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Structural Geology of Cutler Dam Quadrangle and Northern Part of Honeyville Quadrangle, Utah

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STRUCTURAL GEOLOGY OF CUTLER DAM QUADRANGLE AND

NORTHERN PART OF HONEYVILLE QUADRANGLE, UTAH

by

Douglas A. Sprinkel

A thesis submitted in partial fulfillment
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of

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in

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Approved:

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	ii
LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF PLATES	vii
ABSTRACT	viii
INTRODUCTION	1
General Statement	1
Previous Investigations	3
STRATIGRAPHIC UNITS	6
General Statement	6
Paleozoic Units	6
Swan Peak Formation	6
Fish Haven-Laketown Formation	9
Water Canyon Formation	10
Lodgepole Formation	12
Oquirrh Formation	14
Tertiary System	16
Wasatch Formation	16
Salt Lake Formation	17
Quaternary System	20
Colluvial deposits	20
Lake Bonneville Group	20
Alluvial deposits	21
STRUCTURAL FEATURES	22
Regional Setting	22
Normal Faults	25
General statement	25
Junction Hills	26
Long Divide-Cache Butte	27

TABLE OF CONTENTS (Continued)

Page

Wellsville Mountains 37
Wasatch fault zone 42

Landslides 45

Fish Haven-Laketown Formation landslide 45
Salt Lake Formation landslide 45

STRUCTURAL EVENTS 48

General Statement 48
Sevier Events 49
Basin and Range Events 50

Early normal faulting 50
Later normal faulting 53
Early landsliding 53
Later landsliding 54

LITERATURE CITED 56

LIST OF TABLES

Table | Page

1. Paleozoic and Cenozoic stratigraphy of Cutler Dam Quadrangle and northern part of Honeyville Quadrangle, Utah 7

LIST OF FIGURES

Figure Page

1. Index map of north-central Utah showing location of Cutler Dam Quadrangle and northern part of Honeyville Quadrangle, Utah 2

2. North-south-trending normal fault on the eastern side of Junction Hills in northern part of mapped area; aerial view west 28

3. Normal fault in eastern part of Bear River Narrows; aerial view west 29

4. Normal fault in eastern part of Bear River Narrows; view northwest 30

5. Normal fault, east of Cutler Dam, in Bear River Narrows; view northwest 32

6. Normal fault along western side of Cache Butte Divide; aerial view east 38

7. Normal fault crossing northeastern part of Wellsville Mountains; aerial view south 40

8. Normal fault in the northeastern part of Wellsville Mountains; aerial view west 41

9. Wasatch fault zone along western side of Wellsville Mountains; aerial view east 43

10. Landslide, south of Bear River, on western side of Cache Butte Divide; view south 46

11. Structural development of the northwest-southeast-trending graben 52

LIST OF PLATES

Plate Page

1. Geologic map of Cutler Dam Quadrangle and northern part of Honeyville Quadrangle, Utah . . . . . . Pocket

2. Structure section of Cutler Dam Quadrangle and northern part of Honeyville Quadrangle, Utah . . . Pocket

ABSTRACT

Structural Geology of Cutler Dam Quadrangle and
Northern Part of Honeyville Quadrangle, Utah

by

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The mapped area is located in the north-central part of Utah. The northern part of the mapped area is located in the Basin and Range province and the southern part of the mapped area is located in the Middle Rocky Mountain province. The north-south and east-west dimensions of the mapped area are 11.1 miles and 5.1 miles, respectively.

Paleozoic rocks are exposed in Bear River Narrows, in Cache Butte Divide, and in the Wellsville Mountains. Paleozoic strata, in Bear River Narrows, dip west. The Ordovician Swan Peak Formation crops out in the eastern part of Bear River Narrows. It is brown and white orthoquartzite. Westward, undifferentiated Fish Haven-Laketown Formation is exposed in Bear River Narrows and in Cache Butte Divide. The Fish Haven-Laketown is dolomite of Ordovician-Silurian age. The Devonian Water Canyon Formation is exposed west of Bear River Narrows and also on the western side of Cache Butte Divide. It is light-gray dolomite. A fault block of limestone of Mississippian Lodgepole Formation is present on the western side of the Wellsville Mountains northeast of Deweyville, Utah. The limestone is medium gray. The

Pennsylvanian-Permian Oquirrh Formation is the uppermost Paleozoic unit in the mapped area. It consists of sandy limestone, blue-gray limestone, and calcareous sandstone.

The Wasatch and Salt Lake Formations represent the Tertiary System. The Eocene Wasatch is a pebble and cobble conglomerate that is red. It rests on Paleozoic rocks in the northern part of the Wellsville Mountains and in the Bear River Narrows. The Salt Lake Formation is light-gray tuffaceous limestone, oolitic limestone, and conglomerate. It is exposed in Junction Hills, Cache Butte Divide, and in the northeastern part of the Wellsville Mountains. The age of the Salt Lake Formation, in the mapped area, is middle to late Pliocene.

The Quaternary System is represented by colluvial deposits, Lake Bonneville Group, and alluvial deposits. The Pleistocene colluvial deposits consist of clasts of limestone and orthoquartzite set in an unconsolidated matrix. The Pleistocene Lake Bonneville Group crops out extensively in the mapped area. It is composed of gravel, sand, silt, and clay. The Holocene alluvial deposits include stream alluvium and alluvial fans.

The Sevier orogeny and Basin and Range normal faulting affected northern Utah. The Sevier orogeny produced folds and thrust faults. The Basin and Range normal faulting followed and it is continuing at the present time.

The Sevier orogeny, in the mapped area, is represented by a single thrust fault. A high-angle thrust fault, west of Chocolate Peak, placed Lodgepole Formation over the Oquirrh Formation. Reversed movement occurred during Basin and Range faulting. Thus, the fault is considered to be a normal fault.

Basin and Range events include early and later normal faulting. Early normal faulting dropped the major valley blocks relative to the mountains. The Wasatch fault zone, on the western side of the Wellsville Mountains, and north-south marginal faults, on the eastern side of Junction Hills, formed at this time. Two faults, which diagonally transect the mapped area, form a northwest-southeast-trending graben. The northeastern fault extends along the western side of Cache Butte Divide and placed the Oquirrh Formation, in the graben, down relative to the Fish Haven-Laketown Formation of Cache Butte Divide. The southwestern fault cuts the northeastern part of the Wellsville Mountains and placed the Salt Lake Formation, on the northeast, next to the Oquirrh Formation. Later normal faulting cut the Lake Bonneville Group of Pleistocene age. Lake Bonneville Group is cut by a fault of the Wasatch fault zone as well as the fault that bounds the northeastern margin of the northwest-southeast-trending graben. Both faults placed the Lake Bonneville Group, on the west, next to the Salt Lake Formation.

(68 pages)

INTRODUCTION

General Statement

The mapped area is located in the central part of northern Utah (Figure 1). It consists of the eastern two-thirds of the Cutler Dam Quadrangle and the northern one-fourth of the Honeyville Quadrangle. These quadrangles are 7.5-minute topographic maps published by the Geological Survey of the U. S. Department of Interior. The northern boundary of the mapped area is approximately 8.6 miles south of the Utah-Idaho State Line. Brigham City, Utah, is 21.2 miles south and Logan, Utah, is 11.8 miles southeast of the center of the mapped area. The north-south and east-west dimensions are 11.1 miles and 5.1 miles, respectively.

The northern part of the mapped area is located in the Basin and Range province and the southern part is located in the Middle Rocky Mountain province. The Wellsville Mountains, which are the northernmost part of the Wasatch Range, extend into the southern part of the mapped area. The Junction Hills are in the northern part of the mapped area. Cache Valley, which is the easternmost valley in the Basin and Range province, is east of the mapped area and Bear River Valley is west of the mapped area.

Topographic relief is moderate within the mapped area. The highest elevation, which is located in the Wellsville Mountains, is 6,647 feet and the lowest elevation, which is located on the flood plain of the Bear River, is 4,286 feet. The average elevation, in

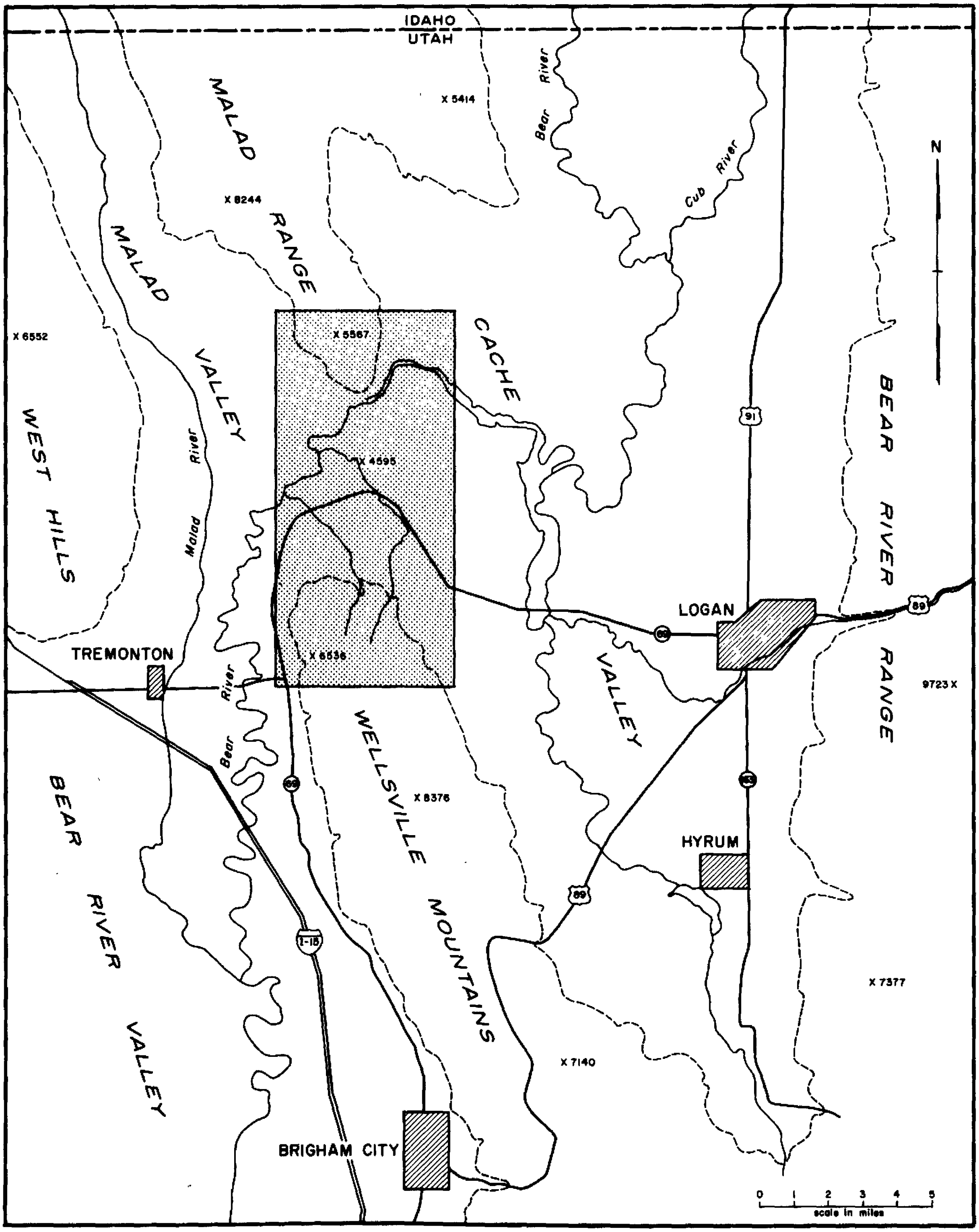


Figure 1. Index map of north-central Utah showing location of Cutler Dam Quadrangle and northern part of Honeyville Quadrangle, Utah.

the northern part of the mapped area, is approximately 5,500 feet; whereas, the average elevation in the southern part of the mapped area is approximately 6,300 feet.

The Cutler Dam Quadrangle and the northern part of the Honeyville Quadrangle was of interest because the structural geology had not been previously mapped in detail. More importantly, the relationship between Ordovician-Silurian Fish Haven-Laketown Formation, which is exposed in Cache Butte Divide and in Bear River Narrows, and the Pennsylvanian Oquirrh Formation, which is exposed in the Wellsville Mountains, was not clearly understood.

The field work was undertaken during the summer and fall of 1975. In the field, the geology was mapped on 7.5-minute topographic quadrangle maps at a scale of 1:24,000. Field notes were transferred to a map at a scale of 1:16,000 (Plate 1). Aerial photographs were used to determine the location and extent of specific features.

Previous Investigations

There have been many previous studies in the Cutler Dam and surrounding areas from 1947 to the present. These investigations provided generalized geological mapping and ages of the stratigraphic units.

The invertebrate paleontology has been studied from near Bear River Narrows to a point southwest of Clarkston, Utah. Yen (1947) studied the molluscan fauna of the Tertiary Salt Lake Formation. He collected samples from Bear River Narrows to a point southwest of Clarkston, Utah. Swain (1947) studied ostracods of the Salt Lake

Formation. He collected samples from near Bear River Narrows. Williams (1948) mapped the Paleozoic rocks of the Logan Quadrangle, Utah, which is east of the mapped area. Brown (1949) studied the plant fossils of the Salt Lake Formation. He collected samples near the mouth of McMurdie Hollow, southern Cache Valley, Utah. Hanson (1949) investigated the stratigraphy and paleontology of Clarkston Mountain, Utah, as well as the area that extends southward to Bear River Narrows. The Tertiary stratigraphy of Cache Valley, Utah-Idaho, was studied by Adamson, Hardy, and Williams (1955). Williams (1958) mapped the geology of Cache County, Utah. In this report, a geological map of Cache County, Utah, was produced. Also, Williams revised parts of the stratigraphic nomenclature for Cache Valley. Beus (1958) studied the structural geology and stratigraphy of the northern part of the Wellsville Mountains, Utah. A generalized map, with the northern boundary at Utah State Highway 69, resulted from the study. He also measured stratigraphic sections of Paleozoic rocks within the Wellsville Mountains. Later, Williams (1962) studied the Lake Bonneville Group of Cache Valley, Utah. Beus (1963) mapped the stratigraphy and structural geology of the central Blue Spring Hills, Utah-Idaho, which are west of Bear River Narrows. Later, Beus (1968) reported on the Paleozoic stratigraphy of Samaria Mountain, which is located in the northern part of the central Blue Spring Hills, Utah-Idaho. Maw (1968) mapped the surficial geology and Lake Bonneville Group of the Cutler Dam Quadrangle. Cluff, Glass, and Brogan (1975) studied the Wasatch fault zone, north of Brigham

City, Utah, and the faults of Cache Valley, Utah. Finally, Gray (1975) mapped the structural geology of the southern part of Clarkston Mountain of the Malad Range in Utah.

STRATIGRAPHIC UNITS

General Statement

The rocks, exposed within the mapped area, are of Paleozoic and Cenozoic ages (Table 1). The Ordovician Swan Peak Formation, Ordovician-Silurian Fish Haven-Laketown Formation, Devonian Water Canyon Formation, Mississippian Lodgepole Formation, and Pennsylvanian-Permian Oquirrh Formation represent the Paleozoic Era. Rocks of Ordovician through Devonian age are exposed in Bear River Narrows as well as in Cache Butte Divide; whereas, rocks of Mississippian and Pennsylvanian age are exposed in the Wellsville Mountains. The Tertiary Salt Lake Formation and Quaternary Lake Bonneville Group are exposed throughout the remainder of the mapped area.

No stratigraphic sections were measured within the mapped area. The stratigraphy has been documented, for the region, by Williams (1948), Hanson (1949), Beus (1958, 1963, 1968), and Adamson, Hardy, and Williams (1955). In the mapped area, the thickness of formations is indeterminate because complete sections of formations are not present due to faulting and unconformable cover.

Paleozoic Units

Swan Peak Formation

The Swan Peak Formation is the oldest formation within the mapped area. It was named by Richardson (1913, p. 409) for the orthoquartzite exposed at Swan Peak in the Randolph Quadrangle, Utah.

Table 1. Paleozoic and Cenozoic stratigraphy of Cutler Dam Quadrangle and northern part of Honeyville Quadrangle, Utah

Units	Lithology	Thickness (feet)
Quaternary		
Alluvial deposits	Stream alluvium and alluvial fans.	
Lake Bonneville Group	Gravel and sand of deltas, spits, and bars, and silt and clay of lake-bottom sediments.	
Colluvial deposits	Sand- to boulder-size clasts of limestone and orthoquartzite in an unconsolidated matrix.	
Tertiary		
Salt Lake Formation	Light-gray tuffaceous limestone, oolitic limestone, and conglomerate.	1,818[a]
Wasatch Formation	Red pebble and cobble conglomerate.	300[b]
Pennsylvanian		
Oquirrh Formation	Blue-gray cherty limestone and brown sandy limestone.	6,643[c]
Mississippian		
Lodgepole Formation	Finely crystalline light- to medium-gray limestone.	338[d]
Devonian		
Water Canyon Formation	Finely crystalline light- to medium-gray dolomite.	683[e]
Ordovician-Silurian		
Fish Haven-Laketown Formation	Finely crystalline dolomite, dark gray in lower part and light gray in upper part, with alternating dark- and light-gray beds at the base of upper part.	1,290[b]
Ordovician		
Swan Peak Formation	Fine-grained brown and white orthoquartzite with interbedded shale in lower part.	574[f]

[a]Adamson, Hardy, and Williams, 1955 [c]Beus, 1958 [e]Taylor, 1963

[b]Williams, 1948 [d]Beus, 1963 [f]James, 1973

The Swan Peak is a distinctive stratigraphic marker because it is between the carbonate units of the Garden City and Fish Haven-Laketown Formations.

The Swan Peak Formation has been subdivided into three members in northern Utah and southern Idaho. In the southern Malad Range, Utah, Hanson (1949, p. 44-45) recognized the following members: (1) lower member of fissile black shale, 50 feet thick, (2) middle member of thin-bedded, brown, reddish-gray, and brownish-gray orthoquartzite, 156 feet thick, (3) upper member of thick-bedded brown and white orthoquartzite, at least 400 feet thick. Thus, the exposed thickness of the Swan Peak, reported by Hanson (1949, p. 44), is at least 606 feet. James (1973, p. 245-246) measured a section of Swan Peak Formation near Gunsight Peak, southern Malad Range, Utah. He recognized the following members: (1) lower member of interbedded light-brown orthoquartzite and gray shale, 79 feet thick, (2) middle member of interbedded light-brown orthoquartzite and green shale, 29 feet thick, (3) upper member of light-gray orthoquartzite, 466 feet thick. The exposed thickness of Swan Peak, near Gunsight Peak, is 574 feet.

In the Cutler Dam Quadrangle and the northern part of the Honeyville Quadrangle, the Swan Peak Formation crops out in Bear River Narrows on both sides of the gorge. Also, an outcrop of Swan Peak is present approximately 1.5 miles northwest of Cache Junction, Utah. The Swan Peak is light-brown orthoquartzite that is brecciated in places.

The lower contact between the Garden City Formation and the Swan Peak Formation is not exposed in the mapped area. The upper contact of the Swan Peak Formation is placed at the base of the Fish Haven-Laketown Formation. The contact between the Swan Peak and Fish Haven-Laketown Formation is unconformable (Williams, 1948, p. 1136; Beus, 1963, p. 19; Beus, 1968, p. 784).

The age of the Swan Peak Formation is considered to be Middle Ordovician (Ross, 1951, p. 33).

Fish Haven-Laketown Formation

The undifferentiated Fish Haven-Laketown Formation unconformably overlies the Swan Peak Formation. The Fish Haven-Laketown Formation is treated as a single unit; however, previous studies treated the Fish Haven and Laketown as separate units. The Fish Haven Formation and the Laketown Formation were named by Richardson (1913, p. 409-410) for rocks exposed in the eastern part of the Bear River Range, Idaho-Utah. The distinction between the Fish Haven and Laketown Formations is based on color (Hanson, 1949, p. 46; Beus, 1968, p. 784). The Fish Haven is mostly dark-gray dolomite and the Laketown is mostly light-gray dolomite with alternating dark-gray and light-gray beds of dolomite in the lower part.

The Fish Haven Formation has been described as dark-gray dolomite containing chert nodules (Beus, 1968, p. 784). At the type section, the head of Fish Haven Creek, Idaho, the Fish Haven is 500 feet thick (Richardson, 1913, p. 407-409). At Green Canyon northeast of Logan, Utah, in the Logan Quadrangle, Williams (1948, p. 1137) measured

140 feet of Fish Haven. The Laketown Formation has been described as consisting of two members: (1) lower alternating dark-gray and light-gray dolomite, (2) upper light- to medium-gray dolomite (Hanson, 1949, p. 49). The thickness of the Laketown Formation at Green Canyon, northeast of Logan, is 1,150 feet. The thickness of the Fish Haven-Laketown section at Green Canyon, northeast of Logan, is 1,290 feet (Williams, 1948, p. 1137-1138).

Within the mapped area, the Fish Haven-Laketown Formation forms Bear River Narrows. It generally strikes north-south and dips west. The lithology of the Fish Haven-Laketown Formation, in Bear River Narrows, is similar to the Fish Haven-Laketown previously described, except the dolomite in Bear River Narrows is extensively brecciated in places.

The Fish Haven-Laketown Formation is Ordovician-Silurian in age (Budge, 1966, p. 46-48).

Water Canyon Formation

The Water Canyon Formation is a conspicuous unit exposed in northern Utah and southern Idaho. Williams (1948, p. 1138-1139) named the Water Canyon Formation for rocks exposed in a tributary of Green Canyon, northeast of Logan, Utah. There, Williams (1948, p. 1138) recognized two members of the Water Canyon Formation: (1) lower argillaceous dolomite member, (2) upper sandstone member. A detailed study was made by Taylor (1963, p. 9-15) and he proposed the names: (1) lower Card Member, (2) upper Grassy Flat Member.

The Water Canyon Formation was measured by Taylor (1963, p. 57) at Coldwater Canyon in the Wellsville Mountains north of Brigham City, Utah. There, the following members are present: (1) lower Card Member of medium- to light-gray argillaceous dolostone, 156 feet thick, (2) upper Grassy Flat Member of calcareous sandstone, arenaceous dolostone, intraformational breccia, and some argillaceous dolostone, 527 feet thick. The thickness of the Water Canyon Formation at Coldwater Canyon is 683 feet (Taylor, 1963, p. 57). The Water Canyon Formation unconformably overlies the Fish Haven-Laketown Formation and it is overlain by the Hyrum Formation (Beus, 1968, p. 788).

The Water Canyon Formation is present north and south of the Bear River in the mapped area. North of the Bear River, it is exposed 0.5 mile west of Cutler Dam. Also north of the Bear River, it is exposed 0.5 mile east of Cutler Dam. South of the Bear River, the Water Canyon is exposed on the western side of Cache Butte Divide.

The Water Canyon Formation, west of Cutler Dam, strikes northwest-southeast and dips west. It is composed of arenaceous dolomite, which weathers reddish brown. A brecciated limestone is present in the upper part. The rocks exposed at that location are similar to the upper member of the Water Canyon. Only the upper member is present because normal faulting has eliminated the lower member. The fault placed the Water Canyon Formation, on the west, next to the underlying Fish Haven-Laketown Formation. The upper part of the Water Canyon is unconformably overlain by the Tertiary Wasatch Formation.

The Water Canyon Formation, exposed 0.5 mile east of Cutler Dam, strikes east-west and dips north. There, a nearly complete stratigraphic section is present. The lower member is in contact with the upper part of the Fish Haven-Laketown Formation, on the south, along a normal fault. The upper part of the Water Canyon is overlapped by the Tertiary Salt Lake Formation and elsewhere it is overlapped by the Quaternary Lake Bonneville Group.

The Water Canyon Formation, exposed on the western side of Cache Butte Divide, strikes northwest-southeast and dips west. There, the Water Canyon unconformably overlies the Fish Haven-Laketown Formation, and it is unconformably overlapped by the Salt Lake Formation. Elsewhere it is overlapped by the Lake Bonneville Group. In places, the upper part of the Water Canyon has been faulted down next to the Fish Haven-Laketown Formation as well as the lower part of the Water Canyon Formation.

The age of the Water Canyon Formation is Early Devonian (Taylor, 1963, p. 35-37; Williams and Taylor, 1964, p. 43; Beus, 1968, p. 785). This is supported by a fish fauna found within the lower part of the upper member of the Water Canyon.

Lodgepole Formation

The Lodgepole Formation is the lowermost Mississippian formation of the Madison Group. It was named by Collier and Cathcart (1922, p. 173) for rocks exposed in the Little Belt Mountains, Montana. The term Lodgepole Formation was extended from Montana by Williams (1958, p. 31).

In the central Blue Spring Hills, Utah-Idaho, Beus (1963, p. 50) recognized four members of the Lodgepole Formation: (1) lower member of thin-bedded, blue-gray, sublithographic limestone containing chert nodules, 50 feet thick, (2) light-blue-gray calcarenite, 134 feet thick, (3) fine-grained medium-gray calcarenite that contains small cross-beds, 116 feet thick, (4) upper member of coarsely crystalline limestone, 38 feet thick. The first and third members of the Lodgepole are cliff-forming units; whereas, the second and fourth members are slope-forming units. The thickness of the Lodgepole Formation in the central Blue Spring Hills, Utah-Idaho, is 338 feet (Beus, 1963, p. 50).

Both the lower and upper contacts of the Lodgepole Formation are unconformable (Beus, 1968, p. 791). The lower contact is placed at the top of the Devonian Beirdneau Formation and the upper contact is placed at the base of the Mississippian Humbug Formation. The lower and upper contacts of the Lodgepole Formation are not exposed within the mapped area.

In the mapped area, only two small outcrops of Lodgepole Formation are present. One is located approximately 1.0 mile north of Long Divide and the other is located near the mouth of South Maple Canyon, Wellsville Mountains, Utah. The Lodgepole Formation, north of Long Divide, strikes east-west and dips north. It is medium-gray limestone that contains abundant crinoid columnals, some brachiopods, and planispiral gastropods. This outcrop of Lodgepole Formation is surrounded by the Salt Lake Formation.

The other outcrop of Lodgepole Formation is a fault block that is located near the mouth of South Maple Canyon, northeast of Deweyville, Utah. There, the Lodgepole strikes approximately east-west and dips south. It is composed of medium-gray limestone with black chert nodules. The limestone contains crinoid columnals, brachiopods, and planispiral gastropods. Faulting has placed the Lodgepole Formation, on the west, next to the Pennsylvanian Oquirrh Formation. The fault contact cannot be directly observed because of the unconformable cover of the Lake Bonneville Group.

The age of the Lodgepole Formation is Early Mississippian (Beus, 1963, p. 47).

Oquirrh Formation

In north-central Utah, the Oquirrh Formation is Pennsylvanian and Permian in age. The Oquirrh was named by Gilluly (1932, p. 34) for rocks exposed in the Oquirrh Mountains, Utah. The Oquirrh Formation has been identified in the Wellsville Mountains by Nygreen (1958) and Beus (1958). Also, Beus (1963, 1968) identified the Oquirrh in the central Blue Spring Hills, Utah-Idaho.

At Samaria Mountain, Beus (1968, p. 797-801) recognized three members in the Oquirrh Formation: (1) lower West Canyon Limestone Member, (2) middle member, (3) upper member. Beus (1968, p. 797-800) described the West Canyon Limestone Member as an autochthonous sequence consisting mainly of blue-gray limestone. Near the base of the West Canyon Limestone Member, there are beds of cross-bedded orthoquartzite and calcareous sandstone. The West Canyon Limestone

Member at Samaria Mountain is 1,307 feet thick; however, the section is incomplete. The middle member is described as an allochthonous sequence consisting of sandy limestone and orthoquartzite. The middle member is 1,100 feet thick. At Samaria Mountain, the section is incomplete. The upper member is described as an autochthonous sequence consisting of light-brown sandy limestone, blue-gray limestone, and calcareous sandstone. It is 1,198 feet thick. The thickness of the Oquirrh Formation at Samaria Mountain, Utah-Idaho, is 3,605 feet (Beus, 1968, p. 797-801). At Samaria Mountain, Utah-Idaho, the lower contact is placed at the top of the Mississippian Manning Canyon Formation. In southeastern Idaho and in the Wasatch Mountains near Salt Lake City, the upper contact of the Oquirrh is placed at the base of the Permian Phosphoria Formation. The lower and upper contacts of the Oquirrh Formation are not present in the mapped area.

The Oquirrh Formation crops out in the northern part of the Wellsville Mountains, Utah. There, Beus (1958, p. 34) reported, based on fossil evidence, that the lower and upper parts of the Oquirrh Formation are missing. Also, Beus (1958, p. 39) measured 6,643 feet of Oquirrh.

On the western side of the Wellsville Mountains, the slopes are Oquirrh talus consisting of small and large blocks of sandy limestone, blue-gray limestone, and calcareous sandstone. Sandy limestone, blue-gray limestone, and calcareous sandstone of the Oquirrh Formation crop out at Chocolate Peak, northeast of Deweyville, Utah, and on the surrounding ridges. Generally, the Oquirrh Formation, in the mapped area, strikes northwest-southeast to east-west and dips north.

The age of the Oquirrh Formation is Early Pennsylvanian through Early Permian (Beus, 1968, p. 797).

Tertiary System

Wasatch Formation

The Wasatch Formation is exposed, in places, throughout northern Utah. Williams (1948, p. 1144) described the Wasatch Formation of the Logan Quadrangle, Utah, as a pebble and cobble conglomerate that is red. It also contains boulders of light-gray orthoquartzite. The Wasatch Formation generally overlies Paleozoic rocks and it is overlain by the Tertiary Salt Lake Formation. The Wasatch Formation ranges from a few hundred feet to more than a thousand feet thick. Stokes (1969, p. 47) reported the thickness of the Wasatch, in the Salt Lake City region, to be more than 3,000 feet. In the Logan Quadrangle, Utah, Williams (1948, p. 1146) estimated the Wasatch Formation to be about 300 feet thick.

The Wasatch Formation is exposed in the northern part of the Wellsville Mountains and west of Bear River Narrows. In the northern part of the Wellsville Mountains, it is pebble and cobble conglomerate that is red. There, the Wasatch Formation unconformably overlies the Pennsylvanian Oquirrh Formation. West of Bear River Narrows, the Wasatch Formation is also pebble and cobble conglomerate that is red. There, it unconformably overlies the Devonian Water Canyon Formation. At both locations, the clasts are carbonate rock and they are cemented by a calcareous cement. The source of pebbles and cobbles of the Wasatch was local formations.

Salt Lake Formation

The light-gray consolidated Tertiary rocks of northern Utah are designated as the Salt Lake Formation. In the valleys of northern Utah, the Salt Lake Formation crops out, in places, through the Lake Bonneville Group along the valley margins. Also, the tuffaceous Salt Lake Formation forms numerous hills in the Cutler Dam Quadrangle and in the northern part of the Honeyville Quadrangle.

Adamson, Hardy, and Williams (1955, p. 4-8) tried to elevate the Salt Lake Formation to group status. They subdivided it into three formations in Cache Valley, Utah-Idaho. There, the following formations were recognized: (1) lower Collinston Conglomerate, (2) Cache Valley Formation, (3) upper Mink Creek Conglomerate. The basal conglomerate and the upper conglomerate were not found in the Cutler Dam Quadrangle and in the northern part of the Honeyville Quadrangle, Utah. The Salt Lake Formation, southwest of Clarkston, Utah, is 1,818 feet thick (Adamson, Hardy, and Williams, 1955, p. 12). In the mapped area, the Salt Lake Formation consists of tuffaceous limestone, oolitic limestone, and conglomerate. The conglomerate contains pebbles, cobbles, and boulders of Paleozoic rocks that are cemented by a calcareous cement. Also, there are pebbles, cobbles, and some boulders of andesite within the conglomerate.

The andesite is porphyritic with an aphanitic groundmass. It is generally pink and green; however, a freshly broken surface is dark to medium grayish white. Phenocrysts compose approximately 15 percent of the rock. They range from 1.0 mm to 5.0 mm in size. The most abundant phenocryst is plagioclase. It composes 90 percent of the phenocrysts. The remaining 10 percent of phenocrysts are ferromagnesian minerals. The groundmass composes approximately 85 percent of the rock and it is aphanitic. Plagioclase probably composes the groundmass.

Petrographic examination reveals that the plagioclase phenocrysts are generally broken and corroded; however, there are some euhedral phenocrysts present within the rock. These phenocrysts display polysynthetic twinning with an extinction angle ranging from 2° to 10°. This suggests a composition of albite-oligoclase. Almost all plagioclase phenocrysts have inclusions of calcite as a result of secondary replacement. In some phenocrysts, replacement is so extensive that the polysynthetic twinning is nearly destroyed. Phenocrysts of ferromagnesian minerals include hornblende, augite, and biotite. Hornblende is the most abundant ferromagnesian phenocryst. Hornblende phenocrysts are corroded and they exhibit flow structures. Some hornblende phenocrysts have reaction rims of magnetite, which may totally or partly surround the phenocryst. Extensive alteration is common to all hornblende phenocrysts in which chlorite seems to be the most abundant alteration product. Augite and biotite phenocrysts are less prevalent than hornblende phenocrysts. Augite phenocrysts have undergone extensive alteration and were identified by cleavage.

Magnetite was the only accessory mineral identified in the rock. It is present as small cubic crystals and as reaction rims that surround hornblende phenocrysts. It is also present along broken edges of plagioclase phenocrysts. Often magnetite will alter to either ilmenite or hematite; however, neither of them were identified.

Andesite clasts are present in the Tertiary Norwood Tuff of Morgan Valley, Utah (Eardley, 1944, p. 846). They are of pebble to boulder size and are present in conglomerate units of the Norwood Tuff.

There are some similarities and contrasts in the mineralogical composition of the andesite clasts present, in the mapped area, and the andesite clasts present in Morgan Valley, Utah, and East Canyon, Utah. Petrographic examination of the andesite clasts of Morgan Valley revealed a glassy groundmass with phenocrysts of plagioclase, hypersthene, hornblende, augite, and biotite (Eardley, 1944, p. 846). Composition of the plagioclase ranges from calcic andesine to calcic oligoclase (Eardley, 1944, p. 846). In the Cutler Dam Quadrangle and in the northern part of the Honeyville Quadrangle, the andesite clasts are composed of an aphanitic groundmass with phenocrysts of plagioclase, hornblende, augite, and biotite. The composition of the plagioclase is albite-oligoclase. Furthermore, alteration of hornblende, augite, and plagioclase seems to be more common because of the presence of magnetite, chlorite, and calcite.

The age of the Salt Lake Formation in the Cutler Dam Quadrangle and in the northern part of the Honeyville Quadrangle has been determined by Swain (1947), Yen (1947), and Brown (1949) to be middle to late Pliocene.

Quaternary System

Colluvial deposits

In the northern part of the Wellsville Mountains, the colluvial deposits consist of clasts of limestone and orthoquartzite set in an unconsolidated matrix. The clasts of limestone and orthoquartzite range from pebble size to boulder size; whereas, the matrix ranges from sand size to gravel size. The colluvial deposits cap ridges in the northeastern part of the Wellsville Mountains. The deposits unconformably overlap Paleozoic and Tertiary rocks.

The clasts are predominately limestone and orthoquartzite, although there are some sandstone, chert, and igneous rocks present. They are subangular to subrounded. The sedimentary rocks, present in the colluvium, were derived from the Pennsylvanian Oquirrh Formation. The igneous rocks, present in the colluvium, were derived from the conglomerate units of the Tertiary Salt Lake Formation. The age of the colluvium is Pleistocene.

Lake Bonneville Group

The Lake Bonneville Group, in Cache Valley, Utah, consists of three formations: (1) older Alpine Formation, (2) Bonneville Formation, (3) younger Provo Formation. Williams (1962) mapped the Lake Bonneville Group of southern Cache Valley. There, he treated the Alpine Formation and Bonneville Formation as an undifferentiated unit. The Alpine and Bonneville Formations consist of lacustrine gravel, sand, silt, and clay (Williams, 1962, p. 137). The Provo Formation was subdivided into two members by Williams (1962, p. 140):

(1) sand and silt member that forms the deltas, spits, and bars along the valley margins, (2) silt and clay member, which represents lake-bottom sediments.

The Lake Bonneville shoreline is the highest conspicuous shoreline found along the mountain fronts. The upper limit of the terrace represents the upper boundary of the Lake Bonneville Group. The formations of the Lake Bonneville Group were not differentiated in the Cutler Dam Quadrangle and in the northern part of the Honeyville Quadrangle. The age of the Lake Bonneville Group is Pleistocene (Williams, 1962, p. 131).

Alluvial deposits

Stream alluvium and alluvial fans are designated as alluvial deposits. Within the mapped area, alluvial deposits are mostly stream alluvium. The most extensive deposit of stream alluvium is the flood-plain deposit of the Bear River.

The alluvial fans are deposits at the mouths of streams at the mountain front. The fan deposits are typically unsorted pebbles, cobbles, and boulders locally derived from the formations exposed within the drainage areas of the streams. Within the Cutler Dam Quadrangle and within the northern part of the Honeyville Quadrangle, the fans are mostly located along the western front of the Wellsville Mountains; however, there are some fans located along Cutler Reservoir in the eastern part of Bear River Narrows. The age of the alluvial deposits is Holocene.

STRUCTURAL FEATURES

Regional Setting

Structural features of northern Utah and southeastern Idaho include folds, thrust faults, and normal faults. The Bannock thrust zone of southeastern Idaho extends along the eastern side of the Bear River Range. Armstrong and Cressman (1963, p. 1) described the Bannock thrust zone as a zone of imbricate thrust faults. The Bannock thrust zone includes the Paris thrust fault, on the west, and the Meade Peak thrust fault, on the east. Near Nounan, Idaho, the Paris thrust fault dips west and had eastward movement, placing the Cambrian Brigham Formation over the Triassic Thaynes Formation (Armstrong and Cressman, 1963, p. 18). This represents a stratigraphic throw of 20,000 feet (Armstrong and Cressman, 1963, p. 7). Eastward, the Meade Peak thrust fault dips west and had eastward movement, placing Paleozoic rocks over Mesozoic rocks.

The Woodruff thrust fault is south of the Bannock thrust zone and it probably connects with the Paris thrust fault of the Bannock thrust zone. The Woodruff thrust fault is exposed west of Woodruff, Utah, along Woodruff Creek. There, it branches and two thrust faults are present. The westernmost thrust fault dips west and had eastward movement, placing Cambrian Brigham Formation over Permian Park City Formation (Armstrong and Cressman, 1963, p. 18). The easternmost thrust fault also dips west and had eastward movement, placing Permian Park City Formation over Triassic Woodside Formation, to the south, and Permian Park City Formation over Jurassic Nugget Formation, to the north. Thus, the stratigraphic throw ranges from 300 to 4,000 feet (Armstrong and Cressman, 1963, p. 18).

Two major thrust faults are exposed in the Wasatch Range northeast of Ogden, Utah. They are the Ogden thrust fault and the Willard thrust fault. The Ogden thrust fault is the lowermost thrust fault. In Ogden Canyon, it dips east and had eastward movement (Crittenden, 1972b, p. 2873). It cuts the Precambrian and Cambrian rocks and, according to Crittenden (1972b, p. 2873), is presumed to have had smaller displacement than the Willard thrust fault. The Willard thrust fault is also an east-dipping thrust fault, which had eastward movement, and placed Precambrian strata over Cambrian strata (Crittenden, 1972b, p. 2872). The eastward movement of the Willard thrust fault is substantiated by a recumbent syncline that is overturned to the east (Crittenden, 1972b, p. 2873). Crittenden (1972b, p. 2876) believed that the Willard thrust fault and the Woodruff thrust fault are connected. He also visualized an allochthon, which extends from the Wellsville Mountains through the Bear River Range as a broad syncline (Crittenden, 1972b, p. 2876).

The Bear River Range, east of the mapped area, is composed of Paleozoic strata that have been folded into a broad syncline and anticline. The Logan Peak syncline generally trends northeast-southwest and its axis forms major peaks within the Bear River Range. The Strawberry Valley anticline is east of the Logan Peak syncline and it nearly parallels the Logan Peak syncline. The Strawberry Valley anticline is exposed in the Logan and Randolph Quadrangles, Utah; however, it is mostly covered by the Tertiary Wasatch Formation.

The western margin of the Bear River Range is the boundary between the Middle Rocky Mountain province, on the east, and the Basin and Range province, on the west (Fenneman, 1946). Westward, in the Basin and Range province, a series of valleys are separated by north-south-trending mountain ranges. Cache Valley, the easternmost valley of the Basin and Range province, is bounded on the east by the Bear River Range and on the west by the Wellsville Mountains and the Malad Range. A north-south-trending normal fault extends along the eastern margin of Cache Valley. According to Williams (1948, p. 1155), the fault extends from the southern part of Cache Valley northward to Preston, Idaho. A number of faceted spurs are present along the mountain front of the Bear River Range. Along the western margin of Cache Valley, a normal fault also extends from the southern part of Cache Valley northward into Idaho.

The southern part of Clarkston Mountain and the Wellsville Mountains bound the western margin of Cache Valley. Clarkston Mountain, the southernmost part of the Malad Range, is composed of east-dipping Paleozoic strata. Thrust faults, low-angle normal faults, and high-angle normal faults are present. The low-angle normal faults have been interpreted as thrust faults that had reversed movement during Basin and Range faulting. Thus, the thrust relationships were destroyed and the faults are considered to be normal (Gray, 1975, p. 37).

The Wellsville Mountains, which are the northernmost extension of the Wasatch Range, are composed of east-dipping Paleozoic strata. The Wellsville Mountains are bounded, on the west, by the Wasatch fault zone and on the east by normal faults. Also, the Wellsville Mountains have been cut by numerous internal normal faults (Beus, 1958, Plate 1). The Wasatch fault zone is a series of nearly parallel normal faults that trend north-south. It drops the valley block, on the west, relative to the mountains. The Bear River Valley is the down-dropped block that separates the Wellsville Mountains, on the east, and the central Blue Spring Hills, on the west.

The central Blue Spring Hills, Utah-Idaho, are bounded on the west by normal faults. Beus (1963, Plate 3) mapped some minor folds in the southern part of the central Blue Spring Hills; however, most of the area is composed of west-dipping Paleozoic rocks. The Paleozoic strata are cut by normal faults. A thrust fault is also present in the northeastern corner of the area.

Normal Faults

General statement

Normal faults are of major importance in the Wellsville Mountains, Cache Butte Divide, and the Junction Hills. They were produced during Basin and Range faulting and are superimposed on the older structural features of the Sevier orogeny.

The faults in the Cutler Dam Quadrangle and in the northern part of the Honeyville Quadrangle are steeply dipping to vertical normal faults. These faults are present as marginal normal faults as well as internal normal faults. The marginal faults, which extend along the base of the mountain ranges, strike north-south. The internal faults are present in the Junction Hills, Cache Butte Divide, and the Wellsville Mountains. In Bear River Narrows, which is located in the northern part of Cache Butte Divide, there are two sets of parallel faults. One set is located in the eastern part of Bear River Narrows. It strikes about east-west and it is associated with an east-west-trending marginal fault. The second set is located in the western part of Bear River Narrows. The faults of the second set are antithetic and they strike north-south. These antithetic faults are associated with a northwest-southeast-trending fault that extends along the western side of Cache Butte Divide.

Junction Hills

The western and eastern sides of the Junction Hills are bounded by normal faults. The Junction Hills are also cut by an internal fault that is located near the northern boundary of the mapped area.

The Wasatch fault zone extends along the western side of the Junction Hills. There, it is covered by a landslide.

An east-west-trending normal fault is exposed 1.5 miles north of Long Divide. This fault strikes N. 38° W. and is vertical. The fault is covered, at its western end, by a landslide. Eastward, it crosses the ridge on the Box Elder and Cache County Line. There, the Tertiary Salt Lake Formation, on the south, is down next to the Pennsylvanian Oquirrh Formation. Eastward, the fault relationships are obscured because the Salt Lake Formation is present on both sides of the fault. It is terminated, at its eastern end, by a north-south-trending marginal fault.

A north-south-trending marginal fault extends along the eastern margin of the Junction Hills (Figure 2). It is terminated, at its southern end, by an east-west-trending normal fault that is southeast of Long Divide. Northward, this fault extends beyond the boundary of the mapped area. It is part of a fault zone described by Williams (1948, p. 1157) and Hanson (1949, p. 71).

Long Divide-Cache Butte

A series of normal faults is exposed in the eastern part of Bear River Narrows, approximately 0.8 mile east of Cutler Dam. These faults generally strike northwest-southeast and are down on the northeast.

The easternmost fault is considered to be a marginal fault. It is located 0.9 mile east of Cutler Dam. It strikes N. 72° W. and it is vertical. This fault extends from near Cache Junction, Utah, to Long Divide (Figure 3). Its eastern end is obscured by the Lake Bonneville Group, but fault relationships are evident in Bear River Narrows. The fault is exposed 0.2 mile southeast of Cutler Reservoir where it cuts the Swan Peak Formation on the south. There, the Swan Peak Formation, south of the fault, forms a north-facing slope and it is extensively brecciated. Along the northern shore of the reservoir, the fault extends through a stream valley where the Salt Lake Formation, on the north, is down next to the Fish Haven-Laketown Formation (Figure 4). Westward, the fault extends across a

Figure 2. North-south-trending normal fault on the eastern side of Junction Hills in northern part of mapped area; aerial view west. Normal fault extends along eastern side of Junction Hills from the right margin of view to an intersecting normal fault near Bear River Narrows. Salt Lake Formation crops out in Junction Hills and underlies Lake Bonneville Group in the foreground. The eastern side of the fault is down. Cache Valley is in the foreground; Malad Valley is beyond the Junction Hills.

Figure 3. Normal fault in eastern part of Bear River Narrows; aerial view west. The fault strikes N. 72° W. and is vertical. North of Cutler Reservoir, the fault places the Salt Lake Formation (Tsl), on the north, down next to the Fish Haven-Laketown Formation (OS). South of the reservoir, the fault is obscured by the Lake Bonneville Group.

Figure 4. Normal fault in eastern part of Bear River Narrows; view northwest. The fault strikes N. 72° W. and is vertical. It places the Salt Lake Formation (Tsl), on the north, down next to the Fish Haven-Laketown Formation (OS) and the Water Canyon Formation (Dwc). Refer to Figure 3. An intersecting vertical fault places the Water Canyon Formation (Dwc) down next to the Fish Haven-Laketown Formation (OS).

low divide. There, it places the Salt Lake Formation, on the north, down next to the Water Canyon Formation. The stratigraphic throw along this fault is at least 5,800 feet. Westward, this fault is obscured by the Lake Bonneville Group.

An east-west-trending normal fault is exposed 0.1 mile south of the previously described fault. It strikes N. 86° W. and dips 75° N. This fault, at its eastern end, terminates against the easternmost fault. There, it cuts the Swan Peak Formation. Westward, this fault crosses the reservoir. At the northern shore of Cutler Reservoir, this fault places the upper part of the Fish Haven-Laketown Formation, on the north, down next to the upper part of the Swan Peak Formation and the lower part of the Fish Haven-Laketown Formation (Figure 5). Westward, it crosses a north-south-trending ridge. The ridge is on the northern side of the peak that forms the northern part of Bear River Narrows. There, the fault places the Water Canyon Formation, on the north, down next to the Fish Haven-Laketown Formation.

East of the reservoir, between the two previously described faults, the contact between the Swan Peak Formation and the Fish Haven-Laketown Formation is present. Westward, across the reservoir, the Fish Haven-Laketown Formation and the Water Canyon Formation are in fault contact. The vertical distance between the top of the Swan Peak Formation and the outcrop of the Water Canyon Formation is insufficient to accommodate the entire thickness of the Fish Haven-Laketown Formation. Therefore, a vertical north-south-trending fault places the Water Canyon and Fish Haven-Laketown Formations

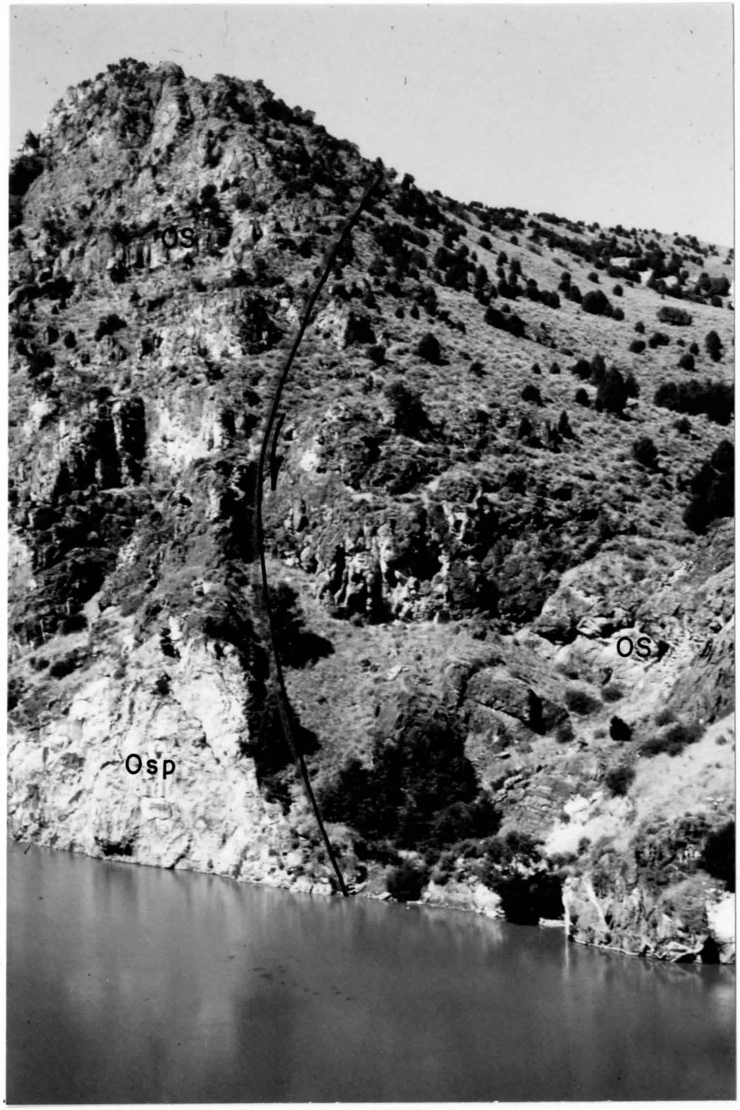


Figure 5. Normal fault, east of Cutler Dam, in Bear River Narrows; view northwest. The fault strikes N. 86° W. and dips north. It places the upper part of the Fish Haven-Laketown Formation (OS) down next to the upper part of the Swan Peak Formation (Osp) and the lower part of the Fish Haven-Laketown Formation (OS).

in fault contact, west of the reservoir.

A vertical east-west-trending fault is exposed 0.5 mile east of Cutler Dam. The fault strikes N. 68° W. At the northern shore of the reservoir, the fault places the Fish Haven-Laketown Formation, on the north, down next to the upper part of the Swan Peak Formation and the lower part of the Fish Haven-Laketown Formation. Westward, it extends to the north-south-trending ridge where it is intersected by the east-west-trending fault previously described. At the ridge crest, the east-west-trending fault seems to be the major fault.

A minor vertical fault is exposed 0.4 mile east of Cutler Dam and it nearly parallels the previously described fault. It is within the Fish Haven-Laketown Formation. This fault displaces a light-gray bed of dolomite on the northern side of the reservoir. On the southern side of the reservoir, the displacement along the fault is not as obvious as on the northern side of the reservoir. On the southern side, light-gray dolomite is present on both sides of the fault; however, the dolomite on the northern side of the fault contains abundant chert nodules and the dolomite on the southern side of the fault does not contain chert nodules. The northern side of the fault is down relative to the southern side.

The eastern part of Bear River Narrows contains numerous minor faults that are too small to map at the scale of 1:16,000. The rocks of the Fish Haven-Laketown Formation and the Swan Peak Formation are extensively brecciated. Slickensides and calcite-filled fractures are present on the southern side of the reservoir along the railroad tracks.

Another series of normal faults is exposed in the western part of Bear River Narrows. They are antithetic faults that generally strike north-south and are down on the east. All of these faults are within the Fish Haven-Laketown Formation.

An east-dipping fault is exposed 0.1 mile east of Cutler Dam. It strikes north-south and dips about 80° E. The eastern side is down. A nearly vertical fault is exposed east of the previously described fault, on the northern side of the reservoir. It strikes N. 52° W. and the southwestern side is down. This fault terminates against the previously described fault at its northwestern end. Southeastward the fault does not seem to cross the reservoir. Both faults displace the dolomite of the Fish Haven-Laketown Formation; furthermore, the dolomite along the fault is brecciated.

West of Cutler Dam, an east-dipping fault extends from a cliff, south of Bear River, past the eastern side of the surge tank to a stream valley north of Bear River. It displaces the dolomite exposed in the cliff south of Bear River. North of Bear River, light-gray dolomite, on the east, is down next to dark-gray dolomite. The dolomite, along the western side of the stream valley, is cavernous and stained. Also, in the stream valley, slickensides are present at a point 0.2 mile north of the stream mouth. There, the fault strikes N. 2° E. and dips 62° E. The eastern side is down.

A minor fault branches from the previously described fault south of the Bear River. It strikes N. 13° E. and is vertical. The fault extends from a cliff south of Bear River, where it displaces the dolomite of the Fish Haven-Laketown Formation, to the northern side of the river. The eastern side of the fault is down. A large slickensided surface is exposed at a point 0.1 mile south of the dam.

Two parallel faults are exposed on a south-facing slope 0.1 mile west of the powerhouse. Both of these faults strike N. 8° E. and displace the dolomite of the Fish Haven-Laketown Formation. The easternmost fault crosses the Bear River, but the westernmost fault does not seem to cross the river. The eastern side of both faults is down.

In general, there seems to be a relatively wide outcrop of Fish Haven-Laketown Formation in the Bear River Narrows. This wide outcrop of Fish Haven-Laketown Formation is the result of normal faulting and the low dip of the beds.

A vertical normal fault, south of Cutler Dam, crosses Cache Butte Divide. It strikes N. 64° W. The fault is terminated, at its western end, by a normal fault on the western side of Cache Butte Divide. There, the Water Canyon Formation, on the north, is down next to the Fish Haven-Laketown Formation. On Cache Butte Divide, the fault relationships are obscured because the Salt Lake Formation is present on both sides of the fault. Southeastward, the fault extends beyond the boundary of the mapped area.

A northwest-southeast-trending fault is exposed from a point 0.5 mile west of Cutler Dam southeastward along the base of Cache Butte Divide. It strikes N. 27° W. and is nearly vertical. North of Bear River, 0.5 mile east of Cutler Dam, the fault places the Water Canyon Formation, on the west, down next to the Fish Haven-Laketown Formation. There, the rocks on both sides of the fault are severely brecciated and form fault gouge at the canal. Southeastward, the fault extends along the base of the western side of Cache Butte Divide. There, the upper part of the Water Canyon Formation, on the west, is down next to the lower part of the Water Canyon Formation. The fault contact between the lower and upper parts of the Water Canyon Formation is covered by the Lake Bonneville Group. Southward, the fault is concealed by a landslide of the Fish Haven-Laketown Formation. Directly east of the fault, the Fish Haven-Laketown Formation is severely brecciated and the dip increases from east to west. The increase of dip from 37° W., on the east, to 44° W., on the west, is interpreted as drag effect along the fault. The fault ends 1.5 miles northwest of Cache Butte.

A small vertical transverse fault connects the two previously described faults 1.0 mile east of Beaver Dam, Utah. This fault strikes N. 44° E. and is vertical. A small outcrop of Wasatch Formation, which is exposed along the left fork of the stream east of Beaver Dam, Utah, is down relative to the ridge of Fish Haven-Laketown Formation on the northwest.

A major fault diagonally transects the middle of the mapped area from the southeastern corner to a point west of Long Divide. It strikes N. 29° W. and dips steeply west. The western side is down. This fault extends from about 1.3 miles west of Long Divide, where it is terminated by the Wasatch fault zone, southeastward across the Bear River. From the Bear River, the fault extends southeastward along the western side of Cache Butte Divide, and it is partly responsible for the relief between the ridge and the valley floor (Figure 6). In the southeastern part of the mapped area, this fault nearly parallels Utah State Highway 69 to the eastern boundary. This fault evidently places the Pennsylvanian Oquirrh Formation, in the graben, down relative to the Ordovician-Silurian Fish Haven-Laketown Formation in Cache Butte Divide. In the graben, the Pennsylvanian Oquirrh Formation is thought to underlie the Tertiary and Quaternary rock units because the younger Oquirrh Formation must have dropped next to the older Fish Haven-Laketown Formation. Recent movement has occurred along this fault. Along Fourmile Creek, where it parallels Utah State Highway 69 in the southeastern part of the mapped area, the fault places the Lake Bonneville Group, on the west, down next to the Salt Lake Formation. There, the Lake Bonneville Group, on the west, is a grayish-white silt and clay. It opposes the Salt Lake Formation, which is a tuffaceous sandstone with shards of volcanic glass.

Wellsville Mountains

Near the eastern side of the Wellsville Mountains, a small north-south-trending fault extends from the head of Willies Hollow southward beyond the mapped area. It places Tertiary Wasatch Formation, on the east, down relative to the Pennsylvanian Oquirrh Formation. Evidence for the existence of this fault is the relatively low outcrop of Wasatch Formation exposed west of John Kidman Flat compared to a high outcrop of Wasatch on the ridge at the head of Smiths Canyon. The Wasatch Formation was deposited on relatively

Figure 6. Normal fault along western side of Cache Butte Divide; aerial view east. The fault strikes N. 32° W. and dips steeply west. It places the Oquirrh Formation, which underlies Lake Bonneville Group in the foreground, down relative to the Fish Haven-Laketown Formation, in Cache Butte Divide. The fault forms the northeastern boundary of a northwest-southeast-trending graben.

planar surface of low relief, in the northern part of the Wellsville Mountains; therefore, any major irregularities in the Wasatch, with respect to relief, can be interpreted as due to faulting.

A normal fault, within the Oquirrh Formation, extends northeastward from the southern part of the mapped area and it is terminated at Threemile Creek by a northwest-southeast-trending normal fault. It was mapped by Beus (1958, Plate 12) in Wide Canyon. In Wide Canyon, this fault is down on the northwest placing the Pennsylvanian Oquirrh Formation next to the Mississippian Great Blue Formation.

The northeastern part of the Wellsville Mountains is cut by a major normal fault that strikes N. 38° W. (Figure 7). The fault dips 80° to 88° E. It places the Tertiary Salt Lake Formation, which forms most of the northeastern part of the Wellsville Mountains, next to the Pennsylvanian Oquirrh Formation (Figure 8). The southeastern end of the fault extends beyond the boundary of the mapped area. Northwestward, this fault crosses John Kidman Flat and intersects a normal fault that strikes north-south. The north-south-trending fault is not offset by the northwest-southeast-trending fault. The northwest-southeast-trending fault diagonally transects the ridges and drainage lines in the northeastern part of the Wellsville Mountains. The western end of this fault terminates against a fault of the Wasatch fault zone.

An outcrop of Wasatch Formation is abruptly terminated on the eastern side of Chocolate Peak by a normal fault, which strikes N. 61° W. and is vertical. The fault places the Wasatch Formation, on the north, next to the Oquirrh Formation. Elsewhere, the fault

Figure 7. Normal fault crossing northeastern part of Wellsville Mountains; aerial view south. The fault forms the southwestern boundary of a northwest-southeast-trending graben. Refer to Figure 6. On the western side of the Wellsville Mountains is the Wasatch fault zone along which Bear River Valley dropped relative to the mountains. Cache Valley is in the foreground. (Photograph by Jerome V. DeGraff)

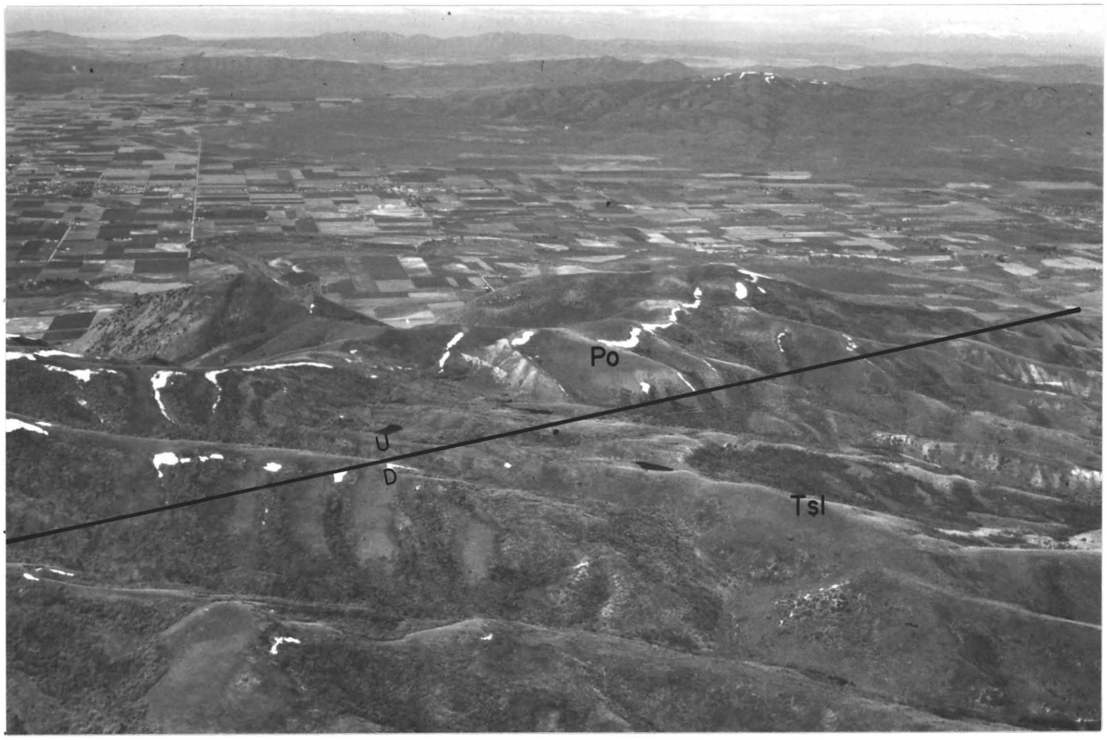


Figure 8. Normal fault in the northeastern part of Wellsville Mountains; aerial view west. The fault strikes N. 38° W. and dips 80° to 88° E. It places the Salt Lake Formation (Tsl), on the northeast, down next to the Oquirrh Formation (Po). Refer to Figure 7.

is confined to the Oquirrh Formation. West of Chocolate Peak, this fault is terminated by a fault of the Wasatch fault zone; whereas, east of Chocolate Peak, it ends in the Oquirrh Formation in a stream valley.

Wasatch fault zone

The Wasatch fault zone follows the base of the Wasatch Range from central Utah to northern Utah. It is a series of normal faults that dip steeply west. Four faults of the Wasatch fault zone are present in the area of the Cutler Dam Quadrangle and the northern part of the Honeyville Quadrangle (Figure 9).

A small fault is exposed near Willow Springs, west of Chocolate Peak, Wellsville Mountains, Utah. It places the Salt Lake Formation, on the west, down next to the Lodgepole Formation. The extent of this fault is about 1.0 mile.

The major fault of the Wasatch fault zone extends from the southern boundary of the mapped area to the northern boundary. In the southern part of the mapped area, this fault is west of an outcrop of conglomerate of the Salt Lake Formation near Willow Springs, west of Chocolate Peak. Northward, it is exposed in the south-facing escarpment of the Bear River. There, the Lake Bonneville Group, on the west, is down next to the Salt Lake Formation. In the northern part of the mapped area, the fault is west of the Junction Hills where it is concealed by a landslide of the Salt Lake Formation.

A normal fault, near the western boundary of the mapped area, is the westernmost fault of the Wasatch fault zone. The southern

Figure 9. Wasatch fault zone along western side of Wellsville Mountains; aerial view east. The fault zone strikes north-south and dips steeply west. The Wasatch fault zone is responsible for the relief between Bear River Valley, in the foreground, and the Wellsville Mountains.

end of the fault is west of a small outcrop of conglomerate of the Salt Lake Formation along Utah State Highway 69 north of the gravel pit near Hawbush Springs. The northern end of the fault is west of an outcrop of conglomerate of the Salt Lake Formation, which forms the small hill northeast of Collinston, Utah.

The fourth fault has a distinctly different strike and it places the Mississippian Lodgepole Formation over the Pennsylvanian Oquirrh Formation. This fault is located at the base of the western side of Chocolate Peak near South Maple Canyon. The fault is interpreted as a high-angle thrust fault which placed the Lodgepole Formation over the Oquirrh Formation. Later reversed movement, during Basin and Range faulting, dropped the Lodgepole Formation down toward the valley but not to its original position. Thus, the fault is considered to be a normal fault. The fault block of Lodgepole Formation has apparently rotated as it was faulted down, because it dips anomalously south; whereas, the Paleozoic strata exposed in the southern part of the Wellsville Mountains dip east and in the northern part of the Wellsville Mountains the rocks dip north. The strike of the fault is N. 22° W., but near Garland Springs, northeast of Deweyville, Utah, it turns southward and extends beyond the boundary of the mapped area. The plane of the fault is not exposed, but it is reasonable to assume that it dips steeply west; however, the fault probably dips less than the near-by faults of the Wasatch fault zone.

Landslides

Fish Haven-Laketown Formation landslide

A landslide, composed of Fish Haven-Laketown Formation, is present on the western side of Cache Butte Divide northeast of Beaver Dam, Utah. The landslide extends 0.3 mile into the valley. The glide plane has been destroyed by erosion except for a section located near the northern margin of the landslide in sec. 34, T. 13 N., R. 2 W., in the Cutler Dam Quadrangle (Figure 10). There, the Fish Haven-Laketown Formation is exposed above and below the glide plane.

The landslide conceals a northwest-southeast-trending normal fault. Movement along this fault and movement along the major fault directly to the west probably caused the landslide.

The Bonneville shoreline of the Lake Bonneville Group cuts the landslide and lake deposits of the Provo Formation overlap the landslide in the northern part. Thus, sliding occurred before the lake reached its highest level.

Salt Lake Formation landslide

A major landslide cuts the western slope of the Junction Hills. The landslide is composed of the Salt Lake Formation. Maw (1968, p. 17) described this landslide as a circular mass 2.0 miles in diameter; therefore, the entire landslide mass is not present in the mapped area. The glide plane of the landslide is not exposed. It is probably within the Salt Lake Formation.

Figure 10. Landslide, south of Bear River, on western side of Cache Butte Divide; view south. The glide plane extends from the right side of the patch of snow on the horizon to the pick at the lower right. The landslide is composed of the Fish Haven-Laketown Formation and it rests on Fish Haven-Laketown Formation in the upper part.

The landslide conceals a fault of the Wasatch fault zone. Movement along this fault probably caused the landslide.

The landslide disrupts the Bonneville or highest shoreline of Lake Bonneville and rests on the Bonneville Formation of the Lake Bonneville Group in the valley. Furthermore, the landslide is overlapped, in places, by the Provo Formation in the valley. Thus, the sliding occurred after the lake reached its highest level.

STRUCTURAL EVENTS

General Statement

The Sevier orogeny and the Basin and Range normal faulting are important periods of structural development in northern Utah. The Sevier orogeny involved crustal shortening characterized by thrust faulting and folding. Basin and Range normal faulting followed the Sevier orogeny and it involved crustal extension.

The Sevier orogeny, according to Armstrong (1968), was responsible for the thrust faulting and folding in northern Utah. Movement on the thrust faults and the development of the folds began as early as latest Jurassic or earliest Cretaceous time (Armstrong and Cressman, 1963, p. 14). Dating the movement of the thrust faults, in the Bannock thrust zone of southeastern Idaho, is based on the deposition of the Ephraim Conglomerate at Gannett Hills, Idaho. The age of the Ephraim Conglomerate is considered to be Early Cretaceous, and the deposition of the Ephraim was the result of uplift to the west accompanied by thrust faulting and folding of the ancestral Bear River Range. Major folding and thrust faulting ceased by Eocene time. In the Huntsville area, Utah, and Causey Dam area, Utah, the Wasatch Formation, which is considered to be Eocene, overlaps the Paleozoic strata (Crittenden, 1972a; Mullens, 1969). The Paleozoic strata were folded during the Sevier orogeny and the Wasatch Formation was deposited unconformably over the folded strata. Thus, the thrust faulting of the Sevier orogeny had ceased before the deposition of the Wasatch Formation or by Eocene time.

Basin and Range faulting followed the Sevier orogeny. Normal faults of the Basin and Range faulting were superimposed on the older features of the Sevier orogeny. Basin and Range faulting is characterized by north-south horsts and graben and it is responsible for tilting the Tertiary strata. The present topography is also partly the result of the normal faulting. The inception of the Basin and Range faulting was in late Eocene time and it is continuing at the present time (Eardley, 1955, p. 41-43).

Sevier Events

The Sevier orogeny was responsible for the thrust faulting of Paleozoic strata in the mapped area. At the base of Chocolate Peak, on the western side, a high-angle thrust fault placed a block of Mississippian Lodgepole Formation over the Pennsylvanian Oquirrh Formation. However, during Basin and Range faulting support was removed from the slope and reversed movement occurred along the fault. Consequently, the Lodgepole Formation dropped down, but not to its original position, and the thrust relationship between the Lodgepole and Oquirrh was destroyed. Thus, the fault is considered to be a fault of the Wasatch fault zone.

Basin and Range Events

Early normal faulting

Early normal faulting cut Paleozoic and Tertiary strata in the mapped area. Movement occurred along marginal faults, which extend along the margins of the mountain ranges, and internal faults, which cut the mountain ranges. Inception of the normal faulting was in late Eocene time (Eardley, 1955, p. 41-43).

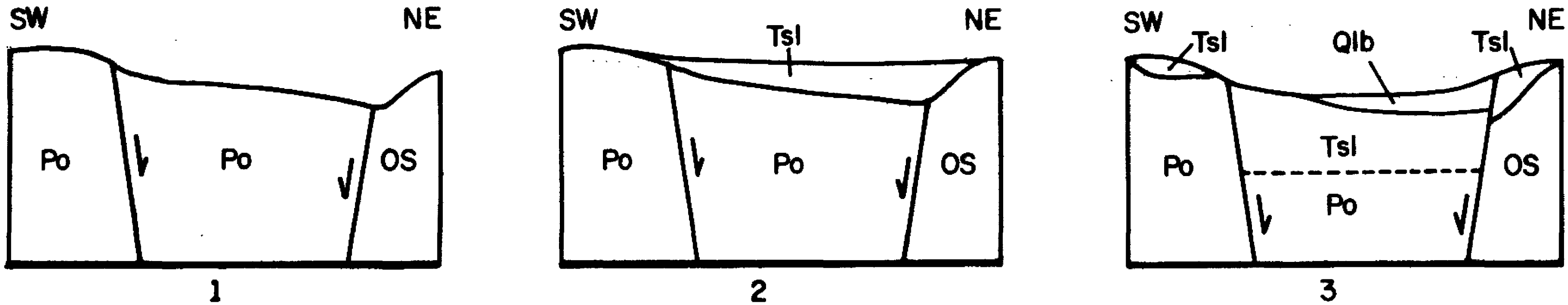
Marginal faulting dropped the valleys relative to the mountains along steeply dipping marginal faults. These faults have accumulated a great amount of displacement. Marginal faults include the Wasatch fault zone and the faults that bound the western margin of Cache Valley.

Internal faulting cut the mountains, in the mapped area, along steeply dipping to vertical faults. These faults have accumulated a lesser amount of displacement than the marginal faults. The internal faults cut Paleozoic and Tertiary strata in the Wellsville Mountains, Junction Hills, and Cache Butte Divide.

Two faults, which diagonally transect the mapped area, form a northwest-southeast-trending graben. The fault that bounds the northeastern margin of the graben extends from the southeastern part of the mapped area along Utah State Highway 69. Northwestward, this fault crosses the Bear River and it is terminated against a fault of the Wasatch fault zone. This fault that bounds the southwestern margin of the graben cuts the northeastern part of the Wellsville Mountains. It extends from the southern part of the mapped area, across John Kidman Flat, to the northwestern part of the Wellsville Mountains. Northwestward, this fault is terminated against the Wasatch fault zone in Bear River Valley. Movement along these two faults, which is responsible for the development of the graben, probably occurred simultaneously.

Two interpretations for the origin of the graben are considered. One interpretation is that the graben developed along two normal faults one of which had greater movement than the other (Figure 11). In the mapped area, the fault that bounds the northeastern margin of the graben had greater movement than the fault that bounds the southwestern margin. The northeastern fault dropped Pennsylvanian Oquirrh Formation, on the southwest, next to Ordovician-Silurian Fish Haven-Laketown Formation. It is also responsible for the westward tilting of the Paleozoic strata from Long Divide to Cache Butte Divide. Simultaneously, the fault that bounds the southwestern margin of the graben dropped Pennsylvanian Oquirrh Formation next to Pennsylvanian Oquirrh Formation. Both of these faults cut the Salt Lake Formation; therefore, they have had post-Pliocene movement.

Another interpretation is that the graben developed along two normal faults one of which is the master fault and the other is a subordinate fault. This interpretation is similar to the previous interpretation, except that the subordinate fault terminates against the master fault at depth. The master fault would be the fault that bounds the northeastern margin of the graben and the subordinate fault would be the fault that bounds the southwestern margin.



Po - Oquirrh Formation
OS - Fish Haven-Laketown Formation

Qlb - Lake Bonneville Group
Tsl - Salt Lake Formation

Figure 11. Structural development of the northwest-southeast-trending graben. Events illustrated are as follows: (1) Faulting of the Oquirrh Formation down relative to the Fish Haven-Laketown Formation along the northeastern fault and faulting of the Oquirrh Formation down relative to the Oquirrh Formation along the southwestern fault, (2) Deposition of the Salt Lake Formation, (3) Continued faulting along both faults. In the Wellsville Mountains, the southwestern fault placed the Salt Lake Formation down next to the Oquirrh Formation and recent movement, along the northeastern fault, placed the Lake Bonneville Group down next to the Salt Lake Formation.

At the present time, both interpretations are possible explanations for the origin of the graben in the mapped area. In the graben, the Pennsylvanian Oquirrh Formation is thought to underlie the Tertiary and Quaternary rock units because the younger Oquirrh Formation must have dropped next to the older Fish Haven-Laketown Formation along the northeastern fault.

Later normal faulting

Later normal faulting cut the Quaternary Lake Bonneville Group in the mapped area. This faulting occurred along two faults in the mapped area. One is a fault of the Wasatch fault zone and the other bounds the northeastern margin of the northwest-southeast-trending graben.

West of Cutler Dam, a fault of the Wasatch fault zone is exposed in a river-cut escarpment of the Bear River. There, the Lake Bonneville Group, on the west, is down next to the Salt Lake Formation. Later movement also occurred along the fault that bounds the northeastern margin of the northwest-southeast-trending graben (Plate 2). Along Fourmile Creek, where it parallels Utah State Highway 69 in the southeastern part of the mapped area, this fault places the Lake Bonneville Group, on the west, down next to the Salt Lake Formation.

Early landsliding

A landslide west of Cache Butte Divide, northeast of Beaver Dam, Utah, formed during the early existence of Lake Bonneville. The landslide is composed of rock of the Fish Haven-Laketown Formation and it slid 0.3 mile westward into the valley. The glide plane is exposed near the northern margin of the landslide and the Fish Haven-Laketown Formation is exposed above and below the glide plane (Figure 10). Toward the toe of the landslide, the Fish Haven-Laketown Formation probably rests on Lake Bonneville Group; however, there is no direct evidence to indicate what formation underlies the landslide.

The faults that extend along the base of Cache Butte Divide probably caused the landslide as the result of down faulting of the valley. As down faulting of the valley continued, support was removed from the slope. This created an unstable condition along the mountain front and the movement of the landslide subsequently followed.

The Bonneville shoreline, which is the highest shoreline of Lake Bonneville, cuts the landslide. Also, the Provo Formation overlaps the landslide along its northern margin. Thus, the landslide formed relatively early in the history of Lake Bonneville.

Later landsliding

A large landslide, composed of the Salt Lake Formation, is present on the western side of the Junction Hills north of Bear River. The landslide cuts the western slope of the Junction Hills, forming a prominent landslide scarp, and it extends westward into the Bear River Valley. The mechanism that triggered the landslide may have been a combination of causes; however, it is reasonable to assume that the movement of the landslide was associated with down faulting of the valley along the Wasatch fault zone. As down faulting of the valley continued, the support was removed from the slope. This created an unstable condition along the western slope of the Junction

Hills and movement of the landslide subsequently followed.

The landslide disrupts the Bonneville shoreline, which is the highest shoreline of Lake Bonneville, and it is cut by the Provo shoreline. The landslide probably rests on the Bonneville Formation. It is covered by the Provo Formation in the valley. Thus, the landslide formed after the deposition of the Bonneville Formation and before any significant amount of deposition of the Provo Formation. It formed relatively late in the history of Lake Bonneville.

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