Structural Geology of the Northern Part of Clarkston Mountain, Malad Range, Utah-Idaho

Steven Mark Burton
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STRUCTURAL GEOLOGY OF THE NORTHERN PART OF
CLARKSTON MOUNTAIN, MALAD RANGE,
UTAH-IDaho

by

Steven Mark Burton

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

Approved:

________________________
Major Professor

________________________
Committee Member

________________________
Committee Member

________________________
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1973
ACKNOWLEDGMENTS

The writer wishes to express appreciation to Dr. Clyde T. Hardy who directed him in a reconnaissance of the area. Hardy also presented helpful suggestions for the preparation of the manuscript. Dr. Donald R. Olsen and Dr. Raymond L. Kerns, Jr., reviewed the manuscript and made suggestions for its improvement. Wayland E. Gray assisted in part of the field work.

The writer wishes to thank his wife, Sherrie W. Burton, for her patience and understanding during both the field work and the writing of the manuscript.

Steven Mark Burton
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ABSTRACT

Structural Geology of the Northern Part of Clarkston Mountain, Malad Range, Utah-Idaho

by

Steven Mark Burton, Master of Science

Utah State University, 1973

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

The northern part of Clarkston Mountain, in northern Utah and southern Idaho, is located about 23 miles northwest of Logan, Utah. It extends across the Malad Range from Malad Valley on the west to Cache Valley on the east. The mapped area measures 4.8 miles in the north-south direction and 6.8 miles in the east-west direction.

The Brigham Formation of Cambrian age is the oldest exposed stratigraphic unit. It consists mainly of quartzite. Younger Cambrian units include the Langston, Ute, Blacksmith, Bloomington, Nounan, and St. Charles Formations. The Garden City Formation of Ordovician age is the youngest Paleozoic unit. The Salt Lake Formation of Tertiary age occupies the northeastern part of the area. It overlies Paleozoic units unconformably. The Lake Bonneville Group of Quaternary age is present both east and west of Clarkston Mountain.

Both thrust faults and normal faults are present in the mapped area. A bedding-plane thrust fault separates the Bloomington Formation from the overlying Nounan Formation. Two north-trending low-angle
thrust faults involve Paleozoic rocks in the eastern part of the area. Eight north-trending low-angle normal faults cut the Paleozoic rocks of northern Clarkston Mountain and dip about 40° W. These formed as thrust faults; however, they are classified as normal faults because of reversed movement. Three north-trending high-angle normal faults also cut the Paleozoic rocks. A marginal normal fault, along which the area of Malad Valley has dropped relative to Clarkston Mountain, extends along the western side of the mountain. A marginal normal fault also extends along the southeastern side of Clarkston Mountain and continues northwestward over the Malad Range. The Salt Lake Formation, north of this fault, is down next to the Paleozoic rocks of Clarkston Mountain.

The thrust faulting with eastward movement is related to the Laramide orogeny, which occurred during the Cretaceous Period and the early part of the Tertiary Period. The bedding-plane thrust fault formed first. North-trending low-angle thrust faults formed later. Normal faulting, related to Basin and Range faulting, began early in the Tertiary Period and continues at the present time. Marginal normal faulting resulted in the great height of Clarkston Mountain relative to the major valleys on the west and on the east.
INTRODUCTION

Purpose and Scope

The purpose of this investigation is to contribute to the understanding of the structural geology of northern Utah and southern Idaho. A detailed geologic map was constructed in order to represent the structural features (Plate 1). Finally, a sequence of structural events was established and related to that of the region.

Location and Accessibility

The mapped area is on the border of Utah and Idaho and is about 23 miles northwest of Logan, Utah (Figure 1). It is in the southern part of the Malad Range. The area measures 4.8 miles in the north-south direction and 6.8 miles in the east-west direction. The southern boundary is 3.4 miles south of the Utah-Idaho State Line; the northern boundary is 1.4 miles north of the Utah-Idaho State Line. The community of Portage, Utah, is situated about 1.4 miles west of the mapped area. The area extends from lat. 41°57'15" N. to lat. 42°01'15" N. and from long. 112°05'00" W. to long. 112°12'30" W.

The western side of the northern part of Clarkston Mountain is readily accessible from Highway U.S. 191. This highway extends north-south along the mountain. Highway Utah 142 extends north-south along the eastern side of Clarkston Mountain and provides access to that area. An unimproved road leads into the north-central part of the area from the eastern side.
Figure 1. Index map of part of Utah and Idaho showing location of the northern part of Clarkston Mountain.
Field Work

Field investigations were conducted during the summer and fall of 1972. Stratigraphic contacts and faults were plotted in the field on vertical aerial photographs at a scale of 1:15,840. This information was then transferred to a base map at a scale of 1:12,000. The base was taken from parts of four topographic quadrangle maps of the Geological Survey of the U.S. Department of Interior. These maps, at a scale of 1:24,000, are Clarkston and Portage, Utah-Idaho, and Henderson Creek and Weston Canyon, Idaho-Utah.

Previous Investigations

The northern part of Clarkston Mountain, in Utah, was represented on a small-scale geologic map by Hanson (1949). Hanson was concerned mainly with stratigraphy. Prammani (1957) included the northeastern corner of the mapped area in his study of the east-central part of the Malad Range, Idaho. Wach (1967) constructed a generalized geologic map that included the northwestern corner of the mapped area in Idaho. Ross (1951) studied the Garden City Formation of Clarkston Mountain south of the mapped area.

Several studies of nearby areas are of particular importance in understanding the geology of the northern part of Clarkston Mountain. Williams (1948) recognized all of the Paleozoic formations of Clarkston Mountain in the Logan Quadrangle, Utah-Idaho. Beus (1968) studied the central Blue Spring Hills located west of the mapped area. Axtell (1967) mapped part of the Malad Range southeast of Malad, Idaho, and made significant observations pertaining to the stratigraphy. Murdock
(1961) investigated the Weston Canyon area northwest of Weston, Idaho, and Raymond (1971) mapped the Oxford Peak area in the southern part of the Bannock Range northwest of Preston, Idaho.
STRATIGRAPHIC UNITS

General Statement

The northern part of Clarkston Mountain consists mainly of Paleozoic rocks (Table 1). The Brigham Formation of Cambrian age is the oldest unit in the mapped area. The Garden City Formation of Ordovician age is the youngest Paleozoic unit. The Swan Peak Formation of Ordovician age and undifferentiated Fish Haven and Laketown Formations of Ordovician-Silurian age are present, in Clarkston Mountain, south of the mapped area (Hanson, 1949, pp. 43-49). Devonian rocks crop out, in the Malad Range, north of the area (Axtell, 1967, p. 30). Mississippian and Pennsylvanian formations are present in the area immediately south of Clarkston Mountain (Hanson, 1949, pp. 52-57).

The Salt Lake Formation of Tertiary age rests unconformably on Paleozoic rocks in the northeastern part of the mapped area. Quaternary deposits include the Lake Bonneville Group, colluvial deposits, and alluvial deposits.

Cambrian System

Brigham Formation

Williams (1948, p. 1132) recognized the Brigham Formation in the Logan Quadrangle, Utah-Idaho. There, the Brigham is gray, pink, and brown quartzite. A unit of interbedded shale and quartzite is present near the top. Crittenden, Schaeffer, Trimble, and Woodward (1971, pp. 592-593) reported 4,200 feet of Brigham in Geersten Canyon, 5 miles
Table 1. Stratigraphic units of Paleozoic age, northern part of Clarkston Mountain and vicinity.

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<th>Unit</th>
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<td>Garden City Formation</td>
<td>Cherty limestone</td>
<td>1,760&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>Intraformational conglomeratic</td>
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<tr>
<td></td>
<td>limestone</td>
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<td></td>
<td></td>
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<td><strong>Cambrian System</strong></td>
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<tr>
<td>St. Charles Formation</td>
<td>Light-gray and medium-gray dolomite</td>
<td>1,073&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Upper member</td>
<td>Silty limestone</td>
<td>630</td>
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<td></td>
<td>Quartzite</td>
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<td>75</td>
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<td>Worm Creek Member</td>
<td>Limestone</td>
<td>1,408&lt;sup&gt;b&lt;/sup&gt;</td>
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<td></td>
<td>Light-gray and dark-gray dolomite</td>
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<td>908</td>
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<td>Nounan Formation</td>
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<td></td>
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<td>Medium-gray limestone, largely oolitic</td>
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<td>Langston Formation</td>
<td>Dolomite</td>
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<td></td>
<td>Limestone</td>
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<td></td>
<td>Limestone and siltstone</td>
<td></td>
</tr>
<tr>
<td>Brigham Formation</td>
<td>Quartzite</td>
<td>4,200&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
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<sup>a</sup>Clarkston Mountain (Ross, 1951).
<sup>b</sup>Clarkston Mountain (Hanson, 1949).
<sup>c</sup>High Creek (Maxey, 1958).
<sup>d</sup>Huntsville, Utah (Crittenden et al., 1971).
north of Huntsville, Utah. The lower member, 1,200 feet thick, consists of arkose and white quartzite. The upper member, 3,000 feet thick, is predominantly quartzite. This quartzite is mostly white with local beds of pale-red and pale-purple quartzite. The Brigham is Early Cambrian in age. Oriel (1965, p. 341) found Olenellus sp. in quartzite 170 feet below the base of the overlying Langston Formation in the Portneuf Range of southeastern Idaho.

The Brigham Formation, in the mapped area, is quartzite and interbedded shale. The quartzite is pink, dark gray, white, greenish brown, and purple. The shale is olive brown. The quartzite weathers yellow brown, which is probably due to the weathering of hematite to limonite. Flakes of muscovite are common in the shale. Fucoidal structures are present throughout the outcrop in both quartzite and shale. The Brigham is at least 1,121 feet thick, in the mapped area, but the base is not exposed (Wach, 1967, pp. 9-12).

The Brigham Formation occurs in a fault block near the northwestern corner of the mapped area. It is especially well exposed along Trail Creek where it forms massive ledges. The lower and upper contacts of the Brigham do not crop out within the mapped area.

Langston Formation

Williams (1948, pp. 1132-1133) recognized the Langston Formation in the Logan Quadrangle, Utah-Idaho, east of the mapped area. Maxey (1958, pp. 654-655) described three members of the Langston at High Creek, north of Richmond, Utah, as follows: (1) lower Naomi Peak Limestone, (2) Spence Shale, and (3) limestone and dolomite member. There, the
Langston is 484 feet thick. The Langston is Middle Cambrian in age (Maxey, 1958, p. 671).

The Langston Formation, in the mapped area, is represented only by the upper part of the lower member and the lower part of the middle member. The Naomi Peak Limestone Member consists of thick-bedded fine-crystalline gray arenaceous limestone and the Spence Shale Member consists of fissile dark-gray shale (Wach, 1967, pp. 12-14). Trilobites are common in the Spence Shale.

The Langston Formation occurs near the northwestern corner of the mapped area. It is in fault contact with the Brigham Formation. Outcrops of the Langston are generally poor.

Ute Formation

Williams (1948, p. 1133) recognized the Ute Formation in the Logan Quadrangle, Utah-Idaho. Maxey (1958, pp. 653-654) described the Ute at High Creek, north of Richmond, Utah. There it consists of interbedded thin-bedded medium-gray limestone and dusky-yellow shale. The basal few feet is interbedded sandstone and limestone. At High Creek the Ute is 745 feet thick. The Ute is Middle Cambrian in age (Maxey, 1958, p. 672).

The Ute Formation, in the mapped area, is medium-gray limestone. Silty partings are common in the lower part of the exposed section; however, they decrease upward. Beds of oolitic limestone are common throughout. The Ute weathers light brown and forms gentle slopes. The Ute is at least 439 feet thick, in the mapped area, but the base is not exposed (Hanson, 1949, pp. 14-15).
Outcrops of the Ute Formation is not exposed in the mapped area. The upper contact was placed at the base of the lowermost ledge-forming gray limestone of the Blacksmith Formation. The contact with the Blacksmith seems to be conformable.

**Blacksmith Formation**

Williams (1948, p. 1133) recognized the Blacksmith Formation in the Logan Quadrangle, Utah-Idaho. Maxey (1958, p. 653) described the Blacksmith at High Creek, north of Richmond, Utah. There, it consists of three members as follows: (1) lower variegated medium-gray and dark-gray dolomite, 345 feet thick, (2) dark-bluish-gray limestone, 60 feet thick, and (3) upper thick-bedded light-gray dolomite, 80 feet thick. At High Creek the Blacksmith is 484 feet thick. Axtell (1967, p. 57) measured 350 feet of Blacksmith near Two Mile Canyon, south of Malad City, Idaho. The Blacksmith is Middle Cambrian in age (Maxey, 1958, p. 672).

The Blacksmith Formation, in the mapped area, is thin-bedded to thick-bedded medium-gray limestone that is largely oolitic. It forms high cliffs that weather dark gray to black and contain many solution cavities. The Blacksmith is 444 feet thick in the mapped area (Hanson, 1949, p. 17).

The Blacksmith occurs, in the mapped area, in three fault blocks on the western side of the mountain. The best exposures are on the northwestern side of Gardner Canyon.

The lower contact of the Blacksmith, with the Ute Formation, was mapped at the base of the lowermost ledge-forming gray limestone of the Blacksmith. The upper contact, with the Bloomington Formation, was
placed at the base of the lowermost shale bed of the Bloomington. Both contacts are gradational and are evidently conformable.

**Bloomington Formation**

Williams (1948, pp. 1133-1134) recognized the Bloomington Formation in the Logan Quadrangle, Utah-Idaho. Maxey (1958, p. 660) studied the Bloomington at High Creek, north of Richmond, Utah. He reported three members as follows: (1) lower Hodges Shale, 595 feet thick, (2) thin-bedded limestone, 720 feet thick, and (3) upper Calls Fort Shale, 180 feet thick. The Hodges Shale consists of gray limestone and green shale. The middle member is medium-gray and light-gray limestone. The Calls Fort Shale consists of gray limestone and olive-brown shale. At High Creek, the Bloomington is 1,495 feet thick. Axtell (1967, p. 16) measured 431 feet of Bloomington at Two Mile Canyon, south of Malad City, Idaho. The Bloomington is Late Cambrian in age (Maxey, 1958, p. 673).

The Bloomington Formation, in the mapped area, consists of the Hodges Shale Member and part of the middle limestone member (Hanson, 1949, pp. 19-21). The Hodges Shale, 326 feet thick, consists of olive-green shale. The middle member, 103 feet thick, consists of thin-bedded medium-gray limestone. The middle member is truncated at the top by a major bedding-plane thrust fault. The Bloomington forms gentle slopes. It is 429 feet thick in the mapped area.

The Bloomington Formation crops out, in the mapped area, on both sides of the mountain. The largest outcrop extends from Gardner Canyon northward to Trail Creek. A parallel outcrop, to the east, extends northward from Gardner Canyon for 1 1/4 miles. An outcrop of Bloomington, on the eastern side of the mountain, extends from Cold Water
Canyon northward to North Canyon.

The lower contact was placed at the base of the first shale bed above the ledge-forming Blacksmith Formation. The upper contact of the Bloomington, with the Nounan Formation, is well defined. This relationship may be due either to erosion at an unconformity (Hanson, 1949, p. 21) or thrust faulting (Raymond, 1971, p. 18). Because of the marked northward reduction in thickness of the Bloomington, in the mapped area, it is concluded that a bedding-plane thrust fault separates the Bloomington and Nounan Formations.

**Nounan Formation**

Williams (1948, p. 1134) recognized the Nounan Formation in the Logan Quadrangle, Utah-Idaho. Maxey (1941, p. 13) described the Nounan at High Creek, north of Richmond, Utah. There, the lower two-thirds consists of thin-bedded light-gray dolomite and the upper third consists of light-gray dolomite with interbedded dark-gray limestone. The Nounan is 1,125 feet thick at High Creek. It is Late Cambrian in age (Williams, 1948, p. 1134).

The Nounan Formation, in the mapped area, consists of a lower dolomite member and an upper limestone member (Hanson, 1949, pp. 24-25). The lower member, 908 feet thick, consists of medium-crystalline light-gray dolomite. The upper member is dark-gray limestone. Many beds are oolitic. Silty partings are common. The estimated thickness of the upper member is 500 feet. The total thickness of the Nounan is 1,405 feet.

The Nounan crops out, in places, throughout the mapped area. The most extensive exposures are on the western side of the mountain. The
formation is particularly well exposed in upper Water Hollow; however, all outcrops have been complicated by faulting.

The Nounan Formation rests on the Bloomington Formation; however, a bedding-plane thrust fault is present between these units. The upper contact is placed at the base of the lowermost quartzite of the Worm Creek Member of the St. Charles Formation.

**St. Charles Formation**

Williams (1948, pp. 1134-1135) recognized the St. Charles Formation in the Logan Quadrangle, Utah-Idaho. Maxey (1941, pp. 13-14) reported three members at High Creek, north of Richmond, Utah, as follows: (1) lower Worm Creek Member, (2) limestone member, and (3) upper dolomite member. There, the St. Charles is 1,015 feet thick. The St. Charles Formation is Late Cambrian in age (Williams, 1948, pp. 1134-1135).

The St. Charles Formation, in the mapped area, displays the three members described above (Hanson, 1949, pp. 31-38). The Worm Creek Member, 75 feet thick, consists of light-brown quartzite. It is an excellent stratigraphic marker. The middle member, 368 feet thick, consists of thin-bedded to medium-bedded silty limestone that is fossiliferous. The silt content diminishes upward in the section. The upper member, 630 feet thick, is medium-to-course-crystalline light-gray and dark-gray dolomite. Chert is common in many beds of the upper member. This member forms cliffs similar to the Nounan Formation but they weather darker. The St. Charles is 1,073 feet thick.

The St. Charles Formation is exposed mostly in the southern quarter of the mapped area. Outcrops are faulted; however, a complete section is present in upper Gardner Canyon.
The lower contact of the St. Charles Formation is mapped at the base of the lowermost quartzite of the Worm Creek Member above the Nounan Formation. The upper contact of the St. Charles is placed at the base of the lowermost limestone of the overlying Garden City Formation.

**Ordovician System**

**Garden City Formation**

Williams (1948, pp. 1135-1136) recognized the Garden City Formation in the Logan Quadrangle, Utah-Idaho. Ross (1951, p. 7) divided the Garden City into two members as follows: (1) lower limestone characterized by intraformational conglomerate and numerous silty partings, and (2) upper cherty limestone. The Garden City is 1,405 feet thick in Green Canyon, northeast of Logan, Utah (Ross, 1951, pp. 21-22). It is Early and Middle Ordovician in age (Ross, 1951, p. 31).

The Garden City Formation is represented, in the mapped area, by only part of the lower member. It displays the intraformational conglomerate and silty partings as noted in the previous paragraph. The Garden City on the western side of Clarkston Mountain, south of the mapped area, is 1,764 feet thick (Ross, 1951, p. 19).

The Garden City is generally restricted to the southern part of the mapped area. The largest outcrop is on the western side of the mountain near the southern boundary of the mapped area. The lower contact of the Garden City is placed at the base of the lowermost limestone above the dolomite of the St. Charles Formation.
Salt Lake Formation

The Salt Lake Formation of the Cache Valley area, Utah-Idaho, was described by Adamson, Hardy, and Williams (1955, pp. 108) as the Salt Lake Group. They recognized three formations as follows: (1) lower Collinston Conglomerate, (2) Cache Valley, and (3) upper Mink Creek Conglomerate. The Collinston Conglomerate lies unconformably on the Wasatch Formation of Tertiary age at the northern end of Wellsville Mountain, east of Collinston, Utah. The Cache Valley Formation consists of tuff, tuffaceous sandstone, tuffaceous oolitic limestone, petroliferous limestone, and pebble conglomerate. The Collinston Conglomerate and the Cache Valley Formation are laterally gradational. The Mink Creek Conglomerate overlies the Cache Valley Formation along the northeastern side of Cache Valley. The Mink Creek also overlaps the Paleozoic rocks of the western flank of the Bear River Range. The Salt Lake Formation of Cache Valley ranges in age from late Eocene (Williams, 1964, p. 273) to middle or late Pliocene (Yen, 1947, p. 268).

The Salt Lake Formation, in the mapped area, consists of conglomerate, tuff, tuffaceous limestone, petroliferous limestone, and tuffaceous sandstone. The conglomerate consists of pebbles and cobbles of quartzite, limestone, dolomite, and chert.

The most extensive outcrop of the Salt Lake Formation is in the northeastern part of the mapped area. South of Steel Canyon, the Salt Lake Formation is faulted down against Paleozoic rocks along the eastern marginal normal fault. In places, south of this fault, it rests unconformably on Paleozoic rocks.
Igneous rocks are present in the Salt Lake Formation in the northeastern part of the mapped area. Flows and intrusions crop out north and south of the mouth of Steel Canyon and north of the lower part of Jenkins Hollow. The igneous rocks are within tuffaceous rock of the Salt Lake Formation. Alteration zones are common near the outcrops of igneous rocks.

**Quaternary System**

**Lake Bonneville Group**

The Lake Bonneville Group was recognized in Cache Valley by Williams (1962, pp. 137-142). He described two units as follows: (1) lower undifferentiated Alpine and Bonneville Formations, and (2) upper Provo Formation. The Alpine is gravel, sand, silt, and clay; the Bonneville is mostly gravel. The Provo consists of gravel, sand, silt, and Clay. The Lake Bonneville Group is Quaternary in age (Williams, 1962, p. 135).

The Lake Bonneville Group, in the mapped area, was not divided into formations. On the eastern side of Clarkston Mountain, the highest shoreline is indistinct; however, east of the mapped area, it is evident in the Salt Lake Formation. The highest shoreline is also present on the western side of Clarkston Mountain. This shoreline is at an elevation of about 5,180 on both sides of the mountain. The Lake Bonneville Group consists mainly of well-sorted silt, sand, gravel, and boulders. The silt and sand were derived from the Salt Lake Formation.
Colluvial deposits

Colluvial deposits consist of fine-grained unconsolidated material and boulder accumulations. They are Quaternary in age.

The fine-grained deposits are mostly on the eastern side of Clarkston Mountain. They mantle slopes between the canyons. The boulder deposits are mostly high on mountain ridges. Two notable boulder deposits are near the northern end of Clarkston Mountain. The boulders consist mostly of light-brown and white quartzite. They are as large as 6 feet across.

Alluvial deposits

Alluvial deposits consist of material deposited along streams and as alluvial fans. Alluvial deposits are Quaternary in age.

A relatively large deposit, accumulated along a stream, is present in the lower part of Steel Canyon in the northeastern part of the mapped area. Notable alluvial fans exist at the mouth of Sam Stuart Canyon, on the eastern side of Clarkston Mountain, and at the mouth of Gardner Canyon, on the western side of the mountain.
STRUCTURAL FEATURES

Regional Setting

The northern part of Clarkston Mountain, in northern Utah and southern Idaho, is 23 miles northwest of Logan, Utah. The mapped area extends across the Malad Range from Malad Valley, on the west, to Cache Valley, on the east. It is within the Basin and Range Province. The relief is controlled by north-trending normal faults that are typical of the Basin and Range Province.

The Bannock thrust zone, located 42 miles east of the mapped area, extends north-south along the eastern side of the Bear River Range (Armstrong and Cressman, 1963, Plate 4). The Paris thrust fault, on the eastern flank of the Bear River Range, dips west and places the Cambrian Brigham Formation on the Triassic Thaynes Formation. The stratigraphic throw is about 20,000 feet and the displacement is probably many miles. A major north-trending syncline is present in the Bear River Range (Williams, 1948, Plate 1). Deformation, in the Bear River Range began in late Jurassic or early Cretaceous time (Armstrong and Cressman, 1963, pp. 8-14).

The Willard thrust fault, in the Wasatch Mountains south of the mapped area, extends from near Ogden, Utah, northward to Willard, Utah (Eardley, 1944, pp. 847-851). It places Precambrian rocks over Paleozoic rocks. The direction of movement was eastward.
Folds

Minor folds

Minor folds occur in the Blacksmith and Bloomington Formations. They are well displayed on the western side of Clarkston Mountain. Folds up to 100 feet across are present, in the Blacksmith, in Gardner Canyon. Small tight folds, usually only a few feet across, also occur in the Blacksmith at a locality situated about 1.5 miles north of Gardner Canyon. Small folds, a few feet across, are present in the Bloomington Formation in Water Hollow. Most of these are near a bedding-plane thrust fault that separates the Bloomington from the overlying Nounan Formation. The minor folds, throughout the mapped area, formed during the time of thrust faulting.

Anticline

A broad anticline, in the Salt Lake Formation, extends northwestward from Sheep Dip Hollow to the northern boundary of the mapped area. Beds on the western limb dip 20°-25° SW. Beds on the eastern limb dip 20°-25° NE. This anticline may have been caused by differential vertical movements associated with Basin and Range normal faulting of Tertiary age.

Thrust Faults

General statement

Thrust faults, in the northern part of Clarkston Mountain, include one bedding-plane thrust fault and two low-angle thrust faults. The low-angle thrust faults trend north to northwest.
Fault surfaces of north-trending low-angle normal faults formed as west-dipping low-angle thrust faults. These are described, in a later section, as normal faults.

**Bedding-plane thrust fault**

An east-dipping bedding-plane thrust fault is mapped between the Bloomington Formation and the Nounan Formation wherever these formations are in regular stratigraphic succession. The surface, between the Bloomington and the Nounan is abrupt and breccia is common along it. Small folds are present in the Bloomington and are more common upward near the Nounan. The thickness of the Bloomington is less, by about 800 feet, than is normal for the region. Thus, it seems evident that a bedding-plane thrust fault must separate Bloomington and Nounan.

**Low-angle thrust faults**

Two low-angle thrust faults are present, in the mapped area, on the eastern side of Clarkston Mountain. One of these is within the Nounan Formation. Another one thrusts Bloomington Formation over upper Nounan Formation.

The thrust fault, within the Nounan, extends from the southern boundary of the mapped area northward to Cold Water Canyon. It is well exposed on the northern side of Sam Stuart Canyon (Figure 2 and 3). There, it strikes N. 30° W. and dips 20° W. Lower Nounan, above the fault, dips 32°-35° E. and upper Nounan, beneath the fault, is nearly vertical (Figure 4). Estimated displacement is about 500 feet and the direction of movement is eastward.
Figure 2. Low-angle thrust fault on northern side of Sam Stuart Canyon; view north. Lower Nounan Formation is thrust over upper Nounan. Arrow indicates fault plane on breccia.

Figure 3. Slickensided surface on thrust fault, illustrated in Figure 2, on northern side of Sam Stuart Canyon; view north. Surface, on top of breccia, dips 20° W.
Figure 4. Vertical Nounan Formation beneath thrust fault, illustrated in Figure 2, on northern side of Sam Stuart Canyon; view north.
The other low-angle thrust fault extends from the southern side of Cold Water Canyon northward to a point located 0.2 mile south of the Utah-Idaho State Line. This fault strikes N. 30° W. and dips 30° W. Between the southern side of Cold Water Canyon and Old Quigley Canyon, it places Bloomington over Nounan (Figure 5 and 6). Northward, it places lower Nounan over upper Nounan. It terminates northward at the eastern marginal normal fault. Estimated displacement is in excess of 1,000 feet and the direction of movement is eastward. Southward from Cold Water Canyon, this fault becomes a normal fault due to reversed movement as described later.

**Structural interpretations**

The bedding-plane thrust fault is offset by the western low-angle thrust fault (Plate 1, structure section). It is concluded that the bedding-plane thrust fault formed earlier than the low-angle thrust faults.

**Normal Faults**

**General statement**

Normal faults, in the northern part of Clarkston Mountain, are present both within and marginal to the mountain. The normal faults mostly trend northward; however, the eastern marginal normal fault extends northwestward over the Malad Range.

**North-trending low-angle normal faults**

North-trending low-angle normal faults are common in the mapped area. There are six such faults on the eastern side of the mountain and two on the western side. These faults dip less than 45° W., except locally.

Three west-dipping low-angle normal faults, on the eastern side of the mountain, extend from the southern boundary of the mapped area northward to Cold Water Canyon. They are immediately west of a low-angle
Figure 5. Low-angle thrust fault on northern side of Old Quigley Canyon; view north. Bloomington Formation, in covered slope at upper left, is thrust over Nounan Formation. Fault, at top of prominent breccia, dips 30° W.

Figure 6. Breccia along low-angle thrust fault, illustrated in Figure 5, 0.5 mile southwest of Thompson spring; view north. Bloomington Formation, in covered slope at upper left, is thrust over Nounan Formation. Fault dips west.
thrust fault, within the Nounan Formation, that extends along the base of the mountain. These faults strike N. 15° W. and dip 40° W. The Worm Creek Member of the St. Charles Formation is down on the western side of each of these faults opposite the Nounan Formation on the eastern side. Displacement is less than 400 feet on each fault.

The west-dipping low-angle normal fault, located immediately west of the group of normal faults described in the previous paragraph, extends from the southern boundary of the mapped area northward to Cold Water Canyon. It continues northward as the major thrust fault previously described. Between the southern boundary of the mapped area and Cold Water Canyon, it is within the St. Charles Formation. Upper St. Charles Formation, on the west, is down opposite the lower part of the upper member of the St. Charles Formation, on the east.

A west-dipping low-angle normal fault, on the eastern side of the mountain, extends northward from the southern boundary of the mapped area to the Utah-Idaho State Line. It is located about 0.3 mile west of the major low-angle thrust fault, previously described, and parallels the latter. It strikes N. 20° W. and dips 38°-42° W. This fault is within the St. Charles Formation from the southern boundary of the mapped area northward to the western fork of Cold Water Canyon. Between Cold Water Canyon and North Canyon, upper Nounan Formation is down, on the west, opposite Bloomington Formation, on the east. This relationship is well exposed in Old Quigley Canyon (Figure 7 and 8). Northward from North Canyon, upper Nounan Formation, on the west, is down opposite lower Nounan, on the east. The fault terminates at the eastern marginal normal fault. Displacement is at least 800 feet.
Figure 7. Low-angle normal fault on northern side of Old Quigley Canyon; view north. Nounan Formation, on left, is down next to Bloomington Formation, on right. Fault dips 38° W.

Figure 8. Breccia along low-angle normal fault, illustrated in Figure 7, on southern side of Old Quigley Canyon; view north. Fault dips 38° W.
Another west-dipping north-trending low-angle normal fault extends northward from the southern boundary of the mapped area for about 1.2 miles. It is located 0.1-0.3 mile west of the major low-angle normal fault described in the preceding paragraph. The strike is N. 5° W. and the dip is 40° W.

This fault is well exposed in the upper part of Sam Stuart Canyon where the Garden City Formation, on the west, is down opposite the St. Charles Formation, on the east (Figure 9). The displacement is 200-300 feet.

The Gunsight fault, on the western side of the mountain, was recognized by Hanson (1949, pp. 72-73). It is well exposed at a point 1.0 mile south of the southern boundary of the mapped area (Figure 10). This fault extends northward from the southern boundary of the mapped area, through Precipitous Canyon, and over the main divide of Clarkston Mountain into the upper part of Old Quigley Canyon. It strikes about N. 10° W. and dips 36°-41° W. A zone of brecciation is present on each side of the fault. In Precipitous Canyon, the St. Charles and Garden City Formations, on the west, are down opposite the Nounan and St. Charles Formations, on the east. Northward, the St. Charles and Garden City, on the west, are down opposite the St. Charles, on the east. The displacement seems to diminish northward and the fault disappears under cover of Salt Lake Formation and colluvial deposits in the upper part of Old Quigley Canyon.

A west-dipping north-trending low-angle normal fault, on the western side of Clarkston Mountain, is located near the base of the mountain. It extends from the first canyon south of Gardner Canyon northward to the Utah-Idaho State Line. This fault strikes generally N. 20° W. and dips 40°-48° W. In Gardner Canyon, the St. Charles Formation is down, on the west, opposite the Ute, Blacksmith, and Bloomington Formations, on the east (Figure 11). Northward for about
Figure 9. Low-angle normal fault, near ridge top, in upper Sam Stuart Canyon; view north. Garden City Formation, in slope at upper left, is down next to St. Charles Formation, on lower right. Fault, indicated by pick, dips 40° W.
Figure 10. Gunsight fault, 1.0 mile north of Gunsight Peak; view south. Nounan Formation, on left, is down next to Garden City Formation, on right. Fault, indicated by pick, dips west.
Figure 11. Low-angle normal fault on northern side of Gardner Canyon; view north. St. Charles Formation, on left, is down next to Blacksmith Formation, on right. Fault dips west.
2.5 miles, the Nounan and St. Charles Formations are down, on the west, opposite the Blacksmith Formation, on the east. Between a northeast-trending normal fault and the Utah-Idaho State Line, Nounan and St. Charles Formations, on the west, are down opposite the Bloomington Formation, on the east. The Nounan and St. Charles Formations, on the western side of the fault are extremely brecciated. Displacement is 3,000-3,500 feet. This fault is evidently offset westward into Malad Valley by an east-northeast-trending normal fault that is located in the first canyon south of Gardner Canyon. Northward, it is covered by the Lake Bonneville Group of Malad Valley.

Northwest-trending normal faults

Seven short northwest-trending normal faults are located in the southeastern part of the mapped area. Five of these faults are closely associated and are aligned along a trend that extends from the southern boundary of the mapped area northwestward to Cold Water Canyon. The five faults, toward the southeast, have St. Charles Formation, on the southwest, down opposite Nounan Formation, on the northeast. One of these is clearly exposed on the northern side of New Quigley Canyon (Figure 12). It dips 52°-60° S. The fault in Cold Water Canyon is aligned with the five faults described previously; however, it has St. Charles Formation, on the southwest, down against Bloomington Formation, on the northeast. The northwestern fault displays about the same strike as the others but it is located about 0.2 mile to the northeast. It has St. Charles, on the southwest, down opposite Nounan, on the northeast. Displacements on these faults are less than 1,000 feet.
Figure 12. Northwest-trending normal fault on southern side of New Quigley Canyon; view west. St. Charles Formation, on left, is down next to Nounan Formation, on right. Fault, indicated by pick on top of breccia, dips 52° S.
East-northeast-trending normal faults

Two east-northeast-trending normal faults are present, on the western side of the mountain, between the southern boundary of the mapped area and Gardner Canyon. These faults are approximately aligned and were continuous before offset by an intersecting north-trending high-angle normal fault. They strike about N. 60° E. The dip is unknown but may be as low as 50° S.

The western east-northeast-trending normal fault is located in the first canyon south of Gardner Canyon. The St. Charles and Garden City Formations, on the south, are down opposite the St. Charles and Nounan Formations, on the north. The St. Charles, on the north, rests on a west-dipping north-trending normal fault beneath which the Ute, Blacksmith, and Bloomington Formations are present. The latter formations crop out in Gardner Canyon. The east-northeast-trending normal fault offsets the west-dipping north-trending normal fault westward into Milad Valley on the southern side. West-dipping shears in the St. Charles Formation, south of the east-northeast-trending normal fault, suggest that the north-trending normal fault is immediately west of the mountain front (Figure 13).

The eastern east-northeast-trending normal fault places Garden City Formation, on the south, down opposite Nounan and St. Charles Formations, on the north. It terminates eastward, in the upper part of Precipitous Canyon, at the Gunsight fault.

Northeast-trending normal faults

Five northeast-trending normal faults are present in the northwestern part of the mapped area. Two additional normal faults, which
Figure 13. East-northeast-trending normal fault in St. Charles Formation, in first canyon south of Gardner Canyon; view southeast. Fault, in canyon bottom, extends from upper left to lower right. West-dipping shear, at upper right, is not present in foreground.
trend approximately east-west, are grouped with the northeast-trending normal faults.

A northeast-trending normal fault is present, in the northwestern part of the mapped area, near the northern boundary. It is vertical and strikes N. 70° E. The Langston Formation is down, on the north, next to the Brigham Formation, on the south. The displacement is 300-400 feet.

Another northeast-trending fault is present, in the northwestern part of the mapped area, near the northern boundary. It is vertical and strikes N. 30° E. and dips 75° S. The Bloomington Formation is down, on the southeast, next to the Brigham Formation, on the northwest. This fault extends from the western marginal normal fault northeastward to the eastern marginal normal fault. Displacement is 1,500-2,000 feet.

A northeast-trending normal fault is present, in the northwestern part of the mapped area, north of Water Hollow and west of Sheep Dip Mountain. It is nearly vertical and strikes N. 40° E. The Bloomington Formation, on the north, is down next to the Blacksmith Formation, on the south. This fault seems to have offset the west-dipping north-trending normal fault that extends along the mountain front. Northward, it terminates at the eastern marginal normal fault; southward, it probably terminates at the western marginal normal fault. Displacement is 400-500 feet.

Two northeast-trending normal faults are present, in the north-central part of the mapped area, south of Sheep Dip Mountain. One is 0.3 mile southwest of Sheep Dip Mountain. It is vertical and strikes N. 65° E. The Worm Creek Member of the St. Charles Formation is down,
Figure 14. Northeast-trending normal fault in first canyon south of Trail Canyon; view north. Brigham Formation, on left, is down next to Bloomington Formation, on right. Fault, in valley bottom, extends from upper left to lower right.
on the north, opposite Nounan Formation, on the south. This fault terminates southwestward and northeastward at north-trending high-angle normal faults. Displacement is 50-100 feet. The other is 1.1 miles south of Sheep Dip Mountain. It is vertical and strikes N. 65° E. also.

The Nounan Formation is down, on the north, next to St. Charles Formation, on the south. This fault terminates southwestward and northeastward at north-trending high-angle normal faults. Displacement is 50-100 feet.

An east-trending normal fault, grouped with the northeast-trending normal faults, is on the ridge east of upper Gardner Canyon on the western side of the mountain. It is vertical and strikes N. 80° W.

The Nounan, St. Charles, and Garden City Formations are down, on the south, next to the Nounan and St. Charles Formations, on the north. This fault offsets the Gunsight fault. It terminates westward at a major north-trending high-angle normal fault. The displacement is about 400 feet.

An east-trending normal fault, also grouped with the northeast-trending normal faults, is present, near the northeastern corner of the mapped area, in Jenkins Hollow. It is vertical and strikes N. 80° E.

The upper member of the St. Charles Formation is down, on the north, next to the Worm Creek Member of the St. Charles Formation, on the south. This fault terminates, both westward and eastward, at north-trending high-angle normal faults. The displacement is 800-900 feet.

North-trending high-angle normal faults

Six north-trending high-angle normal faults, exclusive of marginal normal faults, are present in Clarkston Mountain. Three others are
located in the northeastern part of the mapped area.

A north-trending high-angle normal fault is located, near the mouth of Trail Canyon, in the northwestern part of the mapped area (Figure 15). It is vertical and strikes N. 3° W. The Brigham and Langston Formations are down, on the west, next to the Brigham Formation, on the east. This fault terminates northward and southward at northeast-trending normal faults. The displacement is 300-400 feet.

Another north-trending high-angle normal fault is located about 0.4 mile east of the one described in the preceding paragraph. This fault is vertical. It strikes N. 10° W., in the southern part, and N. 5° E., in the northern part. The Bloomington and Nounan Formations are down, on the west, next to the Bloomington Formation, on the east. This fault terminates southward at the major north-trending low-angle normal fault that extends along the mountain front. Northward, it terminates at a north-trending high-angle normal fault. The bedding-plane thrust fault that separates the Bloomington and Nounan is offset by this fault. Displacement is only 200-300 feet.

A north-trending high-angle normal fault, on the western side of the mountain, extends from the first canyon north of Gardner Canyon northward to the northern boundary of the mapped area. It strikes N. 10° W. for 2.0 miles northward from the southern end. The northern part strikes N. 30° W. It dips 75°-80° W. At its southern end, this fault is intersected by the major west-dipping low-angle normal fault that extends along the base of the mountain. Northward from the southern end for a mile, the Bloomington Formation is down, on the west, opposite the Ute and Blacksmith Formations, on the east. For
Figure 15. North-trending normal fault in first canyon south of Trail Canyon; view north. Langston Formation, on left, is down next to Brigham Formation, on right.
the next 1.7 miles, the Bloomington is down, on the west, next to the
Bloomington and Nounan Formations, on the east. Northward from the
Utah-Idaho State Line, the Bloomington and Nounan in one fault block
and the Brigham Formation in another, on the west, are opposite the
Bloomington, Blacksmith, Ute, and Langston Formations, on the east.
The displacement is 400-500 feet.

A north-trending high-angle normal fault, on the western side of
the mountain, extends from the southern boundary of the mapped area
through the upper part of Gardner Canyon. It continues northward,
west of Sheep Dip Mountain, to the eastern marginal normal fault.
This fault strikes N. 10° W. and dips 78°-85° W. Near the southern
boundary of the mapped area, the Garden City Formation, on the west,
is next to the St. Charles Formation, on the east. In Gardner Canyon,
the Blacksmith and Bloomington Formations, on the west, are opposite
the Bloomington and Nounan Formations, on the east. Northward, the
Nounan Formation is present on both sides of the fault.

A north-trending high-angle normal fault, parallel to the one
previously described, is located east of Sheep Dip Mountain. It is
vertical and strikes N. 4° W. The Nounan and St. Charles Formations
are down on the east, opposite the Nounan Formation, on the west. This
relative displacement is unusual in the mapped area. Southward, this
fault intersects the north-trending high-angle normal fault that
generally parallels it on the west. Northward, it intersects the eastern
marginal normal fault. The displacement is 400-500 feet.

A north-trending high-angle normal fault is located about 0.3
mile east of the one described in the preceding paragraph. It extends
along the western side of an elongate northwest-trending ridge for about 0.7 mile. This fault is vertical and strikes N. 17° W. The Worm Creek Member of the St. Charles Formation is down, on the west, opposite the Nounan Formation and the Worm Creek Member of the St. Charles Formation, on the east. Northward, it terminates at the eastern marginal fault; southward, it is covered by the Salt Lake Formation. The displacement is 100-200 feet.

In the northeastern part of the mapped area, a north-trending normal fault extends northward from its intersection with the eastern marginal normal fault, between Sam Stuart and Cold Water Canyons, to the northern boundary of the area. It is vertical and strikes N. 4° W. The Salt Lake Formation is down, on the east, opposite the Nounan Formation and the Worm Creek Member of the St. Charles Formation, on the west. One outcrop of the upper part of the St. Charles Formation is adjacent to the fault, on the eastern side, and is overlapped unconformably by the Salt Lake Formation. The displacement is 700-800 feet.

A north-trending normal fault intersects the one described in the preceding paragraph just north of the Utah-Idaho State Line and extends northwestward to the boundary of the mapped area. It is nearly vertical and strikes N. 40° W. The Salt Lake Formation is down, on the west, next to the Nounan and St. Charles Formations, on the east (Figure 16).

Another north-trending normal fault, located near the northeastern corner of the mapped area, extends along the eastern side of hills composed of the Salt Lake Formation. The eastern side of these hills seems to represent a fault scarp; however, the fault is covered throughout its length by colluvial deposits.
Figure 16. North-trending normal fault on western side of Jenkins Hollow; view north. Salt Lake Formation, on left, is down next to Nounan Formation, on right.
Marginal normal faults

A marginal normal fault extends along the western side of the northern part of Clarkston Mountain from the southern boundary of the mapped area to the northern boundary (Figure 17). The area of Malad Valley, on the west, dropped relative to the mountain, on the east. This fault is part of the Wasatch fault zone. In the mapped area, it presumably cuts the Lake Bonneville Group on the western side of the mountain; however, no fault scarps have been identified in the Quaternary deposits.

The eastern marginal normal fault extends northward from the southern boundary of the mapped area for about 1.7 miles. It then curves northwestward and extends nearly across the Malad Range after which it continues northward to the boundary of the mapped area (Figure 18). This fault strikes N. 20° W., in the southern segment, on the eastern side of Clarkston Mountain. There, it is covered by colluvial deposits. Throughout the middle and northern segments, the Salt Lake Formation is down, on the northeast, opposite Paleozoic rocks of Clarkston Mountain. It strikes N. 35° W. near the northern boundary of the mapped area.
Figure 17. Western marginal normal fault south of Utah-Idaho State Line; view east. Fault is at change of slope.
Figure 18. Eastern marginal normal fault in Steel Canyon; view southwest. Salt Lake Formation, in foreground, is down next to Paleozoic rocks, in background. Fault is at change of slope.
Structural interpretations

Reversed movement took place on a number of west-dipping low-angle fault surfaces. These surfaces formed as thrust faults with eastward movement of the overriding block. The principal evidence that these faults represent original thrust faults is the low angle of dip. The dip is generally about 40° W. Normal faults that formed initially in Tertiary time are usually more or less vertical.

Other structural relationships confirm reversed movement on original thrust faults as a result of normal faulting. A major thrust fault, on the eastern side of Clarkston Mountain, places Bloomington Formation over Nounan Formation as a result of eastward movement of the overriding block. Southward, this fault becomes a normal fault with the western side relatively down. Reverse drag is present, in Old Quigley Canyon, beneath a north-trending low-angle normal fault (Plate 1, structure section). Shale of the Bloomington Formation dips 30° E. beneath this fault; whereas, the fault dips 38° W. The relatively steep dip of the Bloomington, near this fault, represents drag due to thrust faulting that preceded normal faulting. Also, the severe brecciation associated with the west-dipping low-angle normal faults probably did not form under conditions of extension; therefore, early thrust faulting is indicated.

The reversed movement could have been caused in either of two ways. Westward sliding might have taken place as a result of slope instability due to relative collapse of the area of Malad Valley, west of Clarkston Mountain, along the western marginal normal fault. Displacements of this type have been recognized elsewhere. Galloway (1970, pp. 52-60)
came to the conclusion that westward sliding into the area of Cache Valley, Utah, took place along a pre-existing thrust fault. Curry (1954, p. 59) described thrust faults in southeastern Death Valley along which blocks might have slid into the valley (Curry, 1954, p. 54). Hunt and Mabey (1966, p. 150) also recognized the possibility of detachment of blocks above thrust faults in the same area. A more reasonable method of producing reversed movement, in the mapped area, is by regional extension in the east-west direction. Appropriate extension has been described by Stewart (1971) for the Basin and Range Province. Thompson (1959, p. 227) suggested east-west distension of about 30 miles across the Basin and Range Province. This mechanism could explain the reversed movement as well as the normal faulting characteristic of the Basin and Range Province.

Greater relative downward movement, toward the southern part of the mapped area, is shown by the thrust fault that changes southward to a normal fault as a result of reversed movement. The Gunsight fault seems to confirm this concept. It seems to start in the central part of the mapped area and the displacement increases southward. South of the mapped area, near Gunsight Peak, it is a major west-dipping low-angle normal fault. Also, the northwest-trending and east-northeast-trending normal faults, near the southern boundary of the mapped area, are generally down on the south. This relationship suggests greater relative collapse of the area toward the south.

The north-trending high-angle normal faults are relatively down on the western side. This relationship holds for two north-trending normal faults in the northwestern part of the mapped area. It is also
illustrated by the parallel north-trending high-angle normal faults that extend from Gardner Canyon northward to the eastern marginal normal fault. This systematic displacement indicates relative collapse into the area of the Great Basin, west of Clarkston Mountain, due to normal faulting.

Landslides

Eastern side

A landslide, on the eastern side of Clarkston Mountain, is preserved on the ridge between the upper parts of Sam Stuart and Cold Water Canyons (Figure 19). It consists of limestone of the Garden City Formation, which rests on the St. Charles Formation. This landslide remnant is 0.3 mile long in the east-west direction and 0.2 mile wide in the north-south direction. The displaced rock strikes N. 25° W. and dips 31° E. East-dipping Garden City is exposed, near the top of the mountain, west of the landslide. The distance between the upper end of the landslide and the lower part of the Garden City outcrop is about 0.2 mile.

Western side

Three remnants of a landslide, on the western side of Clarkston Mountain, are present, on ridge tops, north and south of a canyon located 0.5 mile north of Gardner Canyon. They are composed of the Nounan and St. Charles Formations. The remnants rest on the Blooming-ton and Nounan Formations.

The largest remnant, north of the canyon, is about 0.2 mile long in the east-west direction and about 0.1 mile wide in the north-south direction. It consists of Nounan Formation on the west and St. Charles
Figure 19. Landslide of Garden City Formation, north of Sam Stuart Canyon; view north. Landslide surface is indicated.
Formation on the east. The St. Charles strikes N. 70° E. and dips 11° S. The lower end of the landslide rests on the Bloomington Formation; however, the major part of it overlies the Nounan. The landslide surface slopes about 25° W. The lower remnant, south of the canyon, consists of Nounan Formation. It covers the contact of the Bloomington and Nounan Formations. The upper remnant, south of the canyon, is composed of the Worm Creek Member of the St. Charles Formation. It rests on the Nounan Formation.

The surface, beneath the three masses, may represent the low-angle normal fault that extends along the mountain front at a lower elevation. This fault places Nounan and St. Charles, down on the west, next to the Blacksmith Formation.
STRUCTURAL EVENTS

General Statement

Two major events of crustal deformation are recognized in the northern part of Clarkston Mountain. The first is the Laramide orogeny, which began as early as late Jurassic or early Cretaceous and may have continued into Paleocene (Armstrong and Cressman, 1963, p. 14). Laramide structures are folds and thrust faults. The second event is Basin and Range normal faulting, which is thought to have started as early as Eocene (Armstrong and Oriel, 1965, p. 1862). This normal faulting started before the deposition of the Salt Lake Formation of Tertiary age and has continued to the present time.

Laramide Events

Bedding-plane thrust faulting

The earliest Laramide structure, recognized in the mapped area, is the east-dipping bedding-plane thrust fault between the Bloomington Formation and the Nounan Formation. It eliminated the upper part of the Bloomington. The direction of movement was eastward. This fault formed before the low-angle thrust faulting inasmuch as a low-angle thrust fault offsets the bedding-plane thrust fault.

Low-angle thrust faulting

Two west-dipping low-angle thrust faults are present on the eastern side of Clarkston Mountain. These formed after the bedding-plane thrust
fault as evidenced by the fact that one of them offsets the bedding-plane thrust fault. Other west-dipping north-trending low-angle thrust faults formed at the same time. Reversed movement occurred on the latter with the result that they are classified as normal faults.

**Basin and Range Events**

**Early normal faulting**

The northern part of Clarkston Mountain stands high, relative to Malad Valley on the west, as a result of collapse of the valley block along the western marginal normal fault. Clarkston Mountain also rises above the area to the east as a result of collapse of the Cache Valley area along the eastern marginal normal fault. This faulting started as early as Eocene (Armstrong and Oriel, 1965, p. 1862).

Normal faulting began, in the mapped area, before deposition of the Salt Lake Formation. The Salt Lake Formation was deposited in valleys that formed as a result of normal faulting (Adamson, Hardy, and Williams, 1955, p. 21).

Early normal faulting is also evidenced by the apparent overlap of the northwest-trending normal fault, located near the northeastern corner of the mapped area, by the Salt Lake Formation. A northwest-trending normal fault, near the northeastern corner of the mapped area, may also have formed at an early date. The Salt Lake Formation seems to overlap this fault in places; elsewhere, the fault scarp is resurrected.
Late normal faulting

Late normal faults displace the Salt Lake Formation. The eastern marginal normal fault is an example. An anticline, in the Salt Lake Formation in the northern part of the mapped area, is also related to this event. It is attributed to differential vertical movements associated with normal faulting.

Great relief was produced by late normal faulting and, as a result, major landslides formed. Normal faulting has continued, in many parts of northern Utah and southern Idaho, to the present time. Continued activity is evidenced by the well-defined fault scarp that cuts the Lake Bonneville Group near the mouth of Logan Canyon (Galloway, 1970, pp. 85-86). Earthquakes also indicate continued normal faulting (Cook and Smith, 1957, p. 698).
LITERATURE CITED


