Structural Geology of Eastern Part of James Peak Quadrangle and Western Part of Sharp Mountain Quadrangle, Utah

Steven L. Rauzi
Utah State University

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STRUCTURAL GEOLOGY OF EASTERN PART OF JAMES PEAK QUADRANGLE AND WESTERN PART OF SHARP MOUNTAIN QUADRANGLE, UTAH

by

Steven L. Rauzi

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Geology

UTAH STATE UNIVERSITY
Logan, Utah
1979
ACKNOWLEDGMENTS

I am sincerely thankful to Dr. Clyde T. Hardy, under whose direction this work was done, for suggesting the study and providing valuable suggestions and criticism both in the field and on the manuscript. Gratitude is also expressed to both Drs. Richard R. Alexander and Peter T. Kolesar, members of my committee, for reviewing the manuscript. Dr. Alexander also aided in the identification of some of the fossils collected by the writer. Suggestions from Dr. Robert Q. Oaks, Jr., are also appreciated. I thank Mike Rampton for providing occasional companionship in the field and Joey Chaffee whose optimistic spirit was a great help to the author.

Thanks also go to Scott Rampton for providing his home during the 1978 summer field season and to Mr. Richard E. Redden, geologist and first president of the Red Creek Corporation, who provided financial support for the completion of the manuscript and map. Last, but certainly not least, I thank my parents for providing invaluable moral and financial support throughout the investigation.

Steven L. Rauzi
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ABSTRACT

Structural Geology of Eastern Part of James Peak Quadrangle and Western Part of Sharp Mountain Quadrangle, Utah

by

Steven L. Rauzi, Master of Science
Utah State University, 1979

Major Professor: Dr. Clyde T. Hardy
Department: Geology

A detailed study was made of the James Peak-Sharp Mountain area, in the southern part of the Bear River Range, Utah. The mapped area is located in north-central Utah between lat. 41°22'30" N. and lat. 41°30' N. and long. 111°42'30" W. and long. 111°46' W. It measures about 3.8 miles in the east-west direction and 8.7 miles in the north-south direction. The area is centered about 22 miles south-southeast of Logan, Utah.

Stratigraphic units of late Precambrian to Mississippian age underlie the mapped area. The Precambrian units include the Mutual and Browns Hole Formations. The Brigham, Langston, Ute, Blacksmith, Bloomington, Nounan, and St. Charles Formations make up a complete Cambrian section. The Ordovician Garden City and Swan Peak Formations, the Ordovician-Silurian Laketown Formation, the Devonian Water Canyon and Hyrum Formations, and the Mississippian Lodgepole and Humbug Formations overlie the St. Charles in normal succession.
The oldest unit, the Precambrian Mutual Formation, crops out in the southern part of the area on the eastern side of James Peak. The rock units are progressively younger toward the northern part of the area. Mesozoic rocks are not present. The Salt Lake Formation of Tertiary age directly overlies the Paleozoic rocks.

The main structural feature of the area is an asymmetrical north-south-trending anticline. The eastern flank dips more steeply than the western flank. The anticline plunges gently north and dies out southward. This anticline is one of a series of asymmetrical anticlines, all steeper on the east than on the west, that includes the Strawberry Valley anticline to the east and the anticline exposed in upper Wolf Creek Canyon to the west. The late Precambrian and early Paleozoic formations, which dip northeast on the eastern flank of James Peak, make up the northeastern flank of the anticline exposed in upper Wolf Creek Canyon. The early Paleozoic to Devonian formations that form Sharp Mountain and dip gently west make up the western flank of the Strawberry Valley anticline.

Low-angle thrust faults have disrupted the Precambrian and Paleozoic formations on the eastern and southeastern flanks of James Peak. Displacement on the thrust fault north of upper Wells-ville Creek is about 2,000 feet. Movement was generally from the west.

Normal faults have disrupted the Paleozoic and Tertiary formations along the eastern margin of Cache Valley and the Paleozoic formations east of McKenzie Mountain. Displacement is indeterminate along the eastern margin of Cache Valley. Maximum displacement,
east of McKenzie Mountain, is about 1,750 feet. The normal faults truncate the folds and thrust faults.

The folds and thrust faults were formed during the Laramide orogeny. The normal faults were formed during Basin and Range normal faulting. Basin and Range normal faulting is active at the present time.
INTRODUCTION

Purpose and Scope

This investigation was undertaken in order to determine the geologic structure and stratigraphic units of the eastern part of the James Peak Quadrangle and the western part of the Sharp Mountain Quadrangle, Utah, and to represent them by means of a detailed geologic map and several structure sections (Plates 1 and 2). The structural features will be discussed in the light of the structural events of the surrounding region.

Location and Accessibility

The mapped area is located in north-central Utah mostly in Cache County but it also includes a small part of Weber County. This county boundary extends over James Peak, across the Powder Mountain ski resort, and along the broad divide that more or less parallels the southern boundary of the mapped area (Plate 1). The area is located between lat. 41°22'30" N. and lat. 41°30'N. and long. 111°42'30" W. and long. 111°46' W. (Figure 1). Only 1.6 miles of the eastern part of the James Peak Quadrangle and 2.2 miles of the western part of the Sharp Mountain Quadrangle are considered in this study. About 33 square miles are covered by the mapped area.

James Peak and Sharp Mountain are both located in the southern part of the north-northeast-trending Bear River Range. The Bear River Range is in turn a part of the Middle Rocky Mountain physiographic
Figure 1. Index map of part of north-central Utah showing location of eastern part of James Peak Quadrangle and western part of Sharp Mountain Quadrangle.
province as defined by Fenneman (1946). The north-northwest-trending Wasatch Mountain Range is west of James Peak and Sharp Mountain. Cache Valley is north of James Peak and west of Sharp Mountain. Ogden Valley is south of James Peak. James Peak stands as an imposing divide between Cache and Ogden Valleys; whereas, Sharp Mountain is east of Cache Valley and northeast of James Peak. Sharp Mountain is not bounded to the north and south by down-faulted valleys as is James Peak but by ridges of the Bear River Range.

The northern boundary of the mapped area is just south of Porcupine Dam and Reservoir. The dam and reservoir are about 6 miles east of the town of Avon, Utah, the southernmost community in Cache Valley. Avon is about 15 miles south of Logan, Utah, along Utah Highway 162 that connects Cache and Ogden Valleys. The western boundary of the area extends southward through Cache Valley and through the main parking lot at Powder Mountain ski resort near the southwestern corner of the area. The ski resort also marks the southern boundary that somewhat parallels the broad ridge between Sharp Mountain on the north and Ogden Valley on the south. The eastern boundary is just east of Sharp Mountain. This boundary extends through the head of Davenport Creek on the south to just west of Porcupine Ridge on the north. Figures 2 and 3 are general views of the area.

Utah Highway 162, a graded dirt road, connects the northern and southern parts of the area. Various unimproved roads branch eastward toward James Peak from this road. One of these branching roads ends at the Bluebell mine on the northern flank of James Peak. The Bluebell mine is just west of the mapped area. Access into the
Figure 2. Western front of Sharp Mountain; view north from eastern flank of James Peak. Shows, from east to west, the western front of Sharp Mountain, McKenzie Mountain, and Cache Valley.
Figure 3. James Peak; view south from top of McKenzie Mountain. Shows, from east to west, the broad ridge east of James Peak and James Peak.
southern part of the area is by way of the paved road that extends eastward along the South Fork of Wolf Creek and northward to the divide at the Powder Mountain ski resort. Access is by foot from the ski resort. Access can be made to the central part of the area by way of a private jeep road that extends along the entire length of Davenport Creek. At the head of Davenport Creek, this road connects with another unimproved dirt road that continues eastward to the La Plata mine and Utah Highway 39. This highway connects Huntsville and Woodruff, Utah. Access into the northern part of the area can be accomplished by way of private farm and logging roads that branch southward from the graded county road between Avon, Utah, and Porcupine Reservoir. This road continues eastward beyond the reservoir along the East Fork of Little Bear River to the Mineral Point mine. A road branches southward from this road immediately west of Porcupine Dam and extends along Porcupine Creek to its head. Another branch, southward from the Porcupine Creek road, is an abandoned logging road that extends to the head of Bald Head Creek and the northwestern flank of Sharp mountain. A farm road, in Cache Valley, branches southward from the graded county road about 2 miles west of Porcupine Dam. This unimproved dirt road trends southward on McKenzie Flat through fields to Pole Creek from which access is by foot.

**Topography and Drainage**

Sharp Mountain is a north-south-trending ridge of the Bear River Range that extends across the length of the eastern half of the mapped area. The highest elevation, in the area, is the summit
of Sharp Mountain at 9,082 feet above sea level. Sharp Mountain drops off rapidly westward to a small valley in the northern part of the area and southward to Davenport Creek in the southern part of the area. The lowest elevation, about 5,800 feet above sea level, is along the western boundary of the mapped area from Davenport Creek to the northern boundary of the area. McKenzie Mountain trends slightly west of north and separates Cache Valley from the small valley adjacent to Sharp Mountain. Both McKenzie Mountain and this small valley terminate in the central part of the area at which point the western front of Sharp Mountain lies directly adjacent to Cache Valley (Figure 2). South of Davenport Creek are sharp and twisted ridges which lead up to the broad and gentle divide that drops rapidly into Ogden Valley (Figure 3). The southwestern corner of the area consists of the steep eastern flank of James Peak that is separated from the sharp and twisted ridges south of Sharp Mountain by Wellsville Creek (Figure 3).

The area is well drained by six perennial streams and one intermittent stream. Davenport Creek is the major stream of the area and drains the southern flank of Sharp Mountain. It flows northwestward into Cache Valley. Wellsville Creek heads on the eastern flank of James Peak just below the main parking lot at Powder Mountain ski resort and is a major tributary of Davenport Creek. East Pole Creek drains the small valley east of McKenzie Mountain and flows into the East Fork of the Little Bear River just below Porcupine Dam. Three streams drain the western front of Sharp Mountain. They are Smith Creek, Bald Head Creek, and Pole Creek. Pole Creek is to
the north and Smith Creek is to the south. Porcupine Creek is the intermittent stream. It is located entirely in the northeastern part of the mapped area and drains the northeastern flank of Sharp Mountain.

The area usually receives a heavy amount of snowfall during the winter months and it often remains well into the summer. However, the area is classified as semiarid since evaporation exceeds precipitation (Blair, 1942, p. 123).

Field Work

The field work for this study was done during the summer and early fall of 1978. Time was also spent in the field during the summer of 1979. Field observations were plotted on vertical 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 photographs taken.

Information, plotted on the vertical aerial photographs, was transferred to a base map at a scale of 1:12,000. The base map was prepared from the eastern part of the 7.5-minute James Peak Quadrangle and the western part of the 7.5-minute Sharp Mountain Quadrangle.

Previous Investigations

The James Peak-Sharp Mountain area was represented on the Geologic Map of Northwestern Utah by Stokes (1963) whose information was based on a map of the northern Wasatch Mountain Range compiled by Hardy and Williams (1953). Hafen (1961) described the geology
and measured stratigraphic sections in the Sharp Mountain Quadrangle. King (1965) studied the Paleozoic stratigraphy of the James Peak Quadrangle, and Blau (1975) studied the geology and measured the Precambrian Mutual Formation of the southern part of the James Peak Quadrangle. Mullens and Izett (1963; 1964) studied the stratigraphy and structure of the Paradise Quadrangle, northwest of the Sharp Mountain Quadrangle and north of the James Peak Quadrangle. Maxey (1958) published a detailed description of the Cambrian sections in northern Utah and southeastern Idaho. The High Creek section, in the Bear River Range, is as good as any in the region and was used as a reference for correlation. Crittenden and others (1971) described the younger Precambrian and basal Cambrian rocks exposed east and northeast of Huntsville, Utah. They renamed the Brigham Formation as Geertsen Canyon Quartzite. Crittenden (1972) mapped the geology of the Browns Hole Quadrangle southeast of the James Peak Quadrangle and south of the Sharp Mountain Quadrangle. His work established the Precambrian stratigraphic section for the region. None of these studies gave detailed information on the structure or stratigraphic units of the area between James Peak and Sharp Mountain.
Stratigraphic units of late Precambrian through Mississippian age underlie the mapped area (Table 1). About 18,000 feet of strata are present in the mapped area. The lithology and thickness of the stratigraphic units in the James Peak and Sharp Mountain Quadrangles have been the subject of previous investigations (Hafen, 1961; King, 1965; Blau, 1975).

Neither Hafen, King, nor Blau recognized rocks of Mesozoic age and none were observed by the author during his study of the structure of the area between James Peak and Sharp Mountain. However, Mesozoic strata have been reported to the north in southeastern Idaho (Mansfield, 1927, p. 99) and to the south along the Weber River (Eardley, 1944, p. 837) suggesting that either they have been removed from the area by erosion or lie beneath a thrust mass of Paleozoic rocks.

The Tertiary Salt Lake Formation lies directly on Paleozoic rocks in the north-central part of the area. Colluvial deposits overlie the Precambrian and Paleozoic rocks in the southern part of the area and cap some of the ridges between James Peak and Sharp Mountain. Some canyon bottoms are floored by colluvial deposits. Two canyons, north and east of James Peak, also contain Quaternary moraines. An outwash fan is present in Cache Valley north of James Peak. Holocene alluvial deposits are found along the main streams but they are generally quite thin.
Table 1. Stratigraphic units of Precambrian, Paleozoic, and Tertiary ages, eastern part of James Peak Quadrangle and western part of Sharp Mountain Quadrangle. Approximate thickness from reference sections.

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<th>Unit</th>
<th>Dominant lithology</th>
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<td>Salt Lake Formation</td>
<td>Conglomerate and limestone</td>
<td>500*</td>
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<tr>
<td>Mississippian</td>
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<tr>
<td>Humbug Formation</td>
<td>Sandstone and limestone</td>
<td>1,100a</td>
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<td>Lodgepole Formation</td>
<td>Dolomitic limestone</td>
<td>750a</td>
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<td>Devonian</td>
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<td>Hyrum Formation</td>
<td>Dolomite</td>
<td>960a</td>
</tr>
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<td>Water Canyon Formation</td>
<td>Dolomite and limestone</td>
<td>460b</td>
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<td></td>
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<td>Swan Peak Formation</td>
<td>Shale and siltstone</td>
<td>20b</td>
</tr>
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<td>Garden City Formation</td>
<td>Limestone and shale</td>
<td>1,580</td>
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<tr>
<td>Cambrian</td>
<td></td>
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<td>St. Charles Formation</td>
<td>Dolomite and sandstone</td>
<td>970b</td>
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</tr>
<tr>
<td>Mutual Formation</td>
<td>Orthoquartzite</td>
<td>2,553d</td>
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*Estimated thickness.

a Paradise Quadrangle, Utah (Mullens and Izett, 1964).
b Sharp Mountain Quadrangle, Utah (Hafen, 1961).
c Huntsville Quadrangle, Utah (Sorenson and Crittenden, 1974).
d James Peak Quadrangle, Utah (Blau, 1975).
Precambrian Units

Mutual Formation

The Mutual Formation was named by Crittenden and others (1952, p. 6) for exposures of orthoquartzite in the Cottonwood Canyon area near Salt Lake City, Utah, where it is the youngest Precambrian unit. The Mutual was subsequently recognized in the Huntsville area, Utah, by Crittenden and others (1971, p. 591-592). Crittenden (1972) noted that the Mutual Formation ranges in thickness from 435 to 1,200 feet in the Browns Hole Quadrangle just southeast of the mapped area. The Mutual Formation is late Precambrian in the Huntsville area (Crittenden and others, 1971, p. 597).

The Mutual Formation is the oldest rock unit recognized in the mapped area. It is restricted to the eastern front of James Peak where it dips northeast (Figure 4). The base of the formation is not exposed in the mapped area, but it is exposed beyond the western limit of the mapped area where the Mutual overlies the Precambrian argillite unit of Blau (1975, p. 15). The Browns Hole Formation overlies the Mutual Formation in the mapped area. Blau (1975, Appendix) measured the Mutual Formation with a steel tape on the western flank of James Peak where the formation attains a thickness of 2,556 feet.

The Mutual Formation of the mapped area consists of thick to very thick beds of orthoquartzite with conglomerate lenses. Cross-bedding is common throughout. Grain size of the orthoquartzite ranges from fine to coarse. Isolated, well-rounded pebbles are also common,
Figure 4. Mutual, Browns Hole, and Brigham Formations north of Powder Mountain ski resort at head of Wellsville Creek; view north-northwest. Shows Precambrian Mutual Formation (p€m) on the west. Precambrian Browns Hole Formation (p€bh) extends through the densely vegetated saddle. The Cambrian Brigham Formation (Gb) overlies the Browns Hole Formation on the east. The formations dip northeast.
especially in the conglomerate lenses. The formation has a distinctive purple color that Blau (1975, p. 16) attributed to concentrations of hematite as grain coatings and also as matrix material. The purple color becomes darker toward the top of the unit where the formation is readily differentiated from light-colored orthoquartzite of the Brigham Formation.

Browns Hole Formation

The Browns Hole Formation was named by Crittenden and others (1971, p. 592) for exposures along the Middle Fork of Ogden River in the Browns Hole Quadrangle. Crittenden (1972) subsequently mapped the formation in the Browns Hole Quadrangle and reported a lower volcanic member and an upper member of "terra cotta" quartzite. Crittenden (1972) reported a range in thickness from 180 to 460 feet for the lower volcanic member. The stratigraphic position of the Browns Hole Formation places it in the Precambrian. Crittenden and others (1971, p. 592) considered the Browns Hole Formation to be Precambrian.

The Browns Hole Formation is found on the eastern front of James Peak where it provides a distinct stratigraphic marker between the thick-bedded orthoquartzite of the underlying Mutual Formation and the thick-bedded orthoquartzite of the overlying Brigham Formation (Figure 4). The Browns Hole Formation overlies the Mutual Formation in the mapped area. Quartzite, assigned to the Brigham Formation, overlies the Browns Hole Formation. The Browns Hole Formation generally supports a dense cover of vegetation. A 12-foot
thickness of lava flows is exposed on the ridge west of Wellsville Creek in the eastern part of sec. 36, T. 8 N., R. 1 E.; however, the estimated total thickness of volcanic rock is about 58 feet (Blau, 1975, p. 17). The lower part of the volcanic unit is covered at that locality. The writer correlates the volcanic rocks described by Blau (1975, p. 17-19) with the lower volcanic member of the Browns Hole Formation described by Crittenden (1972) in the Browns Hole Quadrangle. Blau (1975, p. 17-19) did not report a "terra cotta" quartzite in the James Peak area.

The Browns Hole Formation of the mapped area consists of lava flows in the upper part. The lower part of the formation is covered in the area but it is also believed to consist of volcanic rocks. Thin-section work and x-ray analysis by Blau (1975, p. 17) indicated that the lava is andesite and that most of the iron oxide is present as hematite. Blau (1975, p. 17-19) described the mineralogy of the lava in detail.

Cambrian System

Brigham Formation

Walcott (1908a, p. 8) named the Brigham Formation for exposures of quartzitic sandstone on the western front of the Wasatch Mountain Range just northeast of Brigham City, Utah. The base of the formation is not exposed, and thus, Walcott (1908b, p. 199) left the base of the Brigham Formation undefined. Crittenden and others (1971, p. 590-592) discussed the terminology problem arising from the undefined base of Walcott's type section and raised the term "Brigham" to group
rank and renamed the Brigham Formation as the Geertsen Canyon Quartzite. Crittenden (1972) reported that the Geertsen Canyon Quartzite ranges in thickness from 3,426 to 4,833 feet in the Browns Hole Quadrangle just south of the mapped area. Crittenden and others (1971, p. 593) considered the lower part of the Geertsen Canyon Quartzite to be Precambrian. The Brigham Formation of the 30-minute Logan Quadrangle is correlated with the Geertsen Canyon Quartzite and, like the Geertsen Canyon Quartzite, is considered to be Precambrian in the lower part. The upper part is older than Middle Cambrian and is probably Early Cambrian (Waucobian) in age (Williams, 1948, p. 1,132). Both the Brigham Formation and the Geertsen Canyon Quartzite have the fossil tubes, Skolithus, near the top.

The Brigham Formation is found on the eastern front of James Peak, in the mapped area, where it can be readily distinguished from the Mutual Formation by its lighter color. The Brigham Formation overlies the Browns Hole Formation (Figure 4). The Langston Formation overlies the Brigham Formation. The thickness of the Brigham Formation, as estimated from the map between accurately placed upper and lower contacts on the eastern front of James Peak, is about 4,000 feet.

The Brigham Formation of the mapped area consists of light-brown and white, medium- to very coarse-grained orthoquartzite. Thick beds and cross-bedding are common throughout. Weathered surfaces are darker than the fresh rock and some exhibit a rough sugary texture. Conglomerate lenses are more common in the middle part of the formation where they contain rounded quartzite clasts about 1 inch in diameter.
The fossil tubes, *Skolithus*, have been used to identify the top of the basal Cambrian quartzite by several writers (Williams, 1948, p. 1,132; Ezell, 1953, p. 7; King, 1965, p. 11; Crittenden and others, 1971, p. 593). These tubes are also present, in the mapped area, near the top of the Brigham Formation in sec. 30, T. 8 N., R. 2 E., where they are about 1 1/2 inches long and 1/16 inch in diameter and are perpendicular to the stratification.

**Langston Formation**

Walcott (1908a, p. 8) named the Langston Formation for Langston Creek, Idaho, but designated a type locality in Blacksmith Fork Canyon, Utah. Williams and Maxey (1941, p. 280) showed that the Langston Formation, at its type locality, consists of two distinctive brown-weathering dolomite members separated by a limestone member. They also pointed out that the formation is not representative at Walcott's type locality, but a section that is typical of the region is present approximately 1 mile north-northwest along the strike on the western side of the left fork of Mill Creek. The Langston Formation is 338 feet thick in the Left Fork of Blacksmith Fork (Maxey, 1958, p. 656-670). The Langston Formation is Middle Cambrian in age (Williams and Maxey, 1941, p. 277).

The Langston Formation crops out east of the Brigham Formation on the densely vegetated ridge west of lower Wellsville Creek. A small outcrop is also present near the stream just east of the junction of the upper and lower segments of Wellsville Creek. The Langston Formation overlies the Brigham Formation in the mapped area. Williams
could find no evidence of unconformity between the Brigham and Langston Formations in the 30-minute Logan Quadrangle. The Ute Formation overlies the Langston Formation in the mapped area. Hafen (1961, Appendix) measured the Langston Formation on the northeastern front of Sharp Mountain where it is about 270 feet thick.

The Langston Formation, in the mapped area, consists of greenish-gray shale overlain by distinctive brown-weathering dolomite. The greenish-gray shale grades into the underlying Brigham Formation. The dolomite is medium gray on fresh surfaces and is generally found as angular blocks and chunks in the soil.

Ute Formation

Walcott (1908a, p. 7-8) named the Ute Formation for Ute Peak in the Bear River Range. The Ute Formation contains limestone and shale at the type locality. Maxey (1958, p. 657) reported the thickness of the Ute Formation in the Left Fork of Blacksmith Fork, about 10 miles north of the mapped area, as 675 feet. Both Williams (1948, p. 1,130) and Maxey (1958, p. 672) considered the Ute Formation to be Middle Cambrian (Albertan) in age.

The Ute Formation is exposed on both sides of Wellsville Creek in the southern half of the mapped area. The formation dips east to northeast. The Ute Formation overlies the Langston Formation. The Blacksmith Formation overlies the Ute. Maxey (1958, p. 671) reported both of these contacts to be conformable in the Bear River Range. Hafen (1961, p. 17) reported a thickness for the Ute Formation of 1,090 feet, in East Canyon, just south of the East Fork of the
Little Bear River. This is 300 feet more than in any previously measured section.

The Ute Formation of the mapped area consists of alternating beds of thin-bedded limestone, silty limestone, and green shale. The limestone is generally medium to dark gray and fine crystalline to aphanitic. Oolites are common in some of the limestone beds but are not frequent throughout the formation. Some of the limestone beds are dolomitic. The silty limestone characteristically weathers to various shades of red and brown.

**Blacksmith Formation**

The Blacksmith Formation was named by Walcott (1908a, p. 7) for exposures of limestone in Blacksmith Fork Canyon about 15 miles east of Hyrum, Utah, and about 10 miles north of the mapped area. Walcott (1908b, p. 195) reported the thickness in Blacksmith Fork Canyon to be about 570 feet. The Blacksmith Formation was recognized throughout the 30-minute Logan Quadrangle by Williams (1948, Plate 1). Maxey (1958, p. 672) placed the age of the Blacksmith Formation as Middle Cambrian (Albertan).

The Blacksmith Formation crops out near the crest of the steep ridge east of Wellsville Creek and extends northwest across the creek and beneath a low-angle thrust fault on the eastern front of James Peak. The formation dips east and northeast. The Blacksmith Formation overlies the Ute Formation and the Bloomington Formation overlies the Blacksmith Formation. The Blacksmith Formation also crops out near the head of Davenport Creek where it dips gently west. Hafen
(1961, Appendix) measured the Blacksmith Formation on the eastern front of Sharp Mountain and reported a thickness of 409 feet. The formation thickens southward to about 900 feet in the Huntsville Quadrangle (Sorenson and Crittenden, 1974).

The Blacksmith Formation of the mapped area consists of dolomite and dolomitic limestone. The dolomite is light to medium gray and medium to coarse crystalline. The dolomitic limestone is medium to dark gray and fine crystalline to aphanitic. Bed thickness ranges from 1/2 inch to 2 feet. Fine parallel laminae and thin zones of intraformational breccia are present. Oolites are present in some of the beds. Weathered surfaces are lighter in color and some have a mottled appearance and powdery texture.

**Bloomington Formation**

The Bloomington Formation was named by Walcott (1908a, p. 7) for Bloomington Creek west of the town of Bloomington, Bear Lake County, Idaho. The Bloomington Formation contains limestone and shale at the type locality. Williams (1948, p. 1,133) recognized the formation in the 30-minute Logan Quadrangle. Maxey (1958, p. 653-654) reported a thickness of 1,495 feet at High Creek and dated the formation as Middle Cambrian (latest Albertan).

The Bloomington Formation crops out at the crest of the steep ridge east of lower Wellsville Creek and extends northwest across Wellsville Creek and beneath the low-angle thrust fault on the eastern flank of James Peak. The formation dips east and northeast in these outcrops. It overlies the Blacksmith Formation. The Nounan Formation
overlies the Bloomington Formation. The Bloomington Formation also crops out south of Sharp Mountain near the head of Davenport Creek where the creek flows southwest paralleling the strike of shaly beds. The formation dips gently west in the outcrops south of Sharp Mountain. Hafen (1961, Appendix) measured the Bloomington Formation on the eastern side of Sharp Mountain where a thickness of 604 feet was found. The formation thickens southward to about 1,250 feet in the Huntsville Quadrangle (Sorenson and Crittenden, 1974).

The Bloomington Formation, in the mapped area, consists of medium- to dark-gray, fine-crystalline to aphanitic limestone and some dolomite interbedded with a considerable amount of brownish-green to yellowish-green shale. Red silt streaks are conspicuous in some of the limestone beds. Oolites are more common in the dolomite. Limestone nodules are conspicuous in the shale beds and if the limestone nodules have weathered out, holes and gaps are conspicuous.

Nounan Formation

Walcott (1908a, p. 6) named the Nounan Formation for exposures of limestone on the eastern flank of Soda Peak, west of the town of Nounan, Bear Lake County, Idaho. The formation was mapped throughout the 30-minute Logan Quadrangle by Williams (1948, Plate 1). Williams (1948, p. 1,134) pointed out that most of the Nounan Formation could be characterized as dolomite in the 30-minute Logan Quadrangle. Maxey (1958, p. 651) measured the Nounan Formation at High Creek where it is 1,125 feet thick. He regarded the formation as Late Cambrian (Croxian) in age.
The Nounan Formation crops out east of the Bloomington Formation on the ridge east of lower Wellsville Creek. The formation extends north and then northwest to the mountain front near the confluence of Wellsville and Davenport Creeks. The Nounan Formation overlies the Bloomington Formation and the St. Charles Formation overlies the Nounan. The Nounan Formation is also exposed south of Sharp Mountain and extends southwest across Davenport Creek. The formation dips gently west in these outcrops. The formation was measured by Hafen (1961, p. 21) just north of Sharp Mountain where a thickness of 1,145 feet was found.

The Nounan Formation is dominantly light- to medium-gray, fine- to medium-crystalline dolomite. The dolomite of the lower part of the formation is generally lighter in color and less silty than the dolomite of the upper part. The dolomite of the lower part also weathers lighter in color than that of the upper part. Oolite and pisolite beds occur throughout the formation and are quite conspicuous in some places. Numerous zones, 1 to 2 inches thick, of mottled dolomite are also conspicuous in the lower half of the formation. The upper part of the formation contains silt in thin parallel layers and weathers light brown to gray. Medium-gray dolomite is present at the top and is easily differentiated from the overlying sandy Worm Creek Quartzite.

St. Charles Formation

The St. Charles Formation was named by Walcott (1908a, p. 6) for exposures west of the town of St. Charles, Bear Lake County,
Idaho. Richardson (1913, p. 408) designated the lower part of the formation as the Worm Creek Quartzite Member. Both the Worm Creek Quartzite Member and the upper dolomite of the St. Charles Formation were recognized by Williams (1948, p. 1,134) in the 30-minute Logan Quadrangle. Maxey (1941, p. 28) reported a thickness of 1,015 feet for the St. Charles Formation at High Creek, 75 feet of which was assigned to the Worm Creek Quartzite Member. The age of the formation is Late Cambrian (Croxian) (Williams, 1948, p. 1,134).

The St. Charles Formation crops out both north and south of Davenport Creek in the central part of the area where it overlies the Nounan Formation. The Ordovician Garden City Formation overlies the St. Charles Formation. Williams (1948, p. 1,130) indicated that the upper and lower contacts of the St. Charles Formation are disconformable in the 30-minute Logan Quadrangle. The St. Charles Formation, north of Davenport Creek, forms a syncline and an anticline. The St. Charles Formation is also exposed south of Sharp Mountain. It extends northeast from beneath the colluvial deposits south of upper Davenport Creek. The formation extends across Davenport Creek and continues northeast on the eastern side of Sharp Mountain. Hafen (1961, Appendix) measured the St. Charles Formation on the northern front of Sharp Mountain in East Canyon where it is 970 feet thick. The lower 90 feet he assigned to the Worm Creek Quartzite Member.

The St. Charles Formation of the mapped area is silty and arenaceous dolomite in the lower part and dolomite in the upper part. The Worm Creek Quartzite Member, at the base of the formation, contains two thin quartzite beds separated by thin beds of sandy dolomite.
Fucoids are common in the quartzite beds. The remainder of the Worm Creek Quartzite Member consists of sandy dolomite that weathers gray to dark brown. Thin beds of green shale are also present in this lower member. The upper part of the St. Charles Formation is medium-to light-gray, fine-to medium-crystalline dolomite. Sand and silt are notably absent in the dolomite. Occasional chert nodules and oolitic beds are also present in the upper part. Bluish-gray limestone beds are present in the lower part of the upper member.

**Ordovician System**

**Garden City Formation**

Richardson (1913, p. 409) recognized the Garden City Formation as the Garden City Limestone for exposures along Garden City Canyon, west of the town of Garden City, Rich County, Utah. Williams (1948, p. 1,135-1,136) recognized the Garden City Formation in the 30-minute Logan Quadrangle. The Garden City Formation maintains a fairly uniform thickness throughout north-central Utah. Williams (1948, p. 1,135) reported a thickness of 1,400 feet for the formation in Green Canyon northeast of Logan, Utah. Detailed paleontologic work was done on the Garden City Formation by Ross (1949; 1953, p. 22) and he designated the formation as Early-Middle Ordovician (earliest Ordovician to early Chazyan).

The Garden City Formation crops out in a north-trending series of hills just west of Sharp Mountain. It overlies the St. Charles Formation. The Swan Peak Formation overlies the Garden City Formation. At the northernmost extent of this linear outcrop, the
formation is covered by the younger Ordovician–Silurian Laketown Formation. The southern half of the western front of Sharp Mountain is also formed by the Garden City Formation. The thickness of the Garden City Formation on the western front of Sharp Mountain, as estimated from the map between accurately placed upper and lower contacts, is about 1,580 feet.

The lithology of the Garden City Formation contrasts sharply with that of the upper member of the St. Charles Formation. Two informal members can be recognized in the Garden City Formation in the mapped area. The lower member is a complex of interbeds of intraformational limestone conglomerate, shaly limestone, and fine-crystalline to aphanitic limestone. The limestone is generally bluish gray, thin to medium bedded, and weathers pale olive to brownish gray. Ripple marks and cross-bedding are conspicuous in some beds. Figure 5 shows a typical outcrop of this lower member. The upper member, comprising about one-third of the formation, consists of dark-to medium-gray dolomite with a high content of layered black chert. The dolomite weathers medium gray and in some areas abundant lichens give the rock an orangish-brown color when viewed through field glasses or from afar with the naked eye.

Swan Peak Formation

The Swan Peak Formation was named by Richardson (1913, p. 409) for exposures at Swan Peak on the eastern side of the Bear River Range just south of the Utah–Idaho border. The Swan Peak Formation is mostly quartzite at Swan Peak. Williams (1948, p. 1,136-1,137)
Figure 5. Garden City Formation north of Pole Creek; view north. Shows a typical outcrop of the lower intraformational conglomerate and shaly limestone member of Ordovician Garden City Formation. Water jug is 1 foot high. Outcrop is exposed in a road cut in sec. 32, T. 9 N., R. 2 E.
recognized three thin but persistent units in the Swan Peak Formation; however, only the basal unit of sandy limestone is present in Blacksmith Fork Canyon east of the town of Hyrum, Utah. Oaks and others (1977, p. 101-118) described each of these three units in some detail. The Swan Peak Formation is 340 feet thick northeast of Logan, Utah, in Green Canyon where all three units are well represented (Williams, 1948, p. 1,136). Ross (1949, p. 472) dated the Swan Peak Formation as Middle Ordovician (early Chazyan) in age based on the contained trilobite, brachiopod, and ostracod fauna.

The Swan Peak Formation is found in the central part of the northern half of the mapped area where it forms a thin interval between the underlying Garden City Formation and the overlying Laketown Formation. The outcrops, in the northern half of the area, indicate a conformable contact with the underlying Garden City Formation. Exposures are poor except along occasional road cuts. Williams (1948, p. 1,137) observed a conformable contact between the Swan Peak and Garden City Formations within the 30-minute Logan Quadrangle. The Ordovician-Silurian Laketown Formation, undifferentiated from the Fish Haven Dolomite, overlies the Swan Peak Formation in the mapped area. A thin interval of the Swan Peak Formation also extends from the eastern boundary of the mapped area southeastward into the central part of the area (Plate 1). Hafen (1961, Appendix) measured the Swan Peak Formation on the northeast-facing slope at the head of Porcupine Canyon where it is a mere 22 feet thick. Only the lowermost part of the basal unit is present in the Sharp Mountain-James Peak area.
The Swan Peak Formation, in the mapped area, consists of poorly sorted, sandy siltstone overlain by green shale. The sandy siltstone weathers to various shades of brown and red, and it is generally found as angular chunks in the soil. Bioturbation and the trace fossil Chondrites are common in the sandy siltstone beds. The graptolite Didymograptus bifidus and the brachiopod Orthambonites swanensis were collected by the writer from the siltstone. This fauna aided in the identification of the Swan Peak Formation. The shale and siltstone are interlayered as thin beds and, as a consequence, generally form small saddles.

Ordovician-Silurian System

Laketown Formation

The name Laketown Dolomite was first used by Richardson (1913, p. 410) for outcrops in Laketown Canyon, 4 miles southeast of the town of Laketown, Rich County, Utah. Richardson (1913, p. 409-410) also designated the underlying unit of dolomite as the Fish Haven Dolomite for exposures west of the town of Fish Haven, Bear Lake County, Idaho. This designation was based, in part, on the darker color of the Fish Haven Dolomite which contrasts sharply with the lighter color of the Laketown Formation at some localities. Hafen (1961, p. 30) reported Ordovician fossils from beds he called the Fish Haven Dolomite in the Sharp Mountain area. However, no distinctly dark-gray dolomite or identifiable fossils of Late Ordovician age were observed by the writer, and thus, beds that overlie the Swan Peak Formation are undifferentiated and are referred to as the Laketown
Formation in this report. Williams (1948, p. 1,137-1,138) reported a thickness of about 1,290 feet for the undifferentiated unit in Green Canyon northeast of Logan, Utah. The Laketown Formation is considered to be Late Ordovician in the lowermost part (Budge, 1966, p. 24; Beus, 1968, p. 784). The upper part of the Laketown is Middle Silurian (Niagaran) in age (Williams, 1948, p. 1,137). The age of the Fish Haven Dolomite, where it can be differentiated, is late Ordovician (Richmond) (Ross, 1953, p. 25).

The steep cliffs of the western front of the northern half of Sharp Mountain (Figure 6) and the northern front of Sharp Mountain are formed by the Laketown Formation. The Laketown Formation overlies the Swan Peak Formation and the Water Canyon Formation overlies the Laketown Formation. The Laketown Formation also forms a conspicuous band surrounding the outcrop of the underlying Swan Peak and Garden City Formations in the central part of the northern half of the area (Plate 1). The Laketown Formation, in the central part of the area, is continuous with the Laketown Formation on the western front of Sharp Mountain. Hafen (1961, Appendix) reported a thickness of about 1,365 feet for the Fish Haven and Laketown Formations on the northeast-facing slope at the head of Porcupine Canyon.

The Laketown Formation is composed entirely of dolomite and cherty dolomite in the mapped area. The dolomite is generally light to medium gray and medium to fine crystalline. The rock weathers very light to medium gray with faint mottling as a common feature. Thick beds, with a massive aspect, are common. Several zones of chert nodules and, in some areas, beds of layered chert are present.
Figure 6. Laketown and Water Canyon Formations on western front of northern half of Sharp Mountain; view east. Gentle slopes above cliffs are in the Devonian Water Canyon Formation. Steep cliffs are in the Ordovician-Silurian Laketown Formation. The rounded hills below the steep cliffs are formed by the Ordovician Garden City Formation. The Tertiary Salt Lake Formation forms the gentle slopes in the foreground.
The chert is particularly common near corals and as a replacement of corals. Corals are abundant in the uppermost units where *Favosites* sp. was collected from the cliffs on the western front of Sharp Mountain.

**Devonian System**

**Water Canyon Formation**

Williams (1948, p. 1,138-1,139) named the Water Canyon Formation for exposures of sandy and silty dolomite in Water Canyon, a tributary of Green Canyon, northeast of Logan, Utah. A composite section of the Water Canyon Formation was measured by Williams (1948, p. 1,138-1,139) in Green and Logan Canyons where the formation is about 400 feet thick and was separated into a lower and an upper member. Williams (1948, p. 1,139) noted that the lower member is absent in Blacksmith Fork Canyon and the upper member is missing about 15 miles to the southwest, near Dry Lake, where the lower member is represented by about 400 feet of strata. Subsequent studies of the Water Canyon Formation by Williams and Taylor (1964) have added considerable detail to the understanding of the Water Canyon of the Bear River Range. The Water Canyon Formation is Early Devonian (Ulsterian) in age (Williams, 1948, p. 1,138). Poole and others (1967, p. 884-885) also report the Water Canyon Formation as Early Devonian.

The Water Canyon Formation crops out in the northeastern part of the mapped area where it caps the northern ridge of Sharp Mountain. Good exposures of the lower contact with the underlying Laketown Formation, showing the distinct change in lithology and aspect of the two formations, are present on the northern flank of the northern
ridge of Sharp Mountain (Figure 7). The Hyrum Formation overlies the Water Canyon Formation on the northern ridge of Sharp Mountain. Mullens and Izett (1964, p. 5) reported an unconformity, in the Paradise Quadrangle just north of the mapped area, between the Water Canyon and overlying Hyrum Formation with a gently channeled surface on the Water Canyon Formation. The Water Canyon Formation is also found in the northeastern part of sec. 6, T. 8 N., R. 2 E., where it is in fault contact with the Mississippian Humbug Formation (Plate 1). Hafen (1961, p. 34) reported a thickness of about 460 feet for the Water Canyon Formation in the Sharp Mountain area.

The Water Canyon Formation consists essentially of conspicuously bedded, silty and sandy dolomite and some limestone (Figure 7). The dolomite is generally medium gray, fine to medium crystalline, and characteristically weathers white to very light gray. The limestone is light to medium gray and aphanitic. The limestone also weathers very light gray. Fish bones were collected from the formation by the writer in the northeastern corner of sec. 8, T. 8 N. , R. 2 E.

**Hyrum Formation**

Peale (1893, p. 27) named and described the Jefferson Formation for exposures near Threeforks, Montana, along the Jefferson River. Williams (1948, p. 1,138-1,141) recognized the Jefferson Formation in the 30-minute Logan Quadrangle and separated the formation into two members. The lower member he designated Hyrum Dolomite for its excellent exposures in the mouth of Blacksmith Fork Canyon, east of the town of Hyrum, Utah. The upper member was named the Beirdneau
Figure 7. Laketown and Water Canyon Formations on northern flank of Sharp Mountain; view north. Shows the contact between the Ordovician-Silurian Laketown Formation (OSl) and the Devonian Water Canyon Formation (Dwc). Note the craggy and massive aspect of the Laketown Formation in contrast to the gentle slopes and distinct bedding of the Water Canyon Formation.
Sandstone for its continuous exposures about the base of Beirdneau Peak in the Bear River Range (Williams, 1948, p. 1,139). Subsequent studies of Devonian strata by Benson (1966), Poole and others (1967), and Sandberg and Mapel (1967) have indicated that the Hyrum Dolomite and Beirdneau Sandstone Members are enough different from equivalent rocks in Wyoming and Montana to be accorded formational rank. Therefore, Williams (1971, p. 219) officially designated the Hyrum Formation. The Hyrum is 1,108 feet thick along the Beirdneau Peak trail, 840 feet thick in Logan Canyon, and 1,200 feet thick in Blacksmith Fork (Williams, 1948, p. 1,140). Mullens and Izett (1964, p. 4) reported a thickness of about 960 feet in the Paradise Quadrangle just north of the mapped area. The Hyrum Formation is Middle-Late Devonian (Givetian) in age (Williams, 1971, p. 219).

The basal part of the Hyrum Formation forms a small cap overlying the Water Canyon Formation on the northern ridge of Sharp Mountain. This small cap is the only exposure of the Hyrum Formation in the mapped area. The upper part of the formation has been stripped away by erosion. Mullens and Izett (1964, p. 5) reported an unconformity between the Water Canyon and Hyrum Formations, with a gently channeled surface on the Water Canyon Formation, just north of the mapped area in the Paradise Quadrangle. About 50 feet of the Hyrum Formation is present on the northern ridge of Sharp Mountain.

The dominant rock type of the Hyrum Formation, in the mapped area, is dark-gray dolomite. The dolomite is generally thin bedded with thin laminae common in some of the beds. Weathered rock, near the base, is dark gray to black and contrasts sharply with the
white-weathering dolomite of the underlying Water Canyon Formation.

**Mississippian System**

**Lodgepole Formation**

The name of Madison was applied to a section of carbonate rocks of Carboniferous age, in the vicinity of Three Forks, Montana, by Peale (1893, p. 32). Collier and Cathcart (1922, p. 173) designated the lower thin-bedded limestone as the Lodgepole Formation and the upper limestone as the Mission Canyon Formation. They also recognized the Madison as a group. Williams (1948, p. 1,141, Plate 1) recognized the Madison Limestone in the 30-minute Logan Quadrangle. Strickland (1956, p. 54) extended Lodgepole Formation into northern Utah in preference to Madison Limestone. The Lodgepole Formation is 845 feet thick in Logan Canyon (Williams, 1948, p. 1,130). The formation thins to about 750 feet just north of the mapped area (Mullens and Izett, 1964, p. 6). Mullens and Izett (1964, p. 7) also point out that the Lodgepole Formation is locally only 500 feet thick along the mountain front. Holland (1952, p. 1,731) assigned an Early Mississippian (Kinderhookian) age to the Madison in Leatham Hollow, a tributary of the Left Fork of Blacksmith Fork. Sando and others (1976, p. 467) considered the Lodgepole Formation to be Early Mississippian (Kinderhookian and early Osagean) in age.

The Lodgepole Formation, in the mapped area, is represented by a single outcrop on the eastern flank of McKenzie Mountain where Pole Creek has cut through the mountain (Figure 8). The base of the Lodgepole Formation is not exposed in this outcrop due to an
Figure 8. Lodgepole and Humbug Formations on eastern side of McKenzie Mountain at Pole Creek; view west. The upper part of the Mississippian Lodgepole Formation (Ml) forms the cliff and the overlying Mississippian Humbug Formation (Mh) forms the gentle slopes above the cliff. Outcrops are located in the southeastern corner of sec. 30, T. 9 N., R. 2 E.
unconformable cover of Salt Lake Formation east of McKenzie Mountain. The Humbug Formation overlies the Lodgepole Formation. Mullens and Izett (1964, p. 8) reported a conformable contact with the overlying Humbug Formation just north of the mapped area in the Paradise Quadrangle. The Lodgepole Formation dips gently west. Between 50 and 70 feet of the uppermost part of the Lodgepole Formation is present in the James Peak-Sharp Mountain area.

The Lodgepole Formation of the mapped area consists of light-to medium-gray, coarse-crystalline dolomitic limestone. The dolomitic limestone is thin bedded, interlayered with black chert, and contains fossils. The chert layers are generally about 1 to 3 inches thick and are quite conspicuous (Figure 9). Weathered limestone is also light to medium gray, and it weathers in relief relative to the layers of black chert.

Humbug Formation

The Humbug Formation was named by Tower and Smith (1899, p. 625) for exposures of limestone and sandstone in the vicinity of the Humbug mine in the Tintic district southeast of Eureka, Juab County, Utah. Sadlick (1956, p. 74) extended the use of the formation name into the 30-minute Logan Quadrangle in preference to Unit 1 of the Brazer Formation as used by Williams (1943, p. 596; 1948, p. 1,142) and Williams and Yolton (1945, p. 1,145). Unit 1 of the Brazer Formation, equivalent of Humbug Formation, is 900 feet thick in the Dry Lake section north of Mantua, Box Elder County, Utah, about 12 miles northwest of the mapped area (Williams and Yolton, 1945,
Figure 9. Layered black chert of Lodgepole Formation exposed on eastern front of McKenzie Mountain; view east. Pencil is 5 inches long. Outcrop is located on cliff of Lodgepole Formation shown in Figure 8.
Mullens and Izett (1963; 1964, p. 8-9) referred to the Humbug Formation as Member A of Brazer Formation in the Paradise Quadrangle. The Humbug Formation is Late Mississippian (Meramecian and possibly Late Osagean) in age (Sadlick, 1955, p. 53; Williams, 1958, p. 31).

The Humbug Formation crops out near the northwestern corner of the mapped area. McKenzie Mountain and Bald Head are formed of this unit. The Humbug Formation overlies the Lodgepole Formation. The upper contact of the Humbug is not exposed in the mapped area since the Great Blue Formation, equivalent of Members B and C of the Brazer Formation as recognized by Mullens and Izett (1963), has been stripped away by erosion. Mullens and Izett (1964, p. 8-9) reported conformable lower and upper contacts in the Paradise Quadrangle just north of the mapped area. The Humbug is in fault contact with the Tertiary Salt Lake Formation along the western front of McKenzie Mountain; whereas, the Salt Lake Formation overlies the Humbug Formation with angular unconformity on the eastern front of McKenzie Mountain. The Humbug Formation is in fault contact with the Devonian Water Canyon Formation in sec. 6, T. 8 N., R. 2 E. Mullens and Izett (1963) reported a thickness for the Humbug Formation of about 1,100 feet just north of the mapped area in the Paradise Quadrangle.

The Humbug Formation of the mapped area consists of quartzitic sandstone and calcareous sandstone, interbedded with light- to dark-gray dolomite and limestone. The sandstone is generally white to light gray and weathers brown to red with a rough sugary texture.
The carbonate rock is fine to coarse crystalline and fossiliferous in places. A conspicuous ledge of medium-gray dolomite, with a fairly high content of layered black chert, is present near the base and phosphatic rock is present locally at the base. The formation is generally less fossiliferous than the underlying Lodgepole Formation, but the trace fossil *Domichnia* is common in the calcareous sandstone.

**Tertiary System**

**Salt Lake Formation**

Hayden (1869, p. 192) named the Salt Lake Formation for exposures in Morgan Valley in the Wasatch Mountain Range of northern Utah. Peale (1879, p. 640) subsequently recognized the Salt Lake Formation in Cache Valley. Adamson (1955) described in detail the Salt Lake Formation of Cache Valley, Utah and Idaho, and discussed the separation of the formation into three units in that area as follows: 1) basal conglomerate, 2) tuffaceous unit, and 3) upper conglomerate. Williams (1948, p. 1,147) reported a thickness of 1,140 feet for the Salt Lake Formation exposed in the Junction Hills west of Logan, Utah. Adamson, Hardy, and Williams (1955, p. 20) reported a thickness of 1,600 feet in Big Spring Hollow, 6 miles northwest of the mapped area. The Salt Lake Formation is of Pliocene age in Cache Valley (Yen, 1947, p. 272). Adamson (1955, p. 4) and Adamson, Hardy and Williams (1955, p. 2) regard the Salt Lake Formation as Miocene to Pliocene in age. The Norwood Tuff, which is lithologically identical to the Salt Lake Formation, is reported to be as old as late Eocene in Morgan Valley, Utah (Gazin, 1959, p. 137).
The Salt Lake Formation, exposed in the mapped area, is probably best correlated with the tuffaceous unit of Adamson (1955, p. 1). The Salt Lake Formation is exposed in Cache Valley, west of McKenzie Mountain, and also in the small valley east of McKenzie Mountain. In the small valley east of McKenzie Mountain, the Salt Lake Formation rests with angular unconformity on the Laketown, Water Canyon, Lodgepole, and Humbug Formations. There, about 500 feet of the tuffaceous unit of Adamson is present.

The Salt Lake Formation of the mapped area is dominantly calcareous conglomerate, which is locally tuffaceous. The clasts consist of black chert, medium- to dark-gray dolomite, and pink, white, and brown quartzite. Clasts are commonly rounded to subangular, 1/2 to 2 inches in diameter, but range up to 10 inches in diameter in some areas. Beds of medium- to coarse-grained carbonate sandstone intertongue with lenses of pebble conglomerate. Conglomerate of the Salt Lake Formation is shown in Figure 10. White limestone chips and stromatolitic limestone cobbles are common constituents of the overlying soil in some areas.

Quaternary System

Colluvial deposits

Colluvial deposits consist of quartzite and carbonate pebbles, cobbles, and boulders set in a matrix of fine-grained, unconsolidated material which is mostly sand and silt. Carbonate clasts are notably scarce in the deposits except near the mountain front in Cache Valley. The rounded to subangular boulders are generally 1 to 2 feet in


Figure 10. Conglomerate of Salt Lake Formation in valley between McKenzie Mountain and northern Sharp Mountain; view northeast. Memo pad is 5 inches long. Outcrop is located in southwestern corner of sec. 29, T. 9 N., R. 2 E.
diameter, but a quartzite boulder 9 feet in diameter is present in upper Wellsville Creek a considerable distance from any outcrops of quartzite. The quartzite boulders are purple, pink, brown, and white, and the carbonate boulders are generally medium to dark gray and some contain chert. The concentration of boulders in some areas could be the result of erosion washing away the finer material.

A thin but fairly widespread colluvial deposit covers the Salt Lake Formation along the eastern margin of Cache Valley in the northwestern part of the area. The broad ridge in the southeastern part of the area is covered with a sheet of colluvial deposits that forms a continuous, gently sloping surface up to the exposures of Precambrian rocks south of the mapped area. Remnant colluvial deposits of probable Tertiary age cap McKenzie Mountain (Figure 11).

The colluvial deposits were considered to be Pleistocene and Holocene in age by Blau (1975, p. 22). Mullens and Izett (1964, p. 16) presumed that the colluvial deposits accumulated under more humid conditions than those that prevail in the area now. The colluvial deposits are in transport down slopes at the present time in the mapped area.

Moraines

Lateral and terminal moraines are evidence of the existence of glaciers in two canyons, north and east of James Peak, during Pleistocene time. Sediment deposited directly by glaciers is discussed as moraine in this report without differentiating the different kinds of moraine.
Figure 11. Colluvial deposit capping McKenzie Mountain; view northeast. Boulders are purple, brown, and white orthoquartzite. This is a remnant colluvial deposit of probable Tertiary age.
The moraines exist in the southwestern part of the area on the eastern and northern flanks of James Peak. They are linear in a north-south direction and fill valley bottoms. Lobate termini are present at their northern ends. The lowest elevation of the moraines is at about 7,000 feet above sea level in both the central part of sec. 24, T. 8 N., R. 1 E., and in the south-central part of sec. 30, T. 8 N., R. 2 E.

The moraines are similar to colluvial deposits in that they consist of purple, white and brown quartzite clasts and light- to dark-gray dolomite and limestone clasts. Silt and sand particles are abundant.

**Outwash fans**

Outwash fans represent accumulations of glacial sediment redeposited by streams at the mouths of canyons. The fans have lobate shapes and gentle, even gradients in contrast to the moraines.

The eastern part of an outwash fan is present, on the northern flank of James Peak, in the eastern part of sec. 24, T. 8 N., R. 1 E. Flow lines on the fan are evident on vertical aerial photographs. The flow lines radiate from the northern end of the moraine in the canyon at the head of the fan. The conformity of the fan to the pre-existing topography suggests that the previous drainage pattern was changed little or not at all by the glaciation. The fan overlies the Salt Lake Formation north of James Peak.

The average diameter of particles decreases downslope on the outwash fan. Clay and silt are predominant at the distal parts of the fan.
Alluvial deposits

Alluvial deposits are a direct result of stream deposition in valley bottoms. Most of the alluvial deposits formed during Pleis­tocene time. The gradient of the streams flowing today is sufficient to prevent much deposition, and the alluvial bed of most of the streams is in storage during intervals between floods and high spring run off. The snow pack, in the mapped area, is sufficient to maintain a high stream discharge until mid-June or July. An average of 10 feet of snow pack accumulates at Powder Mountain ski resort.

Subangular to rounded cobbles and boulders are common constituents of alluvial deposition. Silt, sand, and pebbles are also present. Purple, white, and brown quartzite clasts dominate the deposits in the valley of Wellsville Creek and its tributaries. Carbonate clasts are common along Davenport Creek and the creeks north of Davenport Creek.
STRUCTURAL GEOLOGY

Structural Setting

The James Peak-Sharp Mountain area is located at the southern end of the Bear River Range in the Middle Rocky Mountain province. James Peak is a structural high between the Cache Valley graben to the north and the Ogden Valley graben to the south. Sharp Mountain, on the other hand, is within the main part of the Bear River Range. Other structural features that relate to the tectonic development of the area between James Peak and Sharp Mountain include the Wells­ville Mountain block, about 15 miles northwest of Sharp Mountain, and the fault blocks of the Rendezvous Peak area about 7 miles west of Sharp Mountain. In addition, three thrust faults have been mapped in the surrounding region, the Willard, Paris, and Meade Peak thrust faults. The Willard thrust fault is exposed west of Sharp Mountain near the top of Willard Peak and the Paris and Meade Peak thrust faults are exposed in southeastern Idaho.

The Bear River Range is formed from Paleozoic rocks that are broadly and gently folded. Rocks are dominantly carbonate but some quartzite and shale are included. A major syncline and major anticline, trending north-northeast to northeast, were identified by Williams (1948, Plate 1) in the 30-minute Logan Quadrangle. The syncline is referred to as the Logan Peak syncline and the anticline is known as the Strawberry Valley anticline. Sharp Mountain, formed by formations that dip west, is situated about midway between the
axis of Logan Peak syncline and the axis of the Strawberry Valley anticline. The axis of the Strawberry Valley anticline is about 2 miles east of Sharp Mountain and can be observed in Scare Canyon just northeast of Sharp Mountain (Hafen, 1961, p. 44). The axis of the Logan Peak syncline is truncated by the north-trending East Cache faults about 5.5 miles northwest of Sharp Mountain (Williams, 1948, Plate 1). The axis of the Logan Peak syncline is not extended to the western front of the Bear River Range by Mullens and Izett (1963).

Cache Valley is about 60 miles long and about 20 miles wide. Williams (1948, p. 1,154; 1958, p. 74) named the Cache Valley graben and the East Cache faults which define the eastern margin of the graben. The stratigraphic throw on the East Cache faults was estimated to be at least 1,000 feet between the eastern margin of the Cache Valley graben and the Bear River Range block in the Paradise Quadrangle (Mullens and Izett, 1964, p. 18). The southern part of the Cache Valley graben is bounded on the west by the Wellsville Mountain horst and to the south by James Peak. The eastern and western margins of Cache Valley are sharply delineated by high-angle normal faults; whereas, the southern margin gradually rises to the higher elevations of Rendezvous and James Peaks.

Wellsville Mountain is the northernmost mountain ridge of the Wasatch Mountain Range of northern and central Utah. Williams (1948, p. 1,149) described Wellsville Mountain as a northeast-dipping homocline, and it was regarded as a northeast-dipping horst bounded by
north-northwest-trending high-angle normal faults by Gelnett (1958, p. 58) and Beus (1958, p. 48). The western front of Wellsville Mountain is steep and rugged. It is defined by the well-known and well-studied Wasatch fault zone. This fault zone can be traced approximately 115 miles through central and northern Utah in a general north-south direction (Eardley, 1939, p. 1,305). The eastern front of Wellsville Mountain is also bounded by high-angle normal faults. High ridges of the Wasatch Mountain Range continue south-southeast from Wellsville Mountain.

The Rendezvous Peak area borders the southern end of Cache Valley and is just west of James Peak. The Wasatch Mountain Range is just west of the Rendezvous Peak area. The Rendezvous Peak area is characterized by a northeast-trending syncline involving Paleozoic rocks. The syncline plunges 40° NE. and disappears beneath strata of the Salt Lake Formation at the southern end of Cache Valley (Ezell, 1953, p. 26). A number of high-angle normal faults, trending north-south, east-west, and northeast-southwest, were also described and shown diagrammatically by Ezell (1953, Figure 3, p. 26-27). North-south faults, one with about 5,000 feet displacement, are the most important and control the structure of the western part of the James Peak Quadrangle (Blau, 1975, p. 35). Both Rendezvous Peak and James Peak are bounded on the south by the high-angle normal fault that defines the northern side of Ogden Valley (Leggette and Taylor, 1937, p. 99).

The Willard thrust fault is exposed near the top of Willard Peak, about 10 miles west of Sharp Mountain, and can be traced along
the Wasatch Mountain Range southward to about Ogden, Utah (Eardley, 1939, p. 1,286-1,287; 1944, Plate 2). The Willard thrust fault dips east and is believed to continue southeast beneath the alluvium that floors Ogden Valley. Crittenden (1972) recognized what he considered a branch of the Willard thrust fault near the south-central part of the Browns Hole Quadrangle on the eastern side of Ogden Valley.

Mansfield (1927, p. 150) recognized a low-angle thrust fault, in southeastern Idaho, which he named the Bannock thrust fault. Richardson (1941, p. 38-39) identified this thrust fault in the 30-minute Randolph Quadrangle and suggested that it extends at least as far as Woodruff Creek which is about 20 miles east of Sharp Mountain. Further study of the Bannock thrust fault by Armstrong and Cressman (1963, p. 8) indicated the presence of two thrust faults, the Meade Peak and Paris thrust faults. The Meade Peak thrust fault is exposed east of Georgetown, Bear Lake County, Idaho, and crops out east of the Paris thrust fault. The Paris thrust fault is exposed west of Liberty, Bear Lake County, Idaho, and crops out above the Meade Peak fault. The Paris thrust fault has been correlated with the Willard thrust fault which is exposed east and northeast of Ogden (Crittenden, 1961, p. 129). If this is the case, James Peak, which contains numerous, small thrust faults (Blau, 1975, p. 25) and Sharp Mountain have been transported from the west by as much as 40 miles (Crittenden, 1961, p. 129).
Structural Features

Folds

The eastern part of the mapped area, including Sharp Mountain, consists of gently west-dipping Paleozoic formations that make up the western flank of the Strawberry Valley anticline. The axis of the anticline is located about 1 1/2 miles east of the mapped area and trends approximately north-northeast (Hafen, 1961, Plate 1). The western flank of this fold extends from the northern boundary of the mapped area to the southeastern part of the area where it is covered by colluvial deposits. A normal stratigraphic section from the Cambrian Blacksmith Formation to the Devonian Hyrum Formation is exposed on the western flank of the anticline in the mapped area (Plate 1). The formations dip from 17° W. to 22° W., near the crest of Sharp Mountain, and from 40° W. to 55° W., near the western base of Sharp Mountain. The presence of younger formations only in the northern part of the area indicates a slight north plunge on the Strawberry Valley anticline. The anticline evidently continues southward to the Middle Fork of Ogden River, about 5 miles northeast of Huntsville, Utah (Crittenden, 1972).

An anticline, informally referred to as the central anticline in this report, is located west of Sharp Mountain and extends from a point just north of Davenport Creek to the northern boundary of the mapped area (Plate 1). The axis of the anticline trends approximately N. 10° E. (Figure 12). A normal stratigraphic section from the Cambrian St. Charles Formation to the Ordovician-Silurian Laketown
Figure 12. Anticline in Garden City Formation between Bald Head and North Fork Smith Creeks; view southeast. Oblique view showing axis of the central anticline. Water jug, 1 foot high, is placed on the axis of the anticline. Beds dip toward the viewer west of the jug and away from the viewer east of the jug. Outcrop is located along upper Bald Head Creek in sec. 5, T. 8 N., R. 2 E.
Formation is exposed on the central anticline north of Davenport Creek and south of the normal fault in the canyon of South Fork Smith Creek. A normal stratigraphic section from the Ordovician Garden City Formation to the Devonian Water Canyon Formation is exposed on the central anticline north of the normal fault that trends east-west through the canyon of South Fork Smith Creek.

The eastern flank of the central anticline has an average dip of 65° E., south of Pole Creek, and an average dip of 26° E., north of Pole Creek. The western flank of the anticline has an average dip of 47° W., south of Pole Creek, and an average dip of 31° W., north of Pole Creek. Thus, the eastern flank is steeper along most of the central anticline except near the northern boundary of the mapped area where the western flank is a little steeper than the eastern flank. The central anticline has a gentle north plunge indicated by the restriction of younger formations to the northern part of the area.

A syncline, located west of the central anticline south of South Fork Smith Creek, separates the central anticline from the eastern flank of the anticline exposed in upper Wolf Creek Canyon (Blau, 1975, p. 25-27). Horizontal beds of the Ordovician Garden City Formation are exposed on the axis of this syncline in the northwestern part of sec. 17, T. 8 N., R. 2 E. A normal stratigraphic section from the Garden City Formation down to the Precambrian Mutual Formation is exposed on the western flank of this syncline. On the steep ridge east of the junction of the upper and lower segments of Wellsville Creek, the formations strike north. Northward, in sec. 19, T. 8 N.,
R. 2 E., they strike northwest. Thus, the syncline seems to begin just south of Davenport Creek.

A syncline, east of the central anticline, separates the central anticline from the western flank of the Strawberry Valley anticline on the western front of Sharp Mountain. Horizontal beds of the Ordovician-Silurian Laketown Formation are exposed on the axis of this syncline in the north-central part of sec. 28, T. 9 N., R. 2 E. (Figure 13). South of Davenport Creek, in the northeastern part of sec. 29, T. 8 N., R. 2 E., this syncline separates the eastern flank of the anticline of upper Wolf Creek Canyon (Blau, 1975, p. 25-27), exposed on the eastern front of James Peak, from the western flank of the Strawberry Valley anticline which is exposed south of Sharp Mountain.

The Mississippian formations that dip west in McKenzie Mountain and Bald Head, in the northwestern part of the area, seem to be continuous with the eastern flank of the Logan Peak syncline beyond the northern limit of the mapped area. These formations include the Mississippian Lodgepole and Humbug Formations. They dip about 25° W. A high-angle normal fault, at North Fork Smith Creek, separates these formations from the central anticline.

Local small-scale folds are exposed in places in formations containing abundant shale. These formations include the Cambrian Ute and Bloomington Formations and the Ordovician Garden City Formation. Excellent exposures of locally severe twisting and folding of the limestone beds of the Garden City are present on the ridge top in
Figure 13. Syncline in Laketown Formation on northern front of Sharp Mountain; view south. Shows horizontal beds in axis of syncline between the central anticline on the west and Strawberry Valley anticline on the east. The horizontal beds are in the Laketown Formation. Outcrop is located in the north-central part of sec. 28, T. 9 N., R. 2 E.
the southern half of sec. 29, T. 8 N., R. 2 E., and also near the southeastern corner of sec. 7, T. 8 N., R. 2 E. (Plate 1).

**Bedding-plane thrust faults**

Bedding-plane thrust faults are especially common in formations containing an appreciable amount of shale. Such faults are present in the Cambrian Ute and Bloomington Formations east of lower Wellsville Creek. A bedding-plane thrust fault is present between the Bloomington and Nounan Formations at the top of the ridge east of lower Wellsville Creek. A notable discordance in dip occurs between the two formations at that point. Slippage along bedding planes has reduced the thickness of the Ute and Bloomington Formations; however, the reduction is not great.

Bedding-plane thrust faults have disrupted the Garden City Formation in several places in the northern part of the area. These faults are associated with local small-scale folds.

**Low-angle thrust faults**

Two low-angle thrust faults are present on the eastern front of James Peak in the southwestern part of the mapped area (Plate 1). The first of these thrust faults extends from a point located near the central part of the mapped area, just west of lower Wellsville Creek, southward along the eastern side of the prominent ridge that rises to James Peak (Blau, 1975, p. 29). It strikes about N. 65° E. and dips about 25° N. to 27° N. In sec. 19, T. 8 N., R. 2 E., orthoquartzite of the Brigham Formation is thrust eastward over the Cambrian Bloomington Formation that crops out along Wellsville Creek.
The stratigraphic throw is about 3,000 feet at that point. In sec. 25, T. 8 N., R. 1 E., the lower contact of the Brigham Formation, above the fault, is displaced eastward about 2,000 feet from its position below the fault in sec. 36, T. 8 N., R. 1 E. (Blau, 1975, p. 29).

The second low-angle thrust fault extends eastward from the southwestern edge of the mapped area into the upper part of the canyon of Wellsville Creek. It strikes about N. 46° E. and dips about 35° S. The Cambrian strata are severely deformed near the head of Wellsville Creek. This chaotic mass is considered to represent the Cambrian Langston and Ute Formations. Lack of good outcrops makes identification difficult, but the presence of green shale and laminated, silty limestone suggests that this mass is Langston and Ute. The Blacksmith Formation seems to overlie the Ute Formation in the first saddle on the ridge that trends southeast from the main parking lot at Powder Mountain ski resort where small angular pieces of light- to medium-gray dolomite are prevalent in the colluvial deposits. The Cambrian strata of this area are represented as undifferentiated Langston and Ute Formations on the map (Plate 1). Thrusting of Langston and Ute Formations over Precambrian Mutual Formation indicates a stratigraphic throw of at least 4,000 feet. 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 eastward over Brigham along this fault. This thrust mass of Brigham is separated from the tentatively identified Langston and Ute Formations, which underlie it, by a low-angle thrust fault on its western and southern
sides (Blau, 1975, p. 33). Movement seems to have been from the west on this fault.

A low-angle thrust fault is also exposed in the southwestern corner of the mapped area in the upper canyon of South Fork Wolf Creek. Undifferentiated Langston and Ute Formations overlie the Cambrian Ute Formation on this fault. It probably joins the previously described thrust fault in the upper canyon of Wellsville Creek. The Ute Formation, below this thrust fault, is continuous with the normal stratigraphic succession that overlies the Brigham Formation in the Huntsville Quadrangle to the south (Sorenson and Crittenden, 1974).

**Strike-slip faults**

Two important strike-slip faults are present east of the summit of James Peak near the western boundary of sec. 31, T. 8 N., R. 2 E. A smaller strike-slip fault parallels the northern strike-slip fault (Plate 1). The strike-slip faults occur within the stratigraphic section below the two low-angle thrust faults on the eastern front of James Peak.

The northern strike-slip fault is located near the eastern side of sec. 36, T. 8 N., R. 1 E. It strikes N. 47° E. and dips 43° S. (Blau, 1975, p. 35). This fault cuts the upper part of the Precambrian Mutual Formation, the Browns Hole Formation, and the lower part of the Brigham Formation. The northern side is displaced toward the northeast by about 100 feet (Blau, 1975, p. 33).

The southern strike-slip fault is located in the upper part of the valley of Wellsville Creek near the western side of sec. 31,
T. 8 N., R. 2 E. This fault parallels the northern strike-slip fault and shows displacement toward the northeast on the northern side. Blau (1975, p. 35) mapped this southern fault because the Browns Hole Formation, north of the fault, opposes orthoquartzite of the Brigham Formation, south of the fault. No evidence of the Browns Hole Formation is found south of the fault. The Browns Hole Formation, north of the fault, is inferred to have been displaced northeast. The Browns Hole presumably lies beneath the thrust mass of Brigham Formation in the southwestern part of sec. 31, T. 8 N., R. 2 E. Another possibility for the absence of the Browns Hole Formation, south of the upper valley of Wellsville Creek, could be that a local pinchout of the Browns Hole occurs at this particular locality.

**Normal faults**

A high-angle normal fault, just west of Sharp Mountain, extends southward from sec. 28, T. 9 N., R. 2 E., to the southern part of sec. 20, T. 8 N., R. 2 E. It strikes approximately N. 12° E. Maximum displacement is on the ridge between Pole and Bald Head Creeks. At that point on the southern boundary of sec. 33, T. 9 N., R. 2 E., the lower white-weathering dolomite beds of the Devonian Water Canyon Formation, west of the fault, are in fault contact with the Ordovician-Silurian Laketown Formation, east of the fault. Relative displacement is down on the west. Displacement at that point is about 150 to 200 feet. The fault dies out, in the northeastern part of the mapped area, in a syncline that involves the Laketown Formation in the
central part of sec. 28, T. 9 N., R. 2 E. (Plate 1). The fault is inferred to extend southward to the southeastern corner of sec. 20, T. 8 N., R. 2 E., based on topography and thin zones of breccia 6 to 8 inches thick present on ridge tops. Little or no displacement of formation contacts, traced across the fault, suggests that the fault dies out at that point. The fault seems to parallel the synclinal axis along the western front of Sharp Mountain; however, it seems to diverge from the axis just northeast of Davenport Creek (Plate 1).

A high-angle normal fault is also located just north of North Fork Smith Creek in the northeastern part of sec. 6, T. 8 N., R. 2 E. This fault is essentially vertical and trends northeast at its southern end and north-northeast at its northern end. Northward, it seems to parallel the eastern side of McKenzie Mountain beneath a cover of Tertiary Salt Lake Formation. Mullens and Izett (1963) indicated no evidence of this fault beyond the northern limit of the mapped area. In fact, a normal stratigraphic section from the Devonian Water Canyon Formation through the Pennsylvanian Oquirrh Formation was reported (Mullens and Izett, 1964, p. 4-12). Thus, the fault is considered to die out just east of Bald Head. Southward, it curves west and terminates against the East Cache faults along the mountain front near the central part of sec. 6, T. 8 N., R. 2 E. Maximum displacement occurs at that point where the upper part of the Devonian Water Canyon Formation, east of the fault, is in fault contact with the lower part of the Mississippian Humbug Formation, west of the fault. Relative displacement is down on the west. The
Mississippian Lodgepole and Devonian Beirdneau and Hyrum Formations are eliminated along this fault indicating a stratigraphic throw of about 1,750 feet. Tabular fault breccia crops out along the northern part of this fault.

The eastern margin of Cache Valley is defined by the East Cache faults of Williams (1948, p. 1,154-1,155). Three fault segments make up a fault zone in the mapped area. One is north of Smith Creek, one south of Smith Creek, and a third is inferred to bound the northern front of James Peak. The fault segment, north of Smith Creek, strikes approximately N. 10° W. and the segment, south of Smith Creek, strikes approximately N. 25° E. The inferred segment, north of James Peak, trends approximately N. 60° E. The faults of all three segments are vertical.

The segment, north of Smith Creek, extends to the northern boundary of the mapped area and bounds the western front of Bald Head and McKenzie Mountain. Southward, it terminates beneath colluvial deposits just south of South Fork Smith Creek. The Tertiary Salt Lake Formation, which underlies the eastern margin of Cache Valley, is in fault contact with the Mississippian Humbug Formation on McKenzie Mountain. Since the Paleozoic formations are not exposed west of the fault along the eastern margin of Cache Valley, no direct indication of the amount of stratigraphic throw is evident. Relative displacement is down on the west. Thick zones of tabular fault breccia crop out where this fault extends across Pole Creek and South Fork Smith Creek.
The fault segment, south of Smith Creek, extends southwest from South Fork Smith Creek to the southwestern part of sec. 18, T. 8 N., R. 2 E., where it is covered by the colluvial deposits on the northern front of James Peak. North of Davenport Creek, the Tertiary Salt Lake Formation, which underlies the eastern margin of Cache Valley, is in fault contact with the Cambrian St. Charles Formation exposed on the mountain front. The fault is obscured by the colluvial deposits south of Davenport Creek but is assumed to terminate against the segment along the northern front of James Peak. Relative displacement is down on the west. No direct evidence of the amount of stratigraphic throw was found.

The segment that bounds the northern front of James Peak is inferred to trend about N. 60° E. beneath the outwash fan in the northeastern part of sec. 24, T. 8 N., R. 1 E. This fault segment seems to terminate against the segment south of Smith Creek near the northwestern corner of sec. 19, T. 8 N., R. 2 E. No direct evidence of the amount of stratigraphic throw was found due to the presence of the outwash fan. Lack of fault scarps within the outwash fan, however, indicates that movement has not occurred since Pleistocene time.

A high-angle normal fault extends westward from the eastern boundary of the mapped area through the bottom of the canyon just east of the summit of Sharp Mountain to the mountain front. This fault strikes N. 80° W. and is vertical. On the eastern front of Sharp Mountain in the western half of sec. 10, T. 8 N., R. 2 E., the Ordovician Garden City Formation, north of the fault, is in fault
contact with the Cambrian St. Charles Formation, south of the fault. The Garden City Formation has dropped about 500 feet, north of the fault, at that point. On the western front of Sharp Mountain near the northeastern corner of sec. 7, T. 8 N., R. 2 E., the Laketown Formation, north of the fault, is in fault contact with the Laketown and Garden City Formations, south of the fault. The Laketown and Garden City Formations, south of the fault, are folded into a syncline; whereas, no evidence of the syncline exists north of the fault where the Laketown Formation maintains a constant west dip. Relative displacement is down on the north and the elimination of the syncline and most of the Laketown Formation indicates about 1,000 feet of stratigraphic throw. This fault seems to terminate against the East Cache faults in sec. 7, T. 8 N., R. 2 E., but it could be obscured in the Cache Valley graben. Vertical slickensides and a tabular fault breccia with crude east-west alignment are exposed in the Laketown Formation along the fault trace near the northwestern corner of sec. 8, T. 8 N., R. 2 E. Steepened north dip, suggesting drag along the fault, is present in the Laketown Formation north of the fault near the head of South Fork Smith Creek.

A high-angle normal fault of small extent is located on the steep ridge east of lower Wellsville Creek in the northeastern part of sec. 30, T. 8 N., R. 2 E. It strikes approximately N. 55° E. and seems to die out near the valley bottom and also near the crest of the steep ridge. It cuts the Ute, Blacksmith, and Bloomington Formations. Limestone of the Ute Formation, north of the fault, is
in fault contact with shale of the Ute Formation, south of the fault. The limestone, south of the fault, is displaced down about 100 feet and exhibits steepened south dip suggestive of drag along the fault.

**Structural Events**

**General statement**

The tectonic deformation of the eastern part of the James Peak Quadrangle and western part of the Sharp Mountain Quadrangle can be correlated with two major geologic events. The two events were of regional extent. The older involved compression of the crust and the younger involved extension of the crust. The folds exposed within the James Peak-Sharp Mountain area resulted from the older event, and the normal faults and the high relief along the mountain front resulted from the younger event.

The older event is known as the Laramide orogeny and produced north-south folds and related thrust faults in Precambrian, Paleozoic, Mesozoic, and Paleocene rocks. Armstrong and Cressman (1963, p. 9-10) dated the inception of the Laramide orogeny as latest Jurassic or earliest Cretaceous based on clasts of Paleozoic rocks in the Ephraim Conglomerate in the Gannett Hills of southeastern Idaho. The basal part of the Ephraim is reported to be as old as Late Jurassic and the upper part is reported as Early Cretaceous (Armstrong and Cressman, 1963, p. 11). Mesozoic formations are cut by the Bannock thrust zone in southeastern Idaho. Paleocene rocks have been cut by thrust faults in western Wyoming; however, Early
Eocene beds, in southeastern Idaho and westernmost Wyoming, are not known to be cut by thrust faults. Thus, Armstrong and Cressman (1963, p. 19) concluded that the Laramide orogeny had ceased by Eocene time. The Wasatch Formation of Paleocene to early Eocene age (Gazin, 1959, p. 132), has not been affected by thrust faults or folds in the Browns Hole Quadrangle just south of the mapped area (Crittenden, 1972). The Wasatch Formation is essentially horizontal and unconformably overlies the folded Precambrian and Paleozoic rocks in that area. The Salt Lake Formation in Morgan Valley, Utah, is late Eocene in age (Gazin, 1959, p. 137) and has not been affected by the thrust faults associated with the Laramide orogeny.

The younger event is known as Basin and Range faulting and produced high-angle normal faults which mostly trend north-south. The formation of horsts and grabens, typical of the Basin and Range physiographic province (Fenneman, 1946), was the result of the high-angle normal faulting. The Tertiary Salt Lake Formation was deposited in down-faulted valleys (Williams, 1948, p. 1,160; Adamson, Hardy, and Williams, 1955, p. 21). Thus, the normal faulting began before the deposition of the Salt Lake Formation which is late Eocene in the lower part (Gazin, 1959, p. 137). The Salt Lake Formation was subsequently faulted by Basin and Range faulting after its deposition in the grabens. Armstrong and Oriel (1965, p. 1,862) reported high-angle normal faults that cut the Wasatch Formation of late early Eocene age; whereas, other similar faults do not displace the Wasatch. Thus, Armstrong and Oriel (1965, p. 1,862) dated the inception of
normal faulting as Eocene. Recent earthquake activity indicates that this faulting is active at the present time (Cook and Smith, 1967).

**Laramide events**

The Precambrian and Paleozoic formations of the mapped area have been folded and thrust faulted. No Mesozoic rocks are present in the area. The Salt Lake Formation unconformably overlies the Paleozoic formations and is not folded or disrupted by thrust faults. Thus, the folds and thrust faults, within the mapped area, were formed during the Laramide orogeny.

The north-south-trending folds of the mapped area were produced relatively early during the Laramide orogeny. They include the Strawberry Valley anticline of which the western flank is in the eastern part of the mapped area, the syncline just west of Sharp Mountain, the central anticline, and the syncline just west of the central anticline south of South Fork Smith Creek of which the western flank is exposed on the eastern front of James Peak. The formations, which dip west in McKenzie Mountain, are continuous with the eastern flank of the Logan Peak syncline. The axis of the Logan Peak syncline is truncated by the normal fault along the front of the Bear River Range just north of the mapped area (Williams, 1948, Plate 1). The general north-south trend and steep dip of the eastern flank of the central anticline suggests a force acting toward the east in the mapped area.

The low-angle thrust faults on the eastern front of James Peak
were also produced during the Laramide orogeny but later than the folds. Evidence for the later formation of the thrust faults is present on the eastern flank of James Peak, west of lower Wellsville Creek, where the thrust faults truncate the folded Precambrian and Paleozoic formations. South of upper Wellsville Creek, the thrust faults truncate folded Paleozoic formations. On the eastern flank of James Peak, the base of the Brigham Formation was thrust eastward. This agrees with the direction of movement on the Willard thrust fault (Crittenden, 1961, p. 129).

The strike-slip faults on the eastern front of James Peak probably formed contemporaneously with the thrust faults. The strike-slip faults affect formations beneath the thrust faults. The trend of the strike-slip faults parallels the general direction of movement on the thrust faults.

Basin and Range events

The high-angle normal faults on the eastern margin of Cache Valley, the normal fault north of North Fork Smith Creek, and the high-angle normal fault just west of Sharp Mountain, as well as the east-west-trending normal fault that crosses the summit of Sharp Mountain, are the result of Basin and Range faulting. These faults cut the folds and thrust faults formed in the earlier Laramide orogeny.

The east-west-trending fault suggests a period of north-south extension of the crust during an early phase of Basin and Range faulting. The early phase of north-south extension was minor in comparison to the later phase of east-west extension of the crust.
The north-south-trending faults are evidence of the east-west extension of the crust. During this event, the Salt Lake Formation was down-faulted along the eastern margin of Cache Valley. The Salt Lake evidently overlies the normal fault in the small valley east of McKenzie Mountain as well as the east-west-trending normal fault in sec. 7, T. 8 N., R. 2 E. Thus, the latter two faults seem to have been inactive since the deposition of the upper part of the Salt Lake Formation or since Miocene-Pliocene time.

The presence of an unfaulted outwash fan of Pleistocene age, overlying the high-angle normal fault that defines the southern margin of Cache Valley, suggests that movement resulting in fault scarps at the surface has not occurred since Pleistocene time. Earthquake activity centered at Avon, Utah, indicates that even though fault scarps have not been detected at the surface, the faults that define the eastern margin of Cache Valley are seismically active at the present time (Cook and Smith, 1967, p. 716).
LITERATURE CITED


