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Geology of the West-Central Part of the Malad Range, Idaho

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GEOLOGY OF THE WEST-CENTRAL PART

OF THE MALAD RANGE, IDAHO

by

Phillip H. Wach

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

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
1967
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The author wishes to express appreciation to Dr. Clyde T. Hardy, who suggested the problem, directed the author in a reconnaissance of the mapped area, and presented helpful criticism of the manuscript. Dr. J. Stewart Williams, Dr. Donald R. Olsen, and Dr. Robert Q. Oaks, Jr. reviewed the manuscript and made suggestions for its improvement. Drew C. Axtell assisted in the measuring of stratigraphic sections. The author is grateful for the assistance of Mrs. Phillip H. Wach in criticism and preparation of the manuscript.

Phillip H. Wach
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The west-central part of the Malad Range is located in south-eastern Idaho. This area was the site of thick marine deposition in the early Paleozoic period. In the Tertiary and Quaternary periods continental deposition occurred, covering the Paleozoic rocks. Quartzite and shale units of the Brigham Quartzite are found near the base of the Cambrian section. Carbonate with shale interbeds is found in middle and late Cambrian units. Limestone and silty limestone are found in the early and middle Ordovician time overlain by the middle Ordovician Swan Peak Quartzite. The Laketown Dolomite includes units of late Ordovician and Silurian age. Paleozoic units younger than Silurian and Mesozoic units are not found in the mapped area. Red conglomerates mark early Tertiary deposition, and water-lain tuff, fresh-water limestone, conglomerate and sandstone are of middle and late Tertiary age. Tertiary-Quaternary rocks, found in the mapped area, are composed of deposits of boulders resting on older Tertiary and Paleozoic rocks. These deposits show rough polygonal structures and stone stripes. Quaternary deposits are composed of sediment from the late Pleistocene Lake Bonneville and Quaternary alluvium.
Northwest-trending faults, northeast-trending faults, and north-trending faults are found in the mapped area, with northwest-trending faults predominating. The northwest-trending faults are high-angle faults and have resulted in Tertiary rocks being faulted against lower Paleozoic rocks. Northeast-trending faults are roughly parallel and predate the middle and late Tertiary rocks. North-trending faults are high-angle faults involving both Paleozoic and Tertiary rocks. One northwest-trending fault has evidence of horizontal movement. The structures are assigned to three periods of movement: 1. early Cretaceous to early Tertiary, 2. late Tertiary to middle Tertiary, 3. middle Tertiary to Recent.

(79 pages)
INTRODUCTION

General Statement

The west-central part of the Malad Range is one of the few remaining areas in the southeastern part of Idaho which has neither been mapped in detail nor subjected to a geologic study. The purpose of this investigation is to provide such a study of this area and to relate the structure and stratigraphy to that of northeastern Utah and southeastern Idaho.

The Malad Range is located near the northeastern boundary of the Basin and Range province (Fenneman, 1931). The mapped area is located between lat. 42° N. and 42°06′ N. and long. 112°06′ W. and 112°15′ W. The southern boundary is marked by the Utah-Idaho state line, the western boundary by the Malad River; the eastern boundary lies 1 mile west of the Oneida-Franklin County line; the northern boundary extends east from Cherry Creek (see Plate 1). The area encompasses approximately 42 square miles. The mapped area is located 35 miles northwest of Logan, Utah, and 15 miles south of Malad City, Idaho. The community of Cherry Creek, Idaho, is situated near the northern boundary, and the community of Woodruff, Idaho, lies southwest of the area. Malad Valley, extending from the Utah-Idaho line to 3 miles north of Malad City, lies to the west of the mapped area. Cache Valley, which extends from Paradise, Cache County, Utah, to Swanlake, Bannock County, Idaho, lies
Figure 1. Index map of northeastern Utah and southeastern Idaho
to the east of the area. The Logan quadrangle, which includes most of Cache Valley and the Bear River Range, extends from the Utah-Idaho line on the north to Mantua, Box Elder County, Utah, on the south and includes most of Cache County, Utah. The Randolph quadrangle is immediately adjacent to the Logan quadrangle on the east and includes most of Rich County, Utah, as well as a part of Uinta County, Wyoming.

Other significant geographical localities in the northern Utah and southeastern Idaho area include:

1. Two Mile Canyon, 2 miles southeast of Malad City, Idaho
2. Blacksmith Fork Canyon in the Bear River Range, 7 miles southeast of Logan, Utah
3. Calls Fort, 6 miles north of Brigham City, Box Elder County, Utah
4. High Creek in the Bear River Range, 15 miles north of Logan, Utah
5. Baker Canyon in the Wasatch Range, 2½ miles north of Brigham City, Utah

Malad City, Idaho, receives an average of 14 inches of precipitation annually (Mower and Nace, 1957, p. 28). Precipitation in the Malad Range is approximately 20-25 inches annually. The west-central Malad Range has sparse to thick growths of desert vegetation with sagebrush and juniper dominating. Higher elevations have some Douglas fir and spruce. Most of the mapped area lies between 5,000 and 7,000 feet.

The west-central Malad Range is accessible from mid-April through October. Roads into the area are maintained by the U. S. Forest Service at Dry Canyon, Black Canyon, and north from Steel Canyon to Black Canyon.
A jeep trail runs from Cherry Creek to Cold spring connecting with a Forest Service road from Two Mile Canyon to Dry Canyon.

**Field Work**

Field research for the project was conducted during the summer and fall of 1966. Formation contacts, faults, and other features were plotted in the field on aerial photos at a scale of 1:20,000. These data were transferred from the photos to a U. S. Forest Service map of Caribou National Forest having a scale of 1:24,000.

A Brunton compass was used to determine attitudes of beds and faults. Stratigraphic sections were measured with a 50-foot steel tape and a Brunton compass. True thicknesses were derived by trigonometric functions. Samples were collected from each unit of measured sections and fossils were identified in the laboratory. Hydrochloric acid was used to identify limestone and calcite-cementing material.

The following terminology is used in this study with reference to thickness of beds: beds less than 6 inches thick are thin bedded; beds 6 inches to 12 inches thick are medium bedded; beds 1 foot to 3 feet thick are thick bedded, and beds greater than 3 feet thick are massive bedded.

**Previous Investigations**

The earliest recorded investigation in the area of the Malad Range and Malad Valley was the Hayden expedition of 1872 (1872, p. 13-26). The Hayden party passed through Cache Valley, Utah, and described the
mountain range to the west as separating Cache Valley from Malad Valley. Members of this expedition studied the Malad Range and correlated the older quartzitic sandstone with the Quebec Group of the province of Quebec, Canada. Six years later in 1878, geologists of the Green River Division under the leadership of Peale (1879, p. 606-608) described the northern part of the Malad Range as a syncline with west dipping beds. This expedition also recognized that younger Tertiary rocks were deposited unconformably against Paleozoic rocks (Peale, 1879, p. 521). In 1877 Gannett (Peale, 1879, p. 703) considered the Malad Range as a direct continuation of the Wasatch Range, separated by the long low depression in the vicinity of the "Gates of the Bear" now called Junction Hills.

In 1908 Walcott (1908a, p. 5-9; 1908b, p. 191-200) published descriptions of Cambrian sections in northern Utah and southern Idaho. Walcott divided the Cambrian into formations, defined type areas, and collected fossils. Two Mile Canyon in the Malad Range was one of the localities where sections were measured (Resser, 1939b, p. 9-11). Richardson (1913), in his work on the Randolph quadrangle, defined and named most of the remaining Paleozoic formations. In 1927 Mansfield (1927) published his classic paper on southeastern Idaho and contributed to the knowledge of the structure and stratigraphy of the region. In 1948, Williams (1948) published the results of several years work in Logan quadrangle. He named the Water Canyon Formation, recognized the Salt Lake Formation and members of the Wasatch Formation and Jefferson Formation.

Walcott's measured sections of the Cambrian Formations of northern
Utah and southern Idaho were published by Resser (1939b, p. 9-11). In the same year Resser published descriptions of the fauna he had collected from the Spence Shale Member of the "Ute Formation" (Resser, 1939a, p. 1-29) and the Ptarmigania fauna (Resser, 1939b, p. 1-72) collected by Walcott and Resser. Deiss (1938, p. 279-281) reworked the Cambrian section in Blacksmith Fork Canyon where Walcott had indicated most of his type sections were found. New thicknesses and changes in formation boundaries were reported by Deiss in his revised sections. The most significant change was the reassignment of 777 feet of the St. Charles Formation into the Ordovician Garden City Limestone (Deiss, 1938, p. 1,117). In 1941 the Spence Shale was reassigned from the Ute Formation of Walcott (Resser, 1939b, p. 10) to the Langston Formation by Williams and Maxey (1941, p. 279-281).

Other geologic studies in the vicinity of the mapped area have been made by Beus (1963), who worked on the geology of the Blue Spring Hills to the west of the present area; Hanson (1949) in the southern Malad Range; Prammani (1957) studied the geology of the east-central part of the Malad Range immediately to the east; Axtell (1967) studied the northern part of the Malad Range immediately north of the present area; and Murdock (1961), who studied the geology of the Weston Canyon area in the Bannock Range northeast of the present area. Ross (1951) made a detailed study of the Garden City Formation.
STRATIGRAPHIC GEOLOGY

General Statement

Cambrian rocks present in the area of study include all formations from the Brigham Quartzite to the St. Charles Formation. No Precambrian rocks are known from the present area although Hanson (1949, p. 11-12) tentatively correlated quartzite found in the vicinity of Trail Creek with the Precambrian schists and gneisses of the Cottonwood Creek region of the central Wasatch Mountains. This exposure is not Precambrian as Hanson had supposed but is the Brigham Quartzite of Cambrian age.

Ordovician rocks exposed in the mapped area include the Garden City Limestone and the Swan Peak Quartzite. No Fish Haven Dolomite is exposed although it no doubt was present in the area. Only one outcrop of rocks of Silurian age is present, near the northwest boundary of the mapped area, consisting of the Laketown Dolomite.

Rocks of Devonian to Early Tertiary age were not found and either are not exposed or were removed by erosion. It is probable that all systems were originally deposited but have been eroded prior to deposition of the Tertiary rocks. Rocks of Devonian age are exposed in the northern part of the range (Axtell, 1967), and rocks of Mississippian and Pennsylvanian ages were found by Hanson in the southern Malad Range (Hanson, 1949, p. 52-56). Rocks of Pennsylvanian and Permian ages are found to the south and east of the mapped area (Beus, 1958; Mansfield, 1927).
<table>
<thead>
<tr>
<th>Unit</th>
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<th>Thickness (feet)</th>
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<tr>
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<td></td>
</tr>
<tr>
<td>Alluvium</td>
<td>Mud, sand, gravel</td>
<td></td>
</tr>
<tr>
<td>Lake Bonneville Group</td>
<td>Mud, sand, gravel</td>
<td>700</td>
</tr>
<tr>
<td>Tertiary-Quaternary</td>
<td></td>
<td></td>
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<tr>
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<tr>
<td>Tertiary</td>
<td></td>
<td></td>
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<tr>
<td>Salt Lake Formation</td>
<td>Limestone, tuff, shale, sandstone</td>
<td>902</td>
</tr>
<tr>
<td>Wasatch Conglomerate</td>
<td>Conglomerate</td>
<td>100</td>
</tr>
<tr>
<td>Silurian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laketown Dolomite</td>
<td>Dolostone, some chert</td>
<td>700</td>
</tr>
<tr>
<td>Ordovician</td>
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<td></td>
</tr>
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<td>Quartzite</td>
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<tr>
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<td></td>
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<tr>
<td>St. Charles Formation</td>
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<tr>
<td>Nounan Formation</td>
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<td>Bloomington Formation</td>
<td>Shale, intraformational conglomerate, some dolostone, limestone</td>
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</tr>
<tr>
<td>Blacksmith Formation</td>
<td>Limestone, some dolomitic limestone</td>
<td>200</td>
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<tr>
<td>Ute Formation</td>
<td>Limestone, shale</td>
<td>439</td>
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<tr>
<td>Langston Formation</td>
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<td>132</td>
</tr>
<tr>
<td>Brigham Quartzite</td>
<td>Quartzite, shale, conglomerate</td>
<td>1121</td>
</tr>
</tbody>
</table>
Although no Mesozoic rocks are found in this part of the Cordilleran geosyncline, it is possible that they were deposited and later removed by erosion. The author believes that there is also a good possibility that Mesozoic rocks were never deposited in the present area. Mesozoic rocks are found to the east and south of the Malad Range, but none have been found in the Bear River Range or northern Wasatch Range.

Tertiary rocks include thin outcrops of conglomerate of early Tertiary age which rest on the Paleozoic rocks called the Wasatch Conglomerate and extensive outcrops of conglomerate, limestone, sandstone, and shale belonging to the Salt Lake Formation. Tertiary-Quaternary rocks mapped as a unit include considerable areas veneered by boulders which may be as old as late Tertiary. Quaternary deposits include stream alluvium, colluvium, and unconsolidated gravel, mud, and sand deposited in Lake Bonneville.

Paleozoic Rocks

Cambrian System

Brigham Quartzite. The Brigham Quartzite was named by Walcott (1908a, p. 8) from an exposure northeast of Brigham City, Box Elder County, at the west front of the Wasatch Range. The formation was described as massive quartzitic sandstone. A section measured by Walcott at Blacksmith Fork Canyon consists of 1,232 feet of gray-to-green quartzitic sandstone and green sandy shale with the base of the section not exposed. Eardley and Hatch (1940b, p. 811) measured the Brigham Quartzite at the type area in Baker Canyon (now called Antimony Canyon) and described
the formation as at least 1,775 feet of massive gray- to greenish-gray quartzite with interbedded conglomerate. Prammani (1957, p. 11) reported 565 feet of Brigham Quartzite at Dry Canyon in the east-central Malad Range. He described it as massive-bedded brownish-gray to olive-gray quartzite and thin-bedded olive-gray shale. Axtell (1967) remeasured the Brigham Quartzite section of Walcott, described by Resser (1939a, p. 11) at Two Mile Canyon east of Malad City, Idaho, and found 670 feet of red, white, green, and black, medium- to coarse-grained thin- to thick-bedded quartzite and green and yellow-brown micaceous shale.

In the west-central part of the Malad Range, the Brigham Quartzite occurs as a wedge in fault contact with younger Cambrian formations. It forms two steep-sloped rounded hills near the southwestern boundary of the mapped area. The slopes of these rounded hills are veneered with brown-weathering quartzitic talus. At Trail Creek and Burnett Canyon the quartzite forms prominent ledges. The Brigham Quartzite at Trail Creek consists of at least 1,121 feet of dark-gray, pink, white, and greenish-brown, medium- to coarse-grained, thin- to thick-bedded quartzite and dark-gray to olive-brown, thin-bedded, micaceous and argillaceous shale. Some thin beds of quartzitic conglomerate are found in the quartzite layers. Much of the quartzite is cross-bedded. Fucoid markings are common near the top of the section, and worm burrows have been observed by the author (Plate 1). Calcareous sandstone is present near the top of the section. The base of the Brigham Quartzite is not exposed in the mapped area.

No fossils were collected from the Brigham Quartzite in the present area, and formation does not yield an abundant fauna although Williams
Figure 1. Worm burrows in the Brigham Quartzite, near top of section in southwest-dipping beds. Picture taken half a mile south of Trail Creek.

Figure 2. Front ridge of the west-central part of the Malad Range. The hills in the foreground consist of Brigham Quartzite. View taken a quarter of a mile north of Burnett Canyon looking southeast. Burnett Canyon is the canyon to the right of center in the photo.

Plate 2. Brigham Quartzite
and Maxey (1941, p. 227) collected *Albertella* sp. and *Kochaspis* sp. in the basal member of the overlying Langston Formation.

The presence of these fossils above the Brigham led to an assignment of early Cambrian age to the Brigham Quartzite. Oriel (1964, p. 341) found a specimen of *Olenellus* 170 feet below the base of the Langston Formation in the Portneuf Range southeast of Lava Hot Springs, Idaho. This find lends credence to an early Cambrian age for the Brigham Quartzite.

**Langston Formation.** The Langston Formation was named by Walcott (1908a, p. 8) from Langston Creek, Idaho. The type section of the Langston Formation was designated by Walcott to be at Blacksmith Fork Canyon, where he described massive-bedded bluish-gray limestone in the upper part, with the lower part consisting of massive-bedded dark-gray arenaceous limestone and gray calcareous sandstone. Walcott measured a total thickness of 498 feet. Walcott’s original section of Langston was changed by Deiss in 1938 (Deiss, 1938, p. 1,117) to 575 feet. The Spence Shale Member of the Langston Formation originally was included in the Ute Formation by Walcott. Williams and Maxey (1941, p. 276-285) included the Spence Shale as part of the Langston Formation, and Maxey (1958, p. 654-655) described at least three members of the Langston from Calls Fort, Utah, as follows: 1. the basal Naomi Peak Limestone, 2. the Spence Shale, 3. an upper limestone and dolomite unit. Maxey recorded a total thickness of 484 feet at Calls Fort. Williams (1948, p. 1,130) measured 380 feet of Langston at Blacksmith Fork Canyon. Axtell (1967) measured 132.6 feet of Langston at Two Mile Canyon, including the basal
Naomi Peak or *Ptarmigania* Limestone, the Spence Shale, and an upper limestone unit.

The Langston Formation in the mapped area forms a series of low hills in fault contact with and west of the Brigham Quartzite. The hills are below the Bonneville level terrace of the late Pleistocene Lake Bonneville and are thinly veneered with Quaternary deposits; however, good exposures of Spence Shale are found in stream gullies. The base of the Langston is not exposed here, and the upper limestone unit has been removed by erosion. North of this outcrop the basal Langston and a part of the Spence Shale are in fault contact with the Brigham Quartzite along an east-west-trending fault. This unit is thin because of removal of most of the unit through erosion and outcrops are poor.

Only the lower two members of the Langston Formation are present in the west-central part of the Malad Range. The Naomi Peak Limestone occurs in isolated outcrops and rests on transitional calcareous sandstone of the Brigham Quartzite. It consists of light- to medium-gray, fine crystalline, arenaceous, thick-bedded limestone with lenses of coarse-crystalline limestone. In most localities this member contains a trilobite fauna known as the *Ptarmigania* fauna. Exposures are poor in the mapped area, and no attempt was made to collect fossils from the Naomi Peak Limestone Member.

The Spence Shale Member of the Langston is exposed in the southwest corner of the area. It extends northward from the Utah-Idaho boundary to Trail Creek and again south of Burnett Canyon. It forms low rounded hills and consists of fine-grained, fissile, dark-gray, thin-bedded shale. Trilobites, especially agnostids, are abundant in this member. Some of
the shale layers are calcareous and a few thin beds of medium-gray shaly limestone are found in this member. Fossils collected from the Spence Shale in the west-central Malad Range include:

"Agnostus" bannerensis Resser

Elrathia spencei Resser

Spencia typicalis Resser

Alokistocare punctatum Resser

Agnostus brighamensis Resser

Kiwetinokia utahensis Walcott

Oryctocephalus walcotti Resser

Zacanthoides idahoensis Walcott

The Langston Formation is assigned a medial Cambrian age on the basis of its trilobite fauna (Williams, 1948, p. 1,130). The contact between the Brigham Formation and the Langston Formation appears to be transitional in the west-central Malad Range. The sandstone of the Brigham Formation becomes more calcareous near the basal arenaceous limestone of the Langston Formation. The transitional nature of the contact is borne out by work done by Prammani (1957, p. 16) and by Axtell (1967).

**Ute Formation.** The name Ute was first used by King (1878, p. 232-233) of the Fortieth Parallel Survey with reference to 2,000 feet of limestone containing Cambrian fossils and overlying Cambrian quartzite. Walcott (1908a, p. 7-8) restricted the original Ute to a zone of thin-bedded limestone and shale 729 feet thick in Blacksmith Fork Canyon with a fauna characteristic of the lower part of the Ute Formation of the Fortieth Parallel Survey. Deiss (1938, p. 1,120-1,121) redefined the type section
in Blacksmith Fork Canyon and measured 685 feet of Ute. Williams (1948, p. 1,130) measured 665 feet of Ute Limestone at Left Fork and Blacksmith Fork Canyons. The thickest section of Ute is measured at High Creek, Utah, where 745 feet of thin shale and arenaceous limestone are measured (Maxey, 1958, p. 654). Hanson (1949, p. 14) measured a partial section of Ute in the southern Malad Range, where the base of the formation is not exposed, and found 439 feet of limestone and shale.

In the west-central Malad Range the Ute Formation crops out in fault contact with the Brigham Quartzite along the eastern part of the low hill between Burnett Canyon and Trail Creek. The outcrop continues for a few feet north of Burnett Canyon and is cut off on the east by a north-south-trending fault which drops the Tertiary Salt Lake Formation down next to the Ute. The outcrop is limited in areal extent and is intensely broken by faulting.

The Ute Formation exposed in the mapped area is composed of fine-crystalline orange to light-brown limestone with silty partings and dark-gray oolitic and pisolitic limestone. This unit is medium- to thick-bedded and contains irregular calcite veins, and forms ledges. Both above and below this unit are steep slopes formed by thin-bedded silty limestone and orange to light-brown shale. Outcrops of the Ute Formation are poorly exposed and neither the top nor the bottom of the formation is visible. The probable contact between the Ute and the Blacksmith is covered by Tertiary and Quaternary alluvium and talus.

Although no fossils were collected by the author from the Ute Formation, the age is considered to be Albertan (Williams, 1948, p. 1,130; Williams and Maxey, 1941, p. 281-284). Maxey (1958, p. 672) reported
that *Olenoides* sp., *Emmaniella* sp., ?, *Alokistocare* sp., and *Obulus* sp. occur about 400 feet above the base of the Ute Formation in Northern Utah. These fossils are all typical Medial Cambrian and are characteristic of the *Bathyuriscus-Elrathina* zone of Medial Cambrian age.

**Blacksmith Formation.** Walcott (1908a, p. 7) designated Blacksmith Fork Canyon as the type area of the Blacksmith Limestone. He measured and described 570 feet of "gray arenaceous limestone in massive layers." Deiss (1938, p. 1,112-1,113) redefined Walcott's section and measured 450 feet of thick-bedded gray dolomite and interbedded magnesian limestone. The Blacksmith Dolomite is 485 feet thick at High Creek (Maxey, 1958, p. 672). Hanson (1949, p. 17) measured 444 feet of thin- to thick-bedded medium-gray limestone, which is largely oolitic in the southern Malad Range. Axtell (1967) measured 350 feet of Blacksmith Formation near Two Mile Canyon.

The Blacksmith Formation crops out in a narrow band on the east side of the front ridge of the Malad Range just north of the Utah-Idaho border. It is in fault contact with the Tertiary Salt Lake Formation on the east and the Brigham Quartzite on the northwest. The base of the Blacksmith Formation is covered by alluvium. The contact between the Blacksmith and the Bloomington is drawn at the lowermost shale bed of the Bloomington. The Blacksmith Formation is a conspicuous stratigraphic marker. It forms sheer cliffs and weathers dark gray to black. The Blacksmith Formation is extensively faulted over its areal extent resulting in a change from a northwest dip near Trail Creek on the north to a southwest dip to the south where it dips under the Bloomington.
Formation. Irregular calcite veins and fault breccia are common in the formation.

The Blacksmith Formation consists of very massive, ledge-forming, fine-crystalline to lithographic, light-gray to dark-gray limestone. Sandy and silty limestone is present locally. Much of the limestone is composed of oolites and some pisoliths. The formation shows a remarkably uniform composition throughout. Near the top of the section the limestone is medium to thick-bedded and is silty suggesting a transitional contact. The Blacksmith here is estimated to be about 200 feet thick.

Fossils are rare in the Blacksmith Formation of the Malad Range, and the formation has yielded few fossils from any of its outcrops. It is dated Medial Cambrian because of its stratigraphic position between the Medial Cambrian Ute and Bloomington Formations. The only fossils found in the Blacksmith belong to the *Thompsonaspis* faunule of Denson (1942, p. 26) and the *Bathyuriscus-Elrathina* zone (Maxey, 1958, p. 672). These fossils indicate a Medial Cambrian age for the Blacksmith Formation.

**Bloomington Formation.** Walcott (1908a, p. 7) named the Bloomington Formation from an outcrop of limestone and shale at Bloomington Creek about 6 miles west of the town of Bloomington, Bear Lake County, Idaho. Richardson (1913, p. 406) defined a lower shale member and named the Hodges Shale after Hodges Creek, which enters Bear Lake 1½ miles south of Garden City, Utah. Mansfield (1927, p. 55) redescribed the formation in southeastern Idaho, recognized the basal Hodges Shale, and changed the type locality to Mill Creek near Liberty, Idaho. Williams and Maxey
(1941, p. 381) recognized two shale units, an upper, unnamed shale unit and a basal shale unit, the Hodges Shale of Richardson. Denson (1942, p. 24) named the upper shale unit the Calls Fort Shale. Maxey (1958, p. 672) recognized three units: 1. the Hodges Shale Member, 2. a middle unnamed thin-bedded limestone member, and 3. the upper Calls Fort Shale Member. He recorded a total thickness of 1,085 feet at Calls Fort. Hanson (1949, p. 20) measured only two members in the Bloomington: 1. a lower shale member 326 feet thick, and 2. an upper limestone unit 103 feet thick. Axtell (1967) recorded a total thickness of 431 feet of Bloomington in Two Mile Canyon.

In the west-central part of the Malad Range the Bloomington Formation is extensively exposed in the front ridge from the Utah-Idaho border north to Trail Creek. It is in fault contact with the Brigham Quartzite on the west along a northeast-trending fault south of Trail Creek and rests conformably on the Blacksmith Limestone on the east. The Bloomington Formation forms very gentle slopes and contrasts sharply with the overlying cliff-forming Nounan and the underlying ledge-forming Blacksmith.

A partial section of the Bloomington Formation was measured with the top missing because of erosion, and 329 feet of dark-gray, fine-crystalline to lithographic, thin-bedded silty limestone and light brown, olive, and red shale was measured. This unit is probably equivalent to the Hodges Shale. The upper part of this member has an increasing number of thin- to medium-bedded, light-gray limestone and limestone intraformational flat-pebble conglomerate beds. These beds are interlayered with silty and shaly medium-gray limestone which
weathers to thin plates. Much of the limestone in this lower member is oolitic. The lower member is overlain by 92.4 feet of very dark-gray medium- to thick-bedded, fine-crystalline, dense, silty limestone. The upper unit was measured near a fault separating the Bloomington from the Nounan and the thickness may not be accurate because of a change in dip in the Bloomington as the fault is approached. A total thickness for this partial section is 421.4 feet, which is close to the thicknesses measured by Axtell and Hanson.

Nowhere in the mapped area is the upper shale member (Williams and Maxey, 1941, p. 381; Denson, 1942, p. 24) present although the contact between the Nounan and Bloomington may be examined in several localities. The absence of this unit led Hanson (1949, p. 20-21) to suggest the "possibility of the existence of an unconformity between the Bloomington and Nounan formations." The author agrees that this is possible although the possibility of a thinning to the north and change in lithology certainly is not to be overlooked.

The Bloomington Formation has been dated as latest Medial Cambrian (Denson, 1942, p. 24). The author collected the brachiopods Obulus sp. and Lingulella sp. from the lower member, but trilobites are rare and unidentifiable fragments were all that could be collected.

Maxey (1958, p. 660) collected the following fossils from the Hodges Shale:

- Olenoides sp.
- Hyolithes sp.
- Westonia sp.
Lingulella sp.
Obulus sp.

He tentatively placed the Bloomington Formation in the Asaphiscus-Bolaspidella zone.

Nounan Formation. Walcott (1908a, p. 6-7) named the Nounan Formation for the town of Nounan in Bear Lake County, Idaho. He stated that the best exposures of Nounan occur in Blacksmith Fork Canyon, and he described this section (Walcott, 1908b, p. 193) measuring 1,041 feet. Deiss (1938, p. 1,122-1,123) redefined this section and measured 900 feet of Nounan, which was predominantly dolomite. Resser (1939, p. 9) described a section of Nounan measured by Walcott at Two Mile Canyon in the Malad Range as consisting of 1,088 feet of massive-bedded dirty- to bluish dolomite and thin-bedded bluish-gray limestone. Williams (1948, p. 1,130) measured 1,125 feet of Nounan at High Creek in the Wasatch Range. He described the Nounan as being thin- to medium-bedded dolomite with some beds of limestone with the upper third of the formation characterized by thin-bedded limestone with uneven bedding and shaly and silty partings. Axtell (1967) measured 932 feet of Nounan from Two Mile Canyon.

The Nounan is limited to the southwestern and extreme northeastern parts of the west-central Malad Range. The formation outcrops over a rather broad area but is highly complicated by faulting. The contact between the Bloomington and the Nounan is sharp and marked by an abrupt change from the slopes of the Bloomington to the steep cliffs typical of the lower Nounan. A broad band of Nounan is persistent along its strike to the south, and Hanson (1949, p. 24-25) measured and described
this outcrop. He described a lower dolomite member 908 feet thick and an upper limestone member which he estimated to be 500 feet thick although this upper member may be complicated by faulting.

Lithologically, the Nounan consists of thick- to massive-bedded medium-crystalline dolomite which is medium to dark gray in the lower part and light gray in the upper part. Locally arenaceous and silty dolomite is present, and many of the beds are speckled with both light-gray and dark-gray dolomite. Some of the dark layers have calcite veins which may be faint indicators of brachiopods. Higher in the section the Nounan Formation has thin-medium beds of dark-gray limestone which are silty and have silty partings. This unit resembles the limestone of the Bloomington Formation. The contact between the Nounan and the St. Charles Formation is sharp with the Worm Creek Quartzite of the St. Charles Formation marking the contact.

The age of the Nounan Formation is considered to be early Late Cambrian from an early Cedaria fauna collected by D. C. Duncan from the limestone beds of the upper unit of the Nounan (Williams and Maxey, 1941, p. 284). Hanson (1949, p. 27) collected the following fossils from the upper limestones in the south part of the Malad Range:

- Meteoraspis sp.
- Blountia sp.
- Blountia cf B. beltensis Duncan
- Coosella sp.

These fossils were collected from the same outcrop of Nounan that continues into the author's mapped area, and they indicate an early Late Cambrian age for the Nounan Formation.
St. Charles Formation. The St. Charles Formation was named from outcrops found to the west of the town of St. Charles, Bear Lake County, Idaho, by Walcott. Like many of the other formations in the Cambrian, the type section was taken from Blacksmith Fork Canyon in Utah (Walcott, 1908a, p. 6). Richardson (1913, p. 408) named a conspicuous quartzite found at the base of the St. Charles the Worm Creek Quartzite and measured 1,300 feet of St. Charles in the Randolph quadrangle. In 1938 Deiss (1938, p. 1,117) redefined the Blacksmith Fork section of Walcott and moved 777 feet of the St. Charles Formation into the Ordovician, leaving a total thickness of 400 feet. Williams, (1948, p. 1,135) pointed out that this thickness was probably in error since Deiss did not find the Worm Creek Quartzite. Williams (1948, p. 1,130) measured 1,015 feet of St. Charles from High Creek and characterized the formation as consisting of: 1. the basal Worm Creek Quartzite, which is a light brown, fine- to medium-grained, medium-bedded quartzite ranging from 6 feet at Calls Fort to 400 feet thick in the Randolph quadrangle, 2. a middle limestone, and 3. an upper, cliff-forming, thick, dark-gray dolomite. Hanson (1949, p. 31-32) described the same three members and measured: 1. 75 feet of Worm Creek Quartzite, 2. 368 feet of the middle limestone, and 3. 630 feet of the massive, cliff-forming dolomite.

The Worm Creek Quartzite member is found in only one small isolated outcrop in the west-central part of the Malad Range near the Utah-Idaho border. It consists of platy, thin- to medium-bedded, light-brown to pink colored, fine-grained orthoquartzite. Some thin-bedded limestone, intraformational conglomerate and silty dolomite were also found resting on the Worm Creek Quartzite. The base of the Worm Creek member was not exposed, and most of the middle limestone member was removed by erosion.
The upper dolomite member of the St. Charles Formation is exposed in Burnett Canyon 1½ miles east of the front ridge of the Malad Range. This outcrop is overlapped by Tertiary Salt Lake Formation, and erosion of the Salt Lake Formation has resulted in the exposure of the underlying St. Charles Formation. Here the latter is thin- to medium-bedded, fine-crystalline, medium- to dark-gray, sandy and silty dolomite. Pink chert nodules and veins are abundant in the lower part of the outcrop. Thin white quartzite boulders and cobbles are found on the top of this outcrop probably left by the erosion of the conglomerate of the Salt Lake Formation. Along the strike of this outcrop to the northwest, another small outcrop of St. Charles is exposed which consists of dark-gray, medium- to massive-bedded, saccharoidal dolomite with minor chert.

Fossils are abundant in the middle member of the St. Charles Formation but this member does not crop out in the west-central Malad Range, and no fossils were found in the dolomite member. However, Hanson (1949, p. 32-38) attempted to zone the middle, limestone member and suggests that it "is probably the age equivalent of the Elvinia, Ptychopleurites, Conaspis and Prosaukia-Ptychaspis zones of the standard section." It is probable that the upper dolomite is Late Cambrian since it is conformably overlain by the Garden City Limestone of Canadian age.

**Ordovician System**

**Garden City Limestone.** Richardson (1913, p. 408) named the Garden City Limestone for its occurrence in Garden City Canyon near the town of Garden City, Rich County, Utah. Richardson's type section consists of nearly 1,000 feet of thin-bedded, gray limestone and intraformational
conglomerate. Deiss (1938, p. 1,123-1,124) added 777 feet of Walcott's original St. Charles Formation to the Garden City Limestone in Blacksmith Fork. Ross (1953, p. 22-26) zoned the Garden City Formation on the basis of trilobites and divided the formation into two members:

1. The lower member is made up of two-thirds of the total thickness and includes a complex of interbedded, intraformational conglomerate, muddy limestone and crystalline- to cryptocrystalline limestone. 2. The upper member includes one-third of the total thickness and is limestone and dolomitic limestone with as much as 50 percent black chert which decreases upward in section. Some dolomite is found near the top of the formation in most localities. Hanson (1949, p. 41) defines four units in the Garden City Limestone: 1. a basal unit 900 feet thick of limestone and intraformational conglomerate, 2. a unit 583 feet thick of silty and argillaceous limestone, 3. a unit 170 feet thick of thin-interbedded limestone and chert, and 4. an upper unit of massive dolomite 156 feet thick.

The Garden City Limestone is widely exposed in the northern half of the mapped area. The outcrops form a series of steps from the western front of the range to the eastern boundary of the mapped area. These steps are caused by a series of nearly parallel north-northwest-trending faults. Near the front of the range the Garden City Limestone is exposed. Although the contact between the Garden City and the St. Charles is not exposed, one of the dolomite beds described in the south Malad Range by Hanson (1949, p. 41) as being near the base is present. Although extensively faulted, representative stratigraphy from both of Ross' two members is exposed with older rocks exposed in the west and younger rocks on the east.
Rocks from the lower member consist of thin- to medium-beded, blue-gray, light-gray, fine-crystalline- to lithographic limestone and limestone intraformational conglomerate with a limestone matrix.

Thin-beded silty and shaly limestone is also abundant. Fossils of crinoids, gastropods, brachiopods, and trilobites are abundant in this member.

Rocks typical of the upper member are found in the high rolling hills south of Dry Canyon Forest Camp (See Plate 1). They consist of thin- to thick-beded, light-gray to dark-gray, fine- to coarse-crystalline limestone and cherty limestone with minor intraformational conglomerate and silty limestone. In some outcrops chert veins and nodules make up 30-40 percent of the rock. These cherty outcrops cap many of the hills in the area and form ledges. Black chert is abundant in the lower part of this member. It is less abundant upward in section where the lithology changes to thin- to medium-beded, arenaceous, dark-gray, cherty dolomite which is coarsely crystalline and locally contains irregular calcite veins. The Garden City Limestone is extensively faulted. Brecciation, calcification, and drag folding are common near the faults in most outcrops. Fossils are common in the upper member and include the same fossils as previously mentioned plus some straight-shelled cephalopods. The contact between the Garden City Limestone and the overlying Swan Peak Quartzite is not exposed in the mapped area although the sandy and silty dolomite near the top of the section may indicate a transitional contact between the Garden City Limestone and the lower quartzite and shale members of the Swan Peak Quartzite.
The Garden City Limestone has been closely studied and zoned by Ross (1951, p. 27-32), who placed the boundary between the Canadian and Chazyan Series in the upper cherty member of the formation. Therefore, the Garden City is in part Canadian and in part Chazyan in age.

Swan Peak Quartzite. Swan Peak in the Randolph quadrangle is the type locality for the Swan Peak Quartzite named by Richardson (1913, p. 408). This particular section is incomplete (Ross, 1951, p. 11) with only 314 feet measured at the type locality. A more complete section of Swan Peak Quartzite is found in Green Canyon north of Logan, Utah, where Williams (1948, p. 1,136) measured 340 feet. The Swan Peak Quartzite was divided by Williams into three members: 1. a lower member of black shale with thin beds of bluish-brown sandy limestone, 2. a middle member of brown quartzite, shale and fucoidal quartzite, and 3. an upper orange-brown quartzite. These three units are also found at Wellsville Mountain (See Figure 1) by Beus (1958, p. 23), where he measured 427 feet. The upper two units are found in the central Blue Spring Hills (Beus, 1963, p. 18). Hanson (1949, p. 44-45) described two members of the Swan Peak Quartzite from the southern part of the Malad Range: 1. The lower member consists of 50 feet of black fissile shale with some thin-bedded, gray, coarse-crystalline, fossiliferous limestone. 2. The upper member is over 500 feet thick and is composed of thin-bedded sandstone and fucoidal quartzite in the lower part and thick- to massive-bedded vitreous quartzite in the upper part.

Only a partial section of Swan Peak Quartzite is exposed in the west-central Malad Range. This quartzite is equivalent to the upper
member of Williams' (1948, p. 1,136) Green Canyon section. It is evident, however, that the Swan Peak Quartzite was widespread over the area because of its presence in Tertiary conglomerates and Tertiary-Quaternary boulders to be discussed later. The lone outcrop of Swan Peak Quartzite is bounded on the east and west by faults and is overlapped by water-laid tuffs of the Salt Lake Formation. It is exposed at Henderson Creek east of the range front. The upper quartzite member is composed of medium- to massive-bedded, yellow, white, and red vitreous quartzite which weathers medium to dark gray and forms cliffs and ledges. A few beds of orange and red sandstone are present near the base of the partially exposed section which is estimated to be 200 feet thick. The lower shale unit is not exposed in the mapped area.

No fossils were found in the Swan Peak Quartzite, but Ross (1953, p. 22-25) assigned the formation to the Champlainian Series along with the upper part of the Garden City Limestone. The Swan Peak Quartzite ranges in thickness from northwest to southeast and disappears entirely in the southeastern part of the Bear River Range (Hansen, 1964, p. 5). The lithology also changes as the upper quartzite increases in thickness and amount of the formation to the northwest. These changes may indicate regressive deposition from northwest to southeast with a possible range in the age of the formation from northwest to southeast.

Silurian System

Laketown Dolomite. The Laketown Dolomite was named by Richardson (1913, p. 410) from Laketown Canyon, which is southeast of Laketown, Rich
County, Utah. Richardson described the Laketown Dolomite as consisting of over 1,000 feet of massive light-gray to white dolomite with lenses of calcareous sandstone. Williams (1948, p. 1130-1137) measured 1,510 feet of Laketown Dolomite from Green Canyon in the Logan quadrangle. He described the formation as consisting of: 1. a lower member of light-gray dolomite, 2. a middle member of dark-gray, thin- to massive-bedded, fine- to coarse-crystalline dolomite, and 3. an upper, light-gray, crystalline dolomite containing *Halysites* sp.

Hanson (1949, p. 49) estimated a thickness of 2,000 feet for the Laketown from the southern Malad Range. Beus (1963, p. 21) measured 1,540 feet of Fish Haven and Laketown from the central Blue Spring Hills west of the present area. Axtell (1967) measured a partial section of Laketown from south of Four Mile Canyon in the Malad Range and reported 700 feet of light-gray and dark-gray dolomites.

The Laketown Dolomite is exposed east of Cherry Creek in a low hill at the range front. It is in fault contact with the Garden City Limestone on the west and the base is not exposed. A small deposit of red conglomerate of the Wasatch Conglomerate overlies the Laketown unconformably in the southeastern part of the outcrop. The Laketown here corresponds with the upper member of Williams (1948, p. 1137) and is composed of white coarse-crystalline massive-bedded dolomite with large lenses of pink and white chert. Fault breccia is common. Overlying this cherty unit are massive-bedded, light- to medium-gray, fine-crystalline dolomite and calcareous dolomite with exceptionally well-preserved fossils consisting of *Halysites* and *Favosites*. The fact that the dolomite here is calcareous probably contributes to the excellent
state of preservation of the corals. Crinoid columnals are also common in this unit.

The age of the Laketown is considered by Budge (1966, p. 47-49) to range from upper Ordovician to middle Silurian in age. Budge was not able to assign any of the Laketown strata to an upper Silurian age which may be indicative of a hiatus between the Laketown and the Water Canyon Formations.

Cenozoic Rocks

Tertiary System

Wasatch Conglomerate. The term Wasatch was first used by Hayden (1869, p. 90-91) to designate strata underlying the Bridger Formation on the north flank of the Uinta Mountains. The type locality for the Wasatch Conglomerate is now considered to be in Echo and Weber Canyons, east of Ogden, Utah. Veatch (1907, p. 88) subdivided the Wasatch Group of southwest Wyoming into the following formations: 1. the Almy Formation of middle Paleocene (?) age, 2. the Fowkes Formation of upper Paleocene (?) age, and 3. the Knight Formation of lower Eocene (?) age. Tracy and Oriel (1959, p. 130) redefined the Wasatch and eliminated the Almy, Knight, and Fowkes formations as valid subdivisions for the Wasatch Group. They retained the name Wasatch and applied it to Eocene conglomerate, sandstone, and shale of Veatch's Wasatch Group and demoted it to formation status. They retained the Fowkes Formation but determined that it was younger than Veatch had supposed and was equivalent to the Bridger Formation of upper Eocene age.
The Wasatch Formation is mainly conglomerate, shale, and sandstone and is considered to be a continental deposit. Williams (1948, p. 1,144-1,145) separated a basal limestone from the Wasatch Formation in the Logan quadrangle. This basal algal limestone was named the Cowley Canyon unit by Williams. The author prefers to apply the term Wasatch Conglomerate to outcrops in the mapped area because the formation in the mapped area is composed entirely of conglomerate. Williams (1962, p. 133) assigned small outcrops of cobbles and pebbles in a red sandy matrix on the west side of Cache Valley to the Wasatch Formation.

The Wasatch Conglomerate is limited to three isolated outcrops near the northern boundary of the mapped area, and rests unconformably on the Garden City Limestone and the Laketown Dolomite. These outcrops consist of limestone, dolomite, and quartzite cobbles and pebbles in a red sandy matrix. The formation forms red slopes that are distinctive and easily recognized in the field. No fossils were found in the Wasatch Conglomerate; however, it was considered to be Eocene on the basis of gastropods collected by Williams (1948, p. 1,146-1,147), which include *Physa bridgerensis* Meek and *Planorbis* sp. indef.

**Salt Lake Formation.** The term Salt Lake was first introduced by Hayden (1869, p. 192) and applied to beds found in Weber Canyon, Utah. Peale (1879, p. 588, 640) extended the Salt Lake Group to include rocks of similar composition in valleys to the north and west. Hayden reported 1,000 to 1,200 feet of sand, sandstone, and marl to which he assigned a late Tertiary age. Williams (Smith, 1953, p. 73-76) described three formations for the Salt Lake Group in Cache Valley, Utah. Included in
this group were: 1. a lower conglomerate formation, 2. the West Spring
Formation, and 3. the Cache Valley Formation. Keller (1952, p. 73)
named an upper tuff and conglomerate member the Mink Creek Formation
for outcrops found in the vicinity northeast of Preston, Franklin
County, Idaho. Adamson et al. (1955, p. 1) described three formations
in the Salt Lake Group: 1. a lower conglomerate (the Collinston
Conglomerate of Williams), 2. a middle tuffaceous unit (the Cache
Valley Formation of Williams, which also incorporates a part of Keller's
Mink Creek Formation), and 3. an upper conglomerate (equivalent to the
upper part of Keller's Mink Creek Formation and called the Mink Creek
Conglomerate by Adamson). Adamson et al. (1955, p. 2) listed at least
1,500 feet for the Collinston Conglomerate. Eardley (1944, p. 845)
reported on a tuffaceous bed in Morgan Valley and identified and named
the Norwood Tuff, which was dated Oligocene on the basis of vertebrate
fossils. This unit had been considered by Mansfield (1927, p. 110) as
part of his Salt Lake Formation and equivalent to the Salt Lake beds
in Cache Valley. Williams (1962, p. 133-134) reassigned the Salt Lake
Group in Cache Valley to a formation status and listed three units:
1. a lower conglomerate consisting of boulders and cobbles in a white
matrix, 2. a middle tuff unit 1,200 feet thick consisting of soft
earthy-gray tuff with minor pebble conglomerate, and 3. an upper sand-
stone and pebble conglomerate unit.

In the west-central Malad Range the Salt Lake Formation terminology
of Williams (1962, p. 133-134) is used since correlation of the various
units is difficult. The Salt Lake Formation is widely exposed over much
of the mapped area, and it forms low hills and gentle slopes immediately
Figure 1. Bedded tuff and tuffaceous shale of the Salt Lake Formation. Photograph taken in the E½, sec. 12, T. 16 S., R. 36 E.

Figure 2. Massive tuffaceous sandstone of the Salt Lake Formation. Note the spheroidal weathering near the Brunton compass. Location same as above.

Plate 3. Salt Lake Formation
behind the front ridge. The formation was deposited in a lacustrine and fluviatile environment, and there is great lithologic range along the strike of beds. In the southern part of the present area Salt Lake Formation conglomerate forms very low hills with slopes covered with cobbles and boulders. This unit may be equivalent to Williams basal conglomerate and is weakly resistant to erosion. East and north of this area the Salt Lake Formation forms ledges and steep slopes. In the central part of the mapped area rocks of Salt Lake Formation are exposed in the front of the range and form cliffs and steep slopes. Here a partial section was measured consisting of 902 feet of pebble conglomerate, bedded tuff and tuffaceous limestone, petroliferous limestone, and tuffaceous sandstone. This section is apparently equivalent to the middle unit of Williams (1962, p. 134). No upper conglomerate was recognized by the author, but isolated conglomerate outcrops possibly belonging to this unit are exposed near the northeast corner of the present area.

An interesting feature of the Salt Lake Formation in the west-central Malad Range is the great amount of petroliferous limestone present in the formation. Petroliferous limestone forms most of the high hills south of Dry Canyon Forest Camp and is extensively exposed throughout the west-central Malad Range. It is possible that this limestone represents an offshore facies of the middle tuff unit or a facies equivalent to the upper conglomerate unit. The Salt Lake Formation is difficult to correlate and is complicated by faulting so that it is impossible to assign the limestone to any of the formations of the Salt Lake Group of Williams. Much of the limestone is secondarily
cemented with opal. Since this lithology is present near faults, it is possible that this siliceous cement is the result of deposition along faults by hot springs.

Another interesting facet of the Salt Lake Formation is its presence in some of the highest hills in the mapped area, which may be indicative of faulting, for hills at equal or lower elevations have no Salt Lake Formation on them. It also appears likely that the Salt Lake Formation was deposited along existing valleys in Paleozoic rock because it is found overlapping Paleozoic rocks that have been exposed by erosion and appear to continue along the strike in a general northwest-southeast trend.

Gastropod fossils were collected by the author from the tuffaceous limestone and petroliferous limestone of the Salt Lake Formation. Two species of the genus *Lymnaea* were identified, but preservation was not good enough to make a more precise identification possible. The Salt Lake Formation, in the mapped area, is considered to be correlative with the Salt Lake Formation in Cache Valley. There Brown (1949, p. 224-227) identified plants collected on the east side of Hyrum Bench, south of Logan, Utah, as late Pliocene in age. Yen (1947, p. 274-277) identified fresh-water mollusks collected by Williams from the south end of the Malad Range as probably late Pliocene. Adamson et al. (1955, p. 2) placed the basal conglomerate partly in the Miocene Epoch. Recent potassium-argon dates obtained by Williams, (1964, p. 273) indicate that the Salt Lake Formation may be as old as upper Eocene and as young as Pliocene.
Plate 4. Salt Lake Formation. View looking toward the east. The cliff is cut in massive limestone with interbedded tuff and sandstone. View taken half a mile north of Muddy Creek.
Tertiary and Quaternary Systems

Tertiary and Quaternary Boulders. Extensive deposits of boulders of considerable thickness are exposed in the northern part of the mapped area, where they rest on Paleozoic rocks and sediments of the Salt Lake Formation. These boulders should not be confused with boulders and cobbles elsewhere in the mapped area that obviously were eroded from conglomerates of the Salt Lake Formation. The most distinctive feature about the boulder fields is the size of the boulders involved, many reaching 20 to 30 feet in diameter. Most of these boulders consist of Swan Peak Quartzite although Garden City Limestone and Fish Haven Dolomite are also found. Ezell (1953, p. 22) described deposits of boulders in the Rendezvous Peak area that were composed of Precambrian and Cambrian quartzite presumed to be deposited on an old erosion surface. He considered these deposits to be pre-Salt Lake in age.

Inasmuch as the origin of these boulders is not known, dating them is a difficult task; however, evidence of Quaternary periglacial effects indicates that they likely are at least Quaternary in part. Such periglacial features include: 1. crude stone stripes extending down a long low hill 2 miles east of Cherry Creek (See Plate 5), 2. several crude polygonal structures, and 3. possible solifluction lobes (See Plate 10, Figure 2). It was not possible to determine whether these features still are active or whether they are related to a cooler Pleistocene climate; however, the author believes them to be of Pleistocene origin with downslope movement continuing to the present. This would also explain the presence of boulders that rest on the late Tertiary Salt Lake Formation.
Plate 5. Tertiary-Quaternary boulders. View looking west toward Malad Valley from a point 2 miles east of Cherry Creek. Note probable stone stripes and rough polygonal structures in middle of photo.
The author believes that either or both of two hypotheses may explain the origin of the boulders. The first theory is that the boulders, chiefly Swan Peak Quartzite, may be remnants of Swan Peak Quartzite that originally rested on the Garden City Limestone and were lowered to their present position through erosion of the intervening shale and sandstone beds. During periglacial times the resulting blocks were moved downslope to form the stone stripes and polygons. The second theory is that after uplift, probably during the Laramide orogeny, the Swan Peak Quartzite was extensively broken, exposed to erosion, and thereby formed a conglomerate or breccia along an erosion surface. Later erosion removed the matrix and left the more resistant boulders. It is the belief of the author that the larger boulders have not moved a great distance from their place of origin because of their large size. The larger blocks are located at approximately the same topographic level and would lend credence to either theory.

**Quaternary System**

**Lake Bonneville Group.** Pleistocene rocks exposed include sediments from Lake Bonneville. The Lake Bonneville Group consists of sand and gravel distributed along the front of the mountain range, especially in fans and deltas, and silt and clay that predominates in Malad Valley. According to Mower (Mower and Nace, 1957, p. 9), thickness of Lake Bonneville sediments exceeds 700 feet locally where water wells deeper than 700 feet do not penetrate to bedrock.
Quaternary Alluvium. Alluvium includes clay and marl eroded from the Salt Lake Formation and redeposited along stream courses, stream gravel and sand, and silt and clay which fill basins in the higher hills. Some colluvium is present in the form of talus near Paleozoic outcrops, but no attempt was made to map these small deposits.
Figure 1. Lake Bonneville delta deposits near the mouth of Trail Creek.

Figure 2. Lake Bonneville gravel. Note the lake terraces on the hill in the middle of the photo. This hill was an island in Lake Bonneville when the lake attained its highest level (Bonneville level). Picture taken 1 mile east of Cherry Creek looking south.

Plate 6. Lake Bonneville Group
STRUCTURAL GEOLOGY

General Statement

The west-central part of the Malad Range lies near the northeastern boundary of the Basin and Range province and the Middle Rocky Mountain province. Structures typical of Basin and Range faulting are the dominant features although the region undoubtedly was affected by the Laramide period of deformation as well. To the east of the present area is the Bannock thrust zone (Armstrong and Cressman, 1963, p. 5-18) where thrust faulting is extensive over an area from south of Bear Lake in northern Utah and southern Idaho to the vicinity of Idaho Falls, Idaho. Many separate thrust faults are mapped in this area as the Bannock thrust zone. To the south Eardley (1944) reported at least three major thrust faults from the Wasatch Range near Ogden, Utah, including the Taylor, Ogden, and Willard thrust faults. Murdock (1961) reported a thrust fault from the Weston Canyon area to the northeast of the present area. Folding is typical of areas to the south and east. Williams (1948) described an anticline and syncline (Logan Peak) from the Logan quadrangle. Beus (1963) reported anticlines and synclines from the Blue Spring Hills to the west of the present area. The formation of these Laramide structures probably resulted in uplift and deformation in the region.

The southern part of the mapped area is a northward continuation of the general structural features described by Hanson (1949, p. 68-73) and the dominant features are northwest-trending and northeast-trending faults.
The mapped area, to the north and southeast includes west-trending faults and northwest-trending and northeast-trending faults. The northern part of the mapped area consists mainly of Ordovician rocks which dip from 25° SW to 30° SE. Locally near faults the beds dip to the northeast. Strikes of these beds range from about N. 20° E. to N. 20° W. In general, the beds near the western front of the range dip to the southwest while those near the eastern boundary of the mapped area dip to the southeast. This variation in dip may represent a pre-Basin and Range structure such as a plunging anticline or dome formed by compressional forces of the Laramide orogeny.

In summary, structural features in the Malad Range consist of northwest-trending and northeast-trending faults and east-trending faults. Some strike-slip movement is noted on at least one northwest-trending fault.

**Faults**

**Northwest-trending Faults**

The western margin of the Malad Range is bounded by a fault which may be traced south of the Utah-Idaho border and was called the Plymouth Fault by Williams (1948, p. 1,151). This fault extends from the SE\(\frac{1}{4}\) sec. 25, T. 16 S., R. 36 E., to the NW\(\frac{1}{4}\) sec. 25, T. 15 S., R. 36 E., where it leaves the mapped area. This fault is interpreted by the author as being a marginal fault separating the Quaternary basin sediments on the west from the Paleozoic and Tertiary rocks of the Malad Range. Movement along this fault occurred prior to deposition of Lake Bonneville.
group, and basin rocks no doubt include Paleozoic and Tertiary rocks although Quaternary sediments exceed 700 feet locally. The fault trace is concealed over its total length, and no recent movement has been noted. This fault is no doubt a part of the Wasatch fault zone of northern Utah where recent movements have been noted (Eardley, 1939, p. 1,300). The trend of the fault is northwest near the Utah-Idaho border and northeast in the vicinity of Henderson Creek.

A major northwest-trending fault enters the mapped area from the southeast and was named the Clarkston fault by Hanson (1949, p. 71). In the south Malad Range it extends from the state line in the SW¼ sec. 29, T. 16 S., R. 37 E., to the NW¼ sec. 13, T. 16 S., R. 36 E., where it terminates against the marginal fault. The Salt Lake Formation has been downfaulted along the fault. These Cambrian rocks, consisting of the Ute, Blacksmith, Bloomington, and Nounan Formations, are in fault contact with shale and conglomerate of the Salt Lake Formation of Tertiary age. The Tertiary shale and conglomerate are less resistant than the Cambrian rocks, and a prominent scarp has formed along the trace of the fault. Near the Utah-Idaho border in sec. 29, T. 16 S., R. 37 E., the fault plane is intensely brecciated, and a small wedge of thin-bedded limestone of the Bloomington Formation has been intensely deformed with individual beds exhibiting dips as steep as 90°. This small wedge is in contact with the Nounan Formation on the west and the Salt Lake Formation on the east. Brecciation and formation of slickensides are common along the length of the fault although much of the fault plane has been eroded.

Another prominent northwest-trending fault is found to the east of and parallel to the above mentioned fault. Together these two faults
Figure 1. Northeast-trending fault half a mile south of Trail Creek, looking north, with the Bloomington Formation on the right in contact with the Brigham Quartzite on the left.

Figure 2. Northwest-trending fault just north of the Utah-Idaho border and 2 miles east of U. S. Highway 191. View taken looking south. The Nounan Formation on the right is in fault contact with the Bloomington Formation on the left. Note the long smooth Bloomington slope which contrasts sharply with the steeper Nounan slope.

Plate 7. Faults involving Cambrian rocks
form a graben consisting of conglomerate, tuffaceous shale, and limestone of the Salt Lake Formation. The fault on the east side of the graben extends from the SW¼ sec. 29, T. 16 S., R. 37 E., to the SW¼ sec. 35, T. 15 S., R. 36 E., where it terminates against the marginal fault. Late Cambrian rocks of the St. Charles Formation and early Ordovician rocks of the Garden City Limestone on the northeastern side of the fault have been overlapped by tuff and limestone of the Salt Lake Formation. These rocks are in contact with the Salt Lake Formation of the southwestern side of the fault. There is a distinct possibility that movement along this fault occurred during deposition of the upper part of the Salt Lake Formation because the fault trace is difficult to follow through the Salt Lake Formation and may be concealed. At Muddy Creek the trace of this fault is marked by numerous springs. In sec. 35, T. 15 S., R. 36 E., prominent ledges of limestone of the Salt Lake Formation exhibit noticeable change in dip as the fault plane is approached. Ledges on the southwestern side of the fault have a regional dip of 10°-15° SE. Along the fault plane the dip changes to 15° SW. Near the terminus of the fault limestones on the northeastern side of the fault have dips up to 45° into the fault plane, i.e., to the southwest. It is probable that these changes in dip represent folding and fracturing caused by movement along the fault and indicate relative downward movement of rocks on the southwest and upward movement of rocks on the northeast.

Extending from the NW¼ sec. 20, T. 16 S., R. 37 E., to the NW¼ sec. 25, T. 15 S., R. 36 E., is another northwest-trending fault. This fault involves Garden City Limestone and Salt Lake Formation on the
Figure 1. Northwest-trending fault half a mile north of Muddy Creek and 1 mile east of U. S. Highway 191. View taken looking north. Salt Lake Formation on the left is in contact with the Garden City Limestone on the right. Note how the beds of the Salt Lake Formation change from a regional easterly dip to a westerly dip near the fault.

Figure 2. Northeast-trending fault 1 mile north of Dry Canyon Forest Camp. Salt Lake Formation is in fault contact with the Garden City Limestone. View looking toward the northeast.

Plate 8. Faults involving the Garden City Limestone and the Salt Lake Formation.
northeast in fault contact with Salt Lake Formation on the southwest. This fault has a strong topographic expression over its length and separates the low front part of the range from the high rolling hills at the top of the range. Numerous springs mark the fault trace, and much of the drainage for the west part of the range either parallels or is perpendicular to the fault scarp. An interesting feature of this fault and several other faults which involve porous limestones of the Salt Lake Formation is a filling of the pore space with opal. This secondary cementing with siliceous material may be evidence for thermal activity along or near the faults since it is always noted near fault planes.

Another northwest-trending fault extends from the SE¼ sec. 31, T. 15 S., R. 37 E., to the NE¼ sec. 25, T. 15 S., R. 36 E. It is possible that this fault extends farther to the southeast, but the trace is lost under a cover of Tertiary rocks. On the northeastern side of this fault cherty dolomite of the Laketown Dolomite is in contact with limestone of the Garden City Limestone on the southwest. Tertiary conglomerate of the Wasatch Formation resting on the Paleozoic rocks is found on both sides of the fault. Stratigraphic throw along this fault is from 2,000 to 3,000 feet as rocks near the base of the Garden City Limestone are in contact with the upper part of the Laketown Dolomite. An interesting feature of this fault is the presence of horizontal slickensides along most of the fault plane. These slickensides are indicative of strike-slip movement. It is possible that all of the displacement along the fault was horizontal. Another possibility is that the fault trace was formed as a strike-slip fault and later had
vertical displacement. The fault plane may be traced into the Garden City Limestone to the south where little vertical displacement is noted, but this could be explained by differential vertical movement, i.e., greater displacement to the northwest and less to the southeast. If movement were all of a strike-slip nature, this would explain the apparent slight displacement where the fault is confined to the Garden City Limestone.

Other northwest-trending faults are noted in the mapped area. Most of these are a small displacement and are located from the Utah-Idaho border to Burnett Canyon. Here Cambrian rocks have been extensively faulted. Many of these faults involve the Bloomington and Nounan Formations. Most have a limited areal extent and are terminated against the major northwest-trending faults.

Northeast-trending Faults

Several small northeast-trending faults are mapped in secs. 24 and 25, T. 16 S., R. 36 E. and secs. 19 and 20, T. 16 S., R. 37 E. Most of these faults trend about N 15°-20° E. and are small in displacement and short in length. One exception, however, is a fault of rather large displacement. This fault extends from the SE1/4 sec. 25, T. 16 S., R. 36 E. to the SW1/4 sec. 19, T. 16 S., R. 37 E., where it changes its trend to northwest and terminates in the NE1/4 sec. 24, T. 16 S., R. 36 E. The fault plane is nearly vertical, and the Brigham Quartzite of early and Medial Cambrian age is in contact with the Bloomington Formation and the Ute Formation of Medial Cambrian age. Stratigraphic throw is estimated at 1,500 to 2,000 feet.
Figure 1. Northwest-trending fault from a point northeast of Cherry Creek, looking north. Wasatch Conglomerate and Garden City Limestone on left are in fault contact with the Laketown Dolomite on the right. This fault has horizontal slickensides. The Tertiary Wasatch Conglomerate rests unconformably on the Ordovician Garden City Limestone.

Figure 2. Northeast-trending fault south of Burnett Canyon. The Langston Formation on the north is in contact with the Brigham Quartzite on the south. View taken looking east.

Plate 9. Faults in Paleozoic rocks
North-trending Faults

Several faults with northward trends are found in the northeastern part of the area. These faults are either within the Garden City Limestone or the Salt Lake Formation or involve the Garden City Limestone in contact with the Salt Lake Formation. Almost all of these faults have a small stratigraphic displacement although displacements within the Garden City Limestone may be measured in thousands of feet. Some of these faults show intense brecciation and silicification as well as some slight deformation of beds near the fault planes.

West-trending Faults

No faults with a west trend were noted in the mapped area. Axtell (1967) reported west-trending faults from the northern part of the Malad Range and Beus (1963, p. 118) reported a major west-trending fault from the Blue Spring Hills. The trace of this fault may cross Malad Valley, but the author was unable to find any evidence that it continues into the Malad Range. It is possible that the fault terminates before it reaches the Malad Range or that its trace is concealed under a Tertiary and Quaternary cover.

Age of Structures

In general, structures in the west-central Malad Range can be assigned to three categories: 1. Laramide structures, 2. Post-Laramide but pre- and during deposition of Salt Lake Formation structures, and 3. structures formed after the deposition of the Salt Lake Formation.
Figure 1. North-trending fault scarp in Salt Lake Formation, 1.5 miles south of Dry Canyon Forest Camp, at the head of Trail Creek. View taken looking east. The scarp is formed in weakly resistant tuff and tuffaceous limestone.

Figure 2. Tertiary-Quaternary boulders, 1.5 miles north of Dry Canyon Forest Camp, looking south. Probable solifluction lobes in foreground may be indicative of a periglacial climate, probably in the late Pleistocene.

Plate 10. Recent fault scarp and Tertiary-Quaternary boulders
Structures typical of the Laramide orogeny include all the faults which trend a few degrees north of east, faults within the wedge of Cambrian rocks from the Utah-Idaho border to Muddy Creek, the northwest-trending fault with strike-slip movement and a possible pre-Basin and Range faulting anticline in the northern half of the mapped area. It is generally believed that the Laramide orogeny involved compression with the principal stress axis oriented in an east-west direction. The age of this compression is from early Cretaceous to Eocene. The structures mentioned above are compatible with horizontal forces and do not involve Tertiary rocks.

It is believed by the author that most of the major northwest-trending faults formed prior to the deposition of the Salt Lake Formation and that movement continued throughout the deposition period. These faults belong to the second category and are typical of Basin and Range structures which resulted in the formation of horsts and graben. Valleys and ridges were formed by these faults which controlled the deposition of the Salt Lake Formation.

Structures belonging to the third category probably include the marginal fault and north-trending faults within the Salt Lake Formation. Possible recent movement is evidenced by a scarp in weakly resistant Salt Lake tuff along one of two north-trending faults at the head of Burnett Canyon and Trail Creek. Although these north-trending faults also involve Ordovician rocks, it is believed by the author that they are post-Salt Lake Formation in age.

In summary, northwest-trending faults within Cambrian rocks, east-trending faults, the strike-slip fault, and a possible anticline in
Ordovician rocks are assigned to the first category. Major northwest faults are assigned to the second category, and the marginal fault and north-trending faults are assigned to the third category.
Figure 2. Structural cross section, northern part of west-central Malad Range, Idaho
SURFICIAL GEOLOGY

Geomorphology

Much of the west-central Malad Range is composed of rocks of Tertiary age which are weakly resistant to erosion. As a result, the Tertiary rocks have been extensively dissected with the formation of deep canyons. Fault scarps and fault-line scarps are prominent where the Tertiary rocks are in fault contact with more resistant Paleozoic rocks. A smooth rolling topography is typical of hills eroded in the Garden City Limestone in the eastern part of the mapped area. No extensive erosional surfaces were noted by the author although the deeply dissected Tertiary rocks may have had an erosional surface prior to the recent downcutting.

Features of Lake Bonneville are well developed, and both the Provo and Bonneville shorelines extend from the Utah-Idaho border to the northern boundary of the area. Deltas are present at the mouths of most streams, and an especially well-preserved delta is found at the mouth of Muddy Creek. Much of the deltaic material consists of mud, marl, and gravel which has been reworked from the Salt Lake Formation. Channel filling and cross-bedding features are common. One prominent hill composed of Tertiary rocks north of Henderson Creek stood as an island (See Plate 6, Figure 2) when Lake Bonneville was at its highest level. Deposits of sand and gravel are common and have been utilized as road material.
Periglacial features are of special interest in the mapped area. The Tertiary and Quaternary boulders in the northern part of the area show definite evidence of stone stripes, and rough polygonal features are found on slopes which are less than 10°. One polygonal structure was more than 20 feet across. According to Thornbury (1954, p. 88), stone structures are believed to be caused by repeated freezing and thawing. This is typical of a periglacial climate which probably was in effect at this elevation during glacial periods of the Pleistocene. The author believes these boulders to be at least in part Quaternary because of the periglacial features. No glacial features were observed in the west-central Malad Range, but glaciers were present during the Pleistocene in the Bear River Range and on Wellsville Mountain south of the mapped area (Beus, 1958, p. 65).

**Surface and Ground Water**

There is not an abundance of surface water in the west-central Malad Range. Most of the area is less than 7,000 feet in elevation and does not receive a heavy snow pack. Runoff is in the form of both ground water and surface water. Springs feed the few perennial streams. Trail Creek, Burnett Creek, Muddy Creek, and Henderson Creek are the major streams draining the western part of the area. All are intermittent over most of their length. Muddy Creek has a considerable amount of flow in its lower reaches where it is fed by numerous springs with a total mid-summer flow of about 1 second-foot. The other streams are spring fed near their headwaters, but in mid-summer the springs have a
low flow, and much of the water infiltrates or evaporates. Springs are either contact springs or emerge along faults.

Malad Valley is an artesian basin with valley-fill sediments providing both the aquifers and confining beds. Recharge is fed into the aquifers through fan and deltaic sediments where streams enter the valley. Mower and Nace (1957, p. 29) reported approximately 300 flowing wells in Malad Valley.
GEOLOGIC HISTORY

Precambrian Era

No rocks of Precambrian age are found in the Malad Range. Murdock (1961) and Ludlum (1943) report exposures of Precambrian rocks to the northeast and north of the Malad Range respectively. Thick deposits of clastic Precambrian rocks are found east of Ogden and in Big Cottonwood Canyon southeast of Salt Lake City, Utah, in the Wasatch Range (Cohenour, 1959, p. 34-39). For the most part Precambrian rocks record a long history of clastic sedimentation with a probable continental environment of deposition. Volcanic rocks are reported southeast of the Pocatello, Idaho, area by Ludlum (1943), and glaciation is recorded by the presence of tillites in the Bannock Range to the east of the mapped area (Murdock, 1961, p. 10-11).

Paleozoic Era

Rocks of known Early Cambrian age are missing from southeastern Idaho and northeastern Utah although the Brigham Quartzite is at least in part early Cambrian as evidenced by Olenellus collected by Oriel (1964, p. 61) from the Brigham Quartzite in the Bannock Range. The Brigham Quartzite is interpreted as being a littoral deposit with ripple marks and cross-bedding. The upper part of the Brigham Quartzite records a deepening of the seas to the west (Lochman-Balk, 1959, p. 45)
as limestone and calcareous sandstone were deposited. This sea, which was near the eastern margin of the Cordilleran geosycline, was persistent throughout the Cambrian and early Ordovician time with minor oscillations of sea level recorded by arenaceous carbonate and quartzite found in rocks of late Cambrian age. The Cambrian and early Ordovician seas were shallow and marine life was abundant.

During middle Ordovician time the seas retreated from the area as indicated by the Swan Peak Quartzite which is a regressive deposit (Hanson, 1949, p. 84) which thickens to the north. The sea returned to the area in late Ordovician time (Hanson, 1949, p. 84), and the carbonate of the Fish Haven Dolomite was deposited. Early and middle Silurian times were marked by continuous deposition of the marine carbonate rocks of the Laketown Dolomite (Budge, 1966). The seas probably retreated at the end of the Silurian time as no known upper Silurian rocks are found in the northern Utah or southeastern Idaho area (Budge, 1966).

Early Devonian time was marked by the return of a very restricted sea which formed in a linear belt from Alberta, Canada, through Montana, Idaho, Wyoming, Utah, and Nevada (Sandberg, 1961, p. 1,309). It was in this trough that the Water Canyon, Beartooth Butte, and Sevy Formations were deposited. These formations record an abundance of fish in early Devonian time. After retreat of early Devonian seas, the area was once again covered by the sea, and the Jefferson Formation was deposited. The clastic nature of the Beirdneau Sandstone (Hanson, 1949, p. 84) is indicative of a positive source area. Rigby (1959, p. 60-62) postulated that there was uplift at this time to the south and southwest of the mapped area which provided a source for the clastic rocks in the upper
Devonian rocks of Utah.

Mississippian deposition took place in a linear belt or trough extending from western Montana to southern Nevada. Uplift probably was concurrent with the trough formation (Eardley, 1949, p. 665) and abundant detrital material was deposited along with marine carbonates. The formation of marine basins and local uplift persisted throughout the Pennsylvanian and Permian periods with formation of the Oquirrh Basin and the Phosphoria Sea (Beus, 1963, p. 131-134) in which thick sections of marine carbonate and clastic rocks were deposited.

**Mesozoic Era**

There are no known Mesozoic rocks exposed in the Malad Range. It has been postulated by other workers in the area that Mesozoic rocks were present but were removed by erosion prior to Cenozoic deposition. Among those who hold to this theory was Beus (1963, p. 132) who worked on the geology of Blue Spring Hills across Malad Valley to the west of the mapped area. Inasmuch as no Mesozoic rocks exist in the mapped area and no evidence of Mesozoic rocks is found in Tertiary sediments, the author assumes that rocks of Mesozoic age were probably not deposited or were limited in extent in the area of the west-central Malad Range.

In general, rocks of Mesozoic age were deposited to the east and north of the mapped area (Hanson, 1949, p. 86). It is possible that the Malad Range and vicinity were a positive area throughout most of the Mesozoic and might well have provided some sediments for Mesozoic deposits to the east, southeast, and north.
The late Cretaceous period and the early Tertiary period are characterized by strong crustal deformation which has been termed the Laramide orogeny. East-west compression resulting in crustal shortening was the dominant force involved. The Laramide forces resulted in the formation of thrust faults located to the south, east, and west of the mapped area (Eardley, 1944). Extensively folding resulted in the formation of anticlines and synclines throughout the region and may have formed an anticline in the northern part of the mapped area. Shear faulting and north-south faults involving severe deformation of Paleozoic rocks are assigned to the Laramide orogeny.

Cenozoic Era

After regional uplift produced by the Laramide orogeny, extensive erosion resulted in the formation of wide-spread gravel throughout the area. This gravel makes up the Wasatch Formation, which is considered to be Eocene in age (Williams, 1948, p. 1,146-1,147). Much of this formation has been removed by subsequent erosion.

During the Miocene epoch the region was broken by Basin and Range faulting with the resultant formation of horsts and graben typical of the Malad Range. Most of the marginal faults probably formed at this time, with movement continuing through the Cenozoic to the present.

In Pliocene time extensive beds of Salt Lake Formation were deposited over the mapped area. These beds were formed in both a lacustrine and fluviatile environment. Thick deposits of water-laid tuff and limestone are indicative of probable intermontane lakes. Conglomerate and grit are no doubt fluviatile in origin. The presence
of volcanic ash and lava flows (Prammani, 1957, p. 37) in the Salt Lake Formation of the Malad Range are evidence of extensive vulcanism in the area.

In late Tertiary and Quaternary times Basin and Range faulting continued with displacement of the Salt Lake Formation next to Paleozoic rocks. Quartzite boulders which had probably been extensively broken and jointed during earlier faulting formed stone structures during the Pleistocene with downslope migration continuing to the present.

During the Pleistocene Epoch, changes in climate resulted in the formation of Lake Bonneville, which occupied Malad Valley on the west and drained through Red Rock Pass north of Preston, Idaho to the north-east (Williams, 1962, p. 143-145) at its highest level. Streams draining into the lake formed deltas, and wave action cut prominent benches at both Provo and Bonneville levels.

The climate again changed near the close of the Pleistocene, and Lake Bonneville retreated with only a small remnant, Great Salt Lake, remaining. Erosion is continuing at the present time. Downcutting of canyons and old stream deltas is especially noticeable. Pedimentation is proceeding in the area but has not resulted in the formation of large pediments. Some recent fault scarps probably attest to continuing activity in the Wasatch fault zone.
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APPENDIX
Measured Sections

**Brigham Quartzite**

Section No. 1, Trail Creek, a tributary of the Malad River, Idaho. Section of Brigham Quartzite measured on a south-facing slope on the north side of Trail Creek approximately 1 mile east of U. S. Highway 191 and 1.5 miles north of the Utah-Idaho border, NW¼, SW¼, sec. 19, T. 16 S., R. 37 E., and NE¼, NE¼, sec. 25, T. 16 S., R. 36 E. Section begins at creek bottom where Trail Creek enters the canyon from the east.

**Alluvium**

<table>
<thead>
<tr>
<th>Thickness (feet)</th>
</tr>
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<tbody>
<tr>
<td>9. Quartzite and shale, interbedded. Quartzite, red-brown, fine-grained, thick- to massive-bedded, weathers dark brown to black. Shale, sandy micaceous, olive-green, platy. Unit forms steep, blocky ledges, and top of unit grades into dark-brown, fine-grained sandstone which marks top of section 188.1</td>
</tr>
<tr>
<td>8. Shale, olive-green, thin laminae. Unit forms slopes and contains fucoidal markings 17.0</td>
</tr>
<tr>
<td>7. Quartzite and shale, interbedded. Quartzite, medium-gray, pink, white, medium-grained to conglomeratic, thick- to massive-bedded, weathers reddish brown. Shale same as Unit 8. Unit forms steep ledges and cliffs 174.2</td>
</tr>
<tr>
<td>6. Quartzite and shale, interbedded. Quartzite, gray to white, medium to coarse-grained, beds 1 to 3 ft. thick, weathers dark brown. Shale, micaceous, green. Unit forms slopes 212.2</td>
</tr>
<tr>
<td>5. Quartzite and shale, interbedded. Quartzite, pink to white, coarse-grained, sugary, thin at base to massive at top of unit, weathers yellowish brown, cross-bedded. Shale, sandy, olive-brown. Unit forms ledges 145.4</td>
</tr>
<tr>
<td>4. Shale, micaceous, olive-green, thin laminae. Unit forms slopes 73.1</td>
</tr>
<tr>
<td>3. Quartzite and shale, interbedded. Quartzite, medium-gray, fine-grained matrix, recrystallized quartz fragments, thin- to medium-bedded, weathers reddish brown. Shale, argillaceous, dark-brown to gray. Unit forms cliffs 171.5</td>
</tr>
</tbody>
</table>
2. Shale, argillaceous, medium-gray, thin laminae. Unit forms slopes

1. Conglomerate, quartzitic, pink to white, quartz pebbles 0.25 to 0.50 in. in diameter in quartzite matrix, thick-bedded, weathers reddish brown. Unit is jointed and forms blocky ledges and cliffs

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<tr>
<td>102.0</td>
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<td>37.7</td>
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<td>1,121.2</td>
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Base not exposed
Bloomington Formation

Section No. 2, Trail Creek, a tributary of the Malad River, Idaho. Partial section of Bloomington Formation measured on east-facing slope of hill 0.5 mi. south of Trail Creek and 1.5 miles east of U. S. Highway 191, SW¼, NE¼, sec. 30, T. 16 S., R. 37 E. Section measured from contact of Blacksmith Formation up slope to top of hill.

Bloomington Formation

3. Limestone, silty, dark-gray, fine-crystalline, dense, medium- to thick-bedded. Unit forms ledges and is complicated by faulting, dip changes upslope as fault trace is approached 178.6

2. Limestone and conglomerate. Limestone, silty, medium-gray, fine-crystalline to sublithographic, thin- to medium-bedded, weathers light gray. Conglomerate, intraformational, light- to medium-gray, medium-bedded with flat limestone pebbles in limestone matrix. Unit forms ledges and covered slopes 92.4

1. Shale and limestone. Shale, calcareous, tan and red, thin-bedded. Limestone, silty, dark-gray, thin-bedded. Unit forms slopes. Obulus and Lingulella 61 ft. above base 149.4

Total 421.4

Blacksmith Formation
Salt Lake Formation

Section No. 3, Muddy Creek, a tributary of the Malad River, Idaho. Section of Salt Lake Formation measured on south-facing cliff approximately half a mile north of Muddy Creek and 1 mi. east of Idaho secondary highway. No. 36, E½, sec. 12, T. 16 S., R. 36 E. Section measured from creek bottom to top of hill.

<table>
<thead>
<tr>
<th>Salt Lake Formation</th>
<th>Thickness (feet)</th>
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</thead>
<tbody>
<tr>
<td>5. Limestone, petroliferous, brown, aphanitic to fine-crystalline, weathers light gray to white. Unit becomes tuffaceous at top of hill. Unit forms cliffs in lower part and slopes in upper part. Gastropods of the genus <em>Lymnaea</em> 61 ft. above base of unit</td>
<td>351.4</td>
</tr>
<tr>
<td>4. Sandstone and shale, interbedded. Sandstone, calcareous and tuffaceous, gray with brown and orange iron staining, medium- to coarse-grained, angular to subrounded. Shale, tuffaceous, white, beds 1 to 3 in. thick. Unit forms ledges and steep slopes</td>
<td>222.2</td>
</tr>
<tr>
<td>3. Limestone and shale, interbedded. Limestone, petroliferous, brown, fine-crystalline, medium- to massive-bedded, weathers dark brown and medium gray. Shale, sandy and tuffaceous, light-gray and white, thin beds. Unit forms steep slopes</td>
<td>124.5</td>
</tr>
<tr>
<td>2. Limestone and shale, interbedded. Limestone, tuffaceous and siliceous, white and yellowish-brown, aphanitic to crystalline, thin- to medium-bedded, weathers light gray. Shale, calcareous, light-gray. Unit forms gentle slopes</td>
<td>126.2</td>
</tr>
<tr>
<td>1. Conglomerate, pebble and sandstone, interbedded. Conglomerate, dark-gray limestone, pink and white quartzite, and chert pebbles. Sandstone, white to light-gray, coarse-grained matrix, thin- to medium-bedded. Sandstone, tuffaceous, white, yellow, orange, and brown, fine- to coarse-grained. Unit forms steep slopes</td>
<td>78.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>902.4</strong></td>
</tr>
</tbody>
</table>

Base not exposed