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Structural Geology of Southeastern Margin of Bear River Range, Idaho

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STRUCTURAL GEOLoGY OF SOUTHEASTERN MARGIN
OF BEAR RIVER RANGE, IDAHO

CLINTON L. DAVIS

1969
STRUCTURAL GEOLOGY OF SOUTHEASTERN MARGIN
OF BEAR RIVER RANGE, IDAHO

by
Clinton L. Davis

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

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah
1969
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Clinton L. Davis
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<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>Field Work</td>
<td>3</td>
</tr>
<tr>
<td>Previous Investigations</td>
<td>3</td>
</tr>
<tr>
<td>STRATIGRAPHIC GEOLOGY</td>
<td>5</td>
</tr>
<tr>
<td>General Statement</td>
<td>5</td>
</tr>
<tr>
<td>Paleozoic Rocks</td>
<td>7</td>
</tr>
<tr>
<td>Cambrian System</td>
<td>7</td>
</tr>
<tr>
<td>General statement</td>
<td>7</td>
</tr>
<tr>
<td>Brigham Formation</td>
<td>7</td>
</tr>
<tr>
<td>Langston Formation</td>
<td>10</td>
</tr>
<tr>
<td>Ute Formation</td>
<td>12</td>
</tr>
<tr>
<td>Blacksmith Formation</td>
<td>13</td>
</tr>
<tr>
<td>Bloomington Formation</td>
<td>14</td>
</tr>
<tr>
<td>Nounan Formation</td>
<td>15</td>
</tr>
<tr>
<td>St. Charles Formation</td>
<td>16</td>
</tr>
<tr>
<td>Ordovician System</td>
<td>18</td>
</tr>
<tr>
<td>General statement</td>
<td>18</td>
</tr>
<tr>
<td>Garden City Formation</td>
<td>18</td>
</tr>
<tr>
<td>Swan Peak Formation</td>
<td>20</td>
</tr>
<tr>
<td>Fish Haven Formation</td>
<td>21</td>
</tr>
<tr>
<td>Silurian System</td>
<td>22</td>
</tr>
<tr>
<td>Laketown Formation</td>
<td>22</td>
</tr>
<tr>
<td>Mississippian System</td>
<td>23</td>
</tr>
<tr>
<td>General statement</td>
<td>23</td>
</tr>
<tr>
<td>Lodgepole Formation</td>
<td>23</td>
</tr>
<tr>
<td>Little Flat Formation</td>
<td>25</td>
</tr>
<tr>
<td>Pennsylvanian System</td>
<td>27</td>
</tr>
<tr>
<td>Wells Formation</td>
<td>27</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Permian System</td>
<td>28</td>
</tr>
<tr>
<td>Phosphoria Formation</td>
<td>28</td>
</tr>
<tr>
<td>Cenozoic Rocks</td>
<td>29</td>
</tr>
<tr>
<td>Tertiary System</td>
<td>29</td>
</tr>
<tr>
<td>General statement</td>
<td>29</td>
</tr>
<tr>
<td>Wasatch Formation</td>
<td>30</td>
</tr>
<tr>
<td>Salt Lake Formation</td>
<td>31</td>
</tr>
<tr>
<td>Quaternary System</td>
<td>31</td>
</tr>
<tr>
<td>General statement</td>
<td>31</td>
</tr>
<tr>
<td>Boulders</td>
<td>32</td>
</tr>
<tr>
<td>Lake deposits</td>
<td>33</td>
</tr>
<tr>
<td>Slope wash and stream deposits</td>
<td>33</td>
</tr>
<tr>
<td>STRUCTURAL GEOLOGY</td>
<td>35</td>
</tr>
<tr>
<td>General Statement</td>
<td>35</td>
</tr>
<tr>
<td>Structural Features</td>
<td>39</td>
</tr>
<tr>
<td>General Statement</td>
<td>39</td>
</tr>
<tr>
<td>Folds</td>
<td>40</td>
</tr>
<tr>
<td>Thrust Fault</td>
<td>42</td>
</tr>
<tr>
<td>Reverse Faults</td>
<td>49</td>
</tr>
<tr>
<td>Gravity Faults</td>
<td>49</td>
</tr>
<tr>
<td>Structural Events</td>
<td>57</td>
</tr>
<tr>
<td>General Statement</td>
<td>57</td>
</tr>
<tr>
<td>Folding</td>
<td>58</td>
</tr>
<tr>
<td>Thrust Faulting</td>
<td>59</td>
</tr>
<tr>
<td>Reverse Faulting</td>
<td>60</td>
</tr>
<tr>
<td>Gravity Faulting</td>
<td>61</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>62</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>65</td>
</tr>
</tbody>
</table>
LIST OF PLATES

Plate                                                                 Page
1. Geologic map of southeastern margin of Bear River Range, Idaho .... Pocket
2. West-east structure section along south side of St. Charles Canyon, Idaho Pocket

LIST OF TABLES

Table                                                                 Page
1. Stratigraphic units of Paleozoic age 6

LIST OF FIGURES

Figures                                                                 Page
1. Index map of southeastern Idaho and north-central Utah showing area mapped 2
2. Cambrian formations on north side of St. Charles Canyon, Idaho, secs. 16-18, T. 15 S., R. 43 E.; view north 9
4. Paris thrust fault on south side of St. Charles Canyon, Idaho, SW 1/4 sec. 15, T. 15 S., R. 43 E.; view south 37
5. Paris thrust fault in ravine, SW 1/4 sec. 34, T. 15 S., R. 43 E.; view north 38
6. Paris thrust fault 1 mile northwest of Fish Haven, Idaho, SW 1/4 sec. 11, T. 16 S., R. 43 E.; view north 38
<table>
<thead>
<tr>
<th>Figures</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Small asymmetric folds in Phosphoria Formation on north side of Bloomington Canyon, Idaho, SE(1/4) sec. 21, T. 14 S., R. 43 E.; view north</td>
<td>41</td>
</tr>
<tr>
<td>8.</td>
<td>Small asymmetric folds in Little Flat Formation on north side of Dry Canyon, Idaho, near center of sec. 10, T. 15 S., R. 43 E.; view north</td>
<td>43</td>
</tr>
<tr>
<td>9.</td>
<td>Crushed and faulted quartzite of Brigham Formation near mouth of Worm Creek Canyon, Idaho, SW(1/4) sec. 34, T. 14 S., R. 43 E.; view north</td>
<td>45</td>
</tr>
<tr>
<td>10.</td>
<td>Crushed dolomite of Fish Haven Formation on south side of canyon (\frac{1}{2}) miles southwest of St. Charles, Idaho, NW(1/4) sec. 27, T. 15 S., R. 43 E.; view south</td>
<td>46</td>
</tr>
<tr>
<td>11.</td>
<td>Reverse fault in Garden City Formation on north side of Green Canyon, Idaho, SW(1/4) sec. 15, T. 15 S., R. 43 E.; view north</td>
<td>50</td>
</tr>
<tr>
<td>12.</td>
<td>Overturned Swan Peak Formation thinned by reverse faulting on north side of small canyon in SE(1/4) sec. 3, T. 16 S., R. 43 E.; view north</td>
<td>52</td>
</tr>
<tr>
<td>13.</td>
<td>Gravity fault between Rex Chert Member of Phosphoria Formation and Wasatch Formation, SE(1/4) sec. 3, T. 15 S., R. 43 E.; view north</td>
<td>53</td>
</tr>
<tr>
<td>14.</td>
<td>Angular unconformity between Rex Chert Member of Phosphoria Formation and Wasatch Formation, SE(1/4) sec. 3, T. 15 S., R. 43 E.; view south</td>
<td>54</td>
</tr>
<tr>
<td>15.</td>
<td>West-dipping gravity fault in Garden City Formation on north side of Green Canyon, Idaho, SW(1/4) sec. 15, T. 15 S., R. 43 E.; view north</td>
<td>55</td>
</tr>
</tbody>
</table>
ABSTRACT

Structural Geology of Southeastern Margin
of Bear River Range, Idaho

by

Clinton L. Davis, Master of Science
Utah State University, 1969

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

Seven Cambrian formations and two Ordovician formations, with a total thickness of 9,000 feet, crop out west of the Paris thrust fault and comprise the upper plate. Slices of three Ordovician formations, one Silurian formation, two Mississippian formations, and one formation each of Pennsylvanian and Permian age comprise the low plate. Mesozoic units are not present in the mapped area. Two Tertiary formations and unconsolidated Quaternary deposits are also present.

The major structural feature is the Paris thrust fault which extends north-south throughout the area. It was active during the Laramide orogeny. This fault involved eastward movement and placed Cambrian over Ordovician and later Paleozoic strata. The oldest formation exposed in the upper plate is the Brigham Formation which generally rests on the Garden City Formation. All units of the lower plate have been severely distorted and displaced by folding, thrusting, and reverse faulting. Both horizontal compression and gravity sliding have been invoked to explain this deformation. Gravity sliding is favored by many geologists; however, an
uplifted source area has not been identified. Later, gravity faulting produced the major topographic features of the area today, notably the Bear River Range and Bear Lake Valley.
INTRODUCTION

Purpose and Scope

The purpose of this report is to contribute to the geological knowledge and understanding of southeastern Idaho, especially the structural features related to thrust faulting. The investigation was carried out by field mapping on aerial photographs of the stratigraphy and structure in the subject area (Figure 1). A geologic map was then constructed at a scale of 1:24,000 (Plate 1). The observed features were then related to previously published information concerning southeastern Idaho, north-central Utah, and western Wyoming.

Location and Accessibility

The subject area is on the east side of the Bear River Range and extends from the Utah-Idaho state line north to Bloomington Creek. It includes the communities of Fish Haven, St. Charles, and part of Bloomington, Bear Lake County, Idaho. This area lies between lat. 42°00'00"N. and 42°11'16"N. and between long. 111°12'12"W. and 111°28'52"W. and covers an area of approximately 55 square miles (Figure 1).

Most of the area is accessible by highway or secondary roads. U. S. Highway 89 runs north-south through the area and connects all the communities on the west side of Bear Lake. Several good secondary roads extend west from the highway and provide access to most of
Figure 1. Index map of southeastern Idaho and north-central Utah showing area mapped.
the area; whereas, unimproved roads penetrate some of the remote parts.

Field Work

The field investigation was accomplished during the summer and fall of 1967 and the summer of 1968. The stratigraphy and structure were mapped on aerial photographs, scale 1:20,000, and later transferred to a base map, scale 1:24,000. The base map was taken from a U. S. Forest Service map of the Cache National Forest.

Two stratigraphic sections were described and measured with a steel tape and Brunton compass (Appendix). Three other formations were also measured but were not described in detail. Representative rock samples were collected, while measuring the sections, to facilitate description of the stratigraphic units. These samples were then examined in the laboratory to determine fresh and weathered colors according to the Rock-Color Chart distributed by The Geological Society of America (1963). The particle sizes were determined by comparing the samples with the Wentworth standards produced by The Geological Specialty Company. Bedding terminology was derived from Ingram (1954). Fossils were collected from problem strata and identified in the laboratory by J. Stewart Williams, Utah State University.

Previous Investigations

Hayden (1871), King (1876), and Peale (1877, p. 511-643) all conducted geologic investigations in this general area during the latter part of the 19th century. Early in this century investiga-
tions were carried out by Walcott (1908, p. 1-12), Veatch (1907), and Richards (1910).

With the discovery of phosphate deposits in the Phosphoria Formation of southeastern Idaho in the early part of this century, the U. S. Geological Survey began conducting a study of the area to determine the nature and extent of the phosphate resources. In 1910, Mansfield joined the field party and later was placed in charge of the phosphate survey. Under his direction the study continued until 1916 when it was interrupted by World War I. In 1927, Mansfield published U. S. Geological Survey Professional Paper 152 which is a comprehensive report of the geologic investigations done in the southeastern Idaho area up to that time. This paper has been frequently referred to by all geologists who have worked in the area since its publication.

Later geologic contributors include Richardson (1913, 1941), Deiss (1938), and Williams and Maxey (1941). Ross (1949, 1951) contributed substantially to the study of the Ordovician formations and fauna. The latest contributions were made by McKelvey and his associates (1953, 1955, 1956, 1959), Maxey (1958), Armstrong and Cressman (1963), and Armstrong and Oriel (1965). Several geology students have studied parts of southeastern Idaho and north-central Utah as subjects for unpublished M.S. theses and Ph.D. dissertations.
STRATIGRAPHIC GEOLOGY

General Statement

Precambrian rocks have not been recognized in the mapped area (Mansfield, 1927, p. 52, 173, 179-180; Richardson, 1941, p. 8; Maxey, 1958, p. 667), although their possible presence there has been postulated by Clyde T. Hardy (1968, personal communication). The Precambrian Mutual Formation has been identified on the mountain front northeast of Logan, Utah, where it underlies the Brigham Formation with apparent conformity (Clyde T. Hardy and Cheryl L. Galloway, 1968, personal communication). It is distinguished from the Brigham Formation by basalt flows near the top of the formation. Basalt flows are not present in the mapped area and adequate evidence is not available to indicate the presence of the Mutual Formation.

Most of the strata exposed in the mapped area were deposited during the Paleozoic Era (Table 1) on the shelf of the Cordilleran geosyncline (Mansfield, 1927, p. 171, 176). These rocks were generally deposited under shallow-marine conditions (Maxey, 1958, p. 647, 685). Occasional regressions resulted in unconformities (Mansfield, 1927, p. 173); however, no angular discordance between Paleozoic units of the mapped area is recognized. During the Mesozoic Era a considerable thickness of marine and terrestrial sediments was deposited in southeastern Idaho (Mansfield, 1927, p. 174; Armstrong and Oriel, 1965, p. 1847, 1849), but tectonic disturbances toward the end of that era caused erosion of these
Table 1. Stratigraphic units of Paleozoic age.

<table>
<thead>
<tr>
<th>System</th>
<th>Formation</th>
<th>Description</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permian System</td>
<td>Phosphoria Formation</td>
<td>Chert, phosphatic shale,</td>
<td>450a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>limestone</td>
<td></td>
</tr>
<tr>
<td>Pennsylvanian</td>
<td>Wells Formation</td>
<td>Sandstone, sandy limestone</td>
<td>2,400b</td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mississippian</td>
<td>Little Flat Formation</td>
<td>Sandy dolomite</td>
<td>965c</td>
</tr>
<tr>
<td>System</td>
<td>Lodgepole Formation</td>
<td>Limestone</td>
<td>773d</td>
</tr>
<tr>
<td>Silurian System</td>
<td>Laketown Formation</td>
<td>Dolomite</td>
<td>1,000e</td>
</tr>
<tr>
<td>Ordovician System</td>
<td>Fish Haven Formation</td>
<td>Dolomite</td>
<td>500f</td>
</tr>
<tr>
<td></td>
<td>Swan Peak Formation</td>
<td>Quartzite, shale</td>
<td>500g</td>
</tr>
<tr>
<td></td>
<td>Garden City Formation</td>
<td>Limestone</td>
<td>1,221h</td>
</tr>
<tr>
<td>Cambrian System</td>
<td>St. Charles Formation</td>
<td>Limestone</td>
<td>800i</td>
</tr>
<tr>
<td></td>
<td>Upper Member</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Worm Creek Member</td>
<td>Quartzite, sandstone</td>
<td>150j</td>
</tr>
<tr>
<td></td>
<td>Nounan Formation</td>
<td>Limestone, dolomite</td>
<td>1,125k</td>
</tr>
<tr>
<td></td>
<td>Bloomington Formation</td>
<td>Shale, thin-bedded shaly</td>
<td>53l</td>
</tr>
<tr>
<td></td>
<td></td>
<td>limestone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blacksmith Formation</td>
<td>Sandy limestone, dolomite</td>
<td>309l</td>
</tr>
<tr>
<td></td>
<td>Ute Formation</td>
<td>Limestone, shale</td>
<td>709l</td>
</tr>
<tr>
<td></td>
<td>Langston Formation</td>
<td>Sandy limestone, dolomite</td>
<td>274l</td>
</tr>
<tr>
<td></td>
<td>Brigham Formation</td>
<td>Quartzite</td>
<td>3,413l</td>
</tr>
</tbody>
</table>

a. Phosphoria Gulch, Georgetown Canyon, Idaho (Mansfield, 1927, p. 75)
b. Wells Canyon, Idaho (Mansfield, 1927, p. 72)
d. Brazer Canyon, Utah (Sando, Dutro, Gere, 1959, p. 2746)
e. Laketown Canyon, Utah (Mansfield 1927, p. 58)
f. Fish Haven Canyon, Idaho (Mansfield, 1927, p. 58)
g. Five miles north of Utah-Idaho state line in Montpelier quadrangle (Richardson, 1941, p. 16)
h. Garden City Canyon, Utah (Ross, 1951, p. 11-13)
i. St. Charles Canyon, Idaho (Mansfield, 1927, p. 56)
j. St. Charles Canyon, Idaho (Haynie, 1957, p. 7-8)
k. High Creek, Bear River Range, Utah (Maxey, 1958, p. 651)
l. St. Charles Canyon, Idaho (this report)
units in the mapped area.

The Cenozoic Era was marked by intermittent uplift and the only deposits of this era are continental (Mansfield, 1927, p. 174). The Tertiary Wasatch and Salt Lake Formations were both deposited after the Laramide orogeny. Other Tertiary units, which may have been deposited in this area, have since been removed by erosion. The most recent stratigraphic deposits consist of slope wash, stream deposits, lake deposits, and isolated patches of large quartzite boulders of problematical origin.

**Paleozoic Rocks**

**Cambrian System**

General statement. The Cambrian Period was characterized by submergence of southeastern Idaho beneath a shallow sea. During this tremendous span of time, a great thickness of marine strata was deposited. Seven Cambrian formations, with approximately 7,000 feet total thickness, are recognized in the mapped area. All of these formations are located in the upper plate of the Paris thrust fault and occur in normal stratigraphic succession (Plate 2). The best exposure of these units in the mapped area is on the north side of St. Charles Canyon, Idaho, beginning at the Paris thrust fault and extending west (Figure 2).

Brigham Formation. The Brigham Formation was named by Walcott (1908, p. 8-9) for the conspicuous quartzite exposures northeast of Brigham City, Utah, where it is approximately 2,000 feet thick. It is 1,250 feet thick in Blacksmith Fork Canyon, Utah, and 1,000 feet
Figure 2. Cambrian formations on north side of St. Charles Canyon, Idaho, secs. 16-18, T. 15 S., R. 43 E.; view north. Csc-St. Charles Fm., Cn-Nounan Fm., Cbo-Bloomington Fm., Cbl-Blacksmith Fm., Cu-Ute Fm., Cl-Langston Fm., Cb-Brigham Fm.
Most workers concluded that the age of the Brigham Formation is Early Cambrian, possibly extending into Middle Cambrian near the top (Mansfield, 1927, p. 52, 180; Deiss, 1938, p. 1119; Williams, 1948, p. 1132). Walcott (1908, p. 8-9) considered it to be of Middle Cambrian age and much younger than the Prospect Mountain Quartzite in Nevada. The Prospect Mountain Formation and the Brigham Formation are merely regional names for the same transgressive deposit, and any age difference is merely due to this transgressive nature. Maxey (1958, p. 667-669) thought that the quartzite, Prospect Mountain, was Early Cambrian or older and that the topmost shale unit, Pioche Shale, was late Early or early Middle Cambrian in age. An Early Cambrian age is most probable for the Brigham Formation.

Langston Formation. The Langston Formation was named by Walcott (1908, p. 8) for its exposure on Langston Creek, Idaho. The most accessible exposure and type locality of the formation is in Blacksmith Fork Canyon, Utah, where Walcott measured a thickness of 107 feet. Walcott also studied this formation west of Liberty, Idaho, where the thickness is 30 feet. Deiss (1938, p. 1119) disagreed with Walcott's Blacksmith Fork section both as to thickness and fossil content. Williams and Maxey (1941, p. 279-281) disagreed, in turn, with Deiss and gave the Blacksmith Fork thickness as 380 feet. After re-examining the Spence Shale Member at Spence Gulch, Idaho, Williams and Maxey (1941, p. 279-281) reassigned it to the upper part of the Langston Formation rather than to the base of the Ute Formation as Walcott (1908, p. 2, 200) had done.
This reassignment of the Spence Shale Member has been accepted by all subsequent workers in the area. Maxey (1958, p. 671) described the Naomi Peak Member as an arenaceous limestone which overlies the uppermost shales of the Brigham Formation and underlies the Spence Shale Member. Mansfield (1927, p. 52) identified the Langston Formation in the mapped area. The thickness of this formation ranges from 250 to 600 feet in southeastern Idaho.

The Langston Formation lies immediately west of the Brigham Formation and is conformable with both overlying and underlying units. It parallels the Brigham Formation throughout the mapped area and is also in the upper plate of the Paris thrust fault (Figure 2; Plate 2). This formation consists of four distinctive units where it was measured on the north side of St. Charles Canyon, Idaho (Appendix). It generally consists of arenaceous limestone and dolomite which weather gray to brown and often form low rounded cliffs or ledges. The Spence Shale Member was not observed in the mapped area. The total thickness of the Langston Formation on the north side of St. Charles Canyon is 274 feet (Appendix). The lower contact is placed at the base of the first limestone or dolomite bed above the interbedded micaceous shale and quartzite of the Brigham Formation (Maxey, 1958, p. 669). The upper contact is placed between brown arenaceous dolomite and a thin-bedded green shale which occurs at the base of the Ute Formation.

Walcott (1908, p. 8), Maxey (1958, p. 671), and Mansfield (1927, p. 53) all considered the Langston Formation to be of early Middle Cambrian age on the basis of fossil evidence.
Ute Formation. The Ute Formation was first described by King (1876, p. 477), of the Fortieth Parallel Survey, as 2,000 feet of limestone which conformably overlies the uppermost shale of Cambrian age. Walcott (1908, p. 7-8, 200) restricted the name Ute to the lower beds of King's original Ute Limestone and prescribed Ute Peak, Cache County, Utah, as the type locality. According to Walcott, the redefined Ute Formation is 759 feet thick in Blacksmith Fork Canyon, Utah, and 731 feet thick west of Liberty, Idaho. At the type locality it consists of thin-bedded finely crystalline blue to bluish-gray limestone interbedded with shale. Walcott's redefinition of the Ute Formation, except for the Spence Shale Member, has been accepted by all subsequent workers, except Deiss (1938, p. 1120). Mansfield (1927, p. 52-55) first described the Ute Formation of the mapped area and listed the thickness as 760 feet. He accepted the Spence Shale Member as the basal unit of the Ute Formation.

In the mapped area, the Ute Formation lies with apparent conformity on the brown arenaceous dolomite of the Langston Formation. It occurs in a belt through the mapped area, in the upper plate of the Paris thrust fault (Plate 2), just west of the Langston Formation and approximately parallel to it. The best exposure of this formation is on the north side of St. Charles Canyon, Idaho, where it is 709 feet thick (Figure 2). The Ute Formation was also measured in the southernmost of the three tributary canyons in sec. 4, T. 16 S., R. 43 E., where it is 687 feet thick. The Ute Formation consists of nonresistant thin-bedded light-gray to bluish-gray shaly limestone. Its base is at the bottom of about 6 feet of thin-bedded green shale which directly overlies the brown dolomite of the
Langston Formation. The upper contact is at the base of the conspicuous cliffs of the Blacksmith Formation.

The Ute Formation is recognized by all workers as a Middle Cambrian unit (Walcott, 1908, p. 8, 200; Mansfield, 1927, p. 52; Deiss, 1938, p. 1120; Maxey, 1958, p. 672).

Blacksmith Formation. The Blacksmith Formation was first described by Walcott (1908, p. 7, 200) as consisting of gray arenaceous limestone in massive beds. He gave 570 feet as the thickness at the type locality in Blacksmith Fork Canyon, Utah, and 23 feet as the thickness west of Liberty, Idaho. Deiss (1938, p. 1121) remeasured the Blacksmith Fork section and obtained a thickness of 450 feet. In the Randolph quadrangle, south of the mapped area, Richardson (1941, p. 11) noted that the Blacksmith Formation is resistant and causes rugged topography. Mansfield (1927, p. 51, 55) recognized this formation in the mapped area and gave the thickness as 750 feet. He described it as a cliff-making arenaceous limestone at the base; whereas, higher beds are thin-bedded limestone.

The Blacksmith Formation lies with apparent conformity on the Ute Formation and occurs in a belt through the western half of the mapped area just to the west of the Ute Formation. The best exposure of this formation is on the north side of St. Charles Canyon, Idaho, where it is 309 feet thick (Figure 2). It was also measured in the southernmost tributary canyon in sec. 4, T. 16 S., R. 43 E., where it is 414 feet thick. The rugged cliffs of the Blacksmith Formation rise quite abruptly from the nonresistant Ute Formation. The upper contact is between the resistant arenaceous brown limestone
or dolomite at the top of the Blacksmith Formation and the first shale beds of the Hodges Shale Member at the base of the Bloomington Formation.

All workers have assigned this formation to Middle Cambrian time (Walcott, 1908, p. 7, 200; Mansfield, 1927, p. 51; Maxey, 1958, p. 672-673).

**Bloomington Formation.** Walcott (1908, p. 7, 199) described the Bloomington Formation and designated a type locality about 6 miles west of Bloomington, Idaho. According to Walcott, the Bloomington Formation consists of argillaceous shale and thin-bedded bluish-gray limestone. In Blacksmith Fork Canyon, Utah, it is 1,320 feet thick; west of Liberty, Idaho, it is 1,162 feet thick. Richardson (1913, p. 406) first described the Hodges Shale Member at the base of the Bloomington Formation. Mansfield (1927, p. 51, 55) recognized both the Bloomington Formation and its Hodges Shale Member in the mapped area. He gave the total thickness as 1,500 feet and the thickness of the Hodges Shale Member as 300 feet.

In the mapped area, the Bloomington Formation lies immediately to the west of the Blacksmith Formation which it conformably overlies. The best exposure is on the north side of St. Charles Canyon, Idaho, where it is 534 feet thick (Figure 2). In the southernmost tributary canyon in sec. 4, T. 16 S., R. 43 E., it is 732 feet thick (this report). This formation consists of shale, thin-bedded shaly limestone, and occasional limestone beds up to 2 feet thick near the top. Both the underlying Blacksmith Formation and the overlying Nounan Formation are resistant cliff-making carbonate units and
effectively outline the Bloomington Formation which causes depressions in the ridges.

All workers have assigned the Bloomington Formation to Middle Cambrian time on the basis of fossil evidence (Walcott, 1908, p. 7, 199; Mansfield, 1927, p. 51; Maxey, 1958, p. 673).

**Nounan Formation.** The Nounan Formation was originally described by Walcott (1908, p. 6-7, 199) for its exposure on the east slope of Soda Peak, west of Nounan, Idaho. The Nounan Formation consists of light- to dark-gray arenaceous limestone. In Blacksmith Fork Canyon it is 1,041 feet thick; west of Liberty, Idaho, it is 814 feet thick. Mansfield (1927, p. 51, 55-56) recognized the Nounan Formation throughout much of southeastern Idaho and in the mapped area. He gave the thickness as 1,050 feet.

The Nounan Formation lies with apparent conformity on the Bloomington Formation and occurs in a belt throughout the mapped area just to the west of the Bloomington Formation. It is overlain conformably by the Worm Creek Quartzite Member of the St. Charles Formation. The Nounan Formation is composed of resistant limestone and dolomite and stands in sharp contrast to the nonresistant Bloomington Formation. The Nounan cliffs weather with gray and brown patterns which can be seen for several hundred yards. The best exposure of this formation is on the north side of St. Charles Canyon, Idaho (Figure 2), although it is also well exposed on the south side of the canyon where the steep rugged cliffs stand above the pine trees. This formation was not measured in the mapped area.

Walcott (1908, p. 6-7, 199) assigned the Nounan Formation to
Middle Cambrian time on the basis of fossils he found in the lower part, but Mansfield (1927, p. 180-181) implied that the upper part may be Late Cambrian. Deiss (1938, p. 1132) stated that this formation should be considered to be of Middle Cambrian age unless conclusive evidence is found to prove that the upper part is Late Cambrian. No attempt was made to date this formation in the mapped area.

**St. Charles Formation.** Walcott (1908, p. 6, 199) first described the St. Charles Formation in St. Charles Canyon, Idaho, but it is also accessible in Blacksmith Fork Canyon, Utah. He described it as consisting of bluish-gray to gray arenaceous limestone passing at the base into thin-bedded gray to brown sandstone. In Blacksmith Fork Canyon it is 1,225 feet thick; west of Liberty, Idaho, it is 1,197 feet thick. In 1913, Richardson (1913, p. 406-408) described the basal Worm Creek Quartzite Member of the St. Charles Formation. This quartzite is approximately 300 feet thick in the Randolph quadrangle, Utah.

Deiss (1938, p. 1124) claimed that the Worm Creek Quartzite Member could not be identified in Blacksmith Fork Canyon; however, Williams (1948, p. 1135) noted that it is definitely present there. Also the 250 feet of limestone and intraformational conglomerate, which Deiss included at the top of the formation, are actually basal Garden City strata and contain Ordovician fossils (Williams, 1948, p. 1135). Mansfield (1927, p. 51, 56) recognized both the St. Charles Formation and the Worm Creek Quartzite Member in the mapped area. He listed the thickness of the Worm Creek Quartzite
Member as 200 feet and the total thickness of the St. Charles Formation as ranging from 950 to 1,200 feet.

The St. Charles Formation occurs in a belt through the mapped area immediately west of the Nounan Formation and near the western margin of the mapped area. One small outcrop also occurs in the NW sec. 34, T. 15 S., R. 43 E., where it is apparently beneath the Paris thrust fault and is overlain by the Brigham Formation. The best exposures are on the north side of St. Charles Canyon, Idaho (Figure 2), and in the high country between St. Charles Canyon and Green Canyon. In general, the Worm Creek Quartzite Member is easy to recognize and consists of brown to white quartzite or quartzitic sandstone. This quartzite overlies the resistant dolomite of the Nounan Formation with apparent conformity. Upward the Worm Creek Quartzite Member becomes more calcareous and grades into the limestone and dolomite of the upper part of the St. Charles Formation. This formation is overlain conformably by the Garden City Formation. The upper contact is placed between the gray to light-brown dolomite of the St. Charles Formation and the light-gray limestone of the Garden City Formation.

Walcott (1908, p. 6, 199) believed that most of the St. Charles Formation was Late Cambrian in age, but that the upper part was Early Ordovician. Mansfield (1927, p. 51) listed the formation as Late Cambrian. Armstrong and Oriel (1965, p. 1849) also implied that it was deposited in Late Cambrian time. Actually the St. Charles Formation is Late Cambrian in age; the first Ordovician fossils are found in the overlying Garden City Formation (Ross, 1949, p. 6).
Ordovician System

General statement. Mansfield (1927, p. 181) recognized an unconformity beneath the Garden City Formation which supposedly represents the erosion of several hundred feet of Upper Cambrian strata. During most of Early Ordovician time, the region was submerged while the Garden City and Swan Peak Formations were deposited. The Swan Peak Formation represents regression of the sea until, during Middle Ordovician time, emergence and erosion resulted in an unconformity which now separates the Swan Peak Formation from the Fish Haven Formation (Mansfield, 1927, p. 56-57, 181). As little sandstone or quartzite occurs in the lower part of the Fish Haven Formation, it appears that the renewed transgression must have occurred too rapidly for the deposition of significant sandstone.

Garden City Formation. The Garden City Formation was originally described by Richardson (1913, p. 408) as 1,000 feet of thin-to thick-bedded gray limestone which outcrops west of Garden City, Utah. Mansfield (1927, p. 51, 57) recognized the Garden City Formation in southeastern Idaho and listed the thickness as 1,250 feet, which is much thicker than the 500 feet measured by Ross (1951, p. 5) in St. Charles Canyon, Idaho.

Ross has done the most authoritative and extensive study of the Ordovician formations in this area, and he specifically concentrated on the Garden City Formation. Ross (1951, p. 6) placed the lower boundary of this formation as the base of the lowest limestone bed above the dolomite of the St. Charles Formation; this boundary also separates Cambrian and Ordovician strata on the basis
of fossil evidence. On a lithologic basis, Ross (1949, p. 475; 1951, p. 7-8) divided the Garden City Formation into two members: (1) the lower member consists of interbedded intraformational limestone conglomerate, muddy limestone, and crystalline limestone; (2) the upper member is composed predominantly of thick resistant beds of dark-gray cryptocrystalline limestone with a high content of chert. The lower member resulted from drying and cracking of lime mud on low subaerial flats and the incorporation of the fragments into a younger deposit (Ross, 1951, p. 33). The upper boundary of the Garden City Formation is at the base of the lowest noncarbonate bed of the Swan Peak Formation, although limestone layers are sometimes encountered higher (Ross, 1949, p. 477-478).

The Garden City Formation is exposed in a wide belt parallel to the St. Charles Formation at the western margin throughout most of the mapped area. It is also exposed immediately east of the Brigham Formation in the lower plate of the Paris thrust fault. It can be found in this position in a belt running north from Fish Haven, Idaho, to sec. 10, T. 15 S., R. 43 E. Most of the formation exposed in the lower plate of the Paris thrust fault has been severely contorted and faulted. The limestone of the Garden City Formation is light-gray to bluish-gray and the embedded limestone fragments are easily visible. The upper and lower contacts of this formation in the mapped area are as described by Ross (1951, p. 6; 1949, p. 477-478).

The Garden City Formation is highly fossiliferous, especially in trilobites, and on this basis all previous workers have assigned it to Early Ordovician time (Mansfield, 1927, p. 51; Ross, 1951,
Swan Peak Formation. The Swan Peak Formation was originally described by Richardson (1913, p. 409) as 500 feet of white to gray quartzite which overlies the Garden City Formation conformably. Williams (1948, p. 1136) recognized the Swan Peak Formation in the Logan quadrangle, Utah, and described it as consisting of three members: (1) a lower black shale member, (2) a middle brown quartzite member, (3) an upper light-brown quartzite member. Mansfield (1927, p. 51) recognized the Swan Peak Formation in the mapped area and gave the thickness as 500 feet. He (Mansfield, 1927, p. 51) also noted thin phosphate beds in the Swan Peak Formation west of Fish Haven, Idaho. According to Ross (1949, p. 484-485), the Swan Peak Formation is at least 500 feet thick in St. Charles Canyon, Idaho.

The Swan Peak Formation is found mainly in the highest country in the southwestern part of the mapped area. The only other occurrences are immediately east of the Paris thrust fault in the lower plate. The lower-plate occurrences are extremely contorted and faulted and generally represent only a partial thickness of the formation. On the north side of a canyon in SE₂₄ sec. 3, T. 16 S., R. 43 E., the Swan Peak Formation has been thinned by faulting. The Garden City and Fish Haven outcrops are about 30 feet apart with a thin slice of the Swan Peak Formation between them (Figure 12). On the north side of a canyon in SE₁₂ sec. 34, T. 15 S., R. 43 E., the Swan Peak Formation seems to have a complete thickness present between the Garden City and Fish Haven Formations. Most of
the quartzite layers exhibit cross-bedding and fucoidal markings. Thin beds of green shale are common throughout much of the formation especially on the fucoidally marked surfaces. Near the lower contact considerable shale and shaly limestone are interbedded with limestone layers. This makes it quite difficult to locate a distinct contact between the Garden City and Swan Peak Formations. The upper contact occurs at the top of the highest quartzite bed below the resistant dark-gray dolomite of the Fish Haven Formation.

Mansfield (1927, p. 51) listed the age of the Swan Peak Formation as Lower Ordovician; however, Ross (1949, p. 33) stated that it is definitely earliest Middle Ordovician on the basis of fossil evidence.

**Fish Haven Formation.** The Fish Haven Formation was originally described by Richardson (1913, p. 409-410) as about 500 feet of medium-bedded dark-gray dolomite. The type locality is in Fish Haven Canyon, Idaho, in the southern part of the mapped area. Mansfield (1927, p. 51, 58) also studied the Fish Haven Formation in the mapped area and gave its thickness as 500 feet. Both Mansfield (1927, p. 181) and Williams (1948, p. 1137) recognized an unconformity between the Fish Haven and Swan Peak Formations representing part or all of Middle Ordovician time.

This formation is only found in the faulted interval in the lower plate of the Paris thrust fault, generally east of the Swan Peak Formation. It has been severely contorted and displaced by reverse faulting in the complexly faulted area on the south side of St. Charles Canyon, Idaho, near the center of sec. 15, T. 15 S,
R. 43 E. In a good exposure in a canyon 1½ miles southwest of St. Charles, sec. 27, T. 15 S., R. 43 E., the Fish Haven Formation has been shattered and granulated by the thrusting (Figure 10). It consists of dark-gray dolomite which has a fetid odor when freshly broken. At the lower contact the dolomite of the Fish Haven Formation overlies the quartzite of the Swan Peak Formation with apparent conformity, although a Middle Ordovician unconformity occurs between the two formations. At the top the Fish Haven Formation is overlain conformably by the light-brown dolomite of the Laketown Formation.

The Fish Haven Formation is Late Ordovician in age (Mansfield, 1927, p. 51; Williams, 1948, p. 1137).

Silurian System

Laketown Formation. The Laketown Formation was originally described by Richardson (1913, p. 410) near Laketown, Utah, as approximately 1,000 feet of light-gray to white dolomite. In the Logan quadrangle, Utah, Williams (1948, p. 1137) recognized this formation and gave its thickness as 1,500 feet along the Logan Peak syncline on the west side of the Bear River Range. Mansfield (1927, p. 51, 58-59) recognized the Laketown Formation in the mapped area and listed the thickness in southeastern Idaho as ranging from 0 to 1,000 feet.

This formation lies adjacent to the Fish Haven Formation, probably in fault relationship, in the faulted interval east of the Paris thrust fault. It consists of light- to medium-brown dolomite and contains some beds of calcareous, nearly quartzitic,
sandstone, and locally a bed of purple shale. Normally the Laketown Formation overlies the Fish Haven Formation conformably, but this relationship cannot be observed in the mapped area because of folding and faulting. The upper contact of the Laketown Formation cannot be observed in the mapped area because of an incomplete Laketown thickness. This formation forms the easternmost noses of several ridges near St. Charles, Idaho.

Most previous workers in the area have assigned this formation to the Silurian Period (Richardson, 1913, p. 410; Mansfield, 1927, p. 51; Williams, 1948, p. 1137).

**Mississippian System**

**General statement.** During Mississippian time, two major transgressions of the sea occurred across what is now southeastern Idaho (Sando, 1967, p. 36). The first transgression is now represented by the predominantly carbonate Lodgepole Formation (Sando, 1967, p. 36). The second transgression is represented by the Chesterfield Range Group in most of southeastern Idaho (Sando, 1967, p. 36-37), but only the predominantly detrital Little Flat Formation is present in the mapped area.

**Lodgepole Formation.** The first use of Lodgepole as a formation name was by Collier and Cathcart (1922, p. 173) who designated it as the lower formation of the Madison Group. They defined it as 800 feet of thin-bedded fossiliferous limestone and shale. Prior to Collier and Cathcart, the Madison Limestone, including the present Lodgepole Formation, had originally been described by Peale
(Strickland, 1956, p. 51) as a series of carbonates of Carboniferous age. Peale did not specify a type locality for the Madison Limestone, but he did divide it into three members: (1) a lower laminated limestone, (2) a middle massive-bedded limestone, (3) a top jaspery limestone. According to Strickland (1956, p. 54), the present Lodgepole Formation comprises the lower laminated limestones of Peale. Strickland (1956, p. 51) designated Lodgepole Canyon in the Little Rocky Mountains, Montana, as the type locality.

Because of similarities in lithology, bedding characteristics, and fossils, Holland (1952, p. 1697-1698) determined that the Madison Formation in the Bear River Range was the same age as the Lodgepole Formation in Montana. Sando, Dutro, and Gere (1959, p. 2746) studied the Lodgepole Formation in the Crawford Mountains, Utah. They divided it into three members and gave the total thickness as 773 feet in Brazer Canyon.

Although no previous workers have recognized the Lodgepole Formation in the mapped area, it has been identified in the region (Sando, Dutro, Gere, 1959, p. 2746; Holland, 1952, p. 1697-1698; Strickland, 1956, p. 51). In the mapped area, this formation was identified in two small outcrops. The best exposure is on the north side of Dry Canyon, Idaho, SE_4 sec. 10, T. 15 S., R. 43 E. The other exposure occurs near the mouth of Worm Creek Canyon, Idaho, sec. 34, T. 14 S., R. 43 E. The Lodgepole Formation is in the lower plate of the Paris thrust fault and is separated from the Little Flat Formation by a high-angle fault. The final identification of the Lodgepole Formation was made on the basis of fossils from the Dry Canyon exposure which were examined by J. Stewart
Williams, Utah State University. The fossils include spiriferid brachiopods, rugose corals, pelecypods, and bryozoa. The Lodgepole Formation consists of fossiliferous brown- to white-weathering thin- to medium-bedded limestone with a resistant dolomite interval. This dolomite interval weathers medium-gray and has rugose corals which weather in relief.

The Lodgepole Formation is of Mississippian age (Collier and Cathcart, 1922, p. 173; Holland, 1956, p. 1697; Williams, 1968, personal communication). Sando, Dutro, and Gere (1959, p. 2747) assigned it to Early Mississippian time on the basis of corals, brachiopods, bryozoans, and echinoderms.

**Little Flat Formation.** The Little Flat Formation was first described by Dutro and Sando (1963, p. 1967) as the lowest formation in the Chesterfield Range Group. They designated a type locality in the Chesterfield Range, Idaho, where the Little Flat Formation is 965 feet thick. At the type locality, it is underlain by the Lodgepole Formation and overlain by the Monroe Canyon Formation. Dutro and Sando (1963, p. 1967) divided it into three members: (1) a basal siltstone member, (2) a thick middle sandstone member, (3) a sandy limestone member at the top. The Little Flat Formation replaces the Brazer Formation as formerly used by workers in south-eastern Idaho (Dutro and Sando, 1963, p. 1963, 1967, 1983-1984). Sando, Dutro, and Gere (1959, p. 2768) had previously recognized that the Brazer Formation at the type locality in the Crawford Mountains, Utah, could not be correlated with other Mississippian units outside the Crawford Mountains; therefore, they restricted
the Brazer Formation to the Mississippian dolomite strata found in the Crawford Mountains. At the same time they recognized the need for new nomenclature for the Mississippian strata which had formerly been called Brazer in southeastern Idaho.

It is clear that Dutro and Sando (1963, p. 1983-1984) and Sando (1967, p. 35) intended that the Brazer strata described in southeastern Idaho by Mansfield should be renamed the Little Flat Formation. On this basis, the Little Flat Formation is recognized in the mapped area. This formation is exposed in two small outcrops in the mapped area, both of which are in the lower plate of the Paris thrust fault. The most prominent exposure is on the north side of Dry Canyon, Idaho, near the center of sec. 10, T. 15 S., R. 43 E. This exposure is bounded on the west by slope wash which probably conceals a high-angle fault between the Little Flat Formation and the Fish Haven Formation. On the east, the Little Flat Formation is bounded by the Lodgepole Formation in fault relationship. The other exposure of this formation is near the center of sec. 34, T. 14 S., R. 43 E. Neither the upper nor lower contacts of the Little Flat Formation are exposed in the mapped area because of its fault relationship with adjacent units. This formation consists of thin-bedded dolomitic sandstone which weathers light to medium brown. On the basis of lithology, this strata could be part of the thick middle sandstone member described at the type locality by Dutro and Sando (1963, p. 1967). The Little Flat Formation on the north side of Dry Canyon exhibits small folds which are asymmetrical to the east (Figure 8).

The Little Flat Formation has been assigned to Late Mississippian
time by Sando (1967, p. 35) and Dutro and Sando (1963, p. 1967).

Pennsylvanian System

Wells Formation. The Wells Formation was originally described by Richards and Mansfield (1912, p. 689) as 2,400 feet of sandy limestone, calcareous sandstone, and quartzite. Richardson (1913, p. 415) noted that, in the Randolph quadrangle, Utah, this formation has great differences in thickness and is not fossiliferous. Mansfield (1927, p. 71) recognized and described the Wells Formation of southeastern Idaho, including the mapped area. He (Mansfield, 1927, p. 50) subdivided this formation into three units: (1) the upper unit, 75 feet thick, of fine-grained sandstone and siliceous limestone, (2) the middle unit, 1,700 to 1,800 feet, of sandy limestone, (3) the lower unit, 100 to 750 feet thick, of sandy and cherty limestone and interbedded sandstone. McKelvey and associates (1959, p. 15) assigned the upper siliceous limestone of the Wells Formation to the Grandeur Tongue of the Park City Formation. The present Wells Formation, therefore, is restricted to the sandstone, red beds, and carbonate rock of Mansfield's middle and lower units.

The Wells Formation is exposed only at the northern end of the mapped area in secs. 21 and 28, T. 14 S., R. 43 E., where it is exposed in the lower plate of the Paris thrust fault and underlies the Brigham Formation. The Wells Formation consists of partly silicified limestone which weathers light gray and has poorly preserved rugose corals weathering in relief on some surfaces. This limestone can be seen in the abandoned quarry on the south
of Bloomington Canyon at the location listed above. Although it is possible that these strata might be part of the Grandeur Tongue of the Park City Formation as defined by McKelvey and associates (1959, p. 15), the limited exposure of this unit makes it difficult to identify its exact stratigraphic position; therefore, the name Wells is retained in this report.

Mansfield (1927, p. 50) and McKelvey and associates (1956, p. 2842) listed the Wells Formation as a Pennsylvanian unit. Armstrong and Oriel (1965, p. 1853) claimed that a Permian age is more probable. No attempt was made to date this formation in the mapped area.

Permian System

Phosphoria Formation. In 1909, Gale and Richards (1909, p. 457-535) began studying the phosphate deposits in southeastern Idaho, but they did not name the Phosphoria Formation. Richards and Mansfield (1912, p. 684-687) named the Phosphoria Formation and designated Phosphoria Gulch, Idaho, where the formation is 415 feet thick, as the type locality. According to Richardson (1913, p. 416), the Phosphoria and Wells Formations contain different faunas which can be used in separating them. McKelvey and associates (1959, p. 20-21) gave the thickness near the type locality as ranging from 250 to 450 feet. They recognized four members from base to top: (1) the Meade Peak Phosphatic Shale Member, (2) the Rex Chert Member, (3) the cherty shale member, (4) the Retort Phosphatic Shale Member. Mansfield (1927, p. 75) identified the Phosphoria Formation just to the north of the mapped area.
Although the Phosphoria Formation is present on the north side of Bloomington Canyon as indicated by Mansfield (1927, p. 75), there is no evidence of it on the south side of the canyon in the mapped area. It might be present there under the Wasatch Formation, but it is not exposed at the surface. The Rex Chert Member is exposed in SE$_4$ sec. 3, T. 15 S., R. 43 E. This chert unit consists of red, brown, yellow, and black layers of resistant chert which have been deformed by folding and faulting in the lower plate of the Paris thrust fault. At the southern end of this single exposure, the chert is overlain with angular discordance by the Wasatch Formation (Figure 14). Although only the Rex Chert Member is exposed in the mapped area, the other members of the Phosphoria Formation probably lie at shallow depth under the slope wash or Wasatch Formation.

Mansfield (1927, p. 50) listed the age of the Phosphoria Formation as Permian. More recent studies by McKelvey and associates (1956, p. 2844, 2856-2861; 1959, p. 20, 38-41), on the abundant Phosphoria fossils, definitely indicate that this formation is of Permian age.

Cenozoic Rocks

Tertiary System

General statement. The Tertiary Period was a time of continued emergence above sea level and only two formations represent this period, the Eocene Wasatch Formation and the Pliocene Salt Lake Formation. These two formations are terrestrial or lacustrine in origin (Mansfield, 1927, p. 48). They now occur in patches on some
of the lower hills in the mapped area.

**Wasatch Formation.** Hayden (1869, p. 191) named the Wasatch Group and described it as consisting of colorful red beds. According to Richardson (1941, p. 34), the beds are generally lenticular and were deposited under continental and lacustrine conditions. Mansfield (1927, p. 49) recognized the Wasatch Formation in the mapped area and listed the thickness in southeastern Idaho as ranging from 0 to 1,500 feet. The Wasatch Formation consists predominantly of limestone and quartzite boulders and smaller debris, of Paleozoic age, which were probably derived from the upper plates of the Paris and other thrust faults in the Bannock thrust zone (Mansfield, 1927, p. 200).

The Wasatch Formation is found in irregular patches and outcrops throughout the mapped area. It is common on the higher parts of some of the low ridges just west of U. S. Highway 89, but it is generally absent from the higher ridges in the western half of the mapped area. The largest single exposure of the Wasatch Formation occurs in secs. 27, 28, 33, and 34, T. 15 S., R. 43 E., where it conceals much of the structure and stratigraphy east of the Paris thrust fault. This formation is only poorly consolidated and bedrock outcrops are only seen where the formation is exposed on steep slopes. Many red soils throughout the area can probably be attributed to staining by the Wasatch Formation.

Hayden (1869, p. 191) recognized that the Wasatch Formation was of Tertiary age. Mansfield (1927, p. 49) assigned the Wasatch Formation to the Eocene epoch.
Salt Lake Formation. The Salt Lake Formation was recognized by Hayden (1869, p. 192) in Weber River Valley, Utah. He called it the Salt Lake Group and described it as consisting of 1,200 feet of sand, sandstone, and marl. Williams (1948, p. 1147) stated that the Salt Lake Formation was deposited in an ancient lake. Mansfield (1927, p. 49) recognized the Salt Lake Formation in the mapped area and gave the southeastern Idaho thickness as ranging from 0 to 1,000 feet.

The Salt Lake Formation has about the same distribution in the mapped area as the Wasatch Formation and is often found overlying Wasatch beds. It is even more poorly consolidated than the Wasatch Formation and outcrops are sparse. This formation was difficult to map because its boundaries with other units, especially slope wash, are often gradational over several tens of feet.

Hayden (1869, p. 192) regarded the Salt Lake Formation as a Late Tertiary deposit, but Mansfield (1927, p. 49) assigned it to the Pliocene epoch. More recent investigations by several workers (Eardley, 1944, p. 845; Williams, 1948, p. 1147, 1160; Smith, 1953, p. 73, 75-76) have resulted in the recognition of Salt Lake strata ranging in age from Oligocene to Pleistocene. Mansfield (1952, p. 46) believed that most of the Salt Lake Formation in southeastern Idaho is Pliocene in age, but he admitted that some of the upper beds might be Pleistocene.

Quaternary System

General statement. In the mapped area, deposits of the Quaternary Period are represented by slope wash, stream deposits,
lake deposits, and patches of quartzite boulders. These units are unconsolidated and conceal the structure and pre-Quaternary stratigraphy of much of the eastern half of the mapped area. The Quaternary history of southeastern Idaho has been characterized by erosion, intermittent uplift, climatic changes, and volcanic activity (Mansfield, 1927, p. 175).

**Boulders.** Large quartzite boulders occur in isolated patches throughout the mapped area and in every topographic position from stream beds to ridge tops. These boulder patches have not been mapped as a separate unit because, in most localities, the underlying formations are identifiable and mapping of the boulder occurrences would not be significant structurally. The origin of these boulders has tentatively been explained by Clyde T. Hardy (1967, personal communication) as erosional remnants of the Wasatch Formation, but the present outcrops of the Wasatch Formation in the mapped area do not contain quartzite boulders as large as those observed in the boulder patches. Mansfield (1927, p. 200) noted Wasatch conglomerate beds which included some boulders 3 feet or more in diameter. The ultimate origin of these boulders appears to have been the early Paleozoic units such as the Brigham and Swan Peak Formations. Some boulders show cross-bedding, liesegang banding, pebble layers, worm tubes, and color characteristics typical of the Brigham Formation; other quartzite boulders show the fucoidal markings, shale partings, and color patterns typical of the Swan Peak Formation. These boulders were probably eroded from their parent units and later reincorporated into a post-Paleozoic unit,
possibly the Wasatch Formation, which was itself eroded away leaving only the resistant quartzite boulders.

Lake deposits. The lake deposits are the result of deposition during higher lake levels in the basin of Bear Lake. Mansfield (1927, p. 18) listed three progressively older levels at 11, 22, and 33 feet above the present level; however, more recent work by Williams, Willard, and Parker (1962, p. 24-36) placed the former levels at elevations of 6, 15, and 25 feet above the present maximum lake elevation of 5,923 feet. Mansfield (1927, p. 32) believed that the highest lake levels probably occurred at the same time as the maximum development of Lakes Bonneville and Lahontan. Bear Lake Valley has contained a lake for at least 28,000 years, but the highest lake level occurred about 8,000 years ago (Williams, Willard, Parker, 1962, p. 32, 35). Many of the towns on the west side of Bear Lake are located on the ancient lake terraces (Mansfield, 1927, p. 31). These lake deposits cover much of the mapped area to the east of the highway and some of the country to the west of the highway. They consist of fine-grained debris and invertebrate shells and generally have a chalky-marl appearance which is easy to mistake for the Salt Lake Formation.

Slope wash and stream deposits. Slope wash and stream deposits include all lithologic debris which cannot be reasonably assigned to any of the previous stratigraphic categories. To the west of the Paris thrust fault, little slope wash was mapped because the underlying stratigraphy is generally well exposed and the identification of formations and contacts was not difficult. In the faulted area
immediately east of the Paris thrust fault, considerable slope wash was mapped because it becomes thicker and conceals the stratigraphy and complex structural relationships which probably occur there.
STRUCTURAL GEOLOGY

General Statement

The early Paleozoic formations, west of the Paris thrust fault, have an average strike of N.10°W. and an average dip of 30°W. The formations exposed east of the Paris thrust fault have been intensely deformed by folding and faulting; no average strike and dip values can be realistically applied to these units. Severe distortion of the lower-plate strata, contemporaneous with the folding, thrusting, and reverse faulting, caused the complex structural relations seen just east of the thrust fault in several canyons of the mapped area.

The major structural feature in the mapped area is the Paris thrust fault which can be recognized throughout most of the length of the mapped area (Figures 3, 4, 5, 6; Plates 1, 2). Either horizontal compression or gravitational sliding produced folding and then caused thrusting which formed the Paris thrust fault as well as the many reverse faults. After the cessation of thrusting and reverse faulting, gravity faulting began. Gravity faulting is responsible for the major topographic features in the area today, notably the Bear River Range and Bear Lake Valley (Armstrong and Cressman, 1963, p. 20).

Many of the structural features in the area were first described by Richards and Mansfield during the first quarter of this century. Mansfield (1927, p. 131) noted the long, curved, and looped bands that mark the outcrops of the formations. He postulated that these
Figure 3. Paris thrust fault on north side of St. Charles Canyon, Idaho, NW^4 sec. 15, T. 15 S., R. 43 E.; view north. Cb-Brigham Fm., Ogc-Garden City Fm., Osp-Swan Peak Fm.
Figure 4. Paris thrust fault on south side of St. Charles Canyon, Idaho, SW1/4 sec. 15, T. 15 S., R. 43 E.; view south. Cb-Brigham Fm., Ogc-Garden City Fm., Osp-Swan Peak Fm., Ofh-Fish Haven Fm.
Figure 5. Paris thrust fault in ravine, SW¼ sec. 34, T. 15 S., R. 43 E.; view north. Cb-Brigham Fm., Ogc-Garden City Fm.

Figure 6. Paris thrust fault 1 mile northwest of Fish Haven, Idaho, SW¼ sec. 11, T. 16 S., R. 43 E.; view north. Cb-Brigham Fm., Ogc-Garden City Fm.
curving trends were due to differential stress and show that the direction toward which thrusting occurred was east to northeast. Mansfield (1927, p. 132) also noted the regional extent of some of the folds and believed that the Bannock overthrust had a total length of over 270 miles. Mansfield's concept of an extensive folded overthrust, the Bannock, has been considerably modified by later workers in the area, notably Armstrong and Cressman (1963) and Armstrong and Oriel (1965).

Structural Features

General Statement

The Paris thrust fault, numerous folds in the lower plate, reverse faults, and gravity faults can all be observed in several places throughout the mapped area. Folds, reverse faults, and gravity faults can be observed immediately east of the Paris thrust fault in the lower-plate strata. Three gravity faults can be recognized in the upper-plate strata west of the thrust fault.

Mansfield (1927, p. 171) was probably the first person to consider the origin and causes of the complex structural features observed in southeastern Idaho. He stated that a compressive force acted horizontally. Mansfield (1927, p. 127) speculated that the deformation could have been caused by plutonic intrusions at depth. As all the strata involved in the deformation are Paleozoic and Mesozoic geosynclinal sediments, Mansfield (1927, p. 174) believed that the bottom configuration of the geosyncline and its relationship to the surrounding topography, and the characteristics
geosynclinal sediments may have had a controlling influence on the orogenic forces.

All workers in the area have recognized that the major topographic features of the region are tectonic rather than erosional (Mansfield, 1927, p. 8; Armstrong and Cressman, 1963, p. 20; Armstrong and Oriel, 1965, p. 1847). Post-Laramide gravity faulting resulted in the formation of the present horst ranges and graben valleys which are common in southeastern Idaho and northern Utah (Armstrong and Cressman, 1963, p. 1, 20).

Folds

In the mapped area, all of the Paleozoic formations west of the Paris thrust fault are on the east flank of the large Fish Haven syncline. The lower-plate strata, which are also primarily Paleozoic, have been considerably contorted and the attitude of the beds changes over short distances. In the lower plate north of the mapped area, Mansfield (1927, p. 149) recognized the Paris syncline which is about 9 miles long and 1 1/2 miles wide. He noted that it is asymmetrical or even overturned to the east; whereas, to the west it has been overridden by the Bannock (Paris) thrust fault.

Minor folds in the lower plate can be observed in some of the canyons in the northern part of the mapped area. These small folds have all been folded asymmetrically toward the east and probably were formed as a result of the eastward thrusting. Some of these small folds can be readily observed in an exploration pit in the Phosphoria Formation on the north side of Bloomington Canyon in SE_4
sec. 21, T. 14 S., R. 43 E. (Figure 7). Other similar small folds,
Figure 7. Small asymmetric folds in Phosphoria Formation on north side of Bloomington Canyon, Idaho, SE$_4$ sec. 21, T. 14 S., R. 43 E.; view north.
asymmetrical to the east, can be observed on the north side of Dry Canyon in the Little Flat Formation just uphill from the irrigation ditch near the center of sec. 10, T. 15 S., R. 43 E. (Figure 8).

Thrust Fault

The Paris thrust fault is the major structural feature in the mapped area (Plates 1, 2). It was part of the Bannock overthrust of Richards and Mansfield (1912, p. 695). Mansfield (1927, p. 154-155) studied this thrust fault, as well as several others, throughout southeastern Idaho. The Bannock overthrust was once believed to underlie a large part of southeastern Idaho because of the folds and windows in the upper plate (Armstrong and Cressman, 1963, p. 4). Mansfield (1927, p. 170) reasoned that the Bannock overthrust must have had a low dip for erosion to have exposed so many windows. In the mapped area, the dip of the fault plane ranges from 20°W. to about 45°W. (Figures 3, 4, 6; Plate 2). Mansfield (1927, p. 154) listed the dip as 23°W. in Paris Canyon north of the mapped area. Richards and Mansfield (1912, p. 701-703) postulated that the total probable length of the Bannock overthrust was about 270 miles, the minimum horizontal displacement was in excess of 12 miles from the west, and the minimum stratigraphic displacement was in excess of 12,000 feet. Later Mansfield (1927, p. 158) stated that the horizontal displacement could be as much as 35 miles.

In the mapped area, the strata adjacent to the Paris thrust fault do not seem to have been significantly altered by hydrothermal solutions; however, Mansfield (1927, p. 171) noted some evidences of hydrothermal action, mainly siliceous breccia, at some places
Figure 8. Small asymmetric folds in Little Flat Formation on north side of Dry Canyon, Idaho, near center of sec. 10, T. 15 S., R. 43 E.; view north.
along the fault. In at least one place, the Brigham Formation has been severely shattered and granulated by the thrusting movement. This granulated quartzite can be observed near the mouth of Worm Creek Canyon, Idaho, where it is excavated and used as road metal (Figure 9). Mansfield (1927, p. 171) also noted this exposure and believed that it was granulated quartzite of the Swan Peak Formation; however, it seems to be quartzite of the Brigham Formation, although the severe granulation makes positive identification difficult. Severe shattering due to the thrusting can also be observed in the Fish Haven Formation just east of the Paris thrust fault in a canyon in N\textdegree 3 sec. 27, T. 15 S., R. 43 E., about 1\frac{1}{4} miles southwest of St. Charles, Idaho (Figure 10).

In the mapped area, the Brigham Formation is the oldest formation involved in the thrusting, although a considerable thickness of older strata could have been eliminated during movement. Mansfield (1927, p. 172) noted that no single unit could be identified as control for the thrusting. In other areas, the Precambrian Mutual Formation has been identified below the Brigham Formation, but Precambrian rocks are not exposed in the mapped area.

Mansfield published several descriptions of the Bannock overthrust, Paris thrust fault, in the mapped area. In Bloomington Canyon, Mansfield (1927, p. 154) noted that the easternmost formation above the Paris thrust fault is the Brigham Formation; whereas the underlying formation exposed in the lower plate is the Wells Formation. The formation slices mentioned by Mansfield (1927, p. 154) are deceptive and are probably due to the complex distortion and faulting of a relatively few formations.
Figure 9. Crushed and faulted quartzite of Brigham Formation near mouth of Worm Creek Canyon, Idaho, SW\(\frac{1}{4}\) sec. 34, T. 14 S., R. 43 E.; view north.
Figure 10. Crushed dolomite of Fish Haven Formation on south side of canyon 1.5 miles southwest of St. Charles, Idaho, N\textdegree{}sec. 27, T. 15 S., R. 43 E.; view south.
Mansfield (1927, p. 154) mapped the Brazer and Wells Formations on the south side of Worm Creek Canyon near the center of sec. 34, T. 1½ S., R. 43 E. In this report this outcrop is mapped as the Little Flat and Lodgepole Formations.

Near St. Charles, Idaho, Mansfield (1927, p. 155) noted that the area east of the Paris thrust fault is very complex, and he recognized six faults which had placed slices of several formations adjacent to each other. These faults seem to be steep reverse faults. On the north side of Dry Canyon, Idaho, according to Mansfield (1927, p. 155), the fault-related stratigraphy east of the Paris thrust fault, from west to east, consists of the Garden City Formation, the Swan Peak Formation, the Fish Haven Formation, the Three Forks Formation, the Brazer Formation, the Wells Formation, and the Fish Haven Formation again. At the same location, the lower-plate stratigraphy recognized in this report, from west to east, consists of the Garden City Formation, the Swan Peak Formation, the Fish Haven Formation, the Little Flat Formation, and the Lodgepole Formation. The structure and stratigraphy in this area is certainly complex and still imperfectly understood, but Mansfield may have overcomplicated the problem by including too many questionable formation slices.

Near Fish Haven, Idaho, Mansfield (1927, p. 155) again reported considerable structural detail when he described four faults which had sliced an asymmetrical syncline of Ordovician strata and thrust it eastward over the Fish Haven Formation. The faults in this area are primarily high-angle reverse faults related to the thrusting, but the asymmetrical syncline of Ordovician strata mentioned by
Mansfield could not be located.

To the south of the mapped area, a fault west of Garden City, Utah, has been described by Richardson (1941, p. 39). He believed that this fault, which places the Brigham Formation on the west adjacent to the Garden City Formation on the east, was the southern extension of the Paris thrust fault. Later study of this fault by Armstrong and Cressman (1963, p. 18) indicated that it is probably a gravity fault down on the east. As mapped for this report, the Paris thrust fault projects into Bear Lake just south of Fish Haven, Idaho, and probably extends east of Garden City, Utah.

Armstrong and Cressman (1963, p. 1, 19) considerably modified the Bannock overthrust concept of Mansfield. Their reinterpretation of the evidence for thrusting in southeastern Idaho resulted in the designation of the Bannock thrust zone in place of Mansfield's Bannock overthrust. This Bannock thrust zone was described as a zone of imbricate thrusting several tens of miles wide. It extends from northwestern Montana, through southeastern Idaho and western Wyoming, to north-central Utah. In accordance with this new definition, the area studied and mapped for this report includes approximately 55 square miles near the southern end of the Bannock thrust zone.

Armstrong and Oriel (1965, p. 1856-1857) believed that the Bannock thrust zone was formed when large areas of Idaho and Utah were thrust eastward into Wyoming between the massive Precambrian outcrops of the Uinta and Teton Mountains. The minimum horizontal displacement along the thrusts is at least 10 to 15 miles and may be considerably more (Armstrong and Oriel, 1965, p. 1857).
Reverse Faults

Mansfield (1927, p. 132) noted that the major faults in south-eastern Idaho are reverse faults which are probably associated with the Bannock overthrust; however, he failed to describe these reverse faults, unless he considered thrust and reverse faults as synonymous. In this report, a thrust fault is a low-angle fault, less than $45^\circ$ dip; whereas, a reverse fault has a dip of more than $45^\circ$ and generally has had considerably less horizontal movement than the typical thrust fault. On this basis, the Paris is classified as a thrust fault; whereas, most of the faults exposed east of the Paris thrust fault are reverse faults. Although the faults in this zone are not too difficult to recognize, the relative movement is difficult to determine. It seems that most of the faults east of the Paris thrust fault are reverse faults which dip quite steeply to the west. The only readily observable reverse fault in this zone occurs on the north side of Green Canyon, Idaho, in SW$_4$ sec. 15, T. 15 S., R. 43 E. (Figure 11). This fault exhibits normal drag and shows clearly that the hanging wall has moved up relative to the footwall. Most of the other faults are also believed to have had the same relative movement.

Gravity Faults

Bear Lake Valley has long been recognized as a graben (Mansfield, 1927, p. 150, 167, 169; Richardson, 1941, p. 5). The gravity faults on the east side of the valley can be readily identified by the fault scarp and by hot springs that issue from the fault. In the
Figure 11. Reverse fault in Garden City Formation on north side of Green Canyon, Idaho, SW 1/4 sec. 15, T. 15 S., R. 43 E.; view north.
Randolph quadrangle, Utah, the valley is bordered by gravity faults on the east and the southwest (Richardson, 1941, p. 5). Although good evidence for gravity faulting which could partly account for the formation of Bear Lake Valley has been observed in the Randolph quadrangle, only limited evidence is observable in the mapped area.

Three gravity faults occur west of the Paris thrust fault in the mapped area. One of these faults is located in sec. 29, T. 14 S., R. 43 E., and trends about N. 75°W. Another upper-plate gravity fault is located in SW1/4 sec. 4, T. 15 S., R. 43 E. and trends east-west. A small gravity fault also occurs in the Brigham Formation near the mouth of Worm Creek Canyon, SW1/4 sec. 34, T. 14 S., R. 43 E.; this fault trends north-south and dips approximately 80°W. (Figure 9).

Gravity faults were recognized in three places in the highly faulted interval immediately east of the Paris thrust fault. A west-dipping gravity fault occurs between the Rex Chert Member of the Phosphoria Formation and the Wasatch Formation in SE1/4 sec. 3, T. 15 S., R. 43 E. (Figure 13). The total displacement on this fault is approximately 30 feet. Another fault occurs immediately east of the single outcrop of the Rex Chert Member and is marked by a large spring which issues from the fault. Although this fault is obscure, it could be related to the graben faulting which formed Bear Lake Valley. A small west-dipping gravity fault occurs on the north side of Green Canyon, Idaho, in SW1/4 sec. 15, T. 15 S., R. 43 E. (Figure 15), just east of the prominent reverse fault.
Figure 12. Overturned Swan Peak Formation thinned by reverse faulting on north side of small canyon in SE$_4^3$ sec. 3, T. 16 S., R. 43 E.; view north. Ogc-Garden City Fm., Osp-Swan Peak Fm., Ofh-Fish Haven Fm.
Figure 13. Gravity fault between Rex Chert Member of Phosphoria Formation and Wasatch Formation, SE^2_4 sec. 3, T. 15 S., R. 13 E.; view south. Pp-Rex Chert Member of Phosphoria Fm., Tw-Wasatch Formation
Figure 14. Angular unconformity between Rex Chert Member of Phosphoria Formation and Wasatch Formation, SE₁₄ sec. 3, T. 15 S., R. 43 E.; view south. Pp-Rex Chert Member of Phosphoria Fm., Tw-Wasatch Formation.
Figure 15. West-dipping gravity fault in Garden City Formation on north side of Green Canyon, Idaho, SW$_{15}$ sec. 15, T. 15 S., R. 43 E.; view north.
All gravity faults in the lower plate are located in the fault zone east of the Paris thrust fault and have the same general trend as the reverse faults. It is possible that they were originally steep reverse faults which subsequently underwent gravity faulting. All the gravity faults in the mapped area probably occurred after cessation of the thrusting. Richardson (1941, p. 36-38) described a fault south of the mapped area which he considered to be of tensional origin.

It should be noted that most of the gravity faults recognized in the mapped area could not have contributed to the graben faulting which formed Bear Lake Valley. If a major east-dipping gravity fault is present in the mapped area, it must be covered by slope wash or lake deposits which have effectively concealed it. Bear Lake Valley may have been formed by a tilting movement caused by differential gravity faulting with the east side undergoing more displacement. This would explain the great depths which occur on the east side of Bear Lake, the clear fault scarps, and the hot springs; the west side of the valley in the mapped area exhibits few of these features.

Armstrong and Cressman (1963, p. 20) noted two sets of high-angle faults in southeastern Idaho. They believed that the older east to northeast-trending set was formed during the thrusting by strike-slip movement. The younger set is the result of Pliocene and later block faulting. Other complex gravity and strike-slip faults were observed in the Bear River Range, Idaho, by Armstrong and Oriel (1965, p. 1863) who recognized four sets of faults.
Structural Events

General Statement

Three main stages are evident in the structural and tectonic development of southeastern Idaho. Armstrong and Oriel (1965, p. 1857) listed these three stages as: (1) the changing patterns of tectonic elements in the depositional environment, (2) the development of northward-trending folds and thrust faults, (3) the development of block faulting. The mapped area was part of the Cordilleran geosyncline throughout the Paleozoic Era. This condition persisted well into the Mesozoic Era, but the familiar Paleozoic pattern was less well defined and the breakup of the geosyncline began (Armstrong and Oriel, 1965, p. 1853-1854). Richardson (1941, p. 6) recognized this pre-Laramide stability which was characterized by relatively gentle earth movements which did little to disturb the original nearly horizontal attitude of the beds.

During Late Jurassic and Early Cretaceous time, southeastern Idaho emerged from the sea and mountains were formed (Armstrong and Oriel, 1965, p. 1854). As the destruction of the geosyncline progressed, the eastern flank of the miogeosyncline, including the mapped area, was folded and thrust eastward (Armstrong and Oriel, 1965, p. 1856). The folding, thrusting, and reverse faulting were all due to compressive force (Mansfield, 1927, p. 132). Some folding probably preceded the thrusting and its contemporary reverse faulting, but it also continued at least until cessation of the thrusting.

Apparently this area has not been affected by significant
compressive forces since the end of the Laramide orogeny as the Wasatch and Salt Lake strata are essentially horizontal in the mapped area. Armstrong and Cressman (1963, p. 16) also noted a lack of deformation of the Wasatch Formation south and east of Bear Lake and interpreted this as evidence that the region has not been subjected to strong compressive forces since Eocene time. Volcanic activity occurred extensively in this area during the Pliocene epoch (Mansfield, 1927, p. 175, 203) and much of the Salt Lake Formation consists of volcanic ash which can be attributed to this activity. The Quaternary Period has been relatively quiet in southeastern Idaho. Occasional volcanic outbursts have occurred, but the climatic change to a drier climate has probably been the most important event in the area (Mansfield, 1927, p. 175).

**Folding**

Folding was the first reaction of the geosynclinal sediments to the compressive stress and was probably the only major reaction as long as it could accommodate the forces. Regional folding which probably occurred during the thrusting made it possible for erosion to cut windows in the upper plate of the Paris thrust fault in certain areas (Armstrong and Cressman, 1963, p. 4); however, none of these windows are present in the mapped area.

Mansfield (1927, p. 170) recognized some gentle regional folding which occurred long after the Laramide orogeny and even after deposition of the Wasatch Formation. He believed that some of the deformation of the thrust plane occurred at this time; however, Armstrong and Cressman (1963, p. 5, 16) believed that the folding
of the thrust plane and the folding of the Salt Lake Formation are separate and unrelated.

Thrust Faulting

Mansfield (1927, p. 170) regarded the Bannock overthrust as having occurred relatively late during the period of deformation and believed that it probably represented the climactic phase. Armstrong and Cressman (1963, p. 1) noted that the individual thrust faults in the Idaho-Wyoming thrust belt are progressively younger eastward. Thrusting began in Late Jurassic time in the west and ended as late as Eocene time in the east (Armstrong and Oriel, 1965, p. 1847). The total time during which the thrusting was active could have been as long as 60 million years (Armstrong and Cressman, 1963, p. 16). Concerning the Paris thrust fault, Armstrong and Cressman (1963, p. 14) believed that it started movement in latest Jurassic or earliest Cretaceous time.

Armstrong and Cressman (1963, p. 2-3, 8) objected to Mansfield's attempts to connect the separate individual thrust faults in Idaho, Wyoming, Utah, and Montana. They (Armstrong and Cressman, 1963, p. 18-19) dated the Willard thrust fault as Late Cretaceous or Paleocene and the Paris thrust fault as Late Jurassic or Early Cretaceous; therefore, it is doubtful that they could be parts of a single massive thrust fault. Although Armstrong and Cressman (1963, p. 19) believed that the Paris and Willard thrust faults were not contemporaneous, they believed that the Paris thrust fault probably was contemporaneous with the Ogden and Taylor thrust faults.

Mansfield (1927, p. 171) believed that the physical shape of
the geosyncline and the initial dips of its sediments would control and localize the folding and thrusting. He also regarded it as significant that the upper plate is primarily composed of resistant Paleozoic rocks; whereas, weaker Mesozoic rocks are predominant in the lower plate. In the mapped area, the lower-plate unit at the contact is generally the Garden City Formation which is relatively incompetent as compared to the quartzites and some of the carbonates which characterize much of the Cambrian strata.

It has been postulated by Armstrong and Oriel (1965, p. 1861) that the thrust plate may have slid from a previously uplifted area somewhere to the west. If this were true, basement rocks would be expected to occur at or near the surface somewhere to the west, but gravity surveys have not detected this condition (Armstrong and Oriel, 1965, p. 1861). Eardley (1963, p. 209-210) believed that thrusting in the Rocky Mountains could not be attributed to horizontal compression, but rather that it was due to gravity sliding from vertically uplifted areas. Although Eardley (1963, p. 209-230) presented good evidence for the uplift origin of many thrust faults in the Rocky Mountains, he (Eardley, 1963, p. 212) does not indicate an uplift which could explain the thrust faults in the Bannock thrust zone. Eardley (1963, p. 217-218) favored deep-seated igneous intrusions as the primary mechanism of uplift in the Rocky Mountains.

Reverse Faulting

Mansfield (1927, p. 132) associated the reverse faulting in the mapped area with the thrusting. As the thrust plate moved
eastward, the strata immediately in front of the advancing upper plate were deformed by folding and extensive reverse faulting. With the cessation of thrusting, the reverse faulting also ceased.

**Gravity Faulting**

Although some minor gravity faulting undoubtedly occurred prior to the thrusting, such faults can no longer be identified in the mapped area today. All of the gravity faults observed in the area occurred after the thrusting. The major topographic features of southeastern Idaho are due to gravity faulting which formed the graben valleys and horst ranges (Mansfield, 1927, p. 170; Armstrong and Cressman, 1963, p. 1, 20). Block faulting probably began during Eocene time (Armstrong and Oriel, 1965, p. 1862) and is still active as evidenced by the freshness of some fault scarps, hydrothermal activity, and earthquakes which occasionally occur in the area.
LITERATURE CITED


APPENDIX

Brigham Formation

The Brigham Formation was measured on the north side of St. Charles Canyon, Idaho, near the top of the ridge, beginning at the Paris thrust fault, SW\(\frac{1}{4}\) SW\(\frac{1}{4}\) sec. 10, T. 15 S., R. 43 E., and proceeding west. The lower contact of the Brigham Formation is placed at the top of the first limestone bed of the underlying Garden City Formation. The upper contact of the Brigham Formation is placed at the base of the first carbonate bed above the inter-bedded shale and quartzite.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Shale and quartzite, interbedded . . . .</td>
<td>97 ft</td>
</tr>
<tr>
<td></td>
<td>Shale:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fresh color--pale yellowish brown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weathered color--pale yellowish brown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bed thickness--less than 1 in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other--resistant, micaceous</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quartzite:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fresh color--pale to moderate yellowish brown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weathered color--moderate to dark yellowish brown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Particle size--coarse sand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bed thickness--1 to 4 in.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Quartzite . . . . . . . . . . . . . . .</td>
<td>309 ft</td>
</tr>
<tr>
<td></td>
<td>Fresh color--moderate brown with some orange, gray purple, and yellow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weathered color--moderate to dark brown with yellow, gray, and purple</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bed thickness--4 in. to 4 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Particle size--fine to medium sand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other--some cross-bedding, numerous worm tubes, resistant</td>
<td></td>
</tr>
</tbody>
</table>
4  Quartzite  . . . . . . . . . . . . .  143 ft
   Fresh color--grayish red purple to grayish red purple
   Weathered color--very dusky purple or red purple with some moderate to dark yellowish brown
   Particle size--fine to coarse sand
   Bed thickness--3 in. to 2 ft
   Other--liesegang banding, alternating lenses of colored purples

3  Quartzite  . . . . . . . . . . . . .  1,943 ft
   Fresh color--pale yellowish brown, some orange, gray, purple, and pink
   Weathered color--pale yellowish brown, some orange, gray, purple and pink
   Particle size--medium to very coarse sand
   Bed thickness--2 in. to 6 ft
   Other--excellent cross-bedding in places, some very coarse conglomerate beds, many resistant massive beds

2  Quartzite  . . . . . . . . . . . . .  592 ft
   Fresh color--pale yellowish brown, some pink, red, purple, and orange
   Weathered color--light to dusky yellowish brown with some orange and gray
   Particle size--medium to very coarse sand, some fine sand
   Bed thickness--6 to 18 in.
   Other--occasional layers of quartzite pebbles, generally poor exposures

1  Quartzite  . . . . . . . . . . . . .  329 ft
   Fresh color--grayish red purple to light gray with faint green
   Weathered color--grayish red purple and pale yellowish brown
   Particle size--fine to medium sand
   Bed thickness--2 in.
   Other--exposures are poor (near thrust fault)

Total thickness  3,413 ft
Langston Formation

The Langston Formation was measured about halfway up the north side of St. Charles Canyon, Idaho, SE$_1^4$ NW$_4^1$ sec. 16, T. 15 S., R. 43 E., beginning at the top of the Brigham Formation and proceeding west. The lower contact of the Langston Formation is placed at the base of the first carbonate bed above the interbedded shale and quartzite of the Brigham Formation. The upper contact of the Langston Formation occurs near the bottom of a ravine and is placed at the base of a thin-bedded green shale unit at the base of the Ute Formation.

<table>
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<th>Thickness</th>
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</thead>
<tbody>
<tr>
<td>4</td>
<td>Dolomite</td>
<td>101 ft</td>
</tr>
</tbody>
</table>
|      |           | Fresh color—pale yellowish brown to light olive gray  
|      |           | Weathered color—light to dark yellowish brown  
|      |           | Bed thickness—1 to 4 ft  
|      |           | Other—sandy with calcite veins in some beds, forms ledges and low cliffs |
| 3    | Limestone | 33 ft     |
|      |           | Fresh color—medium to dark gray  
|      |           | Weathered color—moderate yellowish brown  
|      |           | Bed thickness—2 to 6 in.  
|      |           | Other—some calcite veins, nonresistant |
| 2    | Limestone | 78 ft     |
|      |           | Fresh color—dark yellowish brown  
|      |           | Weathered color—moderate brown  
|      |           | Bed thickness—0.5 to 1.5 in.  
|      |           | Other—nonresistant |
| 1    | Limestone | 62 ft     |
|      |           | Fresh color—dark gray to grayish black  
|      |           | Weathered color—light to medium gray  
|      |           | Bed thickness—2 to 18 in. |
Other--sandy, dolomitic in places, weathers into rough pitted surfaces on some beds, chert layers stand in relief on weathered surfaces, contains brachiopods.

Total thickness

274 ft
GEOLOGIC MAP OF SOUTHEASTERN MARGIN OF BEAR RIVER RANGE, IDAHO

EXPLANATION

Quaternary

- Glen deposits
- Slope wash
- Lake deposits
- Salt Lake Formation
- Washakie Formation
- Phosphoria Formation - Basal Clastic Member

Pennsylvanian

- Wells Formation

Mississippian

- Little Flat Formation

Silurian

- Lakeview Formation
- Swan Lake and Fish Haven Formations - undifferentiated

Ordovician

- Fish Haven Formation
- Swan Peak Formation
- Garden City Formation
- St. Charles Formation
- Noxues Formation
- Bloomington Formation

Cambrian

- Blacksmith Formation
- Ute Formation
- Langston Formation
- Brigham Formation

Contact

- Contact - approximately located
- Thrust fault
- Reverse fault (west-dipping)
- Gravity fault

Geology by Clinton L. Davis, 1969
The structure in this area is concealed by unconsolidated Quaternary deposits, but it is probably complex and may involve large-displacement gravity faults.

WEST-EAST STRUCTURE SECTION ALONG SOUTH SIDE OF ST. CHARLES CANYON, IDAHO

Geology by Clinton L. Davis, 1969