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

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STRUCTURAL GEOLOGY OF THE NORTHERN PART OF

ELKHORN MOUNTAIN, BANNOCK RANGE, IDAHO

by

Stephen R. Crook

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of the requirements for the degree

of

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Stephen R. Crook

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ABSTRACT

Structural Geology of the Northern Part of

Elkhorn Mountain, Bannock Range, Idaho

by

Stephen R. Crook, Master of Science

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

Northern Elkhorn Mountain was unmapped previous to this investigation. The mapped area is located north of Malad City, Idaho, in the Bannock Range. It is within the Basin and Range Province. The mapped area measures 5.4 mi. in the north-south direction and 8.9 mi. in the east-west direction.

The oldest exposed stratigraphic unit, within the mapped area, consists of orthoquartzite and is of Early Cambrian age. Cambrian formations of the mapped area, in ascending order, are as follows: Camelback Mountain Quartzite, Gibson Jack Formation, Elkhead Formation, Bloomington Formation, Nounan Formation, and St. Charles Formation. Units of Ordovician age are the Garden City and Swan Peak Formations. The youngest unit of Paleozoic age, found within the mapped area, is the Fish Haven-Laketown Formation of Ordovician-Silurian age. Rock types comprising the Paleozoic units are orthoquartzite, limestone, dolostone, and shale. Tertiary units present, within the area, are the Salt Lake Formation and volcanic

rocks with the composition of andesite. These units occur only in isolated parts of the mapped area. Colluvial and alluvial deposits of Quaternary age are present in the valley west of Elkhorn Mountain and in the southeastern and northeastern parts of the mapped area.

Numerous high-angle normal faults dominate the structure of the area. They trend generally north and northwest. A major high-angle normal fault extends along the western side of Elkhorn Mountain and is responsible for the present topographic relief. Several small asymmetrical anticlines and a low-angle thrust fault are also present.

The structural features, within the area, resulted from two major periods of crustal deformation. The first event was the Laramide orogeny. Compressional forces, generated during this event, produced the anticlines and the thrust fault. Movement was eastward. The second event was Basin and Range faulting. It produced the high-angle normal faults. Basin and Range faulting has been active from Oligocene to Holocene. The marginal normal fault, west of Elkhorn Mountain, is probably active at the present time.

(89 pages)

INTRODUCTION

Purpose and Scope

The purpose of this investigation was to improve the understanding of structural features and geologic events of northern Elkhorn Mountain, southeastern Idaho. This was accomplished by preparing a detailed geologic map of the area (pl. 1), by relating the stratigraphy and structure of the area to that of the region, and by outlining the sequence of geologic events.

Location and Accessibility

The mapped area is located north of Malad City, Idaho, within the central Bannock Range (fig. 1). Wakley Peak, which is located approximately 1.5 mi. south of the northern border of the study area, is situated 14 mi. north of Malad City. The study area measures approximately 5.4 mi. in the north-south direction and approximately 8.9 mi. in the east-west direction. The mapped area lies between lat. 42°15'00" N. and lat. 42°30'00" N. and is between long. 112°07'30" W. and long. 112°22'30" W. The mapped area is represented on the Elkhorn Peak, Downey West, Wakley Peak, and Malad Summit Quadrangles of the Geological Survey of the U.S. Department of the Interior.

The area is accessible on the east by Interstate 15 and old U.S. Highway 191 (fig. 1). U.S. Highway 191 is represented on the

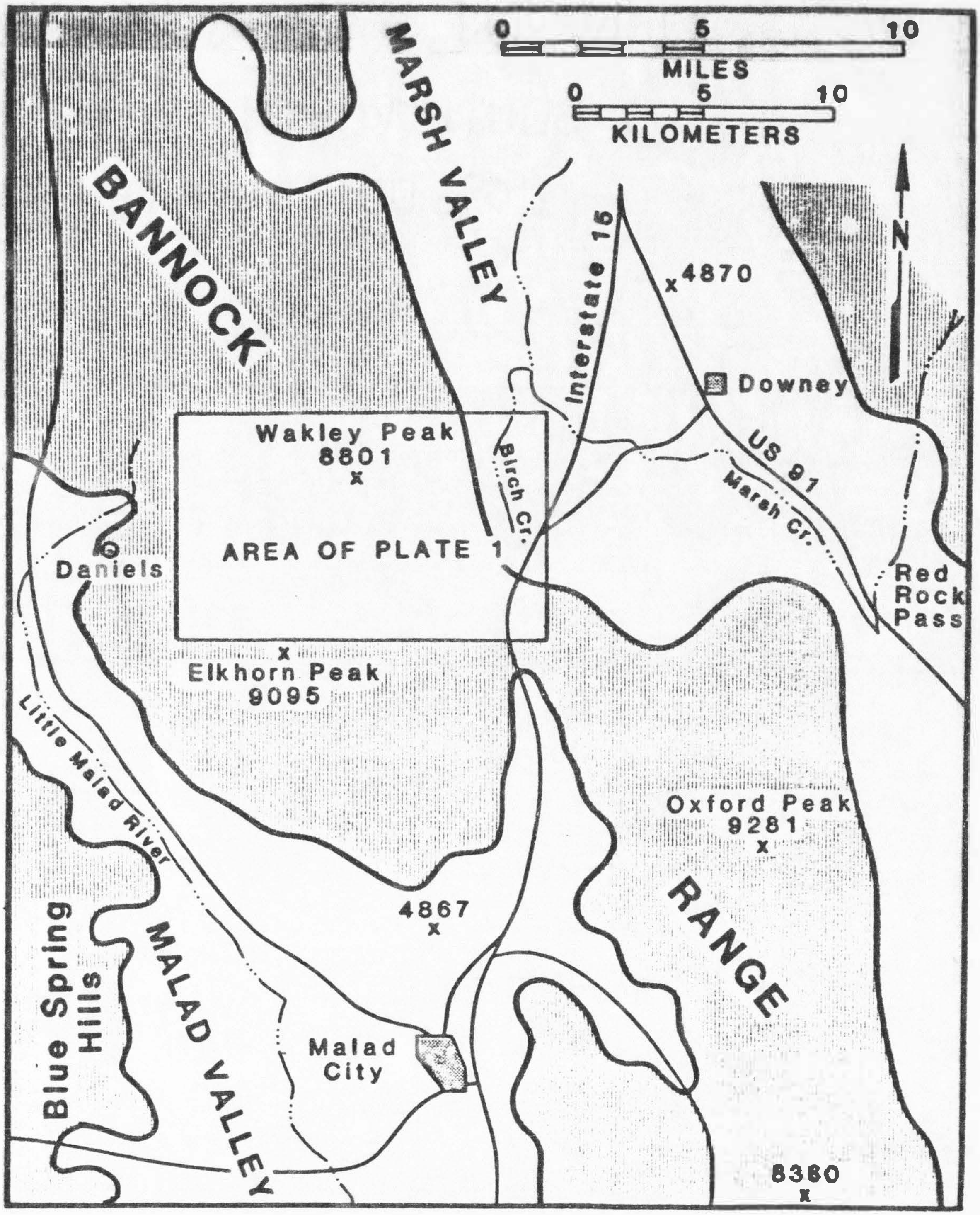

FIGURE 1. Index map of part of southeastern Idaho showing location of the northern part of Elkhorn Mountain.

existing topographic maps, which were published prior to the construction of Interstate 15, but for purposes of illustration it is not shown in figure 1. The area is accessible on the west by the Malad-Daniels paved road (fig. 1). Access into the study area is accomplished by means of unimproved roads and pack trails.

Physiographic Features

The mapped area is located within the Basin and Range Province. It forms part of the Bannock Range and is bounded by Marsh Valley to the northeast and Malad Valley to the southwest (fig. 1). Little Malad River lies to the west and southwest. Elkhorn Peak, 9,095 ft., is immediately south of the mapped area. Shorelines left by Pleistocene Lake Bonneville are found within Malad Valley but are absent in the study area.

The highest elevation, in the mapped area, is 9,025 ft. and is located just north of Elkhorn Peak. Wakley Peak, elevation 8,801 ft., is the second highest peak in the area (fig. 1). The lowest elevation, near the northeastern corner of the mapped area, is 4,750 ft. The relief, in the mapped area, is about 4,275 ft. Much of the field work required mapping at elevations in excess of 6,500 ft.

Field Work

Field investigations were conducted during the summer and fall of 1981. Geologic features were mapped in the field on vertical aerial photographs at a scale of approximately 1:15,840. This information was then transferred to 1:24,000 topographic sheets involving the Elkhorn Peak, Wakley Peak, Downey West, and Malad

Summit Quadrangles of the Geological Survey of the U.S. Department of the Interior. The final base map, at a scale of 1:12,000 (pl. 1), was prepared by enlarging parts of the previously mentioned quadrangles.

Previous Investigations

No previous geologic mapping has been done in the study area. Literature, regarding structure and stratigraphy, is available concerning southeastern Idaho and northern Utah.

Much of the early work, in the region, was accomplished by Walcott (1908) who investigated the Cambrian stratigraphy. Richardson (1913) studied the Paleozoic section of northern Utah. Mansfield (1927) gave detailed descriptions of both stratigraphic and structural features of southeastern Idaho. Deiss (1938) measured the Cambrian formations in the Blacksmith Fork area of northern Utah. Williams and Maxey (1941) investigated the Cambrian section of northern Utah. Ludlum (1942) defined previously unrecognized Precambrian formations in the northern part of the Bannock Range, east of Pocatello, Idaho. Ludlum (1943) again added to the understanding of the area by discussing the Paleozoic stratigraphy within the Bannock Range. Williams (1948) described the Paleozoic rocks and the geologic structures in the vicinity of Logan, Utah. Hanson (1949) mapped and described the general geology of the southern Malad Range, Utah. Ross (1951) made an extensive study of the Ordovician Garden City Formation of northeastern Utah and southeastern Idaho. Adamson and others (1955) described the Tertiary rocks of Cache Valley, Utah and Idaho. Prammani (1957) mapped the geology of the east-central part of the

Malad Range, Idaho. Ross and Forrester (1958) outlined the geology of Idaho.

More recent studies, involving the stratigraphy and structure of the region, were conducted by Murdock (1961) who mapped the geology of the Weston Canyon area, Idaho. This area is located southeast of the study area. Armstrong and Cressman (1963) interpreted the Bannock overthrust as a westward-dipping imbricate thrust zone. Trimble and Schaeffer (1965) studied the stratigraphy of the Precambrian and lowest Cambrian rocks of the Pocatello area, Idaho. Axtell (1967) mapped the northern Malad Range, Idaho. This area is located southeast of the study area. Murk (1968) and Carlson (1968) investigated respectively the geology and volcanic nature of areas in the vicinity of Hawkins Basin, Idaho. Both of these areas are northwest of the study area. Raymond (1971) mapped the Oxford Peak area, Idaho. This area is located east of the study area. Shearer (1975) and DeVries (1977) mapped the geology immediately east and south of the study area, respectively. Trimble and Carr (1976) mapped the geology of the Rockland and Arbon Quadrangles, Idaho. This area is situated northwest of the mapped area.

STRATIGRAPHIC UNITS

General Statement

Sedimentary and volcanic rocks are exposed within the study area. The Paleozoic sedimentary formations range in age from Early Cambrian to Silurian. Strata of late Paleozoic and Mesozoic ages were removed by erosion before deposition of Tertiary sedimentary rocks. The volcanic rocks are of Tertiary age and belong to the andesite family. The Lake Bonneville Group of Quaternary age is not present within the mapped area because the elevation of the area was higher than lake level. Deposits of this group are found directly to the south in Malad Valley (DeVries, 1977, p. 34). Units present, within the study area, are briefly outlined in table 1.

The sedimentary rocks of this complexly faulted area consist mainly of orthoquartzite, limestone, and dolostone. The oldest unit present is orthoquartzite of Early Cambrian age. Formations of Cambrian age, in ascending order, are as follows: Camelback Mountain Quartzite, Gibson Jack Formation, Elkhead Formation, Bloomington Formation, Nounan Formation, and St. Charles Formation. Ordovician units present are the Garden City and Swan Peak Formations. The youngest Paleozoic unit, found in the mapped area, is the Fish Haven-Laketown Formation of Ordovician-Silurian age.

The Salt Lake Formation of Tertiary age, which is present in the mapped area, is found at lower elevations. Volcanic rocks, also of Tertiary age, are found in the vicinity of Farmers Canyon, in the

TABLE 1. Formations of Paleozoic age, northern Elkhorn Mountain and vicinity.

Formation	Lithology	Thickness (feet)
Ordovician-Silurian System		
Fish Haven-Laketown		1,540[a]
	Light- to dark-gray dolostone with some chert	
Ordovician System		
Swan Peak		868[b]
	White orthoquartzite	
Garden City		1,805[c]
	Dark-gray dolostone	
	Gray limestone with interbedded chert	
	Gray limestone with intra-formational conglomerate	
Cambrian System		
St. Charles		1,073[c]
Upper member		998[c]
	Gray dolostone	
	Gray limestone	
Worm Creek Quartzite Member		75[c]
	Orthoquartzite	
Nounan		806[d]
	Gray limestone and dolostone	
	Light-gray and dark-gray dolostone	
Bloomington		429[c]
	Gray limestone	
	Olive-green shale	
Elkhead		2,100[e]
	Fossiliferous gray limestone with grayish-orange siltstone partings	
	Olive-green shale	
Gibson Jack		1,480[e]
	Shale and sandstone	1,000[e]
	Orthoquartzite	115[e]
	Siltstone and argillite	365[e]
Camelback Mountain Quartzite		3,500[e]
	Orthoquartzite	

[a] Samaria Mountain, Blue Spring Hills, Idaho (Beus, 1968)
[b] Elkhorn Mountain (James, 1973)
[c] Clarkston Mountain, Malad Range, Utah (Hanson, 1949)
[d] Two Mile Canyon, Malad Range, Idaho (Axtell, 1967)
[e] Rockland and Arbon Quadrangles, Idaho (Trimble and Carr, 1976)

northwestern part of the study area, and in the vicinity of Big Creek in the northeastern part of the study area. The Tertiary Salt Lake Formation rests unconformably on Paleozoic rocks.

Quaternary deposits, found within the mapped area, are colluvium and alluvium. They rest unconformably on older rocks.

Cambrian System

Camelback Mountain Quartzite

The term Camelback Mountain Quartzite is used in this report instead of the term "Brigham." Specifically, the term "Brigham" was applied in the region by Anderson (1928) and Ludlum (1942, 1943) to all of the rocks between the Blackrock Limestone of Anderson (1928) and the lowermost Cambrian limestone. Their Brigham included about 8,500 ft. of rocks of Precambrian age that underlie the Camelback Mountain Quartzite, the Camelback Mountain Quartzite, and about 1,500 ft. of shaly rock interbedded with sandstone and quartzite that overlies the Camelback Mountain (Trimble and Carr, 1976, p. 10). Crittenden and others (1971, p. 586) assigned the name Camelback Mountain Quartzite to the 3,500 ft. of light-brown, vitreous orthoquartzite that overlies the Mutual Formation in the vicinity of Pocatello, Idaho. It is composed of thick-bedded, medium-grained, vitreous orthoquartzite that weathers white, light brown, and brownish gray. The orthoquartzite is locally cross-bedded. The Camelback Mountain was assigned a Precambrian and Early Cambrian age by Crittenden and others (1971, p. 586). Only the upper part of the formation is exposed in the mapped area. It is probably of Early Cambrian age.

In the mapped area, the Camelback Mountain Quartzite is exposed east of Toro Mountain and north of Reed and North Canyons (pl. 1). It is characterized by thick-bedded, coarse-grained, white, purple, and brown orthoquartzite with cross-bedding. The Camelback Mountain Quartzite lacks the reddish hues found in older units and contains little argillite (Crittenden and others, 1971, p. 586). The Camelback Mountain is both cliff and slope forming (fig. 2). The Camelback Mountain, in the mapped area, is estimated to be approximately 2,500 ft. thick.

The lower contact of Camelback Mountain is conformable and transitional with the underlying Mutual Formation (Crittenden and others, 1971, p. 586). Shearer (1975), working in the area of Oxford Peak, Idaho, was able to map the contact with the underlying Mutual Formation at the top of a grayish-red argillite. The argillite, however, is not present in the mapped area. The upper contact is placed at the base of the first siltstone of the overlying Gibson Jack Formation (Crittenden and others, 1971, p. 587).

Gibson Jack Formation

Argillite with interbedded orthoquartzite and sandstone that overlies the Camelback Mountain Quartzite is named the Gibson Jack Formation (Crittenden and others, 1971, p. 586). The formation is about 1,000 ft. thick in the vicinity of Pocatello, Idaho (Crittenden and others, 1971, p. 586). The units comprising the Gibson Jack Formation were formerly included in the upper part of the Brigham Quartzite of Anderson (1928) and Ludlum (1942, 1943). Three members of the Gibson Jack Formation have been mapped in the Pocatello

FIGURE 2. Camelback Mountain Quartzite north of North Canyon; view northeast.

area, Idaho, by Trimble and Carr (1976). They are as follows: (1) lower argillite, sandstone, and quartzite, (2) middle quartzite, and (3) upper argillite, sandstone and quartzite. The lower member overlies the Camelback Mountain Quartzite and is 365 ft. thick in the Pocatello area, Idaho. The lower 30 ft. of this member is quartzite and sandstone that contains interbeds of siltstone. The siltstone is mostly light brown. The remainder of the lower member is argillite containing some interbeds of sandstone and quartzite. The siltstone and argillite are mainly light brown, olive, and gray green. The quartzite of the lower member is similar to that of the Camelback Mountain Quartzite. The middle member of the Gibson Jack is the lowest quartzite in the shaly sequence above the Camelback Mountain. It is 115 ft. thick in the Pocatello area, Idaho. The quartzite of this member is light gray, fine to medium grained, thin bedded, and weathers grayish orange, gray, and brown. The upper member constitutes the upper two-thirds of the Gibson Jack Formation and is probably at least 1,000 ft. thick. This member is commonly poorly exposed and consists of argillite with many interbeds of sandstone. At least two beds of thin-bedded, argillaceous limestone occur near the top of the upper member, but they are generally poorly exposed.

The first Olenellus known from southeastern Idaho was found in the Portneuf Range by Oriel (1965, p. 341). The discovery was made in the upper 300 ft. of the Gibson Jack Formation. The Gibson Jack is, therefore, assigned to the Early Cambrian, within the mapped area, on the basis of its possible correlation with the Olenellus-bearing beds in the Portneuf Range.

In the mapped area, the Gibson Jack Formation is exposed east of Toro Mountain and in the vicinity of Reed Canyon and Wakley Peak (pl. 1). It is characterized by white, gray, and brown orthoquartzite, which is fine to medium grained, thin to thick bedded, and commonly slope forming. In the vicinity of Reed Canyon, a thin bed of limestone, interbedded with orthoquartzite, was found near the top of the Gibson Jack Formation. Near the top of Wakley Peak, the Gibson Jack consists of thin-bedded sandstone that weathers yellowish brown. The Gibson Jack Formation, in the mapped area, is estimated to be approximately 500 ft. thick.

The lower contact of the Gibson Jack Formation is placed at the top of orthoquartzite of the underlying Camelback Mountain. The upper contact of the Gibson Jack Formation is placed at the base of a limestone unit, several hundred feet thick, that represents the lower part of the overlying Elkhead Formation.

Elkhead Formation

The Elkhead Formation was named by Trimble and Carr (1976, p. 12) for its occurrence at Midnight Creek, Arbon Quadrangle, Idaho. The unit is probably equivalent to all of the Langston, Ute, and Blacksmith Formations. These formations could not be discriminated at Midnight Creek (type locality). The name is used in the mapped area because poor exposures prevent subdivision of the unit into the Langston, Ute, and Blacksmith Formations.

Axtell (1967, p. 10-16), Raymond (1971, p. 16-18), Shearer (1975, p. 18-22), and DeVries (1977, p. 9-12) did, however, recognize at least two of the above three formations in areas near the mapped area.

Each writer, with the exception of DeVries, found clear evidence of the Langston Foramtion. This evidence is particularly apparent with regard to the presence of the middle member of the Langston Formation, the Spence Shale. This member consists of greenish-black to black shale. The Langston Formation is not exposed in the area of DeVries (1977). There, the oldest unit present is the Ute Formation. The Ute and Blacksmith Formations were differentiated by each of these authors with the exception of Shearer (1975). In his area, the Ute is eliminated by a thrust fault which places the Blacksmith Formation in direct contact with the Brigham and Langston Formations.

In other studies, the Ute and the Blacksmith Formations have been distinguished. Williams (1948, p. 1133) described the Blacksmith as a cliff-forming dolomite in the Logan Quadrangle, Utah. It is readily separated from the underlying Ute which consists of slope-forming limestone and shale. Coulter (1956, p. 12) depicted the Blacksmith of the Bear River Range, Idaho, as limestone with alternating light and dark zones on weathered surfaces. Slopes on the Blacksmith are characteristically steep. The lithology and the steep slopes distinguish the Blacksmith from the underlying Ute. In the study area, no such observable differences exist except for a limited exposure of banded limestone near Reed Canyon.

The Elkhead, in the area of Midnight Creek, is 2,100 ft. thick and is composed of limestone except for a shale unit, about 100 ft. thick, that occurs a few hundred feet above the base (Trimble and Carr, 1976, p. 12). The limestone is gray, thin bedded, platy, and ledge forming. In the upper two-thirds, it is mainly thick-bedded, gray, oolitic limestone. Grayish-orange siltstone partings are common, and locally the unit contains intraformational conglomerate (Trimble and Carr, 1976, p. 13). The Elkhead conformably overlies the Gibson Jack Formation and is of Middle Cambrian age (Trimble and Carr, 1976, p. 13).

In the mapped area, the Elkhead is found north of both Reed and North Canyons (pl. 1). The Elkhead consists predominantly of limestone, although a shale unit occurs near the top of the section. The limestone is gray and thin to thick bedded. In places, it contains light-brown siltstone partings. Oolites are common. Oncolites and intraformational conglomerate are found at some localities. The shale of the Elkhead is olive green, yellow, brown, and pink. It is generally more silty and sandy and less fissile than the shale of the Bloomington. The Elkhead is approximately 2,000 ft. thick, within the mapped area, near Reed Canyon.

The lower contact of the Elkhead is drawn at the first occurrence of limestone above the underlying Gibson Jack Formation. The upper contact is placed at the base of the first green shale unit in the interbedded limestone and shale sequence that constitutes the overlying Bloomington Formation (Trimble and Carr, 1976, p. 13). These contacts are located in the fault-bounded block between Reed and Cliff Canyons and also northwest of Station Creek in the northeastern part of the mapped area (pl. 1).

Bloomington Formation

The Bloomington Formation was defined by Walcott (1908, p. 7) for its occurrence in the Bear River Range, west of Bloomington, Idaho. Maxey (1958, p. 651-653) recognized three members at High Creek in the Bear River Range. These units are as follows: (1) lower Hodges shale, (2) middle thin- to thick-bedded limestone, and (3) upper Calls Fort Shale. The total thickness at High Creek is 1,495 ft. The limestone of the Bloomington is oolitic. It is gray to blue gray and is interbedded with yellow-green to olive shale, argillite, and siltstone. In the Arbon Quadrangle, Idaho, the limestone in the upper half of the formation contains intraformational conglomerate (Trimble and Carr, 1976, p. 13). Trimble and Carr (1976, p. 13) also noted that the shale, argillite, and siltstone units contain abundant nodules of fine-crystalline, pale-green limestone. Axtell (1967, p. 58) measured a thickness of 431 ft. at Two Mile Canyon, southeast of Malad City, Idaho. The reduced thickness in comparison to the total thickness at High Creek is probably due to some structural complication, possibly thrust faulting.

The Bloomington conformably overlies the Elkhead Formation (Trimble and Carr, 1976, p. 13) and, where not interrupted by thrust faulting, is conformably overlain by Nounan Formation (Maxey, 1958, p. 673). The age of the Bloomington is considered to be late Middle Cambrian (Maxey, 1958, p. 678).

The Bloomington is exposed in the northeastern part of the mapped area south of Big Creek and in the northwestern part of the area between Reed and Cliff Canyons (pl. 1). The Nounan Formation seems to conformably overlie the Bloomington (fig. 3). In the east-central part of the mapped area, the fissile, olive-green shale and limestone of the upper part of the Bloomington is thrust over the Worm Creek Quartzite Member of the St. Charles Formation.

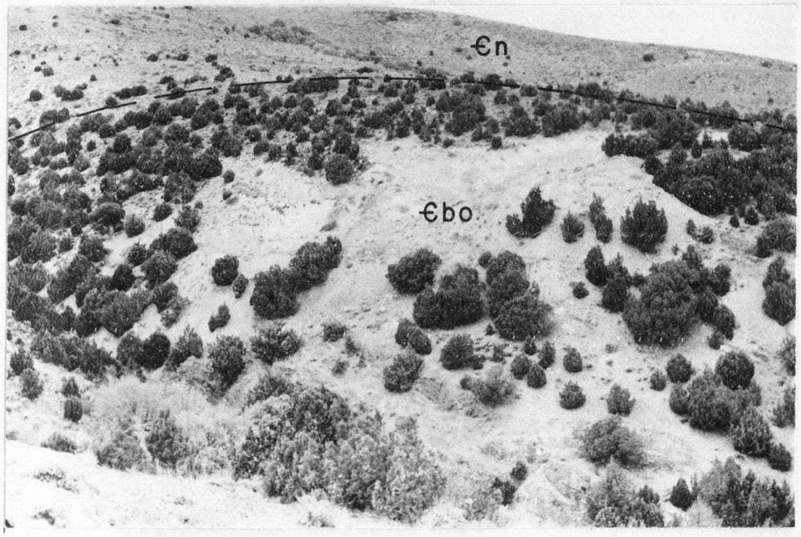

FIGURE 3. Bloomington Formation in northeastern part of mapped area near Prospect Mine; view northwest. Bloomington (Єbo) is composed of limestone interbedded with shale. Nounan Formation (Єn) seems to conformably overlie the Bloomington.

Nounan Formation

The Nounan Formation was named by Walcott (1908, p. 6-7) for its occurrence on Soda Peak, south of Soda Springs, Idaho. Mansfield (1927, p. 51) measured 1,050 ft. of light-gray dolomitic limestone and bluish-gray limestone in southeastern Idaho. Williams (1948, p. 1134) characterized the Nounan as light-gray dolomite in the Logan Quadrangle, Utah. The upper third, however, contains thin-bedded, crystalline, dark-gray limestone with uneven bedding and shale and siltstone partings. Maxey (1958, p. 651) recognized 1,125 ft. of Nounan at High Creek, in the Bear River Range, 7 mi. northeast of Richmond, Utah. Hanson (1949, p. 22-30) described 1,408 ft. of Nounan at Clarkston Mountain, Utah. Coulter (1956, p. 15-16) characterized the Nounan as an alternation of crystalline, medium-gray and very light-gray dolomite that gives a banded appearance to the unit. He concluded that the dolomite content decreases upward in the formation and that cliff-forming, crystalline, white limestone is predominant at the top.

The Nounan Formation conformably overlies the Calls Fort Member of the Bloomington Formation (Maxey, 1958, p. 673) and is conformably overlain by the Worm Creek Quartzite Member of the St. Charles Formation (Hanson, 1949, p. 26). The Nounan Formation is Late Cambrian in age (Maxey, 1958, p. 678).

In the mapped area, the Nounan is exposed north of Bill Morgan Canyon and both north and south of Rowley Canyon (pl. 1). Within the mapped area, the Nounan is approximately 360 ft. thick in the vicinity of Indian Canyon. The lower Nounan is thin-bedded to medium-bedded, crystalline, light-gray and dark-gray dolostone.

In places, the dolostone is brecciated. The upper Nounan consists of thin- to medium-bedded, light- to medium-gray limestone which contains particles of silt and sand. In places, limestone is interbedded with dolostone. The dolostone, in certain localities, forms ledges. In the vicinity of Indian Canyon, the entire section of the Nounan, exposed below the St. Charles Formation, is dolostone.

The upper contact of the Nounan with the overlying St. Charles Formation is placed at the base of the Worm Creek Quartzite Member of the St. Charles Formation. This contact is particularly evident in the southwestern part of the mapped area, where the Worm Creek is a distinctive grayish-orange orthoquartzite.

St. Charles Formation

The St. Charles Formation was named by Walcott (1908, p. 6) for its occurrence west of the town of St. Charles, Idaho. Richardson (1913, p. 408) characterized the basal Worm Creek Quartzite Member as gray quartzite. Deiss (1938, p. 1123) redefined part of the St. Charles as Ordovician, as opposed to Walcott's original Late Cambrian designation. This was done due to the discovery of Ordovician fossils by Deiss in the upper part of the St. Charles. Williams (1948, p. 1135) recognized three members of the St. Charles, in the Logan Quadrangle, Utah, as follows: (1) lower quartzite, (2) middle thin-bedded limestone, and (3) upper dark-gray dolomite that forms ledges. Hanson (1949, p. 30-32) measured and described 1,073 ft. of St. Charles in the vicinity of Clarkston Mountain in the southern Malad Range. He characterized members of the formation as follows: (1) lower brownish-gray quartzite, (2) middle silty limestone, and

(3) upper light-gray dolomite. Axtell (1967, p. 21) measured 704 ft. of the St. Charles in the northern part of the Malad Range, Idaho.

The Worm Creek Quartzite Member of the St. Charles Formation conformably overlies the Nounan Formation (Hanson, 1949, p. 26). Ross (1951, p. 6) considered the upper contact of the St. Charles with the overlying Garden City Formation to be conformable. The age of the St. Charles Formation is Late Cambrian (Williams and Maxey, 1941, p. 284).

In the mapped area, the St. Charles Formation is exposed west of Elkhorn Mountain between Bill Morgan and Reed Canyons. It is also exposed east of Elkhorn Mountain between North Canyon and Big Creek. In the vicinity of Indian Mill Creek, it is approximately 940 ft. thick. The St. Charles, within the mapped area, consists of three members as follows: (1) lower Worm Creek Quartzite Member, (2) middle limestone, and (3) upper dolostone. The Worm Creek is commonly slope-forming orthoquartzite, but it forms well-exposed outcrops of thick-bedded orthoquartzite at some localities (fig. 4). The orthoquartzite is yellow, brown, white, and gray. It is medium to coarse grained. In places, it is calcareous and cross-bedded and has a thickness of approximately 75 ft. The middle limestone member is thin to medium bedded, silty, chert bearing, and somewhat fossiliferous. The siltstone is brown and purplish gray and forms partings between the limestone layers. The upper member is ledge-forming, medium-crystalline, light- to medium-gray dolostone.

The lower contact is placed between the upper limestone and dolostone of the Nounan and the first occurrence of the Worm Creek Quartzite Member. The upper contact of the St. Charles is placed above the ledge-forming dolostone at the first occurrence of

FIGURE 4. Worm Creek Quartzite Member of St. Charles Formation on northern side of Bill Morgan Canyon; view north. Rock hammer lies on top of thick-bedded orthoquartzite of the Worm Creek.

thin-bedded, fine-crystalline limestone, characteristic of the overlying Garden City Formation.

Ordovician System

Garden City Formation

Richardson (1913, p. 408-409) defined the Garden City Formation for its occurrence in Garden City Canyon, west of Garden City, Utah. He described a section of thin- to thick-bedded, gray limestone, approximately 1,000 ft. thick, and noted the presence of intraformational conglomerate or breccia in places. Williams (1948, p. 1135-1136) described the Garden City of the Logan Quadrangle, Utah, as thin-bedded, dark-gray limestone with shale partings. The limestone weathers olive brown. Ross (1951) made a detailed report on the stratigraphy and trilobite faunas of the Garden City. Ross (1951, p. 7-9) described two units, within the Garden City, as follows: (1) lower limestone, and (2) upper limestone and dolomite. He measured 1,222 ft. of Garden City at the type section in Garden City Canyon (Ross, 1951, p. 11-13). Hanson (1949, p. 41) measured 1,805 ft. at Clarkston Mountain in the southern Malad Range, Utah.

The Garden City conformably overlies the St. Charles Formation (Ross, 1951, p. 6) and is conformable and intergrades with the overlying Swan Peak Formation (Williams, 1948, p. 1137). The age of the Garden City Formation is considered to be Early and Middle Ordovician (Chazyan); however, only the upper 30 to 50 ft. is Middle Ordovician (Ross, 1951, p. 31-32).

In the mapped area, the Garden City Formation is exposed south of Tom Perry Canyon on the western side of Elkhorn Mountain. It is also exposed south of North Canyon, east of Elkhorn Mountain. Elkhorn Peak consists of the Garden City Formation (fig. 5). The Garden City is approximately 2,000 ft. thick, within the mapped area, near Indian Canyon. The Garden City, within the mapped area, consists of two members, as follows: (1) lower limestone, and (2) upper limestone and dolostone. The lower part of the formation can generally be characterized as fine-crystalline, light-gray limestone with frequent brown siltstone partings and intraformational conglomerate. The upper part consists of limestone and dolostone, both of which contain black chert. Chert and dolostone are also found at lower stratigraphic levels but are not as abundant as in the upper part of the formation. Ross (1951, p. 8-9) questioned whether or not the dolomite, within the Garden City, is actually a stratigraphic unit. He presented evidence which suggested that the Garden City has been subjected to secondary dolomitization related to zones of faulting or to replacement as a result of weathering prior to the deposition of the overlying Swan Peak Formation.

The upper contact of the Garden City, with the overlying Swan Peak Formation, is placed above the limestone or dolostone of the Garden City and below the first occurrence of shale or siltstone of the Swan Peak. In many places, the basal part of the Swan Peak is covered by vegetation or orthoquartzite debris. This gives the impression that the Garden City is directly overlain by the orthoquartzite of the Swan Peak.

Swan Peak Formation

Richardson (1913, p. 409) named the Swan Peak Formation for its

FIGURE 5. General view of Elkhorn Peak; view southwest. Elkhorn Peak consists of Ordovician Garden City Formation.

occurrence on Swan Peak, in the Bear River Range, 1.5 mi. south of the Idaho boundary. He reported white to gray quartzite, about 500 ft. thick, which lies above the Garden City Formation. Williams (1948, p. 1136-1137) described three units within the Swan Peak Formation in Green Canyon, northeast of Logan, Utah, as follows: (1) lower black shale, (2) middle brown quartzite, and (3) upper light-gray quartzite. The total thickness is 339 ft. Hanson (1949, p. 12, pl. 4) described the Swan Peak of Clarkston Mountain, Utah, with the same general attributes as reported by Williams. He measured a thickness of 606 ft. Ross (1951, p. 8) measured 570 ft. of Swan Peak at Clarkston Mountain, Utah. Ludlum (1943, p. 980) characterized the Swan Peak of the Bannock Range, Idaho, as white, vitreous quartzite which weathers into large blocks. He stated that it is 785 ft. thick in the Bannock Range, Idaho. Coulter (1956, p. 25-26) noted an angular discordance between the Swan Peak and the overlying Fish Haven Formation in the Bear River Range, Idaho. He noted that northward thickening of the Swan Peak takes place in the upper member. The Swan Peak is Middle Ordovician in age (Ross, 1951, p. 33).

James (1973, p. 239-240) measured 868 ft. of Swan Peak Formation immediately south of the study area. There, the Swan Peak consists of two members as follows: (1) lower orthoquartzite and shale, and (2) upper vitreous orthoquartzite. The lower 118 ft. of the formation is covered by talus containing fine- to medium-grained orthoquartzite and yellowish-brown to medium-gray shale. The contact of the lower and upper members is covered. The exposed part of the upper member consists of 750 ft. of fine-grained, white to light-brown, vitreous orthoquartzite.

In the mapped area, the Swan Peak Formation is found primarily south of Reed and North Canyons (pl. 1). Isolated outcrops, however, occur in the northeastern and northwestern parts of the mapped area. Immediately south of the study area, the Swan Peak is 868 ft. thick (James, 1973, p. 239-240). The lower contact is placed at the top of the limestone or dolostone of the Garden City Formation. The Swan Peak, within the mapped area, consists of two members as follows: (1) lower black shale, and (2) upper vitreous orthoquartzite. The lower part of the Swan Peak is concealed under orthoquartzite talus or vegetation. Black shale and sandy siltstone are present above the Garden City at some localities. The upper part of the Swan Peak is well exposed and consists of white to light gray and brown, vitreous orthoquartzite, which forms bold cliffs (fig. 6). It is composed of rounded, fine- to medium-grained, quartz particles in siliceous cement. It has been extensively faulted and is severely brecciated in many places (fig. 7). The Swan Peak is unfossiliferous throughout the mapped area. Horizontal worm burrows, observed in the Swan Peak elsewhere, were not noted within the mapped area.

The lower contact of the Swan Peak is conformable with the underlying Garden City Formation (Williams, 1948, p. 1137). The upper contact is placed at the first occurrence of dark-gray dolomite which disconformably overlies the Swan Peak.

Ordovician-Silurian System

Fish Haven-Laketown Formation

Richardson (1913, p. 407-410) named the Fish Haven and Laketown

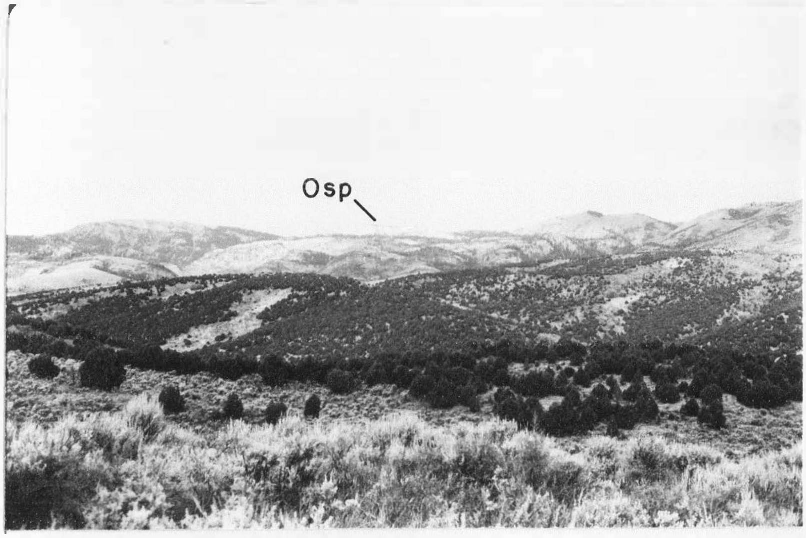

FIGURE 6. Bold orthoquartzite cliffs of Swan Peak Formation north of Mill Creek; view west. Location of Swan Peak Formation (Osp) is noted).

FIGURE 7. Fault surface in Swan Peak Formation in southeastern part of mapped area; view northwest. Fault is not mapped.

Formations for their occurrence in the eastern part of the Bear River Range, Idaho-Utah. Richardson described the Fish Haven as medium-bedded, crystalline, dark-gray dolomite, about 500 ft. thick. He described the overlying Laketown as light-gray dolomite with lenses of calcareous sandstone. It is approximately 1,000 ft. thick. Williams (1948, p. 1137-1138) recognized both Fish Haven and Laketown Formations in Green Canyon, northeast of Logan, Utah. He described the Fish Haven as thick-bedded, medium-crystalline, dark-neutral-gray dolomite about 140 ft. thick. He described the overlying Laketown as containing both light-gray and dark-gray dolomite units which are massive to thin bedded. There, the Laketown is about 1,150 ft. thick. In both studies, the distinction between the formations was based on color. Trimble and Carr (1976, p. 20) placed the lower contact between the two formations where the mottled, gray dolomite of the Fish Haven gradationally changes into the light-gray dolomite of the Laketown. Beus (1968, p. 784), working in the vicinity of Samaria Mountain, located southwest of Malad City, Idaho, found no useful lithologic difference between the two formations. He treated both the Fish Haven and Laketown as a single mappable unit. In the mapped area, these units could not be differentiated and, accordingly, are represented as one formation.

The lower contact of the Fish Haven-Laketown Formation with the underlying Swan Peak is disconformable as discussed in the previous section. The age of the unit is Late Ordovician (Cincinnatian) to Silurian (Coulter, 1956, p. 27-30).

In the mapped area, the Fish Haven-Laketown Formation is exposed south of both Reed and North Canyons (pl. 1). Isolated outcrops of this formation also occur north of Wakley Peak and North Canyon. The Fish Haven-Laketown, in the vicinity of Samaria Mountain about 20 mi. south of the mapped area, is 1,540 ft. thick (Beus, 1968, p. 784). The Fish Haven-Laketown, within the mapped area, is medium-crystalline, light- to dark-gray dolostone. The dolostone contains chert in places. A poorly preserved brachiopod fauna is present. One well-preserved rugose coral (*Streptelasma?*) was found south of Mill Canyon. The Fish Haven-Laketown forms slopes and ridges.

The lower contact with the Swan Peak Formation is placed at the top of the uppermost quartzite and at the base of dark-gray dolostone. The upper contact is not present in the mapped area.

Tertiary System

Salt Lake Formation

The Salt Lake Formation was originally recognized by Hayden (1869, p. 92) in Salt Lake and Weber Valleys. Ludlum (1943, p. 980) recognized the Salt Lake Formation in the Bannock Range, Idaho. There, it consists of poorly cemented conglomerate, sandstone, and volcanic ash, all of continental origin. He noted that it was exposed in small areas on protected slopes. Williams (1948, p. 1147) measured a thickness of 1,140 ft. of the Salt Lake Formation in the Logan Quadrangle, Utah. He stated that this section clearly represents the sediments of an ancient lake where deposition of a traction load of pebbles, sand, and oolites near shore was followed by the accumulation of thin-bedded, tuffaceous limestone as the lake expanded. Adamson and others (1955, p. 4-8) recognized three formations in Cache Valley, Utah and Idaho, as follows: (1) lower Collinston Conglomerate, (2) middle Cache Valley Formation, and (3) upper Mink Creek Conglomerate. The Collinston consists of rounded to subangular pebbles, cobbles, and some boulders of Paleozoic rocks. It contains minor amounts of tuff and red siltstone. It is at least 1,500 ft. thick and is poorly exposed. The Cache Valley consists of tuffaceous limestone, sandstone, and conglomerate. It is as much as 7,674 ft. thick. The Mink Creek is characterized as a light-gray to pale-orange, tuffaceous conglomerate approximately 3,435 ft. thick. Coulter (1956, p. 35) noted that the underlying Wasatch Formation, present in Randolph and Montpelier Quadrangles on the eastern flank of the Bear River Range, bears striking similarity to various units of the Salt Lake Formation, although they undoubtedly differ in age.

The Salt Lake Formation rests unconformably on older rocks (Williams, 1948, p. 1147) and is overlain by various Quaternary deposits. The units of the Salt Lake Formation undoubtedly differ in age from one locality to another (Coulter, 1956, p. 34). Eardley (1944, p. 845) dated the Salt Lake Formation as old as Oligocene based on vertebrate remains found south of Morgan, Utah. Yen (1947) dated the formation as Pliocene based on mollusk evidence in northern Utah. Swain (1964, p. 179) considered the formation to be Miocene in age near Malad City, Idaho. An Oligocene to Pliocene age, therefore, is assigned to the Salt Lake Formation within the mapped area.

In the mapped area, the Salt Lake Formation occurs in two isolated outcrops. These outcrops are located in Cliff Canyon and near Big Creek (pl. 1). The formation rests unconformably on Paleozoic rocks. The Salt Lake is primarily pebble conglomerate with clasts of orthoquartzite, limestone, and dolostone derived from the Paleozoic units of the area. The pebbles are subangular to rounded. Minor amounts of red and brown siltstone are present in this calcite-cemented conglomerate. Rock types of the Salt Lake Formation, in the mapped area, are simlar to those of the Collinston Conglomerate (Adamson and others, 1955, p. 4-6).

Volcanic rocks

Volcanic rocks are found north of Reed and Cliff Canyons and along Big Creek within the mapped area (pl. 1). The mineralogy of these rocks, as seen in hand sample and thin section, shows they are of andesitic composition.

In hand sample, the andesite is reddish gray, green gray, and yellow gray, due to the effects of weathering. The rock is porphyritic with phenocrysts of plagioclase and ferromagnesian minerals set in an aphanitic matrix. Stretched vesicles indicate flow. Outcrops of the andesite display pronounced columnar jointing. This is particularly evident in the northwestern part of the study area. In places, the flows have been so severely weathered that only extensive debris remains (fig. 8).

Thin-section analysis of seven samples reveals extensive alteration of the andesite in addition to evidence of flow origin (fig. 9). Plagioclase feldspar phenocrysts constitute approximately

FIGURE 8. Boulder of volcanic rock along Big Creek; view north.

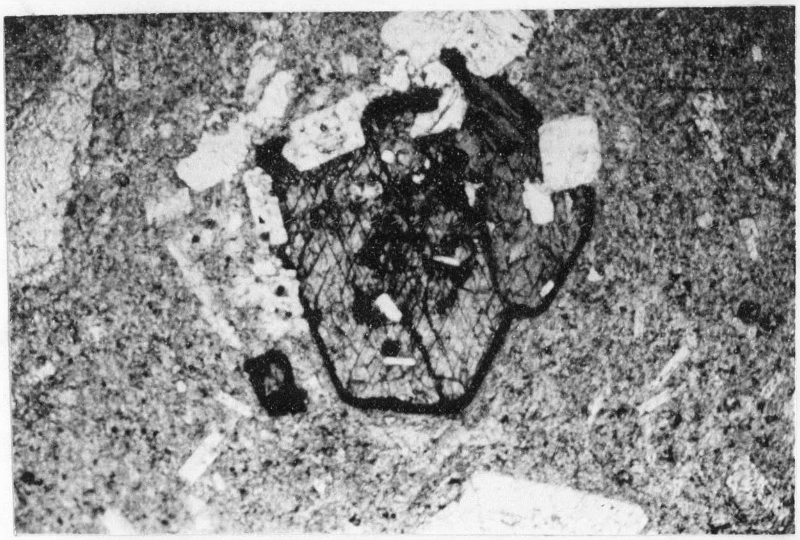

FIGURE 9. Photomicrograph of Tertiary volcanic rock from northwestern part of mapped area. Note dark reaction rims and feldspar phenocrysts. Groundmass is vesicular and contains laths of feldspar that show subparallel alignment and wrapping around of phenocrysts.

40 to 50 percent of the rock (An 35-65), magnetite 5 percent, hornblende and biotite 0 to 3 percent, clinopyroxene (augite) and orthopyroxene (hypersthene) 0 to 2 percent. An undetermined amount of alkali feldspar is also present. Olivine is present in minor amounts in at least one of the thin sections. The phenocrysts range in size from 0.1 mm to 3.5 mm. The groundmass contains laths of feldspar that show subparallel alignment and warpping around of phenocrysts. This suggests a probable flow origin for the volcanic rocks. The interstices between the microlites are occupied by cryptocrystalline material. Glass is found throughout the matrix. The microlites are less than 0.05 mm in length.

Alteration of plagioclase and ferromagnesian phenocrysts is evident in thin section. Hornblende and biotite are commonly surrounded by dark reaction rims. Alteration of these minerals is probably responsible for the relatively large amounts of hematite and chlorite in the flow. The plagioclase is commonly fractured and embayed. In some thin sections, it is apparently altered to clay. This process of alteration within the andesite is probably related to the process of argillitization.

Near the northwestern corner of the mapped area, the andesite flow strikes generally N. 10° E. and dips 14°W. to 20° W. Field evidence suggests that the volcanic rocks unconformably overlap the Fish Haven-Laketown and Swan Peak Formations. Carlson (1968, p. 30-31) found the same relationship north of the mapped area. In the vicinity of Cliff Canyon, pebble conglomerate of the Tertiary Salt Lake Formation possibly overlies volcanic rocks. The volcanic rocks may have formed contemporaneously with the deposition of the Salt Lake. This relationship suggests a late Tertiary age for the flows in the mapped area. It is probable that the andesite flows issued from dikes that originated when magma forced its way through fractures in surrounding rocks.

Quaternary System

Colluvial deposits

Much of the valley bottom and upper slopes along the mountain front, within the mapped area, consist of colluvial deposits (pl. 1). These deposits consist of boulders, gravel, sand, and clay. They are poorly sorted. The coarser material, which is generally found on the higher slopes along the mountain front, consists of orthoquartzite, limestone, and dolostone (fig. 10). The quartzite debris is largely from the Swan Peak Formation. An isolated patch of colluvium occurs at a higher elevation north of Rowley Canyon and may represent a deposit on an old erosion surface (pl. 1). The colluvial deposits are probably Pleistocene to Holocene in age.

Alluvial deposits

Alluvium is present, in the mapped area, along all major stream valleys. It consists of unconsolidated gravel, sand, and silt composed of orthoquartzite, dolostone, and limestone. The alluvial deposits are Holocene in age.

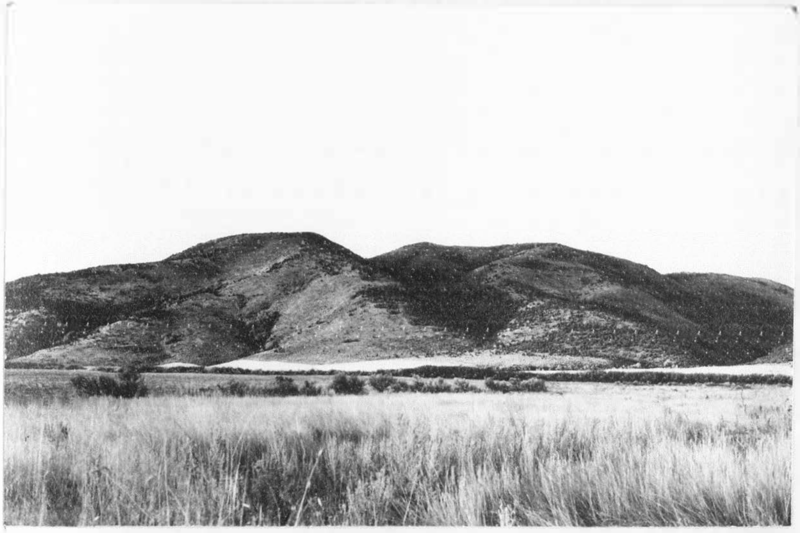

FIGURE 10. Colluvial deposits along mountain front in E½ sec. 14, T. 12 S., R. 36 E.; view west.

STRUCTURAL FEATURES

Regional Setting

The structure of southeastern Idaho and northern Utah is characterized by thrust faults and normal faults. Major thrust faults of great displacement are found in the region. Among the more notable thrust faults are the Paris and the Willard. It is suspected that all are rooted to the west and have brought thicker geosynclinal facies over thinner shelf facies to the east (Crittenden, 1961, p. 128).

The Bannock thrust fault of Richards and Mansfield (1912) has been interpreted by Armstrong and Cressman (1963) as a zone of west-dipping, imbricate thrust faults extending from southwestern Montana through southeastern Idaho and western Wyoming to central Utah. Earlier interpretations of the Bannock envisioned a single large thrust fault of considerable regional extent (Richards and Mansfield, 1912).

The Paris thrust fault, situated on the eastern side of the Bear River Range, was once considered part of the Bannock thrust fault as envisioned by Richards and Mansfield (1912). It is now considered as part of the Bannock thrust zone. The overriding consideration in this concept is the fact that the thrust faults are progressively younger from west to east (Armstrong and Cressman, 1963). The stratigraphic throw on the Paris is 20,000 ft. (Armstrong and Cressman, 1963, p. 18).

The Willard thrust fault may be a southward extension of the Paris thrust fault (Crittenden, 1972). The amount of eastward displacement along the Willard is largely speculative, but estimates of 30 to 40 mi. have been given (Crittenden, 1961, p. 129).

Two interpretations of eastward movement are summarized by Armstrong and Oriel (1965, p. 1861-1862). One interpretation is that the Paleozoic rocks, northward from Ogden, Utah, are a remnant of the upper plate of large thrust plates that moved at least 10 to 15 mi. eastward. The other interpretation involves uplifting of the same area, which caused local gravity sliding eastward.

The region is located within the Basin and Range Province. Structures, within this province, are high-angle normal faults which are responsible for the present topographic relief. The faults have a general northward trend. Within the mapped area, numerous, nearly vertical normal faults are found. These faults generally trend north and northwest. A few northeast-trending and east-west-trending normal faults are also present. In addition, several small asymmetrical anticlines and a thrust fault of limited displacement and probable local extent are present.

Folds

A small asymmetrical anticline is present in the Swan Peak Formation along the ridge north of Wakley Peak in sec. 6, T. 12 S., R. 36 E. There, the Swan Peak dips 29° E. on the eastern limb and 19° W. on the western limb.

In SW¼ sec. 18, T. 12 S., R. 36 E., an asymmetrical anticline is present within the Garden City (fig. 11). The western limb dips approximately 29° W. and the eastern limb is nearly vertical. The rocks are highly brecciated.

An asymmetrical anticline is present in NE¼ sec. 34, T. 12 S., R. 35 E., in the vicinity of Bill Morgan Canyon (fig. 12). The eastern limb is approximately vertical. The anticline is in the St. Charles Formation.

The folding, in the mapped area, is probably the result of east-west compressional forces. The relatively steep dip of the eastern limbs of the anticlines is suggestive of Laramide forces.

Thrust Fault

Low-angle thrust fault

Low-angle thrust faults are those that dip less than 45 degrees, usually 20 to 30 degrees, and which involve crustal shortening. One low-angle thrust fault is present in the mapped area. It extends from sec. 23, T. 12 S., R. 36 E., northward into sec. 14, T. 12 S., R. 36 E. (pl. 1). The thrust fault occurs between the Bloomington and St. Charles Formations. Limestone and shale of the upper part of the Bloomington has been thrust eastward over the Worm Creek Member of the St. Charles (fig. 13). This indicates significant stratigraphic throw and thrusting of older over younger rocks. The thrust fault dips approximately 20° W. Slickensided surfaces are present on the Worm Creek.

Outside of the mapped area, younger rocks have apparently been

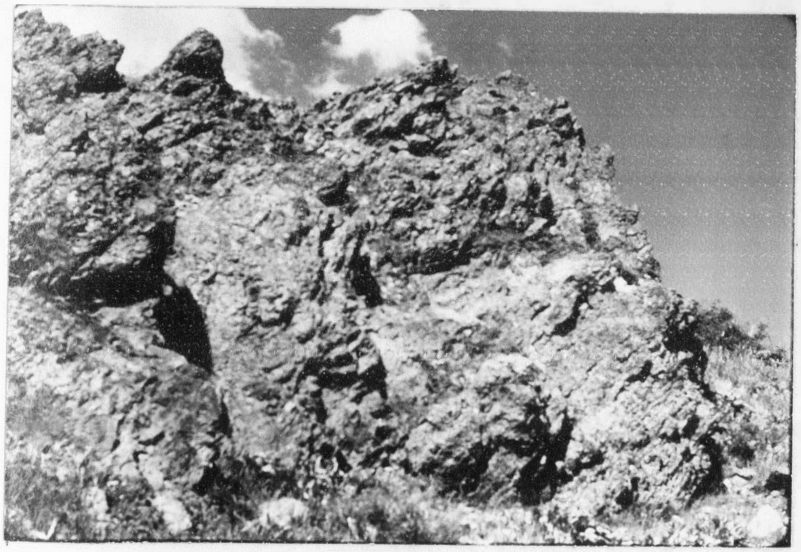

FIGURE 11. Asymmetrical anticline in Garden City Formation near ridge top in SW¼ sec. 18, T. 12 S., R.36 E.; view north. Eastern limb dips more steeply than western limb.

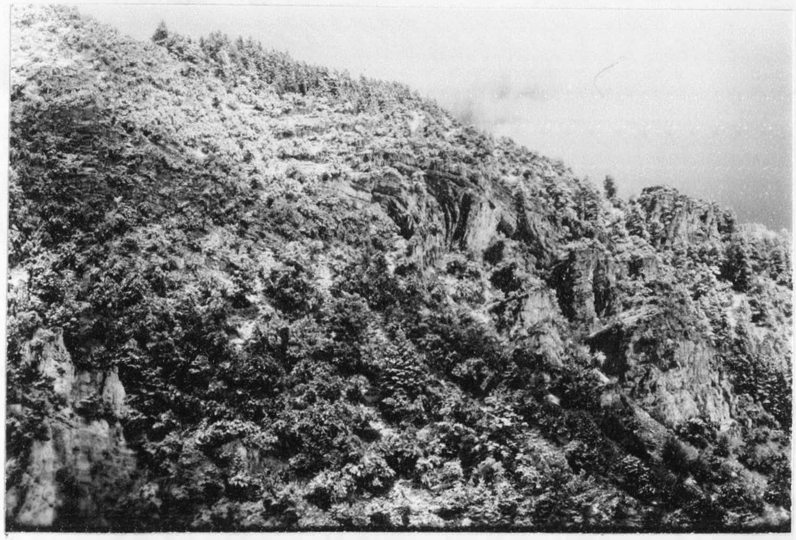

FIGURE 12. Asymmetrical anticline in St. Charles Formation north of Bill Morgan Canyon; view north. Eastern limb is approximately vertical.

FIGURE 13. Low-angle thrust fault between North Canyon and Rowley Canyon; view west. Thrust fault places Bloomington Formation over St. Charles Formation. Base of the rock hammer marks the thrust fault.

thrust over older, as documented by Burton (1973), Shearer (1975), and DeVries (1977). Stratigraphic units, involved in this type of thrusting are Bloomington and Nounan. This indicates gravity sliding along bedding-plane thrust faults. Within the mapped area, however, east-west compression is considered to have been the mechanism for thrusting.

Normal Faults

General statement

Nearly vertical normal faults are abundant within the mapped area (pl. 1). The normal faults are divided into four categories on the basis of trend. The first category consists of northwest-trending normal faults. These faults tend approximately N. 40° W. to N.75° W. They generally extend for great distances. The second category consists of north-trending normal faults. These faults trend approximately N. 25° W. to N. 25° E. They are by far the most numerous and they generally terminate at northwest-trending normal faults. The third category consists of two northeast-trending normal faults that strike about N. 45° E. The fourth category consists of one east-west-trending normal fault. In addition, one marginal normal fault is present along the western side of the mapped area. It may be an extension of the Wasatch fault. Features such as gouge, slickensides, fault breccia, and drag are well exposed at only a few places within the mapped area.

Northwest-trending normal faults

Eleven northwest-trending normal faults are present in the mapped area (pl. 1). These faults will be described as they occur from the southwestern part of the area to the northeast.

The southwesternmost northwest-trending normal fault extends from SW¼ sec. 34, T. 12 S., R. 35 E., and terminates at the marginal normal fault on the western side of Elkhorn Mountain. Displacement is down on the northeast. Nounan and St. Charles are down on the northeast next to Bloomington. Segments of the fault are covered by alluvial deposits in Bill Morgan Canyon.

The second northwest-trending normal fault extends from the southern limit of the mapped area in SW¼ sec. 35, T. 12 S., R. 35 E., south of Bill Morgan Canyon, and terminates at the marginal normal fault in NE¼ sec. 28, T. 12 S., R. 35 E. Displacement is down on the northeast. Garden City is down on the northeast next to Nounan where the fault crosses Bill Morgan Canyon. To the northwest near the intersection of a north-trending fault, St. Charles and Garden City are down on the northeast next to St. Charles. A breccia is present in the St. Charles at that locality. Along the remainder of the fault, Nounan and St. Charles are present on both sides. Offset of the Nounan-St. Charles contact indicates that displacement is down on the northeast.

The third northwest-trending normal fault extends from a north-trending fault in SE¼ sec. 24, T. 12 S., R. 35 E., and terminates at a north-trending fault in SW¼ sec. 24, T. 12 S., R. 35 E. Displacement is down on the southwest. Fish Haven-Laketown is down on the southwest next to Garden City near the elevation of 8,150 ft. To the northwest, Garden City and Swan Peak are present on both sides of the fault. Near the termination of the fault, Swan Peak is down on the southwest next to Garden City.

The fourth northwest-trending normal fault extends from a north-trending fault in NE¼ sec. 33, T. 12 S., R. 36 E., where it is covered by colluvial deposits, and terminates at the marginal normal fault on the western side of Elkhorn Mountain in the vicinity of Indian Mill Creek. Displacement is down on the southwest. Approximately 0.3 mi. south of Summit Guard Station, Swan Peak is down on the southwest next to Garden City. To the northwest and south of Summit Campground, Swan Peak is again down on the southwest next to Garden City. From this point northwest to the intersection of a northeast-trending normal fault, a relatively minor amount of displacement occurs. Displacement is presumed to be down on the southwest. Northwest of the intersection of the northeast-trending normal fault, Fish Haven-Laketown is down on the southwest next to Garden City. Near the center of sec. 24, T. 12 S., R. 35 E., Swan Peak is down on the southwest next to Garden City. In NE¼ sec. 23, T. 12 S., R. 35 E., Garden City is down on the southwest next to St. Charles. The St. Charles-Garden City contact is offset at this locality. From that point northwestward to where the fault terminates at the marginal normal fault, the amount of displacement is relatively minor. In places, the fault is covered by alluvial deposits. Where the fault is exposed, St. Charles opposes St. Charles or Nounan opposes Nounan.

The fifth northwest-trending normal fault extends from a north-trending fault in NE¼ sec. 33, T. 12 S., R. 36 E., where it is covered by colluvial deposits. This fault termiantes at a north-trending fault in N½ sec. 29, T. 12 S., R. 36 E. Displacement is down on the northeast. From where the fault is well exposed northwestward to the intersection of a north-trending fault 0.2 mi. north of Summit Campground, Fish Haven-Laketown is down on the northeast next to Garden City. From that point northwestward to where the fault terminates, Fish Haven-Laketown is down on the northeast next to Swan Peak. A breccia is present along this segment of the fault.

The sixth northwest-trending normal fault extends from a north-trending fault in NE¼ sec. 33, T. 12 S., R. 36 E., where it is covered by colluvial deposits, and terminates at the marginal normal fault on the western side of Elkhorn Mountain in Tom Perry Canyon. Displacement is down on the southwest. From where the fault intersects a north-trending fault west of Summit Guard Station to a point near the elevation of 6,572 ft., Fish Haven-Laketown is down on the southwest next to Swan Peak. From that point northwestward to where the fault intersects a north-trending fault northwest of Summit Campground, Fish Haven-Laketown is down on the southwest next to Swan Peak. A breccia is present along this segment of the fault. From where the fault intersects a north-trending fault near the elevation of 7,621 ft. and continuing to the intersection of a northeast-trending fault in NE¼ sec. 19, T. 12 S., R. 36 E., Fish Haven-Laketown is down on the southwest next to Swan Peak. Northwestward in SW¼ sec. 13, T. 12 S., R. 35 E., near a spring, Garden City is down on the southwest next to Nounan and St. Charles.

From that point northwestward to where the fault terminates, alluvial deposits cover the fault. St. Charles is down on the southwest next to Bloomington and Nounan.

The seventh northwest-trending normal fault extends from a north-trending fault in the SW¼ sec. 22, T. 12 S., R. 36 E., north of North Canyon where it is covered by colluvial deposits, and terminates at the marginal normal fault on the western side of Elkhorn Mountain, near Reed Canyon. The amount of displacement is major and the displacement is down on the southwest. The fault is covered by colluvial deposits from where it begins to the intersection of a north-trending fault near the center of sec. 21, T. 12 S., R. 36 E. Its existence east of the north-trending fault is indicated by an outcrop of Fish Haven-Laketown in SE¼ sec. 21, T. 12 S., R. 36 E., north of North Canyon. Offset occurs along the fault at the intersection of a north-trending fault, resulting in continuation of the northwest-trending fault approximately 0.2 mi. to the south on the western side of the north-trending fault. From that point northwestward in NE¼ sec. 20, T. 12 S., R. 36 E., the fault places Swan Peak down on the southwest next to Camelback Mountain. Northwestward along the fault to its intersection with a north-trending fault in SE¼ sec. 18, T. 12 S., R. 36 E., Garden City is down on the southwest next to Camelback Mountain (fig. 14). From that point to the intersection of a north-trending fault in NW¼ sec. 18, T. 12 S., R. 36 E., Swan Peak is down on the southwest next to Bloomington (fig. 15). A breccia is present, in places, along this segment of the fault. From the latter intersection to its intersection with a

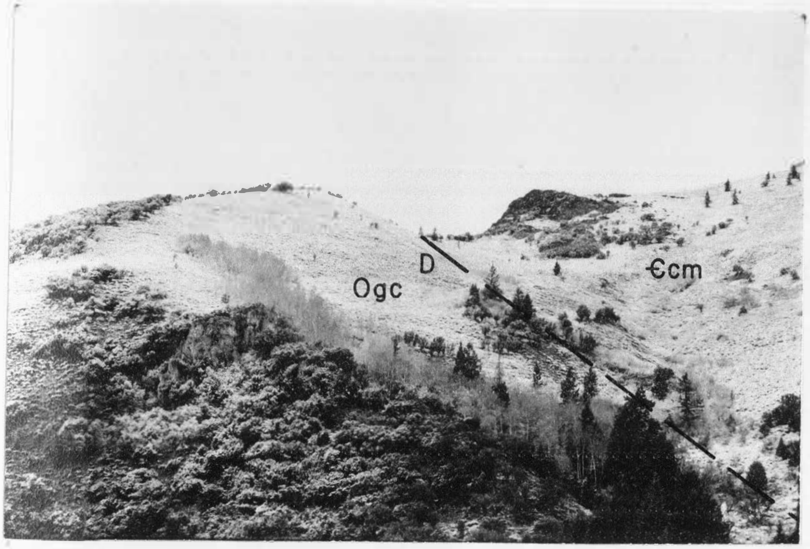

FIGURE 14. Northwest-trending normal fault in SW¼ sec. 17, T. 12 S., R. 36 E.; view northwest. Garden City Formation (Ogc) is down on the left next to Camelback Mountain Quartzite (Ꞓcm).

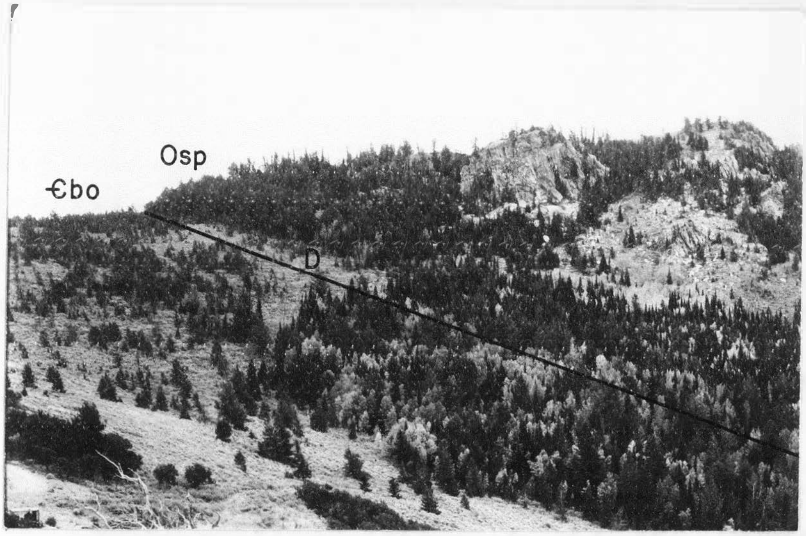

FIGURE 15. Northwest-trending normal fault in NW¼ sec. 18, T. 12 S., R. 36 E.; view southeast. Swan Peak Formation (Osp) is down on the right next to Bloomington Formation (Ɛbo).

north-trending fault near a spring in Reed Canyon, Garden City is down on the southwest next to Elkhead and Bloomington. Northwestward from the intersection of the north-trending fault, Nounan and St. Charles are down on the southwest next to Elkhead. From that area to the termination of the fault at the mountain front, Bloomington and Nounan are down on the southwest next to Gibson Jack and Elkhead.

The eighth northwest-trending normal fault extends from a north-trending fault in NE¼ sec. 18, T. 12 S., R. 36 E., and terminates at the marginal normal fault on the western side of Elkhorn Mountain, south of Cliff Canyon. Displacement is down on the southwest. Northwestward from where the fault begins to the intersection of a north-trending fault in SW¼ sec. 7, T. 12 S., R. 36 E., Bloomington is down on the southwest next to Gibson Jack and Elkhead. From that point to the termination of the fault at the mountain front, Gibson Jack, Elkhead, Bloomington, and Nounan are down on the southwest next to Camelback Mountain. A breccia is present on the fault where it cuts the Bloomington-Nounan contact.

The ninth northwest-trending normal fault extends from a north-trending fault, near the top of Elkhorn Ridge in NE¼ sec. 18, T. 12 S., R. 36 E., and terminates at the marginal normal fault on the western side of Elkhorn Mountain, north of Cliff Canyon. Displacement is down on the southwest. From where the fault begins to 0.45 mi. to the northwest, Elkhead is down on the southwest next to Gibson Jack (fig. 16). From that point to the termination of the fault at the mountain front, Camelback Mountain and Gibson Jack are down on the southwest next to Camelback Mountain.

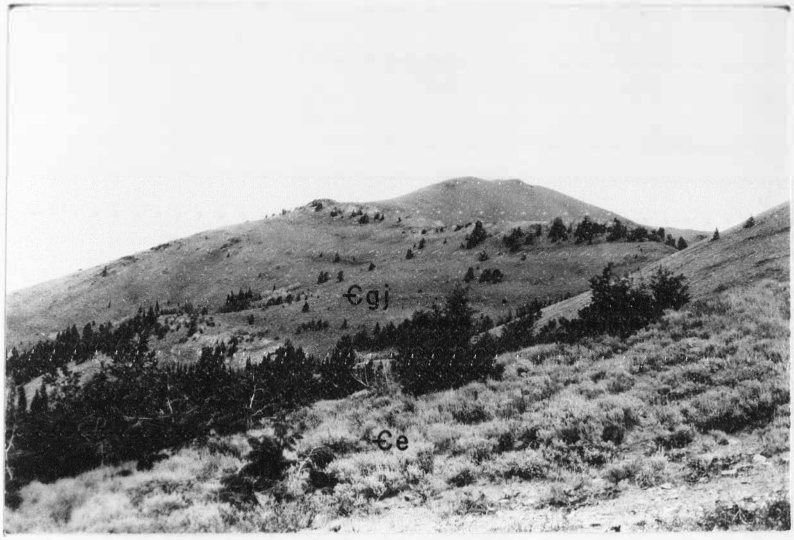

FIGURE 16. Northwest-trending normal fault in SW¼ sec. 7, T. 12 S., R. 36 E.; view northeast. Fault is located in the valley that extends from the lower lefthand corner of the photograph to the upper right. Elkhead Formation (Єe) is down next to Gibson Jack Formation (Єgj).

The tenth northwest-trending normal fault extends from a north-trending fault in NE¼ sec. 26, T. 12 S., R. 36 E., near Birch Creek, and terminates at an east-trending fault in SW¼ sec. 6, T. 12 S., R. 36 E., near an outcrop of Tertiary volcanic rocks. Displacement is down on the southwest and, in places, results in a major amount of stratigraphic separation. In SW¼ sec. 23, T. 12 S., R. 36 E., Garden City is down on the southwest next to Bloomington. Northwestward and near the intersection of three north-trending faults, Fish Haven-Laketown is down on the southwest next to Bloomington and Camelback Mountain. Northwestward from that point to 0.6 mi. south of Toro Peak, Garden City is down on the southwest next to Camelback Mountain and Elkhead. A breccia is present, in places, along this segment of the fault. From that point to the intersection of a north-trending fault west of Toro Mountain, Swan Peak is down on the southwest next to Elkhead. Offset occurs along the fault at the intersection of a north-trending fault in NE¼ sec. 8, T. 12 S., R. 36 E., just south of the elevation of 7,144 ft. This offset results in continuation of the northwest-trending fault approximately 0.5 mi. to the south on the western side of the north-trending fault. From that point northwestward to the termination of the fault, a relatively minor amount of displacement occurs. Early Cambrian units oppose Early Cambrian units along this part of the fault.

The final northwest-trending fault extends from SW¼ sec. 4, T. 12 S., R. 36 E., and terminates in E½ sec. 5, T. 12 S., R. 36 E. Displacement is down on the northeast. In SW¼ sec. 4, T. 12 S.,

R. 36 E., Tertiary volcanic rocks are down on the northeast next to Nounan. Northwestward to the termination of the fault, a breccia is present in the Nounan.

North-trending normal faults

Thirty-five north-trending normal faults are present in the mapped area (pl. 1). These faults are by far the most numerous and in many places terminate at northwest-trending faults. The faults do not display any pronounced pattern with regard to relative movement. The north-trending normal faults are divided into five groups. The first two groups of north-trending normal faults, in the mapped area, originate in T. 12 S., R. 35 E. The first group, consisting of eight faults, extends from the southwestern part of the mapped area. Six of these faults terminate in the vicinity of Indian Mill Creek. The other two terminate in the vicinity of Reed Canyon. The second group, consisting of two faults, extends from a northwest-trending fault that terminates near Tom Perry Canyon. These two north-trending faults terminate south of Cliff Canyon. In addition, one marginal north-trending normal fault is present on the western side of Elkhorn Mountain and is described separately in a later section.

The remaining three groups of north-trending normal faults, in the mapped area, originate in T. 12 S., R. 36 E. The third group consists of eleven faults which extend from the southern part of the mapped area, in the vicinity of Mill Canyon, and terminate at northwest-trending faults as far north as secs. 20 and 21, T. 12 S., R. 36 E. The fourth group consists of six faults which intersect or are located south of a major northwest-trending fault that originates north of North Canyon and terminates northwest of Wakley Peak. The fifth group consists of seven faults which extend northward from the major northwest-trending fault previously described. Certain north-trending normal faults, within these groups, will be described in detail from west to east.

The first group of north-trending normal faults consists of eight faults. These faults generally trend somewhat east of north and cut predominantly Middle Cambrian to Middle Ordovician units. Two faults, within this group, cut Late Ordovician to Silurian units. The amount of displacement on these faults is not great.

The first north-trending normal fault to be discussed within the first group extends from a northwest-trending fault in SW¼ sec. 27, T. 12 S., R. 35 E., and terminates near Reed Canyon in NW¼ sec. 13, T. 12 S., R. 35 E. Displacement is down on the west. This fault is undoubtedly related to the marginal normal fault. As movement occurred on the marginal normal fault, support was removed from below the hanging-wall block of the north-trending fault causing the block to be displaced downward toward the valley. Stratigraphic units involved in the faulting are St. Charles and Garden City, northward to Tom Perry Canyon, and Nounan and St. Charles from that point to the termination of the fault near Reed Canyon. A breccia is present, in places, along the entire trace of the fault.

The second north-trending normal fault to be discussed within the first group extends from the limit of the mapped area in SE¼ sec. 35, T. 12 S., R. 35 E., and terminates in the vicinity of

Reed Canyon in NE¼ sec. 13, T. 12 S., R. 35 E. Displacement is down on the west. Near NE¼ sec. 26, T. 12 S., R. 35 E., Swan Peak is down on the west next to Garden City. Northward, the fault is offset at the intersection of a northwest-trending fault. The north-trending fault is offset to the west 264 ft. on the northern side of the northwest-trending fault. From that point northward for 0.2 mi., Swan Peak is down on the west next to Garden City (fig. 17). Northward to the termination of the fault, Garden City opposses Garden City. Displacement is presumed to be down on the west.

The final north-trending normal fault to be discussed within the first group extends from the southern limit of the mapped area in SW¼ sec. 36, T. 12 S., R. 35 E., and terminates at a northwest-trending fault in SE¼ sec. 24, T. 12 S., R. 35 E., near the top of Elkhorn Ridge. Displacement is down on the east. Northward from where the fault originates, Fish Haven-Laketown is down on the east next to Garden City. Approximately 0.15 mi. north of the center of sec. 25, T. 12 S., R. 35 E., Fish Haven-Laketown is down on the east next to Swan Peak. A breccia is present on the fault at that locality.

The second group of north-trending normal faults consists of two faults. These faults generally trend somewhat east of north and cut Middle Cambrian to Middle Ordovician units. The amount of displacement along these faults is not great.

The first north-trending normal fault to be discussed within the second group extends from a northwest-trending fault in SW¼ sec. 13, T. 12 S., R. 35 E., and terminates at its intersection with a northwest-trending fault near Reed Canyon. Displacement is

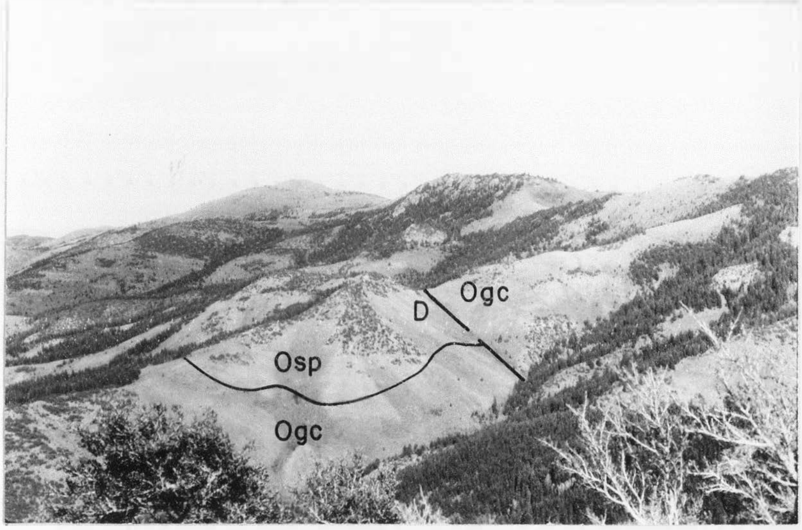

FIGURE 17. North-trending normal fault in NW¼ sec. 24, T. 12 S., R. 35 E.; view northeast. Swan Peak Formation (Osp) is down on the left next to Garden City Formation (Ogc).

down on the east. Garden City is down on the east next to St. Charles along the entire length of the fault. A breccia is present on the north-trending fault where it crosses a saddle. This occurs approximately 0.2 mi. northeast of a spring in Tom Perry Canyon.

The final north-trending normal fault to be discussed within the second group extends from a northwest-trending fault in SE¼ sec. 13, T. 12 S., R. 36 E., and terminates at its intersection with a northwest-trending fault in SW¼ sec. 7, T. 12 S., R. 36 E. Displacement is down on the west. Southward from the northern termination of the fault for approximately 0.3 mi., Nounan is down on the west next to Bloomington.

The third group of north-trending normal faults consists of eleven faults. These faults generally trend north to somewhat east of north and cut Early Ordovician to Silurian units. The amount of displacement on these faults is not great.

The first north-trending normal fault to be discussed within the third group extends from the southern limit of the mapped area in W½ sec. 31, T. 12 S., R. 36 E., and terminates at its intersection with a northwest-trending fault in SW¼ sec. 19, T. 12 S., R. 36 E. Displacement is down on the west. Fish Haven-Laketown is down on the west next to Swan Peak along the northern segment of the fault. A breccia is present on the fault at that locality.

The second north-trending normal fault to be discussed within the third group extends from the southern limit of the mapped area in W½ sec. 32, T. 12 S., R. 36 E., and terminates at its intersection with a northwest-trending fault near the center of sec. 29, T. 12 S., R. 36 E. Displacement is down on the east. Fish Haven-Laketown is down on the east next to Swan Peak along the southern segment of the fault (fig. 18). The general effect of this fault and the next north-trending normal fault to the west is to form a horst of Swan Peak.

The third and final north-trending normal fault to be discussed within the third group extends from a northwest-trending fault in NE¼ sec. 29, T. 12 S., R. 36 E., and terminates north of North Canyon at its intersection with a major northwest-trending fault in NE¼ sec. 20, T. 12 S., R. 36 E. Displacement is down on the east. Fish Haven-Laketown is down on the east next to Garden City along the southern segment of the fault. To the north, the Swan Peak is down on the east next to Garden City. A breccia is present on this fault south of North Canyon.

The fourth group of north-trending normal faults consists of six faults. These faults generally trend somewhat east or west of north and cut Early Cambrian to Late Ordovician-Silurian units. The amount of displacement on some of these faults is considerably greater than the north-trending faults previously described.

The first north-trending normal fault to be discussed within the fourth group extends from a major northwest-trending fault in E½ sec. 18, T. 12 S., R. 36 E., and terminates at its intersection with a northwest-trending fault in SE¼ sec. 6, T. 12 S., R. 36 E. Displacement is down on the west. Near the southern end of the fault, Bloomington is down on the west next to Camelback Mountain. The amount of displacement is significant at that locality. To the north, approximately 0.3 mi., Elkhead is down on the west next to Camelback Mountain and Gibson Jack. Northward from the area,

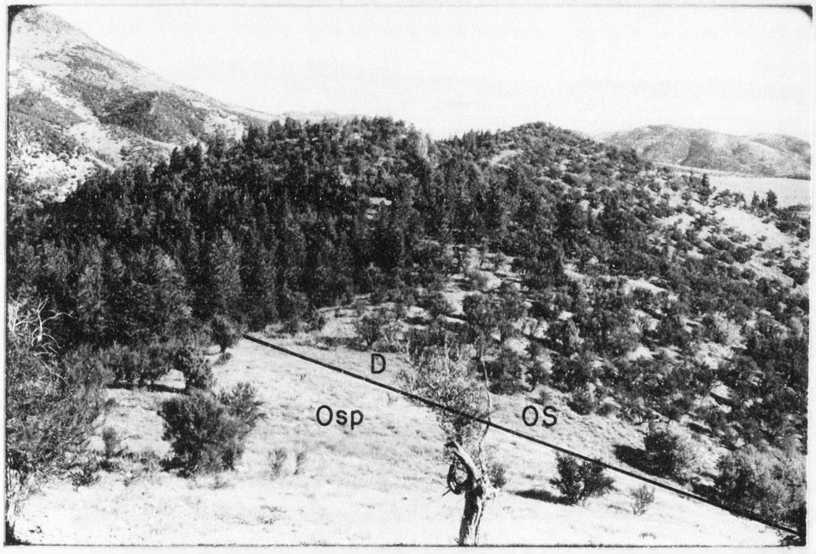

FIGURE 18. North-trending normal fault in NW¼ sec. 32, T. 12 S., R. 36 E.; view northeast. Fish Haven-Laketown Formation (OS) is down next to Swan Peak Formation (Osp).

Elkhead is down on the west next to Gibson Jack. Near where the fault terminates, Gibson Jack opposes Gibson Jack. Displacement is presumed to be down on the west.

The second north-trending normal fault to be discussed within the fourth group extends from the southern limit of the mapped area in NW¼ sec. 34, T. 12 S., R. 36 E., where it is covered by colluvial deposits, into NE¼ sec. 5, T. 12 S., R. 36 E. It possibly continues beyond the limit of the mapped area. Displacement is down on the east. This north-trending normal fault offsets northwest-trending faults at two localities (see discussion of seventh and tenth northwest-trending normal faults). One point of offset is in W½ sec. 21, T. 12 S., R. 36 E., where the northwest-trending fault is offset approximately 0.2 mi. to the south on the western side of the north-trending fault. The second point of offset is in E½ sec. 8, T. 12 S., R. 36 E., where the northwest-trending fault is offset approximately 0.5 mi. to the south on the western side of the north-trending fault. In NE¼ sec. 17, T. 12 S., R. 36 E., Elkhead is down on the east next to Camelback Mountain. Northward near the elevation of 7,144 ft. in NE¼ sec. 8, T. 12 S., R. 36 E., Elkhead is down on the east next to Camelback Mountain (fig. 19). Northward from where the fault intersects an east-west-trending fault, Elkhead is down on the east next to Gibson Jack.

The third north-trending normal fault to be discussed within the fourth group extends from SE¼ sec. 22, T. 12 S., R. 36 E., and terminates at a major northwest-trending fault in SW¼ sec. 23, T. 12 S., R. 36 E. Displacement is down on the east. Fish Haven-Laketown is down on the east next to Garden City. The general effect

FIGURE 19. North-trending normal fault in NE¼ sec. 8, T. 12 S., R. 36 E.; view southeast. Elkhead Formation (Ꞓe) is down on the left next to Camelback Mountain Quartzite (Ꞓcm).

of this fault and the next north-trending fault to the east is to form a graben of Fish Haven-Laketown.

The fourth and final north-trending normal fault to be discussed within the fourth group extends from the area southeast of Malad Summit, where it is covered by colluvial deposits, and terminates in the vicinity of a point labeled "Aqueduct" in NE¼ sec. 23, T. 12 S., R. 36 E. Displacement is down on the east. In N½ sec. 26, T. 12 S., R. 36 E., Swan Peak is down on the east next to St. Charles. Northward, the fault extends along a small outcrop of Swan Peak. Displacement is presumed to be down on the east.

The fifth and final group of north-trending normal faults consists of seven faults. These faults generally trend from west to somewhat east of north and cut Early Cambrian to Middle Ordovician units. The amount of displacement on some of these faults is quite significant.

The first north-trending normal fault to be discussed within the fifth group extends from a major northwest-trending fault in SE¼ sec. 16, T. 12 S., R. 36 E., into NW¼ sec. 4, T. 12 S., R. 36 E. It possibly continues beyond the northern limit of the mapped area. Displacement is down on the west. At the southern end of the fault, Nounan is down on the west next to Bloomington. Northward along the fault in SE¼ sec. 9, T. 12 S., R. 36 E., north of Rowley Canyon, St. Charles is down on the west next to Nounan. Farther northward in SW¼ sec. 4, T. 12 S., R. 36 E., Nounan is again down on the west next to Bloomington. The fault is covered by alluvial and colluvial deposits northward from the area of Big Creek.

The second north-trending normal fault to be discussed within the fifth group extends from a major northwest-trending fault in NE¼ sec. 22, T. 12 S., R. 36 E., into NE¼ sec. 3, T. 12 S., R. 36 E. It possibly continues beyond the northern limit of the mapped area. Displacement is down on the west. South of Rowley Canyon, Elkhead is down on the west next to Camelback Mountain and Gibson Jack.

The third north-trending normal fault to be discussed within the fifth group extends from a major northwest-trending fault in W½ sec. 23, T. 12 S., R. 36 E., into NW¼ sec. 2, T. 12 S., R. 36 E. It possibly continues beyond the northern limit of the mapped area. Displacement is down on the east. Northward from the intersection of the northwest-trending fault to the intersection of a northeast-trending fault, Bloomington is down on the east next to Camelback Mountain. Northward from the intersection of the northeast-trending fault to where the fault is covered by colluvial deposits, Gibson Jack is down on the east next to Camelback Mountain. A breccia is present along this segment of the fault.

The fourth and final north-trending fault to be discussed within the fifth group extends from a major northwest-trending fault in S½ sec. 23, T. 12 S., R. 36 E., where it is covered by colluvial deposits, and probably extends beyond its intersection with a northeast-trending fault in N½ sec. 14, T. 12 S., R. 36 E. Displacement is down on the east. Where the fault is exposed, Swan Peak is down on the east next to St. Charles. The general effect of this fault and the next north-trending fault to the east is to form a graben of Swan Peak.

Northeast-trending normal faults

Two northeast-trending faults are present in the mapped area (pl. 1). These faults will be described as they occur from the west to the east.

The westernmost northeast-trending normal fault extends from a northwest-trending fault in SW¼ sec. 19, T. 12 S., R. 36 E., and terminates at its intersection with a northwest-trending normal fault north of North Canyon in SW¼ sec. 17, T. 12 S., R. 36 E. Displacement is down on the southeast. Northward from where the fault originates to its intersection with a northwest-trending fault in N½ sec. 19, T. 12 S., R. 36 E., Fish Haven-Laketown is down on the southeast next to Garden City. Northward from that point in NE¼ sec. 19, T. 12 S., R. 36 E., Garden City is down on the southeast next to St. Charles. At the northeastern end of the fault, Garden City opposes Garden City. Displacement is presumed to be down on the southeast.

The easternmost northeast-trending normal fault extends from a north-trending fault in SE¼ sec. 15, T. 12 S., R. 36 E., and terminates at a north-trending fault in N½ sec. 14, T. 12 S., R. 36 E., where it is covered by colluvial deposits. Displacement is down on the southeast. From a point just east of its intersection with an intermediate north-trending fault, Bloomington is down on the southeast next to Camelback Mountain. Vertical slickensided surfaces are present along this segment of the fault. Northeastward from that point to where the fault is covered by colluvial deposits, St. Charles is down on the southeast next to Camelback Mountain.

East-west-trending normal faults

One east-west-trending normal fault is present in the mapped area (pl. 1). It extends from the marginal normal fault in SE¼ sec. 1, T. 12 S., R. 35 E., where it is covered by colluvial deposits, and terminates at the intersection of a north-trending fault in SW¼ sec. 5, T. 12 S., R. 36 E. Displacement is down on the north. Eastward for a distance of approximately 0.1 mi., Fish Haven-Laketown is down on the north next to Camelback Mountain Quartzite. Eastward from this point for a distance of approximately 0.8 mi. to the intersection of a north-trending fault, Swan Peak is down on the north next to Camelback Mountain and Gibson Jack. This indicates a great amount of displacement along this segment of the fault. Eastward from the intersection of the north-trending fault to where the fault terminates, Gibson Jack is down on the north next to Camelback Mountain.

Marginal normal fault

One north-trending marginal normal fault is present within the mapped area on the western side of northern Elkhorn Mountain (pl. 1). This marginal fault separates the mountain block from the valley block. Displacement is down on the west, and the amount of displacement is probably on the order of thousands of feet. The marginal fault extends along the entire western front of northern Elkhorn Mountain and is believed to be an extension of the Wasatch fault (fig. 20). The trace of the fault was accurately determined using aerial photographs.

FIGURE 20. Marginal north-trending normal fault along western side of northern Elkhorn Mountain; view southwest. Photograph was taken from hill immediately north of Farmers Canyon.

Landslide

One landslide is present, within the mapped area, south of Bill Morgan Canyon. It covers a small part of sec. 33, T. 12 S., R. 35 E. Quartzite of the Swan Peak Formation rests on limestone and shale of the Bloomington Formation. Low-angle brecciated surfaces of limited extent occur in the Bloomington. The landslide measures approximately 0.3 m. in the east-west direction and approximately 0.2 mi. in the north-south direction. The slide was probably caused by removal of support along the western front of northern Elkhorn Mountain as a result of movement along the marginal north-trending normal fault.

STRUCTURAL EVENTS

General Statement

Two major events of crustal deformation are recognized in the northern part of Elkhorn Mountain. The first event was folding and thrust faulting of the Laramide orogeny, which is generally believed to have begun by late Jurassic time and to have continued into early Tertiary time. The second event was normal faulting, representing the Basin and Range event. This faulting was responsible for the series of generally north-trending mountain ranges and valleys throughout the region. Present topographic relief is a result of Basin and Range faulting. This faulting has been active from Oligocene to the present time.

Armstrong (1968) attempted to separate Sevier deformational structures from Laramide deformational structures. He stated that the folds and thrust faults of the Sevier orogeny are distinctly older than Laramide uplifts. The writer chooses to maintain the term Laramide with respect to the folding and thrust faulting of the mapped area.

Laramide Events

The Laramide orogeny produced several small asymmetrical anticlines and a low-angle thrust fault within the mapped area. The anticlines are in the St. Charles, Garden City, and Swan Peak Formations. The low-angle thrust fault places Bloomington Formation over the St. Charles.

The absence, within the mapped area, of upper Paleozoic and Mesozoic rocks is notable. This is due to removal, by erosion, of these units from topographic highs formed during the Laramide orogenic event.

It is generally considered that the Laramide orogeny started in late Jurassic time and extended into the early part of the Tertiary Period. The thrust faults of the region apparently become progressively younger eastward. Eastward from the Paris thrust fault, stratigraphic evidence shows late Jurassic movement. This is based upon the composition of a late Jurassic to early Cretaceous conglomerate known as the Ephraim. In general, the Ephraim is composed of Paleozoic rocks including boulders of the Swan Peak Formation. It has been suggested by Armstrong and Cressman (1963, p. 13) that the Ephraim is a product of the same orogeny that produced the Paris thrust fault. Armstrong and Oriel (1965, p. 1857) showed that the Prospect thrust fault of western Wyoming is early Eocene in age. This is based on the observation that it cuts the lower part of the Hoback Formation which is of Paleocene and earliest Eocene age but does not cut the upper part of the formation which is of later Eocene age. Therefore, the Laramide orogeny is a late Jurassic to early Eocene event.

Structural Interpretation

The Laramide orogeny subjected the rocks of the mapped area to compressive forces which folded and thrust faulted the strata. The relative timing of the folding and thrust faulting, in the mapped area, is indeterminate. This is because these structures are not closely associated in the field. The asymmetrical anticlines, however, probably formed contemporaneously with the thrust fault. The relatively steep dips of the eastern limbs of the anticlines and eastward movement on the thrust fault are indicative of Laramide compressive forces.

Folding and thrust faulting, in the region, have been attributed either to east-west compressional forces or to sliding under the influence of gravity. Armstrong and Cressman (1963, p. 19) suggested that the Bannock thrust zone formed in response to east-west compressive forces. Armstrong and Oriel (1965, p. 1861) discussed both mechanisms as possibilities for thrusting in the Idaho-Wyoming thrust belt. Crittenden (1972, p. 2879) attributed the Willard thrust fault and Cache allochthon to east-west compressional forces. Scholten and Ramspott (1968) advocated gravity tectonics to explain thrust faulting in the Beaverhead Range, Idaho-Montana. Mudge (1970) also advocated gravity tectonics in the area of northwest Montana. The basic premise of Mudge was that a large segment of the crust of the Earth was raised and thrust plates slid from it due to the influence of gravity. The sliding was from west to east. Studies by Hubbert and Rubey (1959) have theoretically shown gravity sliding to be valid under the appropriate conditions of slope and fluid pressure. High fluid pressures in the strata near the glide plane are particularly essential in areas of gently dipping strata.

The thrust fault, within the mapped area, is characteristic of those caused by east-west compressional forces. The olive-green, fissile shale of the Bloomington has been thrust eastward over the St. Charles on a west-dipping, low-angle thrust fault (pl. 1). As previously stated, the thrust fault places older rocks over younger rocks and eliminates part of the stratigraphic section above and below the thrust fault. The direction of overriding was from west to east. Thus, east-west compression, not gravity sliding, was the mechanism responsible for thrust faulting within the mapped area.

Basin and Range Events

High-angle normal faults, within the mapped area, are a product of Basin and Range faulting. The episode of faulting occurred after the thrust faulting and folding of the Laramide orogeny. Williams (1948, p 1153) assigned faults of essentially north-south trend, which cut the Wasatch and Salt Lake Formations, to Basin and Range events. These faults created relief which ranges up to thousands of feet. The marginal north-trending normal fault, along the western side of the mapped area, has probably undergone recent movement. This premise is based on recent movements that have occurred on the Wasatch fault in the region. If the marginal fault, within the mapped area, is an extension of the Wasatch, then recent movement has probably occurred on it.

Dating Basin and Range normal faulting is based upon the relationship of the faults to the Wasatch and Salt Lake Formations. The Wasatch Formation is thought to have been deposited on a nearly horizontal plain prior to normal faulting (Williams, 1948, p. 1159). The age of the formation is no older than earliest Eocene and no younger than middle early Eocene (Oriel and Tracey, 1970, p. 39). The major topographic features of the region are thought to have existed prior to the deposition of the Salt Lake (Adamson and others, 1955, p. 21). Rocks of the Salt Lake are found to overlap Paleozoic rocks and the Wasatch Formation at lower elevations on surrounding mountains (Adamson and others, 1955, p. 21). This, of course, means that the Salt Lake was deposited following most of the normal faulting within the region. Although the Wasatch Formation is not present within the mapped area, rocks of the Salt Lake Formation are located at lower elevations and rest unconformably on Paleozoic rocks. The Salt Lake Formation ranges in age from Oligocene (Eardley, 1944, p. 845) to Pliocene (Yen, 1947, p. 272). Thus, normal faulting began as early as Oligocene and has continued into the Holocene as evidenced by recent earthquake activity in the region.

Structural Interpretation

All sets of normal faults, in the mapped area, are attributed to Basin and Range faulting regardless of trend. North-trending normal faults are the most numerous. Stewart (1971, p. 1026-1027) characterized the Basin and Range Province as consisting of mountain horsts and valley grabens produced as a consequence of normal faulting. The normal faults are attributed to deep zones of extension over an expanding substratum resulting in collapse of the upper crust (Stewart, 1971, p. 1021).

The northwest-trending normal faults, within the mapped area, often have great stratigraphic displacement. Displacement is generally down on the southwest. Two northwest-trending faults in the southwestern part of the mapped area near Bill Morgan Canyon are down on the northeast. DeVries (1977) mapped a series of northwest-trending faults directly south of the mapped area. Most of the northwest-trending faults, in this area, are also down on the northeast. This relationship suggests that a northwest-trending graben exists between the second northwest-trending fault, within the mapped area, and the tenth northwest-trending fault which is down on the southwest. The latter fault extends from a north-trending fault in NE¼ sec. 26, T. 12 S., R. 36 E., near Birch Creek, and terminates at its intersection with an east-trending fault in SW¼ sec. 6, T. 12 S., R. 36 E., near an outcrop of Tertiary volcanic rocks. The northwest-trending faults are probably the result of tensional forces acting at depth. They may reflect basement control.

North-trending normal faults are the most numerous, within the mapped area, and generally cut the northwest-trending faults. They are either contemporaneous or somewhat younger than the northwest-trending faults. The marginal north-trending fault, along the western side of northern Elkhorn Mountain, is responsible for the topographic relief along the mountain front. This fault may be an extension of the Wasatch fault and reflect a basement fault pattern. One major north-trending fault, on the eastern side of

Elkhorn Mountain, may be an extension of the Wasatch fault zone and also may reflect basement control. This fault extends from the southern limit of the mapped area in NW¼ sec. 34, T. 12 S., R. 36 E., where it is covered by colluvial deposits, into NW¼ sec. 5, T. 12 S., R. 36 E. It possibly continues beyond the northern limit of the mapped area. The fault apparently offsets a major northwest-trending fault as previously described. Displacement is down on the east. Shearer (1975) mapped a marginal north-trending fault on the western side of his area. It projects into the northeastern part of the mapped area, east of Interstate 15, where it is largely covered by colluvial deposits. Displacement on this fault is down on the west. This relationship suggests that a north-trending graben exists in the area between the extensions of these two north-trending normal faults. The north-trending faults are probably the result of tensional forces acting at depth.

Two northeast-trending normal faults are present in the mapped area and are generally limited in extent and amount of displacement. Northeast-trending normal faults of the region have been attributed to strike-slip faulting produced during Laramide thrusting, but detailed field evidence is contrary. Vertical slickensided surfaces on one of the northeast-trending faults indicate that it is the result of tensional forces acting at depth.

One east-west-trending normal fault is present in the mapped area. It is of limited extent, although the amount of displacement along segments of the fault is great. East-west-trending normal faults of the region have been attributed to strike-slip faulting produced during Laramide thrusting, but detailed field evidence is again contrary. Vertical slickensided surfaces on this fault indicate that it is the result of tensional forces acting at depth.

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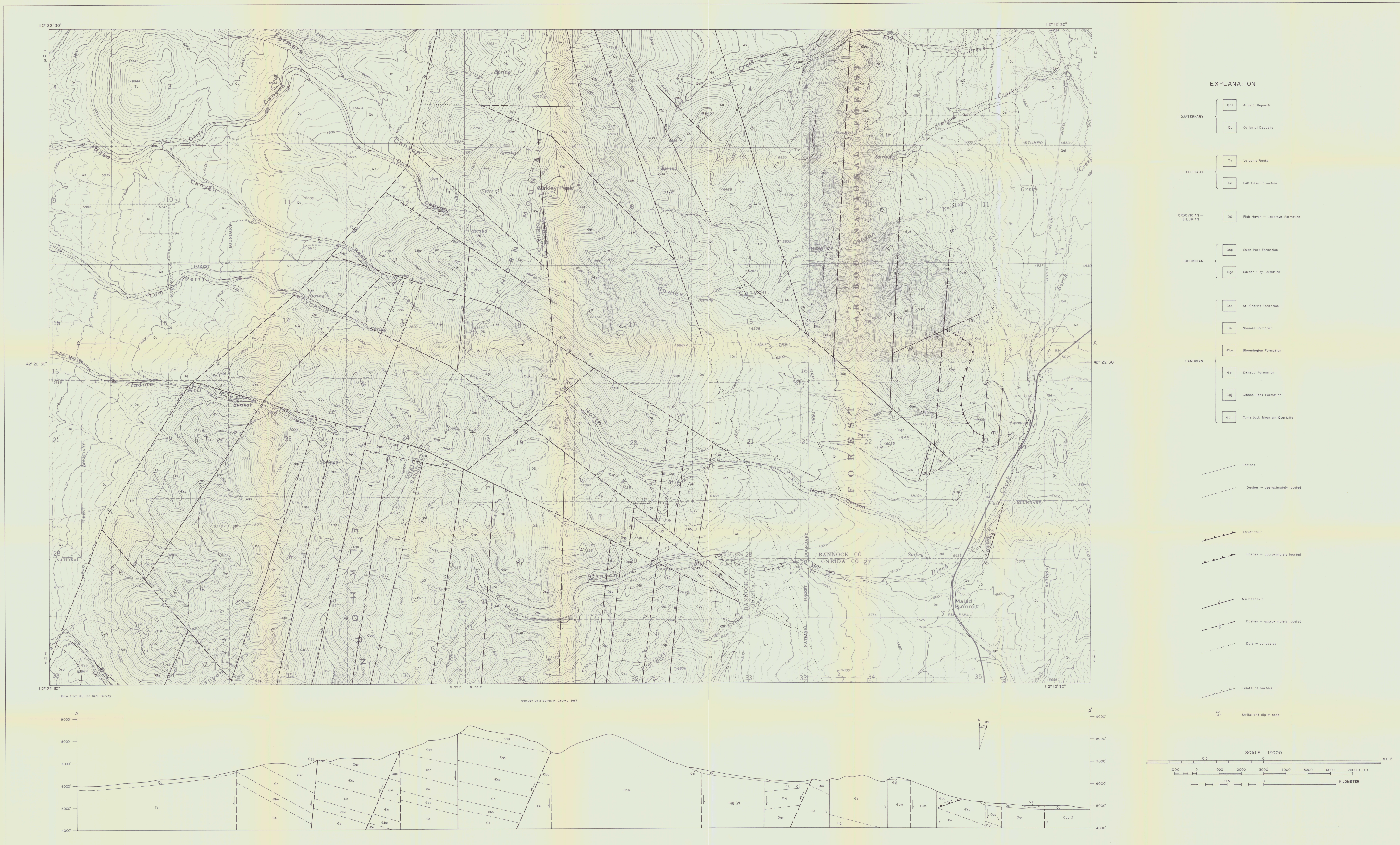

GEOLOGIC MAP OF THE NORTHERN PART OF ELKHORN MOUNTAIN, BANNOCK RANGE, IDAHO