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Structural Geology of the Central Part of Clarkston Mountain, Malad Range, Utah

Douglas A. Green
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STRUCTURAL GEOLOGY OF THE CENTRAL PART OF
CLARKSTON MOUNTAIN, MALAD RANGE, UTAH

by
Douglas A. Green

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

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1986
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The writer is especially grateful to Dr. Clyde T. Hardy for the time spent in the field introducing him to the area and for many helpful suggestions pertaining to the preparation of this manuscript. Gratitude is also extended to Dr. James P. McCalpin and Dr. Donald W. Fiesinger for their careful reading of the manuscript and for the advice and suggestions they made during the course of this study.

The writer is especially appreciative of his wife, Margie, who typed the first drafts, and for his two children, Jeff and Janelle who supplied support and created the incentive necessary to finish this investigation.

Douglas A. Green
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ABSTRACT

Structural Geology of the Central Part of Clarkston Mountain, Malad Range, Utah

by

Douglas A. Green, Master of Science

Utah State University, 1986

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

The central part of Clarkston Mountain is located in north-central Utah in the southern part of the Malad Range. It is northwest of Clarkston, Utah. The mapped area measures 2.5 mi. in the north-south direction and 6.5 mi. in the east-west direction. It is within the Basin and Range Province.

The Ute Formation of Middle Cambrian age is the oldest exposed stratigraphic unit. Other Cambrian units, in ascending order, are: Blacksmith Formation, Bloomington Formation, Nounan Formation, and St. Charles Formation. These units consist predominantly of limestone, dolostone, and shale. Units of Ordovician age include the Garden City Formation and the Swan Peak Formation. They consist of limestone and orthoquartzite, respectively. The youngest Paleozoic unit is the Fish Haven-Laketown Formation of Ordovician-Silurian age. It is dolostone. Units of Quaternary age include colluvial deposits, Lake Bonneville Group, and alluvial deposits.
West-dipping, low-angle normal faults generally trend north and northwest. They were originally thrust faults formed during regional compression. A bedding-plane thrust fault separates the Bloomington and Nounan Formations.

Later reversed movement on the west-dipping, low-angle thrust faults changed the stratigraphic relationships across these faults to those characteristic of normal faults. High-angle normal faults trend northwest, north, and northeast. Major normal faults extend along the western and eastern sides of Clarkston Mountain and are responsible for the present topographic relief.

The structural features of the mapped area are the result of two major tectonic events. The Sevier orogeny produced eastward-directed thrust faults. It began in Late Jurassic and ended in early Eocene. Basin and Range normal faulting caused reversed movement on west-dipping thrust faults, formed by the Sevier orogeny, and also produced many high-angle normal faults. It began in early Eocene and has continued into historic time in the region.

(64 pages)
INTRODUCTION

Purpose and Scope

The purpose of this investigation was to identify and map the stratigraphic units and structural features of the central part of Clarkston Mountain in north-central Utah (pl. 1). The investigation contributes to the understanding of structural relationships and structural events that produced the Malad Range, Utah-Idaho.

Location and Accessibility

The mapped area is located in north-central Utah northwest of the town of Clarkston, Utah (fig. 1). It lies between lat. 41°55'46" N. and lat. 41°57'52" N. and between long. 112°04'28" W. and long. 112°12'02" W. The area extends 2.5 mi. in the north-south direction and 6.5 mi. in the east-west direction.

Access to the western side of the mapped area is provided by U.S. Interstate 15 and a frontage road immediately east of it. Jeep trails extend from this road to the mouths of Gardner, Precipitous, and Elgrove Canyons. The eastern side of the area is serviced by Utah Highway 142. Also, unimproved roads extend north-south along the eastern mountain front.

Physiographic Features

The mapped area extends across the central part of Clarkston Mountain in north-central Utah (fig. 1). Clarkston Mountain forms
FIGURE 1. Index map of part of northern Utah and southeastern Idaho showing location of mapped area.
the southern end of the Malad Range. It extends from the Utah-Idaho state line, on the north, to Junction Hills on the south. The Junction Hills separate Clarkston Mountain from Wellsville Mountain to the south. The valley of the Malad River is located west of Clarkston Mountain and Cache Valley is on the east.

The highest point, within the mapped area, is near the southern margin at an elevation of 8,001 ft. Gunsight Peak, elevation 8,244 ft., is located 0.2 mi. south of the mapped area. It is the highest point of Clarkston Mountain. The lowest part of the mapped area, near the Malad River, has an elevation of about 4,360 ft. The local relief is approximately 3,880 ft.

Clarkston Mountain is within the Basin and Range Province. It is bounded on the west by the Wasatch fault (fig. 2).

Field Work

Field investigation was conducted primarily during the fall of 1979 and the fall of 1980. Formation contacts and faults were located in the field and then mapped, with the aid of aerial photos, on a topographic base at a scale of 1:12,000 (pl. 1). The base map is an enlargement of parts of the Portage and Clarkston Quadrangles, Utah-Idaho. These maps are parts of the 7.5-minute series published by the Geological Survey of the U.S. Department of the Interior.
FIGURE 2. General view of central part of Clarkston Mountain; air view east. Wasatch fault extends along front of mountain. Elgrove Canyon is major canyon on right.
Previous Investigations

Hanson (1949) constructed a generalized geologic map of the southern part of the Malad Range, Utah, during a stratigraphic study of that area. Thicknesses of Paleozoic formations were also measured. Burton (1973) included the northern part of the mapped area in a geologic map of the northern part of Clarkston Mountain, Utah-Idaho. Gray (1975) constructed a similar geologic map of the southern part of Clarkston Mountain, Utah.

Parts of the Paleozoic section, present within Clarkston Mountain, have been included in regional stratigraphic studies. Ross (1951, p. 18-19) measured and described the Garden City Formation. James (1973, p. 245-247) measured the Swan Peak Formation on the southwestern flank of Clarkston Mountain. Hay (1982, p. 103-104) described the Blacksmith Formation at Gardner Canyon.

Many regional studies are helpful in understanding the geology of Clarkston Mountain. The Cambrian stratigraphy was first described by Walcott (1908) and later described by Maxey (1941, 1958). Williams (1948) mapped the Logan Quadrangle, Utah, and described the Paleozoic section of that area. The Tertiary rocks of the region were described by Adamson, Hardy, and Williams (1955). Structural features of the mapped area are similar to those described in the Bannock thrust zone, southeastern Idaho, by Armstrong and Cressman (1963).
STRATIGRAPHIC UNITS

General Statement

Stratigraphic units of Paleozoic and Quaternary ages are present in the mapped area. The Paleozoic units range in age from Cambrian to Ordovician (table 1). They consist of dolostone, limestone, shale, and orthoquartzite.

The oldest Cambrian formation exposed is the Ute. Other Cambrian formations, in ascending order, are: Blacksmith, Bloomington, Nounan, and St. Charles. A bedding-plane fault separates the Bloomington from the overlying Nounan. Ordovician formations include the Garden City Formation and the overlying Swan Peak Formation. The undifferentiated Fish Haven-Laketown Formation is of Ordovician and Silurian age. Complete sections of the Blacksmith, St. Charles, Garden City, and Swan Peak Formations are present. Quaternary deposits include colluvial deposits, Lake Bonneville Group, and alluvial deposits.

Cambrian System

Ute Formation

The Ute Formation was recognized in the Logan Quadrangle, Utah, by Williams (1948, p. 1133). Maxey (1958, p.661-662) described the Ute at Calls Fort, north of Brigham City, Utah, and reported a thickness of 621 ft. He also measured the Ute at High Creek, northeast of Richmond, Utah, and reported a thickness of
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<sup>a</sup> Portage Canyon, West Mountains, Utah (Budge, 1966)
<sup>b</sup> Southern end, Clarkston Mountain, Utah (James, 1973)
<sup>c</sup> Southern end, Clarkston Mountain, Utah (Ross, 1951)
<sup>d</sup> Southern end, Clarkston Mountain, Utah (Hanson, 1949)
<sup>e</sup> High Creek, Bear River Range, Utah (Maxey, 1958)
<sup>f</sup> Gardner Canyon, Clarkston Mountain, Utah (Hay, 1982)
745 ft. (Maxey, 1958, p. 653-654). At both localities, the Ute is
dark-gray to dark-bluish-gray limestone and interbedded, light­
greenish-yellow to olive-green shale. The Ute is Middle Cambrian
in age (Maxey, 1958, p. 672).

In the mapped area, the upper part of the Ute Formation crops
out in lower Gardner Canyon. The base is not exposed. The
Blacksmith Formation overlies the Ute.

In Gardner Canyon, the Ute consists of thin- to medium-bedded,
dark-bluish-gray to medium-gray limestone with numerous silty
partings. The limestone is commonly oolitic. The upper contact
is at the base of ledge-forming, thick-bedded, oolitic limestone
of the Blacksmith Formation. The exposed thickness of Ute in
Gardner Canyon is 439 ft. (Hanson, 1949, p. 14).

Blacksmith Formation

The Blacksmith Formation was recognized by Williams (1948,
p. 1133) in the Logan Quadrangle, Utah. Maxey (1958, p. 660-661)
reported a thickness for the Blacksmith of 805 ft. at Calls Fort,
north of Brigham City, Utah. At High Creek, northeast of Richmond,
Utah, Maxey (1958, p. 653) measured 485 ft. of Blacksmith. At
these two localities, as well as at the type section in the Left
Fork of Blacksmith Fork Canyon, south of Logan, Utah, the Blacksmith
consists of dolostone and some dolomitic limestone (Maxey, 1941,
p. 45-46). Oriel and Armstrong (1971, p. 45-48) stated that the
dolostone disappears to the northwest and that the Blacksmith is
largely limestone in the Malad Range, Utah-Idaho. This observation
is supported by Hay (1982, p. 103-104) who measured 376 ft. of
limestone in the Blacksmith at Gardner Canyon in the mapped area. The Blacksmith is Middle Cambrian in age (Maxey, 1958, p. 672-673).

A complete section of the Blacksmith Formation is exposed in lower Gardner Canyon. It is ledge-forming, thick-bedded, oolitic limestone. The lower contact, with the Ute Formation, is placed at the base of the lowest limestone bed characteristic of the Blacksmith. The upper contact of the Blacksmith is at the base of green shale and bluish-gray limestone of the Bloomington Formation. The gradational nature of both contacts seems to indicate uninterrupted deposition.

The limestone of the Blacksmith, in the mapped area, is largely oolitic. The oolites are generally evenly distributed throughout the limestone. They are not restricted to discontinuous beds as in the Ute and Bloomington Formations. Pisolites, up to 4 mm in diameter, occur in a thin bed near the top of the Blacksmith. A small amount of intraformational conglomerate is present near the top of the Blacksmith. Algal structures are also present in the Blacksmith. The limestone is extensively recrystallized.

Bloomington Formation

The Bloomington Formation was recognized by Williams (1948, p. 1133-1134) in the Logan Quadrangle, Utah. Maxey (1958, p. 660) reported a thickness of 1,085 ft. at Calls Fort, north of Brigham City, Utah, and a thickness of 1,495 ft. at High Creek, northeast of Richmond, Utah. At both localities, he described three members. They are: (1) lower Hodges Shale Member, (2) middle limestone member, and (3) upper Calls Fort Member. At High Creek,
the Hodges Shale consists of 540 ft. of thin-bedded, dark-gray limestone and interbedded, olive-green shale. The middle limestone member is 720 ft. thick and consists of thin- to thick-bedded, dark-bluish-gray limestone. The Calls Fort Shale is 180 ft. thick. The Bloomington is late Middle Cambrian in age (Maxey, 1958, p. 673).

In the mapped area, the lower part of the Bloomington Formation is exposed in Gardner Canyon. It conformably overlies the Blacksmith Formation and is separated from the overlying Nounan Formation by a bedding-plane thrust fault. The Bloomington also crops out in lower Precipitous and Elgrove Canyons.

In Gardner Canyon, the Hodges Shale Member consists of green shale and thin- to medium-bedded, dark-gray limestone. The lower contact is placed at the base of the lowest shale unit above limestone of the Blacksmith Formation. Recognition of the Hodges Shale is aided by the presence of limestone nodules in the green shale. The middle limestone member overlies the Hodges Shale. It consists largely of thin-bedded, gray limestone that weathers bluish gray. Some of the limestone is oolitic and pisolitic. Both members are truncated by a bedding-plane thrust fault. The exposed thickness is about 200 ft.

In Precipitous and Elgrove Canyons, the Bloomington Formation seems to be represented by the Hodges Shale Member. At these localities, the base is not exposed and the formation is separated from the overlying Nounan Formation by a bedding-plane thrust fault.
Nounan Formation

The Nounan Formation was recognized in the Logan Quadrangle, Utah, by Williams (1948, p. 1134). He described a lower, ledge-forming, light-gray dolostone and an upper, dark-gray limestone with shaly and silty partings. Maxey (1941, p. 28-31) measured the Nounan at High Creek, northeast of Richmond, Utah. He reported a lower dolostone, 675 ft. thick, and an upper limestone, 450 ft. thick. There, the total thickness is 1,125 ft. Williams (1948, p. 1134) assigned a Late Cambrian age to the Nounan.

The Nounan Formation is exposed in places on the western side of Clarkston Mountain. The lower part of the formation crops out in Gardner, Precipitous, and Elgrove Canyons. The upper contact extends along the western side of the main ridge of Clarkston Mountain. The Nounan also crops out in the northeastern part of the mapped area.

In the mapped area, the Nounan Formation consists of a lower, ledge-forming, thick-bedded, light-gray dolostone that weathers light gray and an upper, thin-bedded, dark-gray limestone. A bedding-plane thrust fault separates the Nounan from the underlying Bloomington Formation. The top of the Nounan is at the base of the Worm Creek Quartzite Member of the St. Charles Formation. The lower dolostone is 908 ft. thick (Hanson, 1949, p. 24-25). The upper limestone is about 500 ft. thick. The total thickness of the Nounan is about 1,400 ft.
St. Charles Formation

The St. Charles Formation was recognized in the Logan Quadrangle, Utah, by Williams (1948, p. 1134-1135) who stated that it consists of three members: (1) lower Worm Creek Quartzite Member, (2) middle limestone member, and (3) upper dolostone member. Maxey (1941, p. 26-28) measured the St. Charles at High Creek, northeast of Richmond, Utah, and reported a thickness of 1,015 ft. The lower Worm Creek Quartzite Member, 75 ft. thick, consists of gray to light-brown orthoquartzite. The middle limestone member, 295 ft. thick, is light-gray, sandy limestone in the lower part and dark-gray limestone in the upper part. The upper member, 645 ft. thick, consists of medium- to thick-bedded, dark-gray dolostone. The St. Charles is Late Cambrian in age (Williams, 1948, p. 1134-1135).

The St. Charles is extensively exposed in several parts of the mapped area. It extends along the western front of Clarkston Mountain from the northern margin of the mapped area to the southern margin. The St. Charles crops out on both the western and eastern sides of the main ridge of Clarkston Mountain from the northern to the southern margins of the mapped area. It also crops out along most of the eastern side of Clarkston Mountain in the mapped area.

The St. Charles Formation, in the mapped area, consists of three members: (1) lower Worm Creek Quartzite Member, (2) middle limestone member, and (3) upper dolostone member. The lower contact is at the base of the Worm Creek Quartzite Member and at the top of the limestone of the upper member of the underlying Nounan Formation. The upper contact is at the top of the ledge-forming, dark-gray
dolostone of the St. Charles and below thin-bedded dolostone of the Garden City Formation. Hanson (1949, p. 30-32) reported a complete section of the St. Charles located about 2.0 mi. south of the mapped area. He recognized three members: (1) lower Worm Creek Quartzite Member, 75 ft. thick, (2) middle limestone member, 368 ft. thick, and (3) upper dolostone member, 630 ft. thick. There, the total thickness of the St. Charles is 1,073 ft.

The three members of the St. Charles are readily distinguishable in the mapped area. The lower part of the Worm Creek Quartzite Member consists of thin- to medium-bedded, light-gray orthoquartzite that weathers light brown. Cross-bedding is present in places. The lower part of the Worm Creek commonly forms smooth slopes. The upper part of the Worm Creek Quartzite Member consists of light-gray orthoquartzite with interbedded light-brown shale and dark-gray limestone. The lower part of the middle member consists of light-brown, silty shale interbedded with thin-bedded, dark-gray limestone and thin-bedded, medium-gray limestone. The upper part of the middle member is mostly medium-bedded, dark-gray dolostone interbedded with thin-bedded, dark-gray limestone. The middle limestone member forms smooth slopes. The upper member of the St. Charles is mostly medium- to thick-bedded, dark-gray dolostone. The dolostone contains lenses of white chert.

**Ordovician System**

**Garden City Formation**

The Garden City Formation was recognized in the Logan Quadrangle, Utah, by Williams (1948, p. 1135-1136). Ross (1951,
p. 21-22) measured the Garden City at Green Canyon, northeast of Logan, Utah, and reported a thickness of 1,405 ft. Ross (1951, p. 18-19) also measured the Garden City at Clarkston Mountain, Utah, and reported a thickness of 1,764 ft. At both localities, Ross recognized a lower, dark-gray limestone member that contains much intraformational conglomerate and an upper member composed of limestone with interbedded black chert. Ross (1951, p. 37) stated that most of the Garden City is Early Ordovician in age and that the upper 30 to 50 ft. of the formation is Middle Ordovician in age.

The Garden City crops out over much of the mapped area. It extends along the western side of Clarkston Mountain from Gardner Canyon southward to the margin of the mapped area. It is present on the main ridge of Clarkston Mountain between upper Elgrove Canyon and upper Elbow Canyon. It is also present on the main ridge in the northern part of the mapped area.

The Garden City, in the mapped area, consists mostly of thin-bedded, medium-gray limestone. The lower contact is at the top of ledge-forming, thick-bedded, dark-gray dolostone of the St. Charles Formation. The upper contact is at the base of the black shale of the lower member of the Swan Peak Formation. The Garden City is 1,805 ft. thick about 1.0 mi. south of the mapped area (Hanson, 1949, pl. 4).

The Garden City Formation has been divided into informal members that are readily identified in the mapped area. Hanson (1949, p. 41) recognized four members on the southern part of Clarkston Mountain as follows: (1) thin-bedded, medium-gray
limestone with intraformational conglomerate and some white chert, 900 ft. thick, (2) thin-bedded, silty and argillaceous limestone, 583 ft. thick, (3) interbedded limestone and black chert, 170 ft. thick, and (4) thick-bedded, medium-gray dolostone with minor chert, 152 ft. thick. Ross (1951, p. 7) described two members in the Garden City. The lower member is thin-bedded, medium-gray limestone that weathers light bluish gray. Intraformational conglomerate is common. This member forms slopes. The upper member is ledge-forming, thick-bedded, gray limestone. It is characterized by nodules and beds of black chert. Dolostone is generally present at the top of this member.

Swan Peak Formation

Williams (1948, p. 1136-1137) recognized the Swan Peak Formation in the Logan Quadrangle, Utah. He described three members in the Swan Peak in Green Canyon, northeast of Logan, Utah, as follows: (1) lower shale member, (2) middle orthoquartzite and shale member, and (3) upper orthoquartzite member. The lower member, 174 ft. thick, is black shale. The middle member, 28 ft. thick, consists of thin-bedded orthoquartzite and interbedded shale. The upper member, 137 ft. thick, is thick-bedded, light-gray orthoquartzite. The total thickness of the Swan Peak in Green Canyon is 339 ft. James (1973, p. 245-247) measured the Swan Peak near the southern end of Clarkston Mountain, Utah. He described three members: (1) lower orthoquartzite and shale member, (2) middle orthoquartzite and shale, and (3) upper orthoquartzite. The lower member is 79 ft. thick. The middle member, 29 ft. thick, is
characterized by abundant horizontal burrows. The upper member, 466 ft. thick, consists of light-gray orthoquartzite. The total thickness is 574 ft. The Swan Peak is Middle Ordovician in age (Ross, 1951, p. 33).

The Swan Peak Formation crops out on the western side of Clarkston Mountain near the southern margin of the mapped area. It is also exposed, above a west-dipping normal fault, on the main ridge of Clarkston Mountain near the southern margin of the mapped area.

In the mapped area, the Swan Peak consists of orthoquartzite and shale. The lower contact is at the base of black shale above limestone of the Garden City Formation. James (1973, p. 247), working on the southwestern flank of Clarkston Mountain, Utah, stated that this contact is disconformable. Approximately 1.1 mi. to the north, in the NW¼ SE¼ sec. 24, T. 14 N., R. 3 W., the contact seems to be gradational. At that locality, several beds of orthoquartzite are interbedded with limestone and dolostone characteristic of the underlying Garden City Formation. This evidence supports the statement of Hanson (1949, p. 43) that the contact is conformable. The upper contact separates the light-gray orthoquartzite from dark-gray dolostone of the overlying Fish Haven-Laketown Formation. James (1973, p. 75) found orthoquartzite pebbles of Swan Peak in the overlying Fish Haven Formation at a point located about 35 mi. north of the mapped area. This evidence, along with the sharp contact at that location, indicates a disconformable relationship. The Swan Peak is about 600 ft. thick.
at a locality about 0.8 mi. south of the mapped area (Hanson, 1949, p. 44).

The three members of the Swan Peak are readily distinguished in the mapped area. The lower member consists of black shale with interbedded, medium-gray limestone. It commonly forms smooth slopes. The lower member is 50 ft. thick (Hanson, 1949, pl. 4). The middle member is composed of thin-bedded, light-brown to brown orthoquartzite with interbedded green and brown shale. The amount of shale decreases toward the upper part of the member. Horizontal burrows are locally common in the orthoquartzite. The middle member is 156 ft. thick (Hanson, 1949, pl. 4). The upper member consists of fine-grained, white to light-gray orthoquartzite. This member is approximately 400 ft. thick (Hanson, 1949, pl. 4). The total thickness of the Swan Peak, in the mapped area, is about 600 ft.

Ordovician-Silurian System

Fish Haven-Laketown Formation

Williams (1948, p. 1137-1138) recognized the Fish Haven and Laketown Formations in the Logan Quadrangle, Utah. The two formations are combined in this report because of persistent difficulties in defining a contact between them (Hanson, 1949, p. 48; Budge, 1966, p. 15). Williams (1948, p. 1137) measured the Fish Haven in lower Green Canyon, northeast of Logan, Utah, and reported a thickness of 140 ft. He also measured the Laketown at the same locality and reported a thickness of 1,150 ft. (Williams, 1948, p. 1137-1138). Hanson (1949, p. 46) stated that the Fish Haven is approximately 50 ft. thick in the Malad Range,
Utah. Budge (1966, p. 80-82) reported a thickness of 1,862 ft. for the Laketown in an area located approximately 8.5 mi. west-northwest of the mapped area. In all of these sections, the Fish Haven and Laketown Formations consist of dolostone that ranges from light to dark gray. The Fish Haven is Late Ordovician in age (Hanson, 1949, p. 47). The lower part of the Laketown is Late Ordovician in age and the remainder of the formation is Early to Middle Silurian in age (Budge, 1966, p. 46-48).

The Fish Haven-Laketown Formation, in the mapped area, is exposed in the ridge west of the upper part of Elgrove Canyon. The lower contact of this unit crops out on the western side of this ridge. The upper part of the unit has been removed by erosion. The Fish Haven-Laketown Formation is the youngest unit of Paleozoic age in the mapped area.

In the mapped area, the Fish Haven-Laketown Formation consists of medium- to coarse-crystalline dolostone. It is dark gray near the base and grades upward into light gray. The lower contact is at the base of dark-gray dolostone and above light-gray orthoquartzite of the Swan Peak Formation. This contact is regarded as an unconformity (Williams, 1948, p. 1137; Hanson, 1949, p. 43; James, 1973, p. 75). The upper contact is not exposed. The original thickness of the Fish Haven-Laketown, in the mapped area, was probably about 2,000 ft.
Quaternary System

Colluvial deposits

Two types of colluvial deposits occur in the mapped area. One consists of unconsolidated sand, silt, and clay with pebbles of limestone, dolostone, and orthoquartzite. It mantles slopes within canyons and along the mountain fronts. The other consists of unconsolidated, fine-grained material with admixed boulders. It is present on the tops of divides between canyons. The colluvial deposits are of Quaternary age.

Notable deposits that mantle slopes are located on the eastern side of Clarkston Mountain on north-facing slopes in Raglanite, Elbow, and New Quigley Canyons. They are generally heavily vegetated. The lower part of the slope along the eastern mountain front is covered by fine-grained deposits with small clasts. Such deposits cover only a narrow belt along the western margin of Clarkston Mountain.

Deposits, located on divides, are most extensive on the eastern side of Clarkston Mountain. The most abundant clasts consist of white and light-brown orthoquartzite. Limestone and dolostone clasts are also present. The largest deposit of this type is located on the top of the divide between Elbow and Mikes Canyons. There, one unusually large boulder of white orthoquartzite is about 25 ft. across. Another deposit is located on the saddle at the head of Sam Stuart Canyon. On the western side of Clarkston Mountain, a colluvial deposit with boulders occupies the saddle
between Elgrove and Precipitous Canyons. There, the boulders are primarily dolostone.

Colluvial deposits, located on divides, were derived from the main ridge of Clarkston Mountain. They accumulated on lower slopes. Later, canyons were cut through the deposits and into the underlying rock.

Lake Bonneville Group

Three formations, comprising the Lake Bonneville Group, were recognized by Hunt, Varnes, and Thomas (1953, p. 17-21) in Utah Valley, central Utah. These formations, in order of decreasing age, are: (1) Alpine Formation, (2) Bonneville Formation, and (3) Provo Formation. Williams (1962, p. 137-142), working in southern Cache Valley, grouped the Alpine and Bonneville Formations to form an undifferentiated unit found along the valley sides. He recognized the Provo Formation in the lower part of the valley. Differentiation of these units, in Cache Valley, is based primarily on elevations of outcrops and on the relative amounts of gravel, sand, silt, and clay. The Lake Bonneville Group is Pleistocene in age (Hunt, Varnes, and Thomas, 1953, p. 17).

The Lake Bonneville Group is present in the major valleys both to the west and east of Clarkston Mountain. It is separated from the Paleozoic rocks of the mountain by colluvial deposits of Quaternary age. Well-defined shorelines are not evident; however, Crittenden (1963, p. 9) indicated that the shoreline elevation in the vicinity of Clarkston Mountain is approximately 5,150 ft. A wave-cut terrace, located 0.9 mi. south of the mapped area, is at
an elevation of 5,160 ft. The Lake Bonneville Group of the mapped area consists of silt and gravel. The silt is white to light brown.

**Alluvial deposits**

Two types of alluvial deposits are present in the mapped area. Both consist of unconsolidated gravel, sand, silt, and clay and are a result of stream action. Coarse-grained deposits occur along the lower parts of major canyons and as related alluvial fans that extend beyond the mountain fronts. Fine-grained deposits occur as floodplains along streams in the broad valleys both west and east of Clarkston Mountain. The alluvial deposits are Quaternary in age.

The alluvial fans on the eastern side of Clarkston Mountain were deposited on older colluvial deposits and are above the level of Lake Bonneville. The fans below Elbow and New Quigley Canyons have been notably incised. The fans on the western side of Clarkston Mountain were deposited on the Lake Bonneville Group and extend below the highest shoreline of Lake Bonneville. They are not cut by Bonneville shorelines and, therefore, postdate the high levels of the lake.
STRUCTURAL FEATURES

Regional Setting

The structure of north-central Utah and southeastern Idaho is characterized by thrust faults and normal faults. The thrust faults exhibit eastward movement. The normal faults define north-south-trending mountain ranges.

The Bannock thrust zone of southeastern Idaho consists of west-dipping, imbricate thrust faults (Armstrong and Cressman, 1963, p. 19). The Paris thrust fault is the western thrust fault of the Bannock thrust zone. It extends along the eastern side of the Bear River Range. The Paris thrust fault dips west and places the Cambrian Brigham Quartzite over the Triassic Thaynes Formation (Armstrong and Cressman, 1963, p. 7). The stratigraphic separation is about 20,000 ft.

The Woodruff thrust fault is located in north-central Utah between Ogden, Utah, and Evanston, Wyoming. It dips west. The Precambrian Mutual Formation is thrust eastward over the Pennsylvanian Weber Formation. This fault may connect with the Paris thrust fault (Crittenden, 1961, p. 128-129).

The Willard thrust fault, exposed in the Wasatch Mountains in the vicinity of Ogden, Utah, dips east (Crittenden, 1972). Stratigraphic units of Late Precambrian age are thrust eastward over Paleozoic rocks. Crittenden (1961, p. 129) estimated about 40 miles of displacement on the Willard. This fault may be an
extension of the Woodruff thrust fault (Crittenden, 1961, p. 128-129).

Crittenden (1961, p. 128-129) connected the Paris, Woodruff, and Willard thrust faults. Armstrong and Cressman (1963, p. 18) suggested that the Paris thrust fault terminates southward and is not connected with the thrust faults to the south.

Normal faults are abundant in the region of north-central Utah and southeastern Idaho. The Wasatch fault extends along the western front of the Wasatch Mountains in Utah and along the western front of the Malad Range in Idaho. A major normal fault is located along the western front of the Bear River Range in Utah and Idaho. Most of the normal faults trend north-south. Normal faults are responsible for the relief of the north-south-trending mountain ranges.

**Thrust Faults**

**General statement**

Two kinds of thrust faults are recognized in the mapped area. A bedding-plane thrust fault separates the Bloomington and Nounan Formations. Many west-dipping, low-angle faults formed as thrust faults; however, they later became normal faults due to reversed movement.

**Bedding-plane thrust fault**

A bedding-plane thrust fault separates the Bloomington Formation from the overlying Nounan Formation in the mapped area. The Nounan moved eastward. This thrust fault is exposed in lower
Elgrove, Precipitous, and Gardner Canyons.

In lower Elgrove Canyon, the Nounan Formation is thrust over the Bloomington Formation. Shale and limestone beds of the Bloomington are truncated at a low angle by the fault. The shale unit is probably the lower member of the Bloomington Formation; however, the base is not exposed. Also, in lower Precipitous Canyon, the Nounan is thrust over the Bloomington.

The bedding-plane thrust fault is well exposed in lower Gardner Canyon. On the northern side of Gardner Canyon, dolostone of the Nounan Formation is thrust over thin-bedded limestone of the Bloomington Formation (fig. 3). The fault plane is parallel to bedding and dips 20° E. to 30° E. A small drag fold is present below the fault in the Bloomington. The Bloomington, at that locality, is approximately 500 ft. thick. It rests on the Blacksmith Formation in normal stratigraphic succession.

On the southern side of Gardner Canyon, the Nounan Formation is also thrust over the Bloomington Formation on the bedding-plane thrust fault. The fault dips east at a low angle. The Bloomington is about 75 ft. thick at the western end of the outcrop and about 200 ft. thick at the eastern end. This reduced thickness, compared to that on the northern side of Gardner Canyon, indicates that the bedding-plane fault cuts slightly downward in the Bloomington toward the south.

West-dipping thrust faults

Eastward thrust faulting occurred on numerous north-trending, low-angle faults. The low west dips of these faults, as well as
FIGURE 3. Bedding-plane thrust fault separating Bloomington and Nounan Formations on northern side of Gardner Canyon; view north. Nounan Formation (En) is thrust eastward over Bloomington Formation (Ebo). Fold, at lower left, is in thin-bedded limestone of Bloomington.
the drag folds associated with them, suggest a thrust-fault origin. Later reversed movement, down on the west, changed the stratigraphic relationships across these faults to those characteristic of normal faults. Also, the later movement did not destroy the drag folds that formed at the time of the thrust faulting. These faults are classified as normal faults based on the later reversed movement.

West-dipping thrust faults, without reversed movement, are not found in the mapped area. They are present, however, immediately north of the area (Burton, 1973, p. 45) and also south of the area (Gray, 1975, p. 18-19).

Structural interpretations

The bedding-plane thrust fault evidently has regional extent. Burton (1973, pl. 1) mapped a bedding-plane thrust fault between the Bloomington and Nounan Formations northward from Gardner Canyon. Shearer (1975, p. 57) reported that a bedding-plane thrust fault separates Bloomington and Nounan in the area northeast of Malad, Idaho. De Vries (1977, p. 40-43) described this fault in Elkhorn Mountain, north of Malad, Idaho.

The thickness of the Bloomington Formation is less in the mapped area than elsewhere in the region. Maxey (1941, p. 19-20) reported 1,055 ft. of Bloomington near Calls Fort, north of Brigham City, Utah. At High Creek, northeast of Richmond, Utah, the Bloomington is 1,495 ft. thick (Maxey, 1941, p. 19-20). The reduction in thickness of 500-900 ft. is attributed to low-angle truncation by the bedding-plane thrust fault.

Thrust faulting, in the mapped area, resulted from east-west

Folds

Minor folds

Numerous, small-scale folds, in the mapped area, are associated with the bedding-plane thrust fault separating the Bloomington Formation from the overlying Nounan Formation (fig. 3). They are well exposed on the northern side of lower Gardner Canyon. The folds involve thin-bedded limestone of the Bloomington and are asymmetric as a result of the eastward-directed thrust faulting.

Drag folds are present along some of the west-dipping, low-angle faults. These asymmetric, anticlinal folds display steeper dips on their eastern flanks, near the associated fault, than on their western flanks. They formed during eastward-directed thrust faulting. Later reversed movement, down on the west, produced the existing relationship of reverse drag.

Major fold

The Paleozoic formations of the central part of Clarkston Mountain generally dip eastward. The dip on the eastern side is about 10 degrees steeper than the dip on the western side. This evidence suggests that the dipping beds represent the eastern limb of a major north-trending anticline.
Normal Faults

General statement

The central part of Clarkston Mountain is characterized by many normal faults. Selected normal faults of the mapped area are assigned to six categories as follows: (1) north-trending, low-angle normal faults, (2) northwest-trending, low-angle normal fault, (3) northeast-trending, high-angle normal faults, (4) north-trending, high-angle normal faults, (5) northwest-trending, high-angle normal faults, and (6) marginal normal faults.

North-trending, low-angle normal faults

Four north-trending, low-angle normal faults are selected for description. Individual descriptions proceed from the eastern part to the western part of the mapped area.

The first north-trending, low-angle normal fault is located on the eastern side of Clarkston Mountain in the southeastern part of the mapped area. It is near the eastern boundary of sec. 19, T. 14 N., R. 2 W. This fault extends from the southern margin of the mapped area northward to a northwest-trending, high-angle normal fault on the northern side of Elbow Canyon. It strikes about N. 5° W. and dips about 40° W. Near its northern end, the Garden City Formation is faulted down on the west opposite the St. Charles Formation. At the southern margin of the mapped area, upper Garden City is faulted down on the west opposite lower Garden City.

The second north-trending, low-angle normal fault is located in the northern part of the mapped area about 0.2 mi. east of the
main ridge of Clarkston Mountain. This fault extends from the northern margin of the mapped area southward to the head of New Quigley Canyon. It strikes about N. 20° W. and dips 35° W. Near the northern margin of the mapped area, the St. Charles Formation is faulted down on the west opposite St. Charles. Southward, the Garden City Formation is faulted down on the west opposite St. Charles. In the head of New Quigley Canyon, the St. Charles Formation is faulted down on the west opposite St. Charles.

The third north-trending, low-angle normal fault is located immediately east of the main ridge of Clarkston Mountain in the W₁₉, sec. 19, T. 14 N., R. 2 W. (fig. 4). This fault extends from the head of New Quigley Canyon southward to the southern side of Elbow Canyon. It strikes north and dips 35° W. The Garden City Formation is faulted down on the west opposite the St. Charles Formation. Outcrops west of the fault are stratigraphically close to the base of the Garden City. For this reason, the fault is within the Garden City where it crosses the ridge between Elbow and New Quigley Canyons. Projection of the lower contact of the Garden City from its exposure immediately west of the main ridge indicates a displacement of about 200 ft.

The fourth north-trending, low-angle normal fault is located near the western front of Clarkston Mountain between Precipitous and Gardner Canyons. It extends from the northeast-trending, high-angle normal fault in Precipitous Canyon northward to the northeast-trending, high-angle normal fault on the ridge south of Gardner Canyon. It strikes about N. 25° W. and dips 38° W. based on an outcrop immediately north of Precipitous Canyon. The Garden
FIGURE 4. Low-angle normal fault in upper Elbow Canyon; view west. Fault dips west. Garden City Formation (Ogc) is faulted down on west opposite St. Charles Formation (Esc).
City Formation is faulted down on the west opposite the St. Charles and Garden City Formations. Estimated displacement is 400-500 ft.

Northwest-trending, low-angle normal fault

A major northwest-trending, low-angle normal fault extends from the northern margin of the mapped area to the southern margin of the mapped area. It also underlies a peak located on the main ridge of Clarkston Mountain near the southern margin of the mapped area. This fault was noted by Hanson (1949, p. 27). It will be described with reference to four segments from north to south.

The northern segment crosses lower Gardner Canyon at a point located approximately 0.15 mi. east of the mountain front. It extends from the northern margin of the mapped area southeastward to the northeast-trending, high-angle normal fault located in the first small canyon south of Gardner Canyon. In Gardner Canyon, the northwest-trending, low-angle normal fault locally strikes N. 23° W. and dips 50° W. This attitude, near the mountain front, differs from the more representative attitude in Elgrove Canyon. The St. Charles Formation is faulted down on the west opposite Ute and Blacksmith Formations.

The central segment of the northwest-trending, low-angle normal fault is faulted down and is not exposed. This segment extends from the northeast-trending, high-angle normal fault south of Gardner Canyon to the northeast-trending, high-angle normal fault in Precipitous Canyon. The down-faulted block is
bounded on the northeast by a northwest-trending, high-angle normal fault.

The southern segment of the northwest-trending, low-angle normal fault extends from the northeast-trending, high-angle normal fault in Precipitous Canyon southeastward across lower Elgrove Canyon to a northwest-trending, high-angle normal fault in upper Elgrove Canyon. In lower Elgrove Canyon, the fault strikes approximately N. 35° W. and dips 39° W. Between Precipitous and Elgrove Canyons, the St. Charles and Garden City Formations are faulted down on the west opposite the Bloomington and Nounan Formations. The stratigraphic separation is approximately 2,500 ft. On the ridge west of upper Elgrove Canyon, the Fish Haven-Laketown Formation is faulted down on the west opposite Nounan and St. Charles Formations.

The southeastern segment of the northwest-trending, low-angle normal fault underlies a peak, elevation 8,001 ft., on the main ridge of Clarkston Mountain near the southern margin of the mapped area. The fault dips west. The Swan Peak and Fish Haven-Laketown Formations are faulted down opposite the St. Charles Formation. A short distance to the east, a related low-angle fault dips 33° W. at the outcrop. The dip probably becomes less toward the west. The St. Charles Formation is faulted down on the west opposite the Garden City Formation.

Northeast-trending, high-angle normal faults

Six northeast-trending, high-angle normal faults are described.
Individual descriptions proceed from the northern part to the southern part of the mapped area.

The first northeast-trending, high-angle normal fault is located 0.2 mi. southeast of lower Gardner Canyon. It extends from the western marginal normal fault northeastward for about 0.9 mi. and terminates at an east-trending normal fault on the divide between upper Gardner Canyon and Precipitous Canyon. This fault strikes about N. 57° E. and seems to be vertical based on the occurrence of fault breccia in the small canyon immediately south of Gardner Canyon. The St. Charles and Garden City Formations are faulted down on the south next to the Nounan and St. Charles Formations. Displacement on the fault is impossible to determine because of the effects of numerous intersecting faults. On the east-trending normal fault, however, the lower contact of the Garden City is faulted down about 400 ft. on the south opposite the lower part of the St. Charles Formation.

The second northeast-trending, high-angle normal fault is located in lower Precipitous Canyon. It extends from the western marginal normal fault northeastward for about 0.8 mi. to a major northwest-trending, high-angle normal fault. This fault strikes about N. 50° E. In the lower part of Precipitous Canyon, the St. Charles and Garden City Formations are faulted down on the north opposite St. Charles and Garden City on the south. Northeastward, the St. Charles and Garden City Formations are faulted down on the north opposite the Bloomington and Nounan Formations. The latter formations, however, are below the major northwest-trending, low-angle normal fault.
The third and fourth northeast-trending, high-angle normal faults are located on the main ridge of Clarkston Mountain in the northern part of the mapped area in the eastern part of sec. 13, T. 14 N., R. 3 W. They are parallel and extend from a major northwest-trending, high-angle normal fault in middle Elgrove Canyon northeastward to the crest of the ridge where they terminate at a north-trending, low-angle normal fault. The western fault probably dips steeply southeast. The base of the Garden City Formation, near the crest of the ridge, is faulted down about 100 ft. on the east. The eastern fault dips 68° W. as evidenced by fault breccia that crops out north of Elgrove Canyon. The base of the St. Charles is faulted down about 250 ft. on the west.

The fifth northeast-trending, high-angle normal fault crosses Elgrove Canyon near the center of the mapped area in NE1/4 sec. 24, T. 14 N., R. 3 W. It extends from a major northwest-trending, high-angle normal fault northeastward for approximately 0.6 mi. to a north-trending, low-angle normal fault located east of the main ridge of Clarkston Mountain. This fault strikes about N. 55° E. The base of the St. Charles Formation is faulted down on the south opposite the Nounan Formation. Displacement is approximately 200 ft.

The sixth northeast-trending, high-angle normal fault is located south of Elgrove Canyon near the western front of Clarkston Mountain. It extends from the southern margin of the mapped area northeastward to an east-trending, high-angle normal fault on the southern side of Elgrove Canyon. This fault strikes N. 22° E. and dips 77° W. based on a breccia in the lower part of the first
canyon south of Elgrove Canyon. The lower contact of the Garden City Formation is faulted down about 150 ft. on the west opposite the upper part of the St. Charles Formation.

**North-trending, high-angle normal faults**

Nine north-trending, high-angle normal faults are selected for description. Individual descriptions proceed westward across the northern part of the mapped area and thence southward along the western side.

The first north-trending, high-angle normal fault is located in the northeastern part of the mapped area. It extends from a northwest-trending, high-angle normal fault in Mikes Canyon northward to the margin of the mapped area. It dips 60° W. on the ridge between Mikes Canyon and New Quigley Canyon. South of New Quigley Canyon, the St. Charles Formation is faulted down on the west opposite St. Charles. North of New Quigley Canyon, the Nounan and St. Charles Formations are faulted down on the west opposite the St. Charles Formation.

The second north-trending, high-angle normal fault is located about 0.1 mi. west of the previously described fault. It extends from an east-trending, high-angle fault in New Quigley Canyon northward to the margin of the mapped area. This fault strikes N. 8° W. and is vertical based on a fault breccia on the ridge between New Quigley and Sam Stuart Canyons. The Nounan and St. Charles Formations are faulted down on the west opposite the Nounan and St. Charles.

The third north-trending, high-angle normal fault, located west
of the previously described fault, extends from an east-trending, high-angle fault in New Quigley Canyon northward to the margin of the mapped area. A conspicuous fault breccia of orthoquartzite of the Worm Creek Member of the St. Charles Formation is present on the eastern side of the saddle at the head of Sam Stuart Canyon and the next canyon to the north. It dips 57° W. The saddle is covered by colluvial deposits; however, the upper member of the St. Charles Formation is exposed to the west.

The fourth north-trending, high-angle normal fault is located along the eastern base of the main ridge of Clarkston Mountain. It extends from the upper part of Sam Stuart Canyon northward to the margin of the mapped area. The St. Charles and Garden City Formations are faulted down on the east opposite the St. Charles Formation. This fault is probably vertical based on the occurrence of vertical fault breccia on a related fault that is located a short distance to the east.

The fifth north-trending, high-angle normal fault is located in the upper part of Precipitous Canyon. It extends from the major northwest-trending, high-angle normal fault in upper Precipitous Canyon northward to the margin of the mapped area. Nounan, St. Charles, and Garden City Formations are faulted down on the west opposite Nounan and St. Charles (fig. 5). The upper contact of the Nounan is faulted down about 500 ft.

The sixth north-trending, high-angle normal fault is located in the northwestern part of the mapped area in upper Gardner Canyon. This fault extends from a northeast-trending, high-angle normal fault in Gardner Canyon northward to the margin of the mapped area.
FIGURE 5. High-angle normal fault at upper end of Precipitous Canyon; view north. St. Charles Formation (Esc) is faulted down on west opposite Nounan Formation (En) and overlying St. Charles. Fault is vertical.
The Nounan Formation is faulted down on the east opposite the Bloomington Formation (fig. 6). Estimated displacement is approximately 200 ft. A nearly complete section of the Nounan Formation is exposed east of the fault.

The seventh north-trending, high-angle normal fault crosses lower Gardner Canyon at a point about 0.2 mi. above the mouth of the canyon (fig. 7). It extends from the northeast-trending, high-angle normal fault, south of Gardner Canyon, northward to the margin of the mapped area. Limestone of the Blacksmith Formation is faulted down on the west opposite the Ute Formation. The trace of this fault shows that it is vertical.

The eight north-trending, high-angle normal fault crosses the ridge between Elgrove and Precipitous Canyons near the mountain front. It terminates northward at the northeast-trending, high-angle normal fault in lower Precipitous Canyon. On the ridge, the contact of the St. Charles and Garden City Formations is faulted down on the west. This fault dips 62° W. Countless parallel fault surfaces are present near the mountain front.

The ninth north-trending, high-angle normal fault is located in the southwestern part of the mapped area. It extends from a northeast-trending, high-angle normal fault in lower Precipitous Canyon southward to the margin of the mapped area. This fault dips about 60° W. The St. Charles and Garden City Formations are faulted down on the west opposite St. Charles. The displacement is about 200 ft.
FIGURE 6. High-angle normal fault on eastern side of upper Gardner Canyon; view east. Nounan Formation (En) is faulted down on east opposite Bloomington Formation (Ebo). Fault is vertical and has small displacement. St. Charles Formation (Esc) overlies Nounan at upper left.
FIGURE 7. High-angle normal fault on northern side of Gardner Canyon; view north. Blacksmith Formation (6bl) is faulted down on west opposite Ute Formation (6u) and overlying Blacksmith. Bloomington Formation (6bo) overlies Blacksmith at upper right. Nounan Formation (6n), at upper right, is thrust eastward over Bloomington on bedding-plane thrust fault.
Northwest-trending, high-angle normal faults

Two northwest-trending, high-angle normal faults are described. Individual descriptions proceed from the western part of the mapped area to the eastern part.

The first northwest-trending, high-angle normal fault is located on the western side of Clarkston Mountain. It extends from a northeast-trending, high-angle normal fault in Gardner Canyon southeastward to the southern margin of the mapped area. This fault strikes approximately N. 30° W. and dips 70° W. where it crosses Elgrove Canyon. The St. Charles and Garden City Formations are faulted down on the west opposite the Nounan and St. Charles Formations. The block west of the fault, between the northeast-trending, high-angle normal faults in Gardner and Precipitous Canyons, is above the major northwest-trending, low-angle normal fault. The plane of the northwest-trending, low-angle normal fault, from Precipitous Canyon southeastward to the margin of the mapped area, is faulted down on the west by the northwest-trending, high-angle normal fault. Displacement is 300-500 ft.

The second northwest-trending, high-angle normal fault is located in the southeastern part of the mapped area. It extends from an east-trending, high-angle fault in New Quigley Canyon southeastward to the eastern marginal normal fault at a point located near the southern margin of the mapped area. The northern segment of the fault, north of the ridge between Elbow and Mikes Canyons, strikes about N. 35° W. The southern segment, south of the ridge between Elbow and Mikes Canyons, strikes about N. 40° W.
The fault dips steeply west. In general, the Garden City Formation is faulted down on the west opposite the St. Charles Formation.

Marginal normal faults

A marginal normal fault is located along the western front of Clarkston Mountain (fig. 8). In the mapped area, three straight, intersecting fault segments are inferred from the trend of the mountain front. The southern segment strikes about N. 20° E. The middle segment extends from south of Elgroe Canyon to south of Gardner Canyon and strikes about N. 25° W. The northern segment strikes N. 15° W. The dip is impossible to determine directly as the fault is covered with colluvial deposits and alluvial fans. Shear surfaces, near the mountain front, indicate an approximate dip of 60° W.

The Cambrian St. Charles Formation crops out along the western base of Clarkston Mountain. Presumably the Tertiary Salt Lake Formation is faulted down in the valley on the west; however, only Quaternary units are exposed. No fault scarps have been recognized in the Quaternary units. Displacement on the western marginal normal fault may be as great as 8,000 ft. This estimate is based on a thickness of 5,000 ft. of Cenozoic deposits under the valley (Peterson, 1974) in addition to the present topographic relief of about 3,000 ft.

A marginal normal fault extends along the eastern front of Clarkston Mountain. It is covered by colluvial deposits and alluvial fans. A strike of approximately N. 20° W. can be inferred from the trend of the mountain front. A dip of 75° E. is indicated.
FIGURE 8. Marginal normal fault on western side of Clarkston Mountain; air view northeast. Wasatch fault extends along front of mountain.
by a poorly developed surface on a fault breccia located north of the mouth of Mikes Canyon.

Cambrian and Ordovician formations crop out along the eastern base of the mountain. Probably the Tertiary Salt Lake Formation is faulted down in the valley on the east. The Salt Lake crops out just beyond the eastern margin of the mapped area; however, only Quaternary units are exposed near the mountain front. No fault scarps have been recognized in the Quaternary units. Displacement on the eastern marginal normal fault may be as great as 11,000 ft. This estimate is based on a thickness of 8,000 ft. of Cenozoic deposits under the valley (Peterson and Oriel, 1970, p. 117) in addition to the present topographic relief of 3,000 ft.

Structural interpretations

Normal faults are the most prevalent structural features in the central part of Clarkston Mountain. These include both high-angle and low-angle normal faults. West-dipping, low-angle normal faults were originally thrust faults formed during regional compression. Later reversed movement changed the stratigraphic relationships across the faults to those characteristic of normal faults.

The upper plate of the northwest-trending, low-angle normal fault, between the northern margin of the mapped area and lower Gardner Canyon, was thrust eastward over the Cambrian Ute Formation. Reversed movement faulted the St. Charles Formation down to its present position above the Ute. In lower Elgrove Canyon, the upper plate of this fault was thrust eastward over the
Cambrian Bloomington Formation. Later reversed movement faulted the Cambrian St. Charles Formation down over the Bloomington. Likewise, on the ridge west of upper Elgrove Canyon, the Ordovician-Silurian Fish Haven-Laketown Formation was faulted down over the St. Charles Formation.

On the eastern side of the main ridge near the southeastern corner of the mapped area, the upper plate was thrust over the Ordovician Garden City Formation. Reversed movement faulted the St. Charles Formation down over the Garden City. Orthoquartzite of the Ordovician Swan Peak Formation, which crops out on top of the ridge, was thrust over the St. Charles and younger formations. Reversed movement faulted the Swan Peak down over the St. Charles.

Reversed movement on the northwest-trending, low-angle fault in the area east of the northwest-trending, high-angle normal fault involved two stages. The first stage utilized faults that are exposed on the peak, elevation 8,001 ft., on the main ridge. The St. Charles Formation was faulted down on the west over the Garden City Formation on the lower fault. Also, the Swan Peak Formation was faulted down on the west over the St. Charles on the upper fault. The upper fault, at the base of the orthoquartzite of the Swan Peak, is regarded as the major fault because of the greater stratigraphic separation. The second stage requires reconstruction of a normal fault above the main ridge. Such a fault must have joined the northwest-trending, low-angle normal fault west of the northwest-trending, high-angle normal fault. This fault is required to separate the Swan Peak Formation of the main ridge from the east-dipping Swan Peak of the upper plate of
the northwest-trending, low-angle normal fault located to the west. The movement of the second stage was down on the west. The Swan Peak of the main ridge remained at that location.

The upper plate of the northwest-trending, low-angle normal fault is faulted down on the southwest by the northwest-trending, high-angle normal fault in the area between Gardner and Precipitous Canyons. Also, it is faulted down on the southeast by the northeast-trending normal fault south of Gardner Canyon and down on the northwest by the northeast-trending normal fault in Precipitous Canyon. These relationships indicate that high-angle normal faulting followed early thrust faulting and later reversed movement on the plane of the northwest-trending, low-angle normal fault.

Normal faults, the main characteristic of the Basin and Range Province, have been related to east-west extension. Several models have been proposed to explain this extension. Stewart (1971) concluded that the normal faults of the Basin and Range Province form a system of horsts and grabens. He inferred zones of extension, beneath the grabens, related to a plastically extending substratum. Later, Stewart (1980) emphasized the tilted-block aspect of the Basin and Range Province. The blocks are systematically tilted outward on broad anticlinal structures. He invoked buoyancy to explain the systematic tilting. Wernicke (1981) related the normal faulting of the Basin and Range Province to a west-dipping, low-angle fault surface. The normal faults are believed to flatten in depth and to join the underlying fault. The basal fault represents a reactivated west-dipping thrust fault. A
firm conclusion for the origin of the normal faults of the Basin and Range Province has not been reached.

**Landslides**

**Gardner Canyon**

An isolated landslide mass of dolostone of the Nounan Formation is located on the divide between Gardner Canyon and the next canyon to the north. It rests directly on shale of the upper part of the Bloomington Formation. The landslide mass measures about 400 ft. in the east-west direction and about 500 ft. in the north-south direction. Internal stratigraphic continuity remains evident.

The landslide mass was derived from a cliff of dolostone located about 500 ft. up the divide to the north. The mass represents an erosional remnant of a landslide that occurred before deep erosion of Gardner Canyon and the small canyon to the north.

**Western front**

A landslide of dolostone of the St. Charles Formation is located at the western front of Clarkston Mountain between Gardner and Precipitous Canyons. The upper part of the landslide rests on the St. Charles Formation of the mountain. The lower part is covered by the Lake Bonneville Group. The exposed length of the landslide, perpendicular to the mountain front, is about 1,200 ft. Its width is about 1,200 ft. also. Dolostone blocks of the landslide are somewhat disarranged.

The rock of the landslide moved downslope to the west from the steep mountain front located immediately east of the major normal
fault that extends along the western side of Clarkston Mountain. Sliding was facilitated by many west-dipping, high-angle shears that cut the dolostone near the mountain front. The landslide predates the Lake Bonneville Group of Pleistocene age.
STRUCTURAL EVENTS

General Statement

The structural features of the mapped area are the result of two major tectonic disturbances. Thrust faults were produced by the Sevier orogeny (Armstrong, 1968, p. 451). They later underwent reversed movement with the result that they are now regarded as normal faults. The Sevier orogeny, based on regional evidence, began in Late Jurassic and ended in early Eocene.

Normal faults, in addition to those described previously, were produced by the Basin and Range event. It began in early Eocene and has continued into historic time in the region. Major normal faults are responsible for the topographic relief of the mountain relative to the major valleys both to the west and to the east.

Sevier Events

The Sevier orogeny was a time of east-west compression which produced eastward-directed thrust faults. The thrust faulting is thought to represent the culminating effect of compression (Armstrong and Cressman, 1963, p. 13).

Eastward thrusting, along west-dipping thrust faults, was the main result of the Sevier orogeny. The thrust faults underwent later reversed movement in the period of crustal extension which followed; therefore, they are classified as normal faults. The eastward thrusting also moved the Nounan Formation over the
underlying Bloomington Formation along the bedding-plane thrust fault.

Dating of the thrust faults of the north-central part of Clarkston Mountain depends on field evidence from areas where Mesozoic rocks are found. Northeast of Montpelier, Idaho, the Ephraim Conglomerate of Early Cretaceous age contains cobbles and boulders of orthoquartzite from the Ordovician Swan Peak Formation. Uplift and great erosion of the region to the west is indicated. Thus, Armstrong and Cressman (1963, p. 8-14) concluded that the Sevier orogeny began in late Jurassic. It may have continued into Paleocene (Armstrong and Cressman, 1963, p. 14).

**Basin and Range Events**

The normal faults of the mapped area are assigned to the Basin and Range event. This normal faulting is characteristic of the Basin and Range Province. It followed the folding and thrust faulting of the Sevier orogeny and has continued into historic time.

Early normal faulting occurred on west-dipping, low-angle thrust faults that formed during the Sevier orogeny. Reversed movement on these faults changed the stratigraphic relationships across the faults to those characteristic of normal faults. Thus, the western side is faulted down and commonly displays reverse drag. A major northwest-trending, low-angle normal fault is located on the western side of the central part of Clarkston Mountain. It is inferred to extend from the northern margin of the mapped area to the southern margin.
High-angle normal faulting, within the central part of Clarkston Mountain, followed the reversed movement on the northwest-trending, low-angle normal fault. The plane of this fault is faulted down on the west by a northwest-trending, high-angle normal fault. The plate above the northwest-trending, low-angle normal fault is also faulted down between two northeast-trending, high-angle normal faults.

Late normal faulting created the present-day relief between the marginal valleys and the mountain. It is also responsible for the north-south trend of the central part of Clarkston Mountain. The major normal fault on the western side of Clarkston Mountain is the Wasatch fault. This fault has been active into historic time in the region of north-central Utah as evidenced by fault scarps and continued seismic activity (Cook and Smith, 1967).

Evidence for dating the Basin and Range event is not available in the mapped area because of the absence of Tertiary stratigraphic units. Williams (1958, p.69) stated that the Eocene Wasatch Formation represents a piedmont deposit of regional extent in north-central Utah. The Salt Lake Formation, which overlies the Wasatch, consists of limestone, tuff, and conglomerate containing locally derived clasts. It is interpreted to have been deposited in valleys formed by normal faulting (Adamson, Hardy, and Williams, 1955, p. 21). Gazin (1959, p. 137) reported that the Norwood Tuff of Morgan Valley, east of Ogden, Utah, is of late Eocene age. It correlates with the lower part of the Salt Lake Formation. Thus, the normal faulting began in late Eocene. It has been active into
historic time in the region of north-central Utah as evidenced by recent fault scarps and continued seismic activity.
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GEOLOGIC MAP OF THE CENTRAL PART OF CLARKSTON MOUNTAIN, MALAD RANGE, UTAH