Geology of Southern Part of the James Peak Quadrangle, Utah

Jan G. Blau

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GEOLOGY OF SOUTHERN PART OF THE
JAMES PEAK QUADRANGLE, UTAH

by

Jan G. Blau

A thesis submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Geology

UTAH STATE UNIVERSITY
Logan, Utah
1975
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The writer gratefully acknowledges the assistance of Dr. Clyde T. Hardy. He aided in making interpretations in the field and he also reviewed the manuscript. Dr. Donald R. Olsen aided in the interpretation of thin sections and consulted with the writer on mineralogical problems. Dr. Raymond L. Kerns, Jr., helped with the production and interpretation of X-ray data.

The interest of Dr. J. Stewart Williams, in this project, was appreciated. He also provided information on Tertiary formations and events. My sister, Liwana, suggested revisions in the manuscript and did much of the typing.

Jan G. Blau
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<td>1. Geologic map of southern part of the James Peak quadrangle, Utah</td>
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The mapped area, in north-central Utah, is centered about 22.6 miles south of Logan, Utah. It measures about 3.8 miles in the north-south direction and 6.6 miles in the east-west direction. Stratigraphic units of Precambrian and Cambrian age underlie most of the area. The Precambrian units are as follows: (1) Maple Canyon Formation, (2) Kelley Canyon Formation, (3) Orthoquartzite unit, (4) Argillite unit, (5) Mutual Formation, and (6) Volcanic unit. The Brigham Formation, which overlies the Precambrian volcanic unit, is probably of Cambrian age; however, the lower part may be Precambrian. The overlying Cambrian carbonate unit is not differentiated. The Salt Lake Formation of Tertiary age overlaps older rocks in the valley north of James Peak.

The western part of James Peak, east of a major normal fault, consists of east-dipping Precambrian units. The oldest unit, which crops out on the eastern side of Broadmouth Canyon, is the Maple Canyon Formation. The rocks of the eastern part of James Peak also dip generally eastward. A continuous stratigraphic section extends from
the Kelley Canyon Formation, exposed in Wolf Creek Canyon, northeastward to the Brigham Formation. The Cambrian carbonate unit seems to overlie the Brigham in normal stratigraphic succession. A thrust fault, which has about 1,000 feet of displacement, is present on the eastern side of James Peak. Another thrust fault, on the southeastern side of James Peak, places the Cambrian carbonate unit on Precambrian units. A block of the Brigham Formation, near the southeastern corner of the area, is thrust over the carbonate unit and the Brigham.

The thrust faulting is part of the Laramide orogeny that occurred late in the Mesozoic Era and early in the Tertiary Period. Movement was generally eastward. Normal faulting began early in the Tertiary Period and continues at the present time.
INTRODUCTION

Purpose and Scope

The purpose of this investigation is to ascertain the geological features of the southern part of the James Peak quadrangle, Utah, and to represent them by means of a detailed geologic map and structure section (Plate 1). An attempt will be made to relate the stratigraphic units and structural features to those of the region. Indications of mineralization will also be evaluated. Previously, only reconnaissance studies have been undertaken in the area.

Location and Accessibility

The mapped area is centered at approximately lat. 41°24' N. and long. 111°49' W. (Figure 1). Only the southern part of the James Peak 7.5-minute quadrangle is considered in this study. James Peak is part of the Bear River Range in the Middle Rocky Mountain physiographic province (Fenneman, 1946). The Wasatch Mountains are west of the quadrangle. Cache Valley is to the north and Ogden Valley is to the south. James Peak stands as an imposing landmark when viewed from Cache Valley.

Utah Highway 162, a graded road that connects Cache and Ogden Valleys, provides access to the James Peak area. On the northern side, various unimproved roads lead into the mountain; one of these leads to the Bluebell mine. This area is almost all privately owned so travel
Figure 1. Index map of part of north-central Utah showing location of southern part of James Peak quadrangle.
is often restricted. On the southern side, an unimproved road extends into Wolf Creek Canyon. A paved road extends eastward, along the South Fork of Wolf Creek, and northward to the divide. It terminates at a ski resort.

**Physiographic Features**

James Peak, elevation 9,422 feet, rises from Ogden Valley, on the south, and from Cache Valley, on the north. Ogden Valley has an elevation of 5,200 feet near the mountain; the broad valley north of James Peak has an elevation of 6,600 feet. The relief, therefore, is about 4,200 feet on the southern side and 2,800 feet on the northern side.

James Peak has a subradial stream pattern and is well drained. A few perennial springs make the area valuable for grazing. This is the only commercial use made of the area.

Vegetation is mostly grass and brush with a few small stands of Douglas fir, alpine fir, and Utah juniper. Groves of maples and clones of quaking aspen are present in places.

The average annual precipitation in Ogden Valley is 20.86 inches (Leggette and Taylor, 1937, p. 105). In Cache Valley, as recorded by the weather station on the campus of Utah State University, it is only 17.38 inches. The area is classified as semiarid inasmuch as evaporation exceeds precipitation (Blair, 1942, p. 123).
Field Work

The field work was done during the summer and fall of 1968 and 1969. The structure and stratigraphy were plotted in the field on aerial photographs at a scale of 1:20,000, which were obtained from the U. S. Forest Service. These were also used to record locations of rock samples, photographs taken, and observations recorded in the field. Information plotted on the photos was transferred to a base map at a scale of 1:12,000, which was prepared from the 7.5-minute James Peak topographic quadrangle map.

The Mutual Formation was measured with a 50-foot steel tape and Abney level. Rock samples were collected for later description and analysis in the laboratory.

Previous Investigations

Precambrian rock units that crop out between Ogden and Brigham City, Utah, were described and compared with those exposed along the Middle Fork of Ogden River, southeast of the James Peak quadrangle, in 1940 (Eardley and Hatch, 1940, p. 811-818). King studied the Paleozoic rocks of the James Peak quadrangle and recognized older rocks (King, 1965). Crittenden (1972) mapped the Browns Hole quadrangle, southeast of the James Peak quadrangle. His work, initiated after this investigation was underway, established the Precambrian stratigraphic section.

The James Peak area was represented on the Geologic Map of Northwestern Utah by Stokes (1963). His information was based on a
map of the northern Wasatch Mountains compiled by Hardy and Williams (1953). Eardley (1944) described the structure of the north-central part of the Wasatch Mountains, west of the mapped area. Hafen (1961) reported on the structure of the Sharp Mountain quadrangle, which is located immediately east of the James Peak quadrangle.
STRATIGRAPHIC GEOLOGY

General Statement

Stratigraphic units of Precambrian and Cambrian age underlie most of the mapped area (Table 1). The Precambrian section is closely related to that exposed along the Middle Fork of Ogden River, southeast of James Peak (Crittenden, 1972). The Brigham Formation of Cambrian age overlies the Precambrian volcanic unit in the area of James Peak; whereas, west of James Peak, it rests directly on the Mutual Formation. Paleozoic rocks, above the Brigham, are referred to as the Cambrian carbonate unit; however, they contain some shale. The Salt Lake Formation of Tertiary age underlies the broad valley north of James Peak.

The strata of James Peak dip generally eastward with the result that the Maple Canyon Formation of Precambrian age crops out in Broadmouth Canyon, on the southeastern side, and the Brigham Formation is found on the eastern side (Figure 2). West of James Peak, the rocks dip northward. The Paleozoic section of the latter area was studied by King (1965).

Precambrian Units

Maple Canyon Formation

The Maple Canyon Formation of Precambrian age is the oldest stratigraphic unit exposed in the mapped area. It crops out on the
Table 1. Stratigraphic units of Precambrian and Paleozoic age, southern part of the James Peak quadrangle

<table>
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<th>Thickness (feet)</th>
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<td>Carbonate unit</td>
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<tr>
<td></td>
<td>Brigham Formation</td>
<td>4,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Precambrian</td>
<td>Volcanic unit</td>
<td>60&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Mutual Formation</td>
<td>2,600&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Argillite unit</td>
<td>400&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Orthoquartzite unit</td>
<td>2,000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Kelley Canyon Formation</td>
<td>2,000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Maple Canyon Formation</td>
<td></td>
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<sup>a</sup>Browns Hole quadrangle, Utah (Crittenden, 1972).

<sup>b</sup>James Peak area (this report).
Figure 2. Northern side of James Peak; aerial view south. Precambrian orthoquartzite unit (p6o), Mutual Formation (p6m), and Brigham Formation (6b) dip eastward.
eastern side of Broadmouth Canyon at the southern edge of the quadrangle. The base is not exposed due to the fact that the outcrop is terminated on the west by a major normal fault in Broadmouth Canyon. The upper part of the Maple Canyon is orthoquartzite, which is locally conglomeratic. Some cobbles are 6 inches long, but the average length is 2-4 inches. They are commonly elongate with the length being 1 1/2 to 2 1/2 times the other dimensions. The Maple Canyon is overlain, on the east, by the Kelley Canyon Formation.

The Maple Canyon Formation, in the Browns Hole quadrangle, consists of three members as follows: (1) lower argillite, (2) arkose, and (3) upper orthoquartzite (Crittenden, 1972). The lower part of the formation is poorly exposed on the eastern side of Broadmouth Canyon; however, the orthoquartzite makes prominent outcrops. In the Browns Hole quadrangle, the Maple Canyon is as much as 2,000 feet thick (Crittenden, 1972).

**Kelley Canyon Formation**

The Kelley Canyon Formation, in the James Peak area, is chiefly argillite. It is exposed on the eastern side of Broadmouth Canyon and in the bottom of Wolf Creek Canyon. The argillite is dark olive green to gray. In places, however, it is pink to lavender. It is very thin to thin bedded. Thin to thick beds of orthoquartzite are intercalated with the argillite. Orthoquartzite predominates in the lower part of the Kelley Canyon. The thickness of the Kelley Canyon was not measured but it is about 2,000 feet thick along the Middle Fork of the Ogden River (Crittenden, 1972).
The Kelley Canyon Formation is greatly deformed due to tectonic movement. This is most evident on the western side of Wolf Creek Canyon where it is intensely folded (Figure 3). East of Broadmouth Canyon, the Kelley Canyon is folded on a small scale and is also foliated (Figure 4).

**Precambrian orthoquartzite unit**

A unit of orthoquartzite, approximately 2,000 feet thick at the head of Wolf Creek Canyon as determined by calculation from the map, overlies the Kelley Canyon Formation with apparent conformity. This unit is not exposed farther east than the eastern side of Wolf Creek Canyon but it is present to the western edge of the quadrangle. It consists of thick-bedded to very thick-bedded, fine-grained to very coarse-grained, white to light-brown, vitreous orthoquartzite with some beds of red siltstone near the bottom.

The orthoquartzite unit dips generally 30° NE. to 45° NE. and steepens eastward. It generally does not form prominent cliffs although outcrops are plentiful. This could be expected where erosion is not sufficiently rapid to denude the slopes except where they are the steepest.

The Precambrian orthoquartzite unit probably correlates with the Big Cottonwood Formation southeast of Salt Lake City, Utah. The Big Cottonwood is quartzite with interbedded shale (Crittenden, Sharp, and Calkins, 1952, p. 3).

A lava flow crops out in the road cut of Utah Highway 162 in sec. 32, T. 8 N., R. 1 E. It rests on the Precambrian orthoquartzite
Figure 3. Folds in Kelley Canyon Formation on western limb of anticline in Wolf Creek Canyon, sec. 2, T. 7 N., R. 1 E.; view west. Precambrian orthoquartzite unit (pCo) overlies Kelley Canyon (pCk).
Figure 4. Joint set in Kelley Canyon Formation near western boundary of sec. 35, T. 8 N., R. 1 E.; view north.
unit and is mapped as part of the Precambrian argillite unit. The flow is exposed only at that place. It is light olive gray but weathering results in two different aspects. One has alternating light-olive-gray and yellowish-gray bands; whereas, the other is light olive gray and is mottled with yellow spots. X-ray analysis indicated a composition of quartz, feldspar, and chlorite. The lighter rock is aphanitic; the groundmass crystals average less than 5 microns across. Chlorite flakes are oriented approximately at right angles to each other. A few quartz crystals, about a tenth of a millimeter long, are present. The darker rock seems to have scattered phenocrysts; however, thin-section examination indicated that these objects consist of clusters of small crystals. This rock is also aphanitic. It gave the same X-ray data and has the same chlorite arrangement as the lighter rock. It also contains limonite and hematite which, together with the chlorite, are responsible for the rock color. Quartz and feldspar fill cavities that are two-tenths of a millimeter across. Some chlorite flakes are large enough to produce an interference figure.

Precambrian argillite unit

The Precambrian argillite unit is laminated to thin-bedded shale, red in the lower part and green in the upper, and the bed thickness increases upward. According to X-ray analysis, it is composed predominantly of quartz and illite. Microscopic observation of a thin section of shale gave the impression of as much as 30 percent of red hematite. However, the hematite has a flake-like form indicating it
may be a veneer on illite of similar form (Kerr, 1959, p. 413). If this is the case, there is much less than 30 percent of hematite.

A tabular mass of igneous rock, which is probably a sill, is present at or near the top of the Precambrian argillite unit. The best outcrop is near the southwestern corner of the mapped area in sec. 31, T. 8 N., R. 1 W. This exposure is described in the measured section of the Precambrian argillite unit and Mutual Formation (Appendix). The igneous rock crops out, to the east, in a road cut along Utah Highway 162. It is also present east of the valley of Cache Valley Creek, in the east-central part of sec. 32, T. 8 N., R. 1 E., where numerous pieces have been found in an area of poor exposure.

The igneous rock consists of a dusky-yellow-green matrix with pale-blue phenocrysts, which are generally euhedral. It is highly weathered. The contact of the igneous rock and the underlying argillite unit was examined in a pit, near the line of the stratigraphic section, in sec. 31, T. 8 N., R. 1 W. A thin layer of yellow clay is present immediately above the argillite unit. The igneous rock, just above the clay, has a uniform aphanitic texture; however, within about 2 inches from the base, phenocrysts become visible to the unaided eye. They increase in length to about 15 millimeters at a distance of about 6 inches from the base. At this locality, the tabular mass of igneous rock is 23.3 feet thick.

X-ray diffraction analyses of the powdered rock, the blue phenocrysts, and the green phenocrysts indicated talc, chlorite, and calcite. Talc is restricted to the blue phenocrysts and chlorite is not present
in them. Tests with dilute hydrochloric acid indicated calcite in both the blue phenocrysts and the matrix with a much smaller amount in the matrix. The talc has rhombs of calcite and dolomite distributed throughout (Kerr, 1959, p. 404). The matrix and the green phenocrysts contain an abundance of chlorite but the chlorite, pennenite, is restricted to the phenocrysts. Limonite is restricted to the matrix. Hematite, which locally amounts to 6 percent of the rock, is finely divided and uniformly scattered throughout the matrix; however, in the phenocrysts it is more massive and usually occurs either in fractures or along grain boundaries. The green phenocrysts penetrate the blue ones.

The texture of the igneous rock, which is probably too coarse for lava, suggests that it is intrusive. Parallel relationships of the tabular mass with underlying and overlying units of sedimentary rock indicate that it is a sill. Dr. Donald R. Olsen (personal communication) suggested that the mineral composition is that of an altered ultramafic rock, probably an olivine peridotite porphyry. The rock has been so nearly totally altered that only a few small remnants of what may have been the original minerals are present.

Mutual Formation

The Mutual Formation is the most widespread unit of the area and is also extensive throughout northern Utah. About 4,000 feet is present in the western end of the Uinta Mountains where two members were recognized: (1) lower red and green shale, and (2) upper quartzite (Cohenour, 1959, p. 37). It is present in the central Wasatch
Mountains east of Salt Lake City, Utah (Crittenden, Sharp, and Calkins, 1952, p. 6). A unit, 1,000 feet thick, on the southern tip of the Promontory Mountains may be the equivalent of the Mutual Formation (Eardley and Hatch, 1940, p. 801). Unit 16 of this section is quartzite with a few thin beds of green shale. The quartzite is pink, gray, dark gray, pinkish purple, purple, purple red, and brown gray; however, the upper part is mostly purple. In the Sheeprock Mountains of central Utah, the Mutual is 923 feet thick (Cohenour, 1959, p. 38).

The orthoquartzite of the Mutual Formation, in the James Peak area, is fine to coarse grained and thick to very thick bedded. It is generally purple; however, it is also light brown, red, and very dark purple in places. Isolated well-rounded pebbles are frequent throughout. Scattered through the middle part are red nodular areas, about 1 inch in diameter, surrounded by dark-purple halos. Observation with a binocular microscope revealed that a concentration of hematite produces this phenomenon and not a jasper pebble as might be suspected. Conglomeratic beds are common in the upper half. Cross-bedding is common throughout with some minor graded bedding. The Mutual commonly produces prominent ledges and cliffs, as is expected of orthoquartzite, and outcrops are plentiful even on level terrain.

In the upper part, a high concentration of hematite is present in dark-purple orthoquartzite. Near the top of the Mutual, in the area of the measured section, the quartz grains are in a matrix of hematite. A thin unit of ironstone, at the top, contains no quartz grains. This sequence seems to indicate that the deposition of hematite continued
or increased simultaneously with the cessation of deposition of sand. Another condition, implied by the overlying terrigenous deposit and the fact that ironstone indicates a shallow-water deposit (Carrozzi, 1960, p. 352), is that the basin of deposition was filled or the water receded producing an emergent condition.

Precambrian volcanic unit

The Precambrian volcanic unit overlies the Mutual Formation. In the lower part, it is a poorly sorted conglomerate with boulders up to several feet in diameter. Iron oxide from the volcanic unit commonly makes the underlying quartzite of the Mutual Formation dark purple. The upper part of the volcanic unit contains lava flows in places.

Lava flows crop out on a ridge, west of Wellsville Creek, in the eastern part of sec. 36, T. 8 N., R. 1 E. The exposed thickness is 12 feet; however, the total thickness may be as much as 58 feet. The lower part of the volcanic unit is covered. The presence of abundant microscopic vesicles, in the lower part of the outcrop, indicates that two flows are present. A lava flow is also found in the western part of sec. 27, T. 8 N., R. 1 E.

The lava is andesite. Examination under a binocular microscope revealed that most of the iron oxide is hematite although there is a minor amount of magnetite. In thin section, the difference could not be distinguished and it is all referred to as hematite. X-ray data indicated the presence of quartz and plagioclase in every sample and some had chlorite and aegirine. The phenocrysts are of aegirine-augite or pigeonite, euheiral either in part or fully, and nearly free
of alteration although the crystal faces and fractures are altered somewhat. Amphibole was not recognized although pseudomorphs of chlorite, after an amphibole, are present. The plagioclase generally is restricted to the matrix and is too fine for recognition. Occasionally, however, crystal segregation produces plagioclase phenocrysts large enough to permit measurement of extinction angles of twinned crystals. The composition is An 25-An 40, which is in the oligoclase-andesine range. Some orthoclase is also present. Chlorite is the most common alteration mineral and quartz is either associated with the plagioclase or is secondary. The lowermost part of the flow has few phenocrysts but it does have an abundance of vesicles which have been filled with a zeolite or tridymite. Secondary calcite is present in the upper part but was not detected in the lower part. Euhedral crystals of apatite, less than 40 microns in diameter, are present in the lower part.

An unconformity is generally recognized under the Brigham Formation, although field evidence may not always support this conclusion. King (1965, p. 8) thought that the Brigham Formation is conformable with the underlying Mutual Formation in the northern part of the James Peak quadrangle. Evidence for an unconformity has also been reported. Coody (1957, p. 39), in the Durst Mountain area southeast of Huntsville, Utah, reported that the Tintic Quartzite lies unconformably on the Farmington Canyon Complex, which is the same relationship found in Willard Canyon (Eardley and Hatch, 1940, p. 836). These two occurrences are under the Willard thrust fault and the younger Precambrian units,
now found in James Peak, were either never deposited or eroded away. If they were never deposited, the area of the Farmington Canyon Complex may have been high and may have contributed sediments to the younger units.

In James Peak, the unconformity is not apparent but probably exists. The Precambrian volcanic unit is not everywhere present; however, the presence of dark-purple orthoquartzite at the top of the Mutual Formation indicates that the volcanic unit was deposited and was later removed by erosion. The volcanic unit also indicates emergent conditions before deposition of the Brigham Formation.

**Cambrian System**

**Brigham Formation**

The basal Cambrian unit is here called the Brigham Formation because it can be correlated directly to the site of Walcott's type section on the western side of Wellsville Mountain (Walcott, 1908, p. 8). Prospect Mountain was used by Hafen (1961, p. 13) and King (1965, p. 8) but this seems improper because of the close proximity and direct correlation to the type location of the Brigham Formation and because of the structural complexities between this area and the type location of the Prospect Mountain Formation. Coody (1957, p. 14) used Tintic Formation in Durst Mountain as did Eardley (1944, p. 828) in the mountains east of Ogden, Utah. Eardley (1944, p. 828) reasoned that the presence of the Willard and Ogden thrust faults is sufficient reason for not extending the Brigham terminology into that area from
Wellsville Mountain. For these reasons the same unit, which was designated Prospect Mountain by Hafen (1961, p. 13) and King (1965, p. 8), is here called Brigham Formation.

The Brigham Formation is a medium-grained to very coarse-grained vitreous orthoquartzite that is usually light brown but ranges through light purple, green, and gray. It weathers to a color just slightly darker than the fresh rock. The weathered surface, in places, has a sugary texture. This is especially the case along the western side of Davenport Creek. Beds of conglomerate are common and, in places, the formation approximates sandstone. Plagioclase feldspar is a common constituent near the bottom of the formation with laths up to three-eighths of an inch long but one-eighth of an inch is more common. Some green sericitized beds less than 8 inches thick are found, in this area, as they are near the type location (Eardley and Hatch, 1940, p. 811). The fossil tubes, Skolithos, as recognized by King (1965, p. 11) are present near the top of the formation and in some areas they are abundant. The absence of the Precambrian volcanic unit that normally underlies the Brigham Formation, in the area west of Utah Highway 162, suggests the presence of an unconformity.

Cambrian carbonate unit

The units above the Brigham Formation are undifferentiated and are collectively referred to as the Cambrian carbonate unit. They were studied by King (1965, p. 12-23). Limestone and dolomite are the predominant rock types of the carbonate unit; however, shale and sandstone are present.
In secs. 20 and 21, T. 8 N., R. 1 E., the Brigham Formation is overlain by a limestone, which may be the Langston Formation, although it was not positively identified and vegetation covered it almost entirely.

In sec. 30, T. 8 N., R. 2 E., the top of the Brigham was located but the nature of the overlying unit could not be established because of the vegetative cover and poor exposures but fragments of limestone or dolomite and shale were found. The carbonate rocks of this unit impart a pink color to the soil that forms on them and quaking aspen and underbrush grow profusely on these rocks. These characteristics facilitated identification of the rocks and aided in the location of the boundaries of this unit.

Tertiary System

Salt Lake Formation

Exposures of light-olive-green tuffaceous rock, in the broad valley north of James Peak, represent the Salt Lake Formation. They are thought to be part of the Cache Valley Member of the Salt Lake (Williams, 1948, p. 1160; Adamson, Hardy, and Williams, 1955, p. 6). Exposures are rare due to the overlying units. This makes establishing a boundary of the Salt Lake Formation next to impossible. The Salt Lake Formation was deposited in a fresh-water lake which occupied Cache Valley (Williams, 1948, p. 1160). Deposition evidently began as early as late Eocene and continued through Pliocene (Williams, 1964, p. 273; Adamson, Hardy, and Williams, 1955, p. 2). The Salt Lake
Formation is also represented by white fresh-water limestone that is exposed along Utah Highway 162 near the divide between Cache and Ogden valleys. The soil that forms on the Salt Lake Formation is black. It is sticky when wet and commonly displays dessication cracks over a foot deep when dry. These conditions are probably due to montmorillonite in the tuff.

A prominent erosion surface, called the McKenzie Flat surface by Williams (1948, p. 1161), formed on the Salt Lake Formation and older Paleozoic rocks at the southern end of Cache Valley. The valley, between James Peak and Middle Mountain, represents this erosion surface according to Dr. J. Stewart Williams (personal communication).

Quaternary System

Colluvial deposits

Colluvial deposits consist of fine-grained unconsolidated material that mantles slopes. It commonly contains admixed boulders of quartzite. Locally, the fine-grained material may have been washed away by running water leaving a concentration of boulders. Slopes, covered by colluvial deposits, grade upward to the base of the mountain or to outcrops of quartzite. Widespread colluvial deposits cover the Salt Lake Formation in the broad valley north of James Peak. Colluvial deposits are considered to be of Pleistocene and Holocene age. The material is in transport down slopes at the present time.
Moraines

Lateral and terminal moraines evidence the previous existence of four valley glaciers around James Peak during the Pleistocene. Three of these glaciers were 1-2 miles long; the other was much smaller. Sediment deposited directly by the glaciers is herein designated moraine without differentiating the different kinds of moraines. Sediment of glacial origin that was redeposited by stream action is designated as outwash fans.

The glaciers formed on north-facing slopes and flowed down canyons. The cirque floors are at elevations ranging from 8,200 to 8,600 feet, which is in accordance with glaciation elsewhere in the Wasatch Mountains (Flint, 1957, p. 309), and the glaciated valleys terminate at about 7,000 feet. The terminal moraines of the two northernmost glaciers have been breached permitting streams to remove some of the till from the glacial valleys and moraines and deposit it at the foot of the mountain.

Outwash fans

Two coalescing outwash fans radiate from the base of the two terminal moraines north of James Peak. They were built by melt water and by streams which had dissected the moraines. The flow lines of the fans are evident on aerial photographs. The uniform spacing of the contour lines, on the map (Plate 1), indicates the even gradient expected on fans. At their outer extremities, the fans conform to the pre-existing topography so that the previous drainage pattern was changed little or not at all by the glaciation.
Alluvial deposits

Deposits in valley bottoms, which are a direct result of stream action, are grouped together. Fans, which were formed by intermittent streams at the mouths of small canyons, are included in this category. Cobbles and boulders of low to medium sphericity and roundness are common alluvial constituents in valley bottoms, evidencing short transport on the mountain.

Few streams, in the mapped area, have an alluvial bed. Davenport and Wellsville Creeks are notable examples. The alluvium, in the upper part of Wolf Creek Canyon, is probably a product of the spring runoff, as the canyon does not have a perennial stream at that elevation.
STRUCTURAL GEOLOGY

Structural Setting

James Peak is located near the southern end of the Bear River Range in the Middle Rocky Mountain province. Laramide deformation, which produced north-south-trending folds, also produced complex thrust faults. The Bannock thrust zone, to the east, has been regarded as a continuation of the Willard thrust fault east of Ogden, Utah (Armstrong and Cressman, 1963, p. 5). If this is the case, James Peak, which contains numerous small thrust faults, has been transported from the west by as much as 45 miles (Crittenden, 1961, p. 129).

James Peak is about 12 miles east of the Wasatch fault. This fault is the main structural division between the Basin and Range and Middle Rocky Mountain provinces. The East Cache fault bounds Cache Valley on the east (Williams, 1948, p. 1125). It extends as far south as James Peak. Numerous other Basin and Range faults are present in the mapped area.

Structural Features

Folds

The rocks of Wolf Creek Canyon have been folded into a north-plunging anticline that is overturned to the east. On the eastern side, the Precambrian orthoquartzite unit is overturned, in the lower part, and it dips eastward, in the upper part (Figure 5). On the western
Figure 5. Eastern limb of anticline on eastern side of Wolf Creek Canyon; view south. Kelley Canyon Formation (p6k) and lower part of overlying Precambrian orthoquartzite unit (p6o) are overturned eastward and dip westward. Upper part of Precambrian orthoquartzite unit dips eastward.
side, argillite of the Kelley Canyon Formation is intensely folded (Figure 3). Near the head of Wolf Creek Canyon, the anticline is readily mapped.

Precambrian rock units along the Middle Fork of Ogden River, east of Wolf Creek Canyon, are also folded into an anticline. It parallels the anticline of Wolf Creek Canyon. The eastern flank dips more steeply than the western flank. It is probable, therefore, that these folds formed at the same time.

**Bedding-plane faults**

On the eastern side of Broadmouth Canyon, the Maple Canyon Formation and the overlying Kelley Canyon Formation dip eastward in normal stratigraphic succession. The two formations, however, seem to be separated by a bedding-plane fault that terminates northward against the normal fault in Broadmouth Canyon (Figure 6). This fault is at the top of the orthoquartzite of the upper part of the Maple Canyon and beneath argillite of the Kelley Canyon. The orthoquartzite is locally folded below the fault.

Another fault extends across a canyon in sec. 35, T. 8 N., R. 1 E., on the eastern side of Broadmouth Canyon. Argillite of the Kelley Canyon Formation is west of this fault and the Precambrian orthoquartzite unit crops out to the east. On the northern side of the canyon, small step-like drag folds are present in the argillite of the Kelley Canyon immediately west of the fault. The argillite is also jointed at a high angle to the bedding. This fault is represented as a bedding-plane fault.
Figure 6. Bedding-plane fault on eastern side of Broadmouth Canyon, sec. 34, T. 8 N., R. 1 E.; view southeast. Fault dips east and separates orthoquartzite of Maple Canyon Formation (pΣmc) from argillite of Kelley Canyon Formation (pΣk). Precambrian orthoquartzite unit (pΣo) is at upper left.
A bedding-plane fault is present on the eastern side of Wolf Creek Canyon near the southern edge of the quadrangle, in sec. 2, T. 7 N., R. 1 E. (Figure 7). It continues southward into the Huntsville quadrangle. This fault is within the Precambrian orthoquartzite unit on the overturned limb of the anticline in Wolf Creek Canyon. As the rocks were overturned, failure occurred at a low angle to the bedding. Later, the rocks were broken by a low-angle thrust fault that is nearly horizontal. The displacement is eastward and is about 7 feet.

Low-angle thrust faults

Numerous low-angle thrust faults are present in the James Peak area. Movement was generally toward the east or northeast; however, the direction could not be determined on all of the faults. The displacements are relatively small; therefore, no major fault of regional extent is present.

A low-angle thrust fault extends from a point located near the northern edge of the mapped area, just west of Wellsville Creek, southward along the eastern side of the prominent ridge that rises to James Peak. It cuts through the saddle southeast of James Peak and continues around the head of Wolf Creek Canyon nearly to the southern edge of the mapped area. In sec. 19, T. 8 N., R. 2 E., orthoquartzite of the Brigham Formation is thrust eastward over the Cambrian carbonate unit that crops out along Wellsville Creek. The base of the Brigham Formation, above the fault, in sec. 25, T. 8 N., R. 1 E., is offset about 2,000 feet from its position below the fault in sec. 36, T. 8 N.,
Figure 7. Intersection of small faults on eastern limb of anticline in Wolf Creek Canyon, sec. 2, T. 7 N., R. 1 E.; view north. Bedding-plane fault, in Precambrian orthoquartzite unit, is offset eastward by low-angle thrust fault.
R. 1 E. (Figure 8). Thus, along this segment, the Mutual Formation and the overlying Precambrian volcanic unit are thrust over the Brigham Formation. Fault breccia crops out where this fault crosses the saddle southeast of James Peak. The fault continues, from the saddle, across the head of Wolf Creek Canyon and southward along the western side. At the head of Wolf Creek Canyon, the Precambrian argillite unit above this fault is offset to the east. The presence of the argillite unit, north of the fault, is indicated by chips of argillite in the regolith; however, it does crop out to the northwest on the flank of James Peak. This fault is traced with difficulty on the western side of Wolf Creek Canyon because of cover and because of the fact that it is within the Precambrian orthoquartzite unit. Near the southern boundary of the quadrangle, however, it separates outcrops of the orthoquartzite unit that display opposite dip directions. The orthoquartzite unit below the fault dips west, on the western limb of a major anticline, and that above the fault dips east. This change occurs within a distance of 30 feet.

A small low-angle thrust fault is present near the top of James Peak on the eastern side. It is within orthoquartzite of the Mutual Formation. A planar fault surface is evident; however, slickensides were not found.

An important low-angle thrust fault extends from the southern edge of the mapped area, on the eastern side of Wolf Creek Canyon, north-eastward across the head of the canyon of the South Fork of Wolf Creek, and into the upper part of the canyon of Wellsville Creek.
Figure 8. Low-angle thrust faults on southeastern side of northeastern ridge of James Peak; view northwest. Contact of Mutual Formation (p6m) and overlying Brigham Formation (6b) is offset eastward about 2,000 feet by the lower thrust fault.
(Figure 9). It dips generally southeast. Complex structural relationships are present southeast of this fault. The Cambrian carbonate unit, on the south, is thrust over the Mutual Formation, on the north, in the area between the ridge located west of the South Fork of Wolf Creek and the head of the canyon of Wellsville Creek. South of the upper part of the canyon of Wellsville Creek, in sec. 31, T. 8 N., R. 2 E., a mass of the Brigham Formation has been thrust over Brigham along this fault. The orthoquartzite of the thrust mass dips northeast. Its identity is confirmed by the presence of Skolithos. This thrust mass, furthermore, is separated from the Cambrian carbonate unit, which underlies it, by a low-angle thrust fault on its western and southern sides.

Thrust faults are also present in the bottom of the canyon of the South Fork of Wolf Creek near the southern edge of the mapped area. The Cambrian carbonate unit, exposed in the canyon bottom, is continuous with the normal stratigraphic succession that overlies the Brigham Formation in Huntsville quadrangle to the south.

Strike-slip faults

A strike-slip fault is located east of the summit of James Peak in sec. 36, T. 8 N., R. 1 E., and sec. 31, T. 8 N., R. 2 E. It trends northeast. This fault is below the low-angle thrust fault on the eastern side of James Peak. It cuts the upper part of the Mutual Formation, the Precambrian volcanic unit, and the lower part of the Brigham Formation. The northern side is displaced toward the northeast by about 100 feet. A planar surface in orthoquartzite of the Mutual
Figure 9. Low-angle thrust fault on eastern side of Wolf Creek Canyon; view east. Normal stratigraphic succession extends from canyon bottom to upper left and includes Kelley Canyon Formation (p6k), Precambrian orthoquartzite unit (p6o), Precambrian argillite unit (p6a), and the Mutual Formation (p6m). Cambrian carbonate unit (6c), at upper right, rests on southeast-dipping thrust fault. Orthoquartzite of Brigham Formation (6b) is locally present along the fault.
Formation, which evidently represents the fault plane, strikes N. 47° E. and dips 43° S. No slickensides were found on this surface.

A parallel strike-slip fault is located in the upper part of the valley of Wellsville Creek. It is also displaced toward the north-east on the northern side. The Precambrian volcanic unit, mapped as part of the Mutual Formation, opposes the orthoquartzite of the Brigham Formation. This fault evidently extends directly beneath a low-angle thrust fault toward the southwest.

**Normal faults**

Normal faults of the James Peak area are discussed in two groups on the basis of their trends. The north-south faults are the most important, the most numerous, and control the structure of the western part of the mapped area. The east-west faults are few.

Of the north-south faults, the most important one runs through the bottom of Broadmouth Canyon, northward through the saddle at the head of the canyon, to the northern side of James Peak (Figure 10). In the southwestern corner of sec. 34, T. 8 N., R. 1 E., two outcrops of breccia, over 100 feet apart, suggest that it may be a fault zone for part of its length. Near the southern boundary of the quadrangle, normal faults branch on opposite sides of the main fault through Broadmouth Canyon. The top of the argillite of the Kelley Canyon Formation in sec. 27, T. 8 N., R. 1 E., is displaced so as to be nearly opposite the base of the Brigham Formation cutting out the Precambrian orthoquartzite unit, the Precambrian argillite unit, and the Mutual Formation. The displacement is nearly 5,000 feet. This fault may terminate against
Figure 10. Western side of James Peak; view east. Major north-trending normal fault, down on west, extends along the flank of James Peak from colluvial deposits, on the left, to Broadmouth Canyon, on the right. Minor east-trending normal fault, down on the north, intersects the major fault.
the fault bounding the northern side of Ogden Valley (Leggette and Taylor, 1937, p. 99); but because of recent colluvial deposits the relationship at the junction of these two faults is not understood.

A major normal fault parallels the one through Broadmouth Canyon. It is located about three-fourths of a mile west of Broadmouth Canyon. This fault also extends from the southern boundary of the mapped area northeastward to the colluvial deposits of the area north of James Peak. It is down on the west. The Precambrian argillite unit and the base of the Brigham Formation are conspicuously offset.

Another major normal fault parallels the other two. It is located northwest of the valleys of Cache Valley Creek and the South Fork of the Little Bear River. Near the western boundary of the mapped area, the Brigham Formation is down, on the northwest, opposite the Mutual Formation.

A complex fault pattern is present in the area of Cache Valley Creek near the southwestern corner of the mapped area (Figure 11). The part of the area, west of Cache Valley Creek, is broken by east-west and north-south normal faults. The basal contact of the Precambrian argillite unit with the underlying Precambrian orthoquartzite unit is exposed immediately west of the valley of Cache Valley Creek on the southern side of an east-west fault. It is repeated, a short distance to the north, on the southern side of another east-west fault. Northward, at the western boundary of the mapped area, the upper contact of the Precambrian argillite unit with the Mutual Formation is exposed on the northern side of an east-west fault. Several fault blocks,
Figure 11. Intersecting normal faults in valley of Cache Valley Creek, sec. 32, T. 8 N., R. 1 E., view west. Precambrian orthoquartzite unit (p6o), Precambrian argillite unit (p6a), and the Mutual Formation (p6m) dip north. A major north-south normal fault, along Cache Valley Creek, is hidden by the ridge below the road. This fault is down on the east.
between the middle and northern east-west faults, display the Precambrian argillite unit. The continuity of blocks outlined by the east-west faults is disrupted by the north-south faults. The northern east-west fault is offset by the westernmost north-south fault. The offset is probably the result of diagonal slip on the north-south fault.

East of Cache Valley Creek, the outcrop of the Precambrian argillite unit is disrupted by two minor normal faults. They successively offset the Precambrian argillite unit northward from east to west. An important normal fault is interpreted to extend more or less along the valley of Cache Valley Creek. It extends from the southern boundary of the mapped area northward to a broad area of colluvial deposits. On the south, it follows the valley of Cache Valley Creek. Northward, it is located on the eastern side of the valley. At the latter location, the Precambrian argillite unit is continuous across the valley. This fault is down on the east and has the effect of offsetting the Precambrian argillite unit northward on the western side. The structure, east of the fault, is complicated by a narrow block of the Mutual Formation, which has dropped relative to blocks of Precambrian orthoquartzite unit and Precambrian argillite unit to the east.

No normal fault extends along the canyon of Wellsville Creek, northeast of James Peak, as the rocks on both sides of the canyon have the same attitude and seem to be continuous across the canyon (Plate 1). King (1965, p. 6) reported a fault on the western side of Middle Mountain that has a horizontal offset on the Swan Peak Formation of Ordovician age of about 1 1/4 miles. This fault is in line, though a
little divergent, from the fault through Broadmouth Canyon. It is seismically active as evidenced by an earthquake epicenter located at Avon, Utah (Cook and Smith, 1967, p. 716).

An east-west fault is located on the northern side of James Peak. In sec. 27, T. 8 N., R. 1 E., argillite of the Kelley Canyon Formation is terminated by the fault and, in the next canyon to the east, the Precambrian argillite unit is displaced as much as a couple of hundred feet. The amount of displacement is conjectural as outcrops of the argillite unit are nonexistent. The presence of argillite fragments, in the slope, indicates that the northern side is down. This fault seems to be anomalous compared to other structures in the mapped area. Tension, produced by down faulting of Cache Valley, may have produced this fault.

**Structural Events**

**General statement**

Laramide events

The overturned anticline, in Wolf Creek Canyon, and the bedding-plane fault, on the eastern side of Broadmout h Canyon, were produced at a relatively early date during the Laramide orogeny. The bedding-plane fault separates orthoquartzite of the Maple Canyon Formation, below, from argillite of the Kelley Canyon Formation, above. The orthoquartzite, beneath the fault, is folded. The fold parallels this fault and may have been caused by drag during the faulting.

The numerous low-angle thrust faults, on James Peak, were probably produced later. Movement along the strike-slip fault was simultaneous with that on the thrust faults.

Movement was generally from the west or southwest. This corresponds with the direction of movement of the Willard thrust fault (Crittenden, 1961, p. 129).

Basin and Range events

Basin and Range normal faulting began by late Eocene time (Armstrong and Oriel, 1965, p. 1847). The Salt Lake Formation, which has been dated as not older than late Eocene (Williams, 1964, p. 273), was deposited in a graben (Williams, 1948, p. 1160). Basin and Range faulting continues at the present time.

The normal fault, through Broadmout h Canyon, was probably the first Basin and Range feature to be formed. In sec. 27, T. 8 N., R.1 E., the top of the Mutual Formation is nearly opposite the top of the Kelley Canyon Formation. The stratigraphic throw on this fault is about 5,000 feet. Northward, the fault is covered by an outwash
fan from the westernmost glaciated valley on the northern side of James Peak. Movement had ceased, therefore, by the end of Pleistocene.

The east-west normal fault, on the northern side of James Peak, probably postdates the normal fault through Broadmouth Canyon. It seems to have formed subsequent to the down faulting of the area north of James Peak.
ECONOMIC GEOLOGY

Copper Mineralization

The Precambrian volcanic unit contains some copper mineralization at the abandoned Bluebell mine in sec. 25, T. 8 N., R. 1 E. The host rock is a conglomerate, which contains clasts of volcanic rock. Malachite coats fracture surfaces and fills original openings along fractures.

An effort was made to exploit this occurrence, in the decade following 1890, by George G. Wilson, Neils E. Nielson, John F. Squires, Joseph Howell, and associates. According to Mrs. Cleta H. Hansen (personal communication) several wagon loads of rock were shipped.

Iron Mineralization

Exceedingly small amounts of specularite hematite are present in quartz veins, which cut the quartzite of the Mutual Formation, in sec. 33, T. 8 N., R. 1 E. The quartz veins are generally less than 1 centimeter wide. Many of the veins do not contain hematite. The occurrence is of no economic value.
LITERATURE CITED


APPENDIX
Stratigraphic section of Precambrian argillite unit and Mutual Formation along ridge that extends north-northeast from NE 1/4 sec. 31, T. 8 N., R. 1 E., to NW 1/4 sec. 29, T. 8 N., R. 1 E.

Brigham Formation

Mutual Formation

<table>
<thead>
<tr>
<th>Types</th>
<th>Thickness (feet)</th>
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<tbody>
<tr>
<td>10. Orthoquartzite</td>
<td>348.1</td>
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</tbody>
</table>

Orthoquartzite, pale red purple, weathers pale red, medium to very coarse grained with scattered granules, some hematite, limonite, and sericite, exfoliates.

Orthoquartzite, pale red purple, weathers pale red, medium to coarse grained with some granules, some limonite and sericite.

Orthoquartzite, pale red, weathers pale brown, fine to coarse grained, some hematite, limonite, and sericite, purple to red nodular areas with concentrations of hematite.

Orthoquartzite, light grayish purple, weathers grayish red purple, medium to very coarse grained, grading on cross-bedding, granule and pebble layers on bedding and cross-bedding surfaces, some hematite and sericite.

Orthoquartzite, pale red purple, weathers same color, fine to medium grained with scattered granules, graded bedding, hematite throughout but concentrated on bedding surfaces, exfoliates.

Orthoquartzite, pale purple, weathers grayish red purple, unsorted, fine grained to small pebble, granule and pebble sphericity fair-poor, roundness fair-good, some hematite, limonite, and sericite.

Orthoquartzite, dark grayish pink, weathers pale red to pale purple, coarse grained to granule with scattered pebbles, some hematite, limonite, and sericite.
Orthoquartzite, pale red with grayish-purple bands, weathers grayish red with dusky-blue bands, fine to coarse grained with grading to very coarse grains and granules on interbeds, beds of coarse grains have a hematitic matrix giving the banded effect, hematite about 5%, some sericite.

Ironstone, grayish purple, weathers brownish black, contains medium to very coarse sand grains partially suspended in a matrix of hematite, grades upward to a fine-grained ironstone of hematite and sericite with no quartz grains.

Bedding thickness
0.9-2.4 feet

Stratification
Minor cross-bedding

Interbeds
Pebble layers on bedding and/or cross-bedding surfaces, hematite-rich beds throughout

Exposure
Ledges, poorly exposed

9. Orthoquartzite

Types
Orthoquartzite, pale purple, weathers grayish red purple, medium to very coarse grained with scattered granules, hematite 1%, some sericite, vugs.

Orthoquartzite, pale red purple, weathers pale red, well sorted, medium to coarse grained, some hematite.

Orthoquartzite, pale purple, weathers pale red, well sorted, medium to coarse grained with an occasional granule, some hematite.

Orthoquartzite, pale purple, weathers light brown, medium to coarse grained with an occasional granule, some hematite and sericite.
Bedding thickness
1.7-3.5 feet

Stratification
Minor cross-bedding

Interbeds
Pebble layer of white quartz

Structures
Quartz veins

Exposure
Ledges

Weathering
Exfoliates

7. Orthoquartzite

B. Orthoquartzite
Types
Orthoquartzite, pale red purple, weathers pale red, well sorted, medium to coarse grained with scattered small pebbles, friable, exfoliates.

Orthoquartzite, pale purple, weathers slightly darker, well sorted, medium to coarse grained, some hematite and sericite, exfoliates.

Orthoquartzite, pale purple, weathers light brown, poorly sorted, fine grained to granular, some hematite and sericite.

Conglomerate, grayish purple, weathers dark dusky blue, matrix medium to coarse grained, pebbles up to 2 cm of vein quartz and orthoquartzite, hematite about 5%.

Bedding thickness
1.3-3.8 feet

Stratification
Cross-bedding

Exposure
Ledges

Weathering
Liesegang banding associated with cross-bedding
A. Orthoquartzite

Types

Orthoquartzite, grayish pink, weathers grayish orange pink, well sorted, medium to very coarse grained, some hematite, exfoliates.

Orthoquartzite, light pale red purple, weathers moderate orange pink, well sorted, medium to coarse grained with scattered small pebbles, some hematite.

Orthoquartzite, pale red purple, weathers same color, poorly sorted, fine to very coarse grained, some hematite.

Orthoquartzite, light grayish purple with very dusky-red bands, weathers grayish red purple, well sorted, medium to very coarse grained, red hematite colors rock, some specular hematite.

Bedding thickness
1.4-2.6 feet

Stratification

Minor cross-bedding

Interbeds

Scattered quartz pebbles, also dusky-red zones resembling jasper pebbles surrounded by blackish-red halos, large ones 3-5 cm, small ones 1-2 mm

Exposure

Ledges

Weathering

Exfoliates

6. Orthoquartzite

Types

Orthoquartzite, pale red purple, weathers light brown, fine to coarse grained with scattered granules and small pebbles, some hematite and limonite.

Orthoquartzite, pale red, weathers pale reddish brown, well sorted, fine to medium grained with scattered coarse grains and granules, some limonite, hematite, and sericite.

Orthoquartzite, light pale red, weathers light brown, well sorted, fine to medium grained with occasional granules, some hematite and limonite.
Orthoquartzite, grayish red purple, weathers reddish purple, fine to coarse grained, some hematite, minor calcite and/or malachite on joint surfaces, friable.

Bedding thickness
1.6-2.5 feet

Interbeds
Scattered pebbles of white quartz

Exposure
Ledges and cliffs

5. Orthoquartzite and shale

C. Shale
Type
Siltstone, light grayish purple, weathers grayish red purple, some very fine-grained sand, limonite.

Bedding thickness
0.03-0.10 feet

B. Orthoquartzite
Type
Orthoquartzite, light grayish purple with blue bands up to 3 cm wide, weathers pale purple, well sorted, coarse grained, red hematite throughout but concentrated in blue bands.

Bedding thickness
0.45-3.1 feet

A. Orthoquartzite
Type
Orthoquartzite, grayish blue, weathers dusky blue, well sorted, fine grained, limonite on exposed surfaces.

4. Orthoquartzite

Types
Orthoquartzite, pale red purple, weathers pale red, well sorted, coarse grained, some hematite, iron oxide stain on exposed surfaces and in cracks.
Orthoquartzite, dark pale purple, weathers pale red, coarse grained to granule, scattered small pebbles, interbedded laminae of granules, some hematite, limonite, and sericite.

Orthoquartzite, pale red purple, weathers pale red, fine to coarse grained with occasional granule, hematite scattered throughout and concentrated on bedding surfaces.

Bedding thickness
2.2-4.2 feet

Stratification
Cross-bedding

3. Orthoquartzite

Types
Orthoquartzite, light brownish gray, weathers pale red, well sorted, medium to coarse grained, about 7% authigenic calcite, some hematite and sericite.

Orthoquartzite, light brownish gray, weathers slightly darker, medium to very coarse grained with scattered granules, some hematite, limonite, and sericite, solution cavities on weathered surfaces.

Orthoquartzite, light brownish gray with dusky-blue bands 1-3 mm wide, weathers slightly darker, well sorted, coarse to very coarse grained, some hematite and limonite.

Bedding thickness
2.0-3.2 feet

Stratification
Cross-bedding

Exposure
Ledges

2. Orthoquartzite and shale

Types
Orthoquartzite, light grayish purple, weathers grayish purple, fine to coarse grained with scattered medium- to well-rounded small pebbles, some feldspar, hematite, and limonite.
Siltstone, light grayish purple, weathers grayish purple, slightly fissile, interbedded in above orthoquartzite, some sericite.

Orthoquartzite, pale red purple, weathers pale red, fine to coarse grained with scattered granules, some feldspar, hematite, and limonite, small solution cavities on weathered surfaces.

Bedding thickness
2.0–3.1 feet

Exposure
Ledges

Thickness Mutual Formation 2,556.4

Sill 23.3

Type
Olivine peridotite porphyry (?), dusky yellow green, weathers medium bluish gray to dark greenish gray, pale-blue anhedral and grayish–olive-green euhedral phenocrysts up to 15 mm long, some hematite.

Precambrian argillite unit

1. Shale 320.4

B. Shale
Types
Siltstone, light olive gray, weathers slightly darker, specular and red hematite, quartz grains and muscovite.

Siltstone, light olive gray, weathers slightly darker, hematite on interlaminar surfaces, muscovite about 5% with flakes up to 1 mm, hematite throughout.

Siltstone, light olive gray, weathers dark olive gray, very fine- to fine-grained quartz in micaceous argillite matrix, larger muscovite flakes on bedding surface, some limonite.

Siltstone, dark grayish orange pink, weathers pale yellowish brown, some quartz, hematite, and muscovite.
Siltstone, light grayish purple, weathers slightly darker, interbedded laminae of very fine sand, some hematite and muscovite.

Bedding thickness
0.005-0.09 feet

A. Shale and orthoquartzite
Types
Siltstone, pale yellowish brown, weathers yellowish gray, some limonite and hematite on interlaminar surfaces, hematite throughout.

Siltstone, grayish red purple, weathers slightly darker, hematite sufficient to color rock red, some specular hematite, scattered quartz grains.

Siltstone, light reddish gray, weathers slightly darker, hematite imparts red color to rock, hematite concentrated on interlaminar surfaces, limonite on weathered surfaces.

Orthoquartzite, dusky blue, weathers very dusky blue, limonite on weathered surfaces.

Thickness Precambrian argillite unit 320.4

Orthoquartzite fault breccia