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GEOLOGY AND MINERAL RESOURCES OF THE RANDOLPH QUADRANGLE, UTAH-WYOMING

BY

G. B. RICHARDSON

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GEOLOGY AND MINERAL RESOURCES OF THE RANDOLPH QUADRANGLE, UTAH-WYOMING

By G. B. Richardson

ABSTRACT

This report briefly describes the geology and mineral resources of the Randolph quadrangle, which covers an area of 892 square miles in northeastern Utah and southwestern Wyoming.

The quadrangle lies in the zone of mountains and intermontane lowlands of north-south trend in the southwestern part of the Middle Rocky Mountains province. It includes part of the Bear River Range, parts of Bear Lake Valley, the Bear River Plateau, the Bear River Valley, and the Crawford Mountains. Altitudes range from 5,924 feet to 9,114 feet above sea level. The climate is semiarid, the average rainfall being about 13 inches, and semifrigid, the mean annual temperature being about 41°. The Bear River Range includes the Cache National Forest. At the higher altitudes it supports a growth of fir, spruce, and pine trees, but the greater part of the quadrangle is covered with sagebrush and allied desert plants.

The rocks exposed consist of a great mass of sedimentary beds, which aggregate more than 25,000 feet in thickness. They include 7 formations of Cambrian age, 3 Ordovician, 1 Silurian, 2 Devonian, 4 Carboniferous, 3 Triassic, 2 Jurassic, 1 Jurassic and Cretaceous (?), 1 Cretaceous, and 2 Tertiary. In accord with the general structure of the middle Rocky Mountain region the Paleozoic and Mesozoic rocks are folded into northward- and southward-trending flextures, which have been cut by normal faults and dislocated into blocks overthrust from the west. The Tertiary beds are almost horizontal or dip east at low angles, overlying the folded older rocks with pronounced unconformity.

The mineral resources include phosphate rock, limestone, quartzite, and water, but, owing to the remoteness of the area from markets, only the water is utilized at present. Phosphate rock, which formerly was mined in a small way, constitutes a valuable reserve. Enormous quantities of limestone and quartzite are available. Lead and copper occur locally but have not been found in commercial quantity.

INTRODUCTION

The Randolph quadrangle, situated in Rich and Cache Counties, Utah, and in Uinta and Lincoln Counties, Wyo., has an area of 892 square miles and extends from latitude 41°30′ to 42° N., and from longitude 111° to 111°30′ W. This area is in the middle Rocky Mountains province and includes part of the Bear River Range, the Crawford Mountains, and the southern part of Bear Lake. It is crossed by the Bear River. Altitudes range from 5,924 feet above sea level on the surface of Bear Lake to 9,114 feet on the Bear River Range. The climate is semiarid, the average annual rainfall being about 13 inches, and semifrigid, the mean annual temperature being about 41° F. There are large differences in temperature between day and night and between summer and winter. The Bear River Range includes the Cache National Forest. At the higher altitudes it supports a growth of fir, spruce, and pine trees. The greater part of the quadrangle, however, is bare of trees, and most of the surface is covered with sagebrush and allied desert plants. The area is thinly settled and contains only four small towns, Randolph and Woodruff, in the Bear River Valley, and Garden City and Laketown, on Bear Lake. The land is utilized principally for grazing; dairying and farming in a small way by irrigation are accessory industries. For several years phosphate rock was mined, and it constitutes the principal mineral reserve. The quadrangle is not traversed by a railroad. Evanston, Wyo., on the Union Pacific Railroad, 15 miles to the southeast, and Montpelier, Idaho, on the Oregon Short Line Railroad, 22 miles to the north, are the chief transportation centers in the surrounding region. An improved highway connects Evanston and Montpelier by way of Woodruff, Randolph, Laketown, and Garden City, and a highway extends from Garden City southwestward across the Bear River Range to Logan and other towns in Cache Valley. In 1935 a new road connecting Woodruff and Ogden was in course of construction.

The earliest geologic surveys that included this quadrangle were made between 1869 and 1878, when parts of it were examined by Hayden, Peale, and Gannett of the Hayden Survey, and by King, Emmons, and Hague of the Fortieth Parallel Survey.[1] These surveys determined the general character and age of the rocks and served as the chief sources of information concerning the local geology down to the period of the more detailed surveys, which began with Veatch's studies[2] in southwestern Wyoming and followed the discovery of phosphate rock in this region.

The presence of phosphate rock was determined in 1899 as the result of an analysis of a sample from a prospect on Woodruff Creek, 3 miles south of the Randolph quadrangle. Between 1903 and 1906 the discovery of similar deposits in northeastern Utah, southwestern

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[1] U. S. Geol. Survey Terr. 5th Ann. Rept., pp. 100–156, 1872. U. S. Geol. and Geog. Survey Terr., 11th Ann. Rept., pp. 573–710, 1879; 12th Ann. Rept., pt. 2, maps, 1883. U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 326–339, 393–442, atlas, 1877–78.

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

Wyoming, and southeastern Idaho,[3] proved the existence of an extensive phosphate field in the Rocky Mountain region and led to its examination by the Geological Survey. Preliminary statements were published in 1907 and 1908,[4] and a detailed survey, which included part of the Randolph quadrangle, was made by Gale and Richards[5] in 1909. Surveys in Idaho were continued for several years by Mansfield,[6] who prepared an exhaustive report.

In 1912, the writer, assisted by P. V. Roundy, examined the Randolph quadrangle, devoting attention primarily to the rocks lying below the principal phosphate beds, to which particular attention was not given by the parties under Gale and Veatch. Collections of fossils showed the presence of several faunal zones, which necessitated the delimitation of three new formations of Ordovician age, one of Silurian, and one of Mississippian age. It was also shown that instead of one zone of commercial phosphate rock in this area there are two, the lower zone being of Mississippian age, in the Brazer limestone. These results were announced in 1913.[7] Publication of a report on the quadrangle has been delayed by assignment of the writer to other work. In 1935 the area was revisited for a few weeks.

TOPOGRAPHY

The Randolph quadrangle lies in the zone of mountains and intermontane lowlands of north-south trend in the southwestern part of the Middle Rocky Mountains province. (See fig. 1.) It includes the eastern part of the Bear River Range, parts of Bear Lake Valley, the Bear River Plateau, the Bear River Valley, and the Crawford Mountains.

Bear River Range.—The Bear River Range is the northern extension of the Wasatch Range. It includes the upland lying between Cache Valley on the west and Bear Lake Valley on the east and extends northward to the bend in the Bear River near Soda Springs, Idaho. In the Randolph and Logan quadrangles the range is about 20 miles wide and is deeply dissected by the Logan River and Black-

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[3] Jones, C. C., Phosphate rock in Utah, Idaho, and Wyoming: Eng. and Min. Jour., vol. 68, pp. 953–955, 1907; The discovery and opening of a new phosphate field in the United States: Am. Inst. Min. Eng. Trans., vol. 47, pp. 192–216, 1914.

[4] Weeks, F. B., and Ferrier, W. F., Phosphate deposits in western United States: U. S. Geol. Survey Bull. 315–P, pp. 449–462. Weeks, F. B., Phosphate deposits in the Western United States: U. S. Geol. Survey Bull. 340–K pp. 441–448, 1908.

[5] Gale, H. S., and Richards, R. W.: Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430–H, pp. 457–535, 1910.

[6] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927.

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

smith Fork and their branches. The easternmost summits of the range, adjacent to the western border of the Randolph quadrangle, form a curved line of peaks ranging in altitude from 7,500 to 9,114 feet above sea level, which form the boundary between Cache and Rich Counties, Utah. West of this boundary the drainage is tributary chiefly to Blacksmith Fork by way of Curtis, Rock, and Saddle Creeks. On the east, the drainage in the northern part of the quadrangle is tributary to Bear Lake by way of Swan, Garden City, Hodges, and Cheyney Creeks, and the drainage of the Bear River

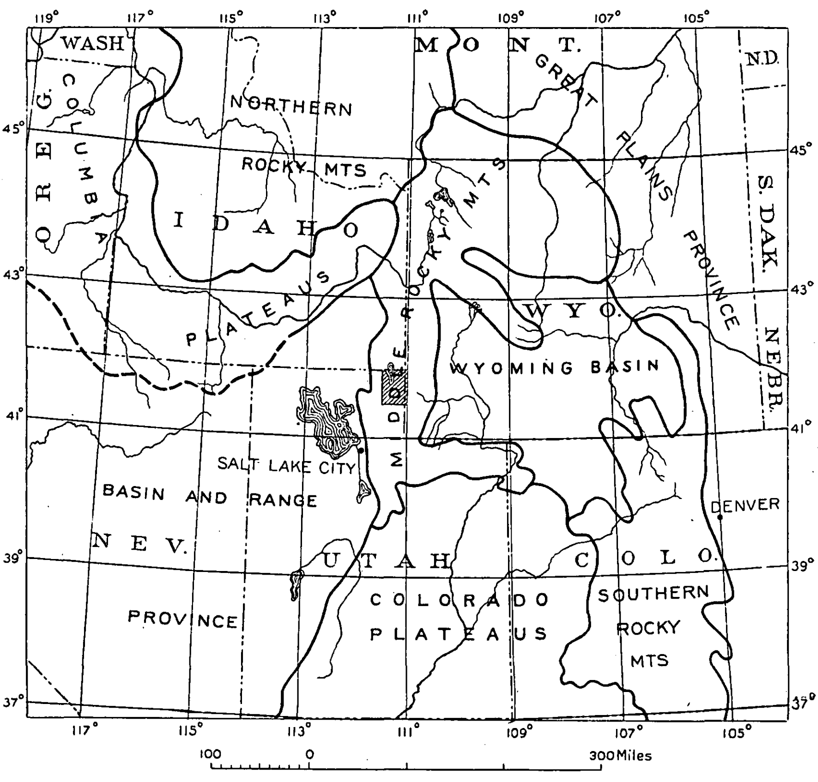

FIGURE 1.—Index map showing physiographic provinces and location of Randolph quadrangle.

Range, in the southern part of the quadrangle, is directly tributary to the Bear River by way of Otter, Randolph, and Big Creeks.

Throughout much of its extent in the Randolph quadrangle the range is capped by flat-lying beds of sandstone or conglomerate of the Wasatch formation, and the surface is open and plateaulike. But streams that have cut through the cap rocks, exposing the underlying tilted Paleozoic sandstones and limestones, occupy narrow canyons. In the northwestern corner of the quadrangle the Wasatch cover has been entirely removed by erosion, and the Paleozoic beds form ledges along the mountain side. (See pl. 2.) Viewed from a distance, the summit of the Bear River Range presents an even sky line that is believed to mark an old erosion surface, which Mansfield has named the Snowdrift peneplain. A less well-defined surface is developed locally about 1,500 feet lower.

Bear River Plateau.—The upland between Bear Lake on the west and the Bear River Valley on the east, and its southern extension, is known as the Bear River Plateau. Its surface is considerably dissected, but the hilltops are flattish or gently eastward sloping, owing to the altitude of the outcropping rocks, chiefly sandstone and conglomerate of the Wasatch formation. (See pl. 4, *A*.) Locally in the valleys adjacent to Bear Lake, where the Wasatch beds have been removed by erosion, thereby exposing steep-dipping Mesozoic and Paleozoic rocks, the topography is rough. The contact of the Wasatch with older formations indicates the character of the pre-Wasatch erosion surface. Altitudes of the contact range from 6,500 to 8,700 feet above sea level. Part of this variation is due to post-Wasatch tilting and differential movements, but local variations ranging from 200 to 700 feet show that this old erosion surface was uneven.

Bear Lake Valley.—Bear Lake Valley is a broad depression extending from the vicinity of Laketown northward to the vicinity of Georgetown, in the Montpelier quadrangle, Idaho, a distance of about 50 miles. The southern end of the valley is occupied by Bear Lake, which is about 19 miles long, and at the Idaho-Utah boundary is 7½ miles wide. In part at least, this valley is of structural origin, and in the Randolph quadrangle is bordered on the east and southwest by normal faults.

In early Quaternary time the level of Bear Lake was higher, as shown by remains of old beaches above the present level of the lake. At several places along the lake front, especially at Garden City and at the mouths of North Eden and South Eden Creeks, well-marked benches indicate former higher levels of Bear Lake. The lower bench is 5 to 10 feet higher than the level of the lake in 1912, and the upper bench is 15 to 20 feet higher. Garden City is built on the upper bench. (See pl. 3.) An indistinct trace of a still higher bench is preserved a little distance from the mouth of Swan Creek, near the level of the irrigation canal, about 75 feet above the lake. At the mouths of North Eden and South Eden Creeks well-developed deltas mark the former higher level of the lake. (See pl. 3, *B*.)

Bear River Valley.—The Bear River rises on the north flank of the Uinta Mountains, in northeast Utah. It follows a circuitous course, flowing northward from Utah to Wyoming, reentering Utah and Wyoming in turn, and then entering Idaho, where it receives the outflow of Bear Lake. Near Soda Springs, Idaho, the river turns southward, flows through Gentile and Cache Valleys, and empties into Great Salt Lake. At the narrows in the southeast corner of the Randolph quadrangle, near the western border of Wyoming,, the Bear River flows in a canyon cut in the Bear River formation. (See pl. 4, *B*.) Thence entering Utah and passing westward around the southern end of the Crawford Mountains, the river flows northward in a meandering course in a flood plain between 2 and 5 miles wide. This part of the valley is under irrigation, and Randolph and Woodruff, the largest settlements in the quadrangle, are situated here.

Crawford Mountains.—The Crawford Mountains, lying north and east of Bear River, form a narrow range about 15 miles long and 1 to 3 miles wide. The summits rise 700 to 1,600 feet above the adjacent lowland, the highest point being 7,993 feet above sea level. The change in trend in the southern part from north-south to northeast-southwest reflects the change in strike of the rocks north and south of a zone of faults that intersects the range between 4 and 5 miles southeast of Randolph. The range is composed of folded and faulted Paleozoic strata. Steeply tilted beds of massive limestone (the Brazer limestone, of upper and middle Mississippian age) form a conspicuous wall along the western front of the mountains. (See pl. 5.)

DESCRIPTIVE GEOLOGY

In the Randolph quadrangle sedimentary rocks of great thickness are exposed, which range in age from Cambrian to Quaternary and aggregate more than 25,000 feet in thickness. This area formed part of the cordilleran geosyncline, an epicontinental marine basin that throughout the greater part of Paleozoic and Mesozoic time was a region of subsidence in which beds of sandstone, shale, and limestone were deposited. The down-warping of the geosyncline, which in general kept pace with the deposition of the sediments, was interrupted at intervals by uplifts. These movements and the corresponding retreats and advances of the sea caused hiatuses and unconformities. Down nearly to the close of the Mesozoic era the movements of the earth were relatively gentle, and the original nearly horizontal attitude of the beds was but little disturbed. At or near the close of the Mesozoic era, however, conditions changed, and during the Laramide revolution the deposition of sediments was succeeded by diastrophism. The Paleozoic and Mesozoic sediments were folded into a series of anticlines and synclines, which locally were overridden by great fault blocks overthrust from the west, and the region was permanently uplifted above sea level. Subsequent deposits were laid down under various continental conditions such as those that produced outwash and fluviatile and lacustrine materials. Small areas of basalt and tuff are the only evidence of igneous activity. Plate 6 shows in columnar section the generalized character, thickness, sequence, and age of the rocks.

STRATIGRAPHY

CAMBRIAN SYSTEM

In this quadrangle the Cambrian system is represented by more than 5,000 feet of strata that are the equivalents of the beds studied by Walcott[8] in the Bear River Range in adjacent areas to the west and north. The formations named by Walcott are present in the Randolph quadrangle, but it was found desirable to recognize two additional units, the Hodges shale member of the Bloomington formation and the Worm Creek quartzite member of the St. Charles limestone.[9] The formations are lithologic units that in general are recognizable by their character and sequence, and the age assignments and correlations have been confirmed through the identification of fossils. The lowest formation, whose base is not exposed, is the Brigham quartzite. In order above it are the massive-bedded Langston limestone; the thin-bedded shaly and richly fossiliferous Ute limestone; the massive-bedded Blacksmith limestone; the Bloomington formation, which consists of fossiliferous thin-bedded limestone and shale; the massive- to medium-bedded Nounan limestone; and, at the top, the St. Charles limestone, which consists of fossiliferous massive limestone, with the Worm Creek quartzite member at the base. The St. Charles is of Upper Cambrian age, and the underlying formations are referred to the Middle Cambrian. Whether the lower part of the Brigham quartzite is Lower Cambrian has not been determined.

BRIGHAM QUARTZITE

The Brigham quartzite was named by Walcott[10] from its occurrence in the vicinity of the town of Brigham, Box Elder County, Utah. The type location is 25 miles west of the southwest corner of the Randolph quadrangle, and correlation has been established by tracing the Brigham quartzite into Walcott's Blacksmith Fork section.

In the Randolph quadrangle the Brigham quartzite crops out in a number of disconnected areas in and contiguous to the Bear River

[8] Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 53, pp. 5–9, 1908; vol. 53, pp. 190–200, 1910; Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 148–153, 1912.

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

[10] Walcott, C. D., op. cit. (Smithsonian Misc. Coll.), p. 8.

Range. The most continuous exposure occurs in a belt about 6 miles long and half a mile wide near the base of the upland west of Garden City. There the quartzite lying at the bottom of the westward-dipping Cambrian section is overthrust along the Bannock fault on westward-dipping Garden City limestone. (See p. 39.) In places along this belt the Brigham quartzite forms bluffs that rise abruptly above softer deposits on the east and descend gradually westward in a dip slope. Two miles south of this outcrop an isolated outlier of quartzite occupies an area of a few square miles. Immediately southwest of Bear Lake and south of Round Valley are two isolated areas of Brigham quartzite that are part of the overridden block, but an extensive overlap of Quaternary and Tertiary deposits conceals the relations. Between 15 and 20 miles south of Round Valley there are two other isolated outcrops of quartzite. At the western border of the quadrangle, in the vicinity of Strawberry Valley, there are small outcrops of quartzite, which can be traced westward into the Brigham quartzite of Walcott's section on Blacksmith Fork.

The Brigham is a massive-bedded fine-grained gray, brown, and pink quartzite, which is remarkably homogeneous over large areas. Locally there are irregularly distributed lenses of conglomerate composed of rounded pebbles of quartz as much as 2 inches in diameter. Thin sections of the quartzite show interlocking quartz grains with little or no interstitial matter which indicates almost complete recrystallization of the original sandstone. Sixteen hundred feet of the Brigham quartzite was measured along the base of the Bear River Range west of Garden City. Walcott reports 2,000 feet at the type locality. In the Randolph quadrangle the base is not exposed.

Fossils are scarce in the Brigham quartzite, and only annelid trails have been found in it in the Randolph quadrangle. Walcott [11] reports that characteristic Middle Cambrian fossils were found in the upper part of the formation west of Liberty, Bear Lake County, Idaho. He considered that the line of separation between the Middle and Lower Cambrian occurs somewhere in the Brigham quartzite, and that the formation probably includes several hundred feet of Lower Cambrian beds.[12] Blackwelder [13] found the Brigham quartzite lying unconformably on pre-Cambrian (?) rocks at Willard, Utah.

LANGSTON LIMESTONE

The Langston limestone was named by Walcott in 1908 from Langston Creek, in the Wasatch Mountains east of Cache Valley.

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[11] Walcott, C. D., op. cit. (Smithsonian Misc. Coll.), p. 9.

[12] Walcott, C. D., op. cit. (U. S. Geol. Survey, Mon. 51) p. 153.

[13] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, p. 523, 1910.

In the Randolph quadrangle the Langston limestone is exposed in several localities, which are separated by areas of overlapping Wasatch beds. The two northernmost outcrops are disconnected parts of a belt of Langston limestone on the east limb of the Fish Haven syncline. West of Garden City the Langston limestone, lying immediately above the Brigham quartzite and below the Ute limestone, crops out in a narrow band about a quarter of a mile wide on the eastern flank of the Bear River Range. It dips northwest at an angle of about 20°. Six miles southwest, at the western border of the quadrangle, the Langston limestone also crops out. The Langston is well exposed in the canyon of Saddle Creek, where it crosses the western border of the quadrangle. There the strata lie almost flat, and about 300 feet of the limestone is exposed. The rocks are traversed by two sets of perpendicular joints striking N. 30° E. and N. 60° W. This outcrop is almost surrounded by Wasatch, but on the south the Langston is overlain in normal sequence by the Ute limestone. Another outcrop of Langston limestone forms a narrow band on the north side of Rock Canyon, at the western brder of the quadrangle, where the limestone lying between the Brigham quartzite and the Ute limestone dips southeast at angles of 30° to 45°.

The Langston limestone (see pl. 7, *A*) is a massive-bedded blue-gray limestone. In the lower part it is notably sandy and grades into the underlying Brigham quartzite. In some places it is coarsely crystalline and in others it is fine-grained. Locally it is spotted white by calcite aggregates. It tends to weather to a brownish tinge unlike any of the other Cambrian formations. Two sets of joints, one parallel and the other perpendicular to the strike, are well-developed in the Langston limestone. A section west of Garden City measured 375 feet in thickness.

Fossils in the Langston limestone are relatively scarce and none were found in the Randolph quadrangle, but in the Blacksmith Fork section Walcott identified a lower Middle Cambrian fauna from this limestone.

UTE LIMESTONE

Ute as a formation name was introduced by the Fortieth Parallel Survey for a series of limestones in the Wasatch Mountains, 2,000 feet thick, which they assigned to the Silurian, but which appear to include the Garden City limestone (Ordovician), and the St. Charles, Nounan, Bloomington, Blacksmith, and Ute limestones of Walcott's 1908 classification. Walcott restricted the name to a zone of thin-bedded limestone and shale, less than 1,000 feet thick, which contains the fossils mentioned by the Fortieth Parallel Survey as characterizing the lower part of their Ute limestone. The name is derived from Ute Peak, in the Wasatch Mountains east of Cache Valley. Walcott introduced the name Spence shale for 30 feet of shale that contains an abundant fauna and occurs at the base of the Ute limestone, the name being derived from Spence Gulch, which is about 5 miles southwest of Liberty, Bear Lake County, Idaho. Walcott's use of these names is followed here, but the Spence shale member, on account of its thinness and the scale of the map, is not mapped separately.

In the Randolph quadrangle, as elsewhere in this region, the Ute limestone consists of a zone of thin-bedded limestone and shale lying conformably between massive limestone formations, the Langston below and the Blacksmith above. The base of the formation is marked by the Spence shale member, but the top is not so clearly shown. The boundary between the Ute and the Blacksmith has been drawn at the change from thin-bedded to massive-bedded limestone. Thus delimited, the Ute limestone is 585 feet thick in Rock Canyon, at the western border of the quadrangle, and 480 feet thick on the eastern flanks of the Bear River Range, west of Garden City.

A complete section of the Ute limestone was not observed in the Randolph quadrangle on account of talus covering, but in places there are excellent exposures of parts of the formation. Thus the Spence shale member is well shown near the top of a hill south of Saddle Creek at the western margin of the quadrangle, in sec. 4, T. 11 N., R. 4 E., where 45 feet of fine-textured fissile drab shale are exposed. Above the Spence shale member the Ute formation consists of thin-bedded limestone, interbedded with argillaceous and calcareous sale, which is usually drab but is locally tinged red or green. West of Garden City, 315 feet above the base of the formation, there is a bed of black oolitic limestone ranging from 3 to 5 feet in thickness.

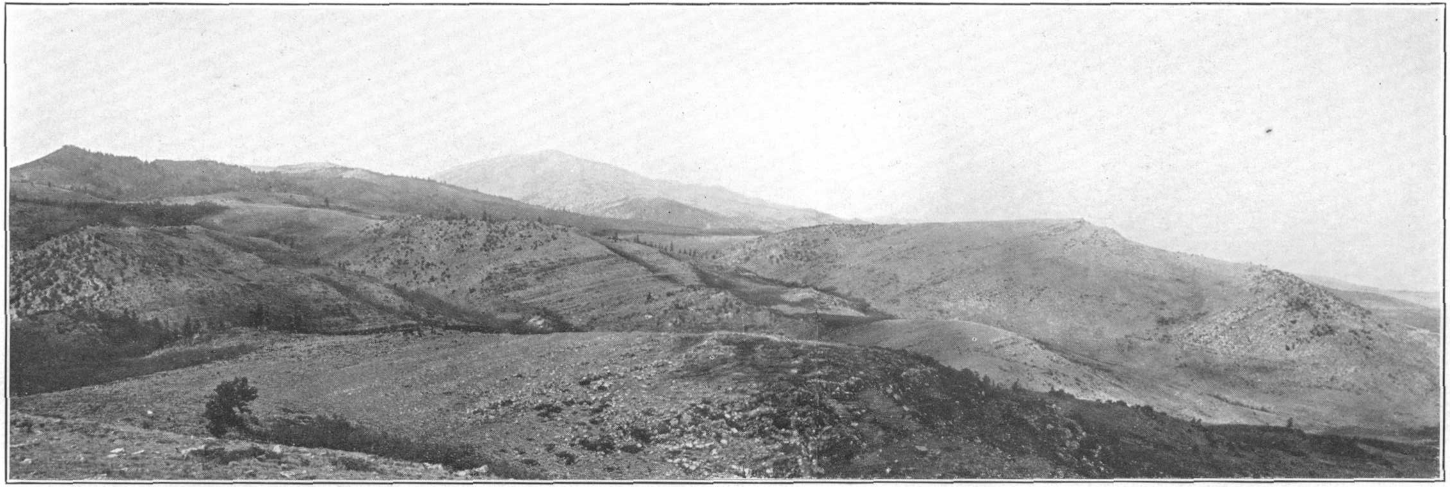
The Ute limestone contains an abundant lower Middle Cambrian fauna.[14] The following genera from the Randolph quadrangle collections have been identified by C. E. Resser of the United States National Museum:

Elrathia.	Obolus.
Kootenia.	Micromitra.
Nisusia.	Glosopleura or Asaphiscus.
Cruziania.	A conchostracan.

BLACKSMITH LIMESTONE

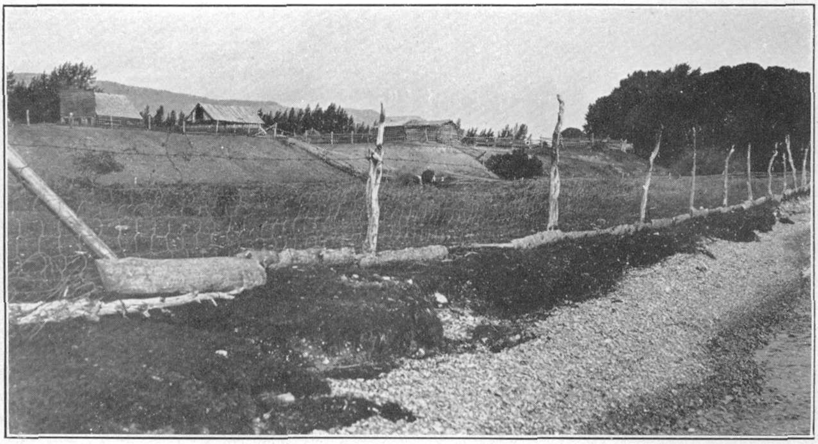
The Blacksmith limestone, originally called Blacksmith formation, was named by Walcott in 1908 from its occurrence along Blacksmith Fork, Cache County, Utah. It is a massive-bedded fine-grained gray to bluish limestone, ocurring in beds that are usually between 3 and 5 feet thick. Lying conformably between the shale and thin-bedded

[14] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 150–152, 1912.



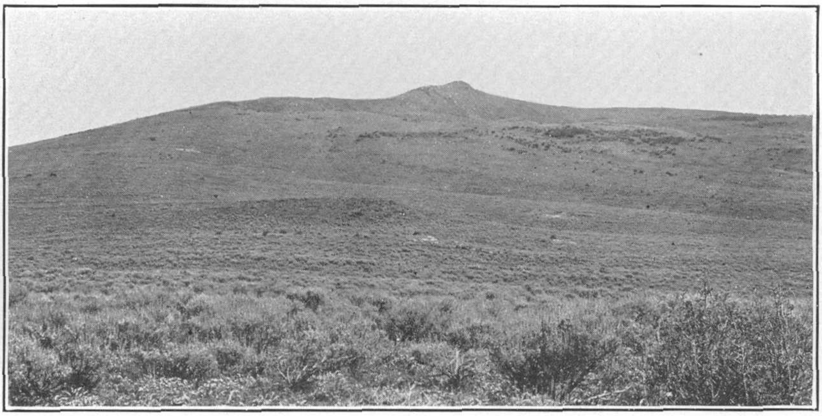
VIEW OF BEAR RIVER RANGE FROM RIM OF HODGES CANYON, SHOWING EASTERN LIMB OF FISH HAVEN SYNCLINE.

Brigham quartzite at right and Swan Peak in middle background.



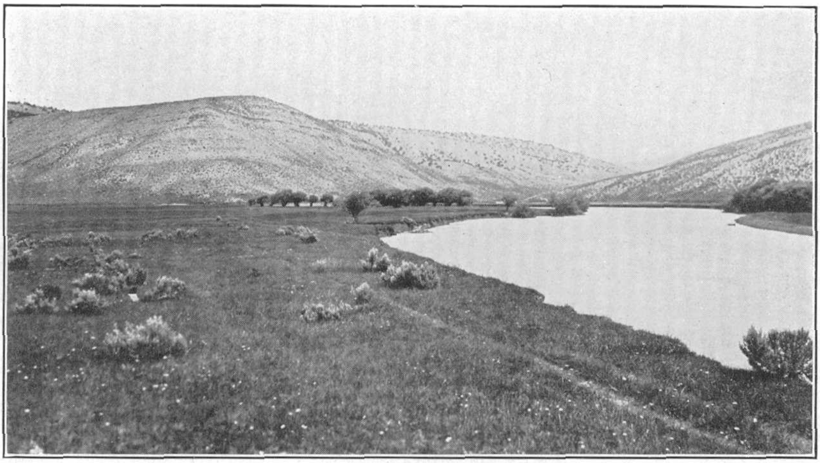
A. UPPER AND LOWER TERRACES OF BEAR LAKE AT GARDEN CITY.

B. DELTA OF NORTH EDEN CREEK AND FORMER SHORE LINE OF BEAR LAKE.

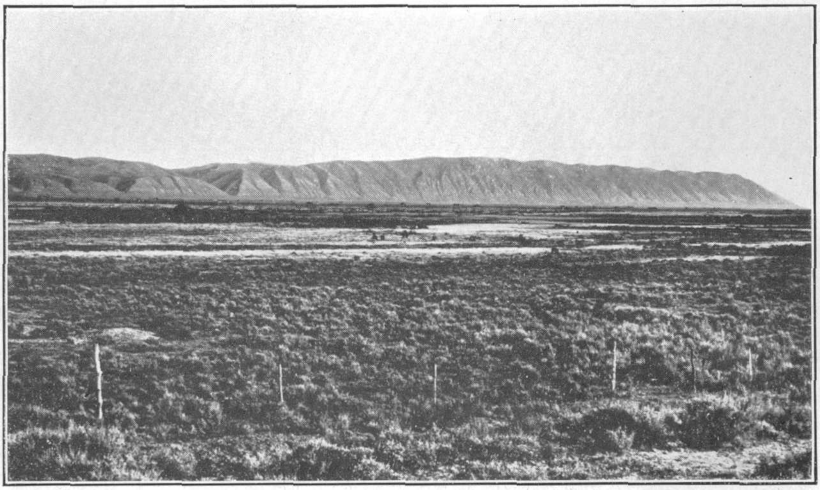


A. VIEW OF BEAR RIVER PLATEAU.

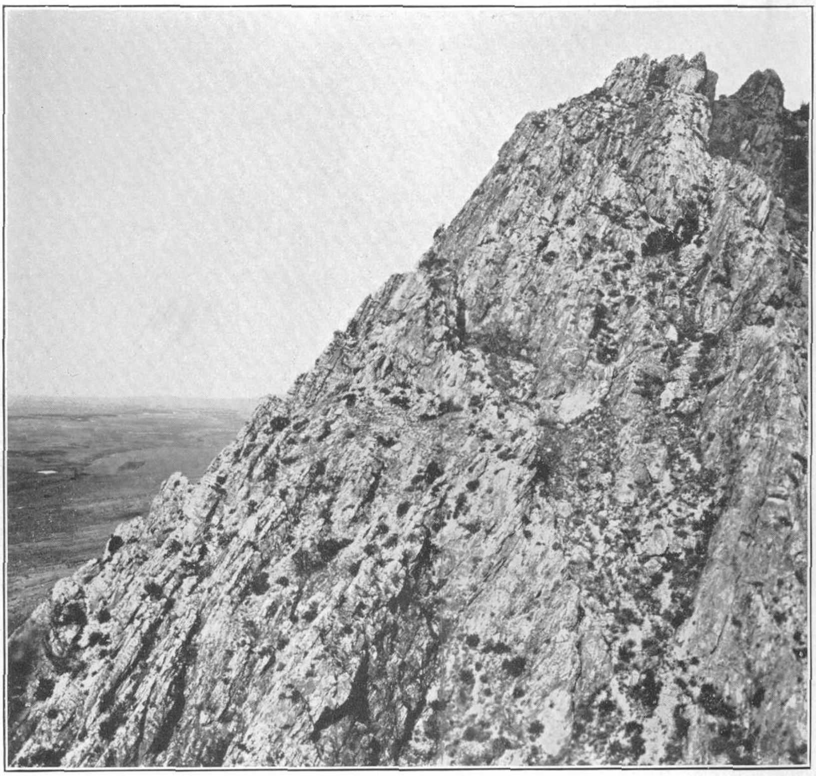
Black Mountain, capped by basalt, in background; Wasatch formation in middle ground.



B. VIEW OF SOUTH ENTRANCE OF BEAR RIVER NARROWS, SHOWING BEAR RIVER FORMATION.

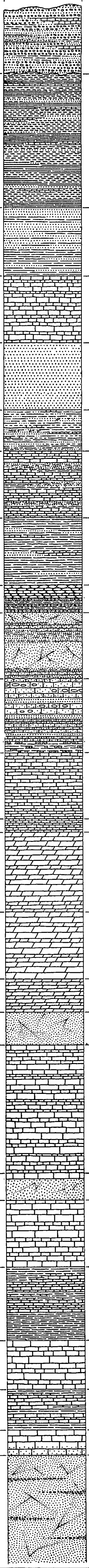


A. VIEW OF CRAWFORD MOUNTAINS FROM BEAR RIVER VALLEY, SHOWING SCARP FORMED BY BRAZER LIMESTONE.

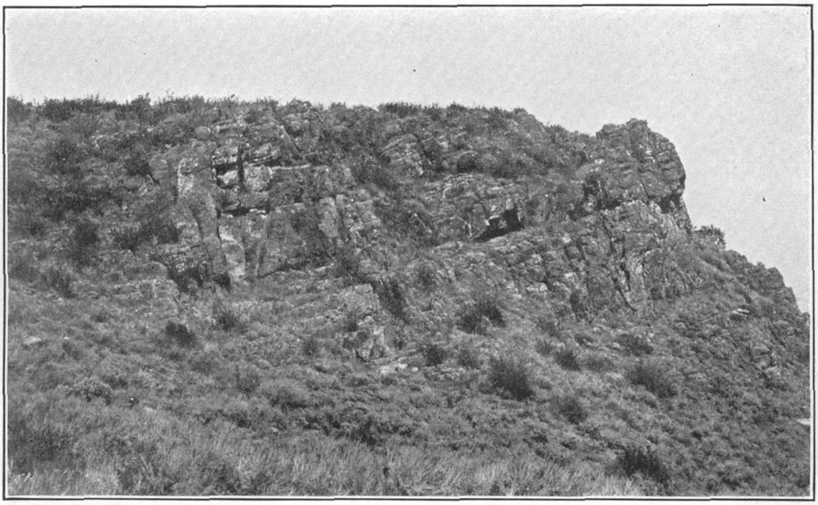


B. DETAIL OF WEST SCARP OF CRAWFORD MOUNTAINS, SHOWING STEEPLY TILTED BRAZER LIMESTONE.

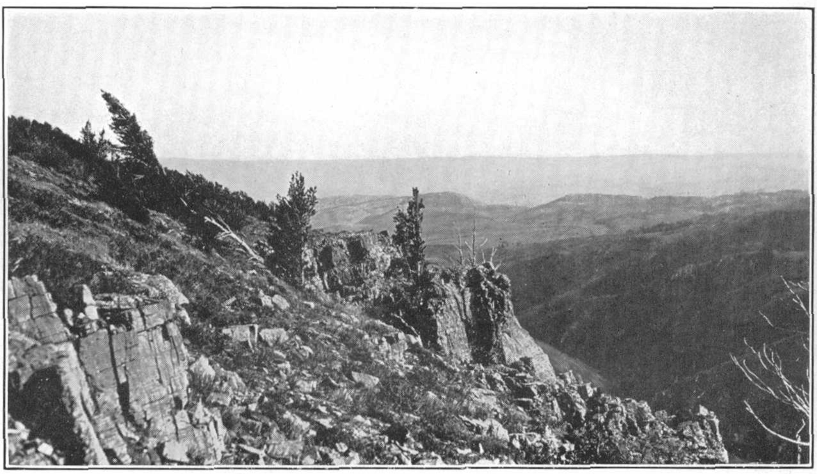
System	Series	Formation	Section	Approximate thickness (feet)	Character of rocks
Tertiary.	Eocene.	Wasatch formation.		1,000+	Varicolored conglomerate and sandstone with subordinate shale, limestone, and tuff.
Cretaceous.	Upper.	Bear River formation.		Complete section not exposed.	Fissile dark clay and carbonaceous shale with interbedded thin gray limestone and buff sandstone.
Cretaceous (?).		Beckwith formation.		Complete section not exposed.	Gray and buff sandstone and shale overlying varicolored shale and sandstone.
Jurassic.	Upper.				
		Twin Creek limestone.		Complete section not exposed.	Thick- and thin-bedded gray limestone; weathers in splintery fragments.
	Middle (?).	Nugget sandstone.		Complete section not exposed.	Thick-bedded, fine-textured red and white sandstone.
Triassic (?).		Ankareh shale.		600	Variegated red and drab sandy and clayey shale, red and gray calcareous sandstone and thin limestone.
Triassic.	Lower.	Thaynes limestone.		Complete section not exposed.	Limestone and calcareous sandstone, locally shaly.
		Woodside shale.		1,000	Varicolored red and green shale, subordinate sandstone and limestone.
Carboniferous.	Permian.	Rex chert member. Phosphoria formation.		400	Chert and limestone, Rex chert member, overlying clayey shale and oolitic phosphate rock.
	Pennsylvanian.	Wells formation.		1,000	Thick-bedded quartzite, calcareous sandstone, and sandy limestone.
	Mississippian.	Brazer limestone.		1,100	Massive gray siliceous limestone and sandstone; in places cherty, lower part thin-bedded and shaly, locally phosphatic.
		Madison limestone.		1,000	Medium- to thin-bedded dark limestone.
Devonian.	Upper.	Three Forks limestone.		200	Thin-bedded limestone, weathers red.
	Middle.	Jefferson dolomite.		1,200	Massive dark dolomite; weathers a characteristic brown tint.
Silurian.		Laketown dolomite.		1,000	Massive light-gray dolomite of Niagaran age.
Ordovician.	Upper.	Fish Haven dolomite.		500	Medium-bedded dark-gray dolomite.
	Lower.	Swan Peak quartzite.		500	Medium- to thin-bedded fine-textured gray quartzite.
		Garden City limestone.		1,900	Thick- and thin-bedded gray limestone.
Cambrian.	Upper.	St. Charles limestone. Worm Creek quartzite member.		400	Massive gray limestone; thick-bedded gray Worm Creek quartzite member at base.
	Middle.	Nounan limestone.		950	Thick- to medium-bedded gray limestone.
		Bloomington formation. Hodges shale member.		1,250	Thin-bedded gray limestone and shale. Hodges shale member at base.
		Blacksmith limestone.		675–725	Massive gray limestone.
		Ute limestone. Spence shale member.		480–585	Thin-bedded limestone and shale. Spence shale member at base.
		Langston limestone.		375	Thick-bedded blue-gray limestone, sandy in lower part.
	Lower (?).	Brigham quartzite.		1,600+	Thick-bedded, fine-grained quartzite; local lenses of conglomerate.



GENERALIZED COLUMNAR SECTION OF THE CONSOLIDATED ROCKS OF THE RANDOLPH QUADRANGLE.



A. LANGSTON LIMESTONE NORTH OF SWAN CREEK.



B. VIEW DOWN GARDEN CITY CANYON FROM BEAR RIVER RANGE, SHOWING SWAN PEAK QUARTZITE IN FOREGROUND.

limestone of the underlying Ute limestone and the basal shale member of the overlying Bloomington formation, the Blacksmith is a distinct lithologic unit. It is a cliff-making formation and usually causes rugged topography. The measured thicknesses of this limestone are 670 feet in the Rock Creek section and 725 feet west of Garden City. The Blacksmith limestone crops out in three localities, where its identity is established by its stratigraphic position. Northeast of Strawberry Valley other isolated outcrops of limestone, which are surrounded by Wasatch and Quaternary deposits, are doubtfully referred to the Blacksmith on the basis of the structure of the region and on the appearance of the limestone.

West of Garden City, near the base of the Bear River Range, the Blacksmith limestone is conspicuously exposed in a zone about 7 miles long. At the north extremity of this outcrop the continuation of the limestone is concealed by Quaternary deposits, and on the southeast it is overlapped by the Wasatch formation. The dip of the limestone, which lies on the east limb of the Fish Haven syncline, is northwest between angles of 20° and 40°. This outcrop of the Blacksmith limestone is marked by cliffs that rise conspicuously above a belt of comparatively low land developed on the softer rocks of the underlying formation. The southwestern continuation of the limestone is exposed in a small area at the west border of the quadrangle, 5½ miles west of Round Valley. The most conspicuous exposure of the Blacksmith limestone is in Rock Canyon, 3 miles south of Strawberry Valley, where the stream, flowing almost parallel to the strike of the rocks, has cut about 4 miles of its course in this massive rock, which there forms precipitous cliffs. The large spring on Swan Creek, in sec. 6, T. 14 N., R. 5 E. (p. 50), issues from the Blacksmith limestone.

Fossils are scarce in the Blacksmith limestone. Walcott reports only fragments of a trilobite and annelid borings at the type locality, and only one form has been obtained from the Randolph quadrangle, a trilobite, which was found in a massive bed of limestone at the base of the formation in sec. 34, T. 11 N., R. 4 E.

BLOOMINGTON FORMATION

The Bloomington formation was named by Walcott in 1908 from its occurrence in the Bear River Range, about 6 miles west of the town of Bloomington, Bear Lake County, Idaho. The name Hodges shale member of the Bloomington formation was given by the present writer to a persistent zone of shale at the base of the formation, the name being derived from Hodges Creek, which crosses the shale and enters Bear Lake 1½ miles south of Garden City. Separate mapping of the Hodges shale is desirable, because it is easily recognized and its delineation on the map serves to emphasize the structure.

The Bloomington formation consists of grayish fossiliferous limestone and shale, which in the Randolph quadrangle is about 1,250 feet thick. The limestone is generally thin-bedded, compared with the massive beds of the contiguous Blacksmith and Nounan limestones, and the formation is further characterized by the presence of beds of clay shale. The thickest and most persistent of these beds is the Hodges shale member. This shale is 325 feet thick in Rock Canyon and 350 feet thick west of Garden City. Another conspicuous shale zone occurs near the top of the formation. This shale is less than 200 feet thick, 180 feet being measured on the north wall of Garden City Canyon. North of this place it thins out and on the northeastern flanks of the Bear River Plateau, at the northern end of the quadrangle, apparently merges with limestone.

The Bloomington formation crops out on the south side of Rock Creek Canyon and on both limbs of the Fish Haven syncline west of Garden City. The Hodges shale is well exposed along the road at the west border of the quadrangle, in secs. 16 and 21, T. 14 N., R. 4 E., and the uppermost shale crops out in sec. 27, T. 14 N., R. 4 E. A number of sinkholes are developed in the limestone of the Bloomington formation along the western border of the quadrangle, in Tps. 13 and 14 N.

Walcott found abundant Middle Cambrian fossils in the Bloomington formation, and the following forms from the Randolph quadrangle have been identified by C. E. Resser:

Obolus.
Lingulella.
Westonia ella (Hall and Whitfield).
Elrathia.

NOUNAN LIMESTONE

The Nounan limestone, originally called Nounan formation, was named by Walcott in 1908 from its occurrence in the Bear River Range west of the town of Nounan, Bear Lake County, Idaho.

The Nounan is a massive- to medium-bedded blue-gray limestone, which lies between the Bloomington and St. Charles formations. In the area under consideration this limestone is approximately 950 feet thick. It crops out on both limbs of the Fish Haven syncline west of Garden City and caps several hills on the crest of the Bear River Range (both north and south of the Logan road from Garden City. Walcott reports finding only a few traces of fossils in the Nounan limestone in the Blacksmith Fork section, and none have been found in this formation in the Randolph quadrangle.

ST. CHARLES LIMESTONE

The St. Charles limestone was named by Walcott in 1908 from its occurrence in the Bear River Range west of the town of St. Charles, Bear Lake County, Idaho. The name Worm Creek quartzite member of the St. Charles limestone was given by the present writer to a persistent bed of quartzite at the base of the formation, which was traced throughout the area mapped. Occurring in the midst of a mass of limestone, it serves as a useful horizon marker. The name is taken from Worm Creek, which crosses the quartzite in the Bear River Range, Bear Lake County, Idaho, 10 miles north of the Randolph quadrangle.

The St. Charles is the uppermost Cambrian formation in this region. In the Randolph quadrangle it crops out on both limbs of the Fish Haven syncline, on the flanks of the Bear River Range west of Garden City, where it is approximately 400 feet thick. The formation consists of the basal Worm Creek quartzite and overlying limestone. The Worm Creek quartzite member is a zone of massive gray quartzite which has an average thickness of 300 feet and is composed of irregular-shaped to partly rounded grains of quartz and occasional particles of feldspar embedded in a siliceous and calcareous cement. It is conspicuously exposed and in places forms prominent knobs. The change from the Nounan limestone to the quartzite is abrupt and pronounced.

Walcott reported a number of fossils of Upper Cambrian age from the St. Charles limestone, and the following genera from the limestone just above the Worm Creek quartzite member in the Randolph quadrangle have been identified by C. E. Resser:

Billingsella.
Obolus.
Idahoia.
Wilbernia.

Unpublished paleontologic studies by Walcott, Ulrich, Resser, Kirk, and Cooper and a recent report by Deiss[15] indicate that approximately the upper 900 feet of the St. Charles limestone as originally defined by Walcott[16] is of Lower Ordovician age. These beds are now included in the Garden City limestone, and the St. Charles limestone is restricted to beds of Upper Cambrian age.

ORDOVICIAN SYSTEM

The Ordovician system likewise is well developed in northeastern Utah. In the Bear River Range, adjacent to the Utah-Idaho bound-

[15] Deiss, Charles, Cambrian formations and sections in part of Cordilleran trough: Geol. Soc. America Bull. 49, p. 1123, 1938.

[16] Walcott, C. D., Nomenclature of some Cambrian Cordilleran formations: Smithsonian Misc. Coll., vol. 53, pp. 1–12, 1908.

ary, it is represented by a section of well-exposed strata almost 3,000 feet thick, which is separated into three formations. At the base is the Garden City limestone, containing a Lower Ordovician fauna; overlying this is the Swan Peak quartzite, containing a Chazy (?) fauna; and at the top of the section is the Fish Haven dolomite, characterized by a Richmond fauna. The Fish Haven dolomite has not been mapped separately in the Randolph quadrangle. The succession is structurally conformable, but hiatuses are indicated by the absence of the intervening faunas. In the southwestern part of the Randolph quadrangle and in the vicinity of Laketown limestones containing Beekmantown and Richmond faunas are present, but the Swan Peak quartzite has not been recognized. In those areas the Ordovician rocks are mapped as "undifferentiated Ordovician."

GARDEN CITY LIMESTONE

The Garden City limestone, named from Garden City Canyon, a tributary of Bear Lake, as originally defined[17] included a succession of thick and thin beds of gray limestone approximately 1,000 feet thick of Lower Ordovician age, lying between the St. Charles limestone and the Swan Peak quartzite. As stated on page 13, the St. Charles limestone of Upper Cambrian age is now restricted to the lower 400 feet (approximately) of the formation as defined by Walcott, and the upper 900 feet (approximately) is now considered to be of Lower Ordovician age and is included in the Garden City limestone. The expanded Garden City limestone consists of approximately 1,900 feet of gray limestone of Lower Ordovician age. A characteristic feature of the formation is the presence of a conglomerate consisting of fragments of limestone as much as 2 or 3 inches in length irregularly imbedded in a matrix of similar composition.

West of Bear Lake the Garden City limestone crops out in two areas, (1) in a belt of low hills near the lake shore, where it is separated by the Bannock thrust fault from a great mass of Cambrian strata on the eastern slopes of the Bear River Range, and (2) near the upper part of the Bear River Range, where the limestone lies on both flanks of the Fish Haven syncline between the St. Charles limestone and the Swan Peak quartzite. In the northwest corner of the quadrangle are two areas of the Garden City limestone, which have been separated by faulting.

The Garden City limestone lies structurally conformably on the St. Charles limestone, but a hiatus is indicated by the absence of intervening faunas represented elsewhere. The following fossils

[17] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, p. 408, 1913.

of Lower Ordovician age from the Garden City limestone in the Randolph quadrangle were identified by Edwin Kirk and C. E. Resser.

From the lower 900 feet of the Garden City limestone:

Westonia iphis (Walcott).
Xenostegium (?) sp.
Eoorthis sp.

The following fossils were found on the east flank of the Bear River Range, 4 miles northwest of Garden City:

From 975 feet below the top of the Garden City limestone:

Deltatreta sp.
Syntrophia near calcifera Billings.
Raphistoma acuta Hall and Whitfield.
Hormotoma sp.
Eccyliopterus sp.

From 800 feet below the top of the Garden City limestone:

Lingula sp.
Asaphoid.

From 650 feet below the top of the Garden City limestone:

Taffia?
Asaphus sp.
A new genus of trilobites allied to Bumastus.

From 610 feet below the top of the Garden City limestone:

Deltatreta sp.
Raphistoma sp.
Maclurea subannulata Walcott.
Isoteloides sp.
Ribeiria sp.

From 300 feet below the top of the Garden City limestone:

Taffia fontinalis White.
Taffia? minor Walcott.
Deltatreta pogonipensis Hall and Whitfield.
Raphistoma var. near R. trohiscus Meek.
acuta Hall and Whitfield.
Maclurea subannulata Walcott.
Hormotoma sp.
Eccyliopterus sp.
"Asaphus" cf. curiosus Billings.
Isoteloides sp.
Pliomerops sp.
Calathium sp.

From the top of the Garden City limestone:

Deltatreta pogonipensis Hall and Whitfield.
Taffia fontinalis White.
Hormotoma sp.
Echinoencrinus sp.
Leperditella sp.

According to Kirk, the fauna of the Garden City limestone is widely spread through the Rocky Mountain and Great Basin regions. It is represented in the El Paso limestone of Texas, the Yellow Hill limestone of southern Nevada, the Pogonip limestone of central Nevada, and the upper Mons of British Columbia. The Garden City limestone cannot with accuracy be correlated with the standard Ordovician section but is approximately of Beekmantown age.

In his paper on the Lower Ordovician El Paso limestone of Texas and its correlatives, published in 1934, Kirk,[18] referring to the Garden City limestone of Utah, states that "the underlying St. Charles [limestone], classed as Upper Cambrian is probably Lower Ordovician in part." The present writer, however, thinks it more appropriate to define the Garden City limestone in the type locality as including all the limestone beds of Lower Ordovician age that lie above the St. Charles limestone, which is limited to beds of Upper Cambrian age.

SWAN PEAK QUARTZITE

The Swan Peak quartzite directly overlies the Garden City limestone in the Bear River Range adjacent to the Utah-Idaho boundary and is named from Swan Peak, which is in the Randolph quadrangle, 1½ miles south of the State boundary. (See pl. 7, *B*.) It is a fine-textured gray quartzite. It is usually massive, in beds about 2 feet thick, but there are local thin layers 1 or 2 inches thick. The color varies, and, though prevailingly gray, in places it is brownish, pinkish, and whitish. The Swan Peak quartzite is composed of rounded to semirounded grains of quartz bound together by a siliceous cement. A rim of silica in optical orientation with the quartz surrounds some of the grains.

The main body of the Swan Peak quartzite caps the summit of the high mountains immediately east of the main divide of the Bear River Range, where it lies almost horizontally, forming the center of the Fish Haven syncline. The quartzite is also repeated by faulting and forms the crest of the mountains at the extreme northwest corner of the quadrangle. Only about 300 feet of the Swan Peak quartzite is exposed in the Randolph quadrangle; the rest of it has been removed by erosion. But in the northward continuation of this outcrop, on the Bear River Range in Idaho, 5 miles north of the State line, Swan Peak quartzite is 500 feet thick and is overlain by the Fish Haven dolomite. West of Fish Haven, Mansfield[19] reports the occurrence of thin lenses of phosphate rock about 100 feet above the base of the Swan Peak quartzite, but no phosphate has been

[18] Kirk, Edwin, The Lower Ordovician El Paso limestone of Texas and its correlatives: Am. Jour. Sci., 5th ser., vol. 28, p. 456, 1934.

[19] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 57, 1927.

found in this formation in the Randolph quadrangle. Apparently the occurrence is not of commercial importance.

The following fossils, identified by Edwin Kirk, were obtained from the Swan Peak quartzite:

From near the Idaho-Utah boundary half a mile east of Garden City Canyon:

Bucanella sp.
Eccyliopterus sp.
Eleutherocentrus petersoni Clark.

From the west slope of the main ridge of the Bear River Range in the NE¼ sec. 9, T. 14 N., R. 4 E.:

Orthis michaelis Clark.
Eccyliomphalus sp.
Endoceras sp.
Symphysurus cf. goldfussi Walcott.
Eleutherocentrus petersoni Clark.
Leperditia sp.
Leperditella sp.

This fauna is referred tentatively by Ulrich and Kirk to the basal Chazy. It is unique and cannot at present be definitely placed. It is tentatively correlated with the apparently related fauna in the basal part of the Simpson group of Oklahoma.

FISH HAVEN DOLOMITE AND UNDIFFERENTIATED ORDOVICIAN LIMESTONE

The Fish Haven dolomite, containing an Upper Ordovician (Richmond) fauna, directly overlies the Swan Peak quartzite in the Bear River Range, at the head of the Fish Haven Creek, 5 miles north of the Idaho-Utah State boundary.

The Fish Haven is a fine-textured medium-bedded dark-gray to blue-black dolomite, which is about 500 feet thick at its type occurrence. A sample from this locality, analyzed by W. C. Wheeler, showed 21 to 35 percent of magnesia. Limestone containing an Upper Ordovician fauna occurs near the top of the Bear River Range in the southwestern part of the Randolph quadrangle. This limestone also is present in Laketown Canyon. At neither locality, however, has the Swan Peak quartzite been recognized, and the limestones containing Beekmantown and Upper Ordovician fossils are mapped together as "undifferentiated Ordovician."

The following fossils, identified by Edwin Kirk, were obtained by R. W. Richards in the Fish Haven dolomite at the head of Fish Haven Creek in the Montpelier quadrangle, Idaho, immediately north of the Randolph quadrangle:

Calapoecia cf. canadensis Billings.
Streptelasma sp.
Halysites catenulatus var. gracilis Hall.
Rhynchotrema capax Conrad.
Columnaria thomii Hall.

From dolomite in sec. 16, T. 10 N., R. 4 E., E. O. Ulrich identified *Streptelasma* sp., *Halysites gracilis*, and *Columnaria* sp.

These fossils represent the Upper Ordovician fauna, which is of widespread occurrence in the cordilleran region. The Fish Haven dolomite is structurally conformable with the underlying beds, but a hiatus is indicated by the absence of intervening faunas.

SILURIAN SYSTEM

LAKETOWN DOLOMITE

The Silurian system is represented in the northern Rocky Mountain region by the Laketown dolomite (middle Silurian), which lies between the Fish Haven dolomite (Upper Ordvician) and the Jefferson dolomite (Middle Devonian). Hiatuses above and below the Laketown dolomite are indicated by the absence of intervening faunas.

The Laketown dolomite is a massive light-gray to whitish magnesian limestone containing bands of siliceous limestone and calcareous sandstone. An analysis of a sample from Laketown Canyon in the SE¼ sec. 17, T. 12 N., R. 6 E., showed 21.38 percent of magnesia (MgO). In the Randolph quadrangle the Laketown dolomite crops out in Laketown Canyon and its branches, as shown on plate 1. Because of the scarcity of fossils the boundaries of the Laketown dolomite are difficult to determine. It is estimated that the formation is approximately 1,000 feet thick.

In the Montpelier quadrangle, Idaho, a few feet of the Laketown dolomite overlies the Fish Haven limestone on the crest of the Bear River Range 5 miles north of the Randolph quadrangle and in a small canyon a mile southwest of St. Charles. It occurs also in Green, Logan, and other canyons on the east side of Cache Valley, Utah, where fossils were obtained by Kindle.[20]

The following fossils, identified by Edwin Kirk, were obtained in the Randolph quadrangle.

From west edge sec. 16, T. 12 N., R. 6 E., on north side of Randolph-Laketown road:

Halvsites catenulatus? Linnaeus.
Favosites sp.
Cyathophyllum? sp.

From SE¼ sec. 17, T. 12 N., R. 6 E.:

Pentamerus cf. oblongus Sowerby.

DEVONIAN SYSTEM

The Devonian system is represented in the Northern Rocky Mountain region by the Jefferson dolomite and the Threeforks limestone of Middle and Upper Devonian age, respectively.

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[20] Kindle, E. M., Occurrence of the Silurian fauna in western America: Am. Jour. Sci., 4th ser., vol. 25, pp. 127–128, 1908.

JEFFERSON DOLOMITE

The Jefferson dolomite, a magnesian limestone that has a widespread distribution in Montana, Idaho, Wyoming, and Utah,[21] was named by A. C. Peale [22] from exposures a few miles above the mouth of the Jefferson River, near Three Forks, Mont. Its physical features, together with its stratigraphic position, usually serve to distinguish the Jefferson dolomite, even in the absence of fossils, which in many areas are scarce. Commonly, it is massive and dark-colored and tends to weather to a characteristic brownish tone.

In the Randolph quadrangle the Jefferson consists of about 1,200 feet of massive fine-grained dark-colored dolomite, which weathers to the characteristic brown. In places the lower strata are thin-bedded. Analysis of a sample from Laketown Canyon by W. C. Wheeler, of the Geoligical Survey, showed the presence of 19.16 percent of magnesia (MgO).

The Jefferson dolomite crops out in the Crawford Mountains and east of Laketown, where the resistant massive beds are well exposed. The Jefferson lies structurally conformably between the Laketown dolomite and the overlying Threeforks limestone. A hiatus is indicated at the lower contact by the absence of faunas representative of the Lower Devonian and of the late Silurian.

In general, fossils are scarce in the Jefferson dolomite, but locally in the Randolph quadrangle they are fairly abundant. Two zones, one in typical massive beds near the top of the formation and the other in the thin beds near the base, yielded the following collections, which were identified by E. M. Kindle:

From East Fork of Laketown Canyon SE¼ sec. 17, T. 12 N., R. 6 E., about 150 feet above the base of the formation:

- Productella sp.
- Spirifer englemanni.
- Nuculites sp.
- Aviculopecten? sp.
- Fish bone fragment.

From East Fork of Laketown Canyon W½ sec. 17, T. 12 N., R. 6 E., from several beds between 200 and 500 feet below the top of the formation:

- Aulopora sp.
- Favosites cf. limitaris.
- Zaphrentis sp.

THREEFORKS LIMESTONE

The Threeforks formation was named by A. C. Peale from its occurrence at the three forks of the Missouri River, in southwest

[21] Kindle, E. M., The Fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Bull. Am. Paleontology, vol. 4, No. 20, 1908.

[22] Peale, A. C., The Paleozoic section in the vicinity of Three Forks, Mont.: U. S. Geol. Survey Bull. 110, p. 27, 1893.

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Montana. At the type locality the formation consists chiefly of calcareous shale lying between the Jefferson and Madison limestones but in some regions, as in the Randolph quadrangle, the formation is chiefly limestone. It has not been recognized over so wide an area as have the immediately underlying and overlying formations. However, in the Randolph quadrangle all three formations are present.

The Threeforks is a soft formation lying between harder ones and usually occupies a belt of debris-covered lowland. Nowhere in the quadrangle is there a complete exposure of the formation, and its exact composition is not known. It is approximately 200 feet thick. The only exposures of this formation found in the quadrangle were thin-bedded impure earthy gray limestone, which weathers to yellowish and reddish tints. Shale, if present, is covered by debris and was not found. This narrow debris-covered reddish zone lying between the more resistant beds of the Jefferson and Madison limestones is an excellent horizon marker. A sample of the Threeforks limestone from the Crawford Mountains analyzed by W. C. Wheeler showed only 0.78 percent of magnesia (MgO).

The following fossils obtained from the Threeforks limestone were identified by E. M. Kindle:

From Crawford Mountains 3 miles east of Rex Ranch, S½ sec. 29, T. 11 N., R. 8 E.:

- Productella coloradensis.
- Camarotoechia cf. contracta.
- Schizophoria striatula var. australis.
- Sprifer notabilis.
  - whitneyi var. animasensis.
- Syringothyris cf. carteri.
- Cleiothyridina sp.

CARBONIFEROUS SYSTEM

The Carboniferous system is represented in the quadrangle by the Madison and Brazer limestones, of the Mississippian series, the Wells formation, of the Pennsylvanian series, and the Phosphoria formation, of the Permian series. The total thickness of these rocks in this area is about 3,500 feet.

MISSISSIPPIAN SERIES

MADISON LIMESTONE

Mississippian time witnessed a widespread submergence and transgression of the sea in the cordilleran region, where a great mass of limestone was laid down. Many disconnected areas of Mississippian limestone are characterized by similar fauna but have been given local names. In the northern Rocky Mountain region the lowermost Carboniferous formation is known as the Madison limestone, being named by Peale[23] from its occurrence in the Madison Range, in southwest Montana.

As developed in the Randolph quadrangle, the Madison limestone is a medium- to thin-bedded fine-grained dark, almost black, limestone. A partial analysis of a sample from the Crawford Mountains by W. C. Wheeler, of the Geological Survey, showed 48.95 percent of lime (CaO), 5.05 percent of magnesia (MgO), and 2.42 percent of insoluble matter. The Madison limestone in this area is rather homogeneous, although local differences are caused by variations in the bedding. In places it is massive, and toward the base it is locally thin-bedded. It averages about 1,000 feet in thickness.

The Madison limestone crops out east and south of Laketown and in the Crawford Mountains. It occurs in the trough of a syncline on the divide between the two forks of Laketown Canyon, between 2 and 3 miles south of the town, where it forms the crest and slopes of a hill. It also forms a narrow strip of steeply tilted beds, which cross old Laketown canyon a mile east of the town and appear again from beneath the cover of the Wasatch formation a mile or so to the south.

In the west-central part of the Crawford Mountains between 3 and 4 miles southeast of Randolph, the Madison limestone crops out in a steeply dipping, overturned belt on the upper slopes and near the crest of the range. Here the Madison lies with the Brazer limestone (which forms the western escarpment of the mountains) on one side and the Threeforks limestone and the Wells formation on the other side. It is separated from the Wells formation by a fault. In the north-central part of the mountains the Madison limestone crops out in a zone about 7 miles long and half a mile wide. There it dips west at an angle of about 50° and is overlain by the Brazer limestone and underlain by the Threeforks limestone. Along the northeastern flanks of the mountains the Madison limestone, standing almost vertically in an outcrop 3½ miles long, is repeated by faulting. Here the Madison lies between the Jefferson and Threeforks limestones.

The Madison limestone, of lower Mississippian age, lies apparently conformably between the Threeforks (Upper Devonian) and Brazer limestones (upper and middle Mississippian), although paleontologically there is a hiatus at the base of the Madison. The Madison limestone is abundantly fossiliferous, and collections from a number

[23] Peale, A. C., The Paleozoic section in the vicinity of Three Forks, Mont.: U. S. Geol. Survey Bull. 110, p. 33, 1893.

of localities in the Crawford Mountains and from the vicinity of Laketown, identified by G. H. Girty, are listed below:

Zaphrentis sp.
Cyathaxonia arcuata Weller.
 sp.
Amplexus aff. fragilis White and St. John.
 aff. radiger Rowley.
 sp.
Menophyllum excavatum Girty.
Aulopora sp.
Michelinia sp.
Acervularia sp.
Ortonia sp.
Spirorbis sp.
Hemitrypa sp.
Fenestella sp.
Pinnatopora, 2 sp.
Streblotrypa sp.
Cystodictya sp.
Schellwienella sp.
Crania rowleyi.
Schizophoria swallowi Hall.
Leptaena analoga.
Schuchertella chemungensis Conrad.
Rhipidomella pulchella Herrick?
 n. sp.
Chonetes logani Norwood and Pratten.
 illinoisinsis Worthen.
 ornatus Shumard?
Productella concentrica Hall.
 arcuata Hall.
 n. sp.
 sp.
Productus aff. mesialis Hall.
 semireticulatus Martin.
 aff. gallantinensis Girty.
 gallantinensis Girty.
 aff. setiger Hall.
Productus parviformis? Girty.
 (Linoproductus) ovatus Hall.
 (Avonia) sampsoni Weller.
 (Pustula) aff. blairi Miller.
 (Pustula) aff. scabriculus Martin.
Rhynchopora? sp.
Camarotoechia herrickana Girty.
Spiriferina sp.
Brachythytis aff. peculiaris Shumard.
Spirifer centronatus Winchell.
 centronatus Winchell var.
 sp.
Reticularia cooperensis Swallow.
Syringothyris carteri Hall.
Ambocoelia parva Weller.
 sp.
Composita humilis Girty.
 immatura Girty.
Cleiothyridina crassicardinalis White.
 incrassata Hall.
Retzia sp.
Cypricardinia sp.
Dentalium? sp.
Platyceras sp.
Loxonema sp.
Bucanopsis sp.
Pleurotomaria, 3 sp.
Straparollus sp.
Euomphalus utahensis Hall and Whitfield.
 sp.
Orthoceras sp.
Goniatites sp.
Proetus sp.
Paraparchites sp.

BRAZER LIMESTONE

The Brazer limestone is named from Brazer Canyon, which is in the Crawford Mountains 6 miles northeast of Randolph.

The Brazer for the most part is a massive light-gray siliceous limestone, but it varies in composition. Locally there are beds of calcareous sandstone, and in places chert is present, occurring in layers of a few inches thick and in irregular bunches. The lower part of the limestone commonly is thin-bedded and shaly. About a mile east of Laketown a bed of phosphate rock occurs in the shaly lower part of the limestone. The Brazer has an average thickness of about

1,100 feet. A partial analysis of a sample of the limestone from 2 miles southeast of Laketown, by W. C. Wheeler, of the Geological Survey, shows the following composition: lime (CaO), 53.77 percent; magnesia (MgO), 0.77 percent; insoluble, 3.08 percent.

In the Randolph quadrangle the Brazer limestone crops out in the vicinity of Laketown and in the Crawford Mountains, where it is exposed in two narrow belts in which the formation is repeated by faulting. The most conspicuous exposure is along the western front of the mountains, where the Brazer limestone, dipping westward at an angle of about 65°, forms a rugged escarpment. (See pl. 5, *B*.) In the west-central part of the mountains this limestone occupies a belt about 7 miles long. The Brazer limestone ranges from about 800 to 1,400 feet in thickness.

The fossils from the Brazer limestone listed below were identified by G. H. Girty, and part of them were collected by him.

Lot 493. From old Laketown Canyon, near center of sec. 32, T. 13 N., R. 6 E.:

Endothyra baileyi Hall.
Zaphrentis sp.
Productus (Linoproductus) aff. ovatus Hall.
Productus, 2 sp.
Dielasma formosum Hall?
Girtyella turgida Hall.
Spirifer bifurcatus Hall?
Composita sp.
Cleiothyridina hirsuta Hall.
Conocardium sp.
Holopea aff. proutana Hall.
Nautilus sp.
Griffithides sp.
Kirkbya, 2 sp.
Paraparchites carbonarius Hall?
Cytherella sp.

Lot 465. From 2 miles southeast of Laketown, NE¼ sec. 5, T. 12 N., R. 6 E.:

Zaphrentis multilamella?
Batostomella? sp.
Leioclema? sp.
Fenestella sp.
Schuchertella? sp.
Productus (Pustula) biseriatus Hall?
  aff. giganteus Martin.
Composita sp.
Cleiothyridina hirsuta Hall?
Aviculipecten Hall?
Cypricardella nucleata Hall?
Euomphalus sp.
Holopea proutana Hall?
Proetus sp.
Paraparchites sp.

Lot 469. From 1¼ miles east of Laketown, near center of W½ sec. 32, T. 13 N., R. 6 E., in shaly limestone associated with phosphate rock near the base of the formation:

Triplophyllum sp.
Michelinia sp.
Rhipidomella sp.
Chonetes illinoisensis Worthen var.
Productella hirsutiformis Walcott?
Productus altonensis Hall.
Martinia? sp.
Spirifer moorefieldanus Girty.
Platyceras sp.
Paraparchites sp.

Lot 476. From the Crawford Mountains, 3¾ miles northeast of Rex Ranch, near center of sec 17, T. 11 N., R. 8 E.:

Zaphrentis sp.
Syringopora sp.
Pentremites sp.
Fenestella, 2 sp.
Schuchertella? sp.
Rhipidomella sp.

Productus (Pustula) aff. punctatus Martin.
Aff. setiger Hall.
Spirifer aff. grimesi Hall.
Syringothyris carteri Hall?
Cleiothyridina aff. incrassata Hall.

Lot 487. From the Crawford Mountains 2½ miles southeast of Rex Ranch, near center of sec. 31, T. 11 N., R. 8 E.:

Syringopora sp.
Menophyllum sp.
Derbya? sp.
Productus aff. giganteus Martin?
Spirifer aff. grimesi Hall?

Lot 489. From the Crawford Mountains, 1 mile south of Rex Ranch, near center of sec. 35, T. 11 N., R. 7 E.:

Zaphrentis sp.
Syringopora sp.
Productus aff. gallatinensis Girty.
Spirifer aff. grimesi Hall.
Aviculipecten sp.

PENNSYLVANIAN AND PERMIAN SERIES

There has been different usage in naming the rocks of Pennsylvanian and Permian age in this region. The Fortieth Parallel Survey introduced the term Weber quartzite, which was taken from a great development of gray quartzite in Weber Canyon, for beds lying between what was then called the "Wasatch limestone" (including beds now known to be of Mississippian, Devonian, and Silurian age) and the "Upper Coal Measures." Boutwell in his report on the Park City district proposed the name Park City formation for calcareous, siliceous, and phosphatic beds lying between the Weber quartzite and the Woodside shale. Gale and Richards in their preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah (including part of the Randolph quadrangle) used the names Weber quartzite and Park City formation. But later work by Richards, Mansfield, and Girty showed the desirability of revising the nomenclature, and the names Wells formation for beds of Pennsylvanian age and Phosphoria formation for beds of Permian age were introduced.[24]

WELLS FORMATION (PENNSYLVANIAN)

The Wells formation was named by Richards and Mansfield,[25] the name being taken from Wells Canyon, in the Crow Creek quadrangle, Idaho. It includes the beds of Pennsylvanian age that lie between the Brazer limestone and the Phosphoria formation.

At the type locality the Wells formation consists of interbedded sandstone, quartzite, and limestone 2,400 feet thick. In the Ran-

[24] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 71–84, 1927.

[25] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, pp. 609–693, 1912.

dolph quadrangle the Wells formation crops out in two areas—east of Laketown and in the Crawford Mountains. Complete sections are not exposed, but measurements of several partial sections indicate that the formation in this area is about 1,000 feet thick. The lower part of the formation is composed of alternating beds of quartzite and limestone, the middle part of massive quartzite in beds rarely less than 2 feet thick, and the upper part of calcareous sandstone and sandy limestone.

Clean-cut exposures of the base of the Wells were not observed. The beds are structurally conformable with the underlying strata, and there is an abrupt change from the massive Brazer limestone to the basal quartzite member of the Wells formation. An unconformity is indicated, however, by the varying thickness of the Brazer limestone and by the apparent absence of a richly fossiliferous horizon near the top of the Brazer limestone, which is present in the Montpelier quadrangle but which has not been found in the Randolph quadrangle.

PHOSPHORIA FORMATION (PERMIAN)

The name Phosphoria formation, derived from Phosphoria Gulch, a branch of Georgetown Canyon, Bear Lake County, Idaho, was given by Richards and Mansfield [26] in 1912 to beds that lie between the Wells formation and the Woodside shale. The Phosphoria formation includes the valuable phosphate beds of this regoin. It is of widespread occurrence in southeast Idaho, northeast Utah, and southwest Wyoming.

In the Randolph quadrangle the Phosphoria formation crops out in two areas, in the vicinity of old Laketown Canyon, east of Laketown, and in the Crawford Mountains. In old Laketown Canyon the exposures are poor, but in the Crawford Mountains the phosphate deposits have been considerably prospected.

The upper part of the formation, which has been named the Rex chert member, from Rex Peak, in the Crawford Mountains 4 miles east of Randolph, consists of black chert, dark cherty limestone, and subordinate interbedded shale, which ranges in thickness from 125 to 200 feet in the Crawford Mountains. This chert zone usually forms a conspicuous outcrop, which serves as a useful horizon marker in prospecting for phosphate. The lower part of the Phosphoria formation is composed of a sequence of brownish clay shale about 250 feet thick containing limestone nodules, subordinate beds of dark limestone, and beds as much as 5 feet thick of phosphate rock, which is commonly oolitic. Almost the entire lower part of the formation is phosphate-bearing, but the commercially important de-

[26] Richards, R. W. and Mansfield, G. R., op. cit., pp. 684–689.

posits are confined chiefly to the beds of phosphate rock as described on pages 45–48. At several localities, notably in the gulch about a mile north of Brazer Canyon, a zone of conglomerate marked by angular to semirounded bits of quartzite like that of the underlying Wells formation, is present at the base of the Phosphoria formation.

The Phosphoria formation carries an abundant fauna, which has been described by Girty.[27]

The following fossils, identified by Girty, were obtained from the Phosphoria formation in the Randolph quadrangle:

From the Rex chert member, NE¼ sec. 18, T. 11 N., R. 8 E.:

Stenopora sp.
Lioclema, 3 sp.
Phyllopora? sp.
Pugnax n. sp.
Aulosteges n. sp.
Spiriferina pulchra Meek
Composita subtilita Hall var.
Deltapecten n. sp.

From near the middle of the phosphate shales, NE¼ sec. 18, T. 11 N., R. 8 E.:

Orbiculoidea missouriensis Shumard.
Chonetes osteolatus var. minusculus Girty.
Productus (Linoproductus) phosphaticus Girty.
Pugnax sp.
Ambocoelia arcuata Girty.
Cardiomorpha? sp.
Leda obesa.
Yoldia mcchesneyana Girty.
Nucula montpelierensis Girty.
Schizodus ferrieri Girty.
Aviculipecten montpelierensis Girty.
Plagioglpyta canna White.
Pleurotomaria aff. nevadensis Walcott.
idahoensis Girty.
Aclisina sp.
Cytherella benniei Jones, Kirkby, and Brady.
Hollina emaciata var. occidentalis Girty.
Jonesina carbonifera Girty.
Primitia? sp.
Paleocypris? sp.

From the base of the phosphate shales, SE¼ sec. 18, T. 11 N., R S E.:

Solenomya sp.
Yoldia mcchesneyana Girty.
Nucula montpelierensis Girty?
Aviculipecten montpelierensis Girty.
Grammysia carbonaria Girty.
Schizodus ferrieri Girty.
Naticopsis n. sp.
Paralegoceras n. sp.

TRIASSIC SYSTEM

The Triassic system in this region is represented by several thousand feet of sediments, chiefly shale and limestone. These beds have been divided into three formations on the basis of a middle limestone zone, the Thaynes limestone, which separates the underlying Woodside shale from the overlying Ankareh shale. Both shale formations are typical red beds in which only a few fossils have been found, but the limestone locally carries an abundant fauna of Lower

[27] Girty, G. H., The fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah: U. S. Geol. Survey Bull. 436, 1910. Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 75–81, 1927.

Triassic age. These formations were named by Boutwell [28] from their occurrence in the Park City district, Utah. When traced over considerable areas, the rocks are found to vary in thickness and composition, and in Idaho Mansfield [29] has made a number of subdivisions and has abandoned the use of the name Ankareh. But in the Randolph quadrangle the three formations constitute mappable lithologic units.

WOODSIDE SHALE

The Woodside shale was named by Boutwell from Woodside Gulch, in the vicinity of Park City, Utah. In the Park City district the Woodside shale is composed of fine-grained dark-red shale. Sixty miles north of the type locality, in the Randolph quadrangle, the Woodside shale is composed of varicolored reddish, greenish, and drab sandy and clay shale and subordinate thin beds of drab calcareous fine-grained sandstone and gray limestone, approximately 1,000 feet thick. Composed of soft beds lying between more resistant rocks, the outcrops of the Woodside shale form relatively low land the surface of which is generally littered with debris derived from the adjacent formations, so that a complete section is not exposed.

The Woodside shale crops out in two localities in this area, east of Laketown and in the Crawford Mountains. East of Laketown the Woodside shale forms part of a sequence of overturned westward-dipping strata that lie between the Phosphoria formation on the west and the Thaynes limestone on the east and outcrop in both branches of Old Laketown Canyon and on the divide between them. The extension of the shale to the north and south is concealed by the overlap of the Wasatch formation. In the Crawford Mountains the Woodside shale is exposed for a distance of about 5 miles in the north-central part of the range, where it occupies the center of a narrow syncline. This outcrop is separated from a smaller one of the same formation 2 miles south of it by folding, which brings older beds to the surface.

A distinct change in conditions of sedimentation, indicative of disconformity, is marked by the contact of the Rex chert member of the Phosphoria formation and the overlying Woodside shale. At the upper contact, calcareous beds of the Woodside shale grade into the overlying Thaynes limestone. Where fossils occur the base of the Thaynes has been considered to be the lowermost occurrence of the ammonoid *Meekoceras*, but in the absence of fossils the top of the Woodside shale is considered to be marked by the change from pre-

[28] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, 1912.

[29] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927.

vailing shale to prevailing limestone, which in this sequence of variable beds is not everywhere a definite horizon. For purposes of small-scale mapping, however, this change serves as a practical division between formations, which on the whole are distinct lithologic units.

In the Randolph quadrangle a small fauna was found near the base of the Woodside shale, in the Crawford Mountains, 5 miles northeast of Randolph. According to G. H. Girty the collections include abundant *Lingula*, probably a new species, *Spirorbis*(?) sp., and a small undetermined gastropod. From a horizon about 500 feet higher *Pteria*(?) sp., *Schizodus*(?) sp., and *Naticopsis*(?) sp. were obtained.

THAYNES LIMESTONE

The Thaynes limestone, named by Boutwell from a canyon in the Park City district, includes the beds lying between the Woodside and Ankareh shales and containing fossils of Lower Triassic age.

The rocks are typically calcareous, consisting chiefly of limestone and calcareous sandstone with some shale, including subordinate red beds. The sequence varies, and in places the formation has been subdivided into several units. In southeastern Idaho Mansfield[30] has divided the Thaynes deposits—there called Thaynes group, into the Portneuf, Fort Hall, and Ross Fork formations, and in the Fort Douglas area, east of Salt Lake City, Utah, Mathews[31] has separated the Thaynes, on the basis of fossil evidence, into two units, to which he has applied the names Pinecrest formation and Emigration formation. The Pinecrest he assigns to the Lower Triassic and the Emigration to the Middle Triassic.

In the Randolph quadrangle there are only a few small areas where the Thaynes formation crops out—east of Laketown, northwest of Woodruff, east of Bear River (north of Sucker Spring), and east of Bear Lake. The exposures are poor and incomplete, showing massive gray limestone and calcareous buff sandstone interbedded with drab calcareous and sandy shale.

ANKAREH SHALE (TRIÁSSIC?)

The Ankareh shale, named by Boutwell from a ridge in the Park City district, is a lithologic unit consisting of red beds lying between the Thaynes limestone and the Nugget sandstone.

In the Randolph quadrangle about 600 feet of variegated red beds, consisting of red and drab sandy and clay shale, red-buff and gray calcareous sandstone, and thin beds of gray limestone lying between the Thaynes limestone and massive beds of the Nugget sandstone, are

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[30] Mansfield, G. R., op. cit., pp. 87–91.

[31] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., No. 1, 1931.

referred to the Ankareh shale. These beds correspond to the lower member of Veatch's Nugget formation.[32] They are exposed in a narrow zone about 5 miles long on the flanks of the upland east of Bear Lake and south of South Eden Creek.

JURASSIC SYSTEM

The Jurassic system is represented by the Nugget sandstone, which is assigned to the Middle (?) Jurassic, and the Twin Creek limestone, of Upper Jurassic age; the lower part at least of the overlying Beckwith formation also is of Upper Jurassic age. Apparently a hiatus, corresponding to the Lower Jurassic, marks the interval between the deposition of the Ankareh shale and the Nugget sandstone.

NUGGET SANDSTONE

The name Nugget formation was introduced by Veatch,[33] from Nugget station on the Oregon Short Line Railroad, 9 miles east of the Randolph quadrangle. As originally defined, the formation included an upper sandstone member and a lower red bed member. As stated on page 28, the red bed member is now correlated with the Ankareh shale, and, following Mansfield,[34] the name Nugget is restricted to the upper sandstone member. Fossils have not been found in the Nugget sandstone, but it is believed to be equivalent to the Navajo sandstone of Eastern Utah.

In this quadrangle there are three far-separated areas in which the Nugget sandstone is exposed by erosion of the overlapping Wasatch formation—along Birch Creek some 10 miles west of Woodruff, in the northeast corner of the quadrangle, and east of Bear Lake. In all of these areas the resistant Nugget sandstone, forming prominent ridges, occurs in closely folded or overturned beds associated with the overlying Twin Creek limestone. A complete section of the formation is not exposed in the Randolph quadrangle, but the sandstone is at least 1,000 feet thick. In this area the Nugget is a massive uniformly fine-textured sandstone composed of small well-rounded grains of quartz. It is prevailingly of a homogeneous brick-red color, the pigment ocurring as a film around the grains of quartz. Locally, however, in the valley of South Eden Creek, 2 miles east of Bear Lake, the Nugget sandstone, near the middle part of the exposure, is almost white. This lack of color appears to be irregularly distributed, but whether it is due to original deposition or to subsequent bleaching is not known.

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[32] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 56, 1907.
[33] Veatch, A. C., op. cit.
[34] Mansfield, G. R., op. cit., p. 96.

TWIN CREEK LIMESTONE

The Twin Creek limestone, originally called Twin Creek formation, was named by Veatch [35] from exposures on Twin Creek east of Sage, Wyo., about 6 miles east of the Randolph quadrangle.

At the type locality the Twin Creek consists for the most part of dark calcareous shale, thin-bedded shaly limestone, and occasional sandstone and has a thickness of 3,500 to 3,800 feet. In the Randolph quadrangle the entire thickness of the Twin Creek limestone is not exposed. It crops out in the same general areas as does the Nugget sandstone, which it overlies, namely, along Birch Creek, in the southern part of the quadrangle, and east of Bear Lake, where the beds are steeply tilted, folded, and overturned. Here the Twin Creek consists of massive and thin-bedded gray limestone traversed by sets of joints, along which the rock tends to split in characteristic splintery fragments.

Marine fossils of Upper Jurassic age are abundant in the Twin Creek limestone, from which the collections listed below were identified by T. W. Stanton.

8174. Twelvemile Creek, 6 miles southwest of Woodruff, Utah:
   Pentacrinus asteriscus Meek and Hayden.
   Ostrea strigilecula White.
   Camptonectes pertenuistriatus Hall and Whitfield.

8178. About 4 miles east of Bear Lake, north side of North Eden Canyon:
   Ostrea strigilecula White.

8179. Six miles east of Bear Lake and 1 mile south of north boundary line of Randolph quadrangle:
   Pentacrinus asteriscus Meek and Hayden.
   Undetermined small gastropods.

8180. One and one-half miles east of Bear Lake, south side of North Eden Canyon:
   Ostrea strigilecula White.

8181. Two miles east of Bear Lake, north side of South Eden Canyon:
   Ostrea strigilecula White.

JURASSIC AND CRETACEOUS(?)

BECKWITH FORMATION

Beckwith formation is the name given by Veatch [36] to the strata that lie between the Twin Creek limestone and the Bear River formation in southwest Wyoming. The type locality is the Beckwith Ranch, just east of Beckwith station on the Oregon Short Line Railroad, 5 miles east of the Randolph quadrangle. Fossils indicate that the lower part of the formation is of Upper Jurassic age, but the upper part may prove to be Lower Cretaceous. In Idaho the rocks above the Twin Creek limestone have been separated by Mans-

[35] Veatch, A. C., op. cit.
[36] Veatch, A. C., op. cit., pp. 57–59, 1907.

field into the Preuss and Stump sandstones of Jurassic age, and the Gannett group, of Cretaceous(?) age, unconformably above which is the Wayan formation, which is tentatively assigned to the Lower Cretaceous.[37]

In the Randolph quadrangle, which includes part of the area occupied by the Beckwith formation described in Veatch's report,[38] only the upper part of the formation is exposed—a thickness of approximately 1,200 feet. Fossils have not been found in these rocks, and their age remains to be determined. The rocks assigned to the Beckwith in this quadrangle crop out in the hills along its easern border, east of the Crawford Mountains, at the southern entrance to the narrows of Bear River, and in Dry Hollow. These rocks consist of light and varicolored sandy shales, sandstone, and conglomerate, the predominant colors being shades of red, orange, yellow, green, and gray. The Beckwith is disconformably overlain by the Bear River formation.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

BEAR RIVER FORMATION

In southwest Wyoming, adjacent to the Bear River in the general vicinity of Evanston, is a series of strata known as the Bear River formation, the age of which has been the subject of much discussion.[39] The early explorers considered these rocks to be of Tertiary age. Later the beds were assigned to the "Laramie." Stanton in 1891 determined that the age of the Bear River formation is near the base of the Upper Cretaceous. Veatch mapped these rocks in 1905, placing the Bear River formation between the underlying Beckwith and the overlying Aspen formation, of Colorado age.

In the Randolph quadrangle the Bear River formation crops out in the vicinity of the narrows of the Bear River, east of Woodruff, and in a few small areas east of the Crawford Mountains. The formation consists of fissile blue-black clay and carbonaceous shale, interbedded thin layers of gray limestone, and buff sandstone. In places there are thin layers of coal, but coal of economic importance has not been found. Locally fossils are so abundant in the lime-

[37] Mansfield, G. R., op. cit., pp. 98–107.

[38] Veatch, A. C., op. cit.

[39] White, C. A., On the Bear River formation, a series of strata hitherto known as the Bear River Laramie: Am. Jour. Sci., 3d ser., vol. 43, pp. 91–97, 1892. Stanton, T. W., The stratigraphic position of the Bear River formation: Am. Jour. Sci., 3d ser., vol. 43, pp. 98–115, 1892. White, C. A., The Bear River formation and its characteristic fauna: U. S. Geol. Survey Bull. 128, 1895. Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 60–64, 1907.

stone layers as to constitute the great mass of the rock. In this quadrangle the Bear River formation is not completely represented. In adjacent areas in southwestern Wyoming Veatch reports that the thickness of the formation ranges from 500 to 5,000 feet.

The unique nonmarine invertebrate fauna of the Bear River formation was described in detail in 1895 by C. A. White.[40] Collections made in 1912 from the Randolph quadrangle were identified by T. W. Stanton as follows:

Bluff northwest of entrance to narrows of Bear River, NW¼ sec. 32, T. 18 N., R. 120 W., Wyoming:

Ostrea sp.
Corbicula durkeei Meek.
Corbula pyriformis Meek.
Pyrgulifera humerosa Meek.

Two miles north of narrows of Bear River, NW¼ sec. 17, T. 18 N., R. 120 W., Wyoming:

Corbicula durkeei Meek.
Corbula pyriformis Meek.
Pyrgulifera humerosa Meek.

Four miles north of narrows of Bear River, NW¼ sec. 5, T. 18 N., R. 120 W., Wyoming:

Ostrea sp.
Corbula engelmanni Meek.
    pyriformis Meek.
Undetermined gastropods.

TERTIARY SYSTEM

EOCENE SERIES

WASATCH FORMATION

Rocks that are representative of the time between the period of deposition of the Bear River formation and that of the Wasatch are not known in the Randolph quadrangle, although a considerable thickness of beds of Upper Cretaceous age is present farther south in Utah and in southwestern Wyoming.

The Laramide revolution, characterized by folding, faulting, and uplift, occurred at or near the close of the Mesozoic era in the Rocky Mountain region, and in the Randolph quadrangle this period of diastrophism was followed by erosion and the deposition of a great mass of continental deposits that were laid down on deformed beds of Paleozoic and Mesozoic age. These continental deposits have been traced southward to the type area of the Wasatch group, which

[40] White, C. A., The Bear River formation and its characteristic fauna: U. S. Geol. Survey Bull. 128, 1895.

was named by Hayden[41] in 1869 for exposures in Echo and Weber Canyons, Wasatch Mountains, Utah.[42]

In the area reported on by Veatch,[43] in southwestern Wyoming and adjacent parts of Utah, including a small part of the Randolph quadrangle, the Wasatch is treated as a group and separated into three formations, the Almy, Fowkes, and Knight. The present writer, however, in his survey of the Randolph quadrangle in 1912 found it impracticable to make this threefold subdivision of the Wasatch group.

In 1935 G. R. Mansfield and the writer while visiting the type locality of the Wasatch formation, in Echo Canyon and along the highway between Echo and Emory stations on the Union Pacific Railroad, southwest of Evanston, Wyo., noted an angular unconformity in the red beds, marked by horizontal rocks superimposed on strata that dip north between 20° and 25°. From the lower beds along the roadside, 5 miles east of Echo, a few fragments of fossil leaves were collected, among which R. W. Brown, of the Geological Survey, identified *Platanus* sp., which he reports ranges in age from the Dakota to the Miocene. The significance of the unconformity in the red beds, which may be only local, remains to be determined.

In the Randolph quadrangle the rocks assigned to the Wasatch formation occupy a belt across the central part of the area, capping most of the Bear River Plateau and extending westward over the summit of part of the Bear River Range. (See pl. 8, *A*.) As here developed the Wasatch formation is composed of varicolored and varitextured continental deposits consisting principally of conglomerate and sandstone, with subordinate amounts of sandy and clay shale, limestone, and tuff. Red is the prevailing color, but there are also pink, orange, buff, gray, and white beds. The conglomerate and sandstone are composed of debris of the older rocks of the region—quartzite, sandstone, and limestone—derived presumably from the Wasatch and Uinta Mountains. Usually the pebbles and boulders of the conglomerate are well-rounded and range in size from a fraction of an inch to as much as 3 feet in diameter. The limestone is fine-textured and is white, gray, or pinkish, and occurs in beds that range from a few inches up to a few feet in thickness. Fresh water shells found in the limestone in the SE¼ sec. 33, T. 12 N., R. 4 E., and in the SW¼ sec. 14, T. 11 N., R. 6 E., were identified by W. H. Dall as *Unio*, *Pachychelius*, and *Goniobasis*. In places the limestone is oolitic or concretionary, consisting of calcareous bands ar-

[41] Hayden, F. V., U. S. Geol. Survey Terr., 3d Ann. Rept., p. 90, 1869.

[42] Wilmarth, M. G., Lexicon of geologic names of the United States (including Alaska): U. S. Geol. Survey Bull. 896, p. 2278, 1938.

[43] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, pp. 87–96, 1907.

ranged concentrically about a nucleus of rounded grains or pebbles that range from a pinhead to 3 inches in diameter. This type of limestone is believed to be of algal origin. A conspicuous occurrence forms the hill immediately north of bench mark 7130, 5 miles southeast of Laketown.

Rhyolite tuffaceous rocks, which apparently are lenses in the Wasatch formation, although stratigraphic relations are concealed by Quaternary hill-wash deposits, crop out in a narrow belt west of the road between Woodruff and Randolph and also in Dry Hollow, east of the Crawford Mountains. The tuff is fine-textured and whitish to gray in color. Some of the exposures show distinct bedding planes, but others are more homogeneous. The rock is composed of glass and subordinate amounts of quartz, feldspar, and biotite. The location of the volcanic vent from which the material was derived is not known. Similar rocks are referred by Veatch [44] to the Fowkes formation, the type location of which is 7 miles south of the narrows of the Bear River.

Variability in composition, texture, and color are conspicuous features of the Wasatch formation. The beds are characteristically lenticular and were deposited under outwash, fluviatile, and lacustrine conditions. In the Randolph quadrangle the Wasatch formation has a thickness of approximately 1,000 feet. The base of the formation is an irregular erosion surface, the altitude of which varies a few hundred feet in nearby areas. The top of the formation is not present, as the upper beds have been removed by erosion. The beds lie approximately flat or dip east at low angles. Locally they are gently warped. They lie with pronounced unconformity on tilted beds of Mesozoic and Paleozoic age. (See pl. 8, *B*.)

The fresh-water shells listed on page 33 are the only fossils that have been obtained from the Wasatch formation in the Randolph quadrangle. The shells are not diagnostic, and the age of these post-Laramide deposits remains to be determined. Whether they are in part Fort Union is not known. Their equivalence to part of the typical Wasatch group of Hayden, however, indicates that they are in part lower Eocene. Final assignment of age must await paleontologic collections.

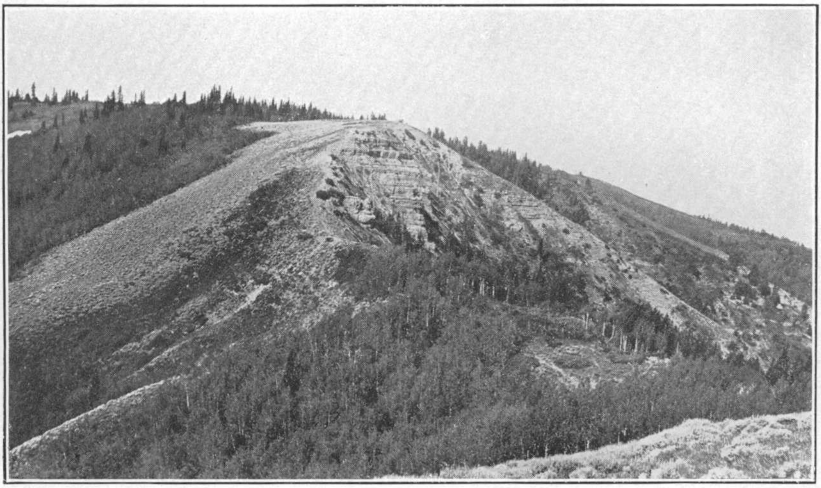
PLIOCENE(?) SERIES

SALT LAKE FORMATION

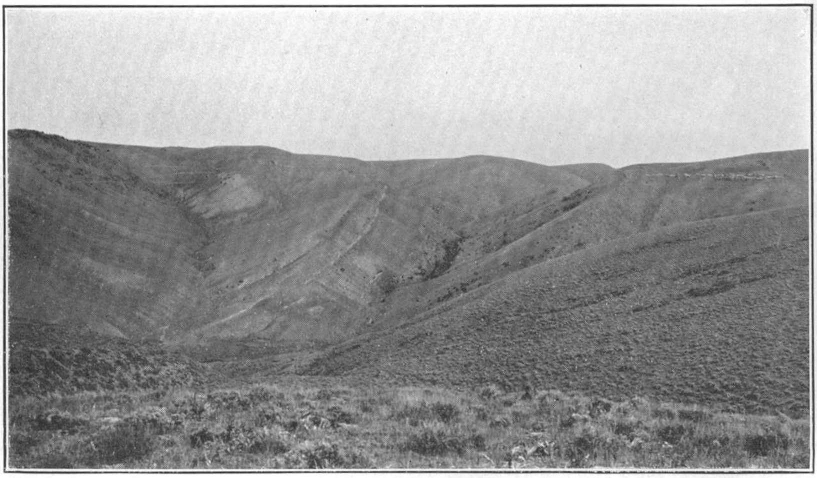
The Salt Lake formation—originally called Salt Lake group by Hayden and Peale—is the name given by Mansfield [45] to generally

[44] Veatch, A. C., op. cit., pp. 90–92.

[45] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 110, 1927.



A. WASATCH FORMATION CAPPING BEAR RIVER RANGE, SEC. 32, T. 11 N., R. 5 E.



B. HORIZONTAL WASATCH FORMATION LYING ON TILTED TWIN CREEK LIMESTONE.
Near north boundary of Randolph quadrangle, 2 miles east of Bear Lake.

light-colored beds of lacustrine and fluviatile origin that occupy lower hills and form foothill slopes along some of the larger valleys in southeastern Idaho, as on the western side of Bear Lake Valley in the Montpelier quadrangle.

In the Randolph quadrangle these beds are represented by occasional exposures of white marl, which are adjacent to the western shore of Bear Lake and extend from the Idaho-Utah boundary southward at least as far as Hodges Canyon. The marl is exposed in road and canal cuts and is generally covered by deposits of Quaternary hill wash. The greatest thickness observed was in the canal cut in the NE¼ sec. 6, T. 14 N., R. 5 E., where 10 feet of soft white marl is exposed. No fossils were found in the marl, which, following Mansfield, is tentatively assigned to the Pliocene(?).

QUATERNARY SYSTEM

Unconsolidated deposits of gravel, sand, and clay, including alluvium and hill wash, occupy the valley bottoms and the lower slopes of the uplands. The flood plain of the Bear River Valley and the lower courses of its principal tributaries are floored by alluvium composed of gravel, sand, and clay. Old benches marking the former extension of Bear Lake (see p. 5) likewise are composed of gravel, sand, and clay. The lower slopes of the uplands, between the outcrops of bedrock and the alluvium in the lowlands, are covered with a heterogeneous aggregate of debris (hill wash), consisting of various sized fragments of the outcropping rocks in the highlands.

IGNEOUS ROCKS

BASALT

Black Mountain, situated between North Eden and South Eden Canyons, 2 miles east of Bear Lake and rising 1,772 feet above it, is capped by basalt. (See pl. 4, *A*.) This is an erosion remnant of a flow of igneous rock that formerly occupied a more extensive area, but the vent from which the lava was outpoured is not known.

Blocks of basalt extend down the mountain side for several hundred feet below the summit. Talus conceals the contact with the underlying Wasatch formation, which is exposed farther down. The basalt is bluish black on a fresh surface and weathers to brownish gray. It is fine-textured and for the most part massive, but some is vesicular. Under the microscope the rock is seen to be composed of minute crystals of lime-soda feldspar and augite and small phenocrysts of olivine embedded in a glassy groundmass.

STRUCTURE

GENERAL RELATIONS

In accord with the general structure of the middle Rocky Mountain region the Paleozoic and Mesozoic rocks of the Randolph quadrangle are folded into northward- and southward-trending flexures that have been dislocated into blocks overthrust from the west (see fig. 2) and cut by normal faults. The Cenozoic beds are almost horizontal or dip eastward at low angles, overlying the older rocks with pronounced unconformity. (See pl. 8, *B*.) These general features, as far as they affect the Randolph quadrangle, are shown on the geologic map, plate 1, and in the structure sections.

BEAR RIVER RANGE

A large part of the Bear River Range in the Randolph quadrangle is covered with horizontal beds of the Wasatch formation, which conceal the structure of the underlying formations. In the northwestern part of the area, however, and in a few canyons that have cut deeply into the range in the southwestern part of the quadrangle, the structure of the older rocks is revealed, showing that the Paleozoic strata are folded and faulted.

Fish Haven syncline.—In the northwest corner of the quadrangle the rocks, which range from the Brigham quartzite at the base to the Swan Peak quartzite at the top, are folded into the gently northward-plunging Fish Haven syncline, named from Fish Haven Creek in the Montpelier quadrangle, Idaho.[46] In that quadrangle beds higher than the Swan Peak are also included in the syncline. On the east, near the base of the range, the Brigham quártzite crops out in low hills, dipping westward at an angle of about 20°, and is succeeded in order westward by the overlying formations up to the Swan Peak quartzite, which forms Swan Peak, altitude 9,114 feet, at the crest of the range about a mile south of the Idaho boundary. Along the axis of the syncline the beds lie almost horizontally. The axis, trending southward, rises in that direction, and 5 miles southwest of Garden City the Paleozoic beds are covered by an overlap of the Wasatch formation. There the Nounan limestone lies in the center of the fold, and the Bloomington formation, tilted eastward in the west flank of the syncline, forms a dip slope of about 10° to 15°. In the northwest corner of the quadrangle a fault cuts the syncline on the west, causing the Swan Peak quartzite and the underlying Garden City limestone west of the fault to abut against the Garden City limestone, St. Charles limestone, Nounan limestone, and Bloomington formation east of the dislocation. (See structure sections

[46] Mansfield, G. R., op. cit., p. 150.

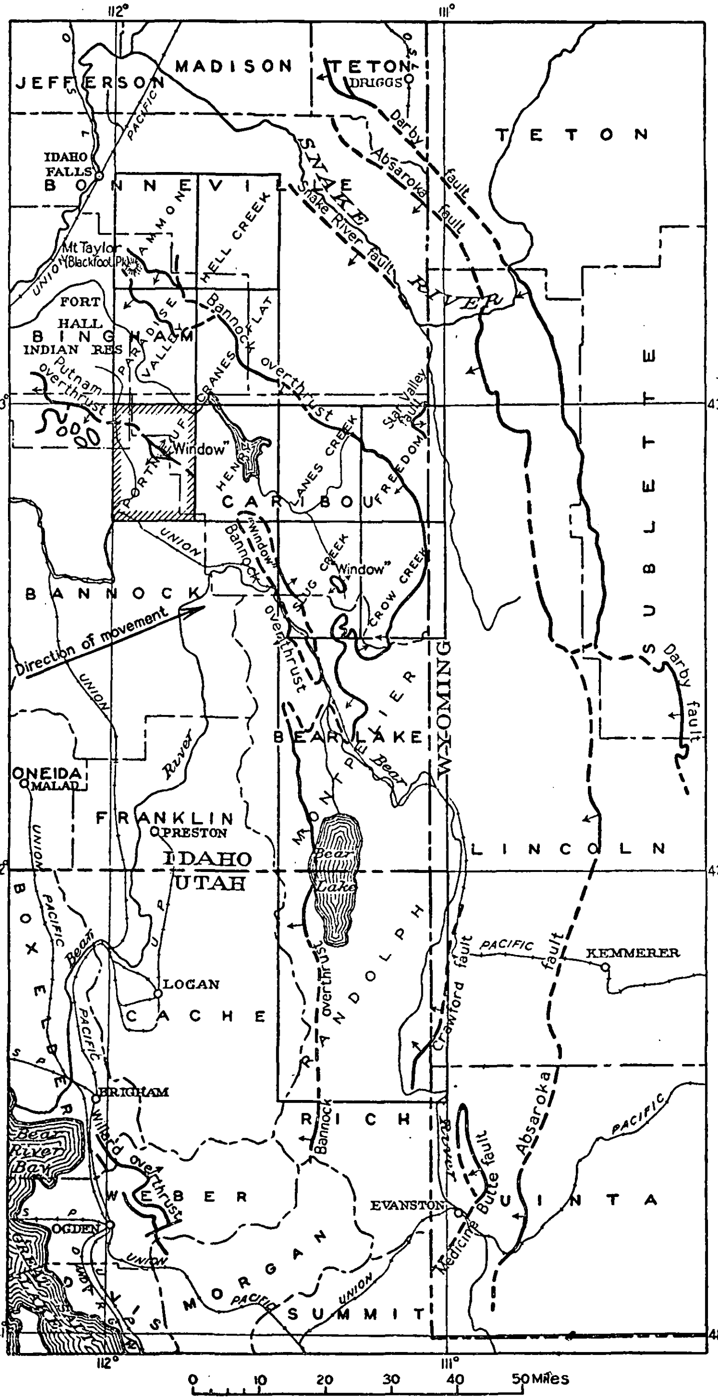


FIGURE 2.—Map showing location of Bannock overthrust and other thrust faults. After Mansfield, U. S. Geol. Survey Bull. 803, fig. 2.

A–A′ and *B–B′*, pl. 1.) The course or trace of the fault, down the mountain side to the west and back, suggests a rather gentle westward dip for the fault plane. Nevertheless, the eastward dip of the beds west of the fault suggests that it is of tensional rather than compressional origin.

Strawberry Valley anticline.—South of the Fish Haven syncline the greater part of the Bear River Range is covered by flat-lying Tertiary and Quaternary deposits, which conceal the underlying Paleozoic rocks. However, from occasional exposures in the valleys of streams that have cut through the younger beds, the general structure is indicated. The axis of a low anticline extends from Strawberry Valley northward 8 or 9 miles to the vicinity of the Logan-Meadowville road. Immediately west of the Randolph quadrangle this fold is marked by a low arch developed on the Brigham quartzite, small patches of which are present in secs. 16 and 32, T. 11 N., R. 4 E. The axis extends west of Saddle Creek in T. 12 N., R. 4 E., where the anticline is marked by several isolated outcrops of the Ute and other Cambrian formations, dipping, respectively, eastward and westward.

Curtis Creek syncline.—The belt of Cambrian formations, which extends northeastward through the southeastern part of T. 11 N., R. 4 E., into the southwest part of the adjoining township, dips gently toward a synclinal axis that appears to extend northeastward in Curtis Creek. Only part of the north limb of the fold is exposed, but the strike of the formations included in that part favors the structure suggested. On the north the Curtis Creek syncline appears to be separated from the Strawberry Valley anticline by a concealed fault, which extends northwestward from sec. 33, T. 11 N., R. 4 E. North of this postulated fault the older formations, where exposed, apparently strike a little east of north, whereas south of this line they strike more nearly east. Similarly, about a mile south of Rock Canyon another concealed fault is thought to extend northeastward, cutting the north limb of the Curtis Creek syncline and bringing undifferentiated Ordovician beds near the west border of the quadrangle into contact below the surface with beds of the Cambrian sequence, probably as low as the Blacksmith limestone.

BANNOCK OVERTHRUST

The Bannock overthrust, first described by Richards and Mansfield[47] and later studied in detail by Mansfield,[48] is one of the major structural features of the Rocky Mountains. It has been traced from

[47] Richards, R. W., and Mansfield, G. R., The Bannock overthrust, a major fault in southeastern Idaho and Northeastern Utah: Jour. Geology, vol. 20, pp. 681–707, 1912.

[48] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 150–159, 1927.

Utah northward into Idaho about 270 miles. The overthrusting was northeastward, its maximum measured overlap being approximately 35 miles.

In the Randolph quadrangle the Bannock overthrust is exposed west and northwest of Garden City, where for a distance of about 2 miles the Brigham quartzite is in contact with the Garden City limestone. Both formations dip west at an angle of about 50°, the Brigham quartzite on the west overriding the Garden City limestone. Locally in sec. 5, T. 14 N., R. 5 E., this fault, or possibly a branch of it, cuts the quartzite. The exact relationship is concealed. West of the fault the quartzite dips west at angles between 20° and 40°, and east of the dislocation the quartzite dips east at angles between 50° and 70°, forming a dip slope that is well exposed a few paces west of the highway.

South of the Garden City area for many miles the location of the Bannock overthrust is concealed by the cover of Tertiary and Quatenary deposits, although its approximate position is indicated at three localities within the Randolph quadrangle. Northwest of Meadowville, in T. 13 N., R. 5 E., the trace of the overthrust is indicated within narrow limits by the broad outcrop of Brigham quartzite, which dips west, and by the narrow zone of Cambrian formations northeast of it, which also dip west and are exposed in the cliffs that border Cheney Creek on the northeast. In Tps. 9 and 10 N., R. 5 E., the Bannock fault plane presumably lies only a short distance east of outcrops of the Brigham quartzite(?) because of the relationships disclosed in Birch Creek near the center of the south boundary of the quadrangle. Here the Brigham quartzite(?), dipping 30° west, is separated by Quaternary deposits from Nugget sandstone, dipping 45° west.

A few miles south of the Randolph quadrangle, in T. 8 N., R. 5 E., what is believed to be the southern continuation of the Bannock overthrust has been mapped by Gale and Richards[49] in the Woodruff Creek phosphate area.

BIRCH CREEK FOLDS

The Birch Creek folds are east of the supposed extension of the Bannock overthrust, at the southern end of the quadrangle. The Nugget sandstone is exposed along the Canyon of Birch Creek for a distance of about 0.9 mile and the Twin Creek limestone for about 3.6 miles farther. An isolated patch of Twin Creek also appears in sec. 8, T. 9 N., R. 6 E. The rocks are obscurely folded and broken. Whether they connect with similar structures east of Bear Lake in

[49] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430–H, pp. 526–528, 1910.

the northern part of the quadrangle is not known. Most of the intervening area is occupied by beds of the Wasatch formation, which conceal the relationships.

VICINITY OF LAKETOWN

Erosion of the former cover of Wasatch in Laketown Canyon and its branches has partly exposed the complex structure of the Paleozoic rocks in that area. Remnants of the Eocene strata, however, obscure relationships. In old Laketown Canyon, immediately east of Laketown, there is a monoclinal succession of steeply tilted beds standing practically on end, which range from the St. Charles limestone on the west to the Nugget sandstone on the east and include two horizons of phosphate rock, one in the Brazer limestone and the other in the Phosphoria formation. Before the finding of fossils in these two horizons of phosphate rock the structure was interpreted as a closely compressed faulted anticline.[50] To the north these steeply tilted beds in old Laketown Canyon are separated by a transverse fault from slightly tilted beds, chiefly of the Nugget formation, of Mesozoic age.

South of Laketown the partial exposures reveal the presence of a southward-plunging anticline and a southward-plunging syncline. The axis of the syncline, trending slightly west of north, lies near the junction of the southeast and southwest forks of Laketown Canyon where the Madison limestone is exposed, flanked by the normal succession of Threeforks and Jefferson limestones and Laketown dolomite. The lowest beds exposed in the anticline are of the St. Charles formation, which occupies the low foothills east and south of Laketown. The highest beds are those of the Devonian, which swing around the north end of the syncline just described. Obscure faults are indicated.

BEAR LAKE VALLEY

The valley of Bear Lake presumably is of structural origin. The bluffs of Brigham quartzite that rise above the southwest shore of the lake suggest that they may be delimited on the east by a concealed fault, which may be the northward continuation of the fault in the southwest fork of Laketown Canyon, 2½ miles southwest of Laketown, that separates the Ute limestone on the west from the Garden City limestone (mapped as undifferentiated Ordovican) on the east. However, as shown below, the fault in Laketown Canyon may be a segment of the Bannock overthrust, of which the fault forming the quartzite bluffs may be a branch.

The Nugget sandstone rises precipitously above the eastern shore of the lake and appears to be bordered on the west by a concealed

[50] Gale, H. S., and Richards, R. W., op. cit., p. 523.

fault. Similar relationships were noted by Mansfield[51] in the Montpelier quadrangle. His Bear Lake fault, for which he cited evidence, may continue into the Randolph quadrangle and be responsible for the scarplike aspect of the Nugget sandstone from the north boundary of the quadrangle as far south as sec. 17, T. 13 N., R. 6 E. Perhaps the east side of the Nugget ridge in secs. 5 and 8 of the same township is also a fault. Here the Nugget is so broken that its structure is not apparent, and slickensided faces are common.

The south end of Bear Lake Valley seems to be closely related to the transverse fault previously noted that separates the Paleozoic rocks exposed in old Laketown Canyon from the Nugget sandstone on the north. This fault, though concealed, is probably of considerable magnitude, and its western extension may possibly offset other north and south structures, such as the folds partly exposed in Laketown Canyon, and perhaps even the Bannock overthrust. This overthrust, after passing between the Cambrian quartzite and the Ordovician rocks in the northwestern part of T. 13 N., R. 5 E., as previously described, may continue southward to the west of the quartzite mass in secs. 15 and 22, T. 12 N., R. 5 E., but it seems more likely that it is offset somewhere in the northern part of Round Valley and then passes southward between the Ute limestone and the Ordovician rocks in Laketown Canyon. The offsetting fault, if continued across the south end of Bear Lake, would probably pass north of the small area of Ordovician mapped in sec. 35, T. 13 N., R. 5 E., which seems to be in the line of strike with the corresponding exposure in Laketown Canyon. Intersecting faults such as those just postulated might well have a bearing on the formation of the Round Valley part of the Bear Lake Valley. The offsetting fault, however, is so thoroughly concealed that nothing is known of its attitude or of the direction of the movements that took place on it.

AREA EAST OF BEAR LAKE

Contiguous to Bear Lake on the east and in North Eden and South Eden Canyons, Triassic and Jurassic formations are exposed in northward-trending anticlines and synclines. Along the eastern shore of the lake, between South Eden Creek and the northern border of the quadrangle, Nugget sandstone, steeply tilted, forms a ridge that rises 1,300 feet above the water. On the east the Nugget sandstone is bordered by a belt of Twin Creek limestone that dips westward at the north and farther south forms part of a northward-plunging anticline. Just above the mouth of South Eden Creek the Nugget sandstone, repeated possibly by faulting, is ex-

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[51] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 167, 1927.

posed underlying the Twin Creek limestone, and the outcrop continues southward for about 7 miles to the vicinity of Laketown, where it is cut off by the transverse fault already described.

The relations of the Nugget to the Twin Creek along the belt just described are not clear. The Nugget may be overthrust eastward upon the Twin Creek, as suggested by the apparent repetition of the Nugget in South Eden Canyon and the broken and slickensided appearance of the Nugget in secs. 5 and 8, T. 13 N., R. 6 E., previously mentioned. However, the Nugget and Twin Creek formations in the Montpelier quadrangle to the north are closely and steeply folded without appreciable faulting. Rocks as brittle as the Nugget are subject to much breaking and local internal movement in the course of adjusting themselves to folding. It seems likely therefore that the structures of this belt in the Randolph quadrangle represent the southward continuation of the folds better exposed in the Montpelier quadrangle and that no appreciable overthrusting has occurred between the Nugget and Twin Creek. The repetition of the Nugget in South Eden Canyon and possibly also the occurrence in secs. 5 and 8 could be explained by local minor folding, though in secs. 5 and 8 local faulting may also have taken place.

In North Eden Canyon, east of the above-mentioned belt of Twin Creek limestone, the Nugget sandstone crops out for a distance of about 2 miles on both flanks of a north-south trending anticline, east of which the Twin Creek limestone is exposed where the Wasatch formation has been eroded. In South Eden Canyon a few square miles of Twin Creek limestone are exposed, forming the flanks of the anticline, the axis of which crosses the canyon about 3 miles east of the lake. In the northeast corner of the quadrangle the Nugget sandstone and Twin Creek limestone crop out, dipping eastward, separated by a fault, as shown on plate 1.

CRAWFORD MOUNTAINS

The Crawford Mountains represent an uplifted block of folded and faulted rocks, ranging in age from the Jefferson dolomite to the Woodside shale including phosphate beds of the Phosphoria formation, which have been preserved in synclinal folds. The steep western face of the mountains, formed by beds of Brazer limestone dipping westward at steep angles, apparently is a fault escarpment. The fault plane lies along the bedding of the Brazer limestone but gradually truncates it in passing southward. The truncated mountain slopes shown in plate 5 appear to have been little eroded since the faulting, and the successive valleys along the mountain front all have sharply V-shaped mouths. Debris accumulations at the mouths of these canyons are relatively insignificant, another fact that testifies to the rather recent date of the faulting.

At the boundary between secs. 7 and 18, T. 11 N., R. 8 E., the escarpment intersects a fault, presumably a thrust that extends southward 5 miles and then branches southwest and southeast. The block included between the escarpment and the supposed thrust includes the Brazer limestone and older beds, extending well down into the Jefferson dolomite.

East of the thrust lies a syncline, more or less interrupted by sags and swells, which includes beds ranging in age from Wells to Woodside. The sags and swells bring in and cut out the phosphate as the beds rise above or sink below the present erosion surface.

Farther east, near the State line, another fault, presumably a thrust, causes repetition of the Madison and Devonian sequence, and the Laketown dolomite also appears. The mountain block as a whole is bounded on the east by a concealed fault, apparently a thrust. This appears to enter the quadrangle in the northwest part of T. 21 N., R. 120 W., in Wyoming, and to extend southward as far as the Bear River, a distance of about 18 miles. West of it lie beds ranging in age from Silurian to Lower Triassic. On the east the pre-Tertiary formations exposed here and there are of Jurassic and Cretaceous age. The only place where this fault may be located at all closely is in sec. 7, T. 10 N., R. 8 E., in Utah, where a small outcrop of the Bear River formation lies in close proximity to exposures of Madison limestone. Farther north, in sec. 33 of the adjoining township and near the State line, the Beckwith formation is exposed within a half or three quarters of a mile of rocks of Madison age. The structural features here described are illustrated in the geologic structure *C–C′*, *D–D′*, *and E–E′*, plate 1.

The northern continuation of the Crawford Mountains, lying north of Bridger Creek just east of the Utah-Wyoming boundary, is known as the Beckwith Hills. It is underlain by closely folded rocks ranging in age from the Jefferson to the Thaynes. As in the Crawford Mountains, the Phosphoria formation lies in a syncline, but relations are concealed by a cover of Quaternary deposits.

NARROWS ANTICLINE

A low anticlinal fold, named by Veatch [52] the Narrows anticline, is shown by him as extending across the southeastern part of the quadrangle in Tps. 18 and 19 N., R. 120 W., in Wyoming. The axis cannot be closely located in this area, but folding is shown by northwestward and southeastward dipping beds in the Beckwith forma-

[53] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 111, 1907.

tion. The distribution of the Bear River formation in the Randolph quadrangle is not fully in harmony with this interpretation, but definite evidence of the actual structure is not available.

MINERAL RESOURCES

The mineral resources of the Randolph quadrangle include phosphate rock, limestone, quartzite, and water, but, owing to the remoteness of the area from markets, only the water is utilized at present. Phosphate rock, which formerly was mined in a small way, constitutes a valuable reserve. Enormous quantities of limestone and quartzite are available, for which, however, there is no present demand. Lead and copper occur locally but have not been found in commercial quantity.

PHOSPHATE ROCK

The Randolph quadrangle includes several disconnected areas of phosphate rock, which form part of the Rocky Mountain phosphate field. Enormous deposits of phosphate rock, occurring chiefly in the Phosphoria formation in Idaho, Montana, Wyoming, and Utah, constitute one of the great reserves of phosphorous in the world. Owing to the cost of transportation, however, the present output of phosphate rock in the Rocky Mountain region amounts to less than 2 percent of the total production of the United States, the great bulk of which comes from Tennessee and Florida. In the Randolph quadrangle the phosphate deposits have been prospected at a number of places and have been mined in a small way, but since 1920 production of phosphate rock in Utah has not been reported.

OCCURRENCE AND CHARACTER

Phosphate rock is known at two horizons in this quadrangle—in the Brazer limestone and in the Phosphoria formation. It has been found at only one locality in the Brazer limestone, a mile east of Laketown. The principal occurrence in this area, as throughout the Rocky Mountain region, is in the Phosphoria formation, which crops out in the Crawford Mountains and their northern continuation, the Beckwith Hills, and east of Laketown, as shown by the red line on the geologic map.

The phosphate rock occurs in beds ranging in thickness from a fraction of an inch to 6 feet, which are interstratified with shale and limestone containing a marine fauna. The rock is dense and characteristically oolitic, consisting of rounded grains of concentrically arranged phosphatic material, which range from a minute speck to half an inch or more in diameter but are chiefly of the smaller size. The rock is commonly dark brown to black, and outcrops are usually grayish. Some weathered surfaces have a characteristic bluish-white coating.

The rock consists essentially of tricalcium phosphate, possibly in large part amorphous colloids allied to collophanite. The mode of origin has caused much discussion, but there is general agreement that the phosphates are originally derived from apatite and related minerals of igneous rocks and after a varied history (phosphorous enters into the life activity of plants and animals) have been carried in solution by streams and finally precipitated on the sea floor. References to many papers on the origin of phosphates are contained in the following selected list:

Clark, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, pp. 523–534, 1924.

Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 361–367, 1927.

Lindgren, Waldemar, Mineral deposits, 4th ed., pp. 282–292, New York and London, McGraw-Hill Book Co., Inc., 1933.

Jacobs, K. D., Hill, W. L., Marshall, H. L., and Reynolds, D. S., The composition and distribution of phosphate rock: U. S. Dept. Agr. Tech. Bull. 364, 1933.

SECTIONS

The following sections of phosphate beds in the Randolph quadrangle and the results of analyses were reported by Gale and Richards.[53]

At the northern end of the Crawford Mountains two mines have been opened in T. 12 N., R. 8 E. In the Arikaree mine, in lot 2, sec. 32, about 1,700 feet S. 30° W. from the 52-mile post on the Utah-Wyoming State line, the dip of the beds is west 50° and the strike is N. 32° E. In the Mandan mine on the opposite side of the syncline, in lot 1, sec. 32, the dip of the beds is about vertical, or they are locally overturned.

The bed that is worked measures from 53 to 60 inches in total thickness but is divided into two parts by the so-called "gray streak." This is a leaner parting, 2½ to 7 inches thick, that separates about a foot of the high-grade ore at the bottom of the bed from the upper part. The most massive or less shaly material and the most coarsely oolitic is considered the best ore. The rock of the workable bed is dark gray when freshly taken out, but dries to a light gray in the air. It is of fine to medium and in part coarsely oolitic texture and shows both massive and shaly structure.

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[53] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430–H, pp. 457–535, 1910.

Representative section of main bed at Arikaree mine

	Thickness	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft. in.	*Percent*	*Percent*
Phosphate, gray, coarsely oolitic	1 9	29.4	64.4
Phosphate, gray, oolitic	1 4	37.6	82.3
Phosphate, brown, shaly, somewhat oolitic (lean streak)	7	21.4	46.9
Phosphate, gray, medium to coarse, oolitic	1	38.0	82.3
Phosphate, fine-grained, shaly, somewhat oolitic (not mined)	9	34.6	75.8

Partial section of phosphate beds at the Mandan mine

	Thickness	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
Main bed:	*Ft. in.*	*Percent*	*Percent*
Phosphate, gray, coarsely oolitic	3 6	33.8	74.0
Phosphate, lean streak	8		
Phosphate, gray, fine, oolitic	1 6		

Section of phosphate and associated beds in NW¼SE¼ sec. 18, T. 11 N., R. 8 E.

	Thickness	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft. in.	*Percent*	*Percent*
Phosphate, dark gray, coarsely oolitic	3 8	32.7	71.6
Phosphate, brown, shaly	5 2	26.3	57.6
Limestone	6		
Phosphate, brownish gray, oolitic	1 6	26.7	58.5

Section of phosphate and associated beds approximately in NE¼NE¼ sec. 19, T. 11 N, R. 8 E.

	Thickness	P_2O_5	Equivalent to $Ca_3(PO_4)_2$
Main bed:	*Ft. in.*	*Percent*	*Percent*
Phosphate, dark gray or black, massive, coarsely oolitic	3 2	34.9	76.4
Phosphate, shaly, brown, weathered, oolitic	8	23.7	51.9
Phosphate, dark, almost black, oolitic	1 2	36.8	80.6
Phosphate, brown, shaly, finely oolitic	5 8	31.0	67.9
Interval, concealed, probably shaly	4 8		
Phosphate, or limestone, dark gray or black, massive	1 8	26.8	58.7
Limestone, cherty	8 0		
Phosphate, dark gray, massive, calcareous	1 2	28.7	62.8
Interval concealed	71 6		
Shale, brown	1 5	23.4	51.2
Phosphate, gray, oolitic	4		
Shale, brown	1		
Phosphate, brown, earthy material	1 7	27.8	60.3

Prospecting in the southern part of the Crawford Mountains had not been carried on down to 1912, the time of the survey upon which this report is based.

In the Beckwith Hills, the northern continuation of the Crawford Mountains, the phosphate deposits have been opened up at a number of places, and the following measurements of the beds and the results of analyses of samples are reported by Gale and Richards.

Partial section of phosphate beds in sec. 2, T. 21 N., R. 120 W.

	Thickness		P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft.	*in.*	*Percent*	*Percent*
Clay, with fragments of phosphate rock	1	2		
Phosphate rock		6	34.7	76.0
Shale		10½		
Phosphate rock, brownish gray, soft	1		27.3	59.8
Limestone	1	7		
Phosphate rock, coarsely oolitic, soft	1	6	31.5	70.0
Phosphate rock, shaly, gray-brown, soft		9	10.0	21.9
Phosphate rock, dark gray, oolitic	2	6	28.4	62.2
Phosphate rock, shaly, brown		6	10.6	23.2

Partial section of phosphate beds in sec. 3, T. 21 N., R. 120 W.

	Thickness		P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft.	*in.*	*Percent*	*Percent*
Shale, gray, soft	1	6	23.5	51.5
Shale, gray, shaly, soft		11	2.7	5.9
Phosphate rock, gray, oolitic, soft	1	7	23.7	51.9
Phosphate rock, coarsely oolitic		4	25.8	56.5
Phosphate rock, gray, hard, grading to black, pebbly at base	2	3		

Partial section of phosphate beds in sec. 10, T. 21 N., R. 120 W.

	Thickness		P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft.	*in.*	*Percent*	*Percent*
Phosphate rock, mostly soil-like, but contains some oolitic material	3	2	28.4	62.2
Shale		7		
Phosphate rock, gray, oolitic		8	25.7	56.3
Phosphate rock, reddish gray, fine grained		10		
Phosphate rock, gray, oolitic	1	10		

Partial section of phosphate beds in sec. 15, T. 21 N., R. 120 W.

	Thickness		P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft.	*in.*	*Percent*	*Percent*
Phosphate rock, dark gray to black, oolitic, hard		4	13.9	30.5
Shale, brown, earthy, thin		5		
Pebble bed		1	36.0	78.8
Phosphate rock, dark gray to black, massive, hard	2	11		
Phosphate rock, fine, grained, oolitic, hard		6	23.7	51.9
Phosphate rock, black, coarsely oolitic		11	34.7	76.0
Phosphate rock, light gray, sandy and shaly		10	34.9	76.4
Shale, soft, iron-stained		1		

In old Laketown Canyon, east of Laketown, two zones of phosphate beds are exposed in sec. 32, T. 13 N., R. 6 E. Formerly these zones were considered to be the same beds, in the Phosphoria formation on both flanks of an anticline, but the present interpretation, which is based on fossil evidence, is that the structure is monoclinal and that the westernmost phosphate beds are in the Brazer limestone and the easternmost are in the Phosphoria formation.

Shallow pits opened in 1907 in the Brazer limestone in the SE¼NW¼ sec. 32, showed a 2-foot bed of high-grade phosphate rock, which averaged 36.6 percent of P_2O_5 or 80 percent of $Ca_3(PO_4)_2$, and 40 feet of material which averaged 13.7 percent of P_2O_5 or 30 percent of $Ca_3(PO_4)_2$.

The character of the easternmost beds is shown below.

Section of phosphate rock in Phosphoria formation in NE¼ sec. 32, T. 13 N., R. 6 E.

	Thickness		P_2O_5	Equivalent to $Ca_3(PO_4)_2$
	Ft.	*In.*	*Percent*	*Percent*
Cherty limestone, phosphate rock, oolitic	1	5	36.3	79.5
Shale, brown		4		
Phosphate rock, gray, coarse, oolitic, friable		5	37.3	81.7
Phosphate rock, gray, fine, oolitic		5	26.4	57.0
Phosphate rock, gray, coarse, oolitic, weathers into flat concretions up to 1 inch in diameter		6	36.7	80.4
Phosphate rock, fine grained, oolitic, weathered		8	26.0	56.5
Phosphate rock, gray, fine to medium, oolitic	2	10	34.1	74.7

The following analysis by George Steiger of a specimen of phosphate rock from the Crawford Mountains is reported by Gale and Richards:[54]

Analysis of phosphate rock from Crawford Mountains

	Percent		Percent
Insoluble	1.82	TiO_2	None
SiO_2	.30	CO_2	1.72
Al_2O_3	.50	P_2O_5	36.35
Fe_2O_3	.26	SO_3	2.98
MgO	.22	F	.40
CaO	50.97	Cl	Trace
Na_2O	2.00	Organic matter	Not determined
K_2O	.47		
H_2O	.48		99.04
H_2O+	.57		

RESERVES

Estimates of minimum available tonnage of rock phosphate, of 70 percent or more of $Ca_3(PO_4)_2$ grade, have been made by Gale and Richards as follows:

	Long tons
Crawford Mountain district	90,000,000
Beckwith Hills district	2,800,000
Laketown district	6,750,000

COPPER AND LEAD

For many years copper and lead have been known to occur in small quantity along the eastern flank of the Bear River Range

[54] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430–H, p. 465, 1910.

west of Bear Lake, but ore has not been found in paying quantity. This mineralized zone has been described by R. W. Richards:[55]

The lead ores consist of galena with small amounts of cerusite and wulfenite in a gangue of iron-stained calcite and dolomite and are found at Swan Creek, Utah, and near St. Charles and Paris, Idaho. They appear to be tabular replacement deposits in limestone more or less parallel to the bedding and cut and limited by fissures. The copper ores consist mainly of the carbonates azurite and malachite in quartz veins. * * * The prospect on Swan Creek, described as Victoria No. 1, is a short distance south of the Utah-Idaho line. It is said to be the center of a group of eight claims. The wall rock is massive limestone. The ore consists of malachite, azurite accompanying barite, and calcite in a much brecciated zone approximately paralled to the stratification of the beds. Recrystallization or marbleization of the limestone is shown at the same horizon 100 yards or more to the south. The amount of ore at this place has not yet been proved to be sufficient to make a commercially valuable property.

WATER

The water supply of the Randolph quadrangle, derived originally from snow and rain, is obtained principally from the Bear River and its tributaries but is supplemented by ground water from springs and wells. Bear Lake is little utilized as a source of water in this area. It serves chiefly as a reservoir to regulate the flow of the Bear River in its lower course.

The climate is mountainous continental. The precipitation is light, ranging from about 10 inches in the Bear River Valley to a little more than 20 inches on the Bear River Range. The mean annual temperature is low, and the temperature range between day and night and between winter and summer is considerable. The growing season for crops is short. Climatological data relating to this region, taken from reports of the Weather Bureau,[56] are summarized in the following tables:

Mean monthly and annual precipitation, in inches

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Randolph	0.80	0.74	0.86	0.93	1.06	0.91	1.01	0.85	1.25	0.93	0.43	0.56	10.33
Laketown	1.81	1.61	1.50	1.55	1.56	.89	.68	.75	1.30	1.49	1.02	.81	14.97
Woodruff	.73	.92	.94	.78	1.05	.86	.77	.64	.74	1.10	.44	.59	9.56

Mean monthly and annual temperature, ° F.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Laketown	21.9	21.6	29.2	41.0	48.9	57.2	64.6	63.2	53.9	43.7	33.3	24.5	41.9
Woodruff	15.7	16.7	27.5	40.3	46.9	55.0	60.7	59.7	51.4	41.2	29.9	19.2	38.7

[55] Richards, R. W., Notes on lead and copper deposits in the Bear River Range, Idaho and Utah: U. S. Geol. Survey Bull. 470, pp. 177–181, 1911.

[56] Summaries of climatological data by sections, U. S. Dept. Agr., Weather Bur., Bull. W, 2 ed., vol. 1, sec. 11, Western Utah, 1926.

Average date of killing frost

	Last killing frost in spring	First killing frost in autumn
Laketown	June 14	Sept. 6.
Woodruff	July 9	Aug. 18.

The Bear River rises on the north slope of the Uinta Mountains and after a circuitous course of more than 300 miles in Utah, Wyoming, and Idaho, finally empties into Great Salt Lake, which is only about 80 miles distant in an air line from its source. Melting snows are the chief source of supply, and the high-water period occurs during May and June. Gaging stations are not maintained on Bear River in the Randolph quadrangle, but for a number of years discharge measurements have been made elsewhere along the river at stations under the supervision of the Geological Survey. The data obtained near Evanston, Wyo., and Harer, Idaho, afford an index of the volume of water flowing in the river in the Randolph quadrangle. At the station located in sec. 1, T. 15 N., R. 121 W., 3½ miles northwest of Evanston, where the drainage area covers 645 square miles, the average discharge of Bear River during the 20-year period 1913–33 was 258 second-feet. The maximum of 3,690 second-feet was recorded on June 14, 1921. No flow occurred during some periods in 1924, 1931, and 1933. Some diversions for irrigation are made above the station.[57]

At the gaging station located in sec. 22, T. 14 S., R. 45 E., three-fourths of a mile north of Harer siding on the Oregon Short Line Railroad, where the drainage area covers 2,780 square miles, the average discharge of the Bear River during the periods June 1913 to September 1916 and January 1919 to September 1933 was 587 second-feet. The maximum of 3,860 second-feet was recorded on June 2, 1920; the minimum, which occurred during the winter, was not recorded. There are numerous diversions for irrigation above the station.[58]

The water table lies near the surface in the lowlands of the Bear River and Bear Lake Valleys, where water is obtained from shallow wells. On the uplands water is generally scarce, although springs occur locally, especially at the contact of flat-lying permeable sandstone and conglomerate of the Wasatch formation and relatively impervious underlying beds. A few springs issue from solution channels in limestone. One of the largest is Swan Creek Spring, in sec. 6, T. 14 N., R. 5 E. It issues from a cavern in the Blacksmith

[57] For detailed measurements see Surface water supply of the United States, 1933, Part 10, The Great Basin: U. S. Geol. Survey Water-Supply Paper 750, p. 12, 1935.
[58] Idem, p. 13.

limestone, and its flow, measured by the Utah Power & Light Co., is about 30 to 35 second-feet in the winter and more than 200 second-feet in May. A small power plant utilizes the flow of this spring in generating electricity for the use of Laketown and Garden City, Utah, and Fish Haven, Idaho.

The domestic water supply for the towns of Randolph, Garden City, Laketown, and Woodruff formerly was obtained from wells, but in 1935 the piping of water supplies from springs located within a few miles of each town was either in operation or was being planned.

Several small irrigation projects are in operation in the Bear River and Bear Lake Valleys within the quadrangle. These are privately owned, and little information concerning them is available. The location of the main canals is shown on the map (pl. 1). The lands below the canals are irrigated, the principal crops being hay and grain.

Bear Lake has been utilized for many years as a reservoir to regulate the flow of the Bear River below the lake, where the water is extensively employed for irrigation and power. The lake, which lies partly in Rich County, Utah, and partly in Bear Lake County, Idaho, occupies an area of about 8 by 21 miles, not including a large swamp and a shallow body of water, Mud Lake, at its north end. The drainage area immediately tributary to Bear Lake covers about 250 square miles, but by means of a canal, water is conveyed to the lake from Bear River near Dingle, Idaho, increasing the tributary drainage area by about 3,000 square miles. A pumping plant located at the northern end of the lake raises the water to the outlet canal, which empties into the Bear River west of Montpelier, Idaho.[59]

The following data relating to the Bear Lake water supply for the period 1925–34 were prepared by the Utah Power & Light Co.:

Annual discharge, in acre-feet, of tributary streams, inlet canals, and outlet canal, Bear Lake, Utah-Idaho

Year	Tributary streams	Inlet canals	Outlet canal
1925	105,000	188,000	315,000
1926	74,400	75,700	421,000
1927	110,000	182,000	208,000
1928	109,000	249,000	224,000
1929	112,000	230,000	128,000
1930	77,200	117,000	186,000
1931	37,100	36,000	249,000
1932	108,000	218,000	75,500
1933	94,800	117,000	147,000
1934	31,000	30,300	239,000

[59] Woolley, R. R., Water powers of the Great Salt Lake basin: U. S. Geol. Survey Water-Supply Paper 517, pp. 42–43, 1924.

High and low altitudes, in feet, surface of Bear Lake, Utah-Idaho

Year	High	Low	Year	High	Low
1925	5,918.90	5,915.27	1930	5,915.17	5,911.87
1926	5,916.27	5,909.27	1931	5,912.74	5,907.14
1927	5,912.29	5,908.60	1932	5,911.92	5,907.32
1928	5,914.71	5,909.82	1933	5,913.02	5,909.23
1929	5,915.03	5,910.40	1934	5,910.05	5,903.99

The low altitude of the surface of Bear Lake in 1934 was 20 feet below its level at the time the Randolph quadrangle was surveyed, in 1909–10, when the surface of the lake was 5,924 feet above sea level.

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