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Geology and Mineralization of the Southeastern Part of the Black Pine Mountains, Cassia County, Idaho

Don E. French

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GEOLOGY AND MINERALIZATION OF THE SOUTHEASTERN PART OF THE BLACK PINE MOUNTAINS,
CASSIA COUNTY, IDAHO

by

Don E. French

A thesis submitted in partial fulfillment of requirements for the degree of

MASTER OF SCIENCE

in

Geology

Approved:

________________________________________
Major Professor

________________________________________
Committee Member

________________________________________
Committee Member

________________________________________
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1975
ACKNOWLEDGMENTS

The author is grateful to Dr. Donald R. Olsen, Dr. Clyde T. Hardy, and Dr. Richard R. Alexander for their assistance in preparation of this report. Helpful comments were also given by Mr. Richard Harris and Mr. Perry West of Newmont Exploration Ltd. and by Mr. Louis Cramer of Salt Lake City, Utah. An important contribution was made by Patricia S. French who provided encouragement and financial and technical assistance.

Don E. French
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ABSTRACT

Geology and Mineralization of the Southeastern
Part of the Black Pine Mountains,
Cassia County, Idaho

by

Don E. French, Master of Science
Utah State University, 1975

Major Professor: Dr. Donald R. Olsen
Department: Geology

The southeastern part of the Black Pine Mountains is located in the southeastern part of Cassia County, southern Idaho. The Utah-Idaho state line is three miles south of the studied area and the Cassia-Oneida county line bounds it on the east. The area is nearly square and encompasses about 30 square miles.

Devonian, Mississippian, Pennsylvanian, Permian, Tertiary and Quaternary sedimentary rocks are exposed within the area. Limestone, dolomitic limestone, quartzite, and bedded chert represent the Jefferson (?) Formation of Devonian age. It is 400 feet thick, however, the base is not exposed.

The Milligen Formation is Early Mississippian in age and is black argillite with interbedded orthoquartzite. The Milligen is about 1,850 feet thick. The Late Mississippian White Knob Formation is 2,400 feet thick and has two members. The lower member is limestone interbedded with calcareous siltstone. Massive blue-gray limestone with some chert nodules characterizes the upper member.
The undifferentiated Pennsylvanian-Permian unit is 1,800 feet of mostly sandy limestone. Quartzite and calcareous sandstone are also present. Tertiary rocks are present in the form of an orangish-white tuff which is considered part of the Salt Lake Formation. Lake Bonneville Group, alluvial, and landslide deposits represent the Quaternary System. Most of these are unconsolidated silt, sand, and gravel deposits. However, the Lake Bonneville Group displays a tightly cemented shore-line deposit in places.

The effects of metamorphism are common in the area. The Milligen shows signs of contact and tectonic metamorphism. In places it has been bleached or altered to slate and phyllite. The White Knob Formation has been marblized at several locations.

Igneous activity has emplaced two small dikes on the eastern flank of the Black Pine Mountains. Although they are highly altered, the original rock was apparently a diabase.

The structure of the area is complex. Three low-angle thrust faults are present which are generally situated along bedding planes. The lower thrust fault separates the Jefferson (?) and Milligen formations. The middle thrust fault intervenes at the Milligen-White Knob contact. Locally, this thrust fault has cut out the lower member of the White Knob. The upper thrust fault is present at the base of the undifferentiated Pennsylvanian-Permian strata. The upper thrust fault overlies the White Knob and, locally, the Milligen. Several high-angle faults are present which displace the low-angle thrust faults. A
major range-front fault is present on the southeastern side of the range. Displacement on it may be as much as 6,500 feet.

Mineralization in the area occurred during two episodes. The first was guided by fractures related to Laramide structure. This episode was characterized by mesothermal deposits of sphalerite, tetrahedrite, and jamesonite. Following the first mineral deposition Basin-and-Range faulting began. New fractures provided a locus for mesothermal and epithermal deposits of the second episode. Calcite, barite, and gold were deposited at this time. Emplantation of the dikes probably accompanied this episode.

(81 pages)
INTRODUCTION

Purpose and Scope

The purpose of this thesis is to map the geology of the Black Pine mining district. In addition, an attempt is made to relate the stratigraphy to that of the region. Mineralization is discussed with respect to previously unrecognized structures. Little detailed work has been done on the geology of the Black Pine Mountains. Recently, Newmont Exploration Ltd. has begun an investigation of the mineralization on the eastern slope of the mountains and the U.S. Geological Survey is preparing a geologic map of the Strevell quadrangle, Idaho. The southeastern part of the mountains has been the scene of some small scale mining activity.

Location and Accessibility

The area under study encompasses about 30 square miles of the southeastern part of the Black Pine Mountains and adjoining Curlew Valley (Figure 1). All but the eastern edge of this area is within the confines of Sawtooth National Forest. The area is nearly square, measuring 5.25 miles north-south by 5.5 miles east-west. The mapped area is located entirely within the southeastern quarter of the Strevell, Idaho quadrangle. The Oneida-Cassia county line bounds the study area on the east. The Utah-Idaho state line is three miles south.
Figure 1. Index map of parts of southern Idaho and northern Utah showing location of the southeastern part of the Black Pine Mountains.
Gravel and unimproved roads provide access to the district from Utah Highway 30, which is paved. Most roads are unimproved and are cuts made in conjunction with mining activities. Although travel is difficult in places, these roads provide good access to remote localities. No place is more than 1.5 miles horizontally and 2,000 feet vertically from a trail passable by a four wheel drive vehicle. During the summer of 1974, Newmont Exploration Ltd. put in some roadwork on the lower slopes of the eastern flank of the range. The new roadwork is not shown on the reconnaissance map.

Physiography

The Black Pine Mountains are situated in the northeastern part of the Basin-and-Range province. The range is 17 to 18 miles long and trends roughly northwest-southeast. It is three miles wide at the northern end and nine miles wide at the southern end. Curlew Valley borders the mountains on the east and south, the Raft River Valley borders the western flank and Juniper Valley limits the range to the northeast.

The mapped area may be divided into three sections. The eastern third lies within Curlew Valley and slopes down gradually eastward from the base of the mountains. This slope is interrupted by three prominent terraces which mark former shorelines of Lake Bonneville.

The middle section is characterized by steep slopes rising from the base of the mountains to a divide which trends north-south. This divide reaches a maximum elevation of 8,008 feet at Black Pine Cone and is deeply cut by
several east-trending draws. The southern reaches of this section have a more subdued topography. Two areas of low hills bracket a gently southeast sloping planar surface known as Burnt Basin.

The western third of the study area encompasses Black Pine Canyon. The canyon drains to the south and is defined on the east by the previously mentioned divide. War Eagle Peak, highest point within the area, is over 8,720 feet above sea level. A series of limestone cliffs separate the canyon from Pole, Mill Fork, and East Dry canyons to the north. A north-south divide, which reaches an altitude over 7,800 feet in places, separates Black Pine Canyon from Formation and Kelsaw canyons. Nearly 4,000 feet of topographic relief is present within the mapped area.

Vegetation and Water Supply

Valleys, canyons, and lower slopes in the southeastern part of the Black Pine Mountains are covered by stands of juniper, sage brush, and grasses. Blueberry and aspen are common in the bottoms of the major canyons.

Sagebrush and grasses are found on upper slopes, hills, and ridges, but are less abundant. Mountain mahogany is common on rugged slopes and dense stands of aspen are centered around springs and drainages. Conifers are found exclusively on north-facing slopes.

The Black Pine Mountains receive between 10 and 15 inches of rainfall annually, which classifies the area as semiarid. Vertical variation of precipitation, however, is great. War Eagle Peak and the area around Silver Hills
mine receive about 35 inches of precipitation per year. In the vicinity of the Tolman mine, the average is 20 to 25 inches. Curlew Valley rarely gets more than 12 inches in a year (Bolke and Price, 1969). Most of the precipitation is in the form of snow during the winter months. Summer moisture is provided by occasional thunderstorms.

The stream in Black Pine Canyon is intermittent and dry by late summer. It carries a substantial amount of runoff in the spring and early summer, which may render the road following the canyon impassable. All perennial springs in the mapped area are in Black Pine Canyon. Several of these have been improved and now supply stock tanks. One, which issues from just below the Silver Hills mine, was utilized during operation of that mine (Anderson, 1931, p. 137). The eastern flank of the mountains is dry. The nearest year-round source of water to the Tolman mine is Black Pine Spring, located three miles southeast and 1,500 feet below the mine. It has been improved for stock and flows at a rate of one gallon per minute (Bolke and Price, 1969, p. 29).

Methods of Investigation

Mapping was done directly on vertical aerial photographs obtained from the U.S. Forest Service at a scale of 1:19,200. Later, details were transferred to a base map drafted from an enlargement of the Strevell, Idaho, 15-minute quadrangle topographic map. The scale of the base map is 1:12,000. It has a contour interval of 200 feet. Stratigraphic thicknesses were estimated
from field observations and structure sections. Field work was begun and representative rock samples were collected in late June, 1974, and continued through October of the same year.

Laboratory work included the preparation of thin sections and disaggregation of samples during the winter months of 1974-75. Samples were disaggregated in acetic acid in an attempt to find microfossils. Fossils were identified by Dr. Richard R. Alexander.

Previous Investigations

Mining activity began in the Black Pine district during the 1880's but drew no attention until 1919 when Esper S. Larsen made a short report on cinnabar deposits at the Valentine property (Larsen, 1919). In 1931, A. L. Anderson made a reconnaissance of eastern Cassia County which included all of the Black Pine Mountains (Anderson, 1931). Northern Curlew Valley was mapped in a gravity survey of northwestern Utah by Cook, Halverson, Stepp, and Berg (1964). Investigations are currently being conducted near the Tolman mine by Newmont Exploration Ltd. The geology of the Strevell quadrangle is being mapped by the U. S. Geological Survey.
STRATIGRAPHY

General Statement

The great thickness of Paleozoic rocks in the Black Pine Mountains was first noted by Larsen (Larsen, 1919, p. 66). Formations of Mississippian, Pennsylvanian, and Permian age were mapped and named Brazer, Wells, and Phosphoria Formations respectively (Anderson, 1931). Anderson (1931) also mapped Tertiary Payette or Salt Lake Formation on the flanks of the range.

Recent field work has revealed the presence of about 6,500 feet of Paleozoic strata (Table 1) as well as rocks of Tertiary and Quaternary age in the study area. In addition, some metamorphic and igneous rocks are present. The Jefferson (?) Formation is the oldest formation exposed. It is about 400 feet thick and represents the Late Devonian. Early Mississippian rocks are present in the form of 1,850 feet of black, nonfossiliferous argillite and interbedded quartzite designated as the Milligen Formation. An overlying thickness of limestone interbedded with some shale and calcareous siltstone represents the White Knob Formation. This part of the section is 2,400 feet thick and is Late Mississippian in age. The Pennsylvanian and Permian Systems are not differentiated in this report and are represented by about 1,800 feet of sandy limestone, calcareous sandstone, and quartzite. No Mesozoic rocks are present in the area. Deposits of Cenozoic age exist in the form of the Tertiary Salt Lake Formation
Table 1. Generalized stratigraphic section of the southeastern part of the Black Pine Mountains.

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<tr>
<td>Undifferentiated Pennsylvanian-Permian unit. Light- to dark-gray, fine- to very fine-grained, sandy limestone and calcareous sandstone interbedded with grayish-brown to reddish-gray orthoquartzite.</td>
<td>1,800</td>
</tr>
<tr>
<td><strong>upper thrust fault</strong></td>
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<td><strong>Mississippian System</strong></td>
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<tr>
<td>White Knob Formation</td>
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<tr>
<td>Upper member. Blue-gray, very finely crystalline, massive limestone with dark-gray chert nodules.</td>
<td>800</td>
</tr>
<tr>
<td>Lower member. Dark-gray, finely crystalline limestone interbedded with calcareous siltstone, black shale, sandy limestone, and light-gray orthoquartzite.</td>
<td>1,600</td>
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<td><strong>middle thrust fault</strong></td>
<td></td>
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<tr>
<td>Milligen Formation.</td>
<td>1,850</td>
</tr>
<tr>
<td>Black to dark-gray argillite interbedded with light-gray lenticular beds of orthoquartzite.</td>
<td></td>
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<td><strong>lower thrust fault</strong></td>
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<td><strong>Devonian System</strong></td>
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<td>Jefferson (?) Formation.</td>
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<tr>
<td>Medium- to light-gray, finely crystalline, limestone interbedded with dolomitic limestone and bedded chert.</td>
<td></td>
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\(^{a}\) Locally separates Pennsylvanian-Permian unit and Milligen Formation.

\(^{b}\) Locally separates upper member White Knob Formation and Milligen Formation.
and the Quaternary Lake Bonneville Formation. Other mapped Holocene de­
posits include colluvium, stream alluvium, landslide debris, and alluvial fans.

Beds of Paleozoic age are involved in a complex structural setting. In­
tense folding and low-angle thrust faulting precluded efforts to obtain precise
formation thicknesses and hampered attempts to reconstruct an accurate
stratigraphic sequence.

**Devonian System**

**Jefferson (?) Formation**

Devonian outcrops have not previously been recognized in the Black Pine
Mountains (Anderson, 1931). In recent years, the existence of Devonian dolo­
mitic limestones have been confirmed in wells in Curlew Valley (Peace, 1956, p.
28-31) and suggested at the surface in the Albion Range (Armstrong, 1968b, p.
1303). The confluence of several structures has provided an isolated exposure
of about 400 feet of dolomitic limestone with interbedded quartzite and chert in
Black Pine Canyon. This outcrop is tentatively identified as the Jefferson (?)
Formation. Although the cliffs in Black Pine Canyon are dissimilar to the type
section of the Jefferson at Three Forks, Montana (Peale, 1893), they do re­
semble upper members of the formation present in the Blue Springs Hills (Beus,
1963, p. 30-42), and the Promontory Range (Olson, 1960, p. 107).

The only outcrops of this formation are located near the center of Black
Pine Canyon. The exposures are at the canyon fork and along the eastern side
of the canyon for a distance of 2,000 feet downstream from the fork. The
formation forms both sides of a small narrow gorge for 0.5 mile up the east fork. Outcrops are continuous from the western wall of the gorge, across the promontory separating the east and west forks, to the eastern wall of the west fork. A small outcrop is present on the western slope overlooking the confluence of the east and west forks.

A maximum thickness of about 400 feet of this formation is exposed. Limestone is the dominant lithology with interbedded dolomite limestone quartzite, and chert. It is thick bedded and beds are separated by undulating gradational contacts. The unit forms a steep, terraced, light-gray to white cliff.

The limestone is medium to thick bedded. Texture ranges from very finely crystalline to lithographic. Fresh surfaces are medium gray and weather light gray. Locally the limestone has thin, irregular fractures healed with coarsely crystalline calcite.

Dolomitic limestone beds are common in the lower parts of the outcrop. There, they are interbedded with limestones and quartzite. The dolomite beds are thick to massive and weather white to grayish-white. Blue-gray chert exists in the middle and upper parts of the outcrops. It is present in the form of lenticular beds 0.5 to 1.5 feet thick. Contact with surrounding beds is normally gradational. The chert beds frequently display slickensides and brecciation. Medium-to thick-bedded, light-gray orthoquartzite is found interbedded throughout the exposure.

The outcrop is discontinuous because of structure. A high-angle thrust fault limits exposures to the south. Elsewhere, the formation disappears.
beneath the overlying black argillite. A bedding plane thrust fault is at the top of the Jefferson (?). The basal contact is not exposed.

The few fossils found in this formation were not identified due to a poor state of preservation. Age was inferred from stratigraphic relationships and lithologic similarity.

Outcrops of dolomitic limestone are rare in this part of Idaho. The nearest recorded existence of Devonian rocks is in Curlew Valley where wildcat wells have bottomed in the Jefferson (?) Formation (Peace, 1956, p. 30). An interesting, metamorphosed sequence is found in the Albion Range 35 miles to the southwest. There, a thick section of dolomite is believed to be equivalent in part to the Jefferson Dolomite (Armstrong, 1968b, p. 1313).

**Mississippian System**

**Milligen Formation**

Mississippian rocks are represented in the southeastern part of the Black Pine Mountains by carbonaceous argillite and limestone. Anderson (1931) mapped both rock types as the Brazer Formation. He described several hundred feet of black shale overlain by thin-beded limestone (Anderson, 1931, p. 30-33). Recent observations revealed a similar sequence but, the carbonaceous argillite formation is estimated to be 1,850 feet thick. It has been demonstrated that the Brazer nomenclature is inappropriate outside of northeastern Utah (Sando, Dutro, and Gere, 1959). Therefore, the terms Milligen and White Knob are used to refer to the argillite and limestone respectively.
The Milligen Formation was first described in the Wood River region of south-central Idaho (Umpleby, Westgate and Ross, 1930). Since then, the Milligen nomenclature has been adopted throughout south-central Idaho as far east as the Idaho-Montana state line. Upper Paleozoic sedimentation was complicated in this region, but significant features have been summarized by Ross (1962b and 1962c). The area of interest for this report is that between the Pioneer Mountains and the Beaverhead Mountains. There, the Milligen is found underlying an upper Mississippian limestone, the White Knob Group. Application of Milligen terminology south of the Snake River Plain has been considered by several workers (Youngquist and Haegele, 1955, p. 2080; Bissell, 1960, p. 1427; Cramer, 1971, p. 1798).

The Milligen Formation is exposed in the upper reaches of Black Pine Canyon. The low divide between the canyon and Kelsaw Canyon, to the west, is also underlain by the formation. The drilling done by Newmont Exploration Ltd. on the eastern flank of Black Pine Cone has penetrated the Milligen at depths of a few hundred feet at several sites.

This formation is about 1,850 feet thick with an estimated maximum of 2,100 feet. The primary lithology is carbonaceous argillite with some interbedded quartzite. Olive-gray siltstones are found near the top and base of the formation. A single conglomerate outcrop is also situated near the base. Locally, metamorphism has altered the argillite to slate or phyllite and has bleached some of the beds. Everywhere, the Milligen shows signs of intense
tectonic activity. It has absorbed far more deformation than the bounding formations above and below.

Black argillite comprises most of the formation. Bedding appears as alternating black and dark-gray laminations. In places, it is fissile but more often weathers as small blocks. Concretions are common in the upper parts of the section. They are usually 2 to 4 inches in diameter, ovoid, and have an iron-rich, orange-brown, core. The argillite can sometimes be found forming low ledges, but it usually weathers to a smooth debris-strewn slope. Fractures lined with iron oxide, often displaying slickensides are abundant. Quartz veinlets are also a common feature.

Lenticular beds of orthoquartzite are distributed throughout the section. Thicknesses range from less than a foot to almost 70 feet. Most beds are massive, though thinner bedding is locally observable in the form of dark-gray laminations. Fresh surfaces have a sugary appearance and are light gray. Weathered surfaces are mottled with colors ranging from light gray to reddish brown. The beds stand out as ledges and knobs in the argillite.

Olive-gray siltstone is interbedded with black argillite just above the basal contact and again near the top of the formation. These beds are fissile and form poor outcrops.

Two parallel ledges of quartzite-pebble and chert-pebble conglomerate are on the western side of the east fork of Black Pine Canyon, about 1,500 feet upstream from the Jefferson (?) exposures. Black argillite is above and below these beds. Each is about 20 feet thick and separated by an equal interval of
cover. The beds are paraconglomeratic with subangular to rounded pebbles set in a matrix of quartz sand, silica cement, and limonite. Lenticular bodies of siltstone that are a few inches long are also present. Chert and quartzite pebbles range from black to light gray. Siltstone is gray to olive gray and streaked with orange-brown limonite. Iron oxides stain weathered surfaces dark reddish brown. The beds seem to be lenticular and form highly jointed and broken ledges.

The Milligen underlies an area of low topographic relief, which is characterized by smooth slopes occasionally interrupted by quartzite ledges and knobs. The slopes are often barren. Both upper and lower contacts of this formation are tectonic.

Fossils were not found in the Milligen in the Black Pine Mountains. Workers in the Sublett Range have reported a shale which has been equated with the argillite exposed in Black Pine Canyon (Youngquist and Haegele, 1955, p. 2080). Samples of the formation in the Sublett Range have been searched for microfossils without success, but a few pelecypods from it have been dated Mississippian or earliest Pennsylvanian (Youngquist and Haegele, 1955, p. 2080). Fossils from the overlying limestone formation in the study area indicate the Milligen cannot be younger than middle Meramecian. In south-central Idaho, the age of the Milligen has been clearly defined as Kinderhookian (Sandburg, Mapel, and Huddle, 1967) through middle Meramecian (Mamet, Skipp, Sando, and Mapel, 1971, p. 21-23).
In the North Promontory Range, 25 miles east of Black Pine Canyon, a section was measured by Louis W. Cramer in 1947 (Cramer, 1974, per. comm.). The section includes over 1,800 feet of black shale overlain by late Mississippian limestone. A correlation of this section to the Milligen of the Black Pine area seems reasonable. To the west, a correlation may exist with the Albion Range. There, a graphitic schist in the View Formation overlies a thick succession of dolomite, which may represent in part the Jefferson (Armstrong, 1968b, p. 1302).

A seemingly anomalous section exists in the Deep Creek Mountains, 40 miles northeast of exposures of the Milligen in Black Pine Canyon. There, the Deep Creek and Lodgepole formations are present instead of the Milligen. The Deep Creek Formation is present on the upper plate of a thrust fault five miles east of the Deep Creek type section. Parts of it contain black shale which was compared to the Chainman shale of northeastern Nevada by Carr and Trimble (1961, p. 181). However, this may represent conditions similar to those described in the Beaverhead Mountains. There, the basal Milligen intertongues with the Lodgepole Formation (Sandberg, Mapel, and Huddle, 1967, p. 130).

Early Mississippian strata of northeastern Nevada and western Utah are represented by the Joanna limestone. A black argillite is present in this region but this formation, the Chainman shale, is generally regarded as upper Mississippian (Sadlick, 1960; Langenheim and Larsen, 1973). In recent years, lower Mississippian shales and dark mudstones have been reported from northern

Attempts have been made to relate the Chainman and Milligen formations (Bissell, 1960, p. 1431; Churkin, 1962; Roberts and Thomasson, 1964). These efforts are inhibited by a lack of detailed work between south-central Idaho and northeastern Nevada. Exposures in the Sublett Range and Black Pine Mountains could provide an opportunity to fill in this gap.

**White Knob Formation**

Late Mississippian limestone present in the Black Pine Mountains was originally considered the upper part of the Brazer Formation (Anderson, 1931). Anderson (1931, p. 30-33) described about 1,000 feet of thin bedded limestone overlain by 400 feet of massive limestone. Recent investigations indicate that the total limestone thickness is about 2,400 feet.

Because the Brazer usage should be restricted to the northeastern part of Utah (Sando, Dutro, and Gere, 1959), the White Knob terminology is adopted for the Late Mississippian limestone of the Black Pine Mountains. The White Knob Formation was first described in the White Knob Mountains of south-central Idaho (Ross, 1962a). Subsequent work has identified the White Knob underlain by the Milligen Formation, (Ross, 1962b) and has elevated the name to group status (Huh, 1967). The White Knob Group displays marked lateral variations north of the Snake River Plain. However, the Upper Pashimeroi section in the
Lost River Range (Huh, 1967) is similar to the White Knob in the Black Pine Mountains. The White Knob terminology has not previously been used south of the Snake River Plain.

Outcrops of the White Knob Formation are widespread in the southern part of the Black Pine Mountains. Impressive cliffs of this limestone are present on War Eagle Peak and the mountain top above the Silver Hills mine at the head of Black Pine Canyon. Less spectacular outcrops are found on each side of the lower part of Black Pine Canyon. On the eastern flank of the mountains, exposures of the formation are nearly continuous from Mineral Gulch to the southern edge of the studied area. The formation is truncated on the high slopes around Black Pine Cone by a thrust fault. Other outcrops outside the mapped area can be found in Kelsaw and Formation canyons and other parts of the southwestern corner of the range.

Two members can be distinguished in the White Knob Formation. The lower one, 1,600 feet thick, is limestone interbedded with silty and sandy beds. The upper member is about half as thick and is mostly massive, thick-bedded, blue-gray limestone.

The lower two-thirds of the White Knob Formation is comprised of interbedded limestone, argillite, calcareous siltstone, sandy limestone, and quartzite. Few beds reach 20 feet in thickness although some are as great as 100 feet thick. The entire member is between 1,550 feet and 1,650 feet thick.

Limestone beds are generally thicker and more common than beds of other rock types. Bedding ranges from platy to massive. Bedding planes are
often irregular. Fresh surfaces reveal a light- to dark-gray limestone which may be finely crystalline to lithographic. These beds are locally recrystallized. Disaggregated samples, collected from a hill above the Tolman mine, had abundant microscopic quartz and euhedral pyrite crystals. Weathered surfaces range from light gray to grayish brown. Usually, the limestone beds have been fractured and healed with coarsely crystalline calcite. Some veins reach a foot in thickness.

Siltstones are common throughout the lower member and are especially abundant near the base. The beds are usually calcareous and are sometimes fissile. Poor exposures usually prevented observations of bedding. The siltstone is usually grayish brown to light brown, but near the base a red bed was observed, which weathers pinkish gray. Black fissile shale beds are common near the base of the member. A few beds of light-gray orthoquartzite are near the base and in the middle of the member. These beds are only a few feet thick and range from light to dark gray. They weather brownish gray and display fractures filled with white quartz.

The lower member forms uneven slopes which are broken regularly by ledges and knobs of the thicker limestone beds. A thrust fault intervenes at the base of the member and locally slices out much or all of it. The upper contact is arbitrarily placed at the base of the first massive bed of the upper member and is believed to be conformable.

The lower member is locally fossiliferous, although most specimens are distorted or silicified beyond useful recognition. Horn corals are abundant at
one horizon near the base. They were identified as Faberophyllum sp. (Figure 2). A few recognizable brachiopods were collected from the middle of the member and have been identified as Composita sp. and Neospirifer sp. Ramose bryo-ozoans and crinoid columnals are abundant in some beds but silicification has prevented more refined identification. A few forms of fenestellids and Stenopora sp. are also present. One sample was found to have some blastoid brachioles which are also silicified (Figure 3). Disaggregation of samples has not resulted in the discovery of microfossils.

The upper 800 feet, ± 50 feet, of the White Knob Formation is a monotonous sequence of massive blue-gray limestone interrupted occasionally by a thin bed of sandy limestone. About 50 feet of interbedded limestone and siltstone is at the top of the member.

Very-finely crystalline to lithographic limestone makes up the bulk of this member. Beds are thick to massive and bedding planes are irregular. Fresh surfaces are usually blue gray to dark blue gray and weather light gray to blue gray. Dark gray chert is common in different forms in this member. It is present as small concentrically layered nodules, and spherical nodules which range up to four inches in diameter. Another distinctive type is present as irregular shaped stringers; these are also dark gray but weather brownish gray and stand out as small knobs on limestone surfaces. Coarsely crystalline veins of calcite are abundant and locally the limestone has been silicified.

This member weathers as steep rugged cliffs and is the most distinctive rock type in the area. A bedding plane thrust fault is present where the upper
Figure 2. Faberophyllum sp. collected from Black Pine Canyon. Late Mississippian horn coral present in the lower member of the White Knob Formation. Longitudinal cross section on left.

Figure 3. Blastoid brachioles collected from hill north of the Tolman mine. The brachioles are present in the lower member of the White Knob Formation and have been silicified.
contact has not been eroded away. The basal contact with the lower member of the White Knob is believed to be conformable. At the Silver Hills mine, thrusting has cut out the lower member, and the massive unit is in tectonic contact with the underlying Milligen. Fossils are uncommon in the upper member and those found were poorly preserved.

The *Faberophyllum* coral zone firmly establishes the base of the White Knob Formation in the Black Pine Mountains as no younger than middle or late Meramec (Dutro and Sando, 1963). A section has been examined in the Lost River Range and its age there is late Meramecian and Chesterian (Mamet, et al., 1971).

Outcrops of upper Mississippian limestone have not been reported in the Sublett Range. Youngquist and Haegele (1955) found volcanic ash and tuff covering the interval between black shale and the adjacent Pennsylvanian sandstones. Later, the presence of a thrust fault between the shale and sandstone beds was verified (Cramer, 1971, p. 1798). In the North Promontory Range, 2,200 to 2,400 feet of upper Mississippian limestone overlying a thick shale sequence were observed by Louis Cramer. Although the section was not described, the presence of a red bed near the base of the limestone was noted (Cramer, 1974, per. comm.).

Late Mississippian limestone is widespread in northern Utah and has usually been mapped as Great Blue Limestone (Olson, 1960; Adams, 1962; Beus, 1963). In northeastern Nevada, this period of time is represented by
the Chainman and Diamond Peak formations (Langenheim and Larson, 1973, Chart 1; Steele, 1960).

Pennsylvanian and Permian Systems

Undifferentiated Pennsylvanian-Permian unit

The Wells and Phosphoria formations undifferentiated were mapped underlying an overthrust in the Black Pine Mountains (Anderson, 1931). The Wells was described as being slightly less than 3,000 feet thick and the Phosphoria as not more than 700 feet thick.

Several names have been applied to rocks of Permian and Pennsylvanian age in the part of southern Idaho where they are widely exposed. In addition to Anderson's work, Piper (1924) described the Wells in the Sublett Range and other areas to the east. Wells terminology has also been used by Bissell (1960, p. 1427) and H. R. Cramer (1971) in the Sublett Range to describe Pennsylvanian rocks. Use of Wells terminology was not favored by Youngquist (1956) who felt that it would be equally appropriate to use the Wood River nomenclature of south-central Idaho. Permian strata have been referred to as the Park City Group by Bissell (1960, p. 1427) and Cramer (1971) in the Sublett Range. In addition, Cramer (1971) introduced the names Hudspeth Cutoff Sandstone, Tussing Sandstone, Trail Canyon Limestone, and Heydlauff Sandstone to describe the lower and middle Permian sections. Usage of the Pennsylvanian-Permian Oquirrh nomenclature has been applied to the Black Pine Mountains (Bissell, 1962),
Raft River Range (Felix, 1956), Albion Range (Armstrong, 1968b), and wells in Curlew Valley (Peace, 1956, p. 28-29). In light of these earlier works, it would seem wisest not to add to the confusion at this time.

Beds of Pennsylvanian to Permian age are widespread within the mapped area. Outcrops are found north of War Eagle Peak and the Silver Hills mine area. East Dry Canyon is cut into the unit. The area between East Dry Canyon and Mineral Gulch is underlain by the same strata. Outcrops are also located on the higher slopes around Black Pine Cone and a series of foothills on the eastern flank of the mountains southeast of the Tolman mine.

Accurate estimates of the thickness of this unit are impaired by its contorted condition and poor outcrops. A minimum of 1,800 feet is believed to be present in the southeastern part of the Black Pine Mountains.

The lower third of the section is dominated by sandy limestone with interbedded calcareous sandstone and a little quartzite. Fresh surfaces of the calcareous rocks are usually light gray but may be dark gray. The sandy limestone weathers medium gray, whereas the sandstone beds have tan or reddish-brown weathered surfaces. Grain sizes are uniform and fall between fine and very fine size limits. Beds are from a few inches to several feet thick and bedding planes are generally even but are locally irregular.

The overlying 1,200 feet are mostly fine-grained, light-gray, calcareous sandstone with subordinate beds of light-gray sandy limestone and quartzite. The quartzite members are grayish brown and weather light brown to dark reddish gray. Where they outcrop, beds are one to six feet thick.
Black Pine Cone is capped by a light- to medium-gray limestone interpreted as the uppermost bed of the unit. The texture is very fine grained. Many coarsely crystalline calcite veins cut the limestone, which overlies the lower beds of sandy limestone and quartzite.

Other beds in the unit are locally cut by calcite veins, but these are less common than in the underlying White Knob Formation. Chert is common in the lower parts of the formation. It is found in the form of lenticular beds one to six inches thick which weather dark grayish brown. Outcrops commonly show local brecciation.

Outcrops of the undifferentiated unit are poor. In many places it has weathered to form smooth steep slopes strewn in places with abundant debris. These debris slopes are a distinctive reddish brown, and make the formation readily identifiable from a distance. The debris are mostly pieces of light-gray calcareous sandstone encased in a siliceous rind which has weathered light brown to dark reddish brown.

The upper contact of this unit has been eroded away. The basal contact is a bedding plane thrust fault.

Fossils are rare and recrystallized. A few indeterminate bryozoans have been found.

The paucity of fossils in the undifferentiated Pennsylvanian–Permian strata has made age determination of the unit difficult. The age of the unit is inferred from stratigraphic position and lithologic correlation.
A thick sequence of Pennsylvanian and Permian strata is known in the Sublett Range (Cramer, 1971; Peace, 1956, p. 19). The rocks in the Black Pine Mountains are similar to the lower half of the section described by Youngquist and Haegele (1955). Their fusulinid study indicated the lower 2,000 feet were Pennsylvanian and earliest Permian in age. On this basis, the Black Pine strata should be equivalent with the Wells Formation in the Sublett Range (Bissell, 1960; Cramer, 1971).

**Tertiary System**

**Salt Lake Formation**

The Tertiary System in eastern Cassia County is represented by igneous and sedimentary rocks. Anderson (1931) mapped beds of ash, tuff, conglomerate, sand, clay, and marl as Payette or Salt Lake Formation. He believed exposures east of the Raft River Valley are similar to the Salt Lake Formation. In the vicinity of the Black Pine Mountains, the Tertiary formation was mapped on the northeastern flank of the mountains in Juniper Valley and on the western flank of the range near its northern end (Anderson, 1931).

A few outcrops, isolated by Quaternary deposits, are found near the southeastern corner of the study area. The exposures are situated in the western margin of Curlew Valley.

The Salt Lake Formation is of unknown thickness in the study area. Perhaps as much as 40 feet of volcanic ash are exposed lying unconformably over the Paleozoic units. Over 3,000 feet of unidentified tuffs and lava beds
have been penetrated by wells in Curlew Valley (Peace, 1956). The rocks are friable and have fine-grained shards. Colors range from white to grayish orange. Outcrops of the Salt Lake are poor and form a very gently rolling topography. No fossils were found.

The Salt Lake Formation has been dated as Pliocene in the Goose Creek district to the west (Mapel and Hail, 1956, p. 15-16). The outcrops in the study area resemble parts of the section described there. Tuffaceous sediments, ascribed to the Salt Lake Formation, are also recorded near the Raft River Range (Felix, 1956), the North Promontory Range, and the Summer Ranch Mountains (Adams, 1962). Felix (1956, p. 87) reported the existence of a Miocene or Pliocene fossil fish.

**Quaternary System**

**Lake Bonneville Group**

The eastern Great Basin region was intermittently occupied by ancient Lake Bonneville during the Pleistocene Epoch. An embayment of this lake extended into the Curlew Valley area and left three prominent terraces. The highest of these is found at an elevation of about 5,180 feet above sea level (Crittenden, 1963, p. 9). The Lake Bonneville Group is present below this elevation near the southeastern corner of the area studied.

Lake Bonneville deposits are mostly unconsolidated silt, sand, and gravel that is poorly sorted. Gravels are composed of subrounded to rounded pebbles, cobbles, and boulders, apparently derived from near-by outcrops of
Paleozoic beds. Soils have developed on the tops of the terraces. Often a cemented conglomerate is present on the terrace slopes. These are made up of sand and gravel tightly cemented with calcium carbonate, generally tufa.

**Other Quaternary deposits**

Quaternary deposits generally consist of unconsolidated silt, sand, and gravel, which is the weathered product of older consolidated rocks. Quaternary deposits are mapped as colluvium, stream alluvium, landslide deposits, and alluvial fans. These unconsolidated deposits are usually found at lower elevations in the area.

Various amounts of silt, sand, and gravel characterize the deposits. They are usually poorly sorted, but stream alluvium is capped by a well-developed soil. Quaternary deposits overlie the various Paleozoic and Tertiary formations with pronounced unconformity. The unconsolidated deposits are Pleistocene and Holocene in age.
Metamorphic Rocks

Metamorphic rocks in the study area are of generally low grades. Outcrops are scattered and small, but they should be noted.

The Milligen Formation displays a variety of metamorphic effects. On the west fork of Black Pine Canyon, beds of carbonaceous argillite have been bleached, apparently by contact metamorphism although no pluton was observed (Figure 4). Black slate with quartz veinlets can be found in the dumps of the Silver Hills mine (Figure 5). Pieces of gray phyllite are present at the base of the steep western face of Black Pine Cone. The slate and phyllite locations are situated near thrust faults and possibly have a tectonic origin.

The marblized parts of the White Knob Formation appear to be tectonic in origin (Figure 6). Best exposures are high on the eastern face of Black Pine Cone. Between the undifferentiated Pennsylvanian-Permian unit above and the White Knob below is a zone of marblized limestone and recrystallized breccia. This zone corresponds to the mapped location of a thrust fault. However, because an intrusive is postulated in the area, the recrystallization may have resulted from contact effects.
Figure 4. Milligen Formation, bleached argillite collected from the west fork of Black Pine Canyon. Light areas are result of contact metamorphism.

Figure 5. Milligen Formation, slate collected from near the Silver Hills mine. White hair-line features are quartz veinlets.
Figure 6. White Knob Formation exposure on eastern side of Black Pine Cone. Marblization is probably the result of tectonic metamorphism.
Igneous Rocks

Two small dikes, which are 1.5 to 3.0 feet wide, are situated a short distance uphill and north of the Tolman mine. They have been exposed by a bulldozer cut. The dikes are a few feet apart and are parallel. They apparently trend north-south and dip steeply, but are so badly weathered that exposures cannot be traced more than a few feet from the cut. Intrusion was into the White Knob Formation.

Two rock types are present in the dikes. The first has a porphyritic, subtrachytic texture. Phenocrysts are generally less than 0.5 mm in diameter. Calcite is abundant in this type as small veins and replaced phenocrysts. Relict pyroxene cleavage is frequently displayed by the calcite. Green secondary muscovite is also common. The orangish-tan iron oxide staining of the rock indicates that the muscovite is an alteration product of biotite. Some iron oxide is concentrated around small altered crystals of pyrite. Quartz is present as small anhedral crystals with undulatory extinction, suggesting stress conditions. It is often concentrated in small veins which are cut by calcite veins. Minor amounts of talc are also present. The second rock type has a porphyritic, subtrachytic texture with phenocrysts ranging from 0.25 to 3.0 mm. Secondary muscovite is present. Iron oxides are concentrated in small, dark reddish-brown euhedral masses which were once pyrite crystals. Quartz is present as microcrystalline replacement of phenocrysts. A few of these appear to be pseudomorphs after an amphibole. Some of the quartz phenocrysts are embayed and replaced by calcite. Some penninite is also present.
The original rock was probably a diabase which had pyroxenes, amphiboles and biotite. The first phase of alteration involved the introduction of silica. Quartz crystallized in small fractures and microcrystalline quartz replaced mafic minerals. Biotite probably altered to muscovite during the first phase. The second phase of alteration involved the introduction of calcite. Calcite is present as replacements of microcrystalline quartz which had formed during the first phase. Calcite also formed veins in new fractures and may have replaced remnant mafic minerals. Pyrite probably formed during the first two episodes of alteration. Alteration of pyrite to hematite and limonite is probably an effect of weathering. No dolomite or magnesite were detected by X-ray diffraction. Apparently the original rock was low in magnesium and may have had a composition more intermediate than basic.

Several lines of evidence indicate the existence of a stock beneath the southeastern part of the Black Pine Mountains. The concentration of mines and prospects there is one indicator. Contact metamorphism of the Milligen Formation in Black Pine Canyon is suggestive. Marblized limestone would also be supporting evidence if it has resulted from contact metamorphism instead of tectonic metamorphism.

Comparison with other near-by igneous rocks is hampered by the highly altered condition of the dike rock. It should be pointed out that intrusive rocks are found in the Raft River and Albion Ranges. Quartz monzonite is reported in the Raft River Range (Felix, 1956, p. 90). Quartz monzonite and granodiorite comprise the Almo pluton in the Albion Range (Armstrong and Hills, 1967,
The nearest exposures of basic igneous rock are basalt flows about 20 miles south and southeast of the mapped area (Howes, 1972; Adams, 1962). Two ages of flow rock are present at the southern edge of the Snake River Plain to the northwest (Anderson, 1931). The difference in composition of the dikes and near-by plutons indicates that there is no genetic relationship between the dikes in the Black Pine Mountains and the postulated pluton beneath the study area.
STRUCTURE

General Statement

The Black Pine Mountains are situated near the northeastern corner of the Basin-and-Range province. Structure in this province generally demonstrates high-angle faulting superimposed on older folds and thrust faults. The Black Pine Mountains fit this pattern.

The complexity of the structure was recognized by Anderson (1931). He mapped the existence of several large folds, high-angle faults, and a thrust fault, which were truncated by a low-angle transverse fault. Concerning the overthrust, he reported that Mississippian beds, the Brazer Formation, had been placed over the younger Wells Formation. Recent investigations indicated the opposite relationship exists. The younger formations have been thrust over older ones.

Folds

In the southern part of the Black Pine Mountains, Anderson (1931) mapped several broad north-trending folds. He also reported the presence of an east-trending fold south of War Eagle Peak across the divide between Kelsaw and Black Pine Canyons. The existence of these folds could not be verified with certainty. Intense deformation of the strata impaired attempts to follow folded structures more than several hundred feet in most cases.
Some folds are mappable in the lower member of the White Knob Formation where it crops out in lower Black Pine Canyon. An anticline is located along the eastern side of the canyon below the fork. This structure roughly parallels the canyon and plunges north. It is truncated to the north by a high-angle thrust fault 0.5 mile south of the canyon fork. The anticline is nearly symmetrical. The limbs dip between 25 and 40 degrees. Width of the fold is about 0.25 mile. A syncline is adjacent on the west, and closely follows the canyon. The syncline is assymetric. The western flank has moderate east dips, 10 to 25 degrees, although several minor superimposed folds interrupt the continuity of the syncline. Magnitude of this fold is uncertain. It might be as wide as one mile. East of the anticlinal fold, the White Knob is masked by the upper thrust fault. However, west dips on the eastern side of the divide suggest that a syncline is present. The syncline is nearly symmetrical, with limbs which dip 30 to 40 degrees. The eastern limb is truncated by a range-front fault.

The Milligen Formation has absorbed much deformation in upper Black Pine Canyon. The interbedded quartzites of the formation have been more resistant and display an anticline bearing N. 20° W. This structure is traceable a short distance northward from near the canyon fork. It is symmetrical and the limbs dip about 35 degrees. This anticline has a width of about 0.75 mile.

As mentioned above, much of the White Knob dips west on the eastern flank of the divide. North of the Tolman mine, however, an overturned isoclinal anticline is present (Figure 7). The anticlinal axis strikes N. 10° W. and dips about 30° W. An overturned syncline adjoins it to the west. These folds are a
Figure 7. Overturned fold in the White Knob Formation on the eastern flank of Black Pine Cone; view north. Syncline and anticline overturned to the east.
few hundred feet wide. The folds are in the upper member of the White Knob Formation just below the upper thrust fault. A relationship to thrusting is implied.

Two recumbent overturned folds have been formed in the Pennsylvanian-Permian beds north of Mineral Gulch. An anticline and syncline are adjacent west to east. They trend N. 5° E. and are overturned to the east.

Low-Angle Thrust Faults

General statement

Three low-angle thrust faults are mapped in the southeastern part of the Black Pine Mountains. The faults are guided largely by bedding planes (Table 1). The lower thrust fault follows the Milligen-Jefferson (?) contact. The middle thrust fault is found at the White Knob-Milligen contact. Pennsylvanian-Permian rocks universally overlie the upper thrust fault, but may be in contact with White Knob or Milligen formations. Stratigraphic displacements are difficult to estimate because thrust faults intervene at inter-formational contacts; therefore, formation thicknesses are uncertain. Based on the figures given previously, stratigraphic displacements range from a few feet to over 2,000 feet. Horizontal displacements are unknown.

Lower thrust fault

This fault is exposed in a limited area in the center of Black Pine Canyon (Figure 8). The fault traces a sinuous pattern roughly following the contour for
Figure 8. Panorama of eastern side of Black Pine Canyon; view south. Undifferentiated Pennsylvanian-Permian strata separated from Milligen Formation by upper thrust fault. Milligen separated from Jefferson (?) Formation by lower thrust fault at left. Northern landslide in center.
most of the distance around the canyon fork. The trace is truncated to the south by a landslide on the eastern canyon wall. Across the canyon it is sliced out by the middle thrust fault.

Gentle east dips on the thrust plane prevail where it is exposed on the eastern side of the canyon. On the western side, the fault assumes a west to northwest dip of variable steepness with a maximum of 25 degrees. There, the contact does not conform to the attitude of the Jefferson (?) Formation as it does elsewhere.

The lower thrust fault places the Milligen Formation above the limestones of the Jefferson (?) wherever it is seen. Evidence for its existence is the breccia zones in the Jefferson (?), which have been previously mentioned, and the discordant nature of the shale-limestone contact.

**Middle thrust fault**

The thrust fault which is found at the Milligen-White Knob contact is well displayed in Black Pine Canyon. It separates limestone from underlying shale on the southern side of War Eagle Peak (Figure 9) and on the slopes bounding the southwestern side of the canyon. The fault is cut off on the eastern and western sides of War Eagle Peak by normal faults. The exposure in the southwestern side of Black Pine Canyon disappears beneath the stream alluvium in the canyon. Another exposure of the thrust fault is below the cliffs near the Silver Hills mine. It is terminated in the saddle east of the mine by a normal fault. The thrust fault is present at the base of the cliffs north and west from the mine for about a mile before it is sliced out by the upper thrust fault. The middle thrust fault is
Figure 9. War Eagle Peak; view west. Middle thrust fault present on War Eagle Peak. Upper thrust fault slices out White Knob Formation and middle thrust fault in middle distance. High-angle thrust fault separates Milligen and White Knob on east side of War Eagle Peak.
covered along most of this trace but is well exposed in the Silver Hills mine portal.

On the eastern side of Black Pine Cone, near its base, the middle thrust fault, or branches from it, can be seen in the Tolman and Hazel Pine mines. Also, a shear zone has been encountered at shallow depth in drill holes in the vicinity of these properties (Richard Harris, 1974, per. comm.).

Wherever it is found, this fault places White Knob Formation over the Milligen Formation. In most places, stratigraphic succession has apparently not been interrupted. The important exception is above the Silver Hills mine where only the upper member of the White Knob is present. About 1,600 feet of the stratigraphic section has been cut out at that location.

Below the cliffs at the head of Black Pine Canyon, the fault dips north to northeast at angles ranging from 10 to 40 degrees. Drill holes and exposures indicate a dip of 10° W. on the eastern side of Black Pine Cone. The fact that the fault does not appear on the western side of Black Pine Cone, however, suggests that the middle thrust fault dips a minimum of 10° E. under the peak. Low-angle east dips are also mapped on the western side of lower Black Pine Canyon.

**Upper thrust fault**

The basal contact of the undifferentiated Pennsylvanian-Permian unit is a thrust fault in the studied area. Consequently, this is the most widely exposed thrust fault in the area. The plane of the upper thrust fault is irregular. It locally slices out the middle thrust fault and all of the White Knob Formation.
At the head of Black Pine Canyon, the upper thrust fault places undifferentiated Pennsylvania-Permian rocks above the Milligen (Figure 9). The trace of the fault is terminated to the west by a normal fault east of War Eagle Peak. To the east, the fault crosses a saddle and follows a tributary into East Dry Canyon. There, the Pennsylvania-Permian strata are placed above the upper member of the White Knob. The upper thrust fault ends against a normal fault in East Dry Canyon. In the area between War Eagle Peak and East Dry Canyon, the fault dips about 40° N.

The thrust fault underlies most of the north-south divide that separates Black Pine Canyon and Curlew Valley (Figure 8). The thrust plane there generally dips west at a low angle. On the canyon side of the divide, the fault has put undifferentiated Pennsylvania-Permian beds above the Milligen in the upper part of the canyon. South of the canyon fork, beds of the lower White Knob Formation underlie the upper thrust fault. The fault is traceable around the southern end of the divide without change in stratigraphic juxtaposition.

On the valley side of the divide, the thrust plane displays variable attitudes making the trace discontinuous. A synclinal undulation of the plane drops the thrust fault outcrop beneath cover at the head of Burnt Basin. The southern limb of this synclinal feature has been eroded to expose the White Knob. These rocks dip 35° W., whereas slickenside surfaces on them dip 20° N. and show N. 88° W. as direction of movement.

On the eastern side of Black Pine Cone, the fault overlies the upper member of the White Knob. Its presence is dramatically displayed by a breccia
locally containing large blocks of White Knob Limestone and Pennsylvanian–Permian sandstone (Figure 10). North of that site, the trace leads into the head of Mineral Gulch. There, the thrust plane assumes a north dip. The change causes the contact to follow the northern side of Mineral Gulch, bearing toward Curlew Valley. Near the mouth of the gulch, the trace crosses to the southern side and disappears under colluvium. Mining operations reveal shear zones which dip 25 to 45 degrees north at this locale.

A klippe of Pennsylvanian–Permian rocks caps the ridge on the southern side of Mineral Gulch. There, the thrust fault intervenes above the underlying White Knob Formation. Stratigraphic deletion by the upper thrust fault ranges widely. On the eastern side of Black Pine Cone, the sequence is believed to be relatively complete. Over 2,700 feet of strata is missing southwest of the same peak where the fault overlies the Milligen.

**High-Angle Thrust Faults**

A high-angle thrust fault extends from Black Pine Canyon, a half-mile downstream from the canyon fork, to the head of Burnt Basin where it is terminated against a range-front fault. Near its western end, the fault is obscured by a landslide. On the western side of the canyon, the fault is lost in the lower member of the White Knob Formation. The strike is about N. 85° W. and the fault dips approximately 70° N. Displacement is minor, between 250 feet and 300 feet, and the northern side is up relative to the southern side. The trace of
Figure 10. Breccia near upper thrust fault; exposure on eastern side of Black Pine Cone. Blue-gray limestone of the White Knob Formation and light-brown calcareous sandstone of the Pennsylvanian-Permian unit present in a matrix of coarsely crystalline calcite.
the upper thrust fault is offset by this fault but more important conditions are found near the base of the eastern wall of Black Pine Canyon. There, the lower member of the White Knob Formation has been faulted down against the Jefferson (?) Formation indicating over 1,800 feet of displacement. Apparently most of the intervening Milligen has been sliced out by low-angle thrust faults.

North-trending normal faults were mapped in Pole Canyon and Mill Fork Canyon adjoining the northern side of the study area (Anderson, 1931). These faults were truncated by the Kelsaw fault as mapped by Anderson (1931). Recent investigations indicate that at least one, the Pole Canyon fault, extends into Black Pine Canyon and is a high-angle thrust fault.

On the eastern side of War Eagle Peak, a high-angle thrust fault is found in the saddle separating Pole Canyon and Black Pine Canyon. The fault strikes N. 20° W. and dips 70° E. (Figure 9). It is lost in the Milligen Formation to the southeast. The eastern side is uplifted relative the western side, but the amount of displacement is made uncertain by the presence of thrust faults. Anderson (1931, p. 79) estimated 500 to 1,000 feet of displacement on the fault in Pole Canyon. The fault on the eastern side of War Eagle Peak is probably an extension of the Pole Canyon fault.

**Normal Faults**

Two parallel faults, bounding a small graben, bracket Black Pine Cone. These strike N. 84° W. but cannot be traced into the lower slopes around the peak. Displacement of the upper thrust fault indicates the southern fault has
dropped the northern wall about 200 feet. The same block has been dropped 200 to 300 feet against the northern fault.

A fault, bearing N. 65° E., crosses a saddle on the northwestern side of War Eagle Peak. This trend takes the fault from the northern side of Kelsaw Canyon to a tributary of Pole Canyon, cutting the northwestern corner of the mapped area. The trace indicates a vertical attitude. The fault has dropped the undifferentiated Pennsylvanian-Permian strata against the upper member of the White Knob Formation. An estimate of displacement is impossible because of the presence of thrust faults.

A north-trending normal fault is located 1.5 miles southeast of War Eagle Peak. It is situated in the saddle between Black Pine and East Dry canyons. It strikes N. 5° E. The fault disappears southward in the Milligen Formation. It is covered to the north in the head of East Dry Canyon. Movement was down to the east but determination of the amount of displacement is again complicated by thrust faults. The magnitude of movement is probably less than 1,000 feet. The fault has placed the undifferentiated Pennsylvanian-Permian unit on the eastern side, next to the upper member of the White Knob on the western side of the fault. The possibility exists that this is an extension of the fault that Anderson (1931) mapped at the head of Mill Fork Canyon.

Between the main mountain mass and the foothills on the southeastern flank of the range, a major range-front fault is located. This fault strikes N. 30° E. and is mapped as vertical. To the south, the fault extends beyond the studied area. Just north of the Hazel Pine mine it disappears beneath cover.
Movement was down to the east and dropped the Pennsylvanian-Permian strata in the foothills down against the lower member of the White Knob on the range flank. Displacement is uncertain but cannot be less than 4,500 feet and is more likely greater than 6,500 feet. Seismic surveys and drilling (Peace, 1956) indicate that this is one of several faults responsible for the relief of the eastern side of the Black Pine Mountains. A gravity survey located two other faults 1.0 and 0.5 mile east of the study area. Valley fill was estimated to be 6,000 feet thick by Cook, et al., (1964, p. 1725). This indicates that the total vertical displacement between the range and the Curlew Valley graben is about 15,000 feet or more. This assumes that the undifferentiated Pennsylvanian-Permian strata underlie the Tertiary and Quaternary valley fill. Drilling has verified this assumption (Peace, 1956, p. 28-30).

**Landslides**

Evidence of landslides is present in two small areas in Black Pine Canyon. They are situated on the eastern side of the canyon at the base of steep slopes of the undifferentiated Pennsylvanian-Permian unit. The areas are about a mile apart. One is located just below the canyon fork. The other is a short distance upstream from it. The northern landslide mass is resting on the Milligen Formation (Figure 8); whereas, the other overlaps the White Knob and Milligen. Neither area shows an alcove or scar. They are 2,000 to 3,000 feet across and debris is present as far as 2,000 feet downhill from the base of the
steep slopes. The debris, found in the irregular terrain mapped as landslide deposit, is from the higher outcrops of calcareous sandstone and sandy limestone.
MINERAL DEPOSITS

General Statement

Prospects are scattered throughout the mapped area but only the five largest workings were examined. The Tolman and Hazel Pine mines are situated on the lower eastern flank of Black Pine Cone. The Ruth mine described by Anderson (1931, p. 137) is located on the southern side of Mineral Gulch near its mouth. The Strevell topographic quadrangle map shows the Ruth mine at the head of Mineral Gulch. Both sites are referred to here as the Ruth mine. The Silver Hills mine is at the head of Black Pine Canyon.

Stratigraphically, these mines and almost all prospects are limited to the White Knob Formation. It should be noted again that this formation is bounded above and below by thrust faults. The limestone is locally marblized, intruded by dikes, and intensely deformed. High-angle faults of small displacement commonly cut the formation. Deposits include limestone replacement bodies controlled by fracturing, and mineralization in shear zones of friable material. Generally, the ores mined were gold and varieties of zinc carbonate, zinc–silver sulfosalts, and lead sulfide.
Primary minerals

The mineral suite described by Anderson (1931, p. 123) is a thorough one. Milky quartz replacing limestone is the principal gangue mineral. Other minerals usually appear as irregular masses and stringers within the quartz veins. Some quartz veins show fracturing with no additional mineralization.

Many of the smaller veins in the White Knob Formation are filled entirely with calcite. These veins are usually less than a foot thick and rarely contain other minerals. Calcite is also present as irregular masses and stringers in the large quartz veins.

Sphalerite, tetrahedrite, and jamesonite are important minerals in the quartz veins. They also take the form of irregular shaped bodies and veinlets within the massive quartz. Small grains of sphalerite are pale-yellow subhedral crystals while larger masses are dark brown with poorly developed crystal faces. Tetrahedrite is granular; colors range from grayish black to dark reddish gray.

According to Anderson (1931, p. 125), the variety found at the Silver Hills mine is the silver-rich freibergite. Jamesonite is usually closely associated with sphalerite and tetrahedrite. Characteristic steel-gray hair-like forms can be found penetrating quartz and sometimes sphalerite. Compact granular forms are also common.

Aggregates of barite crystals projecting into cavities are present at the Tolman mine. The surrounding rock is partly replaced by quartz and has been
brecciated. Barite was also found in small quantities, usually as granular masses or crystals, at several other deposits (Anderson, 1931, p. 126).

The presence of pyrite in quartz veins is widespread although the sulfide is not abundant. It exists as isolated cubes and pyritohedrons which are often of microscopic size.

**Secondary minerals**

A small number of secondary minerals is present at most of the mines. These include mainly zinc and copper carbonates and iron oxides.

Smithsonite is the most important of these minerals. It commonly exists as white or grayish-white botryoidal crusts or small honeycombed masses. Derivation from sphalerite is assumed (Anderson, 1931, p. 127), but the two minerals were not observed together.

Azurite and malachite are present as small bright blue and green patches on the massive vein quartz. Anderson (1931, p. 127) reported these as oxidation products of tetrahedrite. Occasionally the copper carbonates are found associated with some residual tetrahedrite.

Iron oxides are represented by goethite, limonite, and hematite. These minerals range from red to black and are present at all major mine workings, although the quantities may be small. At a few localities, iron oxides along with some manganese oxide, have formed massive caps.

In addition to the primary minerals listed above, Anderson (1931, p. 126) reported the existence of cinnabar and realgar in minor amounts. He also
reported the presence of the secondary minerals: calamine, scorodite, and antimony oxides. All of these minerals are reported to exist in minor quantities. They may be present at locations not discussed in this report.

**Mining Properties**

**General statement**

Except for the Tolman mine, little work has been done on the various mines since 1931. Consequently, the most significant revision of the treatment by Anderson (1931, p. 134-141) is to put the mineral deposits in a new structural framework. The mines examined fall into two categories. The Silver Hills and Ruth mines are in quartz vein replacements of limestone. The major veins at those mines have east-west trends, although smaller veins and veinlets have random orientations. Low-angle and high-angle shear zones are cut by the Tolman and Hazel Pine mines. The mines are also in limestone but quartz veins are less prominent.

**Silver Hills mine**

The Silver Hills mine is situated at the head of Black Pine Canyon. The portal is at the base of a limestone cliff which divides East Dry and Black Pine Canyons. The mine is about 2,000 feet above the floor of Curlew Valley.

The mineralization was found about 1880 and the mine was operated during 1894. The Silver Hills Mining Company was organized in 1920 and was still operating in 1931. More recent records of the mine are not known but it has not
been worked for some time. The primary entrance has nearly been covered by debris. Two tunnels, 100 feet and 560 feet downhill from the main entrance, are caved in. In addition to the main entrance, a shaft remains open where the vein outcrops 75 feet uphill. The Silver Hills mine is the most extensive subsurface mine in the mapped area. Work has been done at three levels, the lowest of which is the site of several drifts. Based on Anderson's descriptions (1931, p. 135) of the mine, little mining was done after his visit.

Most of the mine is in a large irregular shaped vein which cuts the upper member of the White Knob Formation. The vein strikes roughly east-west and dips steeply north. The limestone in this vicinity strikes N. 89° W. and dips 39° N. It is underlain by the middle thrust fault, which separates the White Knob and Milligen formations. The presence of the thrust fault is demonstrated by the crushed condition of the shale and siltstone at the mine entrance. Also a shear zone striking N. 70° W. and dipping 30° S. is present in the entrance tunnel just before it passes into broken limestone. The shear zone is believed to be a subordinate feature of the middle thrust fault, which apparently was not mineralized because of its fine-grained impermeable character.

The vein strikes subparallel to the limestone and dips slightly north of vertical. The plane of the thrust fault probably parallels the limestone strike and dip. Therefore, the vein should be intersected by the middle thrust fault not far below the lowest mine level. Unfortunately the tunnels which might have exposed this condition are now collapsed.
Mineralization in the mine has been replacement of limestone by quartz along fractures. In the largest vein, the quartz carries irregular-shaped bodies and seams of calcite, sphalerite, tetrahedrite, and jamesonite. Solitary pyrite cubes and crystals are widely scattered. An assay of this ore showed: 42.4 ounces of silver, 0.03 ounces of gold, 8.4 percent zinc, 4.5 percent antimony, 3.6 percent lead, and 1.2 percent copper (Anderson, 1931, p. 136). Small patches of azurite and malachite are present at the vein outcrop and with tetrahedrite on samples in the dump.

Ruth mine

Some confusion exists concerning the location of the Ruth mine. It is desirable to differentiate the sites in question. The Ruth mine as shown on the Strevell quadrangle map, refers to several scattered workings in the upper half mile of Mineral Gulch on the northern side near the bottom of the gulch. One is at the head of the gulch across from an abandoned structure. The second site is about 1,000 feet down the gulch from the first.

No production figures are known for these prospects. They were discussed by Anderson (1931, p. 140), but were not considered in detail. The tunnels at the head of the gulch are collapsed and each working is overgrown. This suggests there has been no work for a number of years. The mine down the gulch is also shrouded in vegetation but the tunnel is intact. The tunnel is about 40 feet long and slants downward on a northern bearing into a quartz vein.
Mineralization is probably in the lower member of the White Knob Formation in the upper part of Mineral Gulch. The upper thrust fault is located at the top of the blue-gray limestone a short distance up the northern side of Mineral Gulch. Near the mine, the limestone has been marblized. A fracture striking N. 65° W. and dipping 40° N. can be seen in the roof of the remaining open tunnel. This feature is probably related to the upper thrust fault, which has a similar attitude nearby. In addition, there are several small vertical shear zones exposed by the tunnel which are truncated by the low-angle fracture just mentioned. Mineralization was apparently confined to the White Knob Limestone beneath the upper thrust fault in the area of the Ruth mine as it is shown on the Strevell quadrangle map.

The mineralization at this location is similar to that of the Silver Hills mine, but it is on a smaller scale. Most of the mineralization consisted of replacement of rock minerals by quartz and calcite. The only unaltered primary metallic mineral observed was scattered grains of pyrite. Malachite and azurite patches are common indicating the presence of tetrahedrite. Although no sphalerite was seen, one site had some smithsonite crusts. The upper workings were into a quartz vein with an iron oxide cap. Hematite and limonite were noted.

The Ruth mine as described by Anderson (1931, p. 137) is located near the mouth of Mineral Gulch a short distance above the eastern base of the mountains. The mine is situated on the crest of the ridge separating Mineral Gulch from the first major draw to the south. The mine consists of several pits
dug into the ridge crest between elevations of 6,200 feet and 6,400 feet above sea level.

As of 1931, the only production of this property had been six cars of ore shipped during World War I (Anderson, 1931, p. 138). Apparently little work has been done in the last 40 years.

Ore was mined from the outcrop of a discontinuous, west-trending quartz vein which replaced limestones of the White Knob Formation. A short distance to the east, the upper thrust fault has placed the undifferentiated Pennsylvanian-Permian unit above the White Knob. The thrust fault strikes about N. 60° W. and dips north at a moderately steep angle. Mineralization has occurred in broken limestones beneath the upper thrust fault which have been exposed by erosion. Most of the mine workings have exposed low-angle shear zones undoubtedly related to the thrust fault. The shear zones strike from N. 85° E. to N. 85° W. The dip of the shear zones ranges from 25° N. to 45° N. The larger dip angle was obtained on the northern side of the ridge and consequently closer to the plane of the upper thrust fault. The vertical shear zones seen at the Ruth mine at the head of Mineral Gulch were not observed in the workings just described. The shear zones present at both Ruth mine localities were probably not permeable enough to permit veins to form.

Smithsonite was the main ore of this mine. It can be found lining cavities and fractures as botryoidal crusts. Another form is present as small honeycombed masses. The mineral is white or grayish white. White granular quartz is also common at this mine. Calcite, copper carbonates, and iron oxides are
also present. In addition, Anderson (1931, p. 138) reported minor amounts of sphalerite, cinnabar, realgar, calamine, and scorodite.

Calcite and quartz usually are present as veins in limestone. Azurite and malachite are associated with these. Smithsonite is found in the proximity of the shear zones.

**Hazel Pine mine**

The Hazel Pine mine is at the base of the mountains about 0.75 mile south of the Ruth mine of Anderson's description. It is comprised of several pits, shafts, and tunnels that are scattered along a northeast-southwest trend for about 300 feet south of the mouth of a large ravine. This mine is a few hundred feet above the valley floor.

Anderson (1931, p. 138) reported that 14 cars of ore had been shipped from the mine prior to his reconnaissance. Although the nature of the ore was unknown, it was believed to carry gold, silver, and lead. Assays have shown some zinc and a little lead but less than an ounce of silver and no gold (Anderson, 1931, p. 139). Little or no work has been done at the mine since 1931.

Unlike the previously discussed mines, the Hazel Pine is not in a prominent quartz vein. Instead it follows a shear zone of friable granular material in the interbedded siltstones and limestones of the lower member of the White Knob. It was related earlier in this report that the middle thrust fault, which separates the Milligen and White Knob formations, is believed to exist at shallow depth in this vicinity. The existence of low-angle fault zones exposed in
the mine reinforces this belief. A fault examined in a tunnel at the northern end of the property strikes N. 30° E. and dips 10° W. Another shear zone cut by a pit at the southern end strikes N. 30° E. and dips 30° E. These zones are intersected by high-angle faults with bearings which range from northeast-southwest to east-west. One prominent shear zone strikes N. 45° E. and dips 60° NW. The various workings are roughly aligned to this trend. This fault is probably a reflection of the major range-front fault mapped a few hundred feet to the east. Which shear zones persist and which are truncated is not readily discernable. It seems safe to assume that fault zones paralleling the range-front fault displace the low-angle faults.

Quartz and calcite veins are common at the Hazel Pine mine, but they are not as large as those at the Silver Hills mine. Crusts of iron oxides and a little malachite are found in the quartz veins. Granular quartz and calcite are also present in the mylonitic shear zones. Iron oxides are abundant in the friable material. The exposures are dark red to yellowish-orange. Crusts and small bodies of smithsonite line and fill in cavities in the shear zones. Small amounts of hemimorphite and scorodite were reported by Anderson (1931, p. 139).

**Tolman mine**

A large pit known as the Tolman mine has been excavated on the northern side of a deep ravine which trends southeast from the eastern side of Black Pine Cone. It is 0.6 mile southwest of the Hazel Pine mine. The pit is 1,100 feet above the floor of Curlew Valley.
The mine was active during the 1950's but precise dates and production figures are unknown. A small tonnage valued at four to five dollars of gold per ton is reported shipped from the mine for an indefinite time after 1953 (Richard Harris, 1974, per. comm.).

Mining at the Tolman property resulted in the excavation of a curved pit. Near the ravine, the cut trends southwest but abruptly curves to an east-west bearing away from the draw. The pit is over 500 feet long and at least 50 feet deep. Three chambers with a few branching tunnels have been opened into the northwestern wall. The largest of these is about 30 feet across. A tunnel extends north from it about 50 feet. Bulldozer cuts are scattered around the excavation. One such cut has exposed the weathered remnants of the dikes above the northwestern wall of the pit.

The walls of the Tolman mine pit display dark-gray limestone, and pink, gray, and greenish-brown calcareous siltstone. These are beds of the lower member of the White Knob Limestone which have been complexly deformed. Evidence of horizontal movement dominates the northwestern wall (Figure 11) but high-angle to vertical slickensides are present on the opposite wall. Apparently high-angle faults are present in the vicinity which follow various alignments from north-south to nearly east-west. On the northwestern wall of the pit near its base is a persistent horizontal shear zone. This zone is in the roof or upper part of each chamber in the wall. Slickensides indicate movement in a N. 85° E. direction. Although the zone undulates, the general strike is N. 10° E. and the dip is
Figure 11. Panorama of northwestern wall of Tolman mine pit; view northwest. Limestone and siltstone of the lower member of the White Knob Formation are folded and broken by high-angle and low-angle faults.
30° W. As mentioned before, the middle thrust fault underlies the White Knob at this locale. The low-angle faulting visible in the pit is probably an imbrication from it.

The main ore of the mine was apparently gold. The large quartz and calcite veins like those in Mineral Gulch and the Silver Hills mine are apparently absent here. A considerable amount of material was excavated but tailings indicate it was mostly siltstone. Copper carbonates occasionally show on what vein quartz is present. Most mineralization consists of calcite in fractures and breccia zones. Some cavities and fractures are lined with euhedral crystals whereas other breccias are completely recrystallized. A few bladed barite crystals are associated with the calcite veins. As of fall, 1974, the investigation of Newmont Exploration Ltd. had not revealed appreciable amounts of sulfides (Richard Harris, 1974, per. comm.).
NATURE AND AGE OF MINERALIZATION

Mesothermal and epithermal deposits are present in the mapped area. Whether two episodes of mineralization or a single continuous one are represented is a debatable point.

Mesothermal deposits are generally characterized by the massive replacement of limestone by quartz in the area. The presence of jamesonite, tetrahedrite, sphalerite, and pyrite also supports a mesothermal origin. Replacement of mafic minerals of the dike rock by quartz may also indicate mesothermal conditions.

Epithermal mineralization also occurred. Calcite, barite and native gold are epithermal minerals that are present in the Tolman and Hazel Pine mines. Drusy forms of calcite and barite are often found in zones of loose material. The cinnabar mine reported by Larsen (1919) is also an epithermal deposit. Epithermal mineralization near the Tolman and Hazel Pine mines might have been facilitated by heat associated with the emplacement of the diabase dikes. However, there is no direct proof that the dikes and mineralization are related.

Anderson (1931, p. 131) favored a continuous episode of mineralization. He suggested that deposition of minerals began when temperatures were near mesothermal. However, most veins were formed under epithermal conditions.
which were characterized by falling temperatures and progressive change in the composition of the ore solutions (Anderson, 1931, p. 131).

Evidence presented in this report indicates that intrusive activity in the southeastern part of the Black Pine Mountains may have been more extensive than previously supposed. Therefore, it is possible that mesothermal conditions were more pervasive than originally reported. Also, newly mapped structural features have aided in distinguishing episodes of mineralization.

The initial mineralization was the emplacement of quartz veins. These veins were guided by fractures related to thrust faulting in the White Knob Formation. Small amounts of sulfides accompanied the deposition of quartz. Synchronous with, or closely following this episode, fracturing again occurred allowing sulfides to concentrate as stringers in the major veins. Mesothermal deposits were the result in the vicinity of the Silver Hills and Ruth mines.

Another period of mineralization, perhaps unrelated to the first, coincided with or followed the initiation of Basin-and-Range faulting. Mineral deposition was along new high-angle faults and older low-angle faults. Mesothermal temperatures may have existed initially but most of the ore deposits were epithermal. The intrusion of the dikes possibly occurred during this episode. Gangue minerals deposited were calcite, barite, and quartz. The mineral deposits of the Tolman and Hazel Pine mines were probably formed at this time. Deposition of cinnabar and realgar around hot springs probably ended the episode (Anderson, 1931, p. 131).
Epithermal deposits in Utah, Idaho, and Nevada have been dated as middle Tertiary. Anderson (1931, p. 133) felt that the mineralization in the Black Pine Mountains was similar to these other deposits, and belonged to the same mineralization event.

As stated previously, new evidence indicates two episodes of mineralization have occurred in the southeastern part of the Black Pine Mountains. The first episode of mesothermal mineralization apparently occurred between Laramide and Basin-and-Range structural events. Thrust faults in northern Utah and southern Idaho are related to the Laramide Orogeny which ended in the Paleocene or Eocene (Hintze, 1973, p. 76; Armstrong, 1968a, p. 452). However, thrust faults in the study area can be dated no closer than post-Paleozoic. Basin-and-Range faulting in the study area began after thrust faulting. The dikes present near the Tolman mine trend parallel to the range-front fault on the southeastern flank of the mountains. If they are related to basalt flows to the south, the range-front fault might have been active prior to the Pliocene (Howes, 1972, p. 39).

In the Goose Creek area, about 40 miles to the west, a major normal fault places Miocene beds against Paleozoic strata (Axelrod, 1964, p. 12). Other summaries indicate a wide range of dates for the inception of Basin-and-Range faulting (Nolan, 1943, p. 183; Osmond, 1960, p. 258; Hintze, 1973, p. 75). Intrusive activity during this interval has been reported to the west and southwest. Potassium-argon and rubidium-strontium radioactive isotope dating in the Albion and Raft River Ranges on samples from igneous stocks reveal an Eocene to early Miocene intrusion (Armstrong and Hansen, 1966, p. 123; Armstrong and Hills,
This compares favorably with regional intrusive activity (McKee, 1971, p. 3497; Hintze, 1973, p. 80). Until more evidence is found, it is safe to conclude only that the mineral deposits near the Silver Hills and Ruth mines were probably emplaced during early or middle Tertiary time.

The second episode of mineralization apparently postdated the initiation of Basin-and-Range faulting. This would indicate a middle to late Tertiary age for the mineral deposits near the Tolman and Hazel Pine mines. These deposits may be no older than Pliocene if the dikes are related to the basalt flows to the south and the dikes were instrumental in the mineralization as stated above.
LITERATURE CITED


