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Structural Geology of Eastern Part of Richmond and Western Part of Naomi Park Quadrangles, Utah-Idaho

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STRUCTURAL GEOLOGY OF EASTERN PART OF RICHMOND AND WESTERN PART OF NAOMI PEAK QUADRANGLES, UTAH-IDAHO

by

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Arthur J. Mendenhall

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Structural Geology of Eastern Part of Richmond

And Western Part of Naomi Peak

Quadrangles, Utah-Idaho

by

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The mapped area, which includes the eastern part of the Richmond and the western part of the Naomi Peak quadrangles, Utah-Idaho, is located in the central part of northern Utah and southeastern Idaho. It is located along the eastern side of Cache Valley and western side of the Bear River Range. Cache Valley is in the Basin and Range province and the Bear River Range is in the Middle Rocky Mountain province. The mapped area is about 8.6 miles long, in the north-south direction, and 7.8 miles long, in the east-west direction.

The Mutual Formation of Precambrian age is the oldest stratigraphic unit exposed in the mapped area. It consists of purple and brown quartzite. The Brigham Formation of Early Cambrian age and the Langston Formation of Middle Cambrian age overlie the Mutual in stratigraphic succession. The Salt Lake Formation of Tertiary age unconformably overlies older rocks; it is also faulted against the Mutual Formation. A major landslide of Precambrian, Cambrian,

and Ordovician formations is present in the southern part of the mapped area. It is unconformably overlapped by the Salt Lake Formation. The Lake Bonneville Group of late Pleistocene age is present in Cache Valley and overlaps older rocks along the western side of the Bear River Range.

The Precambrian and Cambrian stratigraphic units, except for those of the landslide, dip eastward and form the western flank of the Logan Peak syncline. A small disharmonic asymmetrical anticline, in the Langston and Ute Formations of Cambrian age, indicates eastward movement. Two bedding-plane faults locally eliminate the basal Naomi Peak Limestone Member of the Langston Formation. A major normal fault, which is nearly vertical, extends along the base of the Bear River Range. Another normal fault, which is probably nearly vertical, parallels the western edge of the foothills.

The folding and bedding-plane thrust faulting involve eastward movement and occurred during the Sevier orogeny. This orogeny began during late Jurassic time and extended into the early part of the Tertiary Period. Basin and Range normal faulting began early in the Tertiary Period. The normal faults produced great relief between Cache Valley and the Bear River Range. The landslide surface is thought to have formed as a west-dipping thrust fault. Reversed movement on this fault, due to removal of support on the valley side, produced the major landslide.

(58 pages)

INTRODUCTION

Purpose and Scope

The object of this investigation is to improve understanding of the structural features of a limited area in the central part of northern Utah and southeastern Idaho. The geologic map and structure sections are in greater detail than previous ones (Plate 1 and 2).

Location and Accessibility

The mapped area is located in the central part of northern Utah and southeastern Idaho (Figure 1). It consists of the eastern two-thirds of the Richmond quadrangle, Utah-Idaho, and the adjoining western half of the Naomi Peak quadrangle, Utah-Idaho. These quadrangles are 7.5-minute topographic maps published by the U. S. Geological Survey.

The northern boundary of the mapped area is less than 0.1 mile north of the Utah-Idaho state line and the southern boundary is about 8.6 miles south of the same state line. The area is about 8.6 miles long, in the north-south direction, and 7.8 miles wide, in the east-west direction.

Features of importance are easily accessible. Major canyons have roads or trails that can be reached from U. S. Highway 91.

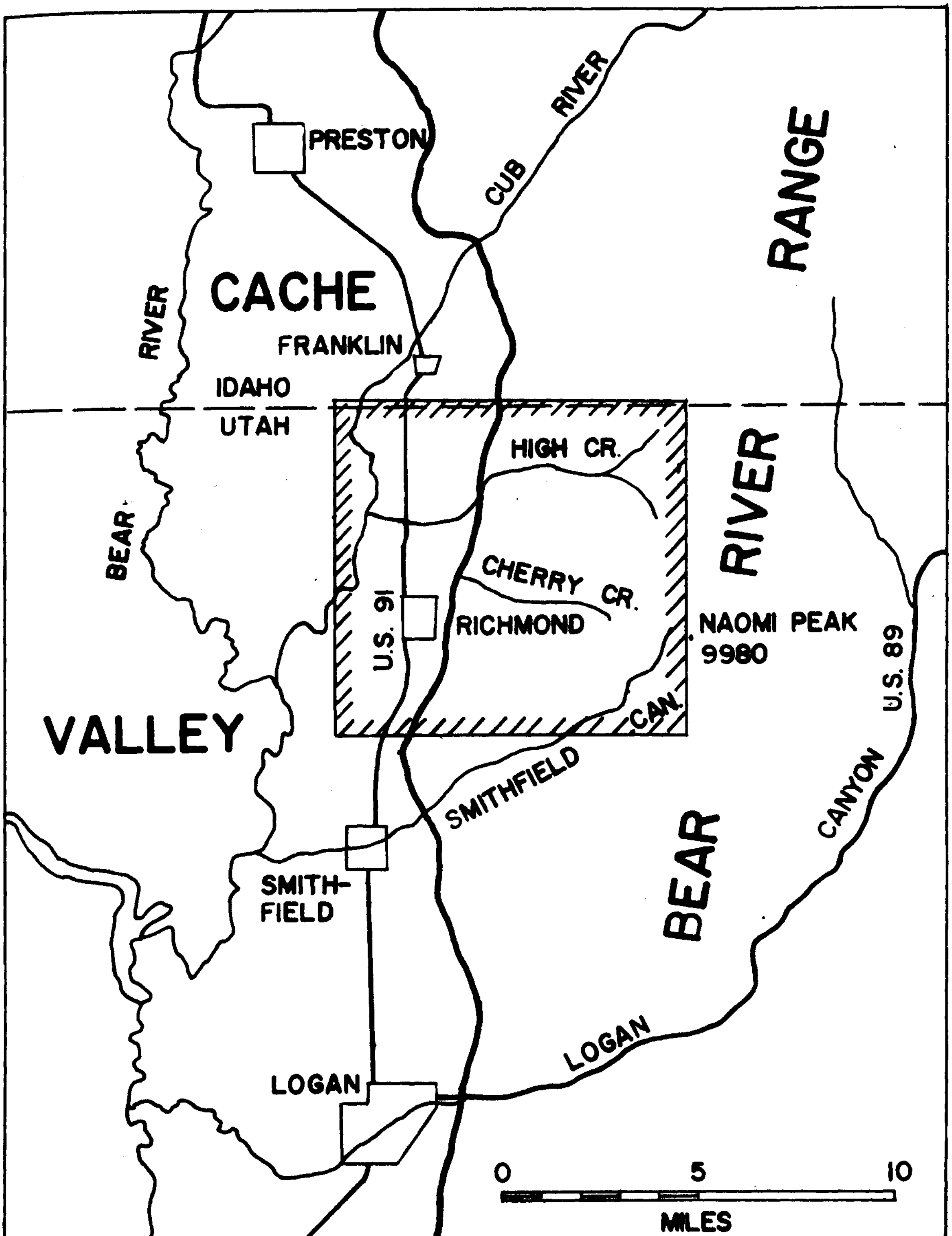

Figure 1. Index map of part of Utah and Idaho showing location of the eastern part of Richmond and western part of Naomi Peak quadrangles, Utah-Idaho.

Field Work

The field work was conducted during the summer and fall of 1973. The geologic features were mapped on aerial photographs and this information was later transferred to a topographic base at a scale of 1:12,000.

Previous Investigations

The first detailed investigation of the Richmond and Naomi Peak quadrangles, Utah-Idaho, was made by Bailey (1927a, 1927b). The next study was a thesis by Maxey (1941) that summarized Cambrian stratigraphy of the region. Peterson (1946) investigated the ground water of Cache Valley. A general geologic map, prepared by Williams (1948, Plate 1), including the Richmond and Naomi Peak quadrangles, Utah-Idaho. Maxey (1958) published a detailed report on the Lower and Middle Cambrian stratigraphy of northern Utah and southeastern Idaho. In 1962, Williams published a study of the deposits of Lake Bonneville in Cache Valley, Utah. Stanley (1971) completed a dissertation related to ground-water conditions in Cache Valley. A year later, he published his results (Stanley, 1972). Microearthquake activity has been investigated by Sbar and others (1972) and by Smith and Sbar (1974).

STRATIGRAPHIC UNITS

Precambrian Rocks

Mutual Formation

The Mutual Formation consists of quartzite and interbedded argillite. It has been identified in the Huntsville area, Utah, south of the mapped area, and in the Pocatello area, Idaho, north of the mapped area (Crittenden and others, 1971, p. 586, 591-592). The quartzite is grayish red and weathers grayish red. The Mutual ranges from 435 to 1,200 feet thick in the Huntsville area, Utah, according to Crittenden (1972a). It is 3,000 feet thick in the Pocatello area, Idaho (Crittenden and others, 1971, p. 586). The Mutual is late Precambrian in age (Crittenden, 1972a).

In the mapped area, the Mutual Formation consists of purple quartzite, which weathers purple, and brown quartzite, which weathers brown. Some feldspar grains are present in the brown quartzite. The exposed thickness of the Mutual is about 3,000 feet. Several beds of gray-red and purple argillite are present. Most of the argillite beds are thin and range from 6 inches to 2 feet thick in short distances. One unit, in the High Creek area, is about 50 feet thick and extends for about 1.5 miles.

The Mutual Formation is the lowermost quartzite unit that is exposed along the mountain front. It is present from the southern limit of the mapped area to the northern limit. In places, it is in fault contact with the Salt Lake

Formation; elsewhere, it is overlapped by the Salt Lake Formation. The thick unit of gray-red argillite is well exposed in the saddles of the ridges north and south of the High Creek campground in secs.4 and 9, T. 14 N., R. 2 E.

The base of the Mutual Formation is not exposed in the area. The upper contact is evidently conformable with the overlying Brigham Formation (Figure 2). Light-purple quartzite of the Mutual underlies the white and light-gray quartzite of the Brigham.

Paleozoic Rocks

Brigham Formation

The Brigham Formation was mapped in the area of the Richmond and Naomi Peak quadrangles, Utah-Idaho, by Williams (1948, Plate 1), but he did not separate the Precambrian Mutual Formation. The Brigham consists of quartzite that is gray, pink, brown, and greenish brown. The color of weathered surfaces is not distinctly different. At the top of the Brigham, brown shale separates thin beds of quartzite (Williams, 1948, p. 1132).

The Brigham Formation underlies the Langston Formation of Middle Cambrian age (Maxey, 1958, p. 671). A trilobite of Early Cambrian age has been found in the upper part of the Brigham in the Pocatello area, Idaho (Oriel, 1965, p. 341). Thus, the Brigham is considered to be of Early Cambrian age.

Figure 2. Mutual Formation, in smooth slope on left, underlies Brigham Formation, in cliffs on right, on northern side of the canyon of Cherry Creek; view north. Dip is east.

The lithology of the Brigham Formation, in the mapped area, is much the same as that described in the previous paragraph. The Brigham is about 2,500 feet thick in the mapped area.

The Brigham comprises much of the mountain front, in the mapped area, and is found at the top of the mountain front north of Cherry Creek. It extends from the southern boundary of the mapped area to the northern boundary. It is between the Mutual and Langston Formations. There are numerous good exposures in the area.

The contact between the Brigham Formation and the underlying Mutual Formation seems to be conformable; however, it may be unconformable. In the Huntsville area, Utah, the Browns Hole Formation separates the Mutual Formation and the Geertsen Canyon Quartzite. The latter is equivalent to the Brigham Formation (Crittenden and others, 1971, p. 591-592). In the Pocatello area, Idaho, the Mutual Formation seems to be conformable with the Camelback Mountain Quartzite, which is also equivalent to the Brigham Formation. The interbedded quartzite and shale, at the top of the Brigham, grades into the sandy limestone of the basal Naomi Peak Limestone Member of the Langston Formation. No indication of hiatus has been recognized in the mapped area (Williams, 1948, p. 1132).

Langston Formation

Williams (1948, Plate 1) recognized the Langston Formation in the mapped area. At the type locality of the Langston, in Blacksmith Fork Canyon of the Bear River Range, it consists of a basal dolomite unit, a limestone unit, and an upper dolomite unit. The dolomites are medium gray and weather brown. Northward, the basal dolomite is replaced by the Naomi Peak Limestone and Spence Shale Members. The Langston, in Blacksmith Fork Canyon, is 380 feet thick (Williams, 1948, p. 1132). It is Middle Cambrian in age (Maxey, 1958, p. 671).

Maxey (1958, p. 654-655) measured the Langston Formation at High Creek. There, it is 484 feet thick. The lower Naomi Peak Limestone Member is 32 feet thick and consists of bluish-gray limestone, which weathers bluish gray. It is interbedded with brown calcareous shale. At the base, there are a few feet of sandstone. The Spence Shale Member, above the Naomi Peak Limestone Member, is 192 feet thick. It is dark-olive and olive-black calcareous shale with lenses of limestone in the basal 7 feet (Maxey, 1958, p. 654-655). The upper carbonate member is 260 feet thick. The limestone of the upper member is bluish gray and weathers light bluish gray; the dolomite is gray and weathers gray and brown (Maxey, 1958, p. 654-655).

The eastern boundary of the mapped area is the contact between the Langston Formation and the overlying Ute Formation of Cambrian Age. This contact extends from the southern boundary of the mapped area to the northern boundary. It is present near the forks of both High Creek and Cherry Creek. The Naomi Peak Limestone Member of the Langston is eliminated by a bedding-plane thrust fault between Smithfield Canyon and Cherry Creek. It is also eliminated by a bedding-plane thrust fault at the top of the ridge up the North Fork of High Creek in sec. 34 (unsurveyed), T. 15 N., R 2 E. Irregular dolomitization of the upper carbonate member is evident in sec. 4 (unsurveyed), T. 13 N., R. 2 E.

The contact between the Brigham Formation and the Langston seems to be conformable (Figure 3 and 4). These two formations are thought to be separated by a bedding-plane fault wherever the Naomi Peak Limestone Member is missing. The contact of the Langston with the overlying Ute Formation also seems to be conformable. Green shale of the Ute directly overlies the upper carbonate member of the Langston. The conformable relationship was previously recognized by Williams (1948, p. 1133).

Cambrian-Devonian units

Stratigraphic units, which range in age from Cambrian to Devonian, overlie the Langston Formation at the eastern margin of the mapped area. They are not differentiated on the geologic map (Plate 1). A summary of these units is presented in Table 1.

Tertiary System

Salt Lake Formation

The Salt Lake Formation of the Worm Creek-Cub River area, Idaho, can be traced southward to the Richmond-Smithfield area, Utah. The lower member,

Figure 3. Brigham Formation, Langston Formation, and overlying Cambrian formations on northern side of the canyon of Cherry Creek; view north-northeast. Brigham-Langston contact is at the bottom of the band of bushes near center of view; top of Langston forms middle peak. Dip is east.

Figure 4. Brigham Formation and overlying Langston Formation between North Fork and South Fork of High Creek; view southeast. Brigham-Langston contact is at top of barren slope and at base of prominent band of trees.

Table 1. Stratigraphic units of Cambrian-Devonian age of the eastern part of the mapped area.

Unit	Lithology	Thickness (feet)
Devonian		
Beirdneau Fm.	Sandstone and dolomite	1,087[a]
Hyrum Fm.	Dolomite	932[a]
Water Canyon Fm.	Dolomite and sandstone	495[b]
Ordovician-Silurian		
Laketown Fm.	Dolomite	1,422[c]
Ordovician		
Fish Haven Fm.	Dolomite	140[d]
Swan Peak Fm.	Quartzite and shale	350[e]
Garden City Fm.	Limestone	1,405[f]
Cambrian		
St. Charles Fm.		1,015[g]
Upper member	Dolomite	940[g]
Worm Creek M.	Quartzite	75[g]
Nounan Fm.	Dolomite	1,125[h]
Bloomington Fm.		1,495[h]
Calls Fort M.	Shale	180[h]
Middle member	Limestone	720[h]
Hodges M.	Shale	595[h]
Blacksmith Fm.	Dolomite	485[h]
Ute Fm.	Limestone and shale	745[h]

[a]Blacksmith Fork Canyon (Williams, 1971).
[b]Water Canyon (Taylor, 1963).
[c]Tony Grove Lake (Budge, 1966).
[d]Green Canyon (Williams, 1948).
[e]Green Canyon (VanDorston, 1969).
[f]Green Canyon (Ross, 1951).
[g]High Creek (Maxey, 1941).
[h]High Creek (Maxey, 1958).

in the Worm Creek-Cub River area, consists of gray tuff, gray sandstone, and gray limestone, which weather gray. It is 7,674 feet thick in the Worm Creek area (Adamson, Hardy, and Williams, 1955, p. 15-16). The upper member, in the Worm Creek-Cub River area, is conglomerate that consists of pebbles and cobbles of dark-gray limestone, tuff, and quartzite. The matrix is tuffaceous in places. The upper member is at least 1,026 feet thick in the Cub River area (Adamson, Hardy, and Williams, 1955, p. 15).

Paleontologic evidence from Cache Valley, Utah, indicates that the lower member of the Salt Lake Formation is of Pliocene age. Ostracods and mollusks, described by Yen (1947, p. 268-277), are of Pliocene age. Plant fossils also indicate a Pliocene age (Brown, 1949). The potassium-argon age of a tuff sample, which was collected at a point several hundred feet stratigraphically above the mollusk and ostracod beds cited above, is Miocene (Williams, 1964, p. 272). Potassium-argon ages, obtained from samples collected from the lower part of the Salt Lake Formation in the southern part of Cache Valley, Utah, suggest an early Tertiary age (Williams, 1964, p. 271-272). Most of the Salt Lake Formation in Cache Valley, however, is evidently of late Tertiary age.

The Norwood Tuff of Morgan Valley, named by Eardley (1944, p. 845-846), is lithologically similar to the Salt Lake Formation of Cache Valley. A vertebrate fossil from the Norwood Tuff indicates a late Eocene age (Gazin, 1959, p. 137). An Oligocene age, based on an evaluation of vertebrate evidence, was previously reported (Eardley, 1944, p. 845). Eardley (1955, p. 40-43) suggested that the Norwood Tuff is older than the Salt Lake Formation of Cache Valley. The potassium-argon dates, obtained from samples collected from the southern part of Cache Valley, seem to indicate that at least part of the Salt Lake Formation of Cache Valley is as old as the Norwood Tuff (Williams, 1964, p. 271-272).

In the mapped area, the lower member of the Salt Lake Formation is poorly exposed. It consists of light-gray tuff, which weathers light gray, and white tuff, which weathers white. The exposed thickness is only about 100 feet. The basal contact does not crop out. The upper member consists of conglomerate that has pebbles and cobbles of limestone, dolomite, and quartzite. The upper member is about 1,100 feet thick.

The lower member crops out, above the shore line of Lake Bonneville, in the area southeast of Richmond, Utah. An excellent outcrop is located east of Richmond, in sec. 35, T. 14 N., R. 1 E., where the Utah Power and Light Company excavated part of the hillside for a power line. The upper member underlies most of the foothill area between the Precambrian and Paleozoic rocks of the mountain front and the shore line of Lake Bonneville. Conglomerate of the upper member overlaps the landslide in secs. 5 (unsurveyed) and 7, T. 13 N., R. 2 E., at an elevation of about 7,000 feet.

The lower contact of the Salt Lake Formation is not exposed in the mapped area. In Worm Creek Valley, north of the mapped area, the lower member unconformably overlies Paleozoic rocks (Adamson, Hardy, and Williams, 1955, p. 17). Outcrops, in the mapped area, are too poor to permit a determination of the nature of the contact of the lower and upper members. In the Worm Creek-Cub River area, Idaho, this contact is thought to be conformable (Adamson, Hardy, and Williams, 1955, p. 7). The upper part of the upper member is in fault contact with quartzite of the Mutual Formation along the mountain front from the High Creek southward to Cherry Creek. South of Cherry Creek, this member unconformably overlaps quartzite along the mountain front as well as the carbonate rocks of a major landslide.

Quaternary System

Boulder deposits

Deposits of boulders, in the mapped area, seem to have had different origins. Some deposits are derived from outcrops of dolomite, limestone, or quartzite. The boulders of some deposits were probably transported from a considerable distance. Boulder deposits, located in the area between Richmond, Utah, on the north, and Crow Mountain, on the south, may have been derived from blocks of a major landslide from the flank of the Bear River Range.

Lake Bonneville Group

The Lake Bonneville Group was mapped in the Richmond quadrangle, Utah-Idaho, by Williams (1962, Plate 6). The Provo Formation of the Lake Bonneville Group consists of a gravel and sand member and a silt and clay member (Williams, 1962, p. 140). It is generally 50 to 75 feet thick. The older Alpine and Bonneville Formations were not differentiated. The Alpine

Formation is gravel, silt, and clay. The overlying Bonneville Formation is mostly gravel (Williams, 1962, p. 137). The undifferentiated Alpine and Bonneville Formations are generally 50 to 100 feet thick (Williams, 1962, p. 131). The Lake Bonneville Group is late Pleistocene in age (Williams, 1962, p. 135).

The upper shore line of Lake Bonneville is mapped at an elevation of 5,140 feet in the southern part of the Richmond quadrangle and at an elevation of about 5,100 feet in the northern part. This decrease in elevation, toward the north, is probably due to isostatic adjustment after the disappearance of Lake Bonneville (Gilbert, 1890, Plate 46).

The Lake Bonneville Group unconformably overlaps both the lower and upper members of the Salt Lake Formation. It also overlaps the quartzite and carbonate rock of Crow Mountain.

Colluvial deposits

Colluvial deposits represent material that has moved downslope by gravity. They are present in the mountains and canyons of the Bear River Range. Colluvial deposits are also present in the foothills about 0.5 mile north of Crow Mountain.

Alluvial deposits

Alluvial deposits are present along streams and as alluvial fans. Notable stream deposits exist below the canyons of High Creek and Cherry Creek. Alluvial fans are found within the canyons and also along the mountain front. The alluvial deposits are Holocene in age.

STRUCTURAL FEATURES

Regional Setting

The mapped area is located in the central part of northern Utah and southeastern Idaho. It is on the border of the Basin and Range province, on the west, and the Middle Rocky Mountain province, on the east (Fenneman, 1946). It occupies the eastern part of Cache Valley and the western flank of the Bear River Range.

The rocks of the Bear River Range are mostly of Paleozoic age and are folded into a broad syncline that trends north-northeast. The Bannock thrust zone extends along the eastern side of the Bear River Range. It is characterized by imbricate thrust faults. These were originally interpreted as parts of a single folded thrust fault that was named the Bannock overthrust by Richards and Mansfield (1912). Later, the area was mapped by Armstrong and Cressman (1963). They reinterpreted the faults as an imbricate thrust zone with faults that are slightly folded in places. The two major thrust faults of the Bannock thrust zone, on the eastern side of the Bear River Range, are the Paris and Woodruff. The Paris is on the north and the Woodruff is on the south.

The Paris thrust fault, near Nounan, Idaho, dips west and places the Brigham Formation over the Triassic Thaynes Formation. There, the stratigraphic displacement is 20,000 feet (Armstrong and Cressman, 1963, p. 7). Southward from Nounan, Idaho, the stratigraphic displacement diminishes and the Brigham is thrust over the Ordovician Garden City Formation (Armstrong and Cressman, 1963, p. 18). Armstrong and Cressman thought that the Paris fault terminates southward, as a result of diminished displacement, and does not connect with the Woodruff thrust fault.

The Woodruff thrust fault dips west. It is exposed at a locality, in Birch Creek, that is 35 miles south of the outcrop of the Paris thrust fault (Richardson, 1941, p. 39). There, it places quartzite of the Brigham (?) Formation, on the west, over the Jurassic Nugget Formation, on the east. Several miles farther south, in Woodruff Creek, Brigham Quartzite is above the Permian Park City Formation (Stokes and Madsen, 1961). The Paris and Woodruff thrust faults may connect to form a major north-trending fault zone.

Several major thrust faults are present in the Wasatch Mountains near Ogden, Utah, 30 miles west-southwest of the Woodruff thrust fault (Eardley, 1944, p. 847-849). In and near Ogden Canyon, three thrust faults dip east. The two lower ones, the Taylor and Ogden thrust faults, cut Precambrian and Cambrian rocks. The higher Willard thrust fault places Precambrian rocks directly over formations that range in age from Cambrian to Mississippian. The mass above the Willard thrust fault consists of Precambrian sedimentary rocks in addition to a thick Cambrian section (Crittenden, 1961, p. 129). It is thrust over a thin Cambrian section that overlies highly metamorphosed Precambrian rocks that are older than those of the upper plate. Stratigraphic relationships suggest that the Willard thrust fault connects with the Paris-Woodruff thrust fault beneath the Bear River Range (Crittenden, 1972b, p. 2877).

Evidence of direction of movement on the Willard thrust fault was inconclusive according to Eardley (1944, p. 867-872). A syncline, near Ogden, Utah, that is overturned to the east and pronounced stratigraphic differences across the thrust fault in units that range in age from Precambrian to Pennsylvanian confirm eastward movement of the upper plate (Crittenden, 1972b, p. 2877). Deformed quartz lamellae also show eastward movement (Hammond and Parry, 1972, p. 1105).

Cache Valley, Utah- Idaho, is a major graben (Williams, 1948, Plate 1). Thus, normal faults, down on the west, extend along the western side of the Bear River Range. Normal faults, down on the east, extend along the eastern side of the mountains west of Cache Valley. These include, from south to north, the Wellsville Mountains of the Wasatch Range, the Malad Range, and the southern part of the Bannock Range. The Wasatch fault or fault zone extends along the western side of these mountains.

Folds

Logan Peak syncline

The rocks of the western front of the Bear River Range dip east on the western flank of the Logan Peak syncline. The axis of this syncline is 1.0-1.5 miles east of the boundary of the mapped area.

In the Smithfield quadrangle, Utah, south of the mapped area, the eastward dip of the Cambrian-Devonian rocks increases westward toward the mountain front (Galloway, 1970, p. 27). In the northern part of the mapped area, near the base of the Mutual Formation, the eastward dip decreases westward toward the mountain front.

Minor anticline

An anticline that involves the upper part of the Langston Formation and the lower part of the Ute Formation is present in the north fork of City Creek in sec. 33 (unsurveyed), T. 14 N., R. 2 E. The Brigham Formation, beneath the anticline, dips about 22° E. It is undeformed by the anticlinal folding. The anticline, therefore, is disharmonic.

The Langston and Ute Formations, on the eastern limb of the anticline, dip 53° E. The same formations, on the western limb, dip 45° W. The greater dip of the eastern limb indicates eastward movement.

Bedding-plane Thrust Faults

Upper thrust-fault zone

The Naomi Peak Limestone Member of the Langston Formation is abruptly eliminated at three places, in the mapped area, by bedding-plane thrust faulting. The Naomi Peak is present on the northern side of Smithfield Canyon. It is not present between the ridge north of Smithfield Canyon and the ridge south of Cherry Creek. It is present from the southern side of the canyon of Cherry Creek northward to the upper part of the North Fork of High Creek. It is not present from the latter place northward to the margin of the mapped area (Figure 5).

Figure 5. Bedding-plane thrust fault separates Brigham Formation (Ꞓb), on left, from overlying Langston Formation (Ꞓl), in central peak, on northern side of North Fork of High Creek; view north. Fault dips east.

The bedding-plane thrust faults that eliminate the Naomi Peak Limestone Member, in the two areas described above, probably connect in the Spence Shale Member of the Langston Formation. The Spence Shale Member displays diverse attitudes in the upper part of the North Fork of High Creek in sec. 2, T. 14 N., R. 2 E.

Slickensided surfaces are present on bedding-planes in quartzite near the top of the Brigham Formation. They occur near or adjacent to the unit of interbedded shale and quartzite that is present at the top of the Brigham. The extent to which the slickensided occurrences connect to form thrust faults remains uncertain. Probably the stratigraphic section is thinned by the faulting as it is in the Langston Formation.

Lower thrust faults

Numerous bedding-plane thrust faults of small displacement are present in the quartzite of the lower part of the Brigham Formation and in the quartzite and argillite of the Mutual Formation (Figure 6 and 7). Certainly many more exist than are represented on the geologic map (Plate 1).

Normal Faults

Western normal fault

A normal fault parallels the western margin of the foothills of the Bear River Range. It is within the area of outcrop of the Lake Bonneville Group: however, its existence is demonstrated by the widespread outcrops of Salt Lake

Figure 6. Mutual Formation (pꞒm), on left, underlies Brigham Formation (Ꞓb), on right, on northern side of the canyon of High Creek; view north. Red argillite of Mutual Formation crops out between dashed line and bedding-plane thrust fault. Formations and fault dip east.

Figure 7. Mutual Formation, on right, underlies Brigham Formation, in cliffs on left, on southern side of South Canyon; view south. Red argillite of upper part of Mutual Formation, illustrated in Figure 6, is eliminated by bedding-plane thrust fault. Formations and fault dip east.

Formation, on the east, and thick unconsolidated valley fill, on the west. No recent fault scarps have been found.

Two locations, within the mapped area, provide control for the location and orientation of the fault. In the northern part of the mapped area, it is located 0.2 mile east of the intersection of Utah Highway 61 and U. S. Highway 91. There, depth to consolidated rock is about 200 feet based on vertical electrical soundings; whereas, a short distance to the west, depth to consolidated rock is at least several times as great (Stanley, 1972, Figure 10). A gravity model shows about 1,500 feet of unconsolidated deposits on the west (Stanley, 1972, Figure 4). This pronounced difference in depth to consolidated rock is evidence of a normal fault with relative downward displacement on the valley side.

West of Richmond, Utah, near the railroad station, a small outcrop of limestone, identified as an undifferentiated Cambrian unit, is surrounded by the Lake Bonneville Group. The outcrop is about 0.4 mile west-northwest of the intersection of Utah Highway 170 and U. S. Highway 91. This limestone mass is part of a major landslide from the Bear River Range. The landslide is overlapped, in places, by the Salt Lake Formation of Tertiary age. In consideration of this fact and in view of the thick down-faulted section of Salt Lake Formation along the flank of the Bear River Range, it is concluded that the limestone mass must rest on the Salt Lake Formation. Thus, the western side of the limestone outcrop serves to establish an easternmost location for the normal fault. This fault is represented on Plate 1 as inferred and it strikes about N. 10° E.

Eastern normal fault

A normal fault extends along the base of the Bear River Range from the northern margin of the mapped area southward at least as far as Cherry Creek. North of High Creek, this fault displaces conglomerate of the Salt Lake Formation down, on the west, next to quartzite of the Mutual Formation. Colluvium that rests on the Salt Lake Formation has also been displaced down, on the west, from colluvium that rests on the Mutual Formation (Figure 8). Southward from High Creek, conglomerate of the Salt Lake Formation is clearly faulted down, on the west, next to the Mutual Formation (Figure 9 and 10). The location of this fault, which is nearly vertical, is evidenced on the southern side of High Creek by quartzite fault breccia and vertical fractures in quartzite. The fault is inferred from Cherry Creek southward to the southern margin of the mapped area. It is not recognized south of the mapped area where conglomerate of the Salt Lake Formation overlaps quartzite of the Mutual Formation.

Minor normal faults

Three minor normal faults that trend generally northeast are present in the upper part of the north fork of Cherry Creek. The northern fault has the least displacement and seems to be down on the north. The middle and southern faults are down on the southeast (Figure 11). No slickensides were found. The contact of the Brigham and Langston Formations is offset by the northern and middle faults. The contact of the Langston and Ute Formations is offset by the middle and southern faults; however, it is not offset by the northern fault.

Figure 8. Eastern normal fault, along mountain front, north of High Creek; view northeast. Conglomerate of Salt Lake Formation is down, on the west, next to quartzite of the Mutual Formation.

Figure 9. Eastern normal fault, along mountain front, south of High Creek; view east. Fault crosses ridge, from north to south, at change of slope beyond high-level horizontal surface at base of mountain front. Conglomerate of Salt Lake Formation is down, on the west, next to quartzite of the Mutual Formation.

Figure 10. Eastern normal fault, at mountain front, on southern side of High Creek; view south. Conglomerate of Salt Lake Formation is down, on the west, next to quartzite of the Mutual Formation.

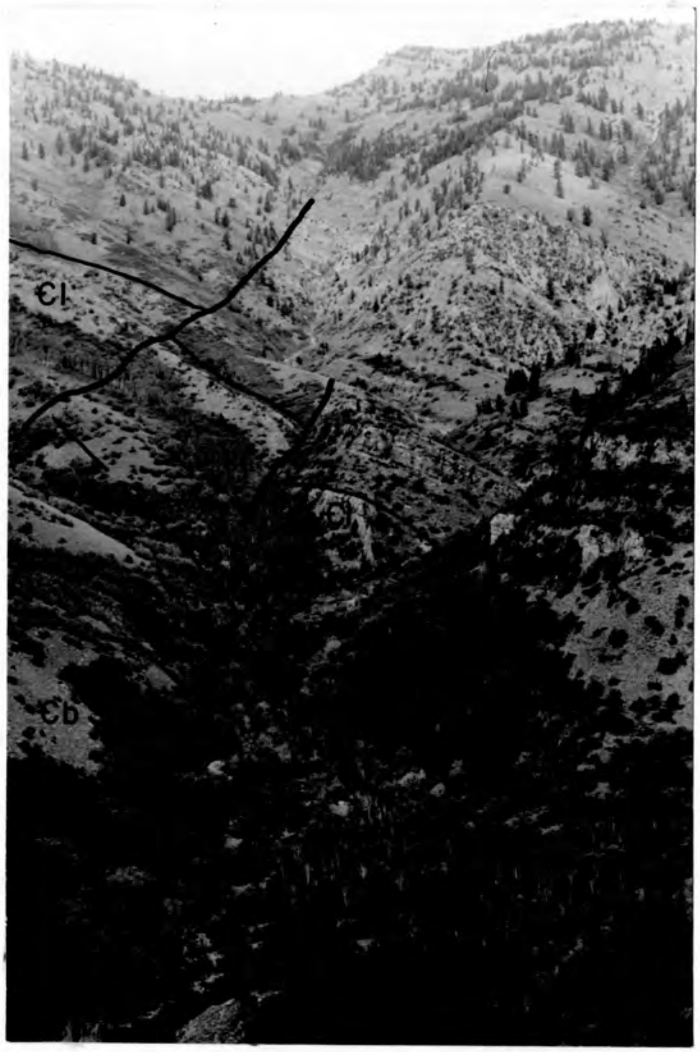

Figure 11. Minor normal faults in north fork of Cherry Creek; view northeast. Left fault cuts upper part of Brigham Formation (Єb), Langston Formation (Єl), and overlying Cambrian formations. Both faults are down on the southeast.

Landslides

Major landslide

A major landslide, from the western side of the Bear River Range, is present in the southern part of the mapped area. The eastern part of the landslide, located at the base of the Bear River Range, consists of St. Charles and Garden City Formation (Figure 12 and 13). The western part, mainly in the area southeast of Richmond, Utah, consists of blocks of the Mutual and Brigham Formations as well as various formations of Cambrian and Ordovician ages. Both parts are overlapped by the Salt Lake Formation of Tertiary age.

The eastern part of the landslide extends from the ridge north of Smithfield Canyon northward through the canyon of Nebo Creek to the ridge south of City Creek. The lower part of this mass is dolomite of the St. Charles Formation of Late Cambrian age. Limestone of the Garden City Formation of Early and Middle Ordovician age seems to overlie the St. Charles in normal stratigraphic succession on the ridge south of Nebo Creek as well as on the ridge north of Nebo Creek. The lower part of the eastern mass rests on the Precambrian Mutual Formation and the upper part is on quartzite of the Brigham Formation of Cambrian age. The landslide surface dips 22° W.

The St. Charles and Garden City Formations of the eastern part of the landslide generally dip eastward. Locally, limestone of the Garden City Formation is overturned to the east in the upper part of the landslide south of Nebo

Figure 12. Major landslide of St. Charles and Garden City Formations on southern side of Nebo Creek; view southwest. Landslide surface is located immediately below trees and dips west. Mutual and Brigham Formations dip east and underlie the landslide.

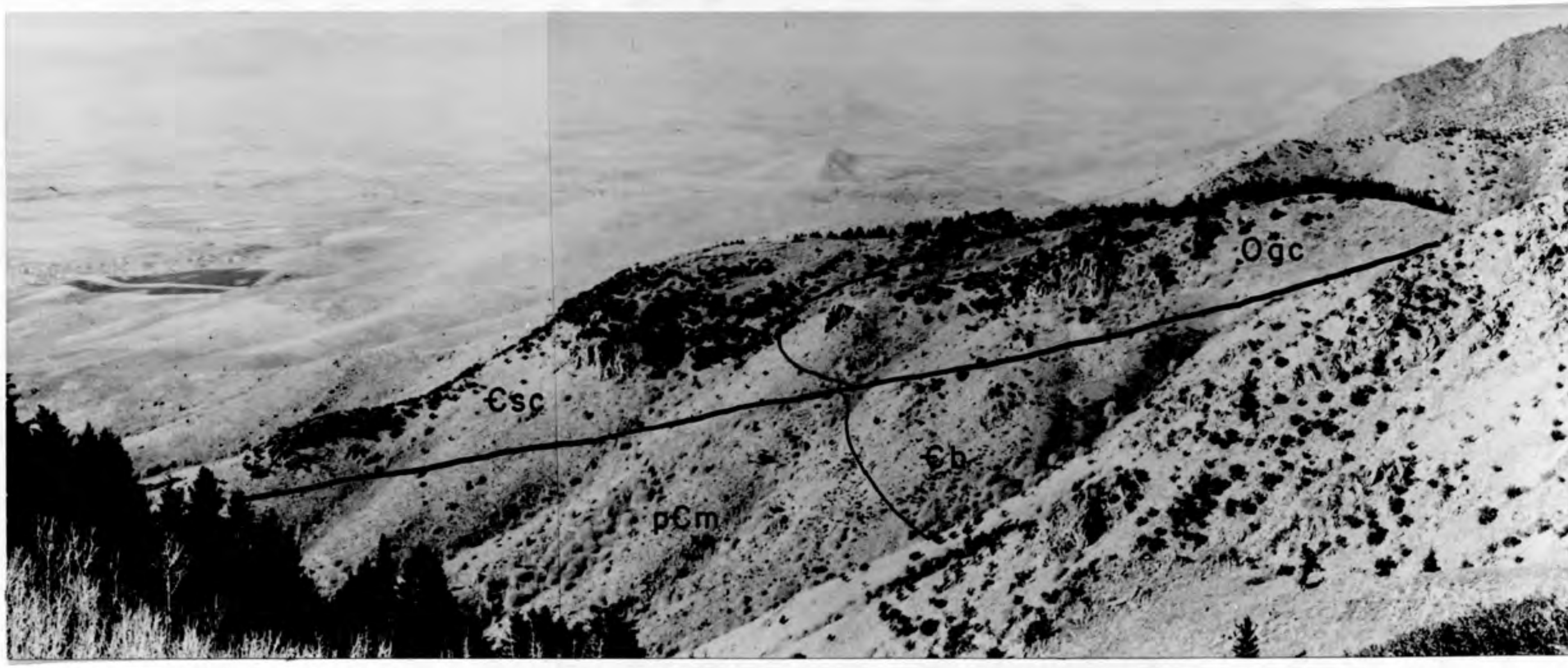

Figure 13. Major landslide of St. Charles (Єsc) and Garden City (Ogc) Formations on northern side of Nebo Creek; view northwest. Landslide is also illustrated in Figure 12. Landslide surface dips west. Mutual (pЄm) and Brigham (Єb) Formations dip east and underlie the landslide.

Creek. Conglomerate of the upper member of the Salt Lake Formation unconformably overlaps the lower part of the eastern part of the landslide.

The western part of the landslide consists of isolated masses of Precambrian, Cambrian, and Ordovician rocks. These masses are unconformably overlapped by the lower tuff member of the Salt Lake Formation and also by the Lake Bonneville Group.

Quartzite of the Brigham Formation forms three landslide masses southeast of Richmond, Utah. The Quartzite is generally severely brecciated. It dips eastward at angles ranging from 10 to 79 degrees. In the central part of sec. 36, T. 14 N., R. 1 E., a block of purple quartzite of the Mutual Formation is faulted against a mass of limestone and green shale that is identified only as undifferentiated Cambrian units. The limestone strikes generally east-west and dips north. The fault trends east-west and certainly formed during the landsliding. Several blocks of undifferentiated Cambrian units are present southward in the vicinity of Nebo Creek. The northern part of Crow Mountain, at the southern margin of the mapped area, consists of a large landslide block. Quartzite of the Brigham Formation, at the northern end, is separated by a fault from the St. Charles Formation. Limestone of the Garden City Formation, at the southern margin of the mapped area, seems to overlie the St. Charles in normal stratigraphic succession. The Brigham Formation dips eastward; whereas, the St. Charles and Garden City Formations dip generally southeastward. A small isolated block of limestone crops out west of Richmond, Utah, near the railroad station. It is identified as undifferentiated Cambrian. The landslide surface, beneath the blocks of the western part of the landslide, is not exposed.

The landslide surface, beneath the eastern part of the landslide at the base of the Bear River Range, is a planar surface. As noted previously, it dips 22^{o} W. This surface is known to extend from City Creek southward to the ridge north of Hyde Park Canyon, in the Smithfield quadrangle (Galloway, 1970, Plate 1). Its known north-south extent is about 6 miles. Westward, the landslide surface probably flattens on the lower tuff member of the Salt Lake Formation beneath the isolated blocks of the western part of the landslide. The contact between the St. Charles and Garden City Formations, in the eastern part of the landslide, has been displaced westward about 10,500 feet and downward about 4,300 feet.

The planar nature of the landslide surface under the eastern part of the landslide suggests that the surface may have formed as a west-dipping thrust fault with eastward movement. Such an origin is supported by the remarkable extent of the surface in the north-south direction. Thus, the landsliding might represent reversed movement due to slope instability following relative down faulting of Cache Valley along normal faults.

Minor landslides

Two small landslides are present, in the foothills of the Bear River Range, on the northern side of Cherry Creek. They both involve conglomerate of the upper member of the Salt Lake Formation. The tuff of the lower member of the Salt Lake Formation is probably responsible for the instability of the slope.

EARTHQUAKE ACTIVITY

General Statement

Many earthquakes, in Utah, have occurred along the boundary zone between the Basin and Range province and the Colorado Plateau-Middle Rocky Mountain provinces. Evidence of an active tectonic zone along this boundary has been reported (Cook and Smith, 1967, p. 697-698). The mapped area is on the border of the Basin and Range province, on the west, and the Middle Rocky Mountain province, on the east. Earthquake activity, along this boundary, is sporadic and may vary considerably with time (Sbar and others, 1972, p. 25).

Seismic Events

Earthquakes that occurred in the area of the Richmond-Naomi Peak quadrangles, Utah-Idaho, from 1850 through June, 1965, are listed in Table 2.

A field investigation of seismicity was carried out in Cache Valley, as part of a study of the intermountain seismic belt, during August 14-18, 1969 (Sbar and others, 1972, p. 19-20). Microearthquake activity, at that time, was moderate for the intermountain seismic belt. Richter magnitudes ranged from 1.0 to 2.5. The microearthquakes were shallow and occurred at depths of less than or equal to 5 km.

Table 2. Earthquakes of Richmond and Naomi Peak quadrangles, Utah-Idaho, 1850 through June, 1965 (Cook and Smith, 1967).

Yr.	Mo.	Day	Lat.	Long.	Mag. (Richter)	Depth (km)	Location
1923	Jun	09	---	---	2.0	---	Richmond
1923	Sep	07	---	---	3.7	---	Richmond
1926	Jul	28	---	---	3.1	---	Lewiston
1926	Jul	29	---	---	3.1	---	Lewiston
1962	Aug	30	41.92	111.78	5.7	40	1 mi. E. of Richmond
1964	May	21	41.92	111.86	2.2	20	2 mi. W. of Richmond
1964	Oct	18	41.88	111.81	4.4	10	3 mi. S. of Richmond
1964	Nov	08	41.92	111.75	---	10	2 mi. E. of Richmond

STRUCTURAL SYNTHESIS

General Statement

The two events that are responsible for the structural features of the mapped area are the Sevier orogeny (Armstrong, 1968) and Basin and Range normal faulting. The Sevier orogeny folded and thrust faulted the Precambrian and Paleozoic rocks of the area. It began during the Jurassic Period and continued into the early part of the Tertiary Period. Basin and Range normal faulting started as early as late Eocene time. It continues at the present time.

Sevier Events

Major folding

The eastward dip of Precambrian and Paleozoic rocks, in the mapped area, is an expression of the Sevier orogeny. The folding probably started during the Jurassic Period and may have continued into the early part of the Tertiary Period (Armstrong and Cressman, 1963, p. 14).

Dating of the folding depends on evidence from other areas. The Ephraim Formation of southeastern Idaho is a conglomerate that was derived, in large part, from formations of Paleozoic age. It includes clasts of quartzite from the Ordovician Swan Peak Formation. It does not include quartzite clasts from the Worm Creek Member of the Cambrian St. Charles Formation or from the Cambrian Brigham Formation. The source area of the Ephraim Formation was near the eastern margin of the present Bear River Range. This is the eastern margin of the area most affected by the Sevier orogeny (Armstrong and Cressman, 1963, p. 9-11). The lower part of the Ephraim Formation is of late Jurassic age and the upper part is of early Cretaceous age. Thus, it is concluded that folding, in the Bear River Range, started as early as late Jurassic time.

The Wasatch Formation of Paleocene and Eocene age overlaps Paleozoic rocks in the Huntsville area, Utah (Crittenden, 1972a). These Paleozoic rocks were folded by the Sevier orogeny. Thus, the Sevier orogeny terminated before the deposition of the Wasatch Formation or in the early part of the Tertiary Period.

Bedding-plane thrust faulting

Bedding-plane thrust faulting probably occurred at the same time as the folding of the Sevier orogeny. It had the effect of reducing, to a slight extent, the thickness of the Precambrian and Paleozoic stratigraphic section.

Basin and Range Events

Normal faulting

The normal faults of the mapped area cut the east-dipping formations on the western flank of the Logan Peak syncline. They are associated with Basin and Range normal faulting that began soon after the termination of the folding and thrust faulting of the Sevier orogeny (Armstrong and Cressman, 1963, p. 20).

In the Huntsville area, Utah, the Wasatch Formation of Paleocene and Eocene age was deposited on a relatively level surface (Crittenden, 1972a). It is now found at elevations ranging from mountain tops, in the Bear River Range, to relatively low levels at the northern end of the Wellsville Mountains. The Salt Lake Formation, generally considered to be of late Tertiary age in Cache Valley, was deposited in valleys formed by normal faulting (Adamson, Hardy, and Williams, 1955, p. 21). Thus, the normal faulting began no earlier than Eocene time.

Landsliding

The major landslide moved during late Tertiary time. Blocks of Precambrian, Cambrian, and Ordovician formations that form the western part of the landslide are unconformably overlapped by the upper hundred feet of the lower tuff member of the Salt Lake Formation. The upper part of the lower tuff member of the Salt Lake Formation, in the vicinity of Cache Valley, is of late Tertiary age. The mass of St. Charles and Garden City Formations of the eastern part of the landslide, near the base of the Bear River Range, is unconformably overlapped by the upper conglomerate member of the Salt Lake Formation.

The slide surface probably formed as a west-dipping thrust fault during the Sevier orogeny. Later, Basin and Range normal faulting removed support on the valley side. As a result, reversed movement occurred, downward to the west, on the west-dipping thrust fault.

Earthquake activity

Earthquake activity, related to normal faulting, began with Basin and Range faulting. It continues at the present time.

The earthquake of August 30, 1962, Richter magnitude 5.7, had an epicenter that was located about 1.7 miles east-southeast of the intersection of Utah Highway 170 and U. S. Highway 91 in Richmond, Utah. This location lies between the western and eastern normal faults. It is 1.0 mile west of the eastern normal fault. The earthquake probably occurred on this fault.

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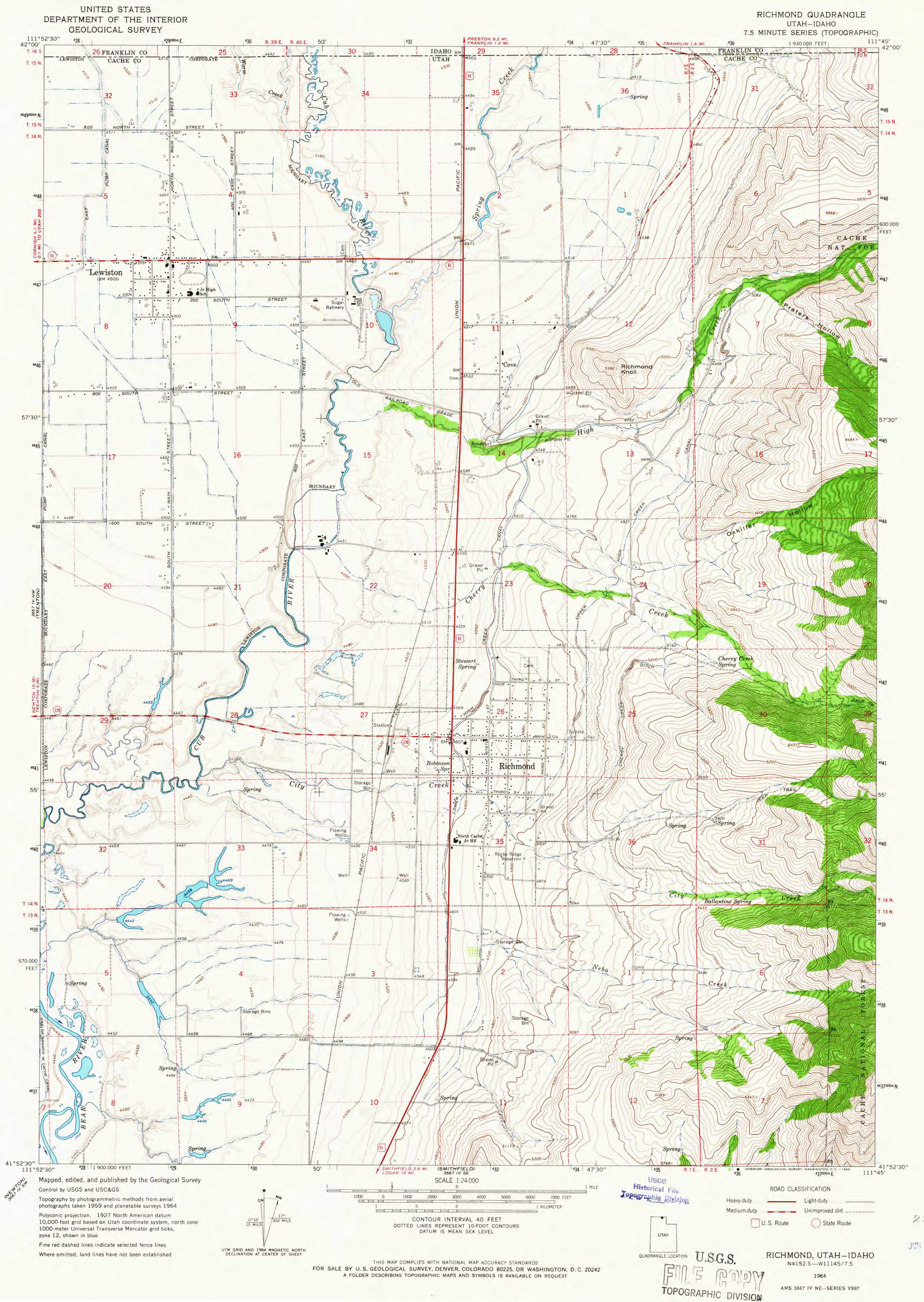
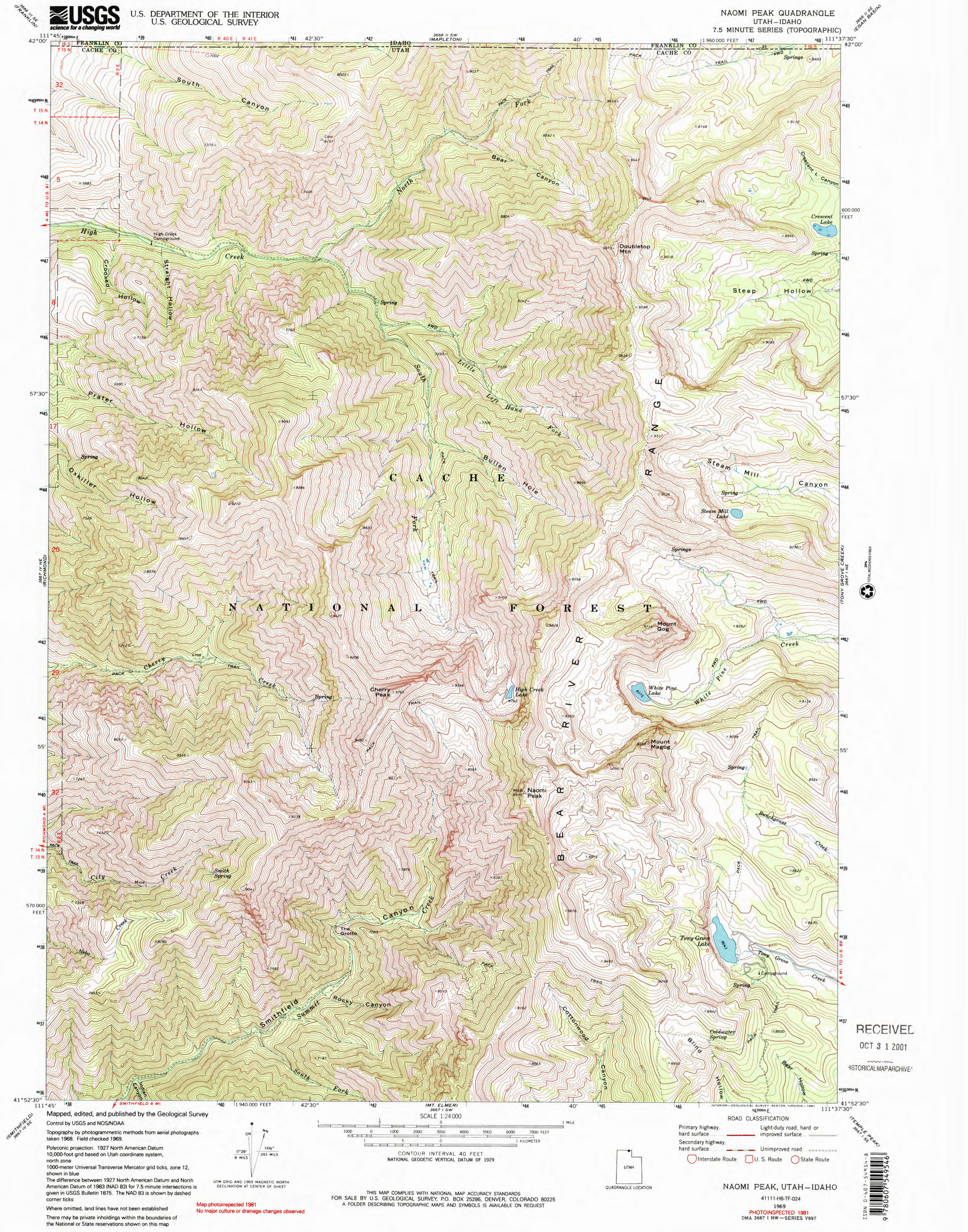
Plate 1, map of Eastern Part of Richmond and Western Part of Naomi Park Quadrangles, is very fragile, these maps were taken from:

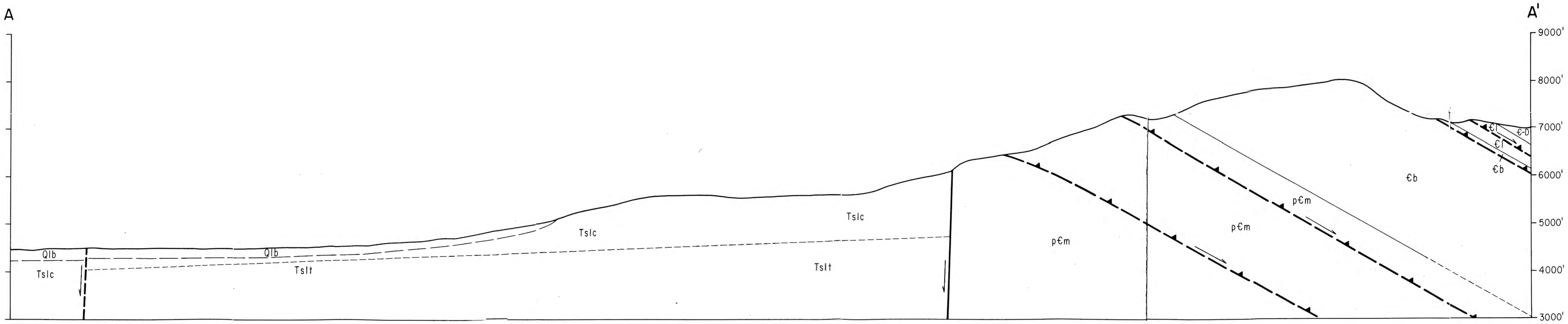
http://store.usgs.gov/b2c_usgs/usgs/maplocator/%28xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT%29/.do (maps are from 1968, accessed 8-14-2013)

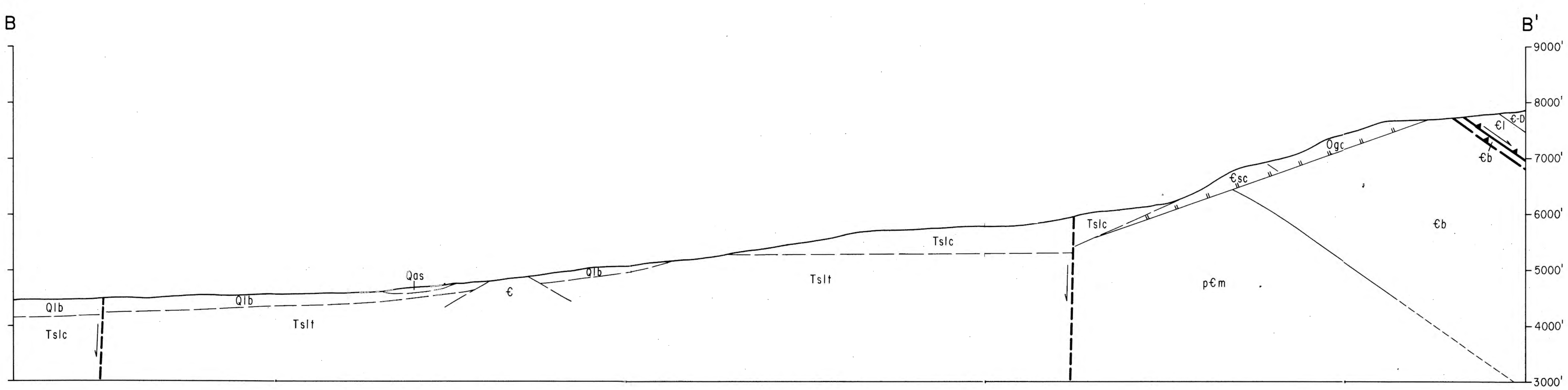
They cover the area referenced in this thesis.

Plate 1 information:
Map Scale: 1:12,000
North Latitude: 42° 0' 0" N (42.0000)
South Latitude: 41° 52' 30" N (41.8750)
East Longitude: 111° 42' 0" W (-111.7000)
West Longitude: 111° 51' 0" W (-111.8500)









EXPLANATION

QUATERNARY

- Qas — Alluvial deposits-stream
- Qaf — Alluvial deposits-fan
- Qc — Colluvial deposits
- Qlb — Lake Bonneville Group
- Qb — Boulder deposits { d-dolomite boulders, l-limestone boulders, q-quartzite boulders }

TERTIARY

- Tslc — Salt Lake Formation-conglomerate member
- Tslt — Salt Lake Formation-tuff member

ORDOVICIAN

- Ogc — Garden City Formation

CAMBRIAN

- €sc — St. Charles Formation
- €-D — Cambrian-Devonian units
- €l — Langston Formation
- € — Cambrian units
- €b — Brigham Formation

PRECAMBRIAN

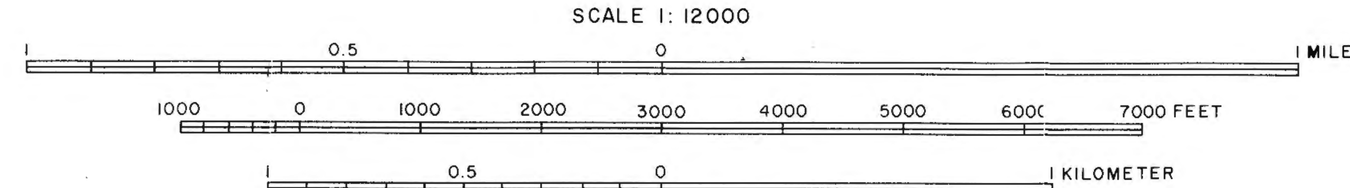
- p€m — Mutual Formation

Contact
Dashes-approximately located
Dots-concealed

Normal fault (U, D)
Long dashes-approximately located
Short dashes-inferred
Dots-concealed

Bedding-plane thrust fault
Long dashes-approximately located
Short dashes-inferred
Dots-concealed

Landslide surface
Dashes-approximately located



from thesis by
A. J. Mendenhall -
USU. 1975

STRUCTURE SECTIONS OF EASTERN PART OF RICHMOND AND WESTERN PART OF NAOMI PEAK QUADRANGLES, UTAH-IDAHO