Geology of the Paradise Quadrangle Cache County, Utah

By THOMAS E. MULLENS and GLEN A. IZETT

CONTRIBUTIONS TO GENERAL GEOLOGY

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A study of the surface geology of the quadrangle and the phosphate deposits which occur in mudstone of Mississippian age

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CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGY OF THE PARADISE QUADRANGLE CACHE COUNTY, UTAH

By THOMAS E. MULLENS and GLEN A. IZETT

ABSTRACT

The Paradise quadrangle includes the south end of Cache Valley and part of the Bear River Range in southern Cache County, Utah. About 4,800 feet of limestone, dolomite, and sandstone of Devonian, Mississippian, and Pennsylvanian age crops out in the mountains; most of these rocks were deposited in a marine environment. Siltstone, sandstone, and conglomerate of Tertiary and Quaternary age crop out in Cache Valley; these rocks were deposited in a continental environment.

Paleozoic rocks in the Bear River Range are gently folded. Along a zone at the mountain front, these rocks are broken by low- and high-angle faults that roughly parallel the north-trending mountains. The low-angle faults are probably normal faults associated with the uplifting of the mountains, but possibly they are west-dipping thrust faults that dip more steeply than the average slope of the mountain front. Cache Valley is probably a graben. Tertiary beds in the valley are folded and faulted, but exposures are too poor to show details of geologic structure. Quaternary beds, consisting mainly of rocks deposited in Lake Bonneville, are not faulted.

A thin zone of phosphatic rock is at the base of the Brazer Limestone of Mississippian age, but the phosphate content of the zone is too low to be of economic importance. Gravel is abundant in bars and deltas that formed in Lake Bonneville, but the lack of a large local market has prevented the development of the gravel deposits. Smithsonite, a zinc carbonate mineral, is locally present in fractured dolomite and limestone along the fault zone at the mountain front. Two carloads of ore were produced in 1915 from a prospect in this zone, but no other production is recorded.

INTRODUCTION

The Paradise 7½-minute quadrangle was mapped in 1960 as part of the U.S. Geological Survey program of classifying lands for which the Federal Government retains certain mineral rights. In the Paradise quadrangle, the Government had retained mineral rights for phosphate in parts of T. 9 N., R. 1 E., and T. 10 N., Rs. 1 and 2 E., that are underlain by a phosphate-bearing zone at the base of the Brazer Limestone of Mississippian age. The chief purpose of mapping was to determine the geologic setting and character of this zone and to appraise the potential for producing phosphate from these lands. A secondary purpose was to map the quadrangle at a scale suitable for use by the Geological Survey in preparing a geologic atlas of the United States. The geologic map (pl. 1) included with this report has been published as U.S. Geological Survey Geologic Quadrangle Map GQ-185 (Mullens and Izett, 1963).

The Paradise quadrangle is in the southern part of Cache County, Utah (fig. 1); it includes the southern part of Cache Valley and part of the Bear River Range. The mountain front, which trends north, rises about 2,000 feet above the east side of the valley. Maximum relief in the area is about 3,500 feet; altitudes range from 4,600 feet below the dam at Hyrum Reservoir to 8,106 feet in the SE¼ sec. 18, T. 10 N., R. 2 E. Local relief is greatest along west-trending canyons cut in the mountains, where canyon floors are as much as 3,000 feet below the divides.

Much of Cache Valley is farmland. Wheat, grown by dry-farming methods as well as on irrigated land, is the chief crop. Land in the mountains is used for grazing sheep and cattle. Hyrum, population about 1,700, and Paradise, population about 400, are local trade and school centers. Logan, population about 18,500 and 7 miles north of the Paradise quadrangle, is the chief trade center in Cache County.

The geology of the Paradise quadrangle was treated in works by Williams that describe the geology of larger regions: the Logan 30-minute quadrangle (Williams, 1948), Cache County, Utah (Williams, 1958), and Lake Bonneville deposits in southern Cache Valley (Williams, 1962). Regional correlations of some stratigraphic units that crop out in the quadrangle have been discussed by Williams (1943), Holland (1952), Parks (1951), Adamson, Hardy, and Williams (1955), and Nygreen (1958).

STRATIGRAPHY

Devonian, Mississippian, and Pennsylvanian sedimentary rocks totaling about 4,800 feet in thickness crop out in the Bear River Range, and Tertiary and Quaternary sedimentary rocks crop out in Cache Valley. Most Paleozoic rocks were deposited in a marine environment, but some of the oldest Devonian rocks were probably deposited in a continental or marginal marine environment; Tertiary and Quaternary rocks were deposited in a continental environment. The areal distribution of formations within the quadrangle and a columnar section of the Paleozoic rocks are shown on plate 1. Representative measured sections of the exposed Paleozoic rocks are given on pages S25 to S30.

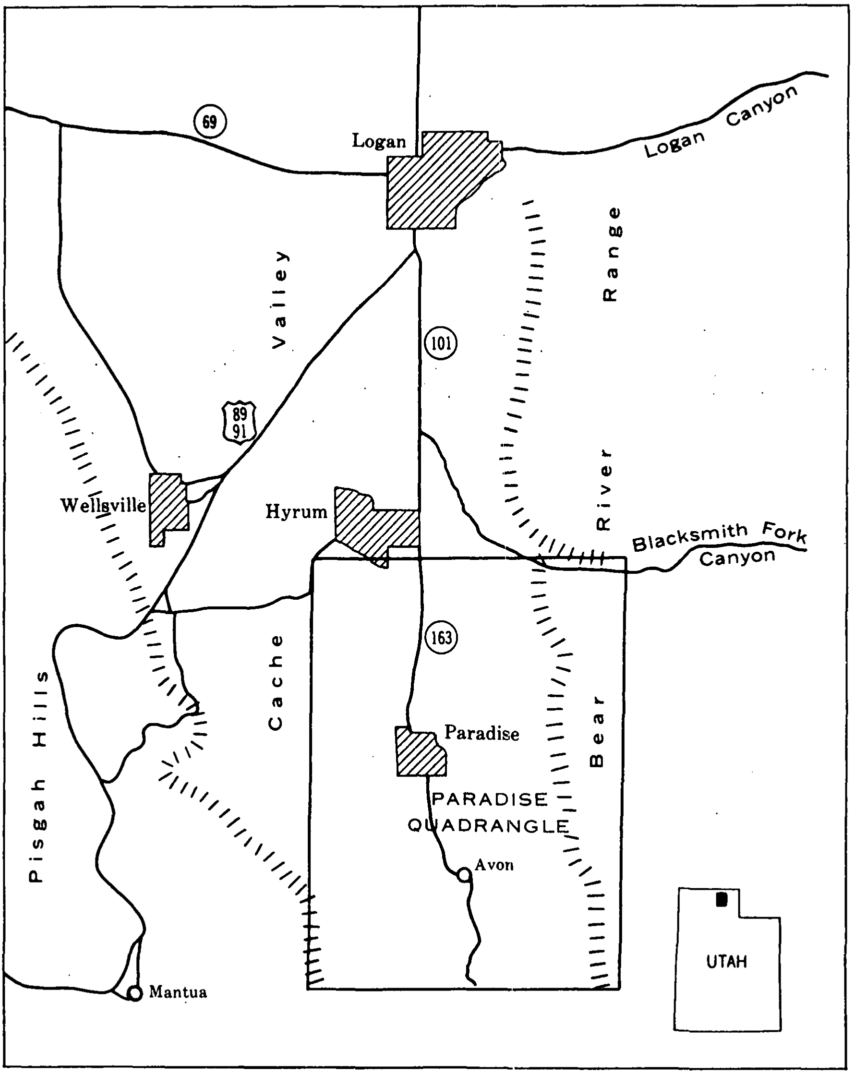

FIGURE 1.—Index map showing location of Paradise quadrangle, Utah.

DEVONIAN SYSTEM

LOWER DEVONIAN SERIES

WATER CANYON FORMATION

The oldest exposed rocks in the quadrangle are assigned to the Water Canyon Formation of Early Devonian age (Williams, 1948, p. 1139). About 400 feet of the Water Canyon is exposed near the mouth of Blacksmith Fork Canyon. This thickness represents almost a complete section, as the formation reaches a maximum thickness of 400–450 feet in nearby exposures north and east of the quadrangle.

The Water Canyon is composed of interbedded siltstone, sandstone, limestone, and dolomite. Most of these rocks are light gray, very fine grained, evenly bedded, and well indurated, but some sandstone is grayish red and conglomeratic. The conglomeratic beds consist of subrounded granules and pebbles of quartz, quartzite, and mudstone in a sandstone matrix. These beds are cross-stratified and lenticular, have scour surfaces at their base, and were probably deposited in stream channels on or near tidal flats. Other rocks in the Water Canyon were probably deposited in a marine environment.

No fossils were found in the Water Canyon Formation in the Paradise quadrangle. Fragments of fish that indicate an Early Devonian age have been collected in the upper part of the Water Canyon in upper Blacksmith Fork Canyon (Williams, 1948, p. 1140). Fish plates were seen by the writers in the Water Canyon at Millville Canyon, which is about 2 miles north of the quadrangle.

UPPER DEVONIAN SERIES

JEFFERSON FORMATION

The Jefferson Formation of Late Devonian age[1] crops out in Blacksmith Fork Canyon and southward along the mountain front to Hyrum Canyon. It is 1,600 feet thick in Blacksmith Fork Canyon but it thins southward and is only 1,300 feet thick about 2 miles east of the quadrangle in sec. 22, T. 10 N., R. 2 E. Williams (1948, p. 1139) divided the formation into two members: the Hyrum Dolomite and the overlying Beirdneau Sandstone. These members are mappable units in the quadrangle.

HYRUM DOLOMITE MEMBER

The Hyrum Dolomite Member of the Jefferson Formation was named by Williams (1948, p. 1139) for exposures at the mouth of Blacksmith Fork Canyon east of the town of Hyrum. He did not publish a measured section for exposures at the mouth of the canyon, but he indicated the Hyrum to be 1,200 feet thick (Williams, 1948, p. 1140). Our measurements indicate that the Hyrum Member is about 960 feet thick along the lower part of Blacksmith Fork Canyon. It consists of fine- to very fine-grained black fetid dolomite that contains veinlets of white calcite. Bedding ranges from thin (less than 2 in.) to very thick (more than 4 ft). Many beds are finely laminated and the laminae are contorted. In Blacksmith Fork Canyon a threefold division of the Hyrum can be made on the basis of bedding and weathering characteristics. The lower and upper thirds are relatively thin bedded and weather to ledgy slopes; the middle one-third is

[1] Since plate 1 of this report was first published (1963), the U.S. Geological Survey has accepted the Jefferson Formation as Late Devonian age in this area.

massive and weathers to a steep slope characterized by 50- to 100-foot cliffs.

In lower Blacksmith Fork Canyon the Hyrum contains only two quartzose sandstone beds, each about 5 feet thick, at 535 and 695 feet above the base, but the member becomes sandier southward.

The Hyrum contains many lenses of intraformational dolomite breccia that consist of angular dolomite fragments in a matrix of calcite and dark-gray fine-grained dolomite. Most of these lenses are thin and grade upward into nonbrecciated dolomite. The largest breccia fragment was about 1 foot long, but the average fragments are less than 2 inches long.

Several small folds of 20–50 feet amplitude with axial planes that dip 30°–60° N. are in the upper part of the member exposed along Blacksmith Fork Canyon. The fact that the folds are not reflected in overlying or underlying rocks indicates the beds were probably deformed shortly after deposition.

The base of the Hyrum Member is an erosional unconformity on the gently channeled surface of the underlying Water Canyon Formation. The Hyrum is gradational with the overlying Beirdneau Sandstone Member of the Jefferson Formation.

Only poorly preserved brachiopods were seen by the writers, but fossils collected from the Hyrum a few miles north of the quadrangle (Williams, 1948, p. 1140) indicate a probable early Late Devonian age.

BEIRDNEAU SANDSTONE MEMBER

The Beirdneau Sandstone Member of the Jefferson Formation was named by Williams (1948, p. 1139) from exposures at the base of Beirdneau Peak about 12 miles north of the Paradise quadrangle. According to Williams, the member is 740 feet thick at Beirdneau Peak. In the Paradise quadrangle, the Beirdneau crops out in Blacksmith Fork Canyon and along the mountain front as far south as Hyrum Canyon. The maximum measured thickness of the Beirdneau Member in the quadrangle is about 710 feet, but the member is locally only 500 feet thick along the mountain front where it thins under an unconformity.

Rocks in the basal 600 feet of the member are light-gray well-indurated irregularly interbedded sandstone, siltstone, and dolomite. Gradations between rock types are common. The rock types are grossly zoned: sandstone is dominant in the lower part and dolomite is dominant in the upper part. The rocks are thin bedded, and some beds show thin contorted laminations. The lower part of the Beirdneau weathers to ledgy slopes.

The upper 100 feet of the Beirdneau is dolomitic limestone that is medium grained, yellowish gray, fetid, and locally contains thin beds of fine-grained quartz sandstone. The upper 25–40 feet of this dolomitic limestone forms a conspicuous ledge known locally as the "Contact Ledge." This ledge has been considered the basal unit of the Mississippian System (Williams, 1943, p. 595; 1948, p. 1141). Holland (1952, p. 1718), however, reported an Upper Devonian fauna from it.

MISSISSIPPIAN SYSTEM

LOWER MISSISSIPPIAN SERIES

LEATHAM FORMATION

The Leatham Formation of Early Mississippian age (Holland, 1952, p. 1719) was named for exposures at Leatham Hollow, in the NW cor., sec. 34, T. 11 N., R. 2 E., which is about 2 miles northeast of the quadrangle. It is as much as 100 feet thick along Blacksmith Fork Canyon but is absent at most places along the mountain front owing to an unconformity. The Leatham forms a talus-covered slope between the "Contact Ledge" and the basal cliff of the overlying Lodgepole Limestone.

The Leatham consists mainly of irregularly interbedded dark-gray siltstone and medium-gray nodular limestone, but it includes scattered beds of fine-grained quartz sandstone. Some of the siltstone contains nodular limestone concretions. The rocks are thin bedded and many are thinly laminated.

At the type section, the Leatham Formation unconformably overlies the Jefferson Formation and conformably underlies the Lodgepole Limestone (Holland, 1952). In the mapped area, an earthy siltstone containing abundant small pellets of limonite occurs locally in the basal few feet of the Leatham and may indicate an unconformity. Along parts of Blacksmith Fork Canyon, the Leatham conformably underlies the Lodgepole Limestone. Near the mountain front the Leatham is present only as isolated remnants; its absence is apparently due to an erosional unconformity that separates Lodgepole Limestone from older rocks.

No fossils were collected from the Leatham Formation in the mapped area. Holland (1952, p. 1720) studied fossils from the type section and concluded that they indicate an Early Mississippian (Kinderhook) age for the Leatham Formation.

LODGEPOLE LIMESTONE

Rocks previously assigned to the Madison Formation in northeastern Utah are now assigned to the Lodgepole Limestone (Williams, 1958, p. 31; Sando and others, 1959, p. 2746). In the quadrangle, the Lodgepole Limestone of Early Mississippian age crops out in Blacksmith Fork Canyon, along the mountain front as far south as Hyrum Canyon, and in East Canyon. The Lodgepole is about 750 feet thick in most exposures, but it is locally only 500 feet thick along the mountain front. Along Blacksmith Fork Canyon, the Lodgepole forms a distinctive outcrop consisting of a lower cliff, an intermediate slope, and an upper cliff. The cliffs are locally known as the lower and upper Chinese Walls.

The Lodgepole consists mainly of dark-gray thin-bedded limestone and dolomite that are very fine grained, fetid, and abundantly fossiliferous. The formation is characterized by thin wavy chert layers along bedding planes in the lower and upper parts of the cliff-forming units. The chert is dark gray to black and most occurs as small nodules and as thin layers an inch or so thick, but some forms irregular masses as much as 2 feet thick. Beds in the Lodgepole average about 2 inches in thickness although they range from about 1 inch to more than 3 feet in thickness. Individual beds in the cliff-forming units are generally noticeable only by close examination, for the general lack of shale partings causes an apparent massiveness. Shaly zones ½ to 4 inches thick are common in the middle nonresistant part. Many beds in the Lodgepole are finely laminated and, in contrast to the Devonian rocks, few of the laminations are contorted.

Well-preserved corals, brachiopods, bryozoans, and gastropods are abundant in the Lodgepole Limestone. Holland (1952, p. 1729) described the fauna of the Lodgepole in this area; he reported that the fossils indicate an Early Mississippian age.

The Lodgepole Limestone is conformable with the underlying Leatham Formation along most of Blacksmith Fork Canyon. Near the mountain front, however, the Lodgepole rests unconformably on the Beirdneau Sandstone Member or isolated remnants of Leatham Formation preserved along an unconformity.

UPPER MISSISSIPPIAN SERIES

BRAZER LIMESTONE

Mississippian rocks overlying the Lodgepole Limestone are referred to as the Brazer Limestone (Richardson, 1913, p. 413) in this report. This nomenclature agrees with that used by Williams (1943, p. 593–596; 1958, p. 31), but not with a recommendation to restrict the name Brazer to rocks exposed in the Crawford Mountains in northeastern Utah (Sando and others, 1959). Regional studies of correlation and age of lithologic units now assigned to the Brazer Limestone in Cache County, Utah, will probably result in abandoning the name Brazer Limestone. Abandonment of the name before these studies are completed, however, is likely to create more nomenclature problems than it would solve.

The Brazer in the Paradise quadrangle ranges from about 1,700 to 2,100 feet in thickness and is divided into three map units on the basis of lithologic criteria. These units are designated members A, B, and C.

MEMBER A

Member A, the lowest unit of the Brazer Limestone, ranges from about 800 to 1,100 feet in thickness. It is mainly sandstone and siltstone but includes limestone and dolomite and a 4- to 30-foot-thick zone of phosphatic mudstone, chert, and limestone at the base. The phosphatic zone at the base is discussed in detail in the section on "Economic geology."

Sandstone in member A is very fine to fine grained and commonly silty and is composed of subrounded grains of quartz and small amounts of feldspar and chert. It is tightly packed and well cemented by carbonate and silica. Most of the sandstone is light to medium gray on fresh surfaces, but it weathers to grayish orange. Beds of sandstone range from a few inches to 8 feet in thickness and typically occur in zones 20–100 feet thick that lack interbeds of siltstone or carbonate. Many of the thicker beds are cross-laminated.

Siltstone in member A occurs in beds 1–6 inches thick, which are commonly in zones that are 10–50 feet thick and that contain little sandstone. Most siltstone is either brownish gray or grayish red. Brownish-gray siltstone is commonly well cemented with carbonate or silica cement and forms resistant ledges on steep slopes, whereas grayish-red siltstone is slightly calcareous and soft and does not form ledges. Commonly, grayish-red siltstone overlies and is interbedded with the upper part of the phosphatic zone at the base of the lower unit.

Limestone and dolomite in member A are dark to medium gray, very fine grained, and dense and are more common near the top, where they intertongue and intergrade with member B of the Brazer Limestone. Carbonate rock in the lower 600 feet of the member generally occurs as lenses 20 to 50 feet thick that extend 2–3 miles before they pinch or grade out. The most conspicuous carbonate bed in the lower part is about 150 feet above the base, is 40 to 90 feet thick, and extends from Hyrum Canyon to at least 2 miles north of the quadrangle. This bed is composed of thin-bedded dark-gray dolomite in most places along the mountain front but grades to limestone eastward. It contains abundant dark-gray chert in nodules and thin layers, and in gross aspect greatly resembles limestone or dolomite in the Lodgepole Limestone. A similar limestone bed 35 feet thick and 240 feet above the base of member A forms a prominent ledge at East Fork Canyon.

The contact of member A and the Lodgepole Limestone is conformable in the Paradise quadrangle. The basal phosphatic zone, however, is absent at Dry Lake (Williams, 1943, p. 595) west of the

Paradise quadrangle. Locally in the Paradise quadrangle, sandstone in member A was deposited in channels cut within 10 feet of the top of the Lodgepole Limestone. Possibly similar, but slightly deeper channels could account for the local absence of the phosphate zone at Dry Lake.

Poorly preserved impressions of brachiopods in the grayish-red siltstone and fragments of brachiopods and crinoid stems in carbonate rock are the chief fossils that were observed in member A.

MEMBER B

Member B, the middle unit of the Brazer Limestone, is 525 to 700 feet thick and conformably overlies member A. In most places, member B is dark-gray limestone, but dolomite and sandstone occur locally. The member is well exposed in steep cliffs along the west-trending canyons but is concealed by soil and colluvium in much of the remainder of its outcrop belt. On the north sides of Hyrum and Paradise Dry Canyons, some limestone in the member has been dissolved, and the upper beds are locally contorted.

Limestone in member B is dark gray, fine grained, dense, fetid, and locally fossiliferous. Dolomite, megascopically similar to the limestone, occurs here and there in the limestone and is the dominant rock type near faults. Small nodules and thin layers of dark-gray chert and large (1 to 1½ in. in diameter) horn corals belonging to the genus *Faberophyllum* are abundant but erratically distributed in the upper two-thirds of the limestone. Smaller horn corals, colonial corals, and brachiopods also occur in the limestone but are fairly scarce. Sandstone occurs mainly near the base of member B, where it intertongues and intergrades with member A. This intergrading and intertonguing of sandstone at the base accounts for the range in thickness of member B.

MEMBER C

Member C, the upper unit of the Brazer Limestone, is on the divides between west-trending canyons and in a fault block along the mountain front south of Hyrum Canyon. The member ranges in thickness, from about 200 to 600 feet, owing mostly to erosion of upper beds beneath an unconformity at the base of the overlying Oquirrh Formation and probably in some measure to facies changes in member C.

The most persistent bed observed in member C is a 2- to 4-foot-thick grayish-yellow siltstone at the base. Above this bed, the member is mainly thin-bedded dolomitic cherty siltstone in exposures south of Paradise Dry Canyon and thin- to medium-bedded limestone in exposures north of Hyrum Canyon. These facies intertongue and intergrade in the area between Hyrum and Paradise Dry Canyons. Exposures are too poor to show detailed relationships, but the dolomitic cherty siltstone is more abundant in the upper part and apparently forms a northeastward-extending wedge that overlaps limestone in the lower part. Large horn corals belonging to the genus *Caninia*, colonial corals, and brachiopods are sparsely distributed through the limestone and dolomite, but the siltstone and chert are not megascopically fossiliferous.

CORRELATION OF UNITS IN BRAZER LIMESTONE

Williams (1943, p. 596; 1958, fig. 2) identified five divisions of the Brazer Limestone at Dry Lake about 4 miles west of the Paradise quadrangle. In ascending order these units are: (1) calcareous sandstone, about 900 feet thick, (2) thick-bedded dark-gray limestone, 400 feet thick, (3) thin- to medium-bedded argillaceous limestone, 470 feet thick, (4) medium- to thick-bedded limestone containing considerable chert, 950 feet thick, and (5) black and gray silty limestone and calcareous siltstone, 950 feet thick. Member A of the Brazer Limestone in the Paradise quadrangle correlates with unit 1 of the Dry Lake section; member B probably correlates with unit 2 of Dry Lake; and member C probably correlates with units 3 and 4 at Dry Lake. The black and gray silty limestone and calcareous siltstone of unit 5 at Dry Lake are not recognizable in the Paradise quadrangle.

Williams (1958, p. 33) suggested that the rocks exposed at Dry Lake might be given north-central Utah names, as follows: Unit 1 equivalent to the Humbug Formation; units 2, 3, and 4 equivalent to the Great Blue Limestone; and unit 5 equivalent to the Manning Canyon Shale. The north-central Utah terminology was not used in the Paradise quadrangle because of difficulties encountered in making lithologic correlations southward.

To the north and northeast of the Paradise quadrangle, fairly reliable correlations can be made with members A, B, and C of the Brazer Limestone. To the north in the Chesterfield Range, in southeastern Idaho, 965 feet of silty and sandy beds assigned to the Little Flat Formation of Late Mississippian age by Dutro and Sando (1963) probably correlates with member A of the Brazer in the Paradise quadrangle. Member B of the Brazer in the quadrangle probably correlates with the lower part and member C, with the upper part of the Monroe Canyon Limestone of Late Mississippian age of Dutro and Sando (1963). Member A of the Brazer probably correlates with units A, B, and C of the Mississippian sequence at Old Laketown Canyon (Sando and others, 1959, p. 2673, fig. 5), 28 miles northeast of the Paradise quadrangle. Member B of the Paradise quadrangle probably correlates with units D, E, and F of the Old Laketown Canyon sequence. Member C of the Paradise quadrangle does not seem to be represented at Old Laketown Canyon. Lithologic correlations between the Brazer Limestone in the quadrangle and the type section of the Brazer Dolomite—described by Sando, Dutro, and Gere (1959)—in the Crawfords Mountains 30 miles east of the quadrangle are uncertain.

PENNSYLVANIAN AND PERMIAN SYSTEMS

OQUIRRH FORMATION

Interbedded sandstone and limestone assigned to the Oquirrh Formation (Gilluly, 1932, p. 34) of Pennsylvanian and Permian age occur locally above the Brazer Limestone in the Bear River Range. No identifiable fossils were found in these rocks in the eastern part of the quadrangle, and the rocks were assigned to the Oquirrh Formation because they resemble rocks in the Oquirrh Formation exposed north and west of the area (Williams, 1958, p. 35; Nygreen, 1958, p. 13). A maximum thickness of about 600 feet of Oquirrh is preserved on the divide between Hyrum and Paradise Dry Canyons. Similar rocks exposed on the west side of the Paradise quadrangle in sec. 6, T. 9 N., R. 1 E., are also assigned to the Oquirrh.

Sandstone is about three times more abundant than limestone in the Oquirrh Formation. The sandstone is composed of subangular to subrounded grains of clear quartz and traces of red and black accessory minerals. It is light gray on fresh surfaces, but it weathers grayish orange. About two-thirds of the sandstone is very fine grained and silty, firmly cemented by silica or carbonate, and structureless or horizontally laminated. The other one-third is mainly medium grained, less firmly cemented, and cross-laminated. Limestone is interbedded with the very fine grained silty sandstone but not with the medium-grained sandstone.

The limestone is light and medium gray, very fine grained, and dense. In general, it weathers smooth, but some beds contain fragments of fossils, ranging in size from 1/16 to 1/32 inch, that form rough surfaces. In places, the limestone and sandstone are cyclic; several zones occur in which layers of sandstone 10–40 feet thick are repeatedly overlain by layers of limestone 3–10 feet thick. In other places the sandstone and limestone are randomly interbedded. Nygreen (1958, p. 26) reported that cyclic sedimentation is characteristic of the Oquirrh Formation in Sardine Canyon about 2 miles west of the Paradise quadrangle.

Except for a minor break, the outcrop of Oquirrh rocks in the western part of the quadrangle can be continuously traced into the "sandy Oquirrh" of Nygreen (1958, p. 14) in the section at Sardine Canyon. The Oquirrh rocks in the eastern part of the map area can on the basis of lithology also be correlated with the "sandy Oquirrh." The "sandy Oquirrh" contains fossils of Middle Pennsylvanian age (Nygreen, 1958, p. 26–27); it overlies a dominant limestone zone 510 feet thick that is also assigned to the Oquirrh Formation (Nygreen, 1958, p. 14). This zone probably correlates with the Early Pennsylvanian Bridal Veil Limestone Member (Baker and Crittenden, 1961) near Provo, Utah.

The contact of the Oquirrh and Brazer Formations in the quadrangle was placed at the base of a dominantly sandstone sequence above the coral-bearing limestone and dolomitic siltstone assigned to the Brazer Limestone. As mapped, the Oquirrh Formation overlies about 600 feet of member C of the Brazer Limestone at the south side of Hyrum Canyon and only 200 feet of member C at McKenzie Mountain in the southeastern part of the quardangle. This evidence indicates an unconformity at the base of the Oquirrh Formation in the east side of the quadrangle. If of an Early Pennsylvanian age, this unconformity would explain the absence of Lower Pennsylvanian rocks indicated by the lithologic correlation between Oquirrh rocks in the quadrangle and in Sardine Canyon.

TERTIARY SYSTEM AND TERTIARY(?) SYSTEM

SALT LAKE FORMATION

Grayish-white tuffaceous conglomeratic sandstone, light-colored earthy limestone, conglomerate, and fanglomerate assigned to the Salt Lake Formation form broad benches and foothills in Cache Valley. Poor exposures, lack of persistent beds, and probable structural complications prohibit determining the thickness of the Salt Lake Formation in the Paradise quadrangle. Adamson, Hardy, and Williams (1955, p. 20) reported about 1,600 feet of Salt Lake Formation between the contact of Salt Lake Formation and Paleozoic rocks in sec. 6, T. 9 N., R. 1 E., and the fault in sec. 5. These authors (1955, p. 16) also reported that the Salt Lake Formation is more than 8,700 feet thick near the north end of Cache Valley.

Exposures of the Salt Lake Formation are so poor in the Paradise area that no subdivisions were mapped. The part of the formation exposed on the west side of Little Bear River contains tuffaceous sandstone beds, limestone, and conglomeratic sandstone. Rocks mapped as Salt Lake Formation on the east side of the river are mainly conglomerate and fanglomerate that contain a large proportion of rocks derived from formations older than those exposed in the quadrangle. The tuffaceous sandstone and limestone beds exposed west of Little Bear River underlie the conglomerate and fanglomerate along Little Bear River in secs. 22 and 23, T. 9 N., R. 1 E. In other parts of the quadrangle, the contact between these parts of the Salt Lake Formation is concealed by a band of younger rocks, 1–3 miles wide.

An isolated area of Salt Lake Formation is inferred to floor the valley east of McKenzie Mountain in the southeastern part of the area. This inference is based on the presence of abundant float composed of stromatolitic earthy limestone similar to limestone at the base of the Salt Lake Formation on the west side of Cache Valley. Distribution of float and sparse outcrops of limestone and tuffaceous sandstone in this valley indicate that the basin in which the Salt Lake Formation was deposited was similar in size and shape to the present valley.

The Salt Lake Formation rests with angular unconformity on Paleozoic rocks on the west side of the Paradise area and in the valley east of McKenzie Mountain. On the east side of Cache Valley, the Salt Lake Formation is in fault contact with Paleozoic rocks in the Bear River Range.

The Salt Lake Formation is assigned to the Pliocene, but the lower and upper age limits of the Salt Lake are not accurately known. Gastropods in an earthy limestone exposed in an old quarry in the SE¼ sec. 8, T. 10 N., R. 1 E., and poorly preserved fragments of plants in silty tuffaceous sandstone exposed in the NE¼NW¼ sec. 4, T. 9 N., R. 1 E., were the only fossils observed in the Salt Lake Formation. Brown (1949) assigned plant fragments collected in sec. 20, T. 10 N., R. 1 E., to the Pliocene, probably middle Pliocene. Adamson, Hardy, and Williams (1955, p. 7) reported that Takeo Susuki identified *Pompholopis minima* Yen, *Vorticifex* cf. *V. tryoni* Meek, and *Physa* sp. indet. from a collection of gastropods made an eighth of a mile southwest of Hyrum Reservoir. Susuki regarded *Pompholopsis minima* Yen as indicative of a probable Pliocene age. The fossils were collected from beds 2,000 to 4,000 feet above the base of the Salt Lake Formation unless unrecognized faults or folds are present. The tuffaceous rocks in the basal part of the Salt Lake are similar to and probably correlate with parts of Norwood Tuff (Eardley, 1944, p. 845) exposed south of the quadrangle in Morgan Valley. Recent studies by Gazin (1959, p. 137) indicate that some Norwood beds are as old as Eocene.

East of the Little Bear River, the conglomerates and fanglomerate assigned to the Salt Lake Formation are cut by a pediment that extends from the front slope of the Bear River Range to a shoreline cut by Lake Bonneville. The age of this surface, named the McKenzie Flat by Williams (1948, p. 1161), is not known but it is older than the Quaternary Lake Bonneville Group. All rocks older than the erosion surface were assigned to the Salt Lake Formation by us, and some of the conglomerates and fanglomerates are possibly from a Quaternary age pre-Lake Bonneville alluvial fan.

An upper 20–40 feet of the conglomerate mapped as Salt Lake Formation possibly rests with angular unconformity on the main mass of conglomerate in places south of Hyrum Canyon. Exposures

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just south of the quadrangle, pointed out by C. T. Hardy, show this relationship. The lack of exposures prohibits separating the upper conglomerate, which is considered to be of Quaternary age by Hardy (oral communication, 1960), if it is present in the quadrangle.

Adamson, Hardy, and Williams (1955) raised the Salt Lake Formation to group rank and subdivided it into three formations. In ascending order they are: the Collinston Conglomerate, Cache Valley Formation, and Mink Creek Conglomerate. Most Salt Lake rocks west of the Little Bear River in the Paradise area correlate with the Cache Valley Formation of these authors. The fanglomerate on the east side of the valley and the Mink Creek Conglomerate were deposited under similar conditions and perhaps at the same time, but physical correlation of the fanglomerate and the Mink Creek Conglomerate cannot be made on available data.

SCATTERED BOULDERS

South of Hyrum Canyon, subrounded boulders of quartzite (not shown on pl. 1) derived from Precambrian and Cambrian formations are scattered on McKenzie Flat. These boulders average about 1 foot in diameter, but some are as much as 3 feet in diameter. The boulders were deposited on a pre-Lake Bonneville erosion surface, the McKenzie Flat surface (Williams, 1948, p. 1161). Similar quartzite boulders occur on the southern part of McKenzie Mountain several hundred feet above the McKenzie Flat surface. These higher level boulders were probably deposited on the Rendevous Peak erosion surface (Williams, 1948, p. 1160), which is preserved along hills south and west of the Paradise quadrangle. Williams (1948, p. 1160) believed that the Rendevous Peak surface was formed and deeply dissected before the Salt Lake Formation was deposited.

QUATERNARY SYSTEM

LAKE BONNEVILLE GROUP

Assignment of rocks of the Lake Bonneville Group is based on the shoreline altitudes of Lake Bonneville when the rocks were deposited. In the Paradise quadrangle, rocks of the Alpine (Hunt and others, 1953, p. 17), Bonneville, and Provo (Gilbert, 1890, p. 126–134) Formations of the Lake Bonneville Group of Pleistocene age are exposed. Rocks deposited at Alpine level, however, are not everywhere distinguishable from overlying rocks deposited at Bonneville level; therefore, Alpine and Bonneville Formations are not differentiated on the geologic map.

Where possible, Williams (1962, pl. 6) mapped the distribution of lithologic types in the Lake Bonneville Group. His map should be consulted for details, as only the subdivisions according to age are made here.

ALPINE AND BONNEVILLE FORMATIONS UNDIFFERENTIATED

The Alpine and Bonneville Formations were deposited when the level of Lake Bonneville ranged from 5,100 feet (Alpine) to about 5,160 feet (Bonneville) above sea level. The formations consist mostly of evenly bedded light-colored calcareous siltstone deposited on a gently sloping lake bottom, although sand and gravel form constructional shore-terrace features near the shoreline. No deltas deposited during Alpine and Bonneville times were recognized in the Paradise quadrangle. The larger streams, Blacksmith Fork and East Fork Rivers, were graded below lake level during these times and deltas might have been deposited some distance upstream.

The upper extent of the Alpine and Bonneville is placed at the base of a cliff, altitude 5,130 to 5,180 feet, cut by the lake during Bonneville time. Williams (1962, pl. 6) indicated that a wave-cut terrace several hundred feet wide in the beds of the Salt Lake Formation separates Alpine and Bonneville rocks from the Bonneville shoreline in most places. In places, Salt Lake beds may underlie the wave-cut terrace below the cliff, but poor exposures make it impossible to consistently separate areas in the terrace where Salt Lake beds form the bedrock. Our studies indicate that the terrace is mainly covered with reworked material from the Salt Lake Formation. Most of the reworking was apparently done by Lake Bonneville currents, although possibly as much as 40 percent is due to recent slope wash and plowing.

The maximum thickness of exposed undifferentiated Alpine and Bonneville Formations is probably less than 100 feet, even though the apparent thickness indicated by the map is locally as much as 340 feet. This apparent thickness is due to the veneer effect on a sloping lake bottom.

The cliff cut by Lake Bonneville during Bonneville time is a conspicuous topographic feature in the Paradise quadrangle. It stands 10–60 feet high and forms a slope of 45°–70° above a gently sloping terrace. The altitude of the base of the slope is about 5,130 feet near Blacksmith Fork Canyon but ranges between 5,160 and 5,180 feet in other parts of the area. In general, the altitude of the shoreline is slightly higher than the 5,135-foot altitude of the Bonneville overflow at Red Rocks Pass reported by Williams (1962). The cliff is not broken by faults. Gilbert (1890, p. 364–386) and Crittenden (1960) attributed some of the variation in the altitude of the Bonneville shoreline in other areas to isostatic adjustment caused by removal of water in Lake Bonneville. Such adjustments might have caused the difference in the altitude of the shoreline in the Paradise quadrangle. However, the shoreline is higher where Lake Bonneville was shallow and lower where the lake was deeper. This situtation is a reversal of the relationship reported by Gilbert (1890, p. 364–386) in areas he believed to be affected by isostatic adjustment. The negative adjustment at Blacksmith Fork Canyon may be due to loading by a large accumulation of gravel deposited near the canyon mouth during the Provo time. Possibly, however, the south end of Cache Valley has risen slightly owing to epeirogenic movement since Lake Bonneville time.

PROVO FORMATION

Sediment deposited in Lake Bonneville at an altitude of about 4,840 feet is assigned to the Provo Formation (Hunt and others, 1953, p. 21). The extensive flat extending northward from Paradise and the flat on the south side of Hyrum Reservoir are underlain by rocks of the Provo. The Provo is younger than the Alpine and Bonneville, but all exposures of Provo beds are at lower altitudes than exposures of Alpine and Bonneville beds.

Most of the Provo Formation in the Paradise area was deposited in deltas formed where Blacksmith Fork and Little Bear River entered Lake Bonneville. In these deltas, the Provo consists of irregularly interbedded poorly consolidated sand, gravel, and silt. Many of the beds are cross-laminated, but no sequence of beds that indicate topset or forset beds in a delta was identified in the quadrangle. A roadcut half a mile north of the quadrangle in sec. 2, T. 10 N., R. 1 E., exposes about 150 feet of gravel and sand in the Blacksmith Fork delta which shows excellent delta-type bedding. The thickness of deltaic material in sec. 2 may not be typical of the Provo in the Paradise quadrangle, as it occurs near the middle or thickest part of the delta.

Provo Formation exposed near the dam at Hyrum Reservoir is mainly thin-bedded calcareous light-colored sandy siltstone. These beds are probably typical of rocks deposited in the deeper parts of Lake Bonneville during Provo time.

LANDSLIDE DEPOSITS

The landslides mapped in secs. 7 and 18, T. 9 N., R. 2 E., involve Paleozoic bedrock that has slipped down canyon walls. Topographically, they form classical examples of hummocky, rubble-covered slopes typical of landslide blocks. Landslides are also common where beds in the Salt Lake Formation have slumped down the cliff cut by Lake Bonneville during Bonneville time, but these landslides were not mapped.

COLLUVIUM

Colluvium, which consists mainly of sand, silt, and fragments of sandstone, mantles bedrock on the erosion surface along the mountain front. The thin colluvial cover is not shown on plate 1. On the basis of composition, the colluvium could not have been deposited under current climatic conditions, as the stratigraphic section contains abundant carbonate rock and the present climate is arid. Presumably, the colluvium accumulated under more humid conditions than those that prevail now.

ALLUVIUM

Alluvium was mapped along East Fork and Little Bear Rivers, along West Canyon, and along the lower parts of the streams in Hyrum and Paradise Dry Canyons. Alluvium in the quadrangle consists mainly of silty and sandy poorly consolidated clay that contains lenses of sand and gravel. It is grayish brown to reddish brown along East Fork and Little Bear Rivers, pale brown to darkyellowish brown along the streams in Hyrum and Paradise Dry Canyons, and pale brown to grayish orange pink in West Canyon. The differences in color are due to variations in organic content and source material.

Alluvium along East Fork River and West Canyon is restricted to the present flood plains. Along Little Bear River, alluvium is preserved in terraces 10–20 feet above the present flood plain. The town of Paradise is on an alluvial fan formed where the stream in Hyrum Canyon joined either a terrace built by Little Bear River or a Provo delta formed in Lake Bonneville. Avon is on a similar but smaller fan deposited at the intersection of the stream in Paradise Dry Canyon and the Little Bear River flood plain.

STRUCTURE

Parts of three tectonic elements are present in the Paradise quadrangle. These are, as named by Williams (1958, p. 74), the Bear River Range block, the Cache Valley graben, and the Pisgah Hills-Wellsville Mountain homocline. The Bear River Range block trends north and in the vicinity of the quadrangle is about 15 miles wide and consists of Paleozoic rocks that are warped by broad folds. The Cache Valley graben, which borders the Bear River Range on the west, is a tropographic low about 60 miles long and at most 20 miles wide. It is floored mainly by Tertiary and Quaternary rocks and is separated from the Bear River Range block by a fault zone. The Pisgah Hills-Wellsville Mountain homocline bounds the southwest side of Cache Valley; it trends N. 30° W. and consists mainly of eastward-dipping Paleozoic rocks. The Pisgah Hills-Wellsville Mountain homocline is represented by the east-dipping Paleozoic rocks in secs. 6, 7, 19, and 20, T. 9 N., R. 1 E., in the Paradise quadrangle.

BEAR RIVER RANGE BLOCK

The structure of the part of the Bear River Range in the quadrangle is relatively simple except along the mountain front. The eastern part of the Paradise quadrangle includes part of the Range where rocks are folded in the Logan Peak syncline, a major fold that extends more than 25 miles north-northeast (Williams, 1948, pl. 1). Most rocks north of Paradise Dry Canyon dip eastward towards the southwest-trending Logan Peak syncline, which ends north of East Canyon. Rocks south of Paradise Dry Canyon dip mainly west. The part of Logan Peak syncline in the quadrangle is asymmetric: dips on the east limb are commonly greater than dips on the west limb. The west limb is modified by minor cross folds, the largest being an east-trending and plunging anticline in Blacksmith Fork Canyon.

The west edge of the Bear River Range block is a structurally complex zone that contains both high- and low-angle faults. Most faults are roughly parallel to the mountain range and trend north, but a few faults trend east. The map (plate 1) shows observed faults and their inferred extensions; probably many other faults are concealed by the colluvium that covers much of the western slope of the Bear River Range.

The westernmost fault in the zone is considered the major fault in the area; it separates Paleozoic rocks from Tertiary rocks and marks the boundary between the Bear River Range block and Cache Valley graben. The fault is concealed in most places, but south of Green Canyon its trace is conspicuously delineated on aerial photographs by a tone change. North of Green Canyon, the fault is entirely concealed, and its trace is not apparent on the aerial photographs. The nearly straight trace of the fault indicates that the fault plane is practically vertical. The fault is interpreted as normal with Salt Lake rocks of Tertiary age on the west side of the fault and Paleozoic rocks on the east side. Stratigraphic throw is probably a few thousand feet, but the lack of exposures of Paleozoic rocks on the downthrown side of the fault prohibits making more than just an estimate of the displacement.

Other faults along the mountain front show a wide range in displacement and attitude of fault surface. A subsidiary fault branches from the major fault near Hyrum Canyon and then roughly parallels the major fault to the south edge of the quadrangle. This fault is downthrown on the west side and has a stratigraphic displacement of at least 1,500 feet near Hyrum Canyon where rocks of member C of the Brazer Limestone are in contact with Lodgepole Limestone. Southward, the relative displacement decreases and at the south boundary of the quadrangle it is probably about 100 feet. This fault plane was not observed, but the trace indicates a range in dips of from 75° W. to vertical. A fault of similar displacement and trend brings member A of the Brazer Limestone in contact with Hyrum Dolomite Member of the Jefferson Formation on the south side of Blacksmith Fork Canyon.

Two faults in the zone near Green Canyon trend east and are downthrown on the south side. The northern fault has about 400 feet of stratigraphic displacement; the displacement of the other fault is measured in the few tens of feet.

Attitudes of the rocks along some spurs at the mountain front indicate faults that dip 20°–40° W. An exposed inclined fault plane on the south side of Paradise Dry Canyon dips 35° W. and separates west-dipping rocks of member C of the Brazer Limestone in the hanging wall from the east-dipping rocks of member B of the Brazer Limestone in the footwall. In secs. 12, 13, and 24, T. 10 N., R. 1 E., rubble-covered inclined fault planes that dip 20°–40° W. separate Mississippian rocks in the hanging wall from Devonian rocks that dip east in the footwall. Rocks in the hanging walls are locally extremely jumbled; blocks of Lodgepole Limestone are mixed with blocks from both members A and B of the Brazer Limestone. Because of this, the hanging walls are mapped as Brazer and Lodgepole Limestones undifferentiated.

The aforementioned relationships can be interpreted as indicating either remnants of a single north-trending fault or as several discontinuous faults. The writers interpret them as discontinuous normal faults formed during early movement on the high-angle faults in the mountain front. Baker (1959, p. 157) reported similar inclined faults along the Wasatch Mountain front near Provo, Utah, and he favors a normal fault interpretation for them. The inclined faults are cut off by the major fault and are older than the latest movement on the major fault. Some minor north-trending faults apparently also cut off the inclined faults.

These inclined faults can also be interpreted as parts of a thrust fault that cut the mountain block at a greater angle than the angle of the present slope. Williams (1948, p. 1149) inferred such a thrust to account for structures in the Bear River Range near Logan, Utah. About a mile north of the quadrangle, Paleozoic rocks along the west part of the mountains are folded in an anticline overturned to the east. The anticline trends south and projects into Cache Valley in the Paradise quadrangle. If the overturned anticline is assumed to continue under Cache Valley, a fairly convincing section showing how the younger rocks were thrust on older rocks at the mountain front can be constructed.

CACHE VALLEY GRABEN

Cache Valley is a topographic and structural low floored with Tertiary and Quaternary deposits. Tertiary beds are exposed at lower altitudes and are in fault contact with Paleozoic rocks at the east side of the valley; they are also at low altitudes but are unconformably underlain by Paleozoic rocks on the west side. Probably

Tertiary rocks conceal a normal fault on the west side of the valley. The structural nature of the valley with respect to the underlying Paleozoic rocks is not known; sparse outcrops of pre-Tertiary beds exposed in Cache Valley north of the quadrangle are Precambrian and early Paleozoic in age (Williams, 1958, p. 76). General consideration of Cache Valley as related to valleys in the Basin and Range Province, however, implies that Cache Valley is a graben.

Tertiary rocks in Cache Valley are tilted and folded, but Quaternary rocks are not. Salt Lake beds dip west along the Bear River Range and mainly east in areas west of Little Bear River. It is not known if the reversal of dip is caused by a fold or a fault. Probably, the Tertiary rocks in the valley graben are broken by several faults, but none of the faults are conspicuously displayed. A fault, named the Willow Grove fault by Williams (1962, p. 147–148, pl. 6), is indicated by changes in dip in the Salt Lake beds exposed in sec. 5, T. 9 N., R. 1 E. Williams extended the Willow Grove fault southward through sec. 22, T. 9 N., R. 1 E., but the reversal in dip in this area is best explained as an anticline. A north-trending fault about a mile west of the front of the Bear River Range and extending from sec. 11, T. 9 N., R. 1 E., to sec. 23, T. 10 N., R. 1 E., is inferred on the basis of physiographic evidence. The east side of the hills west of the fault forms a relatively straight north-trending scarp that seems more likely to be due to faulting than to erosion.

AGE OF DEFORMATION

Rocks of the Lake Bonneville Group, the oldest rocks of definite Quaternary age, are not cut by faults in the Paradise quadrangle. A slight crustal movement in the area during post-Lake Bonneville time is indicated by differences in the altitude of the Bonneville shoreline near the mouth of Blacksmith Fork Canyon and other parts of the area. Whether this movement is related to epeirogenic movement or to isostatic adjustment due to removal of water or local accumulation of sediments is not known. High-angle faults and folds deform the Tertiary Salt Lake Formation and separate it from Paleozoic rocks exposed in the mountains. General consideration of the basin in which the Salt Lake beds were deposited and analogies made with similar basins in the Basin and Range provinces indicate that these high-angle faults were active intermittently through much of Tertiary time.

Williams (1948, p. 1148) dated the folds in the Bear River Range as Laramide, although unequivocal evidence for this date is lacking in the Bear River Range.

ECONOMIC GEOLOGY

PHOSPHATE

The primary purpose of fieldwork in the Paradise quadrangle was to appraise phosphate-bearing rocks in land where the Government retained mineral rights on phosphate. The only known phosphate-bearing rocks in the area are in a zone of dark-gray to black mudstone, chert, and limestone at the base of the Brazer Limestone. This zone ranges from 4 to 30 feet in thickness, but phosphatic rocks occur only in the basal 4–10 feet of the zone. Phosphatic material occurs mainly as subrounded pellets of carbonate-fluorapatite disseminated in chert beds 1 inch to 1 foot thick. The pellets average about one-sixteenth of an inch in diameter. The beds of phosphatic chert are separated by a few inches to a few feet of mudstone and limestone that contain only traces of phosphatic material.

The concentration of pellets in chert beds varies widely between beds and from place to place in the same bed. Most phosphatic cherts contain less than 30 percent pellets by volume, although some parts of beds are composed mainly of pellets. Analyses indicate that the typical phosphatic chert bed contains about 6 percent P_2O_5 and abnormally rich parts of the bed contain about 20 percent P_2O_5. (Analyses by Anal. Lab. Branch, U.S. Geol. Survey, Denver, Colo.) Phosphatic pellets and bluish-white phosphatic bloom are sparsely distributed in mudstone and limestone adjacent to phosphatic chert beds. Samples of these rocks indicate they contain less than 3 percent P_2O_5. As nonphosphatic or slightly phosphatic beds are thicker and more abundant than the phosphatic cherts, average content of zones 3–5 feet thick is less than 4 percent P_2O_5. This zone, therefore, is not currently of economic value, as typical phosphate-bearing rock mined in the western phosphate field contains more than 18 percent P_2O_5.

Representative sections of the phosphatic zone at the base of the Brazer Limestone follow.

Section of phosphate-bearing zone at base of Brazer Limestone measured in NE¼SE¼NE¼ sec. 13, T. 10 N., R. 1 E.

Description	*Thickness (feet)*	P_2O_5 *content*
Siltstone, grayish-red, slightly calcareous, thin-bedded; apparently gradational with underlying black siltstone. Grayish-red color probably indicates this unit is above phosphate zone.	4. 0	Not sampled. No megascopically apparent phosphate.
Siltstone, grayish-black, slightly calcareous, thin-bedded; some bedding surfaces weather grayish red. Gradational with underlying unit.	2. 0	0.8 percent. Phosphate not megascopically apparent.

Section of phosphate-bearing zone at base of Brazer Limestone measured in NE¼SE¼NE¼ sec. 13, T. 10 N., R. 1 E.—Continued

Description	*Thickness (feet)*	P_2O_5 *content*
Siltstone, black, noncalcareous, thin-bedded; contains abundant yellowish-orange stains that are probably iron oxide, as sample is not radioactive; basal beds are locally chertified. Sparse pinhead-sized phosphate nodules and bluish-white bloom indicate some phosphate.	1.5	3.0 percent.
Chert, black, hackly fracture. Abundant phosphatic subspherical pellets that average about one-thirty-second of an inch in diameter are disseminated in chert; locally, bluish-white phosphate bloom occurs.	0.5	4.5 percent.
Contact with Lodgepole Limestone.		
Total thickness of phosphate-bearing zone	4.0	
Average P_2O_5 content for 4-ft zone	------	2.2 percent.

Section of phosphate-bearing zone at base of Brazer Limestone measured in SE¼SW¼NW¼ sec. 25, T. 10 N., R. 1 E.

Description	*Thickness (feet)*	P_2O_5 *content*
Claystone, dark-gray, noncalcareous, and dark-gray chert; locally, yellow iron oxide stains occur on fractures. About one-sixteenth of unit is nonsilicified, about two-thirds is partly silicified, and about one-sixteenth is silicified enough to be classified as chert. All of unit has a hackly fracture, but some of the nonsilicified material cleaves along bedding; locally carbonaceous. Upper 6 ft of unit poorly exposed in grassy slope; remainder of section, trenched.	21.0	Not sampled. No megascopically apparent phosphate.
Siltstone, olive-gray, noncalcareous, hackly fracture; local ½-in.-thick zones are silicified. Gradational with overlying unit.	10.0	Do.
Chert, dark-gray to grayish-brown, hackly fracture; apparently a silicified clay or siltstone. Contains disseminated subrounded phosphate pellets that average about one-sixteenth of an inch in diameter; pellets are locally concentrated, but average rock contains few pellets.	0.5	18.9 percent. Selected sample of material richest in phosphate (megascopically determined). Average rock is about one-third as rich.
Claystone, grayish-brown, noncalcareous; locally grades into chert and cannot be separated from overlying bed; fissile where not silicified.	0.1	Not sampled. No megascopically apparent phosphate.
Contact with Lodgepole Limestone.		

Section of phosphate-bearing zone at base of Brazer Limestone measured in NE¼NW¼SW¼ sec. 17, T. 9 N., R. 2 E.

Description	*Thickness (feet)*	P_2O_5 *content*
Covered. Top of phosphate-bearing zone probably at base of grayish-red mudstone float about 2 ft above underlying chert, but contact not found.		
Chert, dark-gray to black, hackly fractured	0.3	Not sampled. No megascopically apparent phosphate.

Section of phosphate-bearing zone at base of Brazer Limestone measured in NE¼NW¼SW¼ sec. 17, T. 9 N., R. 2 E.—Continued

Description	*Thickness (feet)*	P_2O_5 *content*
Mudstone, medium-gray (local streaks of reddish brown), noncalcareous, slightly fissile; sparse dark-gray fine-grained pellets along some bedding planes; pellets probably phosphatic.	0.7	Not sampled. Estimated 1–2 percent P_2O_5.
Chert, dark-gray, hackly fracture; contains no pellets but has sparse bluish-white bloom that indicates slight P_2O_5 content.	0.2	Do.
Mudstone, light greenish-gray and grayish-red, noncalcareous, subfissile; chiefly clay and siltstone; no sand noted.	0.4	Not sampled. No megascopically apparent phosphate.
Chert, dark-gray to black, hackly fracture; gradational to cherty siltstone in upper part; contains abundant fine-grained phosphatic pellets in disseminations and laminar concentrations; locally, bluish-white bloom occurs.	0.6	6.5 percent.
Mudstone, grayish-red, noncalcareous; chiefly clay and silt.	0.2	Not sampled. No megascopically apparent phosphate.
Chert, dark-gray to black, hackly fracture; speckled and laminated with fine-grained phosphatic pellets; concentration of pellets varies considerably along strike.	0.2	Not sampled. Estimated 5–7 percent P_2O_5 in richest part, 2–4 percent in average part.
Dolomite, silty, grayish-red; becomes cherty in upper part; contains many fragments of crinoids; grades into overlying chert.	0.4	Not sampled. No megascopically apparent phosphate.
Claystone, grayish-red and moderate reddish-brown, noncalcareous, nonfissile.	0.2	Do.
Contact with Lodgepole Limestone.		

Section of phosphate-bearing zone at base of Brazer Limestone measured in SW¼SW¼ sec. 5, T. 10 N., R. 2 E.

Description	*Thickness (feet)*	P_2O_5 *content*
Mudstone, grayish-brown to grayish-red; thinly laminated; weathers to small chips. Grayish-red color indicates probable top of phosphate zone. No higher exposure.	1.5	Not sampled. No megascopically apparent phosphate.
Limestone, dark-gray, fine-grained; local coarse-grained zones; coarse zones very fetid and contain sparse phosphatic pellets; fine-grained material not phosphatic.	0.6	Not sampled. Estimated 1–2 percent P_2O_5 content in coarser grained material.
Chert, dark-gray, dull luster, highly fractured; hackly fracture indicates this unit is a chertified mudstone; local occurrence of bluish-white bloom on rock indicates phosphate, but no phosphatic pellets were observed.	1.3	Not sampled. Estimated 1–2 percent P_2O_5 content because of bluish-white bloom.
Mudstone, brownish-gray, thinly laminated petroliferous; composed of sand, silt, and clay particles.	0.3	Not sampled. No megascopically apparent phosphate.
Limestone, dark-gray, medium-grained, very fetid; no phosphatic pellets.	0.3	Do.
Mudstone, brownish-gray, thinly laminated, petroliferous; composed of sand, silt, and clay particles.	0.2	Do.

Section of phosphate-bearing zone at base of Brazer Limestone measured in SW¼SW¼ sec. 5, T. 10 N., R. 2 E.—Continued

Description	*Thickness (feet)*	P_2O_5 *content*
Chert, dark-gray (nonvitreous luster), highly fractured; hackly fractured probably indicates this unit is a chertified mudstone; abundant bluish-white bloom, but no phosphatic pellets were observed.	1.2	Not sampled. Estimated 1–2 percent P_2O_5 content because of bluish-white bloom.
Covered. One hundred yards west of section, this zone contains brownish-gray petroliferous mudstone. In line of section, this zone forms a steep slope just above vertical cliff of Lodgepole Limestone.	3.0	Not sampled.
Chert, dark-gray (locally, vitreous); abundant phosphatic pellets that average about one-thirty-second of an inch in diameter. Chert forms a plaster on top of Lodgepole Limestone. Described chert from 20-ft-wide flat formed on top of Lodgepole Limestone 50 ft east of beds described above.	0.4	1.7 percent.
Total thickness of phosphate-bearing zone.	8.8	
Contact with Lodgepole Limestone.		

Regionally, the phosphate-bearing zone at the base of the Brazer Limestone increases in thickness and phosphate content to the north and northeast of the Paradise quadrangle. It is at least 15 feet thick and has three beds more than 1.5 feet thick that contain more than 10 percent P_2O_5 in Providence Canyon (Cheney, 1957, p. 36) about 4 miles north of the Paradise quadrangle. At Laketown Canyon, which is 28 miles northeast of the Paradise quadrangle, the zone is 76.2 feet thick and is phosphatic from top to bottom (Cheney, 1957, p. 39). The richest zone at Laketown Canyon is the basal 3.2 feet which contains about 28 percent P_2O_5, but no other zone 3 feet or more thick contains more than 11 percent P_2O_5.

GRAVEL

Gravel is abundant in the deltas and bars in the Provo and Bonneville Formations and gravel deposits have been exploited in secs. 22 and 27, T. 10 N., R. 1 E. Additional deposits could be developed on the extensive flat between Hyrum and Paradise if market conditions become favorable.

ZINC

Tunnels shown on plate 1 in secs. 11 and 13, T. 10 N., R. 1 E., are adits to explore smithsonite deposits in brecciated limestone and dolomite. These adits are unsafe; so, examinations of the deposits were restricted to surface exposures and dump material.

The limestone and dolomite are in the middle unit, member B, of the Brazer Limestone, but the unit is so brecciated that bedding attitudes could not be determined. Smithsonite and limonite are irregularly distributed along steeply dipping fractures. In places along mineralized fractures, the minerals form veins as much as 6 inches wide; in other places along the same fracture the minerals are absent. Little could be determined about the spacing of mineralized fractures. Also, it could not be determined if the minerals were in an oxidized hydrothermal vein or if they were deposited by ground water.

According to Butler and others (1920, p. 218) these deposits were discovered about 1915. They produced two carloads of ore that averaged about 25 percent contained zinc in 1915 (Butler and others, 1920, p. 218), but no other production is recorded.

STRATIGRAPHIC SECTIONS

The following representative sections of Paleozoic sedimentary rocks in and adjacent to the Paradise quadrangle, Utah, were measured with tape and hand level by T. E. Mullens and G. A. Izett.

Partial section of Oquirrh Formation and Brazer Limestone in SE¼ sec. 30, T. 10 N., R. 2 E., in Hyrum Canyon

	Feet
Oquirrh Formation (in part):	
11. Sandstone, light-gray, moderate orange-pink weathering, very fine grained, calcareous, thick-bedded; some chert nodules parallel to bedding planes; intercalated with limy siltstone and medium-gray sandy limestone beds that range from 1 to 6 ft in thickness; forms ledges; top of exposure about 200 ft stratigraphically below top of hill	160
10. Covered	65
9. Sandstone, light-gray, very fine grained, limy, thick-bedded; locally cross-stratified; forms ledge	6
8. Limestone, medium-gray, light-gray weathering, fine- to coarse-grained; abundant fossil debris; forms ledge	6
7. Covered; some light-gray sandstone float	37
6. Sandstone, light-gray, moderate orange-pink weathering, very fine grained, limy, cross-laminated; forms cliff	32
5. Limestone, medium-gray, fine- to medium-grained, fetid odor; locally sandy; forms cliff	32
4. Covered	46
3. Limestone, medium dark-gray, locally conglomeratic; fine-grained limestone matrix containing dark-gray limestone pebbles as much as one-half inch in diameter; forms ledge	1
Measured thickness of Oquirrh Formation	385
Brazer Limestone (in part):	
Member C:	
2. Dolomite, medium dark-gray, very fine grained, fetid; locally contains large horn corals; a few thin limestone beds near top of unit; contact with overlying unit covered; forms cliff	124
1. Limestone, dark-gray and medium-gray, fine- to medium-grained, fetid; locally, shale partings occur; a few fossil fragments in upper part; some chert nodules and bands; forms cliffs	250
Measured thickness of Brazer Limestone	374

Section of Brazer Limestone in sec. 5, T. 10 N., R. 2 E., in Blacksmith Fork Canyon

	Feet
Oquirrh Formation (in part):	
22. Dolomite, light-gray and medium-gray, very thick bedded, sandy; a few fragments of fossils; forms ledge	25
Measured thickness of Oquirrh Formation	25
Brazer Limestone:	
Member C:	
21. Covered	30
20. Limestone, dark-gray, very fine grained; yellowish-brown weathering chert nodules; a few small horn corals; forms scattered ledges	42
19. Covered	122
18. Limestone, dark-gray, very fine grained, dense, hard; a few fragments of fossils; forms ledges	12
17. Siltstone, yellowish-brown, limy; locally contains poorly preserved fossils; poorly exposed	6
Member B:	
16. Limestone, dark-gray, mainly fine grained, dense, fetid, thin- to thick-bedded; abundant large horn corals; dark-gray to black chert beds near top of unit; forms massive cliffs	525
15. Covered	64
Member A:	
14. Sandstone, light-gray, moderate orange-brown weathering, even-bedded, thin- to thick-bedded; forms ledges	110
13. Limestone, medium dark-gray to light-gray, fine-grained, sandy, fetid, dense; locally fossiliferous; forms cliff	126
12. Limestone, dark-gray, locally silty, thin- to very thick-bedded; forms ledges	161
11. Covered	29
10. Limestone, dark-gray, laminated; contains a 3-ft light-gray sandstone bed near base of unit	40
9. Covered	212
8. Sandstone, medium-gray, limy, fine- to coarse-grained; poorly sorted; locally fossiliferous; forms cliff	20
7. Covered; float is grayish-red and brownish-gray mudstone	125
6. Sandstone, medium brownish-gray, very fine grained, silty, limy, interbedded with sandy limestone; locally fossiliferous; forms ledges	35
5. Covered	58
4. Limestone, black, very fine grained, cherty, thin-bedded; unit forms distinctive ledge at most places in Blacksmith Fork Canyon	90
3. Siltstone, medium brownish-gray, silty, limy; forms slope	18
2. Sandstone, light-gray, light orange-brown weathering, very fine to medium-grained, hard, slightly limy, massive; forms first distinctive beds above Lodgepole Limestone	91
1. Covered	91
Total thickness Brazer Limestone	2,007

Section of Lodgepole Limestone in sec. 1, T. 10 N., R. 1 E., in Blacksmith Fork Canyon

	Feet
Lodgepole Limestone:	
7. Limestone, dark- to medium-gray, abundantly fossiliferous, thin-bedded, wavy-bedded; chert occurs in thin bands parallel to bedding planes and as irregular masses; local dark-gray shale partings; forms cliff	130
6. Covered	185
5. Limestone, dark-gray, fine- to coarse-grained; many small horn corals; forms ledge	17
4. Covered	45
3. Limestone, dark-gray, very fine grained, thick-bedded; locally fossiliferous; tabular chert masses parallel to bedding near top of unit; forms ledgy slope	46
2. Covered; some fossiliferous limestone float	100
1. Dolomite, dark-gray and medium dark-gray, very fine to medium-grained, thick-bedded, even-bedded; chert occurs as bands that parallel bedding planes and as irregular masses; locally fossiliferous; dark-gray shale splits; contact with underlying Leatham Formation covered; forms several large cliffs locally known as "Chinese Walls"	167
Total thickness Lodgepole Limestone	690

Section of Leatham Formation in sec. 1, T. 10 N., R. 1 E., in Blacksmith Fork Canyon

	Fee
Leatham Formation:	
3. Covered; float indicates intercalated thin-bedded limestone and laminated limy siltstone	93
2. Siltstone, light-gray; a few phosphorite pellets about one-half millimeter in diameter scattered through rock; forms ledge	3
1. Partly covered; siltstone with iron oxide pellets near base; forms slope	4
Total thickness Leatham Formation	100

Section of Jefferson Formation in sec. 1, T. 10 N., R. 1 E.

	Feet
Bierdneau Sandstone Member:	
31. Dolomite, light- to medium-gray, fine-grained, thin- to very thick bedded, slightly sandy; locally has fetid odor; a few beds of light-gray very fine grained sandstone in upper part; topmost bed, "Contact Ledge," is light-gray fossiliferous very fine grained dolomitic limestone which is sharply overlain by Leatham Formation; forms cliff in upper part	96
30. Partly covered; a few scattered ledges of light-gray sandy dolomite	52
29. Dolomite, light-gray, silty, thin-bedded, rough-weathering; intercalated with a few light-gray siltstone and very fine grained sandstone beds; forms ledges	15

Section of Jefferson Formation in sec. 1, T. 10 N., R. 1 E.—Continued

	Feet
Bierdneau Sandstone Member—Continued	
28. Dolomite, light-gray, silty, thin-bedded; a few scattered rounded quartz grains in fine-grained dolomite matrix which gives a "tapiocalike" texture; interbedded with light-gray very fine grained thin-bedded sandstone beds; forms ledges	53
27. Sandstone, light-gray, very fine grained, laminated to thin-bedded; a few siltstone laminations; ripple marks along some bedding planes; forms ledges	6
26. Sandstone, light-gray, very fine grained, dolomitic, rough-weathering; thin shaly partings; forms ledges	13
25. Siltstone, light-gray, dolomitic, dense, hard, rough-weathering; intercalated with light-gray silty dolomite; thinly laminated to thin-bedded, even-bedded dark-gray dolomite beds 83 ft from base; forms ledges	107
24. Partly covered; a few scattered light-gray very fine grained thinly laminated dolomitic sandstone beds	107
23. Sandstone, light-gray, very fine grained, thin-bedded, dense, rough-weathering; unit is locally conglomeratic, containing subrounded dolomite and sandstone fragments in poorly sorted dolomite sandstone matrix; a few fine-grained dolomite beds in upper part; forms ledges	85
22. Conglomerate; subrounded light- to dark-gray dolomite fragments as much as 2 in. in diameter in a dolomite matrix	1
21. Sandstone, light-gray, very fine grained, thin-bedded, dense; forms massive ledges; intercalated with a few thin beds of light-gray very fine grained dolomite	45
20. Sandstone, light-gray, very fine grained, well-sorted, dense, hard, thin-bedded, dolomitic; forms massive ledge	33
19. Dolomite, medium light-gray, very fine grained, thinly laminated to thin-bedded, wavy-bedded; forms massive cliff; dark-gray dolomite bed 2 ft thick at 9 ft above base	33
18. Quartzite, light-gray, very fine grained, thick-bedded, dense; basal 6 in. is dolomitic	3
17. Sandstone, light-gray, very fine grained, well-sorted, thin-bedded, dense, ragged-weathering; interbedded with light-gray very thin bedded dolomite; forms ledges	50
Total thickness Beirdneau Sandstone Member	699

Contact between Beirdneau Sandstone Member and Hyrum Dolomite Member is at base of sandstone outcrop (unit 17). Contact is conformable.

	Feet
Hyrum Dolomite Member:	
16. Covered; light-gray sandstone and dolomite float	11
15. Dolomite, medium light-gray, very fine grained, dense; bedding indistinct; unit splits into elongate angular fragments	8
14. Covered; gray sandstone and dolomite float	25
13. Dolomite, dark-gray, medium light-gray weathering, thin- to medium-bedded; no shale partings; thin wavy laminations throughout; sparse fragments of fossils; unit forms steep ledgy slope	237

Section of Jefferson Formation in sec. 1, T. 10 N., R. 1 E.—Continued

Hyrum Dolomite Member—Continued	*Feet*
12. Sandstone, yellowish-gray, quartzitic, very fine grained, well-indurated; bedding generally concealed but locally has thin laminations that may be cross-laminations; weathers to sharp angular fragments	4
11. Dolomite, dark-gray, fine-grained, medium-bedded; beds are 6–18 in. thick; no shale partings; rough "sandy" weathering; unit forms top of massive cliff-forming sequence in the middle one-third of Hyrum Dolomite Member	152
10. Sandstone, yellowish-gray, pale yellowish-orange weathering, very fine grained, well-indurated; composed of clear quartz grains and scattered red and black accessory minerals; contains scattered well-rounded fine- and medium-grained clear quartz; local carbonate cement; cross-laminated; basal contact is mainly flat but shallow scours occur locally	5
9. Dolomite, dark-gray, fine- to medium-grained, fetid, thick-bedded; locally contains thin layers of dark-gray chert; basal part of many beds are breccias (angular fragments of dark-gray dolomite that are locally cemented with white calcite); largest fragment about 1 ft long but fragments average about 5 in. in length; breccia zones average about a foot thick and grade upward into massive dolomite; laterally, the zones are lenticular and most do not extend more than 100 ft; unit weathers to massive cliffs 20–50 ft high that are separated by narrow benches	225
8. Dolomite, medium light-gray, very fine grained; irregular nodular weathering in lower 10 ft, thin platy weathering above; unit forms light-colored ledge that caps cliff made up of this unit and unit below; color change distinctive in line of section and westward but not present eastward	17
7. Dolomite, dark-gray, very fine grained, thick-bedded; contains local fragments of fossils	34
6. Dolomite, medium dark-gray, very fine grained; thin even beds average about 2 in. in thickness; upper part of some beds contain abundant fragments of fossils; forms ledgy slope	50
5. Dolomite, dark-gray, very fine grained, wavy-bedded; beds 6 in. to 2 ft thick, separated by shaly zones ¼–2 in. thick; beds in lower half have contorted thin laminations; local zones of breccia contain platy fragments that average about 1 in. in length at base of beds	75
4. Dolomite, dark-gray and grayish-red, silty, very thin bedded; contains fissile siltstone along bedding planes	4
3. Dolomite, dark-gray, very fine grained; beds 2 in. to 1 ft thick separated by shaly zones ¼–1 in. thick; local nodules of white calcite as much as 2 in. in longest dimension; unit forms ledge about 50 ft above road	22
NOTE.—Section for exposures of lowermost rocks in Hyrum Dolomite Member measured about 1,800 ft west of unit 3.	
2. Mainly covered; sparse, isolated ledges of dark-gray to black very fine grained dolomite in upper 40 ft	91

Section of Jefferson Formation in sec. 1, T. 10 N., R. 1 E.—Continued

	Feet
Hyrum Dolomite Member—Continued	
1. Dolomite, dark-gray, conglomeratic; very fine grained for most part but contains subangular to subrounded fragments of dolomite; fragments are as much as 2 in. long but average about half an inch	16
Total thickness of Hyrum Dolomite Member	976
Total thickness of Jefferson Formation	1, 675

Contact of Hyrum Dolomite Member of Jefferson Formation and Water Canyon Formation. Top of Water Canyon Formation gently scoured in line of section, but in general area the scours are sharp and as much as 6 ft deep. No evidence of pre-Hyrum weathering at top of Water Canyon Formation.

Partial section of Water Canyon Formation in secs. 1 and 2, T. 10 N., R. 1 E., in Blacksmith Fork Canyon

	Feet
Water Canyon Formation (in part):	
7. Siltstone, dolomitic siltstone, limestone, and very fine grained sandstone compose this unit as follows: 60, 20, 10, and 10 percent, respectively. Siltstone similar to unit 3. Limestone is medium gray and dense, and contains fine quartz grains. Sandstone is yellowish gray to light brown and very fine to fine grained and is composed of clear quartz and noncalcareous cement. Bedding in unit ranges from thin laminations to massive beds about 2 ft thick; thickest massive bed is limestone, but most laminated beds are also limestone	65
6. Siltstone, light-gray (in lower half), grayish-red and yellowish-gray (in upper half); contains scattered very fine quartz grains; noncalcareous except locally in upper 10 ft; unit is poorly exposed	40
5. Sandstone, grayish to pale-red, poorly sorted; ranges from very fine grained to pebble conglomeratic; finer sizes are mainly subrounded clear quartz grains, granules, and pebbles of quartz, quartzite, and mudstone; larger sizes are most abundant in a zone 4 ft thick at 6 ft above base; low-angle cross-laminations; probable basal scour but contact with underlying unit concealed; forms distinctive red zone in line of section	20
4. Covered	4
3. Siltstone, light bluish-gray (weathers light gray with a faint green tinge), dense, well-indurated; conchoidal fracture; about three-fourths of the rock contains silica cement and one-fourth probably contains dolomitic cement; unit is irregularly bedded, ranging from massive beds as much as 2 ft thick to thinly laminated beds about 2 in thick; most thin beds are contorted	87
2. Covered	12
1. Siltstone, light-gray; contains scattered very fine grains of quartz and abundant very fine grains of black minerals; locally grades to silty dolomite. Unit exposed in roadcut on north side of highway	6
Measured thickness of Water Canyon Formation	234

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