Structural Geology of the Southern Part of Elkhorn Mountain, Bannock Range, Idaho

George A. De Vries

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STRUCTURAL GEOLOGY OF THE SOUTHERN PART OF
ELKHORN MOUNTAIN, BANNOCK RANGE, IDAHO

by

George A. De Vries

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

1977
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George A. De Vries
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF PLATES</td>
<td>viii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ix</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Purpose and Scope</td>
<td>1</td>
</tr>
<tr>
<td>Location and Accessibility</td>
<td>1</td>
</tr>
<tr>
<td>Physiographic Features</td>
<td>3</td>
</tr>
<tr>
<td>Field Work</td>
<td>5</td>
</tr>
<tr>
<td>Previous Investigations</td>
<td>5</td>
</tr>
<tr>
<td>STRATIGRAPHIC UNITS</td>
<td>7</td>
</tr>
<tr>
<td>General Statement</td>
<td>7</td>
</tr>
<tr>
<td>Cambrian System</td>
<td>9</td>
</tr>
<tr>
<td>Ute Formation</td>
<td>9</td>
</tr>
<tr>
<td>Blacksmith Formation</td>
<td>10</td>
</tr>
<tr>
<td>Bloomington Formation</td>
<td>12</td>
</tr>
<tr>
<td>Nounan Formation</td>
<td>16</td>
</tr>
<tr>
<td>St. Charles Formation</td>
<td>18</td>
</tr>
<tr>
<td>Ordovician System</td>
<td>21</td>
</tr>
<tr>
<td>Garden City Formation</td>
<td>21</td>
</tr>
<tr>
<td>Swan Peak Formation</td>
<td>23</td>
</tr>
<tr>
<td>Ordovician-Silurian System</td>
<td>26</td>
</tr>
<tr>
<td>Fish Haven-Laketown Formation</td>
<td>26</td>
</tr>
<tr>
<td>Tertiary System</td>
<td>28</td>
</tr>
<tr>
<td>Salt Lake Formation</td>
<td>28</td>
</tr>
<tr>
<td>Volcanic rocks</td>
<td>31</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary System</td>
<td>34</td>
</tr>
<tr>
<td>Lake Bonneville Group</td>
<td>34</td>
</tr>
<tr>
<td>Colluvial deposits</td>
<td>35</td>
</tr>
<tr>
<td>Alluvial deposits</td>
<td>37</td>
</tr>
<tr>
<td><strong>STRUCTURAL FEATURES</strong></td>
<td></td>
</tr>
<tr>
<td>Regional Setting</td>
<td>38</td>
</tr>
<tr>
<td>Folds</td>
<td>38</td>
</tr>
<tr>
<td>Thrust Fault</td>
<td>39</td>
</tr>
<tr>
<td>Bedding-plane thrust fault</td>
<td>40</td>
</tr>
<tr>
<td>Structural interpretation</td>
<td>43</td>
</tr>
<tr>
<td>Normal Faults</td>
<td>45</td>
</tr>
<tr>
<td>General statement</td>
<td>45</td>
</tr>
<tr>
<td>Northwest-trending normal faults</td>
<td>46</td>
</tr>
<tr>
<td>North-trending normal faults</td>
<td>60</td>
</tr>
<tr>
<td>Northeast- to east-trending normal faults</td>
<td>75</td>
</tr>
<tr>
<td>Structural interpretation</td>
<td>78</td>
</tr>
<tr>
<td>Landslide</td>
<td>80</td>
</tr>
<tr>
<td><strong>STRUCTURAL EVENTS</strong></td>
<td>85</td>
</tr>
<tr>
<td>General Statement</td>
<td>85</td>
</tr>
<tr>
<td>Laramide Events</td>
<td>85</td>
</tr>
<tr>
<td>Basin and Range Events</td>
<td>87</td>
</tr>
<tr>
<td><strong>LITERATURE CITED</strong></td>
<td>89</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Formations of Paleozoic age, southern Elkhorn Mountain and vicinity</td>
<td>8</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Index map of part of southeastern Idaho showing location of the southern part of Elkhorn Mountain</td>
<td>2</td>
</tr>
<tr>
<td>2. General view of part of mapped area showing Elkhorn Peak and Kent Peak; view northeast</td>
<td>4</td>
</tr>
<tr>
<td>3. Ute, Blacksmith, and Bloomington Formations on western side of Limekiln Canyon; view west</td>
<td>11</td>
</tr>
<tr>
<td>4. Southeastern face of Kent Peak showing Nounan Formation overlying Bloomington Formation with thrust fault at contact; view northwest</td>
<td>15</td>
</tr>
<tr>
<td>5. Contact of Swan Peak and Fish Haven-Laketown Formations on hill east of Elkhorn Peak; view east from Elkhorn Peak</td>
<td>29</td>
</tr>
<tr>
<td>6. Volcanic rocks on eastern side of lower Monson Canyon; view east</td>
<td>33</td>
</tr>
<tr>
<td>7. Colluvial deposits, in meadow, near head of Heath Hollow; view northeast</td>
<td>36</td>
</tr>
<tr>
<td>8. Bedding-plane thrust fault on northwestern side of Elkhorn Creek; view northwest</td>
<td>42</td>
</tr>
<tr>
<td>9. Northwest-trending normal fault on southeastern face of Kent Peak; view northwest</td>
<td>49</td>
</tr>
<tr>
<td>10. Fault breccia on western side of Secret Canyon along northwest-trending normal fault of Old Canyon; view west</td>
<td>52</td>
</tr>
<tr>
<td>11. Northwest-trending normal fault of Old Canyon; view northwest from head of Old Canyon</td>
<td>53</td>
</tr>
<tr>
<td>12. Marginal northwest-trending normal fault in vicinity of Elkhorn Creek; view northwest across Elkhorn Creek</td>
<td>57</td>
</tr>
<tr>
<td>13. Northwest-trending normal fault that dips southwest near mouth of Kent Canyon; view east-southeast across Kent Canyon</td>
<td>59</td>
</tr>
</tbody>
</table>


**LIST OF FIGURES (Continued)**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.</td>
<td>Marginal north-trending normal fault along western front of southern Elkhorn Mountain in vicinity of Elkhorn Creek; view east</td>
</tr>
<tr>
<td>15.</td>
<td>North-trending normal fault in Monson Canyon; view north</td>
</tr>
<tr>
<td>16.</td>
<td>Breccia on north-trending normal fault on western side of Limekiln Canyon near its head; view north</td>
</tr>
<tr>
<td>17.</td>
<td>North-trending normal fault east of Secret Canyon; view north</td>
</tr>
<tr>
<td>18.</td>
<td>North-trending normal fault across ridge north of Station Canyon; view northwest across Station Canyon</td>
</tr>
<tr>
<td>19.</td>
<td>North-trending normal fault on eastern side of southern Elkhorn Mountain in area of Birch Spring; view west-northwest</td>
</tr>
<tr>
<td>20.</td>
<td>Landslide block of Swan Peak Formation along mountain front west of Kent Canyon; view east-southeast from Monson Canyon</td>
</tr>
<tr>
<td>21.</td>
<td>Landslide block along front of southern Elkhorn Mountain west of Secret Canyon; view west</td>
</tr>
<tr>
<td>22.</td>
<td>Glide plane of landslide block along mountain front west of Secret Canyon; view southwest</td>
</tr>
</tbody>
</table>
# LIST OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geologic map of the southern part of Elkhorn Mountain, Bannock Range, Idaho</td>
<td>Pocket</td>
</tr>
</tbody>
</table>
ABSTRACT

Structural Geology of the Southern Part of
Elkhorn Mountain, Bannock Range, Idaho

by
George A. De Vries, Master of Science
Utah State University, 1977

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

The area of southern Elkhorn Mountain, a previously unmapped
area, is located north of Malad City, Idaho, in the Bannock Range.
The mapped area is within the Basin and Range province. The mapped
area measures 5.9 miles in the north-south direction and approximately
8.8 miles in the east-west direction.

The oldest stratigraphic unit, in the mapped area, is the Ute
Formation of Middle Cambrian age. Other units of Cambrian age, in
ascending order, are: Blacksmith Formation, Bloomington Formation,
Nounan Formation, and St. Charles Formation. The units of Ordovician
age are the Garden City and the Swan Peak Formations. The youngest
unit of Paleozoic age, in the mapped area, is the Fish Haven-Laketown
Formation of Ordovician-Silurian age. The Paleozoic units are composed
predominantly of limestone and dolomite; some units contain varied
amounts of quartzite and shale. The Salt Lake Formation and associ-
ated volcanic rocks of Tertiary age are present locally in the mapped
area. Lake Bonneville Group, colluvial deposits, and alluvial deposits,
all of Quaternary age, are also present.
A thrust fault, folds, and normal faults are present in the mapped area. A bedding-plane thrust fault is present between the Bloomington and Nounan Formations. A broad anticline is suggested by the attitudes of the Paleozoic rocks of southern Elkhorn Mountain. Small-scale folds are exposed locally. The normal faults are of two major trends, northwest and north. These fault sets are contemporaneous and they cut Salt Lake Formation. These sets intersect and form numerous fault blocks. The normal faults cut the thrust fault and the fold. Thus, the thrust fault and the fold are isolated within various fault blocks throughout the area. The marginal normal faults are responsible for the present topography. Remnant blocks of a major landslide are also present.

The structural features of the area are the result of two major structural events, the older Laramide orogeny and the more recent Basin and Range faulting. The Laramide orogeny, active from Late Jurassic to early Eocene, was responsible for the thrust faulting and folding. The Basin and Range faulting, active from Oligocene to Holocene, was responsible for the normal faults and the landslide. Marginal normal faults are probably active at the present time.

(101 pages)
INTRODUCTION

Purpose and Scope

The purpose of this investigation was to identify the structural features and to prepare a geologic map of southern Elkhorn Mountain, southeastern Idaho (Plate 1). The stratigraphic units were mapped and their interrelationships determined as a means of identifying the structural features. The structural features were then related to the structural events of the region.

Location and Accessibility

The mapped area is located north of Malad City, Idaho, in the central Bannock Range (Figure 1). Elkhorn Peak, 10 miles northwest of Malad City, is 0.1 mile south of the northern boundary of the mapped area.

The mapped area is represented on the Elkhorn Peak and the Malad Summit Quadrangles of the Geological Survey of the U. S. Department of the Interior. It is between lat. 42°15'00" N. and lat. 42°20'08" N. and between long. 112°12'15" W. and long. 112°22'30" W. (Plate 1). The area measures 5.9 miles in the north-south direction and approximately 8.8 miles in the east-west direction.

The area is accessible on the east by Interstate 15 and U.S. Highway 191 (Figure 1). U.S. Highway 191 is now a frontage road of Interstate 15 and is not shown on Figure 1. Unimproved roads and four-wheel drive trails provide access on the north and east of
Figure 1. Index map of part of southeastern Idaho showing location of the southern part of Elkhorn Mountain. Area of Plate 1 is shown.
Elkhorn Mountain from Interstate 15 via Mill Canyon, South Canyon, Station Canyon, and Old Canyon (Plate 1). Access on the south and west is provided by the Malad-Daniels paved road (Figure 1). Joining the Malad-Daniels road are unimproved roads and four-wheel drive trails providing access via Secret Canyon, Kent Canyon, Monson Canyon, Elkhorn Creek, Danish Canyon, and Bill Morgan Canyon (Plate 1).

**Physiographic Features**

Southern Elkhorn Mountain is within the Basin and Range province. It is located north and northeast of Malad Valley (Figure 1). Southern Elkhorn Mountain is separated from the remainder of the Bannock Range to the southeast by a valley. A low divide, at the head of this valley, separates Marsh Valley, to the northeast, from Malad Valley to the south (Figure 1). To the west and southwest of southern Elkhorn Mountain is the Little Malad River. Much of the area of Malad Valley is below the level occupied by Pleistocene Lake Bonneville. To the north of the mapped area is Wakley Peak, 8,801 feet, and the northern continuation of the Bannock Range. The mapped area and the area of Wakley Peak form Elkhorn Mountain.

Elkhorn Peak, at an elevation of 9,095 feet, is the highest peak in the mapped area. Kent Peak, at an elevation of 8,451 feet, is the second highest peak in the area (Figure 2). There are more than 20 peaks over 7,000 feet in elevation joined by ridges many of which also exceed 7,000 feet in elevation. The lowest elevation, in the mapped area, is 4,820 feet on the Little Malad River near the southwestern corner. The relief, in the mapped area, is 4,275 feet.
Figure 2. General view of part of mapped area showing Elkhorn Peak and Kent Peak; view northeast. Elkhorn Peak is on left; Kent Peak is on right. Marginal northwest-trending normal fault extends along mountain front.
There are numerous springs, in the area, most of which are located in or near the bottoms of major canyons (Plate 1). Many springs, found in the area of Paleozoic rocks, issue from just below the top of the Bloomington Formation.

Field Work

Field investigations were conducted during the summers of 1975 and 1976. Geologic features were plotted in the field on vertical aerial photographs at a scale of 1:14,850. This information was then transferred to a base map at a scale of 1:12,000 (Plate 1). The base map was prepared by enlarging parts of two 1:24,000 quadrangles of the Geological Survey of the U. S. Department of the Interior. The maps are the Elkhorn Peak and Malad Summit Quadrangles, Idaho.

Previous Investigations

The study area had not been the subject of any previous geologic mapping. James (1973, p. 239-240) measured a section of the Swan Peak Formation of Ordovician age 1.0 mile east of Elkhorn Peak. A brief description of the geology is contained in an Environmental Impact Statement prepared by the Forest Service of the U.S. Department of Agriculture (1975, p. 17) for a proposed ski lift in South Canyon.

Much of the Cambrian stratigraphy of the region was first studied and described by Walcott (1908) and later studied and described by Maxey (1941). Williams (1948) described the Paleozoic rocks and the structure of Cache Valley, Utah. Hanson (1949), working in the southern Malad Range, and Beus (1968), working in the area of Samaria
Mountain, described the structure and the Paleozoic rocks of their respective areas. Adamson, Hardy, and Williams (1955) described the Tertiary rocks of Cache Valley, Utah and Idaho.

More recent studies of a structural nature were conducted by Shearer (1975) in the Malad Summit Quadrangle, Idaho, which borders the mapped area on the east. Bordering the Malad Summit Quadrangle on the east is the Oxford Peak area, Idaho, which was mapped by Raymond (1971). Axtell (1967) mapped the northern Malad Range, Idaho, and Murdock (1961) mapped the Weston Canyon area, Idaho. Both areas are southeast of the mapped area. Armstrong and Cressman (1963) worked on the Bannock thrust zone east of the mapped area. Trimble and Carr (1976) described the structure and stratigraphy of the Rockland and Arbon Quadrangles, Idaho, located northwest of but not bordering the mapped area.
STRATIGRAPHIC UNITS

General Statement

The Paleozoic units of the mapped area consist of detrital and carbonate rocks. These units are briefly outlined in Table 1. The oldest unit is the Ute Formation of Middle Cambrian age. Other units of Cambrian age, in ascending order, are: Blacksmith Formation, Bloomington Formation, Nounan Formation, and St. Charles Formation.

The Ordovician units are the Garden City and Swan Peak Formations.

The youngest Paleozoic unit, in the mapped area, is the Fish Haven-Laketown Formation of Ordovician-Silurian age. Although the area is cut by numerous faults, a complete thickness of each formation is exposed. Similar Paleozoic formations are present, north of the mapped area, in the vicinity of Wakley Peak (Dane Jensen, 1976, personal communication). Precambrian and lower Cambrian formations are present to the east in the Malad Summit Quadrangle (Shearer, 1975, p. 8) and in the Oxford Peak Quadrangle (Raymond, 1971, p. 5).

The Salt Lake Formation of Tertiary age is present at lower elevations around Elkhorn Mountain. Volcanic rocks of Tertiary age are exposed in the vicinity of lower Monson Canyon. The contact of the Salt Lake Formation with the Paleozoic rocks is in some places an unconformity and in other places a fault.

The Lake Bonneville Group of Pleistocene age is found, in the mapped area, below 5,135 feet in elevation. It rests unconformably on older Paleozoic and Tertiary units. Also present are alluvial and
<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Haven-Laketown</td>
<td>Light- to dark-gray dolomite</td>
<td>1,470&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Swan Peak</td>
<td>White orthoquartzite</td>
<td>868&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Garden City</td>
<td>Light-brown orthoquartzite and gray shale with minor limestone</td>
<td>1,805&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Dark-gray dolomite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gray limestone with interbedded chert</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gray limestone with intraformational conglomerate</td>
<td></td>
</tr>
<tr>
<td>St. Charles</td>
<td>Gray dolomite</td>
<td>1,073&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Upper member</td>
<td>Gray limestone</td>
<td>998&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Worm Creek Member</td>
<td>Light-brown orthoquartzite with gray shale and limestone</td>
<td>75&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nounan</td>
<td>Gray limestone and dolomite with some red siltstone and sandstone</td>
<td>886&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Light- to medium-gray dolomite</td>
<td></td>
</tr>
<tr>
<td>Bloomington</td>
<td>Gray limestone</td>
<td>1,495&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Olive-green shale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gray limestone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Olive-green shale</td>
<td></td>
</tr>
<tr>
<td>Blacksmith</td>
<td>Gray limestone and dolomite</td>
<td>444&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ute</td>
<td>Gray limestone and olive-green shale</td>
<td>745&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Samaria Mountain (Beus, 1968).
<sup>b</sup>Elkhorn Mountain (James, 1973).
<sup>c</sup>Clarkston Mountain (Hanson, 1949).
<sup>d</sup>Two Mile Canyon (Axtell, 1967).
<sup>e</sup>High Creek (Maxey, 1958).
colluvial deposits of Quaternary age that rest unconformably on older rocks.

**Cambrian System**

**Ute Formation**

The term "Ute Formation" was used by Walcott (1908, p. 7-8) to identify a unit of shale and limestone in Blacksmith Fork Canyon east of Hyrum, Utah. The Ute Formation at High Creek, Utah, was described by Maxey (1958, p. 653-654) as consisting of 745 feet of interbedded gray limestone and green arenaceous shale. Hanson (1949, p. 14-15) described an incomplete section, which is 439 feet thick, at Clarkston Mountain. He described the Ute, in ascending order, as follows:

1. thin-bedded, fine-grained, medium-gray limestone with silty partings, 325 feet thick, and
2. thin-bedded medium-gray limestone with interbedded olive-green shale, 114 feet thick.

The Ute Formation conformably overlies the Langston Formation and is conformably overlain by the Blacksmith Formation (Maxey, 1958, p. 671-672). The Ute Formation is of Middle Cambrian age (Maxey, 1958, p. 672).

The Ute Formation is exposed, in the mapped area, only in a small area along the mountain front between Kent Canyon and Monson Canyon (Plate 1). The base is not exposed. The lower Ute is predominantly green shale with minor limestone. It is overlain by 10 to 15 feet of ledge-forming limestone. The upper part of the Ute consists of slope-forming thin-bedded limestone with interbedded green and brown shale. The contact with the overlying Blacksmith
Formation is placed at the base of a ledge-forming limestone unit which overlies the slope-forming limestone and shale of the upper Ute (Figure 3).

The limestone of the Ute Formation is generally thin- to medium-bedded, light- to medium-gray, oolitic limestone with a few oncolites. The limestone of the lower shale unit is generally laminated rather than oolitic.

The shale of the lower unit is olive green and similar to the shale of the younger Bloomington Formation. The shale of the Ute, however, is generally more silty and sandy and generally less fissile than the shale of the Bloomington. The green and brown shale of the upper part of the Ute is generally thin bedded.

Blacksmith Formation

Walcott (1908, p. 7) named the Blacksmith Formation for its exposures in the southern Bear River Range at Blacksmith Fork Canyon 15 miles east of Hyrum, Utah. The Blacksmith Formation at High Creek was described as consisting of 485 feet of light- to medium-gray dolomite with minor dark-bluish-gray limestone (Maxey, 1958, p. 653). At Clarkston Mountain, Hanson (1949, p. 17) described the Blacksmith as consisting of 444 feet of thin- to thick-bedded, medium-gray, oolitic limestone.

The Blacksmith Formation conformably overlies the Ute Formation and is conformably overlain by the Bloomington Formation (Maxey, 1958, p. 671-672). The Blacksmith Formation is of Middle Cambrian age (Hanson, 1949, p. 19).
Figure 3. Ute, Blacksmith, and Bloomington Formations on western side of Limekiln Canyon; view west. Ute (Su), Blacksmith (Sbl), and Bloomington (Sbo) dip gently north.
The Blacksmith Formation, like the Ute Formation, is found only along the mountain front between Kent Canyon and Monson Canyon. The contact with the underlying Ute Formation is placed above the slope-forming upper limestone unit of the Ute at the base of the ledge-forming limestone unit of the Blacksmith (Figure 3). The Blacksmith is approximately 400 feet thick in the mapped area. It is composed entirely of ledge-forming limestone and dolomite. Limestone is predominant.

The lower 300 feet of the Blacksmith Formation is predominantly medium-bedded, medium-gray, oolitic limestone with minor dolomite near the base. Unidentified trilobite fragments and fragments of an orthid brachiopod are found near the base. Oncolites are found throughout the formation but are most common in the lower part.

The upper 100 feet of the Blacksmith Formation is interbedded limestone and dolomite. The limestone of the upper part is similar to the limestone of the lower part. The dolomite of the upper part is medium bedded and light gray. The upper contact is placed below the green shale of the slope-forming lower member of the Bloomington Formation and above the ledge-forming limestone and dolomite of the Blacksmith Formation.

Bloomington Formation

Walcott (1908, p. 7) defined the Bloomington Formation for its exposures in the Bear River Range 6 miles west of Bloomington, Idaho. Maxey (1958, p. 651-653) recognized three members at High Creek. The three members, in ascending order, are: (1) Hodges Shale,
(2) limestone member, and (3) Calls Fort Shale. At High Creek, the Hodges Shale consists of 595 feet of thin-bedded, olive-green to pink, calcareous shale with interbedded thin- to thick-bedded light- to dark-gray limestone. The lower 200 feet of Hodges Shale consists of thin-bedded, fine-crystalline, dark-gray limestone. The middle limestone member consists of 720 feet of thin- to thick-bedded, fine-crystalline, medium- to dark-gray, oolitic limestone. The Calls Fort Shale consists of 180 feet of thin-bedded olive-green shale with some conglomeratic limestone beds. The total thickness of Bloomington Formation at High Creek is 1,495 feet. The Bloomington is 429 feet thick in the area of Clarkston Mountain (Hanson, 1949, p. 19-22) and 431 feet thick at Two Mile Canyon (Axtell, 1967, p. 58).

The Bloomington Formation conformably overlies the Blacksmith Formation and, where not interrupted by thrust faulting, is conformably overlain by the Nounan Formation (Maxey, 1958, p. 672-673). The Bloomington Formation is late Middle Cambrian in age (Denson, 1942, p. 24).

The Bloomington Formation is exposed, in the mapped area, along the mountain front from Secret Canyon on the southeast to Elkhorn Creek and Bill Morgan Canyon on the northwest (Plate 1). It forms low rolling ridges and valleys in the area of Co-op Canyon, and broad ridges in the area between Kent Canyon and Monson Canyon (Figure 3). The Bloomington, where present along the southwestern front of southern Elkhorn Mountain, is cut by numerous normal faults.

The lower contact of the Bloomington with the underlying Blacksmith is exposed in the fault-bounded block that contains the Ute and Blacksmith Formations between Kent Canyon and Monson Canyon.
(Figure 3). The contact is distinct and easily recognizable in the field. Ledge-forming limestone of the Blacksmith occurs below slope-forming shale and interbedded limestone of the Bloomington (Figure 3). The contact is placed at the first occurrence of green shale. The lower Bloomington consists of fissile olive-green shale with interbedded thin-bedded light-gray limestone. Shale increases upward until the unit is predominantly shale with minor limestone. Some shale in the lower part is dark green. The contact of the lower Bloomington with the middle Bloomington is not exposed in this area nor is it exposed elsewhere in the mapped area. The exposed section of lower Bloomington is approximately 540 feet thick.

The middle member of the Bloomington is not well defined in the mapped area. A limestone unit is exposed on the western side of Kent Canyon and is conformable and stratigraphically below the green shale of the upper Bloomington (Figure 4). The limestone is thin to medium bedded and light to medium gray. It has brown and green shale partings. The base is not exposed and the upper contact is gradational with olive-green shale of the upper member. The exposed section of middle Bloomington is approximately 680 feet thick.

The upper Bloomington is exposed in Bill Morgan Canyon, in Elkhorn Creek, in Monson Canyon, in the western ridges of Limekiln and Kent Canyons, in the low valleys and ridges in the area of Co-op Canyon, and in Secret Canyon. The section is complete only on the western ridge of Kent Canyon above the middle member (Figure 4). The lower contact is gradational. The upper Bloomington consists of
Figure 4. Southeastern face of Kent Peak showing Nounan Formation overlying Bloomington Formation with thrust fault at contact; view northwest. Nounan (6n) overlies Bloomington (6bo). Garden City Formation (Ogc) is at right. Northwest-trending normal faults are shown.
medium-bedded, fissile, olive-green shale with some beds of light-to medium-gray limestone. Limestone becomes predominant in the upper 100 feet. Locally the shale and limestone beds of the upper member are contorted. The upper contact of the upper Bloomington is a bedding-plane thrust fault. The thrust fault is present throughout the area and places the ledge-forming dolomite of the Nounan Formation above the slope-forming shale and limestone of the Bloomington Formation. The upper Bloomington is approximately 300 feet thick in the mapped area. The total thickness of the Bloomington Formation is approximately 1,520 feet.

The Bloomington is also exposed, along the mountain front, in canyon bottoms southwest of the mouth of Secret Canyon. The Bloomington, in this area, is mostly covered by Salt Lake Formation and colluvium.

Some springs, in the mapped area, issue from just below the Bloomington-Nounan contact, about where shale becomes predominant. Such springs are located in Elkhorn Creek, in Limekiln Canyon, near the top of the western ridge of Kent Canyon, northwest of Co-op Canyon, and in Secret Canyon.

**Nounan Formation**

Walcott (1908, p. 6-7) defined the Nounan Formation for its exposures on Soda Peak, in the northern Bear River Range, south of Soda Springs, Idaho. Maxey (1958, p. 651) recognized 1,124 feet of Nounan at High Creek, in the Bear River Range, 7 miles northeast of Richmond, Utah. Hanson (1949, p. 22-30) described 1,408 feet of
Nounan at Clarkston Mountain. This section may have been shortened by faulting. He described the Nounan, in ascending order, as follows: (1) thick-bedded light-gray dolomite, 908 feet thick, and (2) thin- to thick-bedded light- to medium-gray limestone, 500 feet thick.

The Nounan Formation conformably overlies the Bloomington Formation (Maxey, 1958, p. 673) and is conformably overlain by the Worm Creek Quartzite Member of the St. Charles Formation (Hanson, 1949, p. 26). The Nounan Formation is Late Cambrian in age (Williams, 1948, p. 1134).

The Nounan Formation, in the mapped area, forms resistant ledges at higher elevations both to the northwest and southeast of Kent Peak (Figure 4). It crops out on the western side of the mapped area and near the southeastern corner of the mapped area. It forms the western ridge of Secret Canyon and is down faulted along the mountain front near Co-op Canyon.

A complete Nounan section is probably not exposed, in the mapped area, due to a bedding-plane thrust fault at the base of the exposed Nounan. A section that is not displaced by normal faults is present in the area of Elkhorn Creek and Danish Canyon. The thickness in that area, from the thrust fault to the base of the St. Charles, is approximately 800 feet. The lower Nounan on the southern ridge of Elkhorn Peak, where the thrust fault seems concordant, consists of a lower, thin- to medium-bedded, medium-gray dolomite overlain by a cliff-forming, thick-bedded, light-gray dolomite that weathers to pinnacles in many places. The lower Nounan, at the thrust fault along Elkhorn Creek, is apparently the pinnacled dolomite.
The upper Nounan is lithologically variable throughout the mapped area. It is predominantly limestone with numerous beds of medium-gray and light-brown limestone and some beds of resistant dolomite. The limestone, which is usually poorly exposed, is thin to medium bedded and light to medium gray. It has red, brown, and light-brown shale partings. The talus which covers much of the limestone of the upper Nounan consists of limestone, dolomite, shale, siltstone, and sandstone. The shale, siltstone, and sandstone are red, brown, and light brown. Above the talus-covered slopes, the upper Nounan contains some light-brown to white quartzite, which is partly calcareous. The quartzite is not considered to be Worm Creek because similar quartzite is found at various stratigraphic positions throughout the mapped area. The rocks, in the southeastern part of the mapped area, from Co-op Canyon to Birch Spring are upper Nounan.

The contact with the overlying St. Charles is placed at the base of the Worm Creek Quartzite. In the eastern part of the mapped area, the contact is above a 15-foot bed of white to white-gray limestone.

**St. Charles Formation**

Walcott (1908, p. 6) defined the St. Charles Formation for its exposures in the Bear River Range west of St. Charles, Idaho. Richardson (1913, p. 408) defined the basal Worm Creek Quartzite Member. Williams (1948, p. 1135) recognized a middle limestone member and an upper dolomite member in the Logan Quadrangle. Hanson (1949, p. 30-38) described 1,073 feet of St. Charles in the area of
Clarkston Mountain. He described three members, in ascending order, as follows: (1) Worm Creek Quartzite Member, (2) middle member, and (3) upper member. The Worm Creek consists of 75 feet of medium-grained light-brown quartzite. The middle member consists of 368 feet of silty limestone with some light-brown shale. The upper member consists of 630 feet of cliff-forming light- to medium-gray dolomite.

Axtell (1967, p. 60) measured 704 feet of St. Charles in a composite section from Two Mile Canyon and Four Mile Canyon in the northern Malad Range. Trimble and Carr (1976, p. 15-17) described the St. Charles, in the Rockland and Arbon Quadrangles, Idaho, approximately 50 miles to the northwest. They described the Worm Creek as consisting of 1,300 feet of quartzite and the upper member as consisting of 200 to 300 feet of dolomite.

The Worm Creek Quartzite Member of the St. Charles Formation conformably overlies the Nounan Formation (Hanson, 1949, p. 26). Williams (1948, p. 1135) considered the upper contact of the St. Charles with the overlying Garden City Formation to be disconformable. Hanson (1949, p. 38) and Ross (1951, p. 6) considered the upper contact to be conformable. The St. Charles Formation is Late Cambrian in age (Williams, 1948, p. 1135).

The St. Charles Formation is exposed above the Nounan Formation on the west, in isolated outcrops below the Garden City Formation on Elkhorn Ridge and in Little Station Canyon, and in a complete section to the southeast in the area of the Dove survey station. The section near the Dove survey station is approximately 800 feet thick.
The Worm Creek Quartzite Member is approximately 100 feet thick in the mapped area. The lower contact is placed at the top of a white limestone bed. The Worm Creek Quartzite Member consists of cross-bedded, light-brown, calcareous quartzite in the lower part with white quartzite and beds of brown quartzite and gray limestone in the upper part. The upper 10 feet of Worm Creek is covered by talus, which contains chips of gray shale. The Worm Creek is easily distinguished from the younger Swan Peak Formation because the Worm Creek is thinner and lacks a vitreous appearance.

The contact of the Worm Creek and the limestone of the middle member is placed above the 10-foot covered interval. The middle member of the St. Charles consists of well-bedded, thin-bedded, argillaceous limestone with brown shale partings and brown to black chert nodules. The limestone of the middle member weathers platy and forms slopes. The middle member is approximately 300 feet thick in the area of the Dove survey station.

The contact of the limestone of the middle member and the dolomite of the upper member is placed at the first occurrence of a ledge-forming medium-gray dolomite. The contact is distinct. The upper member is approximately 400 feet thick. The upper member is a ledge-forming, medium- to thick-bedded, medium-crystalline, light- to medium-gray dolomite. The dolomite is darker gray in the eastern part of the mapped area and lighter gray in the western and central parts. The upper contact is distinct in both areas. It is placed above the cliff-forming dolomite of the upper St. Charles at the
first occurrence of slope-forming, thin-bedded, light-gray limestone of the lower Garden City.

Ordovician System

Garden City Formation

Richardson (1913, p. 408-409) defined the Garden City Formation for its exposures in Garden City Canyon west of Garden City, Utah. He described 1,000 feet of thin- to thick-bedded gray limestone.

Ross (1951, p. 7-9) defined the Garden City, in ascending order, as follows: (1) lower member, approximately the lower two-thirds of the formation, as consisting of "a complex of interbedded layers of intraformational conglomerate, muddy limestone, and crystalline limestone with some layers of compact, thinly-laminated, crypto-crystalline limestone," and (2) upper member as consisting of thin-bedded crystalline limestone with much black chert in the form of "nodules, stringers, and discontinuous beds." Ross (1951, p. 11-13) measured 1,222 feet of Garden City at the type section in Garden City Canyon. He measured 1,764 feet on the western side of Clarkston Mountain (Ross, 1951, p. 18-19). Hanson (1949, p. 40-43) described 1,805 feet of Garden City in the area of Clarkston Mountain.

The Garden City is apparently conformable over the St. Charles (Ross, 1951, p. 6), although it may be disconformable (Williams, 1948, p. 1136). The contact with the overlying Swan Peak is conformable (Williams, 1948, p. 1137). The Garden City Formation is considered to be Early and Middle Ordovician in age; only the upper 30 to 50 feet is Middle Ordovician (Ross, 1951, p. 31-32).
The Garden City Formation, in the mapped area, is exposed on top of Elkhorn Peak, along the northwestern segment of Kent Canyon near its head, and in numerous areas to the west and northwest. The Garden City is nowhere found in a continuous section. From a composite section, in the mapped area, the Garden City is at least 1,200 feet thick.

The lower contact is distinct in Little Station Canyon, in the area south of Old Canyon, and on Elkhorn Peak. Some limestone is found in the dolomite of the upper St. Charles but the contact is placed at the base of the first substantial slope-forming limestone. The lower Garden City consists of thin-bedded light- to medium-gray limestone with much intraformational conglomerate, brown shale partings, and some black chert. Fossil fragments and traces of a planispiral gastropod are present throughout the formation but are more common in the lower part.

The contact between the lower and upper Garden City is gradational. The upper Garden City consists of thin-bedded light- to medium-gray limestone with much black chert, brown shale partings, and some intraformational conglomerate. The Garden City Formation can be generally described as consisting of limestone with much intraformational conglomerate in the lower part and limestone with much black chert in the upper part.

At Clarkston Mountain, Hanson (1949, p. 11, plate 4) described the upper 152 feet of Garden City as consisting of thick-bedded medium-gray dolomite. Ross (1951, p. 18) described the upper 157 feet, from the same area, as consisting of light-gray limestone and
dolomite. This dolomite near the top of the Garden City seems to be discontinuous over the area of northeastern Utah and southeastern Idaho and may be due to dolomitization along or near faults (Ross, 1951, p. 8-9). In the mapped area, dolomite is found at various stratigraphic positions and at various locations in the Garden City. The upper Garden City, on the northern side of the upper parts of Kent Canyon, Station Canyon, and South Canyon, is limestone as high as the contact of the Swan Peak. The upper Garden City, near the head of Heath Hollow, is limestone that contains some dolomite in the upper 20 feet. The Garden City, in the area of Kent Peak near the fault which passes through Kent Peak (Figure 4) and in the fault-bounded block near the head of Evans and Bill Williams Canyon, contains much dolomite, although not necessarily near the top. Both limestone and dolomite are found at different localities in the upper Garden City and along faults within the Garden City. Sufficient data are not available to resolve the problem of the origin, syngenetic or epigenetic, of the dolomite or its relationship to the faults.

The upper contact with the overlying Swan Peak Formation is placed above the limestone or dolomite at the first occurrence of shale or quartzite. Where not exposed, the contact is located by a slope change formed by the weathering of the less resistant lower black shale of the Swan Peak.

Swan Peak Formation

The Swan Peak Formation was named for its exposures on Swan Peak, in the Bear River Range, 0.5 mile south of the Utah–Idaho border.
(Richardson, 1913, p. 409). Williams (1948, p. 1136-1137) described three members in the Logan Quadrangle. At Green Canyon, Williams (1948, p. 1136) described the members, in ascending order, as follows: (1) black shale, 174 feet thick, (2) brown quartzite, 28 feet thick, and (3) brown quartzite, 137 feet thick. The middle and upper members contain fucoidal markings (Williams, 1948, p. 1136). Ross (1951, p. 18) measured 570 feet of Swan Peak and Hanson (1949, p. 12, Plate 4) measured 606 feet of Swan Peak. Both thicknesses were from Clarkston Mountain. Both Hanson (1949, p. 12, Plate 4) and Ross (1951, p. 8) found that the upper member was in fault contact with the overlying formations in that area. Detailed investigations of the Swan Peak Formation have recently been completed by VanDorston (1969), Francis (1972), Schulingkamp (1972), and James (1973).

The lower contact is conformable with the underlying Garden City (Williams, 1948, p. 1137). The contact with the overlying Fish Haven-Laketown Formation is disconformable (VanDorston, 1969, p. 22; James, 1973, p. 75). The Swan Peak is Middle Ordovician in age (Ross, 1951, p. 33).

The most detailed and most recent study of the Swan Peak Formation was done by James (1973). James (1973, p. 239-240) measured a section of Swan Peak in the mapped area. The section is located 1.0 mile east of Elkhorn Peak, south of the junction of T. 12-13 S. and R. 35-36 E. The Swan Peak consists of 868 feet of orthoquartzite and shale in the mapped area. The lower 118 feet is covered by talus. The talus contains fine- to medium-grained brown orthoquartzite and
yellowish-brown to medium-gray shale. Shale is predominant in the lower member. The contact of the lower and upper members is covered by talus. The middle member apparently does not exist in the mapped area. The upper member consists of 750 feet of fine-grained, white to light-brown, vitreous orthoquartzite. The upper member is parallel bedded with beds 0.5 to 2.5 feet thick. The upper orthoquartzite weathers blocky. Some beds show burrows (James, 1973, p. 239) but the Swan Peak, in the mapped area, lacks the fucoidal markings characteristic of the Swan Peak in the Logan Quadrangle.

The lower contact of the Swan Peak with the underlying Garden City, in the mapped area, is generally covered by talus of the lower member. The lower contact is placed at the top of the limestone or dolomite of the Garden City, which is also the base of the shale and quartzite of the Swan Peak. In the absence of good exposures, the lower contact is placed at the slope break between the underlying limestone or dolomite of the upper Garden City and the overlying shale of the lower Swan Peak. The upper contact of the Swan Peak with the overlying Fish Haven-Laketown is placed at the top of the orthoquartzite, which is also the base of the dolomite. The upper contact is, in some cases, covered by float of the less resistant dolomite. A change in slope is also present at the upper contact. This change in slope is conspicuous and, where the contact is not clearly exposed, is used for mapping purposes. James (1973, p. 75) reported reworked pebbles of orthoquartzite in the lower 5.0 feet of the Fish Haven-Laketown north of the mapped area. He believed that these pebbles...
are evidence for a disconformity. Such pebbles are not present in the mapped area.

The Swan Peak is exposed, in the mapped area, to the north and east of Kent Canyon (Plate 1). Only four exposures are found elsewhere. One is in a landslide block west of the mouth of Kent Canyon, one is in a landslide block east of Co-op Canyon, one is on the ridge southwest of the head of Kent Canyon, and the other is near the southern map boundary east of the mouth of Secret Canyon. All these exposures are in fault contact with units of Cambrian age. The Swan Peak forms most of the peaks and high ridges in the area of its exposure. Its conspicuous white color and prominent ledges make it easy to recognize. Of these four exposures, only one does not consist of vitreous white orthoquartzite. This is the exposure near the southern map boundary east of the mouth of Secret Canyon (Plate 1). The Swan Peak in this area is highly brecciated and stained red. Bedding planes are difficult to recognize in this area. This is the only outcrop of Swan Peak, in the mapped area, showing these properties.

**Ordovician-Silurian System**

**Fish Haven-Laketown Formation**

The Fish Haven and Laketown Formations were named by Richardson (1913, p. 407-410) for their exposures west of Fish Haven, Idaho, and Laketown, Utah, respectively. In Green Canyon east of Logan, Utah, Williams (1948, p. 1137-1138) recognized both formations, differentiating them on the basis of color. He described the Fish
Haven as consisting of 140 feet of thick-bedded, crystalline, dark-gray dolomite. He described the Laketown as consisting of 1,150 feet of alternating units of light-gray, dark-gray, and light-gray dolomite. Beus (1968, p. 784), in the area of Samaria Mountain, found no significant difference between the Fish Haven and the Laketown Formations and mapped them as one formation. Shearer (1975), in the area of Malad Summit, also mapped undifferentiated Fish Haven-Laketown. In the mapped area, the lithologic boundaries are not apparent and, on this basis and the usage in the surrounding area, the Fish Haven and Laketown are mapped as one formation.

The lower contact of the Fish Haven-Laketown with the underlying Swan Peak is disconformable (VanDorston, 1969, p. 22; James, 1973, p. 75). The contact of the Fish Haven Formation with the Laketown Formation is considered by some workers to be disconformable (Williams, 1948, p. 1137) and by others to be conformable (Beus, 1968, p. 788-789). Williams (1948, p. 1137) considered the Fish Haven to be Late Ordovician in age and the Laketown to be Silurian in age. Beus (1968, p. 784-785) considered the age of the undifferentiated Fish Haven-Laketown to be Late Ordovician to Silurian with the Ordovician-Silurian boundary located within the lower part of the Laketown.

The Fish Haven-Laketown Formation is exposed north of Kent Peak and east of Elkhorn Peak along the northern border of the mapped area. The top of the formation is not exposed in the mapped area. The lower contact is well exposed at the head of South Canyon and north
of the saddle at the head of Kent Canyon (Figure 5). Approximately 450 feet of Fish Haven-Laketown is exposed in the mapped area.

The contact with the underlying Swan Peak is distinct. The white quartzite ends abruptly at the contact with the dark-gray dolomite. Locally the Fish Haven-Laketown, at the contact, is light-gray dolomite similar to the dolomite of the upper part. The contact is covered in many places by gray dolomite talus, which has moved downslope from above the contact. The lower part of the Fish Haven-Laketown consists of medium-bedded, crystalline, dark-gray dolomite. The lower part weathers medium to dark gray and appears brown from a distance. The lower part forms ledges with some pinnacles. It contains some black chert, both bedded and nodular. The upper part of the Fish Haven-Laketown, in the mapped area, consists of thick-bedded light-gray dolomite. The upper part weathers in pinnacles also but more commonly weathers in blocks.

Fossils, found in the Fish Haven-Laketown, are halysitid corals, streptelasmid corals, and crinoid stems. These fossils are predominantly in the lower dark-gray dolomite.

Tertiary System

Salt Lake Formation

The Salt Lake Formation was first recognized by Hayden (1869, p. 92) in the area of Weber Valley, Utah. The Salt Lake Formation has been studied in the Cache Valley area of northern Utah and southeastern Idaho (Williams, 1948, p. 1147; Adamson, Hardy, and Williams, 1955).
Figure 5. Contact of Swan Peak and Fish Haven-Laketown Formations on hill east of Elkhorn Peak; view east from Elkhorn Peak. Swan Peak (Osp) is overlain by Fish Haven-Laketown (OS). A north-trending normal fault is present in the canyon separating Fish Haven-Laketown in foreground from Swan Peak and Fish Haven-Laketown on hill.
Three formations were recognized, in Cache Valley, by Adamson, Hardy, and Williams (1955, p. 4-8). In ascending order, they are: (1) Collinston Conglomerate, (2) Cache Valley Formation, and (3) Mink Creek Conglomerate. The Collinston Conglomerate is at least 1,500 feet of light-gray tuffaceous conglomerate. The Cache Valley Formation is 7,674 feet of tuffaceous limestone, sandstone, and conglomerate. The Mink Creek Conglomerate is at least 3,435 feet of gray to orange tuffaceous conglomerate.

The Salt Lake Formation is as old as Oligocene in age in Morgan Valley, Utah (Eardley, 1944, p. 845). In Cache Valley, Utah, it is Pliocene in age (Yen, 1947, p. 272). Near Malad City, Idaho, it is Miocene in age (Swain, 1964, p. 179). The Salt Lake Formation, in the mapped area, is considered to be Miocene to Pliocene in age.

The Salt Lake Formation is exposed west, south, and east of southern Elkhorn Mountain. It is not found internally in the block of Paleozoic rocks. It rests unconformably on the Paleozoic rocks of southern Elkhorn Mountain. The Salt Lake Formation is probably also in fault contact with the Paleozoic and Tertiary rocks of the area. The Salt Lake Formation is covered by the rocks of the Lake Bonneville Group below an elevation of 5,135 feet and is covered by colluvial deposits near the mountain front. The Salt Lake Formation is easily distinguished from the shoreline deposits of the Lake Bonneville Group and the colluvial deposits by its comparative lack of boulders. No thickness for the Salt Lake Formation is estimated, but it is probably thousands of feet thick in the valley to the west and south of southern Elkhorn Mountain.
The Salt Lake Formation consists of two rock types in the mapped area. They are tuffaceous conglomerate and tuff. The tuffaceous conglomerate is present along the western and southern sides of the mountain front and to the northeast in the area of Station Canyon. Good exposures are found at lower elevations in Elkhorn Creek, in Monson Canyon, and overlying part of the landslide in the southern part of the mapped area. It is poorly exposed, poorly bedded, white to gray, tuffaceous conglomerate with clasts of predominantly limestone and quartzite. The clasts range in size from 0.1 to 1.0 foot.

The tuffaceous beds are present in the southeastern part of the mapped area. They consist of thin-laminated white to gray tuff. Where this tuff is exposed, no clasts are present in the outcrop. Locally, around these outcrops are covered slopes containing rocks which are similar to the clasts found in the tuffaceous conglomerate. The two types of rocks of the Salt Lake Formation are probably found in close lateral and vertical proximity. The tuff of both rock types is commonly laminated but less commonly nodular.

Volcanic rocks

Volcanic rocks are exposed, in the mapped area, in isolated outcrops near the mouth of Monson Canyon (Plate 1). Flow banding and layers having different compositions are readily apparent in the outcrops. Vesicles indicate that these volcanic rocks are flows. A subparallel alignment of phenocrysts and incipient laths, as determined by thin-section analysis, also indicates flow. The attitude of the flow planes ranges from horizontal to vertical. The major mass of
volcanic rock displays flow planes that are horizontal to generally south dipping (Figure 6). Isolated linear outcrops displaying nearly vertical flow planes are present north of the main mass of volcanic rocks. Vertical flows are also present locally within the main mass of volcanic rocks. The volcanic rocks are believed to have issued from subparallel dikes. The vertical flows are believed to be located where fractures were located. The horizontal and south-dipping volcanic rocks represent lava flows.

The volcanic rocks are believed to have formed contemporaneously with deposition of the Salt Lake Formation. Tuffaceous beds of the Salt Lake Formation are found unconformably over the volcanic rocks with an angular discordance of 2°-5°. Salt Lake Formation is believed to underlie the volcanic rocks. This gives a late Tertiary age for the flows of the mapped area.

A generalized mineral composition was determined from thin-section analysis of five samples. The phenocryst composition is 3 to 30 percent labradorite to andesine (An 55-30), 1 to 3 percent hornblende, and trace amounts of clinopyroxene and orthopyroxene. The phenocrysts are in subparallel alignment. The groundmass is composed of subparallel incipient laths of plagioclase surrounded by unidentifiable submicrocrystalline crystals. Obsidian is also present in some specimens. The obsidian contains subparallel incipient laths of plagioclase. The phenocrysts range in size from 0.1 to 3.0 mm. The incipient laths are approximately 0.01 to 0.05 mm in length. The rock type is andesite to andesite porphyry.
Figure 6. Volcanic rocks on eastern side of lower Monson Canyon; view east. Flow planes are horizontal on left and dip south on right.


Quaternary System

Lake Bonneville Group

Lake Bonneville Group is the name used to identify sediments deposited in Lake Bonneville. The Lake Bonneville Group consists of three formations. In ascending order, they are: (1) Alpine Formation, (2) Bonneville Formation, and (3) Provo Formation (Hunt, Varnes, and Thomas, 1953, p. 17). All three formations consist of clay, silt, sand, and gravel (Williams, 1962, p. 137). The Lake Bonneville Group is Pleistocene in age (Hunt, Varnes, and Thomas, 1953, p. 17).

The elevation of the highest shoreline of Lake Bonneville presently ranges between 5,085 feet and 5,300 feet. The variation is due to post-Lake Bonneville isostatic rebound (Crittenden, 1963, p. 4-6). Williams (1962, p. 137) found the highest shoreline, the Bonneville shoreline, to be at an elevation of approximately 5,135 feet in Cache Valley. Shearer (1975, p. 39) found no shorelines in the Malad Summit Quadrangle, east of Interstate 15, but used an elevation of 5,140 feet to map the upper limit of the Lake Bonneville Group in that area.

Two Lake Bonneville shorelines are present in the southern and southwestern parts of the mapped area. They are located at 5,135 feet and 5,060 feet above sea level. Shorelines are not present in the southeastern part of the mapped area along Dirty Devil Creek (Plate 1). The 5,135-foot elevation was used, in the area of Dirty Devil Creek, as an upper limit for the Lake Bonneville Group.

The shoreline deposits of the Lake Bonneville Group, in the mapped area, are conglomerate. The conglomerate contains clasts of
predominantly quartzite and limestone in a matrix of clay, silt, and sand. The quartzite clasts are predominantly Swan Peak Formation and range from 0.1 to 4.0 feet in diameter. They are subrounded. The limestone clasts are slightly smaller, 0.1 to 2.0 feet in diameter, and are subrounded. The Lake Bonneville Group is generally clay, silt, and sand below the shoreline deposits.

The Lake Bonneville Group rests with angular discordance on the Salt Lake Formation in the mapped area. The contact, in the southern and southwestern parts of the mapped area, is well marked by a shoreline and by a relative lack of boulders in the Salt Lake Formation.

Colluvial deposits

Colluvial deposits are present, in the mapped area, within the mountain block and along the eastern side of southern Elkhorn Mountain. The colluvial deposits are of similar composition. They contain clasts of predominantly quartzite and limestone in a matrix of sand, silt, and clay. A soil is present in most cases. The quartzite clasts are predominantly from the Swan Peak Formation. They are rounded to subrounded and range in size from 0.5 to 4.0 feet. Limestone clasts are generally subrounded to subangular and range in size from 0.3 to 3.0 feet.

Colluvial deposits, found with the mountain block, are present on a small hill 0.2 mile southeast of Secret Spring and in a large meadow at the head of Heath Hollow (Plate 1; Figure 7). The deposit in Secret Canyon is probably quite old, possibly Tertiary. The deposit in Heath Hollow is probably younger, possibly Pleistocene.
Figure 7. Colluvial deposits, in meadow, near head of Heath Hollow; view northeast. North-trending normal fault is down on left. Garden City Formation is present on right of fault.
The colluvial deposits, along the eastern side of southern Elkhorn Mountain, extend from the northern boundary of the mapped area, near Bill Williams Canyon, southward to near Birch Spring (Plate 1). These deposits form broad surfaces with a large number of quartzite boulders. The largest of these surfaces is Old Canyon Meadow (Plate 1). These colluvial deposits generally overlap unconformably on the Paleozoic rocks of the mountain and cover the Salt Lake Formation which is exposed east of the colluvial deposits. The colluvial deposits, along the mountain front, are probably Pleistocene to Holocene in age.

**Alluvial deposits**

Alluvium is present, in the mapped area, along all major stream valleys. The alluvium consists of particles of silt, sand, and gravel. The composition of these particles is generally quartzite, limestone, or dolomite. An alluvial fan is present, south of the mapped area, southeast of the mouth of Secret Canyon. Only a small part of the head of the fan is present in the mapped area; therefore, it is not mapped. The alluvial deposits are Holocene in age.
STRUCTURAL FEATURES

Regional Setting

The area of southeastern Idaho and northern Utah is characterized by thrust faults and normal faults. Thrust faults of large displacement are present in the region. The Bannock thrust zone, east of the mapped area, is considered to be a zone of imbricate thrust faults of regional extent (Armstrong and Cressman, 1963). The zone extends from near Idaho Falls, Idaho, south to Paris Canyon, Utah (Armstrong and Cressman, 1963, p. 17-18). The fault zone may extend northward to near the Idaho-Montana border (Armstrong and Cressman, 1963, p. 17-18). Southwestward, it may connect to the Willard thrust fault northeast of Ogden, Utah (Crittenden, 1972). Displacement on the Willard thrust fault, northeast of Ogden, may be as great as 30 to 40 miles from west to east (Crittenden, 1961, p. 129). The stratigraphic throw is 20,000 feet on the Paris thrust fault (Armstrong and Cressman, 1963, p. 16) and other major thrust faults of the region (Armstrong and Oriel, 1965, p. 1857). Several thrust faults cut Paleozoic rocks in the area north of the Willard thrust fault and west of the Bannock thrust zone (Shearer, 1975; Raymond, 1971; Trimble and Carr, 1976). This region has been considered by Armstrong and Oriel (1965, p. 1861-1862) to be either an allochton of which the Bannock thrust zone is the eastern boundary, an area of uplift from which rocks slid by gravity eastward to form the imbricate thrust faults to the east, or an area that has an unknown relationship to the thrust zone present to the east.
Nearly vertical normal faults are present in the region from the Bear River Range to the Sierra Nevada. These normal faults are the cause of the present topographic relief. Normal faults of the Basin and Range province bound a series of subparallel generally northeast-to northwest-trending horsts and grabens (Stewart, 1971). The mountain blocks of the region also contain nearly vertical normal faults of other orientations. These faults are probably associated with Basin and Range faulting but some faults, generally of east-west or northeast trend, may be associated with earlier thrust faulting (Armstrong and Cressman, 1963, p. 19-20).

A thrust fault and numerous high-angle normal faults are present in the mapped area. The thrust fault is a nearly concordant bedding-plane thrust fault of probable local extent. The normal faults are of two major trends, northwest and north. A few northeast- to east-trending normal faults are present. A marginal northwest-trending normal fault is present along the southwestern mountain front, and a marginal north-trending normal fault is present along the western side of the mountain.

Folds

Southern Elkhorn Mountain is a broad anticline. The axis of this anticline trends generally north and is located approximately in the area of Kent Peak. Numerous intersecting normal faults cut the anticline and result in anomalous attitudes locally. Ignoring these anomalous attitudes, the western limb dips approximately
20°-32° W. and the eastern limb dips approximately 25°-40° E. The plunge of the anticline is gently north. Locally, small-scale folds are present in the Bloomington and Garden City Formations.

A recumbent anticline is present north of the mapped area in the area of Bill Morgan Canyon. The width of the anticline is approximately 30 feet. The axis trends approximately north-northwest. The eastern limb is overturned to the east. The recumbent anticline is in the St. Charles Formation.

The folding, in the mapped area, is a result of east-west compression. Overturning of the recumbent anticline to the east indicates an active force from the west.

**Thrust Fault**

**Bedding-plane thrust fault**

One bedding-plane thrust fault is present in the mapped area. It is between the Bloomington Formation and the overlying Nounan Formation. The thrust fault is exposed, in discontinuous outcrops, from Bill Morgan Canyon on the northwest to the area east of Secret Canyon (Plate 1). The presence of similar thrust faults between the Bloomington and Nounan, in nearby areas, (Shearer, 1975, p. 57; Burton, 1973, p. 10) indicates that the thrust fault may extend beyond the limits of the mapped area. Discordance between the thrust fault, the beds above the thrust fault, and the beds below the thrust fault varies throughout the mapped area.

The best exposure of the thrust fault is on the northwestern
side of Elkhorn Creek (Figure 8). There, the upper shale of the Bloomington is in contact with the dolomite of the lower Nounan. The thrust fault removed the upper limestone of the Bloomington and probably some of the lower dolomite of the Nounan. This indicates a stratigraphic throw of at least 100 feet. The thin stratigraphic section of Nounan above the thrust fault, in this area, may indicate a considerably greater stratigraphic throw. The beds below and above the thrust fault are only slightly discordant in this area. The thrust fault is marked by a slickensided planar surface.

The thrust fault is not readily apparent from the area south of Elkhorn Peak to the area northwest of Secret Spring. The limestone of the upper Bloomington is present below the dolomite of the Nounan. The beds below and above the contact are not visually discordant nor is the fault accentuated by a planar surface. Evidence for a thrust fault in these areas is based on the presence of a bedding-plane thrust fault at the contact elsewhere in the mapped area and differences in the Nounan stratigraphy above the thrust fault. The dolomite of the Nounan is apparently thin in the area of Kent Peak and in the area west of Secret Spring. The lower medium-gray dolomite of the Nounan is not present around Kent Peak. The thrust fault, in these areas, apparently removed some of the lower dolomite of the Nounan. The thickness of dolomite removed is not known.

The thrust fault is exposed only in isolated outcrops in the lower part of Co-op Canyon. The thrust fault removed the upper limestone of the Bloomington and the lower ledge-forming dolomite of the
Figure 8. Bedding-plane thrust fault on northwestern side of Elkhorn Creek; view northwest. Thrust fault is located below the resistant ledge. Planar surface of thrust fault separates the dolomite of the Nounan Formation, above the thrust fault, from the shale of the Bloomington Formation below.
Nounan. This gives an estimated stratigraphic throw of 300 feet or greater. A discordance of 10°–20° between the beds below and the beds above the thrust fault exists in the area of lower Co-op Canyon.

The thrust fault is present in the area west of the mouth of Secret Canyon. It is poorly exposed in that area. Isolated outcrops of Bloomington are present below the thrust fault in that area.

The thrust fault is also present east of Secret Canyon. It places light-gray dolomite of the lower Nounan in fault contact with upper shale and upper limestone of the Bloomington east of lower Secret Canyon. The lower medium-gray dolomite of the Nounan is not present in that area. The upper limestone of the Bloomington is not present everywhere below the thrust fault. These relationships give a stratigraphic throw of 200-300 feet or greater. Discordance between the beds of Bloomington and the beds of Nounan is approximately 30° in that area.

Structural interpretation

The thrust fault, in the mapped area, is folded in the broad anticline of southern Elkhorn Mountain. This indicates that thrust faulting preceded the regional folding of southern Elkhorn Mountain. The thrust faulting caused a varied stratigraphic throw and a varied degree of discordance along the thrust fault from place to place. The recumbent anticline, north of the mapped area, and the small-scale folds may have formed contemporaneously with the thrust fault. After thrust faulting, the thrust fault and the rocks of the area were folded into the broad anticline of southern Elkhorn Mountain.
The folding and thrust faulting could have been caused by east-west compressional forces or by gliding under the influence of gravity. Armstrong and Cressman (1963, p. 19) advocated east-west compression to explain the Bannock thrust zone. Crittenden (1972, p. 2879) also advocated this mechanism for the thrust faulting in the area northeast of Ogden. The movement was from west to east (Armstrong and Cressman, 1963, p. 19; Crittenden, 1972, p. 2879).

Another possible mechanism for the thrust faulting is gliding under the influence of gravity. Scholten and Ramspott (1968, p. 41-43), working in the Beaverhead Range, Idaho-Montana, and Mudge (1970, p. 384-387), working in the disturbed belt of Montana, believed that uplift of large areas and gravity gliding off of these areas produced the thrust faults in their respective areas. Movement was from west to east. Mudge (1970) described gentle folding and low-angle thrust faulting west of more highly disturbed rocks of the Sawtooth Range. The more disturbed rocks form at the leading edge of the glide block; whereas the less disturbed rocks form in the trailing part of the glide block (Mudge, 1970, p. 382). Examples of possible gravity gliding exist (Scholten and Ramspott, 1968; Mudge, 1970) and theoretical mechanics show gravity gliding to be possible (Hubbert and Rubey, 1959). In addition to a vertical component of slope for gravity to act, gravity gliding probably requires high fluid pressure (Hubbert and Rubey, 1959).

A situation similar to that described by Mudge (1970, p. 382), in the area of the Sawtooth Range, exists in the area of southeastern Idaho. The more disturbed area of the Bannock thrust zone, to the
east, could be associated with the leading edge of the glide block, and the gently folded low-angle thrust-faulted area, to the west of the Bannock thrust zone, could be associated with the trailing edge of the glide block. The thrust fault, in the mapped area, is found above the shale beds of the Bloomington (Figure 8). It does not cut across formations but is nearly parallel to bedding. There is generally no deformation in the rocks near the thrust fault. The beds within the recumbent anticline show no thinning. These features suggest that the thrust fault is a gravity-glide feature formed in the trailing half of a larger glide block and not a compressional override feature.

The direction of gliding was from west to east. The overturning to the east of the recumbent anticline indicates eastward movement. The relationship of the disturbed area of the Bannock thrust zone, to the east, with the less disturbed area of southern Elkhorn Mountain may also indicate eastward movement.

Normal Faults

General statement

The structure of the mapped area is dominated by intersecting nearly vertical normal faults (Plate 1). The normal faults are divided into three categories on the basis of trend. The first category consists of northwest-trending normal faults. The northwest-trending normal faults are nearly parallel and generally extend for great distances in the mapped area. The second category consists of north-trending normal faults. The north-trending normal faults are
subparallel and generally terminate at northwest-trending normal faults. The third category consists of northeast- to east-trending normal faults. The northeast- to east-trending normal faults terminate at northwest-trending or north-trending normal faults.

**Northwest-trending normal faults**

Twelve northwest-trending normal faults are present in the mapped area. They strike generally N. 50° W. In addition, three northwest-trending normal faults that dip southwest are present near the southwestern front of southern Elkhorn Mountain. Northwest-trending normal faults are probably present southwest of the mountain front but are not exposed in Salt Lake Formation. The twelve northwest-trending normal faults will be described in detail starting on the northeast and moving toward the southwest. The three northwest-trending normal faults that dip southwest will then be described in the same order.

The northeasternmost northwest-trending normal fault, in the mapped area, extends from a point on the northern map boundary, northwest of South Canyon, to the area south of the radio facility. Displacement is down on the northeast. The Fish Haven-Laketown is down on the northeast next to the Garden City and the Swan Peak northwest of South Canyon. A breccia is present on the ridge between Evans Canyon and Station Canyon at the location of this fault. Garden City and Swan Peak are down on the northeast next to Nounan on the northern side of Station Canyon. Southeastward from Station Canyon, the fault is covered by colluvial deposits. Near the radio
facility, the fault probably cuts Salt Lake Formation.

The next northwest-trending normal fault, to the southwest, extends from an intersection with a north-trending normal fault, north of Station Canyon, to an intersection with a north-trending normal fault north of Maple Spring. Displacement is down on the southwest. Garden City is down on the southwest next to Nounan where the fault crosses Station Canyon. The fault is covered by colluvial deposits and cuts Salt Lake Formation near Little Station Canyon.

The next northwest-trending normal fault extends from an intersection with a north-trending normal fault, south of Station Spring, to an intersection with a north-trending normal fault near the lower part of Heath Hollow. Displacement is down on the northeast. Garden City is down on the northeast next to St. Charles near the head of Little Station Canyon. To the southeast, the fault cuts Salt Lake Formation and is covered by colluvial deposits.

The next northwest-trending normal fault extends from a point on the northern map boundary, east of Elkhorn Peak, to an intersection with a north-trending normal fault 0.5 mile east of Canyon Spring. Displacement is down on the northeast. At the northern map boundary, Fish Haven-Laketown is present on both sides of the fault. Fish Haven-Laketown is down on the northeast next to Swan Peak in the area near the head of Kent Canyon. Southeast of the saddle at the head of Kent Canyon, Swan Peak is down on the northeast next to Garden City. From where the fault crosses Kent Canyon southeastward to an intersection with the north-trending normal fault, Garden City
is present on both sides. The northeastern side is presumed to be
down in this area. Evidence for the fault through this area is
scarce. A breccia is present on the fault on the southwestern side
of Heath Hollow. To the southeast, the fault is covered by colluvial
deposits and cuts Salt Lake Formation.

The next northwest-trending normal fault extends from a point
on the northern map boundary, west of Elkhorn Peak, to an intersection
with a north-trending normal fault 0.6 mile east-southeast of Canyon
Spring. This fault, from a point on the northern map boundary to an
intersection with the north-trending normal fault in Secret Canyon,
has major displacement. Generally Ordovician rocks are down on the
northeast next to Cambrian rocks. Southwest of Elkhorn Peak, Garden
City is down on the northeast next to Nounan. From the eastern side
of Limekiln Canyon to Kent Peak, Swan Peak and Fish Haven-Laketown
are down on the northeast next to Nounan. The fault, through this
area, is well exposed. Southeast of Kent Peak, the fault is poorly
exposed. It places limestone and dolomite of the Garden City down
on the northeast next to Bloomington and Nounan. The fault is marked
by breccias and linear features across the southeastern face of Kent
Peak (Figure 9). Limestone and dolomite are present on both sides
of the fault. Southeast of there, the fault is poorly exposed. A
breccia marks its location at the intersection with the north-trending
normal fault in Secret Canyon.

Southeastward from the intersection with the north-trending
normal fault in Secret Canyon to the intersection with the northeast-
to east-trending normal fault near the head of Secret Canyon, the
Figure 9. Northwest-trending normal fault on southeastern face of Kent Peak; view northwest. Northwest-trending normal fault places Garden City Formation (Ogc) down on the right next to Bloomington (6bo) and Nounan (6n) Formations on left. Thrust fault is at contact of Bloomington and Nounan.
fault places Garden City down on the southwest next to Garden City. Southeastward from there to a point 0.4 mile northwest of Canyon Spring, Garden City and Swan Peak are down on the southwest next to Garden City on the north. Southeastward from the point 0.4 mile northwest of Canyon Spring, the fault is covered by colluvial deposits and cuts the Salt Lake Formation. The difference in sense of displacement along the fault between the part northwest of Secret Canyon and the part southeast of Secret Canyon is the result of differential movement of fault blocks. The two southwestern fault blocks are separated by the north-trending normal fault in Secret Canyon.

The next northwest-trending normal fault extends from a point on the northern map boundary, near Bill Morgan Canyon, to an intersection with a north-trending normal fault southeast of Old Canyon. The area northwest of Limekiln Canyon lacks good exposures. On the ridge south of Elkhorn Peak, Nounan is down on the northeast next to Bloomington. The discordance and linear nature of this contact indicate a normal fault rather than a thrust fault. West of Limekiln Canyon, the Nounan is down on the northeast next of the Bloomington. In the area south of Kent Peak, the Bloomington-Nounan contact is offset (Figure 4). The offset Bloomington-Nounan contact apparently shows displacement down on the southwest. This problem also exists along this same fault near the northern map boundary. The apparent differences in sense of displacement are within the same fault block and are therefore considered to be only apparent differences caused by different attitudes across the fault.
This same northwest-trending normal fault, from Kent Canyon to west of Secret Canyon, is poorly exposed. The fault is located by means of a large tabular breccia 0.1 mile west of Secret Canyon (Figure 10). The fault is well exposed from Secret Canyon to the head of Old Canyon. A short part of the fault, from the north-trending normal fault in Secret Canyon to another north-trending normal fault 0.2 mile to the southeast, places Garden City and Swan Peak down on the southwest next to Garden City. This difference in displacement is a result of differential movement of the block to the southwest between the two north-trending normal faults. The fault, from there to a point 0.2 mile southeast of the head of Old Canyon, is well exposed and places Swan Peak and Fish Haven-Laketown down on the northeast next to Garden City (Figure 11). From a point 0.2 mile southeast of the head of Old Canyon, the fault is poorly exposed but stratigraphic differences across the fault give its approximate location. From a point south of Canyon Spring to its intersection with the north-trending normal fault, the fault is covered by colluvial deposits and cuts Salt Lake Formation.

The next northwest-trending normal fault extends from an intersection with a north-trending normal fault, near the northwestern corner of the mapped area, to an intersection with a north-trending normal fault northeast of Birch Spring. The displacement is down on the northeast. Northwest of Elkhorn Creek, the fault displaces the thrust fault contact of the Bloomington and the Nounan only slightly. The fault is well exposed on both the western and eastern sides of Limekiln Canyon where Bloomington is down on the northeast
Figure 10. Fault breccia on western side of Secret Canyon along northwest-trending normal fault of Old Canyon; view west. Breccia is in Nounan Formation. Strike is N. 50° W. and dip is nearly vertical.
Figure 11. Northwest-trending normal fault of Old Canyon; view northwest from head of Old Canyon. Swan Peak Formation (Osp) is down on the right next to Garden City (Ogc) and Swan Peak Formations on the left. North-trending normal fault is shown in center.
next to Blacksmith. Near the ridge top east of Kent Canyon, Nounan is down on the northeast next to Bloomington. The fault is well exposed on the ridge 0.2 mile east of the fault in Secret Canyon where Garden City is down on the northeast next to Bloomington. A breccia is also present there. To the southeast, the St. Charles-Garden City contact is offset, down on the northeast, on the ridge. The Nounan-St. Charles contact is offset, down on the northeast, northwest of the Dove survey station.

The next northwest-trending normal fault is located on the western ridge of Secret Canyon, 0.3 mile southwest of Secret Spring. The fault extends from an intersection with a north-trending normal fault, near Co-op Canyon, to an intersection with the north-trending normal fault in Secret Canyon. Nounan and St. Charles are down on the northeast next to Nounan. The fault is well exposed on the ridge top.

The next northwest-trending normal fault extends from an intersection with a north-trending normal fault, 0.5 mile east of lower Secret Canyon, to an intersection with a north-trending normal fault 0.1 mile southeast of Birch Spring. St. Charles is down on the northeast next to Nounan and St. Charles southeast of Secret Canyon. The Nounan-St. Charles contact is offset, down on the northeast, southeast of the Dove survey station. A 50-foot bed of light-brown dolomite of the Nounan Formation is offset, down on the northeast, 0.2 mile northwest of Birch Spring. The fault cuts Salt Lake Formation from Birch Spring to its termination.
The next northwest-trending normal fault extends from an intersection with a north-trending normal fault, 0.6 mile west of the Dove survey station, to an intersection with a north-trending normal fault 0.4 mile north of the southern map boundary. Nounan and St. Charles are down on the northeast next to Bloomington and Nounan.

The next northwest-trending normal fault extends from an intersection with a north-trending normal fault, in lower Secret Canyon, to an intersection with a north-trending normal fault 0.1 mile north of the southern map boundary. This fault dips approximately 80° SW. The Nounan is down on the southwest next to Bloomington and Nounan along this fault. The fault is well exposed in an unnamed canyon 0.5 mile east of lower Secret Canyon. In that area, the dolomite of the lower Nounan is down next to the upper shale of the Bloomington. The fault forms a linear feature from the unnamed canyon to where it becomes poorly exposed in Salt Lake Formation.

The final northwest-trending normal fault is a marginal fault along the southwestern front of southern Elkhorn Mountain (Figure 2). This marginal northwest-trending normal fault separates the mountain block from the valley block. Displacement is down on the southwest. The displacement is probably on the order of thousands of feet. The total displacement may not be on one fault but on a number of parallel faults located southwest of the marginal northwest-trending normal fault in the Salt Lake Formation. The marginal northwest-trending normal fault along the mountain front is generally poorly exposed. It probably extends from an intersection with the marginal north-trending
normal fault, near the mouth of Danish Canyon, to a point on the southern map boundary near the mouth of Secret Canyon. Salt Lake Formation is down on the southwest next to Nounan in the area of Elkhorn Creek (Figure 12) and on the western side of Monson Canyon, near the canyon mouth. The fault passes southwest of the outcrops of Nounan near the mouth of Co-op Canyon. Tabular outcrops of dolomite, located near the southwestern edge of the Nounan in the area west of the mouth of Co-op Canyon, are present northeast of the fault in that area. The fault probably passes under the landslide along the mountain front west of Secret Canyon. The fault is poorly exposed to the southeast but probably passes southwest of the Nounan near the mouth of Secret Canyon.

Three northwest-trending normal faults that dip southwest are present along the southwestern front of southern Elkhorn Mountain (Plate 1). These faults dip approximately 50°-60° SW. They all have displacement that is down on the southwest. These faults all terminate at intersections with north-trending normal faults. They all drop a fault block or number of fault blocks down on the southwest toward the valley.

The northeasternmost of these northwest-trending normal faults that dip southwest extends from an intersection with the north-trending normal fault in Monson Canyon to an intersection with the north-trending normal fault in Secret Canyon. It is exposed as a linear feature in the small canyon between Monson Canyon and Limekiln Canyon. Blacksmith is down on the southwest next to Ute in Limekiln Canyon.
Figure 12. Marginal northwest-trending normal fault in vicinity of Elkhorn Creek; view northwest across Elkhorn Creek. Salt Lake Formation (Tsl) is down on the left next to Nounan Formation (6n) on the right. Mine tailings and tunnel are in foreground.
The thrust fault is displaced, down on the southwest, east of Kent Canyon. The northwest-trending normal fault that dips southwest places St. Charles down on the southwest next to Nounan west of Secret Canyon. The fault also forms a linear feature in this area.

A less well-exposed northwest-trending normal fault that dips southwest is present between Monson Canyon and Kent Canyon. It extends from an intersection with the north-trending normal fault in Monson Canyon to an intersection with the northeast- to east-trending normal fault in Kent Canyon. Bloomington is down on the southwest next to Ute and Blacksmith. The Bloomington is generally covered by colluvium southwest of the fault but is exposed in isolated outcrops. A large breccia is present at the mouth of Limekiln Canyon where the fault is present.

The final northwest-trending normal fault that dips southwest is present near the mountain front in the area of Co-op Canyon. It extends from an intersection with the northeast- to east-trending normal fault in Kent Canyon to an intersection with the north-trending normal fault along the western side of the western ridge of Secret Canyon. The northwest-trending normal fault that dips southwest is exposed as a linear feature from the western ridge of Kent Canyon to the thrust fault in Co-op Canyon (Figure 13). Nounan is down on the southwest next to Bloomington in this area. Southeast of Co-op Canyon, Nounan is down on the southwest next to Nounan. A breccia is present north of the landslide block west of Secret Canyon. A linear feature is present from the landslide block to the fault termination.
Figure 13. Northwest-trending normal fault that dips southwest near mouth of Kent Canyon; view east-southeast across Kent Canyon. Nounan Formation (€n) is down on right next to Bloomington Formation (€bo) on left. Both fault traces are of the same fault. Apparent offset of fault is due to topography and direction of photograph.
North-trending normal faults

North-trending normal faults are present throughout the mapped area from the marginal north-trending normal fault on the west to the north-trending normal fault, near the radio facility, on the east (Plate 1). The north-trending normal faults range in strike from N. 34° E. to N. 16° W. They generally intersect northwest-trending normal faults. The north-trending normal faults are divided into five groups. One group of thirteen faults extends from the western map boundary to near the head of South Canyon. The second group consists of three faults in the area of Secret Canyon. The third group consists of two faults in the area of Bill Williams Canyon. The fourth group consists of four faults in the area of Station Canyon. The final group consists of two faults that extend along the eastern mountain front of southern Elkhorn Mountain. The north-trending normal faults within these groups will be described, in detail, from west to east.

The first group of north-trending normal faults consists of thirteen faults. This group includes all north-trending normal faults from the marginal north-trending normal fault, on the west, to the north-trending normal fault north of South Canyon on the east. These faults generally trend north to north-northwest.

The westernmost north-trending normal fault is a marginal fault. It extends from a point on the northern map boundary to an intersection with the marginal northwest-trending normal fault south of Danish Canyon. Displacement is down on the west. There are no exposures
of this fault in the mapped area. The Paleozoic rocks are probably
down on the west at great depths below the Salt Lake Formation. The
north-south linear trend of the western front of southern Elkhorn
Mountain is a result of displacement on this fault (Figure 14). Salt
Lake is down on the west next to St. Charles north of Danish Canyon.
Salt Lake is down on the west next to Salt Lake south of Danish Canyon.

The second north-trending normal fault extends from a point on
the northern map boundary to an intersection with the marginal northwest-
trending normal fault south of Danish Canyon. It is poorly exposed
to the north and south of Danish Canyon. In Danish Canyon, St.
Charles is down on the west next to St. Charles. A major breccia
and linear scarp, on the northern side of Danish Canyon, mark the
fault location.

The third north-trending normal fault extends from a point on
the northern map boundary, west of Elkhorn Peak, to the marginal
northwest-trending normal fault near the mouth of Monson Canyon
(Figure 15). The fault is down on the west. To the north, Garden
City is down on the west next to Garden City and, south of a northwest-
trending normal fault, Nounan is down on the west next to Nounan. A
distinct lithologic break is present across the fault where the
Nounan is displaced. Along the middle part of this fault, upper
Bloomington is down on the west next to Ute, Blacksmith, lower
Bloomington, and middle Bloomington. Approximately 0.3 mile east of
the spring in Elkhorn Creek, the fault is well exposed. It places
Bloomington down on the west next to Blacksmith (Figure 15).
Figure 14. Marginal north-trending normal fault along western front of southern Elkhorn Mountain in vicinity of Elkhorn Creek; view east. Marginal north-trending normal fault is located along mountain front at slope change between gentle slopes of the valley block and the hills of the mountain block. Danish Canyon is on far left.
Figure 15. North-trending normal fault in Monson Canyon; view north. Bloomington Formation (\textit{Ebo}) is down on left next to Blacksmith (\textit{Ebl}) and Bloomington Formations on right. Nounan and St. Charles Formations are on higher peaks in background.
The fourth north-trending normal fault extends from a point on the northern map boundary, north of Elkhorn Peak, to an intersection with a northwest-trending normal fault near the head of Elkhorn Creek. The displacement is down on the west. Garden City is down on the west next to St. Charles and Garden City in the area west of Elkhorn Peak. The fault is marked by a linear feature in that area. Nounan is down on the west next to Nounan along the southern part of this fault.

The fifth north-trending normal fault extends from a point on the northern map boundary, northeast of Elkhorn Peak, to an intersection with a northwest-trending normal fault northwest of upper Limekiln Canyon. Displacement is down on the east. Garden City is down on the east next to St. Charles and Garden City east and south-east of Elkhorn Peak. A breccia is located along the fault near where the fault crosses the Bannock-Oneida County Line. St. Charles and Garden City are down on the east next to Bloomington and Nounan along the southern part of this fault.

The sixth north-trending normal fault extends from a point on the northern map boundary, northeast of Elkhorn Peak, to an intersection with the marginal northwest-trending normal fault near the mouth of Limekiln Canyon. This fault, from the northern map boundary to its intersection with the northwest-trending normal fault through Kent Peak, places Fish Haven-Laketown down on the east next to lower Garden City. Large tabular breccias are present where this fault crosses ridges. The fault places St. Charles down on the west next
to Nounan between the northwest-trending normal fault through Kent peak and the northwest-trending normal fault through Old Canyon. Two large breccias are present along the fault in this area (Figure 16). The fault has little displacement southward from the northwest-trending normal fault through Old Canyon to its termination. The Blacksmith-Bloomington contact is offset approximately 60 feet, down on the west, on the ridge west of Limekiln Canyon. The different sense of displacement along parts of the fault is the result of differential movement of fault blocks.

The seventh north-trending normal fault extends from a point on the northern map boundary to an intersection with a northwest-trending normal fault west of the saddle at the head of Limekiln Canyon. Fish Haven-Laketown is down on the west next to Fish Haven-Laketown along the northern part of this fault. Swan Peak and Fish Haven-Laketown are down on the west next to Swan Peak and Fish Haven-Laketown along the southern part of the fault.

The eighth north-trending normal fault extends from a point on the northern map boundary to an intersection with a northwest-trending normal fault northwest of Kent Peak. Swan Peak and Fish Haven-Laketown are down on the west next to Swan Peak along this fault. The fault is well exposed 0.5 mile northwest of Kent Peak, near the Bannock-Oneida County Line. Fish Haven-Laketown is down on the west next to Swan Peak in that area.

The ninth north-trending normal fault extends from a point on the northern map boundary to an intersection with a northwest-trending
Figure 16. Breccia on north-trending normal fault on western side of Limekiln Canyon near its head; view north. Trend of fault is north. Nounan Formation is on right. St. Charles Formation is on left.
normal fault east of Kent Peak. Swan Peak and Fish Haven-Laketown are
down on the west next to Fish Haven-Laketown along the northern part
of this fault. The fault is exposed in the saddle, at the head of
Kent Canyon, where Fish Haven-Laketown is down on the west next to
Swan Peak. This fault is exposed 0.2 mile northwest of Kent Peak
where it places Swan Peak down on the west next to Garden City.

The tenth north-trending normal fault extends from a point on
the northern map boundary to an intersection with a northwest-trending
normal fault 0.5 mile southeast of Kent Peak. A large breccia of
quartzite is present, near the northern map boundary, 0.1 mile south-
east of the hill having an elevation of 8,012 feet. Fish Haven-
Laketown is down on the west next to Swan Peak and Fish Haven-Laketown
north of Kent Canyon. Garden City is down on the west next to Garden
City in the area east of Kent Peak.

The eleventh north-trending normal fault extends from a point
on the northern map boundary to an intersection with a north-trending
normal fault southwest of South Canyon Spring. It places Swan Peak
down on the west next to Swan Peak. The fault is exposed as a linear
feature where Fish Haven-Laketown is down on the west next to Swan
Peak north of a small canyon near the northern map boundary. A
breccia is present along the fault in the saddle at the head of
South Canyon. Fish Haven-Laketown is down on the west next to Swan
Peak in this area.

The twelfth north-trending normal fault extends from a point
on the northern map boundary to an intersection with a northwest-
trending normal fault near the head of Station Canyon. The fault
places Swan Peak down on the west next to Garden City north of South Canyon. This relationship is exposed for 0.2 mile southward from the northern map boundary and in a small saddle 0.1 mile north of South Canyon. Garden City and Swan Peak are down on the west next to Garden City and Swan Peak south of South Canyon to the fault termination. The Garden City-Swan Peak contact is displaced, down on the west, near the head of Station Canyon.

The final north-trending normal fault of the first group extends from a point on the northern map boundary to an intersection with a northwest-trending normal fault 0.25 mile south of the northern map boundary. The fault is exposed as a linear feature where Fish Haven-Laketown is down on the west next to Swan Peak north of a small canyon. South of the small canyon the fault is poorly exposed.

The second group of north-trending normal faults consists of three faults. These faults are located in the area of Secret Canyon. The faults generally trend north-northwest.

The westernmost north-trending normal fault of the second group parallels the western ridge of Secret Canyon on the western side. The fault extends from an intersection with a northwest-trending normal fault, 0.4 mile southeast of Kent Canyon, to an intersection with the marginal northwest-trending normal fault west of the mouth of Secret Canyon. Displacement is down on the east. The fault is located by a breccia at its northern termination. Bloomington is down on the east next to Bloomington in that area. North of Co-op Canyon, dolomite of the Nounan terminates at a linear feature against shale of the Bloomington. A breccia is present in the saddle south of
Co-op Canyon. Nounan is down on the east next to Nounan in that area. In the area where the fault is intersected by the normal fault that dips southwest, dolomite beds terminate at the fault and a linear feature is present. To the south, the fault is poorly exposed. Nounan is down on the east next to Bloomington and Nounan.

The second north-trending normal fault extends from an intersection with a northwest-trending normal fault, near the head of Secret Canyon, to an intersection with the marginal northwest-trending normal fault near the mouth of Secret Canyon. This fault generally follows Secret Canyon. Garden City is down on the east next to Nounan near the head of Secret Canyon. Dolomite beds of the Nounan terminate on the west against the limestone and dolomite beds of the Garden City. From there, south to its intersection with a northwest-trending normal fault 0.25 mile north of Secret Spring, the fault is in the valley bottom. Garden City is down on the east next to Bloomington and Nounan in that area. South of the intersection with the northwest-trending normal fault, Nounan is down on the west next to Bloomington and Nounan. The fault is generally covered by the alluvium of Secret Canyon along its southern part. Its existence is based on stratigraphic differences across the canyon. A large breccia is present, 0.5 mile south of Secret Spring, where the fault crosses a tributary canyon. On the southern side of Secret Canyon near its mouth where it turns sharply to the west, the attitude is different in similar dolomite across the fault. The different sense of displacement between the northern and southern parts of the fault is due to differential movement of fault blocks.
The easternmost north-trending normal fault of the second group extends from an intersection with a northwest-trending normal fault, 0.2 mile east of upper Secret Canyon, to an intersection with a northwest-trending normal fault 0.6 mile west of the Dove survey station. From its intersection on the north to its intersection with a northwest-trending normal fault 0.3 mile east of Secret Spring, Garden City and Swan Peak are down on the west next to Garden City. Southward from the intersection east of Secret Spring to the intersection with the northwest-trending normal fault 0.6 mile west of the Dove survey station, Nounan, St. Charles, and Garden City are down on the east next to Bloomington and Nounan. Displacement diminishes to the south along that part of the fault. Garden City is down on the east next to Bloomington east of Secret Spring; whereas, Nounan is down on the east next to Bloomington in the area west of the Dove survey station. The fault is marked by limestone and dolomite terminating against shale in the area east of Secret Spring (Figure 17). The fault is marked by breccias to the south where Nounan is present on both sides.

The third group of north-trending normal faults consists of two faults. These faults are located near the head of Bill Williams and Evans Canyons. The faults generally trend north-northwest.

The westernmost north-trending normal fault of the third group extends from a point on the northern map boundary, north of South Canyon, to an intersection with a northwest-trending normal fault north of Station Spring. Garden City and Swan Peak are down on the
Figure 17. North-trending normal fault east of Secret Canyon; view north. St. Charles (\textit{Gsc}) and Garden City (\textit{Ogc}) Formations are down on right next to Bloomington Formation (\textit{Gbo}) on left.
west next to Garden City along this fault. The fault is well exposed on the ridge north of South Canyon where Swan Peak is down on the west next to Garden City. Breccias are present where the fault crosses the northern and southern ridges of Bill Williams and Evans Canyons.

The easternmost north-trending normal fault of the third group extends from a point on the northern map boundary, north of South Canyon; to an intersection with a northwest-trending normal fault south of Evans Canyon. Garden City and Swan Peak are down on the east next to Garden City along this fault. The fault is well exposed on the ridge north of Bill Williams Canyon. Breccias are present where the fault crosses the northern and southern ridges of Evans Canyon.

The fourth group of north-trending normal faults consists of four faults. Three of these faults are located in the area of Station and Little Station Canyons. One of these faults is located near the mouth of Evans Canyon. The faults generally trend north-northeast to northeast.

The westernmost north-trending normal fault of the fourth group extends from an intersection with a northwest-trending normal fault, near the head of Evans Canyon, to an intersection with a northwest-trending normal fault southwest of Station Canyon. Garden City and Swan Peak are down on the west next to Garden City along this fault. On the northern side of Station Canyon, the fault forms a distinct linear feature that terminates the Garden City and Swan Peak on the west against the Garden City on the east (Figure 18).
Figure 18. North-trending normal fault across ridge north of Station Canyon; view northwest across Station Canyon. Garden City (Ogc) and Swan Peak (Osp) Formations are down on left next to Garden City on right.
The second north-trending normal fault of the fourth group extends from an intersection with a northwest-trending normal fault, south of Evans Canyon, to an intersection with a northwest-trending normal fault south of upper Heath Hollow. Garden City is down on the west next to Nounan along the fault from its northernmost point to its intersection with a northwest-trending normal fault northeast of Station Spring. In that area, the fault is located by travertine deposits along the fault and different formations across the fault. South of Station Spring, the fault forms the eastern boundary of a meadow (Figure 7).

The third north-trending normal fault extends from an intersection with a northwest-trending normal fault, south of lower Station Canyon, to an intersection with a northwest-trending normal fault south of upper Heath Hollow. The fault is covered by colluvial deposits to the north and by alluvium in Little Station Canyon. Garden City is down on the east next to St. Charles and Garden City near the head of Little Station Canyon.

The final north-trending normal fault of the fourth group extends from an intersection with a north-trending normal fault, north of the mouth of Evans Canyon, to an intersection with a north-trending normal fault southwest of Lower Station Spring. Garden City and Swan Peak are down on the east, across Evans Canyon, next to Garden City.

The fifth group of north-trending normal faults consists of two faults. These faults are located along the eastern front of southern Elkhorn Mountain. The faults generally trend north.
The westernmost north-trending normal fault of the fifth group extends along the eastern front of southern Elkhorn Mountain from a point on the northern map boundary to a point on the southern map boundary. Swan Peak is down on the west next to Garden City north of Evans Canyon. In the area from Station Canyon to Heath Hollow, the fault is poorly exposed. Different formations across the fault indicate its existence in that area. Southward from there to a point 0.1 mile north of the southern map boundary, the fault is poorly exposed. Southward from there to the southern map boundary, the fault places Swan Peak down on the west next to Salt Lake Formation (Figure 19).

The easternmost north-trending normal fault of the fifth group extends from a point on the northern map boundary to an intersection with a northwest-trending normal fault southwest of the radio facility. Garden City is down on the west next to St. Charles north of lower Station Canyon. The fault cuts Salt Lake Formation north of the exposure near the mouth of Station Canyon. South of this exposure, the fault is covered by colluvial deposits.

Northeast- to east-trending normal faults

There are four normal faults, in the mapped area, that do not fit into the categories of either northwest-trending normal faults or north-trending normal faults. They are located near the mouth of Kent Canyon, near the upper part of Secret Canyon, and near the southern boundary of the mapped area south of Birch Spring (Plate 1).
Figure 19. North-trending normal fault on eastern side of southern Elkhorn Mountain in area of Birch Spring; view west-northwest. Fault is located at base of conspicuous juniper-covered hill near center and extends northward and southward along mountain front. Fault is down on mountain-block side. Dove survey station is on high peak at right. Hill on left consists of brecciated Swan Peak Formation.
A northeast- to east-trending normal fault is located in the area of lower Kent Canyon (Plate 1). It strikes N. 52° E. It extends from an intersection with the marginal northwest-trending normal fault, west of the mouth of Kent Canyon, to an intersection with the northwest-trending normal fault of Old Canyon. Displacement is down on the southeast. The fault is poorly exposed throughout much of its northeastern extent. It separates exposures of shale and siltstone of the Ute, in Kent Canyon, from fissile shale of the Bloomington east of Kent Canyon. A breccia, which marks the fault, is located approximately 0.3 mile west of the spring in Kent Canyon. The fault is poorly exposed southwest of that breccia.

Two northeast- to east-trending normal faults are located in Secret Canyon north of Secret Spring (Plate 1). The northernmost normal fault strikes N. 78° E. and the southernmost strikes N. 60° E. They both terminate, at each end, at normal faults. They both have minor extent and minor displacement. The northernmost fault places lower Swan Peak down on the south next to upper Garden City near the head of Secret Canyon. The other fault places Nounan down on the south next to Bloomington northwest of Secret Spring.

The fourth northeast- to east-trending normal fault is located near the southern map boundary in the area south of Birch Spring (Plate 1). It strikes N. 82° E. and displays major displacement. It extends from beyond the southern map boundary to an intersection with a north-trending normal fault 0.2 mile north of the southern map boundary. It places highly brecciated Swan Peak down on the south next to Nounan (Figure 19).
Structural interpretation

The normal faults, in the mapped area, are Basin and Range faults. The Basin and Range province consists of a series of subparallel generally north-trending mountain ranges with intervening valleys. The ranges and valleys are horsts and grabens, respectively, bounded by normal faults (Stewart, 1971, p. 1026). The normal faults are responsible for the present relief. The normal faults are the result of generally east-west tensional forces acting at depth (Stewart, 1971, p. 1027).

The northwest-trending normal faults approximately parallel the trend of the Bannock Range through the mapped area. The marginal northwest-trending normal fault, along the southwestern front of southern Elkhorn Mountain, is responsible for the relief along that front of the mountain (Figure 1). This marginal northwest-trending normal fault may be the extension of the Wasatch fault. The Wasatch fault has a northerly trend to the south. The other northwest-trending normal faults, in the mapped area, have the effect of placing progressively younger rocks down on the northeast. The result is a northwest-trending horst along the southwestern mountain front with a steep southwestern side and a gradually stepped-down northeastern side. The northwest-trending normal faults are probably the result of tensional forces acting at depth. The set of northwest-trending normal faults that dip southwest is probably the result of removal of support when the valley was down faulted.

The north-trending normal faults, in the mapped area, generally intersect the northwest-trending normal faults and formed
contemporaneously with them. The marginal north-trending normal fault along the western edge of the mapped area, although different in trend, probably has the same amount of displacement as the marginal northwest-trending normal fault. The marginal north-trending normal fault is responsible for the relief along the western front of southern Elkhorn Mountain (Figure 14). This fault may be an extension of the Wasatch fault. The north-trending normal faults, in the mapped area, are the result of tensional forces acting at depth.

The northeast- to east-trending normal faults are generally limited in extent and amount of displacement. The northeast- to east-trending normal faults, in the area of Kent Canyon and Secret Canyon, are the result of tensional forces acting at depth. The northeast- to east-trending normal fault, near the southern map boundary, southeast of the mouth of Secret Canyon, has large displacement and is associated with vertical down faulting of the valley block. It is therefore a normal fault that resulted from tensional forces acting at depth. Armstrong and Cressman (1963, p. 20) described a set of east- to northeast-trending high-angle tear faults that are related to Laramide thrust faulting. No evidence was found, in the mapped area, to indicate that the northeast- to east-trending normal faults are tear faults. The northeast- to east-trending normal faults, in the mapped area, are considered to be Basin and Range features.
Landslide

Two landslide blocks are present along the southwestern front of southern Elkhorn Mountain. One is near the mouth of Kent Canyon, and the other is west of the mouth of Secret Canyon (Plate 1). The two landslide blocks are probably remnants of a larger landslide that extended from the area near the mouth of Kent Canyon to the area near the mouth of Secret Canyon. The slide moved to the southwest. The major part of the slide was removed by erosion. Glide planes of the two remnant blocks dip approximately 11° SW. The slide was caused by removal of support along the southwestern front of southern Elkhorn Mountain as a result of down faulting of the valley block along the marginal northwest-trending normal faults. The source area of the landslide has been removed by erosion. Shale of the Bloomington Formation, which is present under the slide block near Secret Canyon and is present in the area between Kent Canyon and Secret Canyon, probably aided in the landslide movement. The slide is probably Tertiary in age, contemporaneous with the Salt Lake Formation, as Salt Lake is found unconformably overlying part of the slide block west of Secret Canyon.

The landslide block, near the mouth of Kent Canyon, consists of Swan Peak Formation (Figure 20). The Swan Peak of the slide block overlies Nounan in that area. Shale of the Bloomington is present north of the slide block. A glide surface is not seen but the limits of the slide block are placed at the contact of the Nounan and Swan Peak.
Figure 20. Landslide block of Swan Peak Formation along mountain front west of Kent Canyon; view east-southeast from Monson Canyon. Landslide block is white outcrop of Swan Peak in middle distance. Volcanic rocks are in right foreground.
The landslide block, west of the mouth of Secret Canyon, consists of Swan Peak and Fish Haven-Laketown Formations in stratigraphic contact (Figure 21). Shale of the Bloomington is present in isolated outcrops east and southeast of the slide block. Nounan surrounds the rest of the slide block. A low-angle glide plane is exposed along part of the eastern side of the slide block (Figure 22).
Figure 21. Landslide block along front of southern Elkhorn Mountain west of Secret Canyon; view west. Swan Peak (Osp) and Fish Haven-Laketown (OS) Formations are within slide block. Salt Lake Formation (Tsl) overlies the landslide block with angular discordance. Isolated outcrops of Bloomington Formation are in foreground. Glide plane is out of view in canyon bottom in middleground. A close-up view of part of the glide plane is shown in Figure 22.
Figure 22. Glide plane of landslide block along mountain front west of Secret Canyon; view southwest. Landslide block contains Swan Peak and Fish Haven-Laketown Formations. Scale is shown by 6-inch rule. Distant view of slide block is shown in Figure 21.
STRUCTURAL EVENTS

General Statement

The structural features of the region are the result of the older Laramide orogeny and younger Basin and Range faulting. The Laramide orogeny produced folding and thrust faulting in the region. The Bannock thrust zone and its possible southern extensions in Utah (Crittenden, 1972, p. 2875-2876), as well as the thrust faults to the northeast (Oriel and Armstrong, 1966, p. 2620; Mudge, 1970, p. 388-389), are attributed to the Laramide orogeny. The Laramide orogenic interval lasted from Late Jurassic to early Eocene (Armstrong and Oriel, 1965, p. 1857-1858).

Basin and Range faulting produced normal faults in the region. The Basin and Range event formed a series of generally north-trending horsts and grabens throughout the region. These horsts and grabens form mountain ranges and valleys, respectively. The present topography is the result of Basin and Range faulting. Basin and Range faulting has been active from Oligocene to the present.

Laramide Events

The structural features of the Laramide orogeny, in the mapped area, are a bedding-plane thrust fault and a gentle fold. East of the mapped area, in the Malad Summit Quadrangle, numerous thrust faults were caused by the Laramide orogeny (Shearer, 1975, p. 72-73).
Uplift of the region during the Laramide orogeny resulted in the removal of the Mesozoic rocks and some Paleozoic rocks.

Dating of the Laramide orogeny is accomplished by dating movement along individual thrust faults and using these dates as limits. Evidence from the Paris thrust fault, west of Paris, Idaho, gives an older limit for thrust faulting. The youngest rock unit cut by the Paris thrust fault is the Thaynes Formation of Early Triassic age (Armstrong and Cressman, 1963, p. 8). The Paris thrust fault is covered by the Wasatch Formation of Eocene age (Armstrong and Cressman, 1963, p. 8-9). Thus, movement on the Paris thrust fault occurred between Early Triassic and Eocene. A more precise date, although less reliable, is given by the composition of the Ephraim Conglomerate of Late Jurassic to Early Cretaceous age in the Gannett Hills of Idaho near the Idaho-Wyoming border (Wanless and Gray, 1955, p. 55). The Ephraim Conglomerate consists of detritus from pre-Jurassic rocks, generally Paleozoic (Armstrong and Cressman, 1963, p. 9-14). Armstrong and Cressman (1963, p. 9-14) believed that this composition indicated a source area to the west caused by movement on the Paris thrust fault. This indicates a Late Jurassic date for the start of movement on the Paris thrust fault.

A younger limit for the Laramide orogeny is given by the Prospect thrust fault in western Wyoming. The Prospect thrust fault cuts the lower part of the Hoback Formation of Paleocene age (Armstrong and Oriel, 1965, p. 1857). The upper part of the Hoback Formation of Eocene age is not cut by the thrust fault. This gives an early Eocene age for the cessation of faulting (Armstrong and Oriel,
On the basis of this evidence, the Laramide orogeny was active in the region between Late Jurassic and early Eocene.

**Basin and Range Events**

The normal faults, in the mapped area, are the result of Basin and Range faulting. They occurred after thrust faulting and folding. The faults, within southern Elkhorn Mountain, are probably not active today. The only active faults or fault zones, in the mapped area, are the marginal northwest-trending and marginal north-trending normal faults. No fault scarps have been found across the Tertiary or Quaternary rocks in the mapped area. Although direct evidence for recent movement along the marginal normal faults is lacking, the marginal normal faults are considered to have had movement along them in the recent past. This is evidenced by recent movement along similar faults in the region and by the present topographic relief across the marginal normal faults.

The Wasatch and Salt Lake Formations are used to date the inception of Basin and Range faulting in Cache Valley. The Wasatch Formation was deposited on a surface having relief less than 1,000 feet (Williams, 1948, p. 1146). This surface probably predates Basin and Range faulting. The basal Wasatch, which was deposited on this surface, is early Eocene in age (Williams, 1948, p. 1147). Basin and Range faulting began after the deposition of the Wasatch but prior to the deposition of the Salt Lake (Adamson, Hardy, and Williams, 1955, p. 21). The Salt Lake Formation is Oligocene (Eardley, 1944, p. 845-846) to
Pliocene (Yen, 1947, p. 272) in age. Basin and Range faulting has been active to the present. This is evidenced by numerous earthquakes in the Basin and Range province. Two earthquakes, the 1962 earthquake near Richmond, Utah, and the 1975 earthquake in Pocatello Valley, Idaho, indicate recent fault movement near the mapped area. Tilted beds of Salt Lake, found within Cache Valley (Adamson, Hardy, and Williams, 1955, p. 22), indicate movement during or after their deposition. This information gives an Oligocene to Holocene age for the Basin and Range faulting in the region.
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