as a whole dip 24° SE. and strike N. 65° E.

In many places there is an additional member of the series above those shown in the section given. This is a bed 1 to 5 ft or more thick, brick red, pink, drab, or even black, and breaking with a conchoidal fracture into platy fragments 1 to 3 in. thick. When relatively fresh the bed has a silky luster, but when weathered it has a dull earthy appearance like that of brick. In some places different members of the sequence are absent, but the black, glassy material above white or variegated ash is very common. Locally only the uppermost platy variety is present or the stony rhyolitic facies may be thicker.

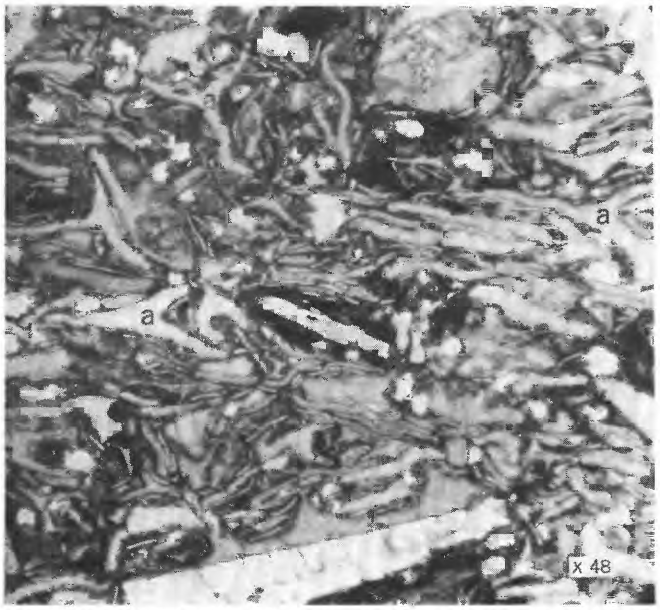


FIGURE 18.—Photomicrograph of welded rhyolitic tuff, showing relatively open eutaxitic texture. Note Y-shaped fragments of walls of former glass bubbles (*a*), all devitrified. Photograph by C. S. Ross.

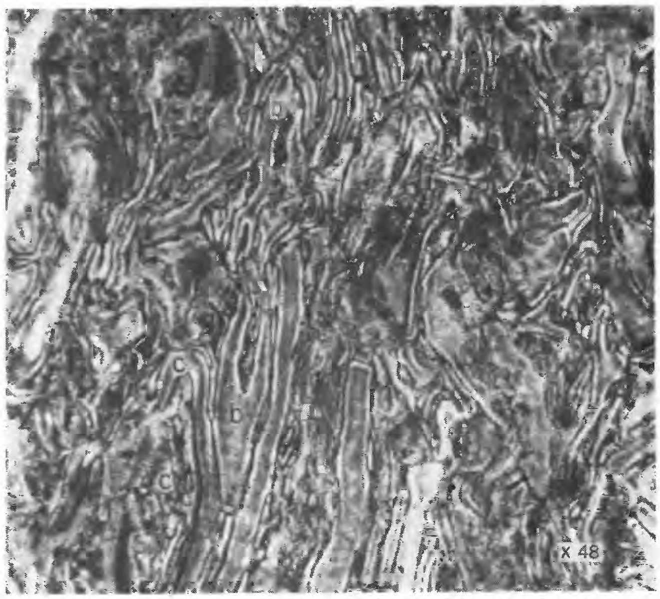


FIGURE 19.—Photomicrograph of welded rhyolitic tuff, showing more compressed eutaxitic texture. *b*, Fragments of walls of former glass bubbles; *c*, compressed bubble, all devitrified. Photograph by C. S. Ross.

RELATION TO UNDERLYING ROCKS

The welded tuff, especially in the northern part of the Ammon quadrangle, commonly lies on bedded volcanic ash, but elsewhere it may overlie any of the older formations. For example, it has been found overlying some basalts and basaltic tuffs, the andesitic tuffs, the Salt Lake formation, and all the older sedimentary formations including even Mississippian rocks. Therefore it was originally very widespread, but it has been so extensively eroded that in the higher parts of the Blackfoot Mountains and on the older formations it is represented only by patches. Commonly these patches are of the higher and more stony members of the sequence and do not include the obsidianlike and perlitic types.

SUCCESSIVE FALLS OF WELDED TUFF

The succession of welded tuff as indicated in the section given for sec. 19, T. 2 N., R. 39 E., is relatively widespread. As the contacts of the different types within it are gradational, it would seem that these types represent facies of a single fall and that their differences may be due to variations in the rate of cooling of the several layers and in the rate and method of expulsion of the contained gases and vapors. However, a considerable time interval may have elapsed between the deposition of this mass and that of the overlying thinner mass with the silky luster. The latter variety occurs in some places directly overlying the bedded volcanic ash or other rocks without the intervention of the obsidianlike and stony types shown in the section. Therefore a time interval sufficient to allow erosion of these rocks from some areas must have elapsed prior to the deposition of the silky variety. This suggestion is supported by the presence here and there of water-laid volcanic ash containing pebbles of obsidianlike material and of what in the field were called rhyolite pebbles, whose source would seem to be the massive layer described.

There is also evidence that this massive layer was itself preceded by at least one earlier fall of welded tuff followed by the deposition of bedded ash before the main fall occurred. The earlier fall was apparently more localized than either of the later falls. For example, in the northeast corner of sec. 13, T. 1 N., R. 38 E., Ammon quadrangle, and in the adjoining parts of neighboring sections, the vesicular type of welded tuff forms the north rim of a small canyon, and in the canyon bottom, 50 to 75 ft lower, another bed of stony, nonvesicular lava appears. This lava (see M336–28 in

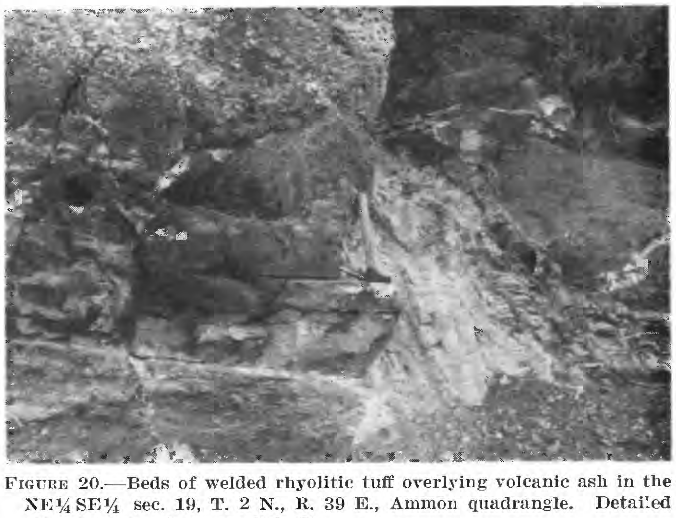


FIGURE 20.—Beds of welded rhyolitic tuff overlying volcanic ash in the NE¼ SE¼ sec. 19, T. 2 N., R. 39 E., Ammon quadrangle. Detailed side view, showing a small fault.

table) was interpreted in the field as a rhyolite flow, but in thin section it proved to be glassy welded tuff later devitrified. Between the two beds is sandy or ashy material largely covered by float from the upper bed. Another example occurs in the SE¼ sec. 26 of the same township. Also, in sec. 11, T. 1 N., R. 40 E., Hell Creek quadrangle, along a dugway leading into Tex Creek, two "rhyolite flows" were observed with tuff between. On the other hand, duplication of the welded tuff by faulting appears to have occurred at places, for example, in the SE¼ sec. 13, T. 1 N., R. 38 E., and extending into the adjoining sec. 18; in secs. 8 and 9, T. 1 N., R. 39 E.; and elsewhere.

THICKNESS

The thickness of the welded tuff varies in different parts of the general area, but thicknesses up to 25 ft are common. In some places, as in secs. 29, 31, and 32, T. 1 N., R 39 E., one gets the impression that the rhyolitic rocks are very thick, as Henry Creek canyon is apparently cut in rhyolitic rocks to depths of 700 ft or more. However, as the welded tuff tends to follow the underlying topography, such thickness may be more apparent than real; some of the canyon walls are so covered by rhyolitic debris from above that they give a false impression of what lies beneath.

In the SW¼ sec. 21 of this township, Jurassic rocks are exposed in a sharply cut canyon whose walls rise about 150 to 200 ft higher than the top of the exposed sedimentary rocks. The surrounding slopes are so steep and so uniformly covered with rhyolitic debris that this figure may represent the approximate thickness of the welded-tuff sequence here. On the other hand, in sec. 4, T. 2 S., R. 39 E., the north side of the canyon has an eroded notch that exposes Jurassic rocks all the way from the canyon bottom to the top of the upland above, showing that the welded tuff may not be more than 50 or 100 ft thick.

VOLCANIC ASH AND TUFF (NOT WELDED)

Volcanic ash and tuff are widely distributed in the area of the two quadrangles, but they are not coextensive with the welded rhyolitic tuff. In many places the ash or tuff is exposed by the erosion of the welded tuff. Elsewhere, if ever present, the ash or tuff was eroded before the welded tuff was laid down. This is especially true on the higher parts of Blackfoot Mountains where patches of welded tuff lie directly on older formations. In a few places some water-worn tuff has been found above the welded tuff, apparently having been washed over it. The soil above the welded tuff on the north slopes and flanks of the mountains contains much wind-blown material, apparently largely of volcanic origin.

The volcanic ash and tuff, not including the andesitic tuff already described, are of two kinds: basaltic and rhyolitic.

BASALTIC TUFF

The basaltic tuff is confined to the south-central part of the Paradise Valley quadrangle. The largest area occupies parts of secs. 35 and 36, T. 4 S., R. 39 E., and adjoining parts of secs. 1 and 2, T. 5 S., R. 39 E. The next-largest area is in secs. 1 and 12, T. 5 S., R. 39 E. Besides these, smaller areas occupy parts of sec. 2, T. 5 S., R. 39 E., and secs. 22, 26, and 27, T. 4 S., R. 39 E.

The basaltic tuff consists chiefly of brownish or reddish scoria and ash. The material is fragmental and friable and contains numerous gas cavities. It is rudely bedded. In most of its occurrences it seems to overlie the Salt Lake formation and to have been involved in some of the disturbances to which that formation was subjected; that is, it dips as much as 15°–30° E. at several localities noted and has a northerly strike. Its localization suggests that it represents a group of eroded tuff cones comparable to those noted in the Henry and Cranes Flat quadrangles farther south but less well preserved.

The mass in secs. 1 and 12, T. 5 S., R. 39 E., is apparently interbedded with rhyolite and basalt, is capped with basalt, and appears to have a gentle synclinal structure with a northerly pitch. The small mass in the SE¼ sec. 2 of the same township is overlain by rhyolite. The three small masses in secs. 26 and 27, T. 4 S., R. 39 E., are overlain by basalt, and the narrow bands in sec. 22 of the same township are interbedded with basalt and rhyolite or rhyolitic welded tuff.

RHYOLITIC ASH AND TUFF (NOT WELDED)

In the Ammon quadrangle, rhyolitic ash and tuff, mostly well bedded, is exposed in many places and is doubtdless widespread beneath cover. It is commonly exposed in connection with the welded rhyolitic tuff, though not everywhere, especially in the higher country, but it is not differentiated in the mapping from the Salt Lake formation except in some places where it is unusually well exposed. Several such areas are mapped in secs. 16, 17, 20, 21, 28, 32, and 33, T. 2 N., R. 39 E., sec. 5, T. 1 N., R. 39 E., sec. 30, T. 1 N., R. 40 E., and sec. 16, T. 1 S., R. 40 E.

The general character of the finer-textured bedded tuff is illustrated in figure 21, which is a view of a roadside cut in the NW¼ sec. 33, T. 2 N., R. 39 E., showing the deformation of the beds since their deposition. A somewhat coarser-textured variety, eroded into pinnacled forms, is shown in figure 22.

A section measured at the first of the two localities follows:

Section of volcanic ash in road cut, NW¼NW¼ sec. 33, T. 2 N., R. 39 E., Ammon quadrangle

	Ft	*in.*
1. Ash, rather coarse, well-bedded, gray and drab, jointed normal to bedding, mingling at top with soil	2	6
2. Volcanic ash, well-bedded, grayish, coarse-textured; individual beds ⅛ to 3 in. thick, mostly containing rather large fragments of pumice; shows cross bedding and includes about 1 ft of brownish dark material	5	4
3. Volcanic ash, coarse; pellets of pumice, ¾ in. across; bits of rhyolite and obsidian; includes about 8 in. of fine ash, rather pinkish	2	2
4. Volcanic ash, coarse, pellets of pumice, and bits of rhyolite and obsidian as above	1	9
5. Volcanic ash, grayish-white, poorly exposed	4	8
6. Volcanic ash, gray and white, well bedded in coarser and finer beds ⅛ to 2 in. thick; coarser beds 4 to 8 in. thick contain pellets of pumice ½ to ¾ in. in diameter with fragments of rhyolite	3	0
7. Volcanic ash, covered or not well exposed	3	0
8. Volcanic ash, similar to unit 6	5	2
9. Volcanic ash, similar to units 6 and 8	5	2
10. Covered	2	7
11. Volcanic ash, light-gray, in beds ranging in thickness from ⅛ to 1 in.; thinner beds of fine material and thicker beds of pumice fragments as much as ¼ in. in diameter; occasional bits of obsidian; yellowish streaks; base not exposed	3	2
	38	6

The strike of the beds is N. 6° E. and the dip 10° W. Three sets of joints lined with limy material are present. Of these one is parallel to the bedding, another is normal to the bedding, and the third strikes approximately N. 20° W. and dips 48° SE. This exposure of volcanic ash extends about half a mile to the northeast, where it broadens and becomes indistinct, and a mile to the southwest, where it passes beneath cover. Near the south end about 30 ft of fine tan-colored ash is exposed beneath 15 to 20 ft of gray ash. The base of the deposit is not exposed. A capping of welded tuff striking about N. 20° E. and dipping 5° W. lies along the exposure for about half of its length and extends about half a mile beyond the point where the ash passes beneath cover.

FIGURE 21.—Beds of volcanic ash in a road cut in the NW¼NW¼ sec. 33, T. 2 N., R. 39 E., Ammon quadrangle.

FIGURE 22.—Eroded volcanic tuff near the road into Willow Creek valley in about the SW¼SE¼ sec. 17, T. 2 N., R. 40 E., just north of the boundary of the Ammon quadrangle.

At a little knoll in the north center of sec. 21, T. 2 N., R. 39 E., another fine section of the ash is exposed for about 100 ft. The capping here is about 10 ft of pinkish welded tuff of the silky variety now weathered to an earthy bricklike texture.

The conspicuous white ridge that extends from the NE¼ sec. 31, T. 1 N., R. 40 E., northward to the center of sec. 30 is capped with welded rhyolitic tuff and bordered on the west side by white or grayish tuff beds that occupy most of the east wall of Rock Creek canyon at that place. The section is not very clearly exposed, but represents about 75 ft of ash and associated calcareous beds with the base not exposed. The dip is about 17° E. The dip of the capping of welded tuff appears to be somewhat less.

In the last two localities some of the beds have been leached, with an accompanying concentration of calcium carbonate or silica in other beds.

The exposure in Willow Creek canyon in the NE¼ sec. 16, T. 1 S., R. 40 E., shows beds of the Salt Lake formation consisting of sands and gravels with pebbles as large as half an inch in diameter faulted against beds of water-laid volcanic ash that contain the plant remains and opercula described on page 46. Willow Creek has cut a sharp bend and undermined its bank where the fault crosses it, exposing 75 ft or more of the ash beds.

In the Paradise Valley quadrangle the most spectacular exposure of water-laid tuff beds is on the north side of the Blackfoot River canyon in sec. 10, T. 3 S., R. 38 E. (fig. 8). Other scattered occurrences have been mapped in secs. 25, 27, 34, and 35, T. 4 S., R. 38 E., secs. 2 and 11, T. 5 S., R. 38 E., and sec. 22, T. 4 S., R. 39 E. The occurrence in sec. 25, T. 4 S., R. 38 E., is noteworthy because it seems to represent a lens of tuff that consists largely of andesitic material, including pebbles described by C. S. Ross (personal communication) as "andesite" in which "the brown hornblende is largely replaced by augite."

BASALTS

DISTRIBUTION

Basalts are areally important in both the Ammon and Paradise Valley quadrangles. They are exposed here and there in the Snake River Plain in and adjoining the northwestern part of the Ammon quadrangle and presumably underlie the entire area mapped as older alluvium. A low basaltic ridge is mapped from sec. 13, T. 2 N., R. 38 E., southward for a mile and a half into sec. 26 of the same township. Along the eastern border of the quadrangle, basalt occurs in and near Willow Creek canyon for most of its course. Southeastward, it expands into what becomes the Willow Creek lava field, also mapped in the Paradise Valley and Cranes Flat quadrangles. Flows or cappings of basalt occur in some of the canyons along the western and northern slopes of the Blackfoot Mountains and in scattered areas.

The Paradise Valley quadrangle, in addition to containing part of the Willow Creek lava field, includes an extensive group of basaltic hills in Tps. 3 to 5 S., R. 39 E. The floor of Paradise Valley, though overspread with older alluvium, is underlain by basalt, and Blackfoot River valley and canyon are largely cut in or bordered by basalt. There are numerous scattered minor occurrences.

CHARACTER

C. S. Ross, who has studied hand specimens and thin sections of material collected by W. B. Lang and the writer, states:

The basalts are in general normal olivine basalts, and that mineral appeared to be absent in only one specimen. As in the andesites [p. 49], the variations are largely textural. The differences in oxidation of the iron-bearing minerals, especially of the groundmass, cause great differences in the appearance of rocks that are essentially similar in mineral composition.

The specimens submitted to Ross, together with his comments on thin sections of them, are listed in the accompanying table.

Basalt from the Ammon and Paradise Valley quadrangles and vicinity

[Thin sections described by C. S. Ross. "L" series of specimens collected by W. B. Lang]

Specimen	Location	Field notes	Description of thin sections
L-3	NE¼ sec. 21, T. 4 S., R. 39 E., Paradise Valley quadrangle.	Glass with feldspar phenocrysts	Basalt. Fresh plagioclase phenocrysts in a strongly oxidized groundmass.
L-7	SE¼ sec. 15, T. 4 S., R. 39 E., Paradise Valley quadrangle.	Intermediate or basaltic intrusion	Fine-grained basalt.
L-41	NE¼ sec. 3, T. 2 S., R. 38 E., Ammon quadrangle.	Dense basalt with phenocrysts of a glassy mineral.	Olivine basalt. Phenocrysts of augite and olivine in a fine-grained basaltic groundmass.
L-55	NE¼ sec. 27, T. 1 S., R. 38 E., Ammon quadrangle.	Basalt band, intrusive; no vesicularity in upper part.	Olivine basalt.
L-99	Center sec. 9, T. 1 S., R. 40 E., Ammon quadrangle.	Basalt. Contains porphyritic crystals.	Basalt with a few large plagioclase phenocrysts.
L-100	E. center sec. 22, T. 1 S., R. 40 E., Hell Creek quadrangle.	Basalt. Forms ridge capping rhyolite.	Basalt. Very coarse grained, with abundant augite and plagioclase and a little olivine.
L-123a	SW¼ sec. 28, T. 1 N., R. 40 E., Ammon quadrangle.	Basalt ?	Basalt. Very fine grained and contains much interstitial basaltic glass.
L-151	SW¼ sec. 17, T. 1 N., R. 40 E., Ammon quadrangle.	Basalt associated with pillow structure.	Basalt with much altered olivine.
M444a	NW¼SE¼ sec. 32, T. 1 N., R. 40 E., Ammon quadrangle.	Basalt from volcanic plug. Groundmass fine, subglassy. Phenocrysts glassy plagioclase half an inch or more across.	Fine-grained basalt with a large proportion of iron oxide in the groundmass.
M456	SE¼NW¼, sec. 35, T. 3 S., R. 38 E., Paradise Valley quadrangle.	Basaltic fragment in andesitic tuff	Basalt with very abundant iddingsite secondary to olivine.
M459	SE¼SW¼, sec. 26, T. 3 S., R. 38 E., Paradise Valley quadrangle.	Basalt float on hill of andesitic tuff	Basalt composed of plagioclase and augite phenocrysts in groundmass that contains a large proportion of iron oxide secondary to ferromagnesian minerals.

As indicated by the descriptions given, the basalts present some differences in texture and appearance, which is natural, for they have been erupted at different intervals and, to some extent, under different conditions for a considerable period of time. For purposes of discussion they are divided into older and younger basalts.

OLDER BASALTS

Basalts have been noted in connection with the andesitic tuffs. These tuffs contain some boulders of basalt (see M456 in table), and basalt occurs apparently as minor intrusions and as cappings here and there in the area occupied by the tuffs. The basalts that occur as cappings and minor intrusions are younger than some of the tuff, at least, but they may not be much younger.

The principal areas of older basalt as here classified are in Tps. 4 and 5 S., R. 39 E., Paradise Valley quadrangle. In general they occupy relatively high ground as basaltic hills and show evidence of deformation by gentle folding or by faulting. For example, the basaltic hills in secs. 1 and 12, T. 4 S., R. 39 E., and secs. 4, 9, and 10 in the same township have gentle synclinal structures. The basalts in the NE¼ sec. 27, T. 4 S., R. 39 E., have gentle easterly dips and have apparently been repeated by faulting. Basalts in sec. 22 and the E½ sec. 16 of the same township have been faulted. Though faults have not been definitely recognized in the basalts of secs. 20, 21, 29, and 30 of this township, the shape and arrangement of these hills is suggestive of faulting.

YOUNGER BASALTS

The younger basalts show no structural disturbance, though, locally, masses of them have slumped here and there. Most of them occupy valley floors or rims on the sides of canyons. Locally, larger or smaller masses scattered here and there without apparent connection with valleys may represent intrusions or flows.

In the Ammon quadrangle all the basalts mapped are tentatively considered as younger basalts, though there have been successive flows in some places—for example, in Willow Creek valley—and some flows have been largely eroded away, as in the valleys of Taylor and Willow Creeks.

In the Paradise Valley quadrangle the principal areas of younger basalts are the Willow Creek lava field in the northeast; Paradise Valley, which connects at the southeast through a gap in the Blackfoot Mountains with the Willow Creek lava field in the Cranes Flat quadrangle; and the Blackfoot River valley and canyon.

SUCCESSIVE FLOWS

In most places where the basalts are exposed in cliffs, it can be seen that more than one flow is present. The time interval between flows at some places has been so short that one flow lies upon another without intervening soil or other formations. At other places the time interval has been sufficient to permit the incision and widening of valleys between successive flows or groups of flows. This is shown notably in the canyons of the Blackfoot River and Willow Creek (figs. 4, 6, and 7).

COLUMNAR JOINTING

Columnar jointing is a common feature of the basalts in the area discussed. It is illustrated in figures 6 and 9.

THICKNESS

In the basaltic hills in secs. 20 and 21, T. 4 S., R. 39 E., topographic relations appear to show that the thickness of the older basalt may, locally, be as much as 750 ft. However, the basalt here overlies the Salt Lake formation, which may have been unevenly eroded before the basalt was poured out upon it. Moreover, both the Salt Lake and the basalt have been gently tilted. The figure given is therefore a maximum, and the actual thickness may be much less. Along the walls of the Blackfoot River, Brush Creek, and Willow Creek canyons thicknesses of 100 to 150 ft are common. In some canyons and in some local occurrences the thickness is probably not over 50 ft. In parts of the Blackfoot River and Willow Creek canyons, which are narrow and deeply cut, a false impression of thickness is given by the blocky talus of basalt, which masks lower slopes of the Salt Lake formation (fig. 9).

FIGURE 23.—Volcanic plug near the junction of Willow Creek and Grays Creek Outlet in the NW¼SE¼ sec. 32, T. 1 N., R. 40 E., Ammon quadrangle.

VOLCANIC PLUG

In the NW¼SE¼ sec. 32, T. 1 N., R. 40 E., Ammon quadrangle, a plug of basaltic rock projects above the surface of a nearly circular hill formed by the deep incision or entrenchment of a former meander of Willow Creek. The rocks that comprise the hill are of Stump sandstone, and the plug has apparently been intruded vertically through these rocks in the middle of the hill. The black masses of the plug stand up like two great teeth, one of which has been split down the middle (fig. 23). The rock of which the plug is composed is not an agglomerate but a porphyritic basalt in which tabular and squarish phenocrysts of yellowish or translucent plagioclase half an inch to three-quarters of an inch long lie in a dark-gray or blackish, fine-grained subglassy groundmass (see M444a in table). The plug apparently does not represent the site of a former cone, as it contains no pyroclastic material, but rather is part of the filling of a pipe or conduit through which basalt was supplied to some flow or flows now largely removed by erosion, for little porphyritic basalt of this type has been found elsewhere in the area. On top of the plug a little gravel containing water-worn pebbles of sandstone, rhyolite, and other materials was found. This gravel may be an erosion remnant of the Salt Lake formation, which now forms the west bank of Willow Creek opposite the plug, or of alluvial gravels deposited before the development of the meander and its entrenchment by Willow Creek.

RELATION OF IGNEOUS TO SEDIMENTARY ROCKS

The andesitic breccia is overlain by patches of the Salt Lake formation. Some uncertainty as to what may properly be called rhyolite in the area here discussed has been introduced by the discovery late in the period of the author's field work that much of what he had been mapping as rhyolite was in reality welded rhyolitic tuff. However, it seems to be clear that rhyolite in the form of flows, cones, dikes, and possibly sills is abundant in the general region of which the Ammon and Paradise Valley quadrangles form a part, as shown in the author's earlier reports (1920a, pp. 57–61; 1927, pp. 117–119, 203; 1929, pp. 41–42). The small areas mapped as rhyolite in the southeastern part of T. 4 S., R. 38 E., the northeastern part of T. 5 S., R. 38 E., the southeastern part of T. 4 S., R. 39 E., and the northwestern part of T. 5 S., R. 39 E., in the Paradise Valley quadrangle, were considered in the field as parts of small rhyolitic flows interbedded with the Salt Lake formation or as small intrusions in that formation. No fresh evidence is available to change that opinion, though rechecking in the field may show that these occurrences too should be classed with the welded rhyolitic tuff.

Beds of volcanic ash consisting of rhyolitic materials are closely associated with the Salt Lake formation and have shared in its deformation. These have been considered in the author's earlier reports as part of the Salt Lake, indicating widespread volcanic activity during the later part of the deposition of that formation. In view of the conditions noted on pages 45 and 46, it may be that the epoch of accumulation of the volcanic ash was not a part of Salt Lake time but later.

The welded rhyolitic tuff is younger and much more widespread than the beds of volcanic ash and lies, not only on this ash and on the Salt Lake formation proper, but also on many older formations without the interruption of the volcanic ash or other beds of the Salt Lake. In general, the deposition of the welded tuff seems to have been considerably later than that of the Salt Lake and its ash beds, because, prior to its deposition, the beds of the Salt Lake formation had been considerably eroded and a topography comparable to that of the present day, though not so deeply carved, had been developed. It was on this topography that the welded tuff was laid down in blanket form. In a few places—for example, in the SE¼ sec. 9, T. 3 S., R. 39 E.—pebbles of sedimentary rock, like those of the typical Salt Lake formation, appear to lie on top of the welded tuff. Material mapped as Salt Lake also apparently overlies the welded tuff in the SW¼ sec. 14 and the NW¼ sec. 23, T. 4 S., R. 39 E. These occurrences may represent the Salt Lake formation exposed by erosion of formerly overlying welded tuff or eroded remnants of outwash deposited on the tuff.

Basalt and basaltic tuff or ash are perhaps more intimately associated with the Salt Lake than with any other formation. They both overlie it, and basalt does so extensively. However, in Willow Creek canyon in the Ammon quadrangle, the basalt overlies Twin Creek limestone and Cretaceous formations here and there, and in sec. 32, T. 1 N., R. 40 E., it is intrusive into the Stump sandstone. In the Paradise Valley quadrangle, basalt overlies the Brazer limestone in sec. 19, T. 3 S., R. 40 E., and in sec. 22, T. 4 S., R. 40 E. Small patches of it lie on Brazer in the south-central part of sec. 28, T. 2. S., R. 39 E.; on Wells in the SW¼ sec. 29, T. 3 S., R. 40 E.; and on Brazer in the NW¼ of the same section.

RELATION OF IGNEOUS ROCKS TO ONE ANOTHER

Throughout the region in general, rhyolitic and basaltic rocks have been erupted more or less alternately for a considerable period of time. These alternations have been discussed elsewhere (Mansfield, 1927, pp. 123–125). In the Ammon and Paradise Valley quadrangles, the oldest basalt apparently is that which occurs as boulders in the andesitic tuff. Patches of basalt and of rhyolite or welded rhyolitic tuff also overlie the andesitic tuff here and there. Rhyolite apparently occurs as sills or small interbedded flows in the basalt of secs. 4 and 10, T. 5 S., R. 39 E., and in the basaltic tuff in secs. 1 and 12 of the same township. Patches of welded rhyolitic tuff lie here and there on the older basalt, as in secs. 20 and 21, T. 4 S., R. 39 E., and elsewhere, and patches of what is presumably a younger basalt lie on the welded rhyolitic tuff, as in secs. 15, 22, and 23, T. 4 S., R. 39 E., and elsewhere. The younger basalt also rims canyons above the welded rhyolitic tuff at many places in the Willow Creek area in the Ammon quadrangle and in Brush Creek canyon and elsewhere in the Paradise Valley quadrangle. Whereas the welded tuff appears to be a blanket deposit uncovered or removed at many places by erosion, the younger basalts in the canyons apparently are remnants of flows that once poured down the canyons but have been subsequently eroded except for remnants that wedge out against the wall rocks of the canyons (figs. 6 and 8).

The relations between the basalt and the welded rhyolitic tuff in the belt extending southward from secs. 3 and 4, T. 4 S., R. 39 E., to sec. 22 in the same township—and also in sec. 2—are puzzling and need further field study. When this area was mapped, the true nature of the rhyolitic rocks as welded tuffs was not recognized, and it was thought that the alternating bands were alternating flows of rhyolite and basalt. The contacts are obscure, but the bands are readily recognizable. As these rhyolites, judged by such few thin sections as are available, now seem to be all welded tuff, it appears probable that the banding is due to intrusions of younger basalt into the welded tuff. Some evidence for such a hypothesis is afforded by the discovery in the NE¼ sec. 11, T. 5 S., R. 39 E., of platy rhyolite, or more probably welded tuff, intruded by a little dike or sill of basalt. The basalt lies between plates of rhyolite, is about 8 in. thick, and has chilled contacts on both sides. It is scoriaceous in the middle.

The younger basalts themselves have been extruded at intervals sufficiently long to permit valleys to be cut in them and widened sufficiently to remove much of a given flow before the next one was poured out. Both the Blackfoot River and Willow Creek canyons show remnants of several successive flows that have taken place at different stages of valley development. Those of the Blackfoot River canyon are especially noteworthy (figs. 6 and 7).

AGE OF IGNEOUS ROCKS

The age of andesitic breccia and tuff has been shown to be possibly as great as Oligocene or early Miocene. Some of the associated basalts are older or at least of comparable age. However, most of the rhyolitic rocks and basalts so widespread in the two quadrangles here discussed are not older than the Salt Lake formation but younger. The beds of rhyolitic ash that contain plant remains (pp. 45–46) and are presumably of Pleistocene age are older than the beds of welded rhyolitic tuff, and this tuff in turn is older than the younger basalts which rim the canyons and occupy valley floors. The older basalts, as shown in secs. 20 and 21, T. 4 S., R. 39 E., and elsewhere in the Paradise Valley quadrangle, are overlain by rhyolitic welded tuff and are therefore older. However, even the older basalts lie on parts of the Salt Lake formation and are therefore not older than Pliocene (?). The basalts underlying the Snake River and Paradise Valley are overspread by older alluvium. They, with the other younger basalts, are therefore considered Pleistocene.

The Pleistocene epoch must have been long enough to have included much volcanic activity and erosion prior to the deposition of the rhyolitic welded tuff and much additional erosion, numerous minor structural disturbances, and intermittent outpourings of basalt after the rhyolitic outbursts.

Recent volcanic activity has taken place in the near vicinity of the Ammon and Paradise valley quadrangles, though not within the quadrangles themselves. For example, the Menan Buttes, about 15 miles north of Idaho Falls, are cones built from volcanic and sedimentary material, including river pebbles, that has apparently been erupted by steam explosions through the alluvium of the Snake River valley (Stearns, Bryan, and Crandall, 1939, pp. 32–36). Standing close to the Snake River, the buttes rise about 500 ft above its flood plain. At the Craters of the Moon National Monument, about 75 miles west of Idaho Falls, are Recent volcanic craters and basalts, some of which contain tree molds, though no charcoal has been found in the molds. From these data and from measurements of the rings of trees that have grown on these basalts, Stearns (Stearns, Crandall, and Steward, 1938 [1939], p. 100) has concluded that the last volcanic eruption probably occurred more than 250 but perhaps not more than 1,000 years ago.

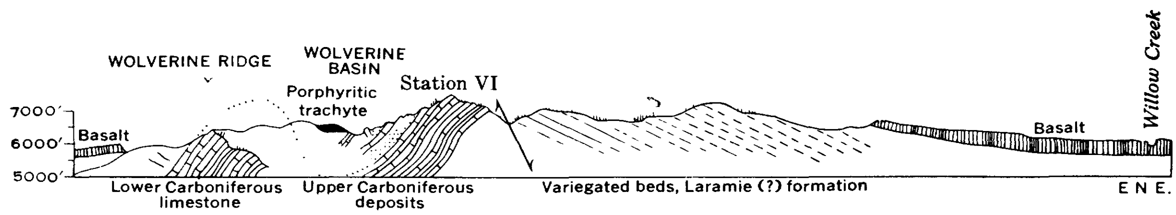
STRUCTURAL GEOLOGY

EARLIER GEOLOGIC WORK

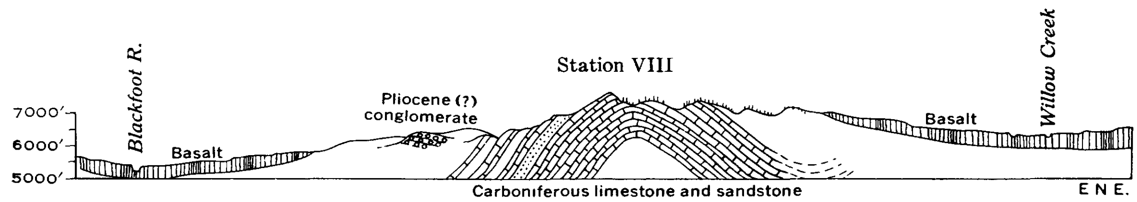
Reference has already been made (pp. 2, 4) to earlier geologic work within the area of the Ammon and Paradise valley quadrangles. Here it is necessary only to emphasize the pioneer work of Orestes St. John, geologist of the Teton Division of the Hayden Survey, whose report (St. John, 1879) is still the only prior record of the area that gives any details of the geologic structures. In his description of the "Blackfoot Range," the Blackfoot Mountains of this report (St. John, 1879, pp. 338–349, pls. 13, 14), he uses a series of six geologic structure sections. Five of them are given in figure 24. These sections compare roughly with geologic structure sections *A–A′*, *H–H′*, *K–K′*, *L–L′*, and *O–O′* (in part) of plate 2 of this report.

The idea of great overthrust faults as a feature of mountainous regions of complex geologic structure had not been conceived in American geology at the time that St. John did his work; hence, much of the complexity of structure caused by overthrusting in the Blackfoot Mountains escaped his notice. However, he noted the fault east of Mount Taylor (fig. 24*A* and section *A–A′* of pl. 2) and recognized its importance, though he considered it normal. He also noted the anticlinal structure of lower Carboniferous rocks (Brazer limestone of this report) in Wolverine Ridge and distinguished the upper Carboniferous rocks (Wells) at station VI (Mount Taylor). At the west base of the mountain he describes an "intensely hard dark, bluish-gray hornstone, standing nearly vertical, and crossing the foot of the mountain in a NW. and SE. direction. The ledge sometimes weathers in two parallel combs, perhaps 10 feet in thickness, and which may be traced some distance, appearing like a dike thrust up in the surface of the slope." Without doubt St. John was describing the prominent ledges of the Rex chert member of the Phosphoria formation (figs. 13 and 14) which extend northwestward along the west foot of the mountain. However, he missed less spectacular exposures of Rex along the east side of the mountain and southward, and he considered the structure monoclinal rather than anticlinal. The beds east of the fault, which he assigned tentatively to the Laramie formation, are now known to contain Jurassic as well as Cretaceous rocks.

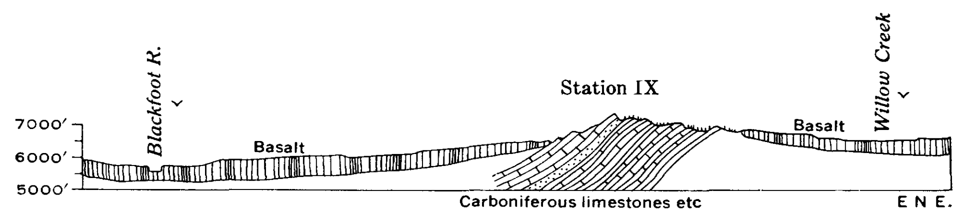
The locations of St. John's other sections are less accurately identified than that of the section just described. The section through his station VIII (fig. 24*B*) is comparable in part to section *H–H′* of plate 2. Here the principal feature is the big anticline in Carbon-



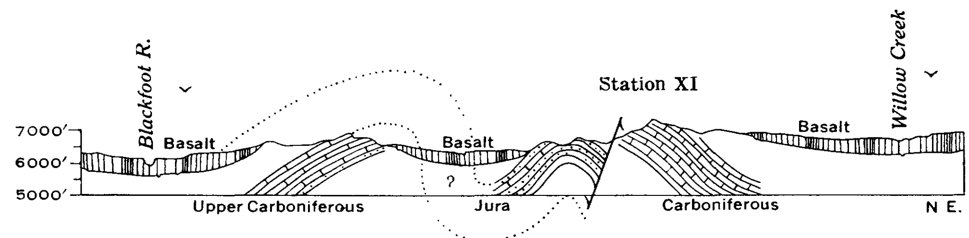
A. Section across northern end of Blackfoot Range, through station VI
(Mt. Taylor, sec. 29, T. 1 S., R. 39 E., Ammon quadrangle)



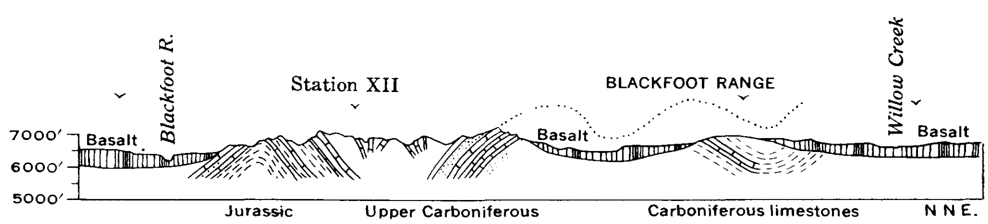
B. Section across Blackfoot Range, through station VIII
(Apparently the summit in the SW¼ sec. 34, T. 2 S., R. 39 E., Paradise Valley quadrangle)



C. Section across Blackfoot Range, through station IX
(Apparently through center sec. 20, T. 3 S., R. 40 E., Paradise Valley quadrangle)



D. Section across Blackfoot Range, through station XI
(Apparently through sec. 32, T. 3 S., R. 40 E., Paradise Valley quadrangle)



E. Section across station XII ridge and southern end of Blackfoot Range
(Apparently through sec. 32, T. 4 S., R. 40 E., Paradise Valley quadrangle)

Base line 5,000 feet above sea level

FIGURE 24.—Structure sections across the Blackfoot Range (Blackfoot Mountains). After Orestes St. John (1879, pls. 13 and 14).

iferous limestones and sandstones. St. John's map shows beds of Laramie age east of the Carboniferous, though these are not shown in his section. The present mapping shows, instead, Triassic and Jurassic strata in folds steeply inclined eastward.

St. John's section through station XI (fig. 24*D*; compare section *L–L′* of pl. 2) shows the upper Carboniferous (Wells) at the west base of the range succeeded on the east by "Jura" (Woodside) and Carboniferous (Brazer). He shows a normal fault between the "Jura" and the Carboniferous, whereas the present interpretation makes the fault a part of the Bannock overthrust.

The section through station XII (fig. 24*E*; compare section *O–O′* of pl. 2) shows anticlinal and synclinal structure in the "Jura" (Triassic of this report) succeeded on the east by upper Carboniferous (Wells) but without the intervening fault shown in the later mapping. The section continues beneath the basalt of Paradise Valley into the southern part of the Blackfoot Mountains, where St. John again recognized Carboniferous limestones.

GENERAL FEATURES

The geologic structures in the Ammon and Paradise Valley quadrangles are doubtless in part the continuation of folds and faults already recognized and studied in areas farther southeast and south. On the other hand, some structures die out after having persisted for greater or less distances and are replaced by others of similar trend and habit, though not in the same line with those replaced. Where older structures are covered by later rocks, the continuity of the structures may be lost or so interrupted as to be uncertain. The cover of Tertiary rocks and lavas in the two quadrangles is so abundant and so widespread that few of the folds recognized in the adjoining quadrangles can be traced into this area.

The Blackfoot Mountains, which form the core of the area, are involved in a broad zone of overthrusting which is believed to be the continuation of the Bannock fault zone described in the areas farther southeast. The major and minor faulting of this zone has produced a great complexity of structure in many places. Especially noteworthy is the window in the fault plane in Tps. 3 and 4 S., R. 40 E., on the east side of Paradise Valley. Another important feature is the deployment of the fault into three principal branches, with numerous subsidiaries, in the Ammon quadrangle.

The Portneuf Mountains, which occupy the Paradise Valley quadrangle west of the Portneuf and Blackfoot River valleys, show closely folded and faulted structures that are continued northwestward for about 15 miles and are described in the author's Fort Hall report (1920a). Southeastward, they pass beneath cover. Whether they connect with corresponding but less compressed folds in the Portneuf quadrangle 10 miles or more away is not known. They involve rocks as high in the stratigraphic column as the Twin Creek limestone, whereas those in the Portneuf quadrangle contain no beds higher than Higham grit.

Normal faulting has played an important part in the structural development of the area. The horst and graben structure (Mansfield, 1927, pp. 162–165) described in the Cranes Flat, Henry, and Lanes Creek quadrangles farther southeast is believed to be continued into the Paradise Valley quadrangle. The faults that have produced this structure are mostly concealed, and their locations are therefore open to some doubt, but it is thought that the evidence of their existence is sufficiently strong to justify their representation on the map with question marks. Numerous other normal faults are shown on the map. In most instances the actual fault plane itself was not seen.

PRINCIPAL FOLDS

SNOWDRIFT ANTICLINE

The Snowdrift anticline is the most persistent and probably the most remarkable fold in the entire region of southeastern Idaho thus far studied. It originates in Snowdrift Mountain near the southwest corner of the Crow Creek quadrangle, extends northeastward for about 12 miles, and then swings northwestward for about 40 miles to the southeast edge of the Paradise Valley quadrangle. During this course of more than 50 miles it is depressed or elevated by cross flexures and faulted and offset at different places, but it is clearly traceable throughout the entire distance. It enters the Paradise Valley quadrangle in about sec. 15, T. 4 S., R. 40 E., and continues northwestward through the quadrangle and into the Ammon quadrangle as far as secs. 34 and 27, T. 1 S., R. 38 E., where it disappears beneath Tertiary cover. Its course within the two quadrangles is about 15 miles long. As shown in structure sections *A–A′* to *N–N′* (pl. 2), it forms part of the overriding block of the Bannock overthrust and is affected by its relations to that fault. Normally it is upright or inclined eastward. Locally it seems to be inclined westward; locally, too, its identity as a fold is uncertain, perhaps because of insufficient observations.

In the Ammon and Paradise Valley quadrangles the Snowdrift anticline is part of the horst and graben structure in which portions of it farther southeast are involved. It is offset by several faults and concealed in places, especially toward the northwest, by the encroachment of Tertiary rocks.

FOLDS BETWEEN BLACKFOOT RIVER AND PARADISE VALLEY

An anticlinal fold enters the Paradise Valley quadrangle from the southeast in the NW¼ sec. 9, T. 5 S., R. 40 E. In the Portneuf quadrangle to the south, this fold has been called the Corral Creek anticline (Mansfield, 1929, pls. 1 and 2). There it brings the Rex chert member of the Phosphoria to the surface, but the gentle northward pitch of the fold causes the Rex to plunge beneath the surface just before the fold enters the Paradise Valley quadrangle, where its core is composed of Woodside shale, flanked on each side by Ross Fork limestone (section *O–O′*, pl. 2).

Northeast of the Corral Creek anticline is an unnamed syncline containing one or more minor folds developed in Ross Fork limestone. A fault intervenes on the northeast between this limestone and the adjacent Rex chert member of the Phosphoria (section *O–O′*, pl. 2), which is in the southwest limb of the succeeding anticline.

This group of folds is strongly developed and doubtless may extend some miles before dying out, but northwestward within 2 or 3 miles it passes under cover of Tertiary strata and southeastward in adjoining quadrangles it passes beneath the Blackfoot lava field within about the same distance.

FOLDS OF PORTNEUF MOUNTAINS

A small part of the Portneuf Mountains is included within the Paradise Valley quadrangle. Much of the structure of the mountain area here is concealed by Tertiary sedimentary and volcanic rocks. The northern part of the Portneuf Mountains was mapped and described in connection with the author's report on the Fort Hall Indian Reservation (1920a, map). Since that report was published, the part of the reservation lying in the Paradise Valley quadrangle has been restudied and some changes made in the mapping. These changes, however, do not alter materially the general picture of the stratigraphy and structure as set forth in the earlier report. The folded structures that enter the Paradise Valley quadrangle are confined chiefly to the northeastern part of T. 4 S., R. 38 E. The structure as now interpreted is shown in structure section *P–P′* (pl. 2). The exposed structures begin at the southwest with a broad anticline that includes beds ranging from the Woodside shale to the Fort Hall formation. This fold is thrust northeastward against a closely folded and faulted group of formations that includes in succession steeply dipping belts of Nugget sandstone, Higham grit, Portneuf limestone, and Timothy sandstone. This group of beds is itself thrust northeastward upon a northeastward-inclined syncline that includes beds ranging from Timothy sandstone to Twin Creek limestone. The latter formation is not exposed in the line of the section, but crops out along the line of strike about 2½ miles farther northwest. The belt of tightly compressed and broken folds and faults between the anticline at the west and the syncline at the east appears to be characteristic of the structure of the northern part of the Portneuf Mountains (Mansfield, 1920a, map and sections).

SEVENTY CREEK SYNCLINE

The Seventy Creek syncline occupies the northwestern part of T. 3 S., R. 40 E., and extends northwestward into the southeastern part of T. 2 S., R. 39 E., and the southwestern part of T. 2 S., R. 40 E. It takes its name from Seventy Creek, which rises in the north-central part of the area occupied by the fold.

The Seventy Creek syncline lies in front of and east of the Bannock overthrust zone and includes beds that range from Timothy sandstone to Twin Creek limestone. As shown in structure sections *H–H′*, *I–I′*, and *J–J′* (pl. 2), it is inclined northeastward. Northeast of it, in sec. 25, T. 2 S., R. 39 E., there is a subsidiary faulted anticline, as shown in structure section *H–H′*, that brings to the surface beds as low in the sequence as the Portneuf limestone. On the east limb of the syncline, as shown in structure section *I–I′*, there is a faulted minor anticline. In structure section *J–J′* a similar minor anticline has been tentatively suggested for the east limb of the syncline to correspond with the recognized occurrences shown in the other two structure sections farther north.

MOUNT TAYLOR ANTICLINE

Emerging from a cover of Tertiary rocks in sec. 13, T. 1 S., R. 38 E., the Mount Taylor anticline extends southeastward to secs. 24, 25, and 26, T. 2 S., R. 39 E., a distance of approximately 11 miles. It takes its name from Mount Taylor (formerly Blackfoot Peak) in sec. 29, T. 1 S., R. 39 E., a prominent landmark in the Blackfoot Mountains. The fold lies between the west and middle branches of the Bannock overthrust and has thus been considerably affected by the thrusting. The core of the fold is composed of rocks of the Wells formation which are resistant to erosion and form prominent ridges. Between them and the massive Brazer limestone of the Snowdrift anticline lies a narrow syncline of relatively weaker Triassic rocks. During the intense compression which caused the overthrusting, these Triassic rocks yielded and allowed the Brazer limestone to override locally the southwest flank of the Mount Taylor anticline. Minor faults, which developed in the thrust zone, also modified the anticline here and there. The middle branch of the Bannock overthrust lies along the east base of the fold for about 2½ miles near its north end.

The general features of the Mount Taylor anticline are shown in structure sections *A–A′* to *G–G′* (pl. 2). In structure section *A–A′* the Snowdrift and Mount Taylor anticlines with the intervening syncline of Triassic rocks are all shown. In structure section *B–B′* the intervening syncline is faulted out, and in structure section *C–C′* the west limb of the Mount Taylor anticline also is faulted out. Southeast of the line of section *C–C′* for 2 or 3 miles minor faults have more or less completely destroyed the anticlinal structure by inserting or removing slices of rock as shown in structure sections *D–D′* and *E–E′*. Farther southeast, as shown in structure section *F–F′* and *G–G′*, the anticlinal structure is restored, though it is still strongly compressed and faulted.

The small anticline shown east of the Seventy Creek syncline in structure section *H–H′* lies in approximately the same line with the Mount Taylor anticline and may perhaps have been originally a part of that structure. It is more likely, however, that this apparent coincidence is accidental, for the Seventy Creek syncline and the little anticline associated with it are separated from the Mount Taylor anticline by a minor branch of the Bannock overthrust, which here swings northeastward, causing one fold to override the other. An anticlinal wedge of Portneuf limestone lies between the minor branch and the west branch of the Bannock overthrust west of the Seventy Creek syncline.

The Mount Taylor anticline has possible economic importance, as it brings beds of phosphate shale to the surface on each flank for much of its length. This fold, however, has been strongly compressed, and the phosphate beds, which are relatively soft, have been extensively sheared.

WILLIAMS CREEK SYNCLINE

The Williams Creek syncline extends along the east side of the Mount Taylor anticline for about 7 miles. It is named for Williams Creek, which rises in its axial area. The north end of the syncline is cut off by the middle branch of the Bannock overthrust. For more than 2 miles south of that fault, its east limb is largely cut away by a minor branch of the Bannock overthrust that brings in the Rex chert member of the Phosphoria formation and the Wells formation along its east side. Its core is composed of Ross Fork limestone, but toward the south end its east limb is again cut out by a minor thrust fault of the Bannock fault zone. The principal features of the Williams Creek syncline are shown in structure sections *A–A′* to *F–F′* (pl. 2).

SELLERS CREEK ANTICLINE

The northwest branch of Williams Creek, which rises in sec. 3, T. 2 S., R. 39 E., is called Sellers Creek. This name may be conveniently applied to the anticline which lies east of the Williams Creek syncline for about 4 miles. The anticline is cut off diagonally on the north by the middle branch of the Bannock overthrust, so that beds of the Wells and Phosphoria formations are overthrust northeastward on Twin Creek limestone. Its east limb also is faulted by a minor branch of the overthrust. A noteworthy feature of the fold is the dip slope developed on the Rex chert member of the Phosphoria as it descends from the divide above Wolverine Creek to the bottom of Sellers Creek canyon. The anticline is shown in structure section *C–C′*. It has possible economic interest because it brings beds of phosphate shale to the surface.

BUCK CREEK SYNCLINE

Named from Buck Creek, which rises in the south-central part of the area occupied by the fold, the Buck Creek syncline is a somewhat quadrilateral-shaped and in part synclinorial structure that appears to represent the effect of a local transverse syncline combined with a longitudinal syncline. It occupies the east-central part of T. 2 S., R. 39 E., and the west-central part of T. 2 S., R. 40 E. It is cut off on the northeast by the middle branch of the Bannock overthrust and on the southeast by a concealed fault supposed to be normal. The main rock mass comprising the fold is Nugget sandstone, but local folds here and there within the general area include Twin Creek limestone. The east side of the fold is sliced by several faults. The west side of the fold also is locally faulted. Parts of the Buck Creek syncline are shown in structure sections *D–D′* and *G–G′* (pl. 2).

WOLVERINE ANTICLINORIUM

East of the middle branch of the Bannock overthrust is the folded mass of Twin Creek limestone here called the Wolverine anticlinorium from Wolverine Creek, whose headwaters lie largely within it. The anticlinorium extends northwestward from the SW¼ sec. 35, T. 1 S., R. 39 E., where it is less than a quarter of a mile wide, to the northwestern part of the township, where it widens to as much as 3 miles and passes under cover of Tertiary beds and welded tuff. In the southeastern part, where exposed in Wolverine Creek canyon, the beds dip steeply, but farther northwest the dips are gentler and there are numerous open folds, some broken by faults, that bring in beds of the Preuss and Stump sandstones. These formations also lie along the east side of the anticlinorium for much of its length, and southward from the SE¼ sec. 16 the east boundary of the anticlinorium is a thrust fault. This fault is cut south of the center of sec. 16 by another thrust, which continues northward with some slicing and offsetting as far as the NW¼ sec. 33, T. 1 N., R. 39 E., and forms the east boundary of the northern part of the anticlinorial area.

BIRCH CREEK SYNCLINORIUM

Lying east of the Wolverine anticlinorium, the Birch Creek synclinorium extends northwestward for about 10 miles from secs. 17 and 18, T. 2 S., R. 40 E., as far as secs. 33 to 36, T. 1 N., R. 39 E., where it ends against faults. In the central part it attains a width of about

3½ miles. It is named from Birch Creek, which rises in the central part of the synclinorium. The rocks contained in it are chiefly formations of the Gannett group but include along the northwest and north some beds of the Preuss and Stump sandstones. Extensive areas in the northern and northeastern parts are covered by welded rhyolitic tuff, and patches of the tuff occupy numerous summit areas and lower knobs throughout much of the total length. On the southeast the synclinorium is bounded by the east branch of the Bannock overthrust and on the southwest in part by the middle branch.

A minor thrust fault, which cuts out part of the Peterson limestone for much of its length and all of it locally, extends from south to north nearly through the middle of the synclinorium. This is offset by several small faults and by one large fault that extends diagonally across the synclinorium from southwest to northeast near the middle. South of the transverse fault, the Ephraim conglomerate and the Peterson limestone, which here form a southward-pitching syncline, are thrust eastward upon Ephraim conglomerate, which is succeeded eastward by Peterson limestone and Bechler conglomerate. North of the transverse fault the Ephraim and Peterson are thrust eastward upon the Bechler. The transverse fault has therefore lowered the northern part of the synclinal area with respect to the southern about 1,200 ft, on the assumption of an offset of 2,500 ft and an average dip of 30° for the beds.

The northern part of the Birch Creek synclinorium is narrower than the central part where the transverse fault crosses. The Peterson limestone is included on the east as well as on the west, but only for short distances along faults. The cover of welded tuff separates the northern part of the synclinal area into two prongs, a northeastern and a northwestern. The ends of each of these prongs are composed of jumbled blocks containing rocks that range from Twin Creek limestone to Peterson limestone or perhaps Bechler conglomerate. These blocks seem to indicate that the margin of the synclinorium at its north end was crinkled into numerous small folds, involving the formations named, and that these minor folds later became shattered by tension faults. Most of the tension faults were very small, but some were of considerable proportions.

The southern end of the synclinorium has been squeezed between the middle and eastern branches of the Bannock overthrust, which probably accounts for the jumbling of fault blocks in secs. 6 to 8, T. 2 S., R. 40 E. In secs. 35 and 36, T. 1 S., R. 39 E., and secs. 1 and 2, T. 2 S., R. 39 E., the synclinorium has been overlapped by masses of rock that once formed part of the upper fault block of the middle branch of the Bannock overthrust. This mass since has been reduced and more or less detached by erosion (p. 68).

The structural features described are in part illustrated by the following geologic structure sections shown on plate 2: *A–A′*, which crosses the synclinorium north of the transverse fault; *B–B′*, drawn south of that fault; *C–C′* and *D–D′*, which cross the squeezed southern end of the synclinorium.

OTHER FOLDS

From sec. 32, T. 3 S., R. 40 E., southeastward to sec. 15, T. 4 S., R. 40 E., Paradise Valley quadrangle, a belt of folded and faulted Triassic rocks extends along the west flank of the Blackfoot Mountains. This group of structures is included in the Paradise Valley window of the Bannock overthrust (p. 65).

In the Ammon quadrangle a minor anticline with a core of Peterson limestone extends northeastward from the NE¼ sec. 9, T. 1 S., R. 40 E., to the SE¼ sec. 33, T. 1 N., R. 40 E. It is largely concealed by Tertiary and Quaternary rocks but is exposed in the canyons of Willow Creek and Grays Lake Outlet.

A fold of considerable proportions is believed to be represented by the ridges of Nugget sandstone and Twin Creek limestone that extend southward from sec. 7 to sec. 19, T. 1 N., R. 40 E. The structure apparently is a syncline containing Twin Creek limestone and having its west limb composed of Nugget sandstone thrust eastward upon the Twin Creek. The northern part of the fold is cut off diagonally by a fault that brings Ephraim conglomerate across the strike of the fold. The southern part of the fold passes under cover of later formations.

Minor anticlines bring up small bands of Peterson limestone in the southern part of sec. 21, T. 1 N., R. 40 E., and in sec. 6 of the same township small broken folds involve beds of Nugget sandstone and of the Ephraim, Peterson, Bechler, and Wayan formations.

The distribution of the welded rhyolitic tuff which is so conspicuous in the Ammon quadrangle suggests a broad anticlinal structure pitching north. Such a structure indeed may be present, but it is thought that the effect now observed is due largely to original deposition on a late mature topography (p. 58).

PRINCIPAL FAULTS

BANNOCK OVERTHRUST

The name "Bannock overthrust" was applied by Richards and Mansfield (1912) to a group of thrust faults which, upon detailed study, seemed to mark the edge of a great block or slice of the earth's crust that had moved east-northeastward, with respect to underlying rocks, for possibly 35 miles or more. Starting in northeastern Utah, the sinuous course of this overthrust was traced northward and northwestward for about 270 miles. Much of the faulted area lies in the group of seven quadrangles east and southeast of the Paradise Valley quadrangle described in the author's larger work

(Mansfield, 1927, pp. 150–159, 379–386), and the reader is therefore referred to that publication and to his 1929 paper (Mansfield, 1929, pp. 55–59) for a more detailed description of this great structural feature. In the 1927 publication a possible connection was suggested between the Bannock overthrust and the Putnam overthrust of the Fort Hall Indian Reservation (Mansfield, 1920a, pp. 62–65, 90, 91, 101–102). The general course of the Bannock overthrust and its relation to other great thrust faults of the general region are shown in figure 25.

One of the remarkable characteristics of the Bannock overthrust is the fact that its thrust plane is systematically warped or gently folded so that the trace of the fault plane is notably sinuous in places, as in the Montpelier and Crow Creek quadrangles (fig. 25). Elsewhere the overlying block is cut through by erosion, thus exposing the rocks of the underlying block. The location of these openings, called windows, is shown in figure 25. One of them is in the Portneuf quadrangle (Mansfield, 1929, p. 56), and another, described in the present report, is in the Paradise Valley quadrangle. Ludlum (1943, p. 984) thinks that the part of the Bannock Range that he studied is probably "connected with (the same as) the Putnam overthrust of similar trend less than 5 miles northeast of the area mapped" and that "the Bannock Range itself is a large window exposed by erosion of the Putnam-Bannock fault."

PARADISE VALLEY WINDOW

As previously mapped (Mansfield, 1927, pl. 2), the Bannock overthrust zone includes a group of thrust faults that pass beneath the basalt of the Willow Creek lava field between the NE¼ sec. 17, T. 3 S., R. 41 E., and the SE¼ sec. 32, T. 2 S., R. 41 E., Cranes Flat quadrangle. The fault zone reappears from beneath the basalt on the west side of the Willow Creek lava field in the area between the NE¼ sec. 18, T. 3 S., R. 40 E., Paradise Valley quadrangle, where it has been offset southwestward for an undetermined distance by a transverse fault, and the NW¼ sec. 8, T. 2 S., R. 40 E., Ammon quadrangle.

About 7 miles southwest of the eastern margin of the fault zone, where it passes diagonally through sec. 35, T. 3 S., R. 41 E., Cranes Flat quadrangle, the Carboniferous limestones of the Blackfoot Mountains give way abruptly and irregularly to Triassic rocks, which emerge from beneath them on the west side of the mountains. These Triassic rocks occupy an area about 4½ miles in length and as much as a mile or more in width along the east side of Paradise Valley, extending from the SW¼ sec. 15, T. 4 S., R. 40 E., to sec. 32, T. 3 S., R. 40 E. As Carboniferous rocks are included again on the northwest side of the Triassic rocks, the area occupied by these rocks is considered a window in the Bannock overthrust and is here called the Paradise Valley window.

The principal structure within the window area is synclinal, with the axial plane apparently inclined southwestward. The syncline is cut off on the east by a gently inclined and eastward-dipping thrust fault interpreted as a part of the Bannock overthrust. The syncline deepens southeastward, bringing in successively higher beds. It is cut diagonally near the middle by a transverse fault extending northeastward that offsets the east boundary of the window northwest of the transverse fault about a quarter of a mile north with respect to the continuation of that boundary southeast of the fault. Northwest of the transverse fault, the syncline contains mostly Woodside rocks but includes two minor pinched-in synclines of Ross Fork limestone. Southeast of the transverse fault, the syncline is deep enough to contain both the Ross Fork limestone and much of the Fort Hall formation, the Fort Hall being faulted down southwest of the Ross Fork. The northwestward extension of the intervening normal fault is offset northwest of the transverse fault about an eighth of a mile to the southwest (pl. 1). Northwest of the transverse fault, the normal fault first separates parts of the Woodside shale and then cuts off, on the southwest, an overthrust slice of Wells formation that laps northeastward on Woodside.

The wedge or slice of Wells just mentioned has been compressed in a direction at right angles to the general strike of the other formations. Evidence of this compression is provided by five minor synclines that contain beds of phosphate shale of the Phosphoria formation, pitch eastward, and are cut off by the thrust fault that forms the east boundary of the wedge of the Wells formation. Similar structure has been noted in a second and smaller wedge of Wells that lies in secs. 29 and 32, T. 3 S., R. 40 E., northeast of the syncline of Woodside shale.

Southwest of the normal fault that marks the southwest boundary of the wedge of the Wells formation, and separated from it by a narrow belt of Woodside shale, is a wedge of Brazer limestone that is overthrust northeastward upon the Woodside shale. The westward extension of this wedge is concealed beneath the older alluvium of Paradise Valley. The wedge widens slightly southeastward but is cut off in that direction by the transverse fault. Northwestward it pinches out between the Woodside and the older alluvium. The faults that bound the eastern edges of the wedges of Wells and Brazer are considered members of the fault zone of the Bannock overthrust, marking the west boundary of the Paradise Valley window.

The structural relations as interpreted for the Paradise Valley window are shown in structure sections *K–K′* to *N–N′* (pl. 2).

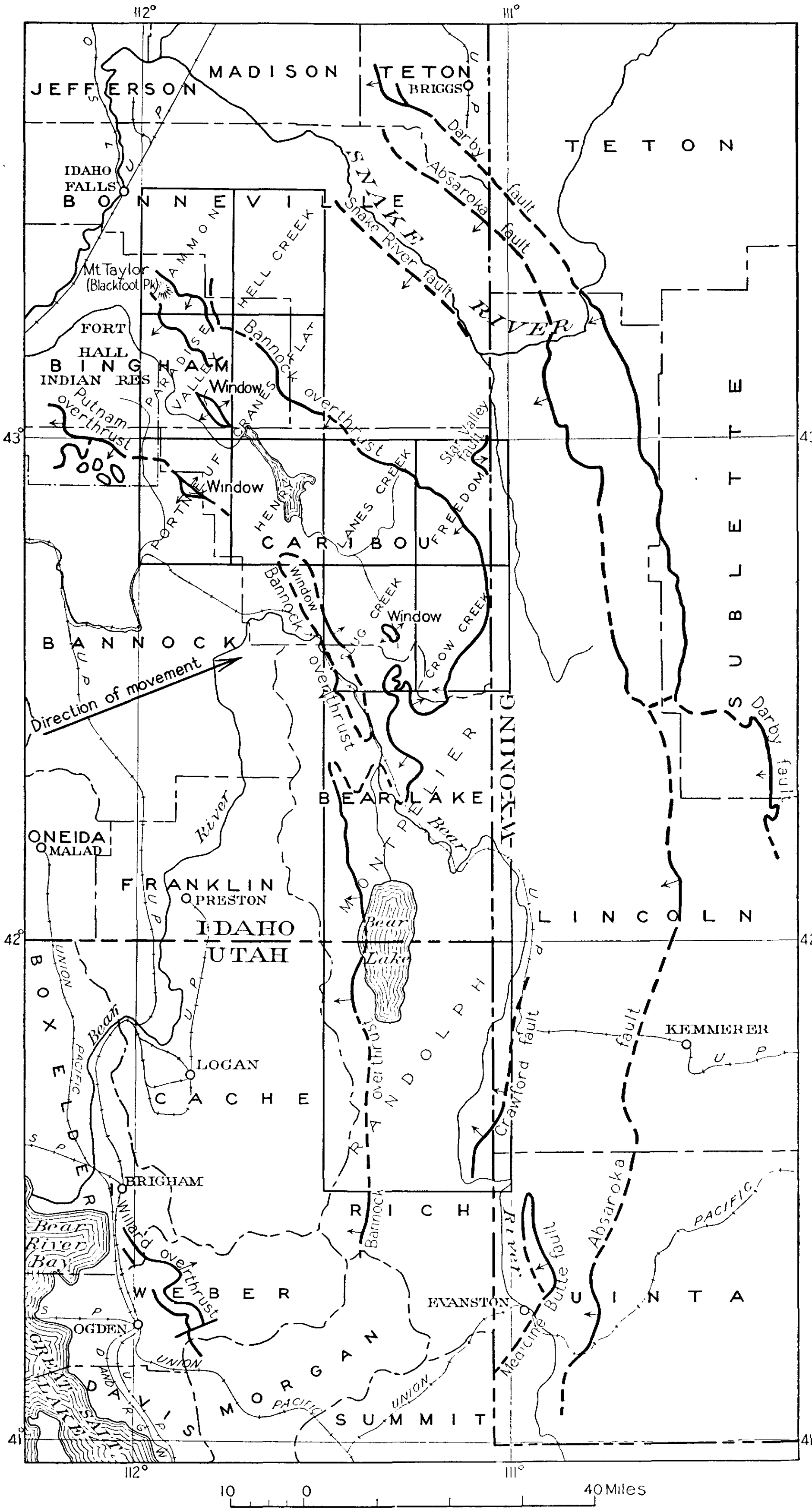


FIGURE 25.—Sketch map of the Bannock overthrust, showing its relations to the Putnam overthrust and to other great overthrusts of the general region. Short arrows show the dip of fault planes. Note the windows.

BANNOCK OVERTHRUST ZONE

The Bannock overthrust zone in the Ammon and Paradise Valley quadrangles comprises three principal branches—west, middle, and east—and several minor faults that together with the principal branches introduce a considerable degree of complexity into the geologic structure of the area as a whole. The three branches and minor thrusts are conceived as originating in a sole, or great thrust fault, of low inclination westward or southwestward, passing at an unknown distance beneath the surface but shallow enough to permit its exposure at the surface where affected by gentle folding or faulting, or by a combination of these processes. At these places, windows such as that of Paradise Valley have been formed. The rocks involved in the faulted overthrust block are oldest at the west, where they include Paleozoic formations. Eastward, successively younger formations are involved, the latest being of Cretaceous age.

The place of origin of the sole is unknown, but presumably it lies some distance west of the Ammon and Paradise Valley quadrangles. Largely because of extensive cover by later formations, it is doubtful whether even detailed field work will bring it to light, although drilling or some fortunate combination of circumstances may eventually reveal it.

West branch.—The west branch of the Bannock overthrust extends irregularly northwestward from the place of its first appearance in the NE¼ sec. 18, T. 3 S., R. 40 E., Paradise Valley quadrangle, as far as the NW¼ sec. 6, T. 2 S., R. 39 E., Ammon quadrangle, where it passes beneath cover of Tertiary rocks. It doubtless continues beneath cover a considerable distance in the same direction. A fault of similar habit is reported by Kirkham (1927, pp. 26, 27) on the Continental Divide near Medicine Lodge Creek. This fault lies in line with the strike of the Bannock overthrust and is intermediate in position between that fault and the Philipsburg faults previously described by Calkins (Emmons and Calkins, 1913, p. 146), with which it is also in line. Possible connections of these faults with one another and with other great overthrusts farther north are thus suggested.

Where first observed in sec. 18, T. 3 S., R. 40 E., the west branch of the Bannock overthrust brings Brazer limestone over Nugget sandstone, which here occupies part of a syncline inclined northeastward, as shown in structure section *J–J′* (pl. 2). Farther northwest, Brazer and, still farther on, Madison limestones override Portneuf limestone as shown in structure sections *I–I′* and *H–H′*. A minor branch, or perhaps an overridden fault in the underlying fault block, diverges northward in sec. 1, T. 3 S., R. 39 E., bringing Portneuf limestone against Nugget and locally against the Timothy, Higham, Deadman, and Wood formations.

In the NW¼ sec. 26, T. 2 S., R. 39 E., the west branch of the Bannock overthrust turns northwest more rapidly. At this point it is thought to override an eastward-trending thrust fault in the underlying block that brings beds of eastward-striking Fort Hall formation over northwestward-striking beds of Portneuf limestone. The west branch continues westward from this point to the SW¼ sec. 21, where it passes under cover of Tertiary beds. Just before doing so, however, it outlines a rocky promontory of Brazer limestone which advances northward nearly half a mile over beds of Ross Fork limestone. In the NE¼ sec. 20, the west branch emerges from cover and continues northwest between Brazer and Ross Fork limestones as far as the NW¼ sec. 18, T. 2 S., R. 39 E., in the Ammon quadrangle, where it again goes under. It next reappears in the NE¼ sec. 7, T. 2 S., R. 39 E., where Brazer is thrust against Wells, first as a small patch emerging from Tertiary cover and then, a quarter of a mile farther north, as larger masses. In the NW¼ sec. 6, it again passes on a northwesterly course beneath cover, not to reappear in this region. In the sharp bend that it makes under cover in the S½ sec. 7, it presumably is joined by, or overrides, two minor thrusts as shown in structure section *D–D′* (pl. 2). The structural relations along its course northwest from sec. 26, T. 2 S., R. 39 E., are shown in structure sections *G–G′*, *F–F′*, and *E–E′*.

That the west branch of the Bannock overthrust is a low-angled thrust is demonstrated by the presence of a klippe of Madison limestone overlying Portneuf limestone in the north-central part of sec. 35, T. 2 S., R. 39 E., about an eighth of a mile in front of the main fault trace. It is further demonstrated by the promontory of Brazer limestone in the SW¼ sec. 21 of the same township.

Middle branch.—The middle branch of the Bannock overthrust apparently enters the area here described in the NW¼ sec. 17, T. 2 S., R. 40 E., Paradise Valley quadrangle. Here, however, because of complications with other faults, it is less easily identified than it is farther northwest. For purposes of description it is therefore better to follow it in the opposite direction. The northwesternmost evidence of its presence is in the NW¼ sec. 18, T. 1 S., R. 39 E., Ammon quadrangle, where a side hill on the west contains float (but no ledge) of the Wells formation in the midst of Tertiary strata, whereas a few hundred yards to the east a ledge of Twin Creek limestone emerges from similar cover. In the SW¼ sec. 18, the main masses of Wells and Twin Creek are separated by the fault. In the NE¼ sec. 19, first Wells, then Phosphoria, forms the front of the main fault block, but two roughly triangular slices of Brazer limestone project nearly a quarter of a mile in front of the main fault trace and overlie Twin Creek limestone. In the NW¼ sec. 20, overlapping into sec.

17, a klippe of the Wells formation caps a summit on a ridge of Twin Creek more than a quarter of a mile in advance of the main fault trace. A similar, smaller klippe of Wells lies half a mile south of the first in sec. 20, a short distance in front of the main fault trace.

From the SW¼ sec. 18 southeastward across the township to the SW¼ sec. 35, the middle branch maintains an irregular course. Throughout this distance the beds in front of the fault are all of Twin Creek limestone except as already noted. The upper fault block, however, contains the Mount Taylor anticline, Williams Creek syncline, and Sellers Creek anticline, which are all cut diagonally by the fault. Hence the Wells, Phosphoria, and Woodside formations are successively opposed to the Twin Creek limestone and, through a minor thrust, are again repeated. The general structural relations are shown in structure sections *A–A′* and *B–B′* (pl. 2).

Southeastward from the SW¼ sec. 35, T. 1 S., R. 39 E., the relations of the middle branch to the beds on either side become more complex. At that place Triassic formations (Woodside shale and Ross Fork limestone) are brought in contact with the Ephraim conglomerate, but southeastward for nearly a mile wedges or slices of Twin Creek limestone intervene between the Ross Fork and the Ephraim. In the NE¼ sec. 2, T. 2 S., R. 39 E., and extending into sec. 35 on the north and sec. 1 on the east, the Ross Fork limestone, which there forms part of the upper block of the overthrust, protrudes northeastward for nearly a mile, causing a corresponding northeastward protrusion of the trace of the middle branch of the Bannock overthrust. The Ross Fork is eroded through in places, exposing Ephraim conglomerate between the protrusion of the fault trace and its main line on the west. The Ross Fork here overlies one or more slices of Twin Creek limestone that are locally exposed by the erosion of the overlying Ross Fork. One slice of the Twin Creek so exposed occurs as a curved band that descends eastward for about half a mile and then expands into a lobe that occupies much of a conspicuous hill in the SW¼ sec. 36, T. 1 S., R. 39 E., where it overlies Peterson limestone. The two limestones look much alike lithologically and the line of demarcation between them is not very clear, but they may be distinguished by the fact that the Peterson contains fresh-water gastropods whereas the Twin Creek contains fragmentary marine fossils of Jurassic aspect.

Southeastward from the west-central part of sec. 1, T. 2 S., R. 39 E., the middle branch continues to the NW¼ sec. 17, T. 2 S., R. 40 E., Paradise Valley quadrangle, where it passes beneath cover. It cuts across the Buck Creek syncline in the upper fault block, thus bringing Triassic and Jurassic formations ranging in age from Ross Fork limestone to Twin Creek limestone, on the southwest, in contact with Ephraim conglomerate on the northeast. It is offset by several minor faults in sec. 7, T. 2 S., R. 40 E., and by a larger concealed fault in Williams Creek that offsets it nearly a quarter of a mile eastward. Erosion has cut through the upper block extensively, leaving slices or masses of Nugget and Twin Creek as klippen of greater or less size overlying Ephraim conglomerate. The largest of these klippen is the Nugget sandstone mass in the E½ sec. 7, T. 2 S., R. 40 E., and the SW¼ sec. 8. Other klippen of Nugget and Twin Creek in the W½ sec. 6 lie nearly three-quarters of a mile in front of the main fault trace of the middle branch. They have already been briefly mentioned under the heading "Birch Creek synclinorium." The structural relations of the southeast part of the middle branch are shown in structure sections *C–C′* and *D–D′* (pl. 2).

The klippen in front of the middle branch of the Bannock overthrust (Brazer and Wells in secs. 19 and 20, T. 1 S., R. 39 E.; Ross Fork and Twin Creek in secs. 35 and 36, T. 1 S., R. 39 E., and secs. 1 and 2, T. 2 S., R. 39 E.; Nugget and Twin Creek in secs. 6 and 7, T. 2 S., R. 40 E.) all show that this branch of the overthrust is a fault of distinctly low inclination.

East branch.—The east branch of the Bannock overthrust does not appear in the Paradise Valley quadrangle. Doubtless, as is probably true of the middle branch, it has been offset southwestward by the fault that offsets the west branch and may lie somewhere beneath the lava in the northeastern part of that quadrangle. Doubtless it has been offset again southwestward by the concealed fault that lies along Williams Creek. It emerges from cover in the NW¼ sec. 8, T. 2 S., R. 40 E., Ammon quadrangle, where it separates the Ephraim conglomerate from beds well above the base of the Wayan formation. Its observed course extends for nearly 5 miles, first northwest and then generally north, as far as the NE¼ sec. 19, T. 1 S., R. 40 E., where it passes beneath cover. Northward from the south-central part of sec. 6, T. 2 S., R. 40 E., it separates red sandstones of the Bechler conglomerate sequence on the west from sandstones, including some shaly and fossiliferous limy beds, and conglomerates of the lower division of the Wayan formation on the east. It therefore cuts out much of the Bechler conglomerate, much of the Draney limestone and Tygee sandstone, present farther southeast, and some of the lower beds of the Wayan, representing a vertical displacement of perhaps 2,000 ft or more.

The trace of the fault is fairly even, and no klippen of beds contained in the upper block have been observed. The inclination of the fault plane is therefore considerably steeper than that of the west and middle branches. The structural relations along the fault are shown in structure sections *B–B′*, *C–C′*, and *D–D′* (pl. 2).

OTHER THRUST FAULTS

Most of the other noteworthy thrust faults have already been mentioned incidentally. Some of these merit further emphasis, and others should be noted. Probably most of them are related to one of the main branches of the Bannock overthrust or to the sole of the overthrust itself.

FAULTS OF MOUNT TAYLOR ANTICLINE

The structure of the Mount Taylor anticline is affected by several groups of minor thrust faults. One in the southwest corner of T. 1 S., R. 39 E., and extending southward into sec. 6 of the next township, involves slices of the Woodside, Ross Fork, and Wells formations that are thrust eastward and are cut by a transverse fault, presumably normal, that cuts off a northwestward-trending belt of Rex chert and phosphate shale at the south.

From the SE¼ sec. 7, T. 2 S., R. 39 E., southward and southeastward into the N½ sec. 18 and the NW¼ sec. 19, a group of faults, supposed to be thrusts, affects the Woodside, Phosphoria, and Wells formations. One of them swings eastward across the Mount Taylor anticline about at the boundary between the two quadrangles and cuts off a mass of Phosphoria, including two bands of phosphate shale, that forms a southward dip slope. In the W½ sec. 16 and the E½ sec. 17 another group of faults, some reverse and some normal, forms a complex of fault blocks that involve chiefly the Wells and Phosphoria formations, containing short, curving bands of phosphate shale.

A cross fault that is probably a flaw, inasmuch as it does not spread or contract outcropping beds of phosphate shale that it intersects, offsets these beds nearly a quarter of a mile north on the east side in secs. 21 and 16, T. 2 S., R. 39 E. Similarly, it also offsets a fault, presumably a thrust, that originates in the NE¼ sec. 17, curves southeastward into the northern part of sec. 21, and—after offset—passes eastward through secs. 22 and 23. This fault affects the Wells, Phosphoria, Woodside, and Ross Fork formations.

FAULTS OF WILLIAMS CREEK SYNCLINE

From the SE¼ sec. 20, T. 1 S., R. 39 E., a subsidiary of the middle branch of the Bannock overthrust extends irregularly southward as far as the NW¼ sec. 4, T. 2 S., R. 39 E., where it originates in the axial area of the fold. It causes the Woodside shale to overlap the Rex chert member of the Phosphoria formation and the Wells formation north of Wolverine Creek canyon, brings in a low-lying ledge of Rex in the canyon bottom, and then passes southward in the Ross Fork and Woodside formations. A small branch fault in the SW¼ sec. 33 cuts off an eastward-trending belt of phosphate shale at the west. Another small branch extending northwestward from the SE¼ sec. 32 as far as Wolverine Creek is apparently the cause of the small travertine deposit in the canyon bottom in the NE¼ sec. 32.

Another fault that joins the middle branch of the Bannock overthrust in the SW¼ sec. 35, T. 1 S., R. 39 E., trends irregularly southward to the east side of sec. 15, T. 2 S., R. 39 E., and then turns southeastward to the NE¼ sec. 23. This fault cuts diagonally across the Williams Creek syncline and gradually cuts out its east limb. Its curve lies mainly between Woodside shale and Ross Fork limestone, but in secs. 15, 14, and 23 it cuts across the western tip of the quadrangular Buck Creek syncline and causes the Ross Fork to overlap the Portneuf limestone.

FAULTS OF BUCK CREEK SYNCLINE

Originating at the fault just described near the point where it bends southeastward in sec. 15, a minor thrust extends northeastward along the west limb of the Buck Creek syncline until it meets the middle branch of the Bannock overthrust near the center of sec. 1, T. 2 S., R. 39 E. Throughout its course it separates Ross Fork on the west from Portneuf on the east.

A neighboring thrust, originating in the SW¼ sec. 14 at the west end of the transverse axis of the syncline, cuts diagonally northeastward across the successive formations from Portneuf to Nugget in normal and reverse order and disappears at Williams Creek. It apparently causes the undue thickness of the Portneuf in the SE¼ sec. 12.

A minor fault between the Higham grit and Deadman limestone north of Williams Creek in sec. 12 cuts out the Higham for most of the distance between that creek and the middle branch of the Bannock overthrust.

FAULTS OF WOLVERINE ANTICLINORIUM

Two thrusts of the Wolverine anticlinorium are noteworthy. The first of these emerges from beneath the middle branch of the Bannock overthrust in the SW¼ sec. 35, T. 1 S., R. 39 E., and trends northwestward to the SE¼ sec. 16, where it ends against the second thrust. At the southeast, it first brings Twin Creek limestone into contact with Ephraim conglomerate, but about a quarter of a mile farther northwest the Stump sandstone comes in and for the rest of its course Stump and Ephraim remain in contact. For most of its course, the Stump occurs as a very narrow band, with a dip of 70° E. in places, southwest of the Ephraim, but in the SE¼ sec. 16 and the NW¼ sec. 21 the dip of the Stump flattens to about 15° and the area occupied by the formation expands to a width of nearly half a mile. The Preuss sandstone, which accompanies the Stump sandstone on the southwest in a somewhat wider band, bends northeastward in the NW¼ sec. 21 and with the Stump is cut off by the thrust in the SE¼ sec. 16.

The second thrust appears to originate in the SW¼ sec. 21 and extends northeastward and northward as far as the NW¼ sec. 33, T. 1 N., R. 39 E. It overlaps the first thrust in the SE ¼ sec. 16, T. 1 S., R. 39 E., and is offset slightly eastward in the NE¼ sec. 16 by a transverse fault. North and south of this fault, it is accompanied by minor thrusts that bring in slices of Stump and Preuss sandstones, and again in secs. 10 and 3 it is accompanied by minor thrusts that bring in similar rock slices. It is offset slightly westward in the NW¼ sec. 33, T. 1 N., R. 39 E., shortly before it passes beneath cover of welded rhyolitic tuff. For most of its course, it lies between Twin Creek and Preuss or within the Preuss, but in the east half of sec. 16 it brings Twin Creek into contact with Ephraim.

FAULTS OF BIRCH CREEK SYNCLINORIUM

Originating in about the SW. corner sec. 6, T. 2 S., R. 40 E., a noteworthy thrust in the Birch Creek synclinorium passes a little west of north through T. 1 S., R. 39 E., to the NE¼ sec. 3, where it is cut off by a normal fault. It is also cut near the middle by a northeastward-trending normal fault that offsets it westward on the north side about 2,500 ft. North of the transverse fault, the thrust lies along and here and there cuts out beds of Peterson limestone. Where the limestone is cut out, beds of Ephraim and Bechler conglomerates are brought in contact. South of the transverse fault, the thrust lies first within the Ephraim, but farther south it causes the Peterson to override Ephraim. Still farther south, it cuts through Peterson and makes Ephraim override Peterson.

In secs. 12 and 1, T. 1 S., R. 39 E., a minor thrust in the northeastern part of the synclinal area affects the relations of the Bechler, Peterson, and Ephraim formations in the same way, but here the Bechler is on the west and the Ephraim on the east. The observed portion of this fault is barely a mile in length, but it is offset by several cross faults.

FAULTS OF PORTNEUF MOUNTAINS

In the northeastern part of T. 4 S., R. 38 E., Paradise Valley quadrangle, Triassic and Jurassic formations are folded closely and the folds broken by four parallel thrusts already mentioned. These faults are apparently steep, though considered as thrusts. They lie 9 or 10 miles southwest of the Bannock overthrust zone. The sole of that overthrust, however, is known to be relatively flat or gently undulating for as great or greater distances from the trace of the fault, as shown by the distribution of the known windows on the fault plane. It seems likely, therefore, that some or perhaps all of these thrusts are offshoots from the sole of the Bannock overthrust, as in part suggested in structure section *P–P′* (pl. 2).

HORST AND GRABEN STRUCTURE

In the Cranes Flat, Henry, and Lanes Creek quadrangles to the east and southeast of the Paradise Valley quadrangle, normal faulting has produced horst and graben structure on a noteworthy scale (Mansfield 1927, pp. 162–165). In addition, these horsts and grabens have been broken by cross faults, which have raised some parts of them and lowered others. The Blackfoot Mountains in the eastern part of the Paradise Valley quadrangle are in considerable part a horst broken by cross faults. Its relations to the similar horsts farther southeast are shown in figure 26.

The horst and graben structure first became recognizable in the northwestern part of the Lanes Creek quadrangle. The Snowdrift anticline is bounded on each side by steep faults and has become a horst. It is accompanied on the northeast side by a depressed fault block or graben. Two cross faults have lowered both horst and graben in the northeastern part of the Henry quadrangle with respect to their extensions both northwest and southeast. In the Cranes Flat quadrangle the horst is again cut by a cross fault that extends a little west of north near the border of the Paradise Valley quadrangle. West of this fault, the extension of the Snowdrift anticline has been raised, with the result that the Blackfoot Mountains are proportionately broadened where they enter the Paradise Valley quadrangle.

As the Snowdrift anticline is one of the structures of the upper block of the Bannock overthrust, it had been inferred that the sole of the overthrust passed beneath the faulted horst and graben and that the sole would be raised or lowered by the steep faults that bound these structures. Confirmation of this inference is afforded in the Paradise Valley quadrangle by the window that occurs in the overthrust on the west flank of the horst in T. 4 S., R. 40 E.

The faults that bound the horst in the Cranes Flat quadrangle are not exposed and their position is not known, though it is inferred that they lie relatively close to the bases of the steep side slopes of the horst. The same conditions hold for the bounding faults of the horst in the Paradise Valley quadrangle. Similarly, the position and direction of the cross fault that raises the northwest segment of the horst, which enters the Paradise Valley quadrangle, are not known. Its position as mapped is inferred from the position of the Carboniferous rocks that appear abruptly on its west side.

The width of the horst between the assumed traces of the faults in the Cranes Flat quadrangle is roughly 1½ miles; similarly, the distance between the corresponding fault traces of the broader segment of the horst in the southeastern part of the Paradise Valley quadrangle is about 2½ miles. Assuming that the traces of the faults bounding the two horst segments lie

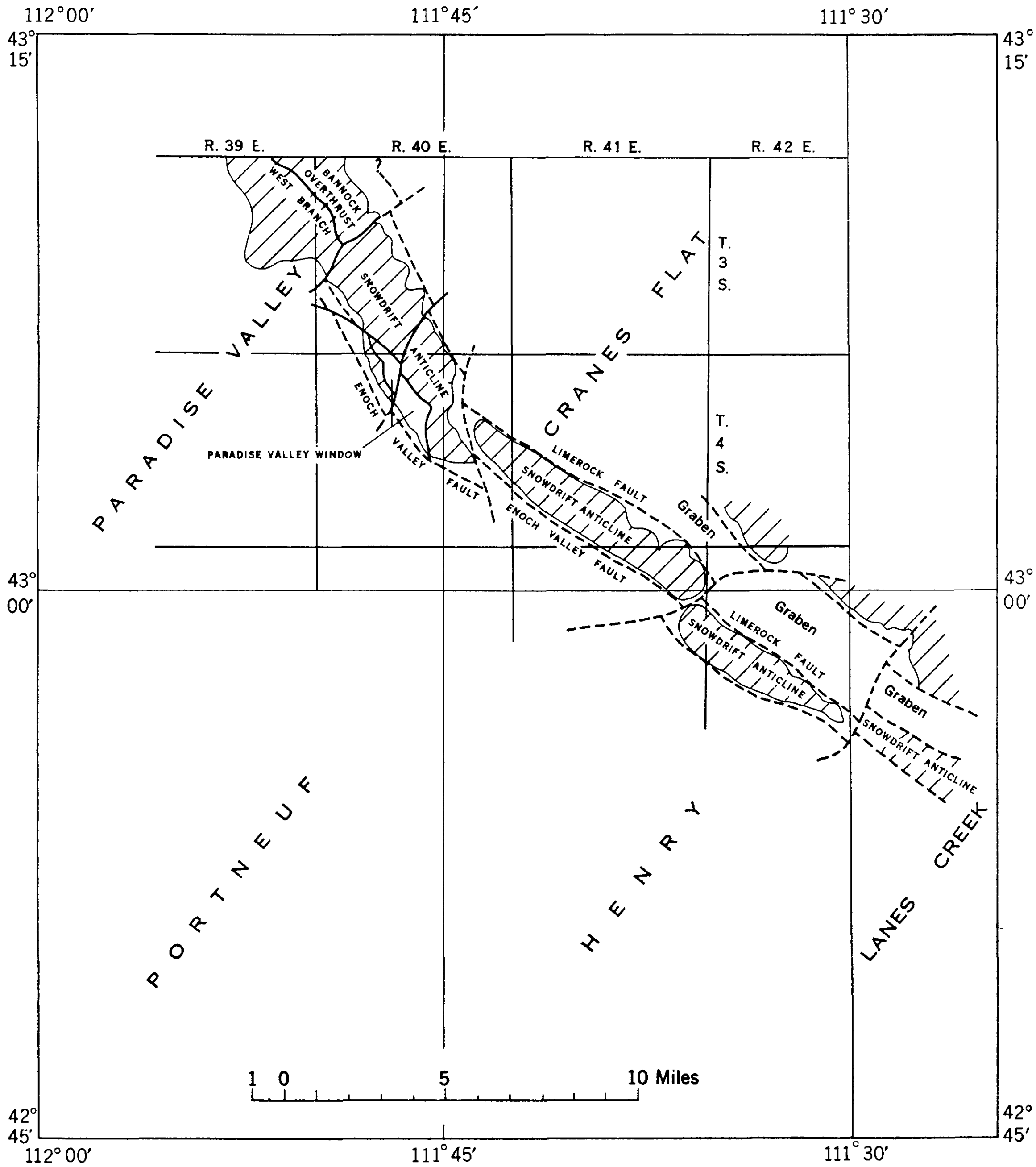


FIGURE 26.—Sketch map, showing the extension of horst and graben structure from the southeast into the Paradise Valley quadrangle.

approximately in the same plane, that the dips of the bounding faults are 60°, and that there has been no rotation, then $H = \frac{1}{2}(D-A)\sqrt{3}$, where $(D-A)$ = difference in width of horsts between bounding fault traces (1 mile) and H = altitude of an equilateral triangle with $(D-A)$ as a base. H, therefore, is approximately 4,600 ft (solution by G. W. Patterson). This figure has value only in suggesting a possible order of magnitude for the upward displacement of the horst segment that enters the Paradise Valley quadrangle and correspondingly for the segment of the sole of the Bannock overthrust contained in the horst.

A second transverse fault crosses the horst from the NW¼ sec. 9, T. 4 S., R. 40 E., to the NE¼ sec. 33, T. 3 S., R. 40 E., raising the segment northwest of the fault with reference to that southeast of it. The displacement and subsequent erosion of the two segments of the horst have not changed its exposed width very much, though the northeast boundary of the window, which is a fault of gentle easterly dip, has been offset about a quarter of a mile north on the northwest side of the fault. The displacement was sufficient to permit the erosion northwest of the fault of most of the beds of Ross Fork limestone and Fort Hall formation that are present southeast of it. It is thought that the vertical displacement is probably not greater than a few hundred feet.

HORSE CREEK FAULT

A third transverse fault, which may be called the Horse Creek fault, passes northeastward up Horse Creek from the NW¼ sec. 19, T. 3 S., R. 39 E., across the divide into the SE¼ sec. 8, where it passes beneath hill wash and basalt. On its northwest side, Nugget sandstone and Brazer limestone, separated by the west branch of the Bannock overthrust, are offset at least 1¼ miles southwestward with respect to beds of Brazer limestone on the southeast side of the fault. As the west branch of the Bannock overthrust dips gently west and the upper fault block has been eroded back down the dip of that fault (structure section *J–J′*, pl. 2), the block on the northwest has been raised with respect to that on the southeast. Whether the structure northwest of the Horse Creek fault is a horst is uncertain, though the structure to the southeast of the fault is believed to be one. The inferred bounding faults of the horst are therefore not indicated northward beyond the Horse Creek fault. The west branch of the Bannock overthrust, if continued south of the Horse Creek fault, would lie somewhere beneath the Willow Creek lava field.

In secs. 23 and 26, T. 4 S., R. 38 E., an isolated mass of Portneuf limestone appears to be offset about 1¼ miles southwest from the nearest mass of Portneuf, which occurs as a band about half a mile wide extending northwestward from the SW¼ sec. 13. A concealed fault trending northeastward is therefore postulated as the cause of the offset. As this fault lies approximately in the strike of the Horse Creek fault extended, and as its effect in producing displacement is comparable to that of the Horse Creek fault, the two are tentatively connected on the map and the name Horse Creek is here applied to the entire fault so constituted. The structure of the Portneuf limestone northwest of the fault is believed to be anticlinal, with the axial plane overturned eastward as shown in structure section *P–P′* (pl. 2). The structure of the Portneuf southeast of the fault is monoclinal with a northeasterly dip. No beds are available on either side of the fault that tie in closely enough to determine the direction and amount of the throw of the fault in T. 4 S., R. 38 E. There seems, however, to be no evidence sufficient to oppose the view that here, as in T. 3 S., R. 40 E., the block northwest of the fault has been raised. The effect of the displacement as a whole appears to be comparable to that produced by the transverse fault that raised the horst in the southeastern part of the Paradise Valley quadrangle and permitted the development of the Paradise Valley window in the Bannock overthrust. It may be noted in this connection that north of the Horse Creek fault the main mass of the Blackfoot Mountains abruptly becomes much wider than it is south of that fault.

OTHER NORMAL FAULTS

PARADISE VALLEY QUADRANGLE

In the SE¼ sec. 34, T. 4 S., R. 40 E., a normal fault enters the quadrangle from the Cranes Flat quadrangle beneath cover. It cuts out part of the Phosphoria formation, all the Woodside shale, and part of the Ross Fork limestone, as shown in structure section *O–O′* (pl. 2).

In the SW¼ sec. 8, T. 5 S., R. 40 E., a normal fault entering the Paradise Valley quadrangle from the Portneuf quadrangle beneath cover is postulated from the fact that in the latter quadrangle lower Ross Fork limestone is brought too near Portneuf limestone to permit the occurrence beneath cover of all the beds that should normally come between them. In the Paradise Valley quadrangle, as in the Portneuf quadrangle, beds of Woodside, with some bordering beds of Ross Fork, rise abruptly from the floor of the Blackfoot River valley with a scarp suggestive of faulting, which locally is discordant with the strike of adjacent rocks. This fault is shown in structure section *O–O′* (pl. 2).

At least three faults of small displacement affect the basalt and welded rhyolite tuff in secs. 9, 16, 21, and 22, T. 4 S., R. 39 E. Another probable fault cuts the basalt in sec. 29 of the same township. In secs. 28, 33, and 34, T. 2 S., R. 39 E., several faults have cut and offset Brazer limestone. Two of these faults have affected the course of Miner Creek, which apparently at one time flowed southward through High Basin (p. 9). At the intersection of two of these faults in the NE¼ sec. 33, a travertine deposit has been formed, over which Miner Creek now cascades. Several small faults in secs. 16, 17, 21, and 22 have offset and broken the Phosphoria and Wells formations, affecting unfavorably the possible exploitation of the phosphate in those sections. Two small faults in sec. 30, T. 3 S., R. 40 E., have let down a wedge of Twin Creek limestone into Nugget sandstone.

AMMON QUADRANGLE

In the NE¼ sec. 6, T. 1 N., R. 40 E., a supposedly normal fault separates beds of Ephraim conglomerate from the Wayan formation. It trends southwestward for about half a mile, bends rather sharply southeastward for a mile and a half, and then passes under cover. At its sharp bend it divides for nearly half a mile and introduces a slice of Nugget sandstone. In the NW¼ sec. 6 another fault separates Nugget from Bechler for a short distance and then passes under cover to the central part of sec. 7, where it cuts off the north end of the faulted syncline of Nugget and Twin Creek rocks and introduces Ephraim across the strike of these beds. In the SE¼SW¼ sec. 8 it passes under cover and may join the fault first described. In the NW¼ sec. 6 it sends off a branch fault that separates differently striking beds of Bechler and Peterson.

In the SE¼ sec. 21, T. 1 N., R. 40 E., beds of northward-striking Ephraim are separated by a northeast fault from northwestward-striking beds of Bechler conglomerate and Peterson limestone. Both sets of beds and the intervening fault are cut off in the SW¼ sec. 21 by a northwestward-trending fault that brings in Ephraim on the west.

In the NE¼ sec. 4, T. 1 S., R. 40 E., just east of Willow Creek, a mineralized spring (p. 14) is believed to mark the location of a northeast fault that separates Bechler with a northeasterly strike from strata of the Ephraim with a more northerly strike.

In secs. 27, 28, 33, and 34, T. 1 N., R. 39 E., a group of normal faults has shattered beds of the Stump, Preuss, and Twin Creek formations into numerous angular blocks. One of the faults, trending southeastward, cuts off the north end of the northwest prong of the Birch Creek synclinorium.

Similarly, beds of the Stump and Preuss formations have been shattered into angular blocks by a group of normal faults at the north end of the northeast prong of the Birch Creek synclinorium in sec. 1, T. 2 S., R. 39 E., and extending northward into adjoining parts of secs. 35 and 36. Possibly the beds beneath cover between the two prongs may be similarly shattered. One of the faults trending northeastward down Rock Creek may continue beneath cover as far as the hill in the center of sec. 30, T. 1 N., R. 40 E., for the volcanic ash beds and overlying welded rhyolitic tuff in that hill have been altered hydrothermally and form a conspicuous white landmark.

A group of small faults in the NE¼ sec. 8 and the NW¼ sec. 9, T. 1 S., R. 40 E., has broken the welded rhyolitic tuff in that area into a series of five short, lopsided ridges with gentle westerly slopes.

Near the boundary of secs. 19 and 20, T. 1 S., R. 40 E., a concealed fault has apparently caused the repetition of the welded rhyolitic tuff and beds of the Salt Lake formation.

The noteworthy fault that cuts northeastward across the Birch Creek synclinorium in secs. 26 and 24, T. 1 S., R. 39 E. has already been described (p. 70).

In secs. 4, 5, 8, and 9, T. 1 S., R. 39 E., several faults have cut the welded rhyolitic tuff into blocks.

Several faults offsetting the phosphate beds of the Mount Taylor anticline deserve mention. One of these is in the NE¼ sec. 25, T. 1 S., R. 38 E.; another in the NE¼ sec. 19, T. 1 S., R. 39 E. A third is in the NW¼ sec. 32 of the same township, and a fourth is in the SE¼ sec. 6, T. 2 S., R. 39 E.

AGE OF FOLDING

The folds of the Ammon and Paradise valley quadrangles involve rocks ranging in age from lower Mississippian (Madison) to Lower Cretaceous (Wayan). The mountain building that produced these folds was therefore later than the deposition of these rocks. It is believed to have been a part of the great mountain-building disturbance that came in the interval between the end of the Cretaceous period and the early part of the Tertiary, generally known as the Laramide revolution.

A subsequent epoch of less intense disturbance is suggested by the arching of the plane of the Bannock overthrust and by the dips now observed in the Salt Lake formation and some of the associated lavas. These dips are commonly as much as 10° and locally as great as 30°. On the present supposition that the Salt Lake formation is of Pliocene (?) age, this second disturbance may be assigned to the end of the Pliocene.

Some evidence of additional earlier epochs of mountain building is furnished by the conglomerates of the Ephraim and Bechler formations, but the effects of these earlier disturbances were largely obliterated by the more intense activity in this region during the Laramide revolution.

AGE OF FAULTING

The Bannock overthrust also is ascribed to the Laramide epoch and probably belongs to the later part of that epoch, because it did not occur until the rocks in what is now the upper block had been intensely folded—indeed, folded practically as much as those of the lower block. This is shown in the Montpelier quadrangle, where the folds of both blocks can be observed. The folding of the fault plane, however, is much more open, more in accord with that of the late Pliocene disturbance. It is believed, therefore, that the folding of the fault plane was much later than the production of the fault plane itself.

The other thrust faults associated with the folding are believed to have been caused by the Laramide disturbance.

The normal faults differ in age, and some are cut by others. In general, they are younger than the Laramide disturbance and hence fall chiefly within the Tertiary period. They were probably produced during the epoch of block faulting that gave rise to the so-called basin and range structure, of which the southeastern part of the Blackfoot Mountains is here considered an outlying representative. This structure is believed to have been developed in about middle Miocene time.

In addition to these faults there are some associated with igneous rocks and Tertiary strata that occurred subsequent to the deposition of the Salt Lake formation and hence presumably in early Pleistocene time. To this group belong the faults that cut the welded rhyolitic tuff in secs. 4, 5, 8, and 9, T. 1 S., R. 39 E., in secs. 4, 5, 8, 9. 16, and 19, T. 1 S., R. 40 E.; in secs. 17 and 20, T. 2 N., R. 39 E.; and in secs. 7 and 18, T. 1 N.,

R. 39 E., all in the Ammon quadrangle. Faults probably of Recent age have been identified in the Montpelier quadrangle. The faults near the center of sec. 33, T. 2 S., R. 39 E., Paradise Valley quadrangle, are thought possibly to have affected the Salt Lake formation as well as the Brazer limestone. Possibly these faults and the one in the NE¼ sec. 32, T. 1 S., R. 39 E., Ammon quadrangle, may be older faults refreshed by later action which gave rise to the travertine deposits associated with them.

RELATION OF STRUCTURE TO PHOSPHATE BEDS

The folds and faults of the Ammon and Paradise Valley quadrangles may be regarded as an influential factor in the preservation of the phosphate beds. These beds, which were originally nearly horizontal, might, if undisturbed, have been buried so deeply by subsequently deposited formations as to be beyond the reach of exploitation. On the other hand, if they had been strongly uplifted without deformation, they might have been destroyed to a greater or less extent in the normal course of weathering and erosion. By means of these structural features, however, some beds have been brought to the surface where they are now accessible, and others have been depressed below the level of erosion and thus preserved for an indefinite period. The effect of the Bannock overthrust, on the other hand, has been to diminish the amount of this phosphate that might otherwise have been ultimately available. Again, the phosphate shale, a group of relatively incompetent beds lying between more massive and harder strata, has been locally sheared during structural disturbances so that phosphate beds within it have been cut out or shattered and thus are lost or made unfit for exploitation.

GEOLOGIC HISTORY

SUMMARY OF RECORD

The latest page of the geologic history of the Ammon and Paradise Valley quadrangles, insofar as the record may be deciphered from the evidence in hand, is the geography of the region as it appears today. The business of historical geology is to reconstruct and interpret in orderly sequence the geographies of past epochs. With even so great a body of sedimentary rocks as is found in southeastern Idaho, the record is very imperfect, for gaps represent the loss of many pages and even of whole chapters and volumes of the story. The total thickness of the strata of southeastern Idaho is about 46,000 ft, or more than 8.7 miles. For the Ammon and Paradise Valley quadrangles the record is less complete, all sediments of Paleozoic age prior to lower Mississippian, as well as those of much of Cretaceous and Tertiary time, being absent.

PROTEROZOIC ERA

Few, if any, pre-Cambrian rocks are exposed in southeastern Idaho, so that inferences regarding the Proterozoic era must be drawn from the evidence furnished by neighboring regions. This evidence suggests that southeastern Idaho, including the Ammon and Paradise Valley quadrangles, was land throughout much of that time but that there was continental deposition, deformation, erosion, and perhaps even glaciation, as in later periods, and that the great continental elements of higher and lower land were already blocked out before the Paleozoic era began.

PALEOZOIC ERA

The Paleozoic record is dominantly marine and thus indicates progressive subsidence of the region. The variations in the character of the sediments, however, and the numerous stratigraphic breaks show that there were at times interruptions in subsidence and even reversals of movement, with erosion. These disturbances were gentle but were fairly well distributed throughout the era. A noteworthy feature is the general dominance of limestone-making processes.

From the record in areas adjacent to the Ammon and Paradise Valley quadrangles, it appears that early in the Cambrian the relatively low and long-eroded surface of southeastern Idaho began to subside and receive sandy sediments, at first probably nonmarine but later marine. The invasion of the sea may not have begun until the later part of Early Cambrian time or the early part of Middle Cambrian time. The sediments of the Middle Cambrian were chiefly limy, but at the beginning of the Late Cambrian the sea became more restricted and sands were again the predominant sediments for a time. This condition was succeeded by the renewal of limestone deposition and even more extended invasion of the sea—the first great transcontinental marine inundation of Paleozoic time.

A brief erosion interval with little change in the attitude of the land separates the Late Cambrian from the Ordovician, when limestone again formed. A reversal of subsidence in the later part of Early Ordovician time brought, first, a change in sedimentation from limestone to sandstone that later became quartzite (Swan Peak), and then an erosion interval that lasted through much of Ordovician time. Toward the end of the Ordovician period, subsidence with deposition of limestone was resumed.

The Silurian period in southeastern Idaho is represented by a single formation, the Laketown dolomite, reported by Kirk to carry Niagaran fossils. In spite of its apparent conformity with the underlying Fish Haven dolomite, a stratigraphic break of some magnitude intervenes. The Silurian sea was widespread in the west, but toward the end of the period it withdrew from the region now occupied by the Rocky Mountains, and that entire region became land.

These conditions continued until Middle Devonian time, when the region was again occupied by the sea and deposition of limestone was resumed without any marked discordance in attitude between the later and the earlier beds. From Middle Devonian through Late Devonian time, the region of deposition was extensively flooded. Gentle earth movements during the period are indicated by changes in the composition and appearance of the beds.

Mild disturbances of the land surface with ensuing erosion are believed to have intervened between the deposition of the Devonian and that of the Carboniferous formations of southeastern Idaho, though the rocks of the two systems show little discordance in attitude.

Thus far the record has been compiled from areas bordering or neighboring the Ammon and Paradise Valley quadrangles, for the rocks described do not appear at the surface in these quadrangles, although they probably are present at depth. Beginning with the Mississippian, however, the exposures within the two quadrangles furnish a fairly continuous record for the upper Paleozoic and much of the Mesozoic.

There is some evidence of interruption in deposition between the two formations of the Mississippian series, though here again there is no conspicuous discordance of the strata. Limestone forms the main body of the rocks of this series, but shale and sandstone also are present, indicating variations in conditions of deposition. Another crustal disturbance marked the interval between late Mississippian and Pennsylvanian deposition. The beds of the Pennsylvanian epoch were more sandy than those of the Mississippian, and in both epochs of the Carboniferous period and in the Permian period subsidence of the sea bottom was intermittent or there were minor oscillatory movements. An unconformity is believed to separate the Permian from the Pennsylvanian beds in the Idaho area, though recent studies show that the boundary between Pennsylvanian and Permian is not yet well established and that the unconformity hitherto recognized may lie within the Permian rather than at its base. The region receiving deposits was in part cut off from the sea on the east and west but had northward, westward, and southward connections with the Pacific. Under special conditions of deposition not yet well understood, beds of phosphate rock that promise to be of great economic importance were formed, and the overlying strata of the same period include beds of massive chert and flinty shale. The history of the Permian in this region thus constitutes a series of interesting stratigraphic problems.

MESOZOIC ERA

The change from the Paleozoic to the Mesozoic in southeastern Idaho is marked by strong faunal contrasts rather than by any noteworthy discordances of strata. The Mesozoic is distinguished by alternations on a great scale between marine and nonmarine conditions of deposition. The later part of the era in southeastern Idaho was characterized by the accumulation of great thicknesses of continental sediments.

Though the North American continent as a whole was a relatively broad land area in the Triassic period, southeastern Idaho was for a time occupied by an arm of the sea connecting with the Pacific at the southwest. In Early Triassic time, open-sea conditions prevailed in southeastern Idaho, but farther east there were shallow marginal areas that dried up at certain seasons and lagoons or estuaries that gave rise to red beds. The shore line of the sea advanced or retreated from time to time, and these movements caused some interfingering of marine and red-bed sediments. Marine sediments, however, predominated.

At the close of Early Triassic time the sea withdrew for a long interval. The time between Early Triassic and Early Jurassic is represented in part by four formations, all nonmarine, whose age is uncertain. The first of these formations, the Timothy sandstone, was formerly considered of Early Triassic age but is now believed to be more probably Late Triassic. The other three formations, the Higham grit, Deadman limestone, and Wood shale, are referred tentatively to the Triassic.

The Jurassic period in southeastern Idaho apparently opened with continental rather than marine conditions, but the record of its beginning is not very clear. The Nugget sandstone, considered to be of Lower Jurassic age, appears to represent widespread desert conditions, but in Middle Jurassic time, the sea returned and limestone deposition was resumed and continued for a long interval. The sea, however, was more restricted than during the great periods of limestone deposition of the Paleozoic, and a higher percentage of silty and clayey material was deposited with the limy muds. Some evidence of volcanic activity during the period, especially in the earlier part, is recorded in bentonitic beds. The shores of the sea could not have been very distant from the principal area of deposition, for at times sandy sediments were laid down and toward the later part of its existence there was some advancing and retreating of the shore line of the Jurassic sea. This caused interfingering of normal marine beds with red sandstones. Finally the sea was closed out and continental conditions with the deposition of red beds were resumed for a time, but the sea returned for at least two brief intervals before the close of the period. One such interval is recorded by the Stump sandstone, consisting of calcareous sandstones and shales that carry a meager Upper Jurassic fauna; the other, by marine fossils found in red beds about 50 ft above the base of the Ephraim conglomerate.

Whether the final withdrawal of the Upper Jurassic sea marked the close of the Jurassic period in southeastern Idaho is not definitely known. The abrupt change in the character of the sedimentation suggests that it did, but the age of the sediments is open to doubt. Unidentifiable dinosaur bones found in the upper part of the Ephraim conglomerate and "gastroliths" in beds near the top suggest a possible Morrison age for the part of the Ephraim above the marine Jurassic beds. However, no distinctive Morrison fossils have been found in the Ephraim, and the dinosaur bones and "gastroliths" could just as well be Lower Cretaceous.

The latest marine beds of the Jurassic were succeeded by red and grayish conglomerates, very coarse toward the south in the Montpelier and Crow Creek quadrangles but with smaller pebbles farther north. These conglomerates were accumulated in considerable thickness and would seem to mark such a quickening of erosion as to suggest a notable uplift of the area that furnished the materials. This uplift was doubtless the Sierra Nevada movement which occurred farther west at the close of the Jurassic. Though its effects were noticeable in southeastern Idaho through the changes in sedimentation, it did not materially affect the attitude of beds already deposited as they were relatively undisturbed.

The deposition of the 1,000 ft or more of conglomerates and associated beds was succeeded by a widespread lacustrine epoch in which about 200 ft of fresh-water limestones, certain beds of which are fossiliferous, were laid down. Conglomerate and fresh-water limestone deposition was repeated, and beds of each type accumulated in roughly corresponding thickness. Further deposition of sandstone took place, at least locally, before erosion again interrupted the process. The succession of conglomerates, fresh-water limestones, and sandstones constitutes the Gannett group, whose lower part is of Upper Jurassic age but which is mostly Lower Cretaceous.

The Wayan formation, which unconformably follows the Gannett group, is partly Early Cretaceous and partly Late Cretaceous in age. It is represented in the Ammon quadrangle by beds comprising part of its lower division and considered Lower Cretaceous, but it is not exposed in the Paradise Valley quadrangle. Conditions of deposition were not very different from those that were prevalent during the Gannett epoch, but there were no coarse conglomerates, such as those of the Ephraim, and the sediments as a whole were finer-textured. There was much sandstone and some small-pebble conglomerate, together with carbonaceous shale and some fresh-water limestone. The carbonaceous shales and associated limestones would seem to indicate that lacustrine conditions prevailed at certain times and places. Enough of the carbonaceous material accumulated at some of these places to form thin layers of a very low grade of coal, which has been locally prospected and burned.

In areas farther southeast the Wayan formation contains evidence, in the form of bentonitic beds, of minor volcanic activity, but no such beds were recognized in the Ammon quadrangle. Also, farther east and northeast the Wayan formation seems to merge with or contain equivalents of the Bear River formation (Upper Cretaceous), a product of brackish-water deposition. In the Ammon quadrangle no fossils of Bear River aspect are known, but such fossils as have been found indicate that the beds from which they came are of Early Cretaceous age. Nonmarine beds of Late Cretaceous age, such as those that contain *Tempskya* farther southeast, are not represented in the Ammon quadrangle. Marine Cretaceous deposits seem not to have transgressed as far west as the Ammon quadrangle, though they did reach what is now the Bighole Mountains west of the Teton Basin in Tps. 4 and 5 N., Rs. 43 and 44 E., in eastern Idaho. If such beds, or any beds containing *Tempskya*, were ever laid down within the area here considered, they have since been eroded.

The close of the Mesozoic was marked by the great Laramide revolution, which produced the folding and thrust faulting responsible for most of the complicated geologic structure now present in the general region. The thrust faulting was apparently a relatively late feature of the disturbance, for the folding in the beds above thrust faults is comparable in extent and magnitude to that of rocks overridden by the upper fault blocks. The position and great thickness of the accumulated sediments are thought to have had a directive influence on the mountain-building forces.

The interval between the Cretaceous and Tertiary deposition in southeastern Idaho was marked by erosion, but in neighboring parts of southwestern Wyoming the coal-bearing Evanston formation was laid down in Early Tertiary (Paleocene) time. The nature of this formation suggests that the reduction of the adjacent mountains of Idaho was well advanced by the beginning of the deposition of the Wasatch formation (Eocene).

CENOZOIC ERA

The Cenozoic in southeastern Idaho was largely an era of erosion interrupted from time to time by crustal disturbances and by the deposition of continental sediments. No beds of Paleocene (Fort Union) age are present, and no beds of Eocene age are exposed in the Ammon and Paradise Valley quadrangles, though beds assigned to the Wasatch formation occur in some of the neighboring quadrangles. The andesitic tuff in T. 3 S., R. 38 E., in the Paradise Valley quadrangle, together with some of its associated basalt, is thought to be as old as Oligocene or perhaps Early Miocene.

The Quaternary history of the region is largely one of erosion interrupted by uplift and modified by climatic changes and volcanic outbursts, which have caused the silting up of valleys. One of the outstanding volcanic phenomena of the period was the eruption from unknown vents and the deposition of the remarkable rhyolitic welded tuff that is so widespread, particularly in the Ammon quadrangle. This phenomenon was not merely local, for the welded tuff extends northeastward around the mountain fronts and up the major valleys to the Yellowstone Park and similar rocks have been noted north of the Snake River valley up to the Continental Divide and possibly beyond. The Elk Valley, Dry Fork, Blackfoot, and Spring Creek erosion cycles have produced the present topographic features, but particularly in the Blackfoot cycle complications have been introduced by the basalt flows that have successively flooded some of the larger valleys—for example, those of the Blackfoot River and Willow Creek.

The Spring Creek cycle (p. 5) represents the Recent erosional activity in the region. Its effects in the Ammon and Paradise Valley quadrangles have not been clearly differentiated from those of the Blackfoot cycle because of the difficulties of interpretation introduced by the basalt flows just mentioned. The effects of the Spring Creek and Blackfoot cycles are regarded as not extensive and as of minor importance.

Late faulting has affected the rhyolitic welded tuff, the basalt, and even the slopes of hill wash in some parts of the general region and has revived some of the earlier faults. Locally, on the Snake River Plain, late Pleistocene wind activity has produced sand dunes.

The Miocene was an epoch of erosion. Although it was a time of great volcanic activity in many parts of the West, no such activity has been recognized in southeastern Idaho unless it is indicated by the andesitic tuff just mentioned. Crustal disturbances in the middle part of the Miocene are thought to have uplifted the old, worn-down surface, remnants of which, in neighboring quadrangles, have been called the Snowdrift peneplain, and to have permitted the development of broad and deep valleys in the latter part of the epoch. Also attributed to these disturbances is the development of the horst and graben structure of which the Blackfoot Mountains in the Paradise Valley quadrangle are an outlying representative.

The erosion of the Miocene may have continued into Pliocene time, but it eventually gave way to the conditions that permitted the Salt Lake formation to accumulate until it blanketed many valleys and the lower hills and even reached altitudes now as high as 7,000 ft. Some climatic fluctuations during the period are suggested by the nature of the Salt Lake formation. There was also volcanic activity on a considerable scale. Further uplift came toward the end of the Pliocene. According to W. C. Alden, the final activities of the Pliocene were probably erosional and included the development of the Gannett erosion surface.

MINERAL RESOURCES

No metalliferous deposits are known in the Ammon and Paradise Valley quadrangles, and none of commercial value are to be expected, for the conditions that generally favor the development of such deposits, such as intrusive masses and dikes of igneous rock and veins, are practically absent. Though extrusive igneous rocks—lava flows and fragmental volcanic rocks—are abundant, they show no evidence of the kind of alteration associated with the accumulation of metalliferous deposits.

Nonmetallic mineral resources of several types are present, however, some of which are of potential if not of immediate commercial value. These are phosphate rock, limestone, road metal, building stone, and volcanic ash. Mention should also be made of coal and nitrate, which have a certain interest but are not of prospective economic importance.

PHOSPHATE ROCK

GENERAL CHARACTER

An extended description of the Western phosphate rock, dealing with its texture, appearance, chemical composition, mode of occurrence, origin, and exploitation, has been given previously (Mansfield, 1927); in the present paper only a brief summary is necessary. Phosphate rock in southeastern Idaho occurs at two horizons, upper Mississippian and Permian, but the Permian beds are the only ones of much commercial importance and the only ones that have been recognized in the Ammon and Paradise Valley quadrangles. This rock is characterized chiefly by its pelletal texture, its dark color, and its odor, which, when the rock is freshly broken, is similar to that of crude petroleum. This odor is not distinctive of phosphate, for many limestones have a similar odor when freshly broken. Weathered material is usually distinguished by a bluish-white coating or bloom that in some specimens has a netlike pattern. The phosphate rock is a bedded deposit of marine origin and must be mined in the same manner as coal.

Phosphate rock is composed chiefly of fluorapatite, $9CaO.3P_2O_5.CaF_2$. Its chemical composition is sometimes referred to in the trade as tricalcium phosphate, $Ca_3(PO_4)_2$, or "bone phosphate of lime" (abbreviated B. P. L.). Percent B. P. L. is calculated by multiplying percent P_2O_5 by 2.18. There are many accessory constituents, among which are silica, iron, alumina, potash, and other minor elements. Tests made some years ago in the Geological Survey laboratory show that the average density of the rock is 2.90 and that the weight of a cubic foot of the more massive rock is about 180 lb.

IRON AND ALUMINA CONTENT

In the Eastern fields the presence of iron and alumina in phosphate rock in excess of 3 to 4.5 percent is considered to lower the grade of the rock below foreign-contract standards. Besides constituting briny impurities that increase the quantity of acid necessary for treatment, these substances are said to produce, in the process of superphosphate manufacture, deliquescent salts which make the drying and shipment of the product difficult. Samples from the Western fields that have been tested in the laboratory of the Geological Survey have generally shown less than 1 percent of either radical computed in the oxide form. Of the samples thus far analyzed from the Ammon and Paradise Valley quadrangles, several tested for iron and alumina taken together showed variations from 1.30 to 5.34 percent. The lower figure represents a sample of high-grade phosphate (77.42 B. P. L.) and the higher figure a sample of very low grade phosphate (35.66 B. P. L.).

VANADIUM CONTENT

The following abstract of a paper by W. W. Rubey (1943) sums up so well the information available on the vanadium content of Western phosphate rock that it is here quoted in full.

> The presence of small amounts of vanadium in western phosphate rock has been known since 1911 [it was discovered by Geological Survey chemists in the course of analyzing material found near Driggs, Idaho] and in the past two years vanadium has been recovered as a by-product from phosphate rock mined by the Anaconda Copper Mining Company at Conda, Idaho. In the course of classification of public lands, the Geological Survey has determined the vanadium content of phosphate rock in Idaho, Wyoming, Montana, and Utah and in recent years of many samples of other rock types associated with the phosphates. Field investigations in 1942 in the region that appeared most promising from available information disclosed several areas that seem to warrant more intensive examination. Some of these areas are now under active exploration by the Metals Reserve Company and the Bureau of Mines.
>
> The region is mountainous and the rocks are sedimentaries that have been intensely deformed and broken by thrust and normal faults. The highest concentrations of vanadium (0.5 to 2.0 percent V_2O_5) are found in carbonaceous and graphitic (?) mudstone. Throughout most of the region the vanadium occurs principally in a single bed about 3 feet thick. Estimates indicate the presence of many million tons of rock that contains 0.75 percent or more of V_2O_5.

DISTRIBUTION OF PHOSPHATE

Phosphate is exposed at the surface in only five townships within the area of the Ammon and Paradise Valley quadrangles. These are T. 1 S., R. 38 E.; Tps. 1 and 2 S., R. 39 E.; and Tps. 3 and 4 S., R. 40 E. On the basis of field work by the author and his associates in the Fort Hall Indian Reservation in 1913 and later revisions in 1923 and 1925, certain portions of Tps. 4 and 5 S., R. 38 E., are reserved as phosphate land (Mansfield, 1920a, pp. 95–103, and 1929, pp. 69–72). These lands, however, do not fall within the area of the two quadrangles named. Elsewhere within the quadrangles either there is no phosphate or it is too deeply buried to be reached without deep drilling (fig. 27).

DESCRIPTION OF TOWNSHIPS CONTAINING PHOSPHATE

T. 1 S., R. 38 E.

LOCATION

The eastern half of T. 1 S., R. 38 E., in Bingham County, Idaho, is in the southwestern part of the Ammon quadrangle. The northern tier of sections lies along a correction line and is therefore slightly deficient in area.

ACCESSIBILITY

The northwest corner of the township is about 10 miles south of Idaho Falls. Shelley, about 4 miles west of the northwest corner, and Firth, about 6 miles west of the southwest corner, are the nearest shipping points on the main line of the Oregon Short Line (Butte division), but Dumas and Goshen are shipping points on a branch railroad about a mile west of the township boundary. The eastern half of the township, which is the only part here considered, is accessible from the north by a fair road up Taylor Creek and from the south by a badly washed road, the continuation of the one just mentioned, that connects with the road in Wolverine Creek canyon. The latter road crosses the Blackfoot Mountains from west to east. Other roads, generally poor, ascend the so-called "benches" here and there from the west or north.

SURFACE FEATURES

The eastern half of the township is a submaturely dissected upland with a relief ranging from less than 100 ft to more than 700 ft; the highest elevation, 6,727 ft, is in the NE¼ sec. 24. The ridge tops and upper slopes are parts of an old erosion surface developed on rocks of different hardnesses and in general have a fairly smooth configuration except where the rocks are hardest. The canyons are sharply cut, with steep sides and narrow bottoms. Ledges of igneous rock form cliffs or rim rocks in some of the canyons. The drainage of this part of the township is chiefly through branches of Taylor Creek on the north and of Wolverine Creek on the south, but minor creeks drain westward.

GEOLOGY

Most of the examined portion of the township is underlain by Tertiary rocks and associated rhyolitic rocks and basalts, but in secs. 13, 24, 25, 27, and 34 to 36 older

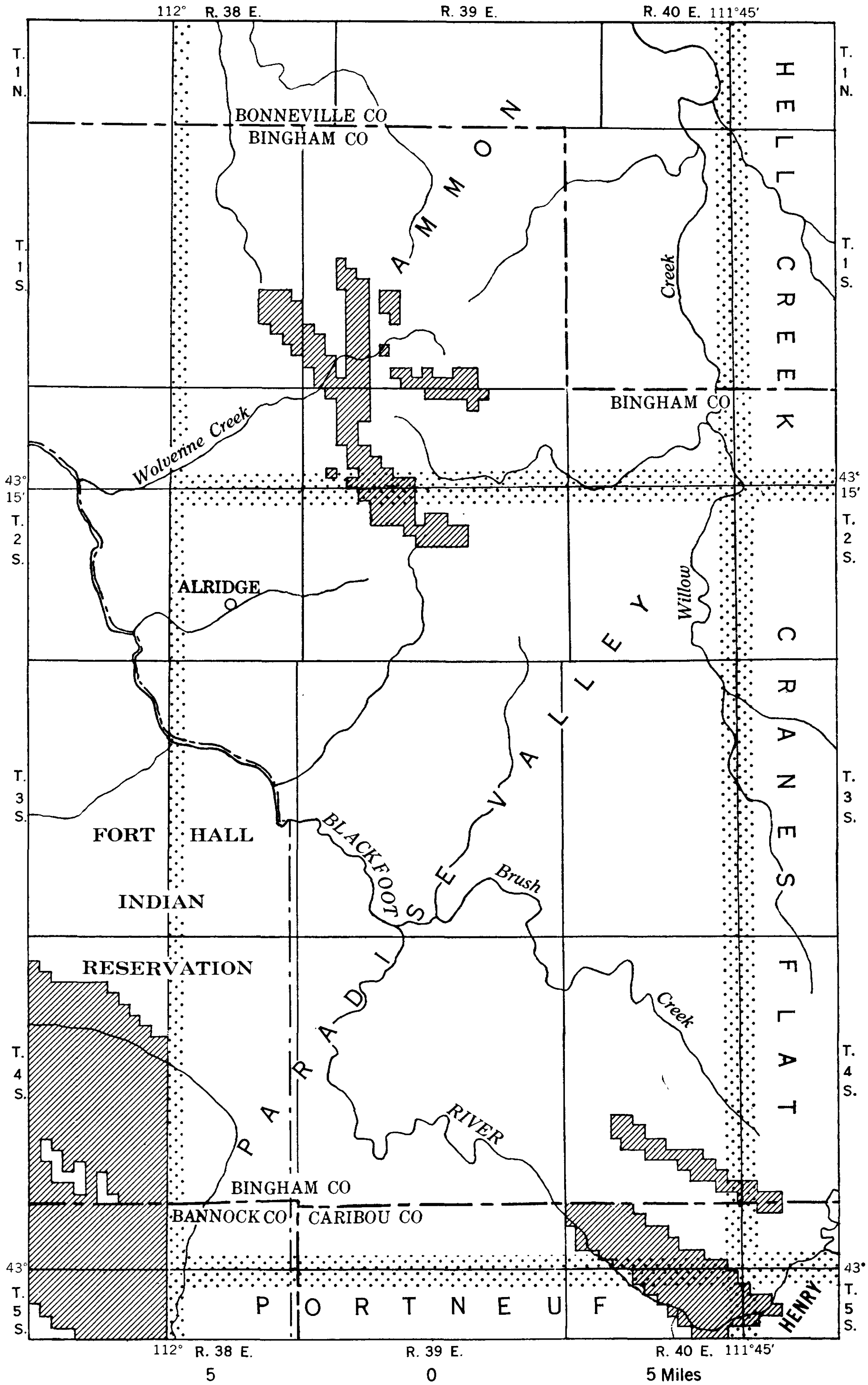


FIGURE 27.—Map showing the distribution of reserved phosphate lands in the Ammon and Paradise Valley quadrangles and in some adjacent areas.

rocks are exposed. The rocks included in the older group are parts of thrust blocks produced by the Bannock overthrust. The west branch of this fault enters sec. 36 from the southeast and brings the Brazer limestone (upper and middle Mississippian) into contact with rocks believed to be Triassic (structure section *A–A′*, pl. 2). The fault trace is concealed in this township but comes to the surface in sec. 6, T. 2 S., R. 39 E., to the southeast. The middle branch of this great overthrust lies under cover just east of sec. 13 and may enter the northeast corner of the township. From relations in secs. 18 and 7 of the adjoining township, it is believed to bring rocks of the Wells formation (Pennsylvanian) into contact with beds of Twin Creek limestone (Jurassic).

PHOSPHATE DEPOSITS

Location.—The phosphate shale member of the Phosphoria formation is exposed in a narrow band extending through parts of the south half of sec. 24 and the east half of sec. 25. The Rex chert accompanies the phosphate along its south and southwest sides, and the Woodside shale is exposed in two areas. One of these areas adjoins the Rex in the northern part of sec. 25, and the other is a long, narrow strip that extends from the SE¼ sec. 25 through the NE. cor. sec. 36 and is separated by Tertiary cover from the Phosphoria on the east.

Character.—No good exposures of the phosphate shale member of the Phosphoria formation were available in this township, and no prospecting was done by the Survey party. Several old prospects were noted near the top of the Wells formation in sec. 25 and just over the line in the adjoining sec. 30, but these shed no light on the character of the phosphate. Likewise, an old prospect was noted in the Rex chert member of the Phosphoria formation a short distance north of the road in Wolverine Creek canyon where the Phosphoria formation crosses that canyon in sec. 31, T. 1 S., R. 39 E. Trenches dug by the Survey party in the NW¼ sec. 29, T. 1 S., R. 39 E., and in the SE¼ sec. 33 of the same township give an idea of the character of the phosphate beds that may be expected in T. 1 S., R. 38 E. In sec. 29 the phosphate beds were badly broken and the section appeared to be partly faulted out. Nevertheless, a sampled zone of shattered gray phosphate 2 ft 2 in. thick, containing some fragments of phosphate as much as 3 in. in diameter, upon analysis yielded 71.40 percent $Ca_3(PO_4)_2$. The trench in sec. 33 contained a bed of phosphate 5 ft 7½ in. thick, from which three samples were taken that yielded an average of 67.2 percent $Ca_3(PO_4)_2$. If the middle sample of this group, which represented 2 ft of material containing 50.9 percent $Ca_3(PO_4)_2$, is disregarded, the remaining 3 ft 7½ in. contains 76.65 percent $Ca_3(PO_4)_2$. Unfortunately, the phosphate shale in T. 1 S., R. 38 E., seems to be affected by faulting, so that probably some if not all of the richer portions of the phosphate shale may be missing. For purposes of computation, however, it seems safe to assume the presence of at least 2 ft of rock with a grade of 70 percent.

Tonnage estimate.—The depth limit for such a bed under current regulations is 1,000 ft. By applying this limit to structure section *A–A′* (pl. 2), the approximate width of the belt of land which may be considered phosphate bearing is obtained. Assuming that this belt maintains a fairly uniform width and follows the strike of the phosphate beds, the approximate acreage included in the belt may be determined. This is 445 acres. Estimated by previous methods of computation (Mansfield, 1927, p. 220), the phosphate reserve in T. 1 S., R. 38 E., is at least 3,115,000 long tons. Classification practice does not ordinarily take cognizance of smaller areas than 40-acre tracts. Accordingly the area classified is considerably larger than the area employed in the tonnage computation (fig. 27).

T. 4 S., R. 38 E.

Lands in T. 4 S., R. 38 E., were classified for phosphate following field work by the author and his associates in the Fort Hall Indian Reservation in 1913 (Mansfield, 1920a, pp. 95–99). Further classification, which excluded from the reserve parts of secs. 25 and 36, followed field work in 1923. Later field work in 1925 showed that any phosphate present in the eastern half of the township is probably deep and therefore inaccessible except by drilling. Accordingly this area, which includes the portion covered by the Paradise Valley quadrangle, is now classified as nonphosphate. The outstanding classified phosphate lands in this township are shown in figure 27.

T. 5 S., R. 38 E.

Lands in T. 5 S., R. 38 E., were classified for phosphate following field work by the author and his associates in the Fort Hall Indian Reservation in 1913 (Mansfield, 1920a, pp. 99–103). Minor revisions in this classification were made after field work in 1923 and 1925 (Mansfield, 1929, pp. 69–72). Only a small part of the township, including secs. 1, 2, and most of 3, together with parts of secs. 10, 11, and 12, is contained in the area here described and forms the southwestern part of the Paradise Valley quadrangle. The presence of the Phosphoria and Woodside formations in secs. 25, 26, 35, and 36 to the south suggests that some phosphate may be present in depth in the northeastern part of the township. This area, however, is covered by Tertiary rocks, and the presence or absence of phosphate can be determined only by deep drilling. The outstanding classified phosphate lands in the northern half of this township are shown in figure 27.

T. 1 S., R. 39 E.

LOCATION

T. 1 S., R. 39 E., in Bingham County, Idaho, occupies the south-central part of the Ammon quadrangle. The northern boundary of the township is a correction line, so that the northern tier of sections is slightly deficient in area.

ACCESSIBILITY

The township lies 10 to 15 miles southeast of Idaho Falls, and the nearest railroad is a branch of the Oregon Short Line that serves the town of Ammon, about 7 miles north of the northwest corner of the township. The road that connects Taylor Creek with Wolverine Creek, mentioned in the discussion of T. 1 S., R. 38 E., joins Wolverine Creek in the SW¼ sec. 31, T. 1 S., R. 39 E. A through road up Wolverine Creek crosses the southwestern part of the township, connecting the Blackfoot River and Snake River valleys on the west with Willow Creek valley and regions to the east and southeast. A poor north-south road traverses the foothills in the eastern part of the township. A better road extends northward in the valley of Willow Creek, about a mile and a half east of the township. This road connects with Idaho Falls and places in the Snake River valley. Poor roads and trails, some of which are impassable for vehicles, occupy most of the larger canyons and ascend the benches here and there.

SURFACE FEATURES

The township is in the heart of the Blackfoot Mountains and is relatively rugged throughout. Mount Taylor (Blackfoot Peak), with an altitude of 7,414 ft, is the highest summit within the township and is a conspicuous landmark of the region. The summit areas are parts of an erosion surface reduced perhaps to late maturity and later dissected by deep canyons. Wolverine and Henry Creeks have the most impressive canyons; in many places their slopes rise abruptly 500 to 750 ft, and on the north side of Wolverine Creek the slopes rise steeply more than 1,600 ft to the summit of Mount Taylor. The divide between Willow Creek and other Snake River drainage lies in the eastern half of the township. Igneous rocks form ledges, cappings, and rims here and there.

GEOLOGY

The township is divided geologically into two units by a great thrust fault that enters sec. 35 from the southeast and passes out northwestward through sec. 7. This fault, which has been designated the middle branch of the Bannock overthrust, has a very irregular trace. Northeast of it the rocks are principally of Jurassic and Cretaceous age, so high stratigraphically that any phosphate beneath must be too deep to be considered exploitable. Southwest of the fault rocks ranging from those older to those younger than the phosphate are present. The complicated structure as here interpreted is shown in structure sections *A–A′* and *B–B′* (pl. 2). The line *C–C′* passes about a mile to the south of the township. In the northwestern part of the township Jurassic strata pass beneath Tertiary sedimentary and volcanic rocks of later age. The eastern half of the township is underlain chiefly by folded and faulted Cretaceous rocks, but in the northeast corner shattered Jurassic formations are present.

PHOSPHATE DEPOSITS

Location.—The phosphate shales are exposed in three bands in this township. The first band enters sec. 30 from the northwest, passes out through sec. 31, and terminates against a fault a short distance south of the township boundary. The second band begins at a fault in the NE¼ sec. 19 and passes southeastward and southward, leaving the township at the south margin of the SW¼ sec. 32. The third band begins at a fault in the SW¼ sec. 33 and extends irregularly eastward to the SE¼ sec. 34.

Character.—No satisfactory openings in the phosphate shales were available for study, though old prospects were observed in the upper part of the Wells formation in the NW¼SW¼ sec. 30 and in the Rex chert member of the Phosphoria formation in the NE¼SE¼ sec. 31 on the north side of Wolverine Creek canyon. The Survey party therefore dug two trenches, one in the NW¼ sec. 29, on the projecting point east of Mount Taylor, and the other in the SE¼ sec. 33. The trench in sec. 29 was 27 ft long, 2 ft wide, and 4 ft deep, with a maximum depth of 4 ft 9 in. It was dug across the strike of the beds, the west end in material derived from the Wells formation. The beds were much shattered and appeared to dip 15° to 43° E., though the bedding could not be identified with assurance. The dips of beds of the associated Wells and Rex are westerly. No very definite beds could be recognized for sampling, but 11 ft from the west end of the trench the party sampled a zone of 26 in. of shattered gray phosphate, some fragments of which were 3 in. in diameter. Above this zone was ground-up reddish-brown shale and, below it, similar material of yellowish-brown color. The sampled zone, upon analysis, showed a content of 32.70 percent P_2O_5, equivalent to 71.40 percent $Ca_3(PO_4)_2$. Iron and alumina combined totaled 2.52 percent. A zone of black broken shale, apparently 31 in. thick at a distance of 16½ ft from the west end of the trench, also was sampled. It yielded only 17.96 percent P_2O_5, equivalent to 39.23 percent $Ca_3(PO_4)_2$. Its combined iron and alumina content was 4.56 percent. Above it was a grayish-brown earthy material; below it, crushed brown limy shale. A float fragment of phosphate rock picked up in the vicinity of the trench yielded 33.68 percent P_2O_5, equivalent to 73.55

percent $Ca_3(PO_4)_2$. Its iron and alumina content was 1.70 percent. Tests of the samples for vanadium oxide yielded negative results. A test on a combined sample of material from each of the three samples showed 1.30 percent fluorine.

The trench in sec. 33 was 26 ft 4 in. long and 2 ft wide and had an average depth of about 3½ ft. Its maximum depth was 5 ft 8 in. The strike of the beds was N. 75° W. and the dip 25° SW. The measurements and analyses are given in the accompanying table.

Phosphatic shales cut by trench in NE¼SE¼ sec. 33, T. 1 S., R. 39 E., Ammon quadrangle, with partial analysis of samples

[Field no. of specimen, M-155-25. J. G. Fairchild, analyst]

	Thickness		Sample no. and length	$(AlFe)_2O_3$	F	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Feet	Inches					
Shale, brown, weathering to powdery yellowish material	0	7					
Phosphate rock, gray to brown, fine-textured, thin-bedded, much-broken	0	10	Sample 1 (2 ft)	2.32		34.85	76.10
Phosphate rock, fine-textured; beds ½ to 1 in. thick, much broken	0	10					
Phosphate rock, fine-textured; beds about 1 in. thick; broken pieces and slabs	1	0					
Phosphate rock, similar to that just above	0	7½	Sample 2 (2 ft, disregarding sandstone).	3.30	1.30	23.30	50.90
Sandstone, brown, fine-textured, yellowish; weathers to yellow powder	0	2					
Phosphate rock, bluish-gray; beds about 1⁄16 to 1 in. thick, much broken	2	4	Sample 3 (1 ft 7½ in.).	1.30		35.46	77.42
Sand, light-colored; nearly pure quartz; probably weathered or leached from Wells formation							
Broken material at south end of trench (duplicating parts of samples 1 and 2)			Sample 4 (2 ft)	3.54		28.94	56.64

The shattered condition of the phosphate in the trench in sec. 29 is rather characteristic of the zone in which it occurs, for at numerous places there are evidences of slipping or faulting in the phosphate beds. It is probably best, therefore, to assume a thickness of only 2 ft for the main phosphate bed in that zone. The depth limit for material of this thickness and of 70-percent grade is 1,000 ft. The same depth limit has for similar reasons been assigned to the phosphate band that enters sec. 30 from the northwest. The phosphate in the prospect in sec. 33 is about 5½ ft thick and averages 67.2 percent in content of $Ca_3(PO_4)_2$. The depth limit for this material and thickness under current regulations is about 4,000 ft.

Tonnage estimates.—If the depth limit of 1,000 ft is applied to the structure section *A–A′* (pl. 2) at the point where the westernmost phosphate bed reaches the surface, the dip of 50° there shown would cause the phosphate bed to extend westward beneath the surface about a quarter of a mile before the indicated depth is reached. A surface strip about a quarter of a mile wide and lying west of the phosphate outcrop is accordingly used in estimating the available tonnage of phosphate in the westernmost belt and in designating the ground to be classified as phosphate land. The width of this belt is broadened a little southeastward to allow for changes in dip and for faulting. On this basis, the area of the phosphate-bearing strip, from the point where it enters the township to the place where it is cut off at the south, is about 250 acres.

The second phosphate-bearing belt, which begins at the northwest in sec. 19, is crossed within the township by the line of structure section *A–A′* and, nearly half a mile south of the township, by that of section *B–B′* (pl. 2). Using the methods described and a depth limit of 1,000 ft, the area along the phosphate outcrop selected for tonnage estimates comprises 470 acres. This land is taken about equally east and west of the phosphate outcrop because the westerly dip of the formations indicates that the phosphate beds are overturned and extend westward beneath the Wells formation for a maximum distance of about 900 ft at the assumed depth limit. The strip of land east of the phosphate outcrop, though underlain by beds stratigraphically higher than the phosphate, may not be underlain by the phosphate itself because of the overturned dip just mentioned. However, the eastward turn of the dip suggested by the structure section may take place at a point nearer the surface than that indicated in the section. This would cause the phosphate beds to underlie some of the surface east of the phosphate outcrop. To provide for this contingency, the area used in computing tonnage is extended to the east boundary of the Rex chert member. As only 2 ft of phosphate is included in the computation, it is believed that the assumed acreage will prove to be conservative.

The third phosphate-bearing belt in secs. 33 and 34 is crossed by the line of structure section *B–B′* (pl. 2). This belt is underlain by the middle branch of the Bannock overthrust, which there has been estimated graphically to have an average southwesterly dip of about 18°. The quality and thickness of the material exposed in the Survey cut in the SE¼ sec. 33 would, as stated, justify a depth limit for classification purposes of about 4,000 ft, but the presence of the fault makes it doubtful if any phosphate is preserved at depths greater than 1,000 ft. For purposes of classification and of tonnage estimate, the entire area underlain by the Phosphoria formation as exposed at the surface is considered phosphate bearing. All of it within this township appears to fall within the 1,000-ft depth limit. The portion of this belt included in T. 1 S., R. 39 E., covers approximately 160 acres.

In addition to the phosphate belts described, there are two isolated areas underlain by the Rex chert member of the Phosphoria formation, but without any exposure of the phosphate shales. The first of these, in secs. 20, 21, 28, and 29, comprises about 60 acres and the second, in the NE¼ sec. 32, about 10 acres. These two areas should probably be included in the tonnage estimates and the classification.

The total area available for tonnage estimates, according to the figures given, is 950 acres. Using previous methods of computation (Mansfield, 1927, p. 220), the available tonnage of phosphate in T. 1 S., R. 39 E., is estimated at 3,325,000 long tons, if the beds are considered as horizontal. Actually, they dip at different angles, so that such an estimate should ordinarily be increased accordingly. On the other hand, the faulting and other uncertainties are factors that may make the available tonnage less than would be calculated on the basis of dip. It is believed, therefore, that the estimate as given is fair and conservative. Phosphate classification is not ordinarily applied to units smaller than 40 acres; the area classified, which follows the 40-acre subdivisions, is therefore considerably larger than the average used in estimating tonnage—2,200 acres.

T. 2 S., R. 39 E.

LOCATION

The two northern tiers of sections in T. 2 S., R. 39 E., and part of the third tier lie in the south-central part of the Ammon quadrangle; the remainder of the township is in the north-central part of the Paradise Valley quadrangle.

ACCESSIBILITY

The township is about 18 miles due east of Blackfoot, the nearest shipping point on the Oregon Short Line Railroad. The distance by road, however, is greater; there are no improved roads or highways, and the township is relatively inaccessible except by pack train, though the northern part is crossed in places by the Wolverine Creek road, which connects Blackfoot with Willow Creek valley and regions to the east, and the central part of the township is reached by a road up Cedar Creek. This road formerly connected eastward with Willow Creek valley by way of Mill Creek valley, but on the east side of the mountains it is now impassable for vehicles. There is also a road which passes within about 2 miles of the southwest corner of the township and connects Blackfoot with Soda Springs by way of the Blackfoot Dam. There are trails or poor roads in most of the canyons.

SURFACE FEATURES

The township lies in the heart of the Blackfoot Mountains and is relatively rugged. The upper slopes are parts of one or more old erosion surfaces developed on rocks of unequal hardness and have rather smooth contours except where the rocks are hard and ridges have been formed. These older surfaces are submaturely dissected by relatively deep and sharp-featured canyons, so that the maximum relief is about 2,000 ft and some of the canyons are as much as 1,250 ft deep. The canyons are generally steep-sided and more or less covered with timber and vegetation; exposures, except locally, are poor. On the ridges, however, there are considerable exposures of bare rock. The drainage is all tributary to the Snake River, but on the eastern side of the township the receiving tributary is Willow Creek, whereas on the west and south Wolverine and Cedar Creeks and the Blackfoot River each receive an appropriate share of the drainage. The principal divide, which is also the crest of the Blackfoot Mountains, is somewhat irregular but passes southward approximately through the middle of the township.

GEOLOGY

The older rocks of the township are of Carboniferous age, and with considerable Tertiary cover they occupy the southwestern part of the township. The northeastern half is underlain by Mesozoic rocks ranging in age from Lower Triassic to Cretaceous. A few patches of rhyolitic rocks lie here and there upon the higher hills. The pre-Tertiary rocks have all been folded and faulted to a considerable degree; in fact, the township is transversed by the fault zone of the Bannock overthrust and thus contains numerous rock slices heaped one against another northeastward. The rock folds show a similar tendency and are in general inclined northeastward also, but they have been broken and displaced by the faulting. Most of this faulting has been associated with the overthrusting, but some of it is normal. The details of the structure from north to south are set forth in the geologic maps and in structure sections *B–B′*, *C–C′*, and *D–D′* in the Ammon quadrangle and *E–E′* to *I–I′* in the Paradise Valley quadrangle (pl. 2). The phosphate beds are involved in some of these structures and have been squeezed and moved in ways that have affected their quality and workability.

PHOSPHATE DEPOSITS

Location.—In the Ammon quadrangle there is a small area of the Phosphoria formation in the northern part of sec. 6 which represents part of a band that enters the township from the north and is cut off by a fault within a short distance after crossing the boundary A second band which enters the northwestern part of sec. 5 continues irregularly southward to the middle of sec. 17, where it is cut off by an oblique fault. In the northern parts of secs. 2 to 4 there is a roughly triangular area, underlain by the Rex chert member of the Phosphoria formation, that constitutes part of an east-west phosphate-bearing band lying mostly in the adjoining township. There is also a sliver of phosphate along a fault line in the SE¼ sec. 7. In the Paradise Valley quadrangle, a closely folded anticline that carries phosphate on its flanks extends in a curving course from sec. 16 into secs. 21 and 22. This has been broken and offset by several faults.

Character.—The Phosphoria formation in T. 2 S., R. 39 E., especially in sec. 16, and its vicinity, is very much faulted and broken. The Rex chert member in this section presents a quartzitic facies not hitherto recognized in this part of Idaho but observed on the west side of the Teton Basin farther north. A few prospects had been dug in the Rex chert member in sec. 16 and its vicinity, some apparently for coal and others for iron. No prospects had been opened in the phosphate shale member, however, and there were no natural exposures of the shales aside from the usual belts in which scattered float fragments of phosphate rock lie on the surface. The Survey party dug a trench in the NW¼ NW¼ sec. 22 on the north side of the anticline mentioned. The strike of the Wells formation at this locality was N. 72° W. and the dip 73° N. The trench was dug at the north edge of the Wells ledge and at right angles to the strike. It was 15½ ft long and 2 ft wide and had a maximum depth of 6 ft 4 in. The measurements made in the trench and analyses of the samples taken are given in the accompanying table.

Phosphatic shales cut by trench in NW¼NW¼ sec. 22, T. 2 S., R. 39 E., Paradise Valley quadrangle, with partial analysis of samples

[Field no. of specimen, M-108-25. J. G. Fairchild, analyst]

	Thickness		Sample no. and length	$(AlFe)_2O_3$	F	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Feet	Inches					
Shale, brown, slightly phosphatic; not measured							
Phosphate rock, gray, finely oolitic, in beds as much as 1½ in. thick	1	0					
Clay, yellow, slightly phosphatic; shear zone	0	1					
Phosphate rock, sheared; broken pieces with calcareous coatings and seams	0	10					
Sandstone, brown, very fine grained, slightly phosphatic	0	8					
Phosphate rock, broken, sheared	2	0	Sample 1	4.60		18.62	40.66
Do	1	2	Sample 2	5.34	0.50	16.33	35.66
Same as two units just above but representing selected material (freer from dirt)			Sample 3 (1 ft 5 in.)	3.38		30.58	66.80

A sample of float phosphate taken from the opposite flank of the anticline, about 750 ft southwest of the trench, upon analysis showed 37.15 percent P_2O_5, equivalent to 81.10 percent $Ca_3(PO_4)_2$. Its iron and alumina content was 1.84 percent. Vanadium oxide was absent, but the sample contained 1.57 percent fluorine. This is remarkably high grade material.

Another sample of phosphate float, which came from the small faulted area in the NW¼ sec. 17, contained only 20.45 percent P_2O_5, equivalent to 44.65 percent $Ca_3(PO_4)_2$. Its iron-alumina and fluorine content were 1.70 and 1.00 percent, respectively, and it contained no vanadium oxide.

The Survey prospects in secs. 29 and 33, T. 1 S., R. 39 E., have been discussed in the description of that township.

In view of the general disturbance of the phosphate beds in this township and of the somewhat conflicting evidence afforded by the samples collected, it seems probable that no thick beds of high-grade phosphate are present. However, the high-grade float sample mentioned and the results of the prospecting in sec. 33, T. 1 S., R. 39 E., suggest that better material than that actually found in the trench is probably present. For purposes of computation, it seems safe to assume the presence of at least 2 ft of phosphate of 70-percent grade.

Tonnage estimate.—Under current regulations for phosphate classification, the depth limit for a bed of the thickness and quality named is 1,000 ft. Applying this limit to the available geological structure sections, the following acreages to be utilized in the computation of reserve tonnages are obtained. For the northwest belt extending from sec. 5 to sec. 17, the figure is 530 acres. As in the estimate for this belt in T. 1 S., R. 39 E., allowance is made for the overturned northwesterly dip and the possibility that the eastward change of dip below ground may take place at shallower depths than those indicated by the structure sections. The area of Rex chert in secs. 2 to 4 comprises about 120 acres, beneath which phosphate may be present within depth limits if not cut out by faulting. The broken anticlinal area in secs. 16 to 22 contains about 380 acres of possible phosphate land. Not counting the two faulted slivers of phosphate in the NW¼ sec. 17 and SE¼ sec. 7, which probably contain little if any recoverable phosphate, the total phosphate-bearing area available for tonnage computation is 1,030 acres. According to previous methods of computation (Mansfield, 1927, p. 220), such an area would contain 3,500,000 long tons of phosphate rock, if the beds are considered horizontal. Although the beds actually have different dips, which would tend to increase the tonnage estimates, any such increase is doubtless offset by the effect of the structural disturbances to which the beds have been subjected. Thus the figure given is regarded as conservative. As it is not the usual practice in phosphate classification to consider legal subdivisions smaller than 40 acres, the actual acreage classed as phosphate bearing is greater than that used as the basis for tonnage computation.

T. 3 S., R. 40 E.

GEOLOGY

The Willow Creek lava field is composed of basalt. The Blackfoot Mountains constitute a broken anticlinal ridge with a core of Mississippian rocks (Brazer limestone) flanked at the southeast by Pennsylvanian rocks (Wells formation) and at the southwest by Pennsylvanian to Triassic rocks (Wells formation to Thaynes group), much faulted and containing minor folds in the Phosphoria formation. From the NW¼ sec. 17 to the northwest corner of the township, Jurassic rocks are exposed, apparently by the unroofing through erosion of a thrust block of which the older rocks named form a part. This thrust fault is here called the west branch of the Bannock overthrust. Paradise Valley is underlain by beds of the Salt Lake formation (Pliocene ?) and associated rhyolitic rocks, which are themselves overspread by basalt and more or less concealed by hill wash.

PHOSPHATE DEPOSITS

Phosphate beds are exposed at several places in secs. 29 and 32 in tiny synclines or downfaulted blocks, which trend generally northeastward and terminate against northwestward-trending faults. Phosphate float collected from one of these localities in south-central sec. 32 yielded 32.95 percent P_2O_5, equivalent to 71.83 percent $Ca_3(PO_4)_2$ with only 1.63 percent $(AlFe)_2O_3$ and 0.10 percent fluorine. Phosphate may underlie the fault wedges of the Woodside shale in secs. 32 and 33, but if so, the amounts present are probably not large and the rock is likely to be much broken.

Phosphate may be present east of exposures of the Wells formation in sec. 34 and northwestward, but its position would have to be determined by boring through basalt. Similarly, it may occur in a corresponding position beneath Paradise Valley in secs. 19, 30, and 31, but here again its location must be determined by boring. At the actual exposures the quantity present is negligible, a few carloads at most.

T. 4 S., R. 40 E.

LOCATION

T. 4 S., R. 40 E., in Bingham County, Idaho, lies mostly in the Paradise Valley quadrangle but includes a 2-mile strip of the adjoining Cranes Flat quadrangle. The south line of the township is the county line.

ACCESSIBILITY

The township is 25 miles or more from a railroad but is connected by fair automobile roads with Blackfoot, Fort Hall, and Soda Springs, shipping points on the Oregon Short Line Railroad.

SURFACE FEATURES

The eastern part of the township, with altitudes of 6,500 to 6,700 ft, is occupied chiefly by parts of the Willow Creek and Blackfoot lava fields, which are basalt-covered areas. The central and southwestern parts, with altitudes ranging up to 7,180 ft, are crossed by slightly divergent ranges of the Blackfoot Mountains. Paradise Valley, which heads in secs. 26 and 35 and has an altitude of 6,300 to 6,400 ft, lies between these ranges and extends northwestward beyond the township corner. The Blackfoot River reservoir covers the southeast corner; the Blackfoot River touches the southwest corner, and its tributaries drain the southwestern half of the township. Wilson Creek drains the east-border region southward to the reservoir. The northeastern part of the township contains the headwaters of Willow and Meadow Creeks; Brush Creek, a tributary of the Blackfoot River, drains Paradise Valley.

GEOLOGY

Paradise Valley and the two lava fields are underlain by basalt. The eastern range of the Blackfoot Mountains is generally anticlinal in structure, with a core of Mississipian limestone (Brazer) flanked by Pennsylvanian to Triassic rocks. This fold is believed to be the northwest extension of the Snowdrift anticline, traceable for 50 miles or more to the southeast. No rocks younger than Wells (Pennsylvanian) are exposed on the east side of the fold. On the west side a window in the Bannock overthrust exposes a faulted complex including rock wedges and slices ranging in age from Brazer limestone to Thaynes group. Phosphate shales are caught in a tiny syncline or downfaulted area at the township line in the NE¼ sec. 5.

The western range contains an anticline with a core of the Wells formation flanked at the southwest by the Phosphoria formation, against which are downfaulted, deeply folded Triassic rocks (structure section *O–O′*, pl. 2). Along the east side of the range the older rocks are concealed by basalt and hill wash. The area between the two ranges is probably underlain by older rocks (Brazer ?) at the head of Paradise Valley and by successively younger rocks for a certain distance northwestward, as the folds at least in the western range pitch in that direction. It is thought that a concealed normal fault, forming the southwest boundary of the horst that contains the main ridge of the Blackfoot Mountains, passes down the northeast side of Paradise Valley from the NW¼ sec. 22. This is perhaps the continuation of the Enoch Valley fault of the Cranes Flat quadrangle (Mansfield, 1927, pl. 2).

PHOSPHATE DEPOSITS

With the exception of the small area in sec. 5, no phosphate deposits are exposed in the eastern range, and the Triassic rocks northward from sec. 16 are so broken by faults as to make doubtful the existence beneath them of minable phosphate. The presence and position of phosphate beneath Paradise Valley and along the east base of the Blackfoot Mountains could be determined only by boring through basalt and other rocks. A well-defined band of phosphate extends from the NW¼NE¼ sec. 2, T. 5 S., R. 40 E., northwestward through the SW¼ sec. 35 and the SW¼ sec. 34, T. 4 S., R. 40 E., to the NW¼ sec. 29. It was prospected in 1916 in the SE¼SE¼ sec. 34 with the results shown in the accompanying table.

Phosphatic shales cut by trench in SE¼SE¼ sec. 34, T. 4 S., R. 40 E., Idaho

[Field no. of specimen, M-129-16. R. M. Kamm, analyst]

	Thickness		Sample no. and length	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Feet	Inches			
Clay, sandy, yellow; top not exposed.					
Phosphate rock, black, finely oolitic, shattered.	1	3			
Phosphate rock, brownish-gray, somewhat shaly, finely oolitic.	2	0	Sample 1	28.66	62.7
Phosphate rock, thin-bedded, shaly, finely oolitic; shatter zone.	2	0			
Phosphate rock, medium-oolitic, brownish-gray, shaly.	1	4	Sample 2	25.03	54.6
Phosphate rock; shatter zone; brown; shaly fragments.	1	10			
Limestone, brown	0	2½			
Phosphate rock, brownish-gray, shaly.	0	3½			
			Sample 3 (about 20 in.).	29.82	65.1
Phosphate rock, brownish-gray, thin-bedded, partly shaly, medium- to finely oolitic.	5	2	Sample 4 (about 20 in.).	25.45	57.9
			Sample 5 (about 20 in.).	21.73	47.4
Phosphate rock; beds 1½ in. thick; brownish-gray, medium- to finely oolitic.	0	5	Sample 6	33.22	72.5
Phosphate rock, thin-bedded, brownish-gray, finely oolitic.	1	3			
Shatter zone; mostly phosphate.	0	8			
			Sample 7 (22 in.).	31.33	68.3
Phosphate rock, brownish-gray; beds ¼ to ½ in. thick; finely oolitic.	3	8	Sample 8 (22 in.)	30.20	65.9
Limestone, brown, weathered.	0	4½			
Phosphate rock, brownish-gray, thin-bedded, finely oolitic.	1	4	Sample 9	28.28	61.8
Limestone, dark brownish-gray.	2	0			
Phosphate rock, brownish-gray, shaly, finely oolitic.	2	0	Sample 10	28.33	61.8
Phosphate rock; beds ¼ to 1 in. thick; dark gray, finely oolitic.	0	6	Sample 11	30.03	65.5
Phosphate rock, brecciated and shattered, weathered almost claylike.	0	7			
			Sample 12 (about 21 in.).	32.92	71.8
Phosphate rock, black with yellow specks; coarsely oolitic; beds ¼ to 1 in. thick.	5	5	Sample 13 (about 21 in.).	33.34	72.7
			Sample 14 (about 21 in.).	30.21	65.9
Phosphate rock, shaly, finely oolitic, and brown shale.	1	0			
Limestone, gray; top of Wells formation, not measured. Strike N. 41° W., dip 62° S.					

Strategically above the section just given but 138 ft farther down the slope, corresponding to about 112 ft above the highest bed included in the section, is a bed of hard phosphate 10 in. thick that forms a ledge. Sample 15, taken from this ledge, yielded 20.70 P_2O_5, equivalent to 45.2 percent $Ca_3(PO_4)_2$. The phosphatic shales here, according to the data given, are at least 145 ft thick.

The section described is unusually rich in phosphate, containing at least 31 ft 6 in. of phosphate rock, of which 24 ft 6 in. was sampled and found to average about 63 percent $Ca_3(PO_4)_2$. One of the richest beds is a few feet above the middle of the trenched portion of the section. It is 1 ft 8 in. thick and averages 72.5 percent $Ca_3(PO_4)_2$. Another bed just above is thicker but of poorer quality; it is 5 ft 2 in. thick and averages 56.8 percent $Ca_3(PO_4)_2$. The bed most important commercially is near the base and is 5 ft 5 in. thick; it averages 70.1 percent $Ca_3(PO_4)_2$. Besides the beds mentioned, there are five others ranging from 13 in. to 3 ft 8 in. in thickness and from 61.8 to 67.1 percent (average of samples 7 and 8) $Ca_3(PO_4)_2$.

The shatter zones and the proximity of the fault already mentioned suggest that some of the phosphate beds may be repeated, but the lithologic details given indicate sufficient differences to show that this is probably not so.

Ten of the samples taken from the trench described were divided into four sets of composites and tested for iron and alumina. The first composite, including samples 3, 4, and 5, yielded 0.51 percent Fe_2O_3 and 2.56 percent Al_2O_3. As the combined amount of these two substances present was less than the limit usually allowed (p. 78), the iron and alumina were not separately determined for the remaining composites, but were grouped in a single determination for each. Thus the second composite, including samples 7 and 8, yielded only 1.96 percent iron and alumina together; the third composite, including samples 10 and 11, yielded 1.92 percent; and the fourth composite, including samples 12 to 14, yielded 1.19 percent.

For a phosphate bed of the thickness and quality of the main bed here shown, the depth limit is 4,500 ft. The phosphate in the belt mentioned is cut off by a fault considerably above that depth. The Triassic beds to the west of the fault are deeply folded, so that the phosphate, if present in normal position, would be near or below the depth limit. There is also the probability that the lower parts of the folds may be cut off by the Bannock overthrust, so that any phosphate formerly present has been lost.

For these reasons, the actual phosphate-bearing area is limited to approximately 360 acres, whereas the area classified in legal subdivisions as phosphate land comprises 960 acres. On the usual basis of computation, the 360 acres would contain approximately 6,931,000 long tons of phosphate if the beds were horizontal. By allowing 60° for the dip, this estimate would be increased to 14,208,000 long tons.

LIMESTONE

Limestone is one of the most abundant mineral resources of the Ammon and Paradise Valley quadrangles. It was deposited at intervals from Mississippian time to the Quaternary. There are many textural varieties, and they range from rocks that might be classed as calcareous shale and sandstone to nearly pure limestone. None could be classed as marble.

CARBONIFEROUS LIMESTONES

The Carboniferous limestones are better adapted for general commercial purposes than most of the others. The Madison and Brazer limestones and the lower part of the Wells formation contain many beds that appear to be relatively pure limestone. The distribution of these formations in the Ammon and Paradise Valley quadrangles is shown in plate 1. On the whole, the beds of the Brazer limestone appear to be more nearly pure than the others, though this formation includes beds of sandstone and possibly shale in addition to limestone. The most promising beds are apparently the more massive ones, such as those exposed in lower Wolverine Creek and Jones Creek canyons and in the Blue Ridge northeast of High Basin. The exposures in the canyons of Wolverine and Jones Creeks are nearest the railroad. Little use of this rock has been made so far, although an old limekiln was seen in Wolverine Creek canyon in the SE¼SW¼ sec. 2, T. 2 S., R. 38 E. The Brazer limestone is the source of the lime formerly burned at the limekilns at Montpelier and is locally reported to have yielded a good product. An analysis made in the Geological Survey laboratory of an average sample from the Montpelier quarry is given in the following table. The sample represents the 20 ft of thick-bedded, broken, calcite-seamed rock exposed along the quarry wall.

Analysis of limestone from quarry at Montpelier, T. 13 S., R. 44 E., Idaho

[W. C. Wheeler, analyst]

Silica (SiO_2)	2.55
Alumina (Al_2O_3)	.43
Iron oxide (Fe_2O_3, total)	.44
Magnesia (MgO)	1.35
Lime (CaO)	51.96
Carbon dioxide (CO_2)	41.08
Loss on ignition less CO_2	1.80
	99.61

No samples for analysis were collected from the Ammon and Paradise Valley quadrangles, but the massive beds of the Brazer limestone appear very similar lithologically throughout much of southeastern Idaho and it is thought that the analysis gives a fair idea of what might be expected of the rock in this area. The Brazer limestone is topographically conspicuous and forms high ridges or striking gateways in canyons (fig. 11).

TRIASSIC LIMESTONES

The upper beds of Woodside shale and the lower beds of the Thaynes group locally consist of relatively pure limestone in quantities apparently sufficient for commercial purposes. The localities where these rocks occur, however, are comparatively remote from railway transportation and from settlements, though they are accessible to some roads. No tests or analyses of these limestones have yet been made.

The Portneuf limestone of the Thaynes group has massive beds that are exposed in T. 4 S., R. 38 E., and T. 2 S., R. 39 E., but these are probably too siliceous to have commercial value.

JURASSIC LIMESTONES

The Twin Creek limestone is a highly calcareous formation, but most of the beds are too shaly and the more massive beds are too impure for commercial use.

CRETACEOUS LIMESTONES

The Peterson limestone has massive beds of fresh-water limestone that are relatively pure and sufficiently abundant for possible local use. They are remote from railroads and settlements but accessible by road. They are exposed in the southeastern part of T. 1 S., R. 39 E., and some adjoining areas. No tests or analyses of these limestones have yet been made.

TERTIARY LIMESTONES

The Salt Lake formation contains marls and limestones whose commercial value has not been investigated, but some of them might possibly be utilized. Beds of these rocks occur at the narrows of the Port-2 miles south of the Paradise Valley quadrangle, and in neuf River in secs. 15 and 22, T. 5 S., R. 38 E., 1 or sec. 3, T. 5 S., R. 39 E.

QUATERNARY LIMESTONES

The beds of travertine in sec. 32, T. 1 S., R. 39 E. and sec. 33, T. 2 S., R. 39 E., are too small and possibly too impure to be utilized, but in some parts of the country travertine is worked for ornamental stone or as a source of lime for cement.

ROAD METAL

Road metal is abundant in the Ammon and Paradise Valley quadrangles, but comparatively little use of it has yet been made. The more accessible materials suitable for road building are Paleozoic limestones and basalt, both of which are desirable but require crushing. The Rex chert member of the Phosphoria formation, though less accessible, would serve the purpose well. The weak material from the Thaynes group and the Woodside and Twin Creek formations, which is locally used in many parts of the general region, is available in both quadrangles, but it is better adapted for yatching and repairs than for permanent road construction.

BUILDING STONE

None of the rocks exposed in the Ammon and Paradise Valley quadrangles have been used to any extent for building, though a small quarry was opened many years ago in the rhyolitic tuff in the NW¼NE¼ sec. 21, T. 2 N., R. 39 E., presumably for this purpose. Very little, if any, of the rock was actually used, however. The Brazer limestone contains thick beds of uniform character, relatively free from chert and other impurities, that might be worked into blocks suitable for building. Some of the welded rhyolitic tuff could perhaps be used also. Such rock, though not from this area, has been used for building in Pocatello, Blackfoot, Idaho Falls, and Rexburg. Basalt, also from outside this area, has been used in constructing a few buildings. Thus Loughlin (1914, p. 1379) notes:

The Zion Cooperative Mercantile Institution building at Idaho Falls, built in 1884, has a front entirely of basalt in dressed blocks, with both rock face and finely tooled surface; some blocks are 6 feet long. The stone is of nearly black color and contains several small to irregularly spaced vesicles. It gives a somber appearance but shows no weathering effects after 30 years of exposure, and door sills where loaded trucks have been passing back and forth have not suffered any noticeable abrasion. Basalt has also been used, and with good effect, in the base of the Methodist Episcopal church at Lewiston, erected in 1907. Here the blocks are mostly small, with rock face exposed.

VOLCANIC ASH

Volcanic ash is abundant in the northern and northwestern parts of the Ammon quadrangle and in the south-central part of the Paradise Valley quadrangle. It is exposed in many places, notably in secs. 16, 21, 28, 32, and 33, T. 2 N., R. 39 E.; in secs. 22 and 26, T. 1 N., R. 38 E.; and in sec. 34, T. 4 S., R. 39 E. (fig. 21). It is usually well bedded and light gray in color. It commonly contains pellets of pumice ranging up to three-quarters of an inch in diameter (see section on p. 55) and locally as much as several inches. Its thickness is variable and ranges up to perhaps as much as 200 ft. No study of its character has been made, but it would seem to have possibilities for economic use in abrasive powders and soaps, acoustic plasters, and concrete aggregates. One concern in Idaho Falls has been using it for aggregates in concrete blocks.

COAL

In 1917 the author examined some coal prospects and mines in southeastern Idaho. One of these, known as the "Cloward entry" (Mansfield, 1920b, pp. 132–133), is in the Ammon quadrangle.

In the SE¼ sec. 6, T. 1 N., R. 40 E., on the hill slope a few rods back of the house of J. A. Cloward, is an entry that was opened in the winter of 1916. It is about 100 feet long and trends about N. 50° E., curving slightly toward the south. The "coal" consists of the more carbonaceous portions of earthy and carbonaceous shaly lenses that wedge in and out and have a white powdery substance in the partings. Nine layers were counted at one place, ranging in thickness from about one-sixteenth of an inch to 18 inches. It is doubtful, however, if enough fuel of this character can be obtained for local needs without involving prohibitive expense.

When the locality was revisited in 1928, Cloward's ranch buildings had disappeared and the prospect had caved. Two or three other caved prospects were noted in similar rocks in the northeast quarter of the same section.

NITRATE

A nitrate prospect visited in 1925 is located in Jones Canyon in the NE¼NW¼ sec. 13, T. 2 S., R. 38 E., in the Ammon quadrangle. The canyon at this place is cut in massive beds of Carboniferous (Brazer) limestone. A cave at the bottom of the canyon on the south side is about 20 ft wide at the entrance but narrows to about 4 ft about 25 ft from the front. A deposit of guano containing about 6 to 8 cu ft of material was noted. A nitrate-bearing breccia, 2 or 3 sq ft in area and about 6 in. thick, adhered to the side of the cave near the mouth. This was practically all the nitrate in sight, though originally 6 to 8 sq ft of the wall appeared to have been covered by the deposit. Much of it had been removed in the course of prospecting. This deposit is a small example of the cave-type nitrate deposits which are common in many parts of the United States but have no prospective commercial value (Mansfield and Boardman, 1932).

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