AN ABSTRACT OF THE THESIS OF

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Title: The Geology, Mineralization, and Geochemistry of the Pine Creek area, Lemhi County, Idaho

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The Pine Creek area is located in Lemhi County, Idaho approximately 20 miles northwest of Salmon, Idaho. The primary goal of this study was to evaluate the potential for economically viable occurrences of molybdenum mineralization in this area.

This region is underlain by three major lithic groups. These consist of metasedimentary rocks of Precambrian age, meta-igneous rocks of Precambrian age and stocks and dikes of Cretaceous to Tertiary age.

The Precambrian metasedimentary rocks include quartzites of the Yellowjacket and Hoodoo (Big Creek) Formations. The Yellowjacket Formation is a very fine-grained micaceous quartzite which is divisible into five units based on variations in composition, grain size, and the presence or lack of certain sedimentary structures. The Hoodoo or Big Creek Formation is a white to light gray, fine-grained quartzite which contains minor amounts of mica. It is found as klippen in the western part of the area.

Igneous rock of Precambrian age include the augen gneiss-rapakivi granite complex and amphibolite. The augen gneiss-rapakivi granite

complex is an assemblage of potassic-rich granitic plutons tentatively dated at 1.4 to 1.5 b.y. (Armstrong, 1975). Although the augen gneiss is very strongly foliated whereas the texture of the rapakivi granite is massive, the presence of rapakivi textures in both rock types and the compositional similarities of both major and trace elements suggest a genetic relationship. The augen gneiss and rapakivi granite have intruded very fine-grained metasedimentary rocks. The amphibolite which has also intruded metasedimentary rocks displays chemical similarities to alkali basalts.

Igneous rocks of Cretaceous or Tertiary age include the Pine Creek stock and dikes of rhyolite and andesite. The Pine Creek stock is a medium crystalline two mica leucocratic granodiorite which may be late Cretaceous in age. Plutonic igneous rocks of this age are the most likely host rocks for a cordilleran-type molybdenum mineralization. Dikes of probable Tertiary age vary from rhyolitic to andesitic in composition. They generally strike north or northeast.

The prominent structural grain in the Pine Creek area has a northwest trend as exemplified by the strike of foliation, bedding, and bedding plane faults in the Yellowjacket Formation and by the trend of the Leesburg fault (the detachment surface between the Hoodoo and Yellowjacket Formations). The Hot Springs fault is the largest of a set of younger northeast-trending faults which offset these older features.

Three different and widely separate areas have been altered by hydrothermal fluids. They include a weak argillic zone in the northern part of the area, a chlorite zone north of Beaver Creek, and a zone of geochemically anomalous quartz veins south of Beaver Creek.

Five hundred samples of soil, stream sediment, and rock were collected and analyzed for copper, lead, zinc, molybdenum, silver, manganese and fluorine. The results from these analyses did not reveal any significant anomalies in the northern part of the Pine Creek area. However, in the southern part there is a large zone (6000 feet by 3000 feet) of anomalous concentrations of molybdenum (≥10 ppm) in soil. This area is coincident with the zone of anomalous quartz veins south of Beaver Creek. Elsewhere in this area, there are also numerous copper anomalies (≥37 ppm) in soil underlain by the Yellowjacket Formation.

There is the potential for two different types of economic mineralization in the Pine Creek area: molybdenum mineralization hosted in plutonic igneous rocks and stratabound copper mineralization. The area outlined by anomalous molybdenum concentrations in soil as well as geochemically anomalous quartz veins offers the best potential for economically significant molybdenum mineralization. Portions of the Yellowjacket sequence may be hosts for stratabound copper mineralization.

The Geology, Mineralization and Geochemistry of the Pine Creek area, Lemhi County, Idaho

by

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INTRODUCTION

The Pine Creek area is situated between two abandoned gold districts in the Salmon River Mountains, the Mineral Hill (Shoup) district to the north and the Mackinaw (Leesburg) district to the south. These two major districts account for most of the past mining activity in the region. The Copper King Mine at Copper Mountain and a small mine on Pine Creek are the only mines in the area with past mineral production. Recent exploration in the region was prompted by the surrounding gold mineralization, the presence of hydrothermally altered rocks at the head of Hot Springs Creek, and by published reports of anomalous molybdenum concentrations in soil and stream sediment in the area.

The Pine Creek area includes 30 square miles in north-central Lemhi County, as shown in Figure 1. The east-central portion of T. 23 N., R. 18 E., the southwest half of T. 23 N., R. 19 E., and the northeast portion of T. 22 N., R. 19 E. (Boise Meridian) encompass the area.

Access varies from good along lower Pine Creek (northern portion) to poor along upper Pine and Beaver Creeks (southern portion). To reach the area from the north, one proceeds east on Forest Service Road 30 (F.S. 30) to the Pine Creek road (F.S. 32), where several gravel roads and numerous old logging roads allow easy travel in the lower Pine Creek area. Access routes to the southern part of the study area require a four-wheel drive vehicle and include Forest Service Road 19 (F.S. 19),

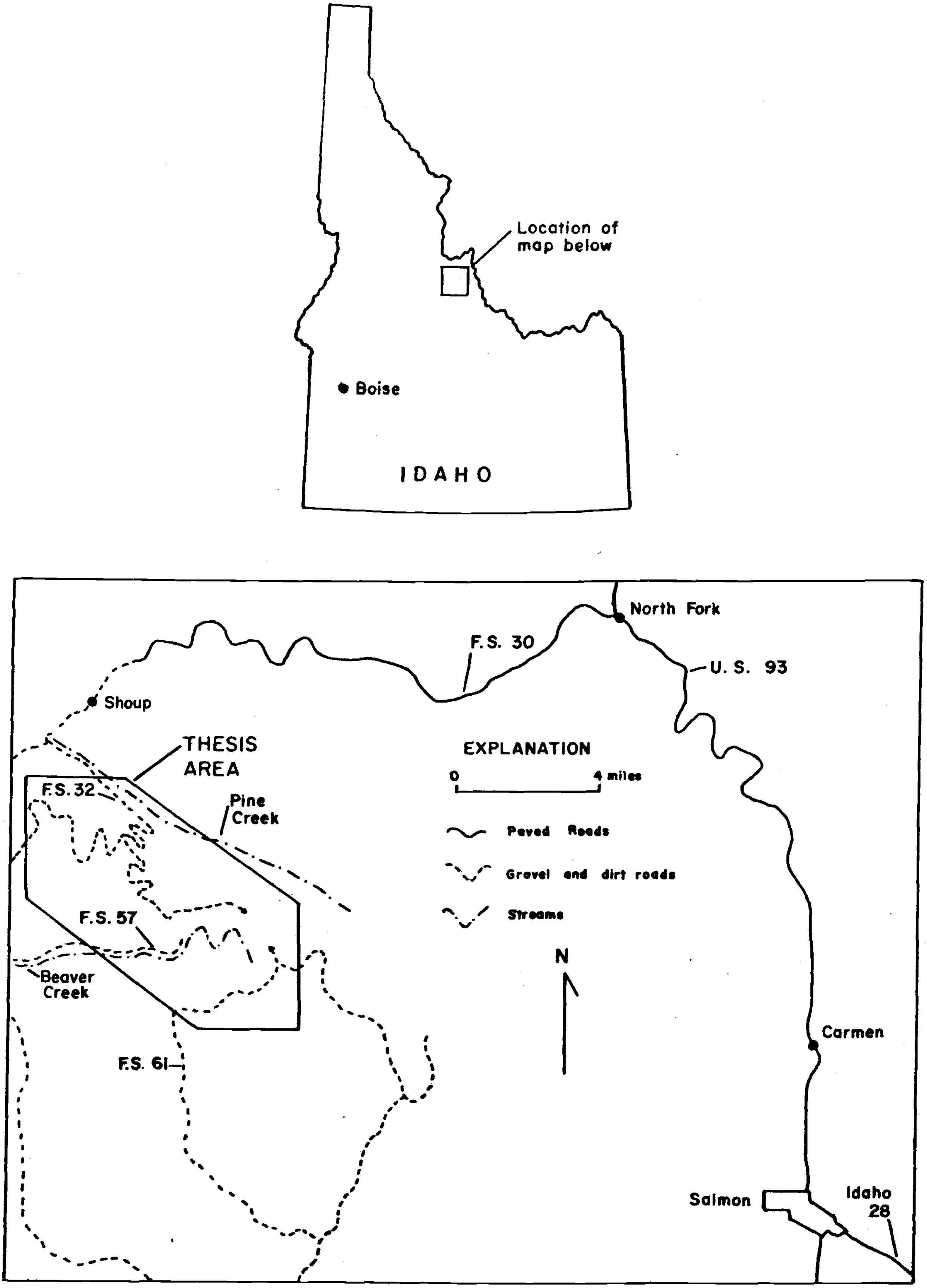


Figure 1. Index maps showing the location of the Pine Creek area, principal roads and towns.

a continuation of the Pine Creek Road, the Moose Creek Road (F.S. 61), and the Beaver Creek Road (F.S. 57).

PHYSIOGRAPHY

Elevations range from 4000 feet on lower Pine Creek to 8721 feet in the southern part of the area. Maximum relief is nearly 2400 feet over horizontal distances of less than one mile with some slopes approaching 35 degrees. The most striking topographic feature is the presence of a Middle Tertiary erosional surface at elevations above 8200 feet (Ross, 1937, p. 8). Topography in the Pine Creek and upper Beaver Creek areas is illustrated in Figure 2.

Drainages have steep V-shaped valleys typical of youthful or rejuvenated streams, and they generally display a trellis pattern. Streams follow either the strike of the metasedimentary units (northwest) or the predominant joint set (northeast). In areas underlain by massive crystalline rocks, drainages show a dendritic pattern. North-facing cirque basins are present at the head of Beaver and Pine Creeks.

CLIMATE AND VEGETATION

Hot dry summers and cold, moist winters typify the Salmon River region. Winter snows account for most of the yearly precipitation in the area. Thunderstorms are common in June and July and may produce some locally heavy rainfall. Temperatures seldom exceed 100 degrees F. in the summer and -15 degrees F. in the winter, according to the official weather recording station at Shoup.

The heaviest vegetation is found on the northfacing slopes and consists mainly of Lodge Pole Pine, Ponderosa Pine and Douglas Fir.

Figure 2a. The middle Pine Creek drainage viewed from the west. Pine Creek flows from the upper left corner (south) to the lower right. Stormy Peak Ridge in the background ranges in elevation from 8000 to 8300 feet.

Figure 2b. Aerial view of the southeastern part of the study area. The ridge in the foreground trends north-northwest and varies from 8000 to 8400 feet in elevation.

South-facing slopes generally lack trees and are covered with grass and small shrubs. Vegetation does not hinder hiking except along streams where dense growths of aspen and small shrubs make passage difficult.

PURPOSE AND METHODS OF STUDY

The purposes of this study were to prepare an accurate geologic map, determine the genesis of the molybdenite occurrences, and evaluate the potential for economically viable occurrences of molybdenum mineralization in the study area.

Field work was conducted during the summer and fall of 1979. Rock type, alteration, and mineralization were mapped using U.S.F.S. aerial photographs (1:15,840) and U.S.F.S. Shoup SE and Ulysses Mtn. SW Orthophoto Quadrangles (1:24,000). Maps constructed in the field were transferred to an enlargement (1:12,000) of these quadrangles.

Rock samples were collected for petrographic analysis, and rock, stream sediment, and soil samples were prepared for chemical analysis. Five hundred samples were analyzed for Cu, Pb, Zn, Mo, Ag, Mn, and F by Bondar-Clegg and Company of Vancouver, British Columbia, Canada.

Thin sections of 60 representative samples were examined using a petrographic microscope at Corvallis, Oregon. Modal compositions of plutonic and quartzite units were performed by counting 600 points per slide with a mechanical stage. The composition of plagioclase was determined by the Michel-Levy and combined Carlsbad-Albite twin methods (Heinrich, 1965). Plutonic rocks were named in accordance with the I.U.G.S. (1973) classification.

PREVIOUS INVESTIGATIONS

Umpleby's (1913) report is the earliest work that includes the study area. This publication gives an excellent account of the mines and geology of Lemhi County. Schockey (1957) published a reconnaissance study of the Leesburg Quadrangle south of the thesis area, and Maley (1974) studied the petrology and structural geology of the lower Panther Creek regions which represents the most-detailed report of the area. Most recently, Bennett (1977) published a reconnaissance survey that encompassed most of the Pine Creek and Beaver Creek region and reported high molybdenum concentrations in soil and stream sediment in the upper Beaver Creek area.

REGIONAL GEOLOGY

The Pine Creek area is part of a region in east-central Idaho that is geologically among the least understood in the northern Cordillera. Much of the lack of understanding results from large gaps in the geologic record. In the Pine Creek area, only three major units are present. They include Precambrian metasediments, the Precambrian augen gneiss-rapakivi granite complex, and Cretaceous to Tertiary stocks and dikes. Sedimentary rocks from the entire Phanerozoic are missing and absolute ages of the rocks present are not known. The general geology of central Idaho and adjacent portions of southwest Montana are portrayed in Figure 3.

Regionally, central Idaho lies within the Cordilleran geosyncline between Paleozoic miogeosynclinal rocks on the east and Permian to Triassic eugeosynclinal rocks on the west. Isotopic evidence suggests that a Precambrian basement is missing beneath the eugeosynclinal assemblage. This assemblage was accreted to the continent during Mesozoic time according to Armstrong and others (1977).

Precambrian rocks exposed beneath the miogeosynclinal assemblage include very fine-grained metasedimentary rocks of the Lemhi Group in central Idaho and the Belt Supergroup in Montana and northern Idaho. Lithologic similarities between the Precambrian Y Belt Supergroup and the Lemhi Group suggest they may be time equivalent (Table 1), although direct correlation is impossible.

Sedimentation of the Belt Supergroup took place in a large continental embayment, as established by Harrison (1972). However, the depositional setting of the Lemhi Group is not clearly understood.

Table 1. A sequence of Precambrian Metasedimentary rocks in east-central Idaho with possible regional correlations (from Ruppel, 1975, p. 5 and 18).

Swauger Formation: Pale-purple to grayish-green, medium-grained, hematitic quartzite; thickness 3100 m.	Missoula Group
Lemhi Group:	
Gunsight Formation: Light-brownish-gray to grayish-red-purple, fine-grained feldspathic quartzite; max. thickness 1830 m.	Helena and Wallace Formations
Apple Creek Formation: Grayish-green siltite containing abundant lenses of fine-grained sandstone; thickness about 850 m.	
Big Creek Formation: (Hoodoo Quartzite) Greenish to light-gray, fine-grained feldspathic quartzite; thickness about 3100 m.	
West Fork Formation: Medium to greenish-gray siltite with lenticular algal limestone; thickness about 460 m.	Ravalli Group
Inyo Creek Formation: Medium to light-gray, fine-grained to very fine-grained feldspathic quartzite; min. thickness 700 m.	
Yellowjacket Formation: Medium to medium-dark gray, fine-grained feldspathic, finely biotitic quartzite, and interbedded siltite; max. thickness about 3100 m.	Prichard Formation

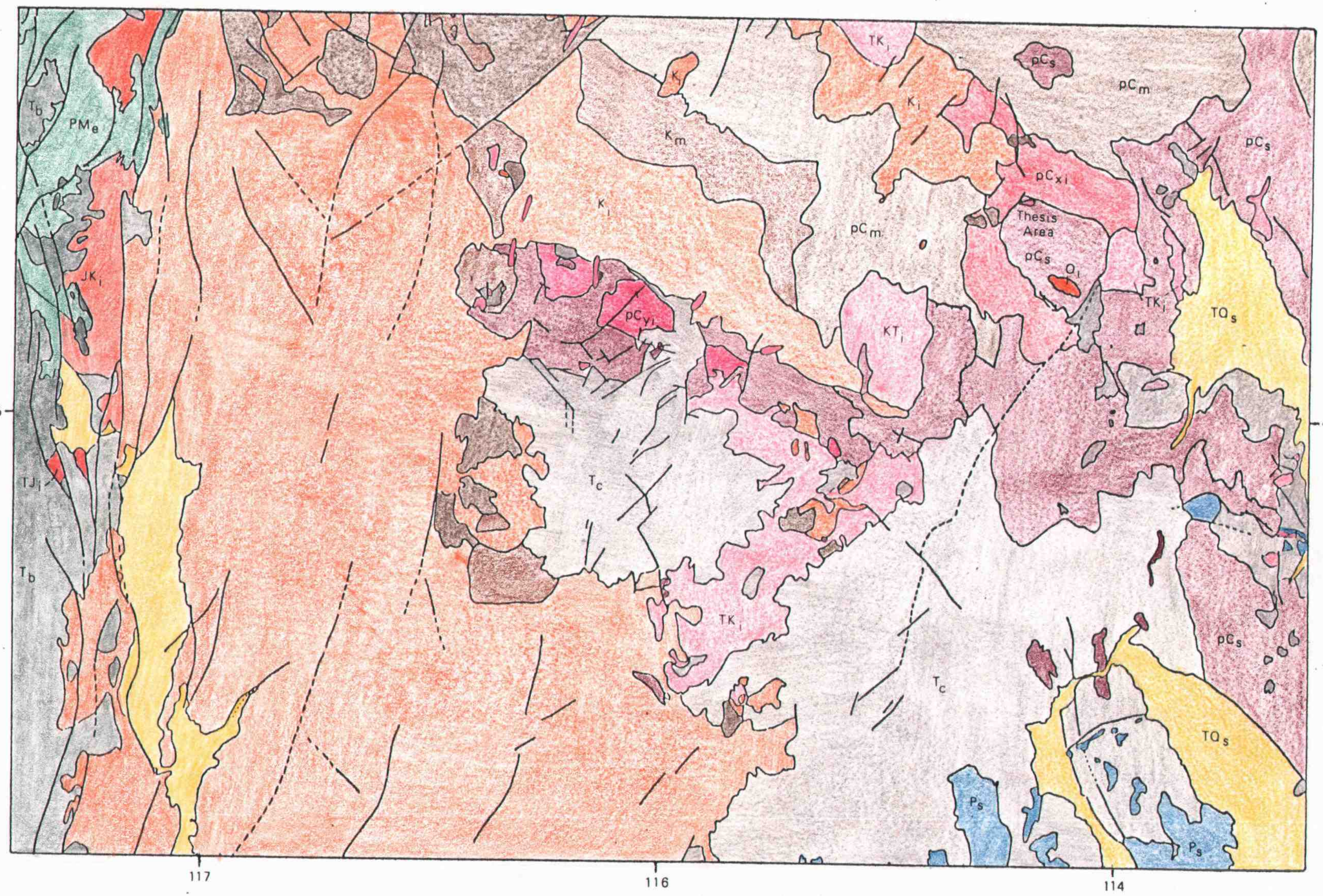


Figure 3. The geology of central Idaho and southwest Montana. (Modified from the Idaho state geologic map (1978) and the Montana state geologic map (1955))

EXPLANATION

One inch equals approximately 19 miles

19 10 0 19 38 miles

Rocks mainly Cenozoic in age

TO_s	Unconsolidated sediments	T_b	Columbia River Basalt
		T_c	Challis Volcanics
		TK_i	Dominately Tertiary age intrusives

Rocks mainly Mesozoic in age

K_m	Cretaceous gneiss associated with the Idaho Batholith	K_i	Idaho Batholith
PM_e	Mesozoic and Late Paleozoic eugeosynclinal sediments	JK_i	Jurassic and Cretaceous intrusives
		TJ_i	Triassic and Jurassic intrusives

Rocks mainly Paleozoic in age

P_s	Paleozoic miogeosynclinal sediments	O_i	Leesburg Stock, Ordovician

Rocks mainly Precambrian in age

pC_s	Precambrian Y metasediments of the Lemhi Group	pC_{zi}	Precambrian Z seyenitic intrusives
pC_m	schist and gneiss	pC_{xi}	Precambrian X augen gneiss rapikivi granite complex

Figure 3. The geology of central Idaho and southwest Montana, continued.

Ruppel (1975) has speculated that deposition occurred to the west along the margin of the continent in the main geosyncline. Thrust faults with up to 100 miles of displacement brought these rocks to their present location. Other workers suggest that sedimentation took place in a continental basin similar to the Belt (G. Brox, 1980, personal communication). The structural or stratigraphic relationship between the Belt and Lemhi Basins is uncertain because the evidence was obliterated by the emplacement of the Bitterroot lobe of the Idaho Batholith.

Detailed isotopic analyses show that Belt sedimentation spans 600 m.y. from 1450 m.y. to 850 m.y. In addition, sedimentation was cyclic rather than continuous, and consisted of three major episodes dated at 1300, 1100, and 850 m.y. according to Harrison (1972) and Obradovich and Peterman (1969). Similar detailed isotopic studies for the Lemhi Group have not been completed and the age of these rocks are not clearly defined. A maximum age is uncertain because the crystalline basement complex is not exposed in central Idaho. A minimum age of 725 m.y. is based on an isotopic analysis of the Ramey Ridge syenite in the Idaho Primitive Area (Armstrong, 1975b).

In the Shoup area, the augen gneiss-rapikivi granite complex (AGRG) intrudes the Yellowjacket Formation. The AGRG was originally thought to be part of the Idaho batholith (Anderson, 1942; Ross, 1963). However, a K-Ar analysis of biotite from the complex resulted in a 425 m.y. date and a whole rock Rb-Sr analysis gave a 1450 m.y. date (Armstrong, 1975a). If the latter date is correct, the Yellowjacket Formation and possibly formations in the Lemhi Group are pre-Beltian in age.

Two other pre-Cretaceous plutons intrude the Lemhi Group. They are the Ordovician Leesburg Stock south of the study area and the Silurian

Beaverhead Pluton near Lemhi Pass, Idaho (Karl Evans, 1980, personal communication; Ramspott and Scholter, 1965). However, Armstrong (1975) has suggested that the Beaverhead Pluton is actually Precambrian in age; the radiometric clock having been reset by subsequent thermal events. Nonetheless, concordant U-Pb and Pb-Pb zircon dates (Karl Evans, 1980, personal communication) for the Leesburg Stock yield an early Paleozoic age. If correct, these stocks would be representative of but a small number of early Paleozoic igneous rocks in the western U.S. Additional isotopic studies may help to define more precisely the age of the AGRG complex, Leesburg Stock and Beaverhead Pluton, and they may provide more reliable data for the age of the Lemhi Group, as well.

Although rocks of Paleozoic age are missing in the Pine Creek area, a part of this stratigraphic section occurs near Challis south of the thesis area. The thin veneer of Paleozoic rocks in central Idaho suggests that the Cordilleran miogeosyncline was not widespread in this area (Ross, 1962).

Idaho was the site of numerous magmatic events during Mesozoic and Cenozoic time. A compilation of dated intrusive rocks for the region suggests at least three episodes of magmatic activity during the intervals from 160 to 130 m.y., 105 to 65 m.y. and from 50 to 40 m.y. (Armstrong and others, 1977; Armstrong, 1975b). On the basis of limited data, a fourth may be present.

The Idaho batholith and Challis events are by far the most important in east-central Idaho. The Idaho batholith consists of two major parts; the older Atlanta Lobe (100 to 75 m.y.) and the Bitterroot Lobe (80 to 70 m.y.). This composite granodiorite to granite pluton exhibits characteristics similar to mesozonal intrusions. The large plutons of

Challis age are similar in composition to the Idaho batholith, although igneous rocks of the Challis event range from basalts to rhyolites in composition. The evidence suggests a westward progression of magmatism in central Idaho.

The Salmon River area is part of the Basin and Range Province, but separated geologically from the main province by the Snake River downwarp. High angle tensional faults, typical of the province, trend northwest and represent the latest tectonic activity. In addition to the younger Basin and Range faults, numerous folds and low angle faults are present. The northwest-trending folds and thrust plates suggest a tectonic movement to the northeast.

Several major lineaments cross central Idaho and are probably Precambrian in age. The Idaho Transdiscontinuity is defined by isotopic, geophysical and geologic differences of the juxtaposed rocks, and may have been an important crustal boundary in Precambrian time (Armstrong and others, 1977). The Lewis and Clark Line in northern Idaho and western Montana is a major zone of right-lateral slip faults. Zietz and others (1971) have presented evidence for several other lineaments in central Idaho based on high altitude aeromagnetic data. The Pine Creek area lies near the end of a northwest-trending magnetic anomaly in a region that the authors believe to be favorable for base and precious metal exploration.

The Idaho-Montana Porphyry Belt consists of a northeasterly trend of mineralized plutons as shown in Figure 4. This trend is well-documented, although geologists cannot agree on a name. Olson (1968) referred to it as the Idaho Porphyry Belt, whereas Jerome and Cook (1967) called it the Tranverse Porphyry Belt. More recently, Armstrong

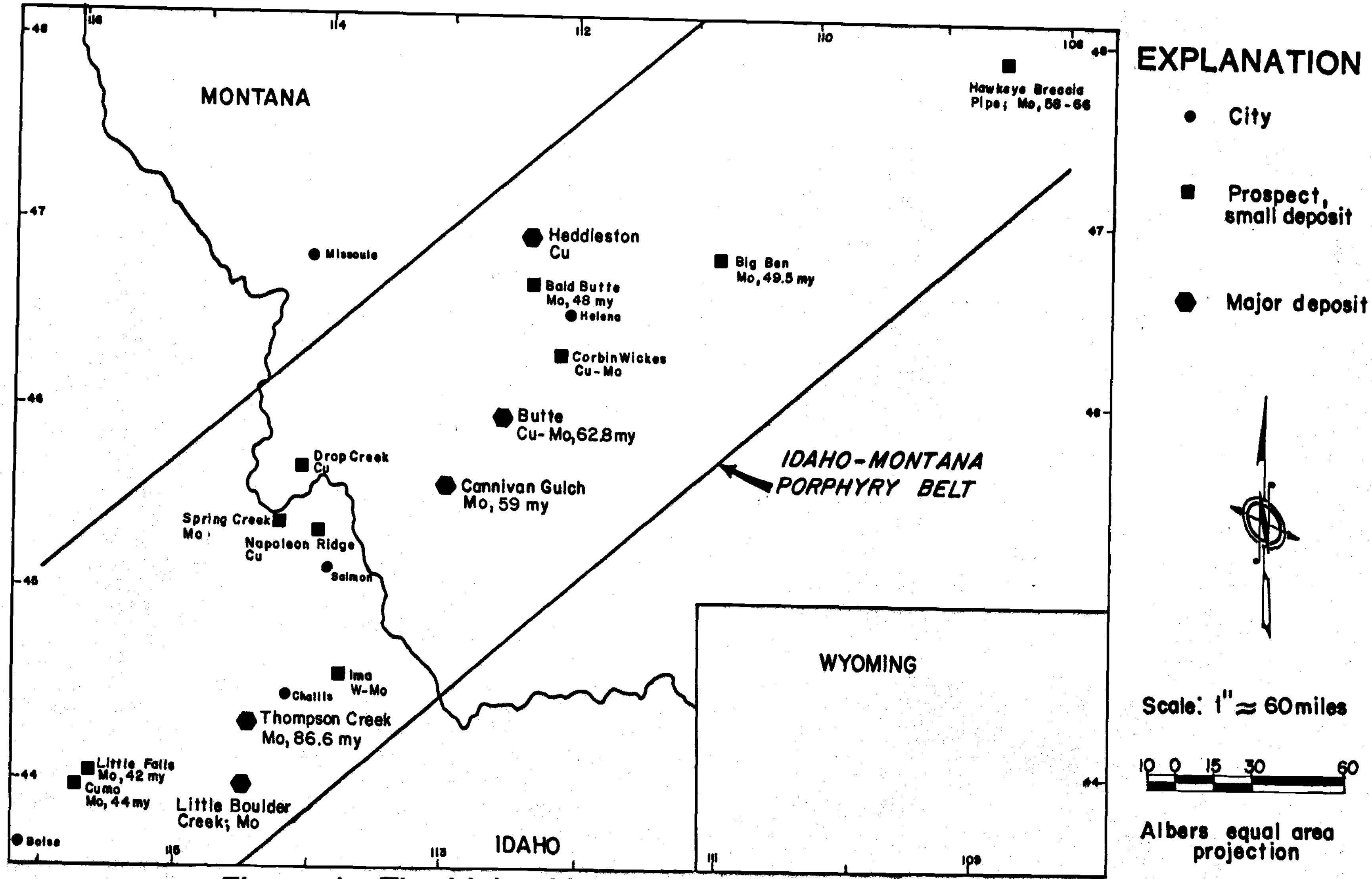


Figure 4: The Idaho–Montana porphyry belt.

and others (1979) have referred to a specific trend within the belt, and named it the White Cloud-Cannivan Gulch Molybdenum Porphyry Belt. Mineral deposits in the trend consist of stockwork, disseminated, or vein-controlled molybdenum, copper, or copper-molybdenum systems. Associated plutons are Late Cretaceous to Early Tertiary in age. However, quartz-feldspar porphyries are not exposed at all deposits that form this belt.

The Idaho-Montana Porphyry Belt transects the major structural grain of the northern Cordillera, and is parallel to another better-known trend, the Colorado Mineral Belt. As has been suggested for the Colorado Mineral Belt, the Idaho Porphyry Belt probably represents a zone of weakness in the underlying Precambrian basement (Tweto, 1968; Olson, 1968; Tweto and Sims, 1963).

PRECAMBRIAN METASEDIMENTARY ROCKS

Precambrian metasedimentary rocks in the Pine Creek area include low-grade quartzites of the Yellowjacket and Hoodoo Formations and high-grade biotite gneiss. The quartzites underlie the area south of the Hot Springs Fault (Plate 1) and comprise 80 percent of the rocks exposed in the Pine Creek area. The biotite gneiss crops out over a small area north of the Hot Springs Fault, and it is spatially associated with the augen gneiss and leucocratic granitoid dikes.

YELLOWJACKET FORMATION

The Yellowjacket Formation is named for the town and mining district of Yellowjacket in central Idaho. At the type locality, Ross (1934, p. 16) separated the Formation into a lower carbonate-bearing member and an upper quartzite member. The estimated total thickness of the Formation is 9,000 feet. This study has defined five informal map units within the Yellowjacket Formation. They include, from the stratigraphic bottom to top, dark gray biotite quartzite, medium light gray laminated quartzite, light gray-brown phyllitic quartzite, and a medium gray-brown garnet quartzite. The cumulative thickness of these units probably exceeds 9,842 feet.

David Lopez (1980, written communication) has divided the Yellowjacket Formation into six members based on his field work throughout east-central Idaho. His preliminary composite section is portrayed in Figure 5, along with the stratigraphic position of the units defined in this study. Lopez estimates that the Yellowjacket Formation may be as much as 19,685 feet thick, although this figure is tentative and is based on a compilation of several measured sections.

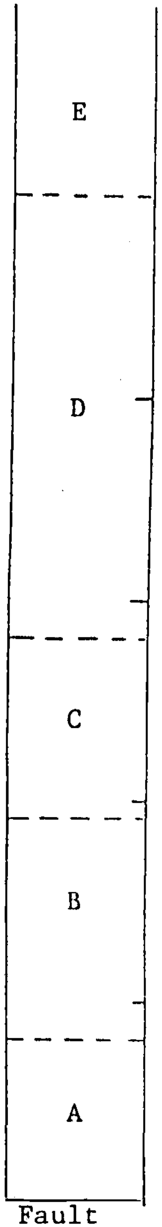
The quartzites in the upper Beaver Creek area are probably overturned. This conclusion is based on detailed analysis of ripple marks and low-angle crossbeds in several isolated outcrops, as well as on their tentative stratigraphic position within the Yellowjacket Formation (Fig. 5).

Biotite Quartzite. Exposures of the biotite quartzite are limited to the far eastern edge of the Pine Creek area. Outcrops are typically small and along steep slopes. The rock weathers to a grayish brown (5 YR 3/2, after the GSA Rock Color Chart) and is medium light gray (N 6) on fresh surfaces. The unit displays faint parallel and cross laminations. Ripple marks were not observed. Carbonate-bearing beds are present within the biotite quartzite on upper Pine Creek, approximately 2,460 feet east of the study area, and they indicate that the unit is probably equivalent to the upper part of member B.

The biotite quartzite consists of quartz (50-60 percent), biotite (15-30 percent), muscovite (2-15 percent), albite (2-11 percent) with traces of magnetite, zircon, apatite, and sphene. Quartz grains average about 0.05 mm in diameter (Fig. 6) with some grains as large as 0.1 mm. The original sedimentary grains are not distinguishable, and the present texture resulting from metamorphism consists of a granoblastic mosaic of unoriented quartz grains. Biotite is tabular and 0.05 to 1.0 mm in length. Muscovite is similar in habit but generally is slightly larger. The mica content averages 30 to 40 percent in the unit, with biotite predominating over muscovite. Albite grains are xenoblastic and range from 0.02 to 0.04 mm in diameter. Albite twins are fairly common and indicate a composition of An_{2-4}.

The biotite quartzite differs from the lower laminated quartzite by

Figure 5. Preliminary composite section of the Yellowjacket Formation (David Lopez, 1980, written communication) and the tentative stratigraphic position of the units in the Pine Creek area.



YELLOWJACKET FORMATION

Unit E. Predominately medium gray quartzite, slightly argillaceous, graded beds, ripple marks, cross laminations.

Unit D. Medium gray to dark gray quartzite, distinct argillite lamellae and beds disappear; graded beds increase to about 1 m thick, parallel laminated, cross-laminated, ripple marks; less argillaceous upwards.

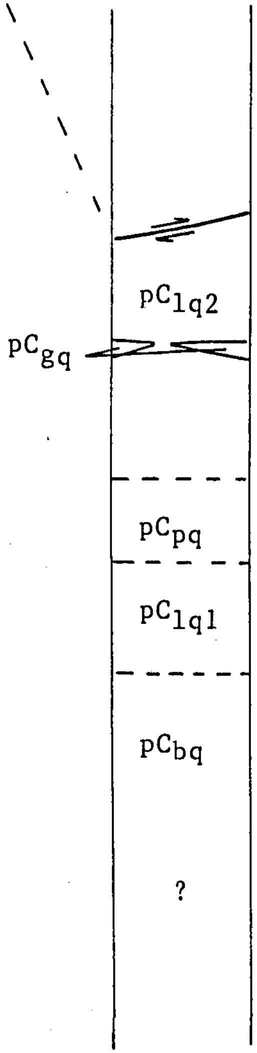
Unit C. Medium to dark gray parallel laminated argillite to argillaceous quartzite in graded beds 1 cm to 15 cm thick; convolute laminations common. Dark gray to light gray argillite-quartzite couplets distinctive.

6500 ft. (2000 m)

Unit B. Mostly medium gray, sandy and silty argillite with "greenish" tinge; graded beds, ripple marks, cross laminations and parallel laminations; carbonate beds.

Unit A. Medium to dark gray, fine to coarse grained quartzite in graded beds up to 1 m thick.

0 ft.



PINE CREEK AREA

Hoodoo (Big Creek) Formation

Yellowjacket Formation

pC_{lq2}. Medium gray laminated quartzite, cross laminations and ripple marks common; muscovite biotite and total mica content decreases upwards.

pC_{gq}. Garnet bearing two mica quartzite and schist; ripple marks, cross laminations and graded beds, locally present.

pC_{pq}. Light gray phyllitic quartzite; thin bedded with biotite rich laminations; ripple marks and cross laminations rare. muscovite ≫ than biotite; mica content generally exceeds 30%.

pC_{lq1}. Medium gray laminated quartzite; laminations and cross laminations common; biotite muscovite.

pC_{bq}. Dark gray biotite quartzite; faint laminations, massive to thickly bedded; biotite muscovite.

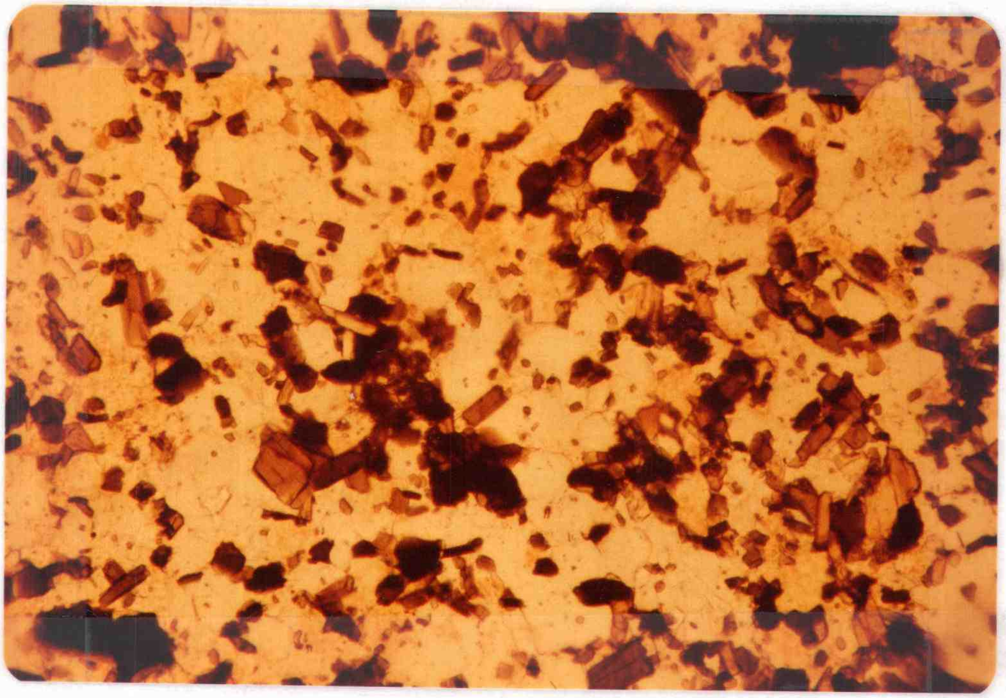


Figure 6. Photomicrograph of the biotite quartzite in plane polarized light illustrating the large biotite content and granoblastic texture of the quartz grains (field of view is 0.8 x 1.2 mm).

its darker color and finer grain size. In addition, the lower laminated quartzite has less biotite and more muscovite, and displays weakly developed laminations. The contact is gradational over several tens of feet and is defined by where the more massive biotite quartzite becomes subordinate to the laminated quartzite.

Laminated Quartzite. Quartzite with parallel and low-angle cross laminations is the most abundant type of metasedimentary rock in the Pine Creek area. Two different laminated quartzite units were distinguished. These were designated as a lower and upper unit, which are separated stratigraphically by phyllitic quartzite. Although both units are very fine-grained, the lower unit is more micaceous and contains a higher percentage of biotite. In addition, ripple marks, which are rare in the lower unit, are very common in the upper unit.

The mineral constituents of laminated quartzite include quartz (70-90 percent), muscovite (5-15 percent), biotite (5-20 percent), idioblastic magnetite (tr-2 percent), albite (tr-5 percent), zircon (tr), and sphene (tr). Quartz grains average 0.1 to 0.15 mm in diameter and some are as large as 0.3 mm. The grains are xenoblastic and unoriented. However, the texture is best described as granoblastic as illustrated in Figure 7. Grains of albite are also xenoblastic, and generally smaller than those of the quartz. Biotite and muscovite are lepidoblastic and up to 0.2 mm in length.

Laminations defined by biotite-magnetite-rich layers are ubiquitous within these units. The lammellae are from 0.5 to 2.0 mm in thickness and are well-displayed. Single laminations may be followed as much as ten feet laterally, although many are shorter. Very low-angle cross laminations are sometimes present. In addition, undulatory

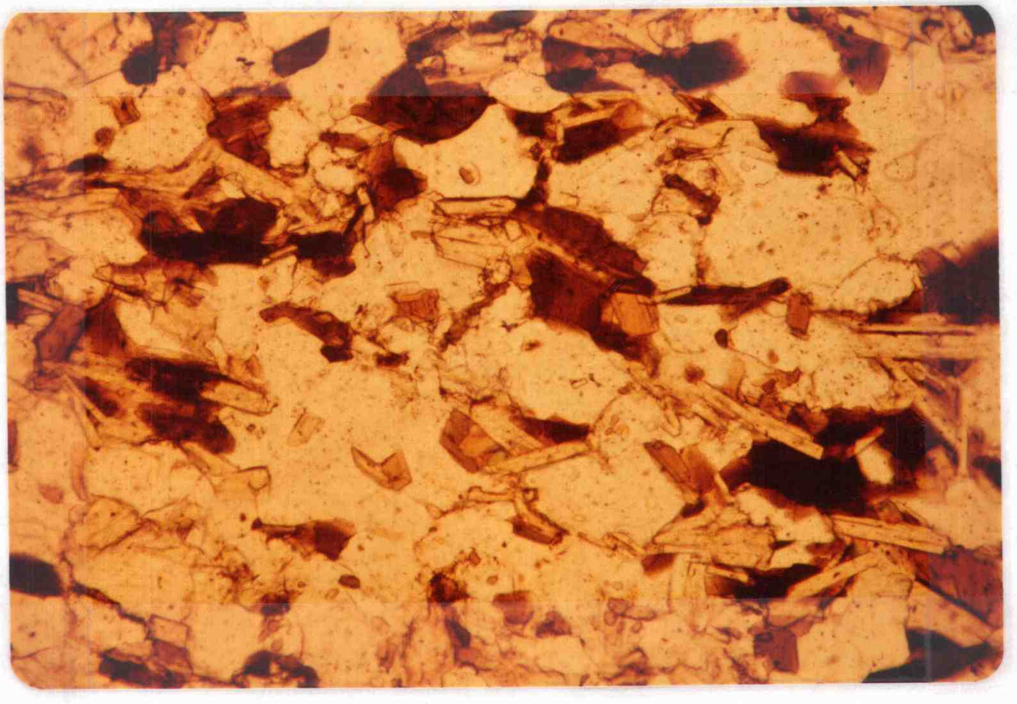


Figure 7. Photomicrograph of the lower laminated quartzite from the lower Pine Creek area near the contact with the biotite granite. Note the texture and content of muscovite and biotite (plane polarized light, field of view 0.8 x 1.2 mm).

symmetrical ripple marks are common in the upper unit.

The contact of the lower laminated quartzite with the phyllitic quartzite is gradational over many feet. It is located where the laminated quartzite is subordinate to muscovite-rich phyllitic quartzite containing thin, widely spaced biotite-rich layers.

Phyllitic Quartzite. Phyllitic quartzite forms the most distinctive unit of quartzite in the study area. Although individual grains are visible with a hand lens, the unit has a phyllitic thin-bedded appearance in the outcrop. It is light gray (N 7) to very pale orange (10 YR 8/2) on fresh surfaces, and moderate yellowish brown (10 YR 5/4) on weathered surfaces. In addition, large porphyroblasts of idioblastic magnetite are ubiquitous throughout and garnet occurs sporadically in the more mica-rich interlayers.

Mineral components include quartz (60-75 percent), muscovite (25-35 percent), biotite (tr-4 percent), feldspar (tr), idioblastic magnetite (tr-3 percent), zircon (tr), garnet (tr), and sphene (tr). Quartz grains average 0.05 to 0.08 mm in diameter, and they are xenoblastic and do not display a preferred orientation. Muscovite averages about 0.05 mm in length, with some up to 0.2 mm. Biotite within the phyllitic quartzite is confined to interlayers less than 10 mm thick (Fig. 8).

The contact of phyllitic quartzite and upper laminated quartzite is gradational and is located approximately on Plate 1. The estimated thickness of phyllitic quartzite is 1,500 feet.

Garnet Quartzite. The garnet quartzite occurs as a thick lens within the upper laminated quartzite that can be followed along strike for about three miles. In addition to garnet and garnet-bearing quartzites, garnet schist is locally present. The best outcrops are along

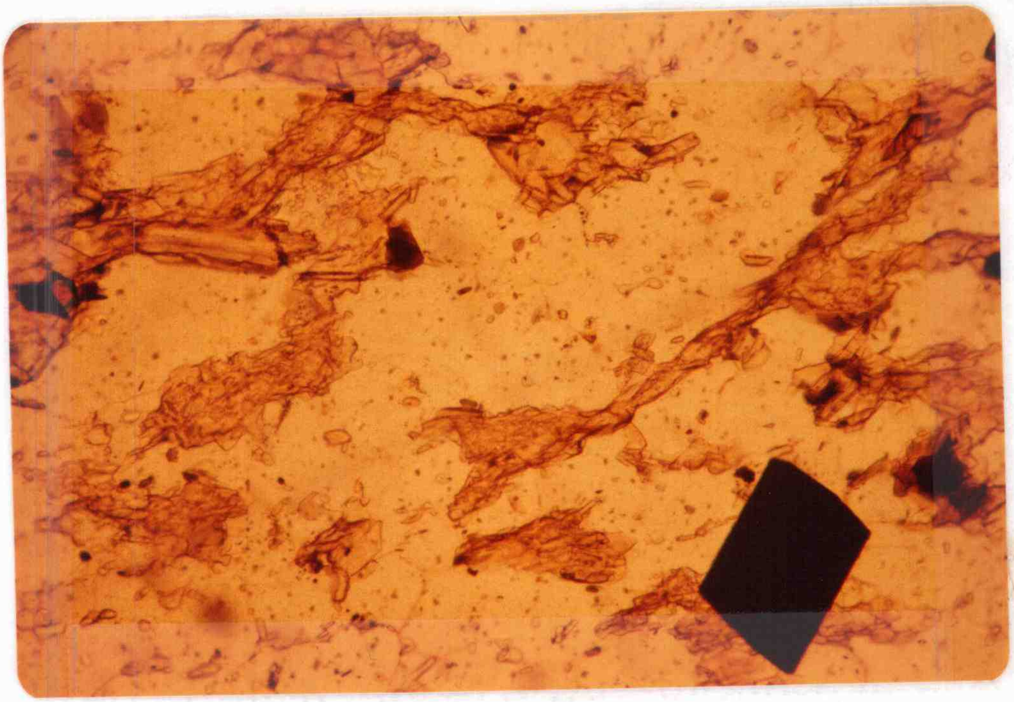


Figure 8. Photomicrograph of the phyllitic quartzite illustrating the large muscovite content and the idioblastic magnetite grains (plane polarized light, field of view is 0.8 x 1.2 mm).

ridge crests south of Copper Mountain. The rock weathers to a pale yellowish brown (10 YR 6/2), and a moderate reddish brown (10 R 4/6) iron stain on fractured surfaces is ubiquitous. Less weathered surfaces have a "salt and pepper" appearance and vary from light brown (5 YR 6/4) to light gray (N 7) in color.

Sedimentary structures, which include parallel laminations, cross-laminations, ripple marks and subtle graded bedding, are present within the garnet quartzite. Although cross-laminations rarely intersect at angles greater than five degrees, careful study of several outcrops near the Copper King Mine indicated that the beds are overturned.

The garnet quartzite consists of quartz (40-83 percent), muscovite (5-40 percent), biotite (5-10 percent), garnet (2-18 percent), zoisite (tr-8 percent), magnetite (tr-1 percent), zircon (tr), and feldspar (tr). Quartz grains are xenoblastic and occasionally display a weak preferred orientation parallel to the long direction of the micas. They range from 0.05 to 0.15 mm in diameter. The micas are tabular and from 0.05 to 0.3 mm in length, although biotite is generally slightly larger. Garnet in thin sections is present as colorless grains with very irregular boundaries. It ranges from 0.05 to 1.0 mm in diameter. Zoisite is found in the more schistose rocks as tabular grains parallel to the schistosity. These range from 0.05 to 0.1 mm long. The zoisite displays weak pleochroism from colorless to pale blue-green with anomalous blue interference colors. The optical data suggest low Fe^{3+} and Mn^{3+} contents of the zoisite. Magnetite is idioblastic and up to 1 mm in diameter.

Metamorphism. The very fine-grained micaceous quartzites in the Pine Creek area have been metamorphosed to the quartz-albite-epidote-biotite sub-facies of the greenschist facies (Turner, 1968). Index minerals include muscovite, biotite, magnetite, and albite. In addition, the occasional occurrence of a reddish garnet suggests metamorphism was near the lower limit of the epidote-amphibolite facies.

Turner (1968, p. 366) lists temperatures from 250° C. to 400° C. and pressures ($P_{load} = P_{water}$) from 2 to 10 kb for this subfacies. These ranges of temperature and pressure require a minimum burial of 19,680 feet and limit the maximum depth to about 49,200 feet.

The granoblastic texture displayed by the micaceous quartzites is anomalous for regionally metamorphosed quartz sands. This texture is more typical of thermal metamorphism or of a quartzite developed by secondary overgrowth at diagenetic temperatures and pressures (Skolnick, 1965; Spry, 1969, Plate XIX and XXX). It is possible that the regional metamorphic event(s) was not at a high enough pressure to impart a preferred orientation to the quartz grains, or that a later thermal event produced the granoblastic texture.

HOODOO QUARTZITE

The Hoodoo Quartzite is named for Hoodoo Creek in Lemhi County, Idaho, where Ross (1934, p. 18) defined the type section. At this locality, the formation consists of a white to vinaceous gray, fine-grained quartzite. Most grains average 0.2 mm, although some are up to 0.75 mm in diameter. Mineral constituents reported by Ross include quartz (70 to 80 percent), microcline plus albite (10 percent) in addition to minor amounts of white mica and chlorite. Bedding is generally indistinct, but may occasionally display parallel and cross-laminations. This formation at the type locality is more than 3,000 feet in thickness. The underlying Yellowjacket Formation is in fault contact with the Hoodoo Quartzite. The upper contact is gradational with a banded, calcareous quartzite. The Hoodoo Quartzite is probably correlative with the Big Creek Formation (Ruppel, 1975).

The Hoodoo Quartzite crops out in the far western portion of the thesis area. It occurs as klippen and larger blocks in fault contact with the upper laminated quartzite. This low-angle surface of detachment is probably a continuation of the Leesburg Fault mapped by Schockey (1957) in the Leesburg Quadrangle to the southeast.

Strong shearing in the upper laminated quartzite near the contact with the Hoodoo Formation is suggested by the rubbly nature of the outcrops and thus "phyllitic" appearance. The Hoodoo Quartzite forms large blocky outcrops more resistant to weathering than does the underlying Yellowjacket Formation. The rock weathers to a medium dark gray (N 4) whereas unweathered surfaces are light gray to white (N 7 to N 9). Sedimentary structures are present and include parallel and cross-laminations. It is not known if the Formation is overturned.

The Hoodoo Formation consists of quartz (92-96 percent), muscovite (3-8 percent), biotite (tr-3 percent), magnetite (tr), and feldspar (tr). The texture is dominated by the quartz grains which form a granoblastic mosaic. The grains range from 0.2 to 1.0 mm in diameter. The micas are very small (0.01 mm in length) and are found only along the margins of quartz grains. The rock is unfoliated.

Although correlation of this clean, fine-grained quartzite is tentative, descriptions of the Hoodoo Quartzite by Ross (1934) and of the Big Creek Formation by Ruppel (1975) suggest that they are equivalent.

BIOTITE GNEISS

The best exposures of the biotite gneiss are along road cuts of the Hot Springs Creek road (F.S. 232), near the divide between Pine and Hot Springs Creeks. The unit is fine-grained and strongly foliated with some small concordant layers of white quartzite and biotite schist. Weak hydrothermal alteration has resulted in a bleached and friable rock (Plate 1). In addition, small to large dikes and stringers of pegmatite and aplite are ubiquitous and comprise as much as 10 to 80 percent of this host in outcrops of the upper Hot Springs Creek area (Fig. 9). The contact of these leucocratic granitoid dikes with the biotite gneiss is gradational. It was defined as being at the transition where the areal extent of the intrusive rocks exceeds that of the metasedimentary rocks.

The biotite gneiss generally strikes to the northwest and has a shallow northeasterly dip. Tight isoclinal folds are visible in some outcrops (Fig. 10) and locally this unit is migmatitic.

The dominant mineral constituents are quartz (50-95 percent), biotite (5-40 percent), oligoclase (tr-10 percent), muscovite (tr-5 percent), zircon (tr), apatite (tr), and sphene (tr). Quartz is from 0.1 to 0.2 mm in diameter and displays undulatory extinction. A slight dimensional preferred orientation is discernible among the grains of quartz. Biotite and muscovite are from 0.05 to 0.30 mm in length and are lepidoblastic. Oligoclase (An_{21-25}) is from 0.05 to 0.15 mm and xenoblastic.

Compositional similarities of this unit with the micaceous quartzites to the south suggest that the biotite gneiss may be a higher-grade metamorphic equivalent. Metamorphic conditions corresponding to at least the epidote-amphibolite facies, as suggested by the presence of

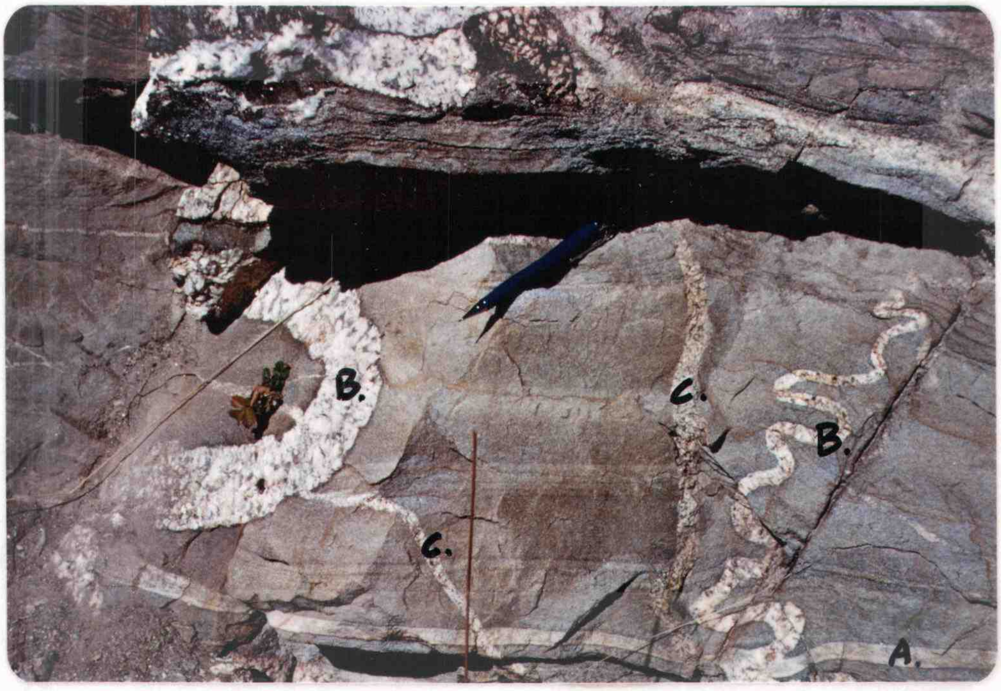


Figure 9. Ptygmatic veins in the biotite gneiss. Probably three different ages of veins with the sequence of emplacement given by (A) oldest biotite-quartz-feldspar vein parallel to the foliation, (B) ptygmatic veins, (C) youngest non-folded quartz-feldspar veins (Pencil is 5.6 inches in length).

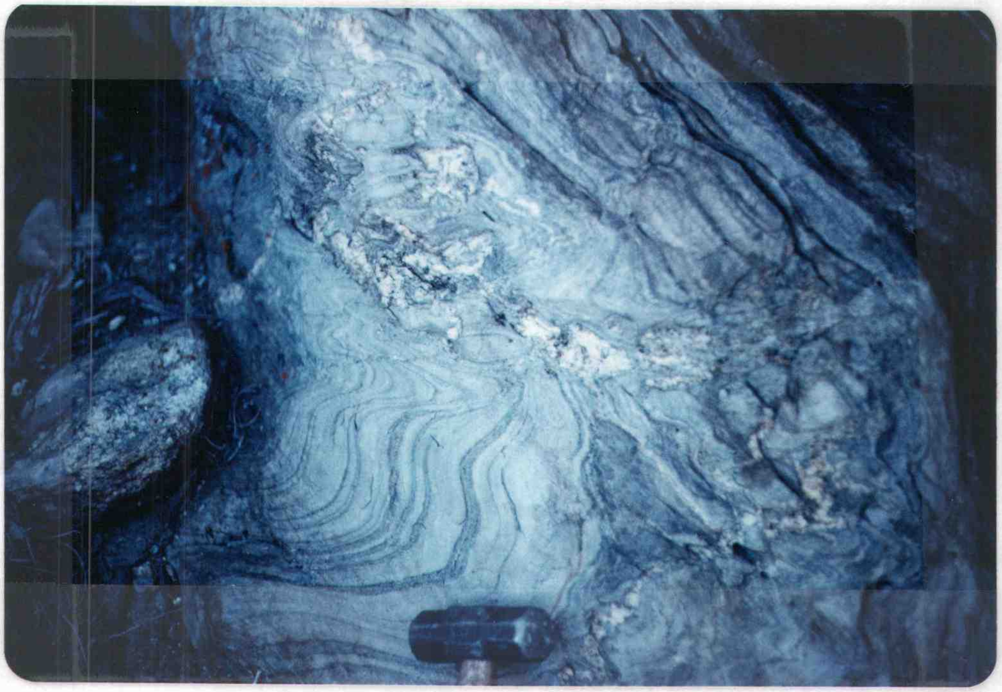


Figure 10. Ductile folds in migmatitic biotite gneiss.

oligoclase, are probably attributable to intrusion of the augen gneiss and spatially related leucocratic granitoid dikes (Plate 1).

PRECAMBRIAN INTRUSIVE ROCKS

Intrusive rocks of probable Precambrian age are exposed in the northern and eastern parts of the thesis area. Five different lithologies are present: amphibolite, augen gneiss, leucocratic granitoid dikes, rapakivi granite and biotite granite. Compositional similarities and spatial associations suggest that three separate magmatic events are represented within these five units.

AMPHIBOLITE

A highly weathered exposure of amphibolite ~~(or metagabbro)~~ crops out along Forest Service Road 232. In addition, numerous other outcrops that are less weathered are found along the ridge crest northeast of the road. Fresh surfaces range in color from grayish olive green (5 GY 3/2) to dusky yellow green (5 GY 5/2) and weathered surfaces are generally a moderate yellowish brown (10 YR 5/4). The amphibolite is finely crystalline and granoblastic to strongly foliated. Foliation and the abundance of plagioclase feldspar increase from the northernmost exposure, southward through the unit, which imply a compositional gradation. The amphibolite intrudes laminated quartzite (pC_{lql}) and field relationships suggest that the amphibolite is sill-like in form.

Petrography. The original mineral constituents and textures of the amphibolite have been obliterated by at least two periods of metamorphism. The present mineralogy of samples PC-237 and PC-241 is shown in Table 2. Sample PC-237 was collected 100 feet northeast of road 232 on the ridge crest, and sample PC-241 was collected 150 feet northeast of PC-237 also along the ridge (Plate 1).

Table 2. The modal composition of the Amphibolite (tr indicates trace amounts).

	PC-237	PC-241
diopside	1	56
hornblende	34	2
oligoclase	30	18
orthoclase	20	tr
biotite	10	16
sphene	4	5
quartz	7	tr
apatite	1	1
opaques	tr	tr
chlorite	tr	tr
epidote	tr	tr

Sample PC-237 consists primarily of idioblastic, tabular green hornblende (0.6 to 3.0 mm in length) and xenoblastic feldspar (0.9 to 2.5 mm in diameter) in a slightly foliated fabric. Hornblende displays a strong yellow-green pleochroism and is associated with biotite. Plagioclase feldspar is untwinned and commonly shows intergrowths with potassium feldspar. Sphene occurs in granular aggregates associated with the mafic minerals. Apatite is idioblastic and forms rods up to 0.9 mm long. Quartz is found in xenoblastic aggregates which appear to be xenoliths of quartzite.

Sample PC-241 is dominated by xenoblastic, equant diopside which varies from 0.05 to 1.0 mm in diameter and is partially surrounded by optically continuous plagioclase feldspar, and thus exhibits a sub-ophitic texture. The plagioclase feldspar, which is probably oligoclase, is xenoblastic and ranges from 0.25 to 0.5 mm in diameter.

Biotite and sphene are associated with the diopside and minor amounts of hornblende. Sample PC-241 is unfoliated and thus may be best described as a granofels.

Geochemistry. Major oxide data for the amphibolite with calculated CIPW normative analyses are shown in Table 3. These data indicate gross similarities with alkali basalts. The average composition of the magma is not clear, however, because of the compositional variability of the amphibolite. Moreover, some remobilization of major constituents may have occurred during metamorphism. The discrepancy between the mode and norm (modal quartz vs. normative nephelite) may be due to the formation of metamorphic hornblende and biotite. These minerals, depending on their compositions, may contain less silica than the original mafic minerals which were probably olivine and clinopyroxene.

Origin and Age. The mineralogy, chemistry and field relationships denote an igneous origin for the amphibolite. This conclusion was also reached by Davidson (1928), Maley (1974), and Berg (1977) for rocks of similar composition and texture in eastern Idaho and southwestern Montana.

The sill shows a gradational increase in feldspar content and a decrease in color index from the northeast to the southwest. Such a trend suggests a compositional zoning that may have resulted from differentiation and crystal settling. These processes are common in sills of this composition (Carmichael, Turner and Verhoogen, 1975). Subsequent regional metamorphism to the greenschist facies has produced a foliated rock composed essentially of hornblende and feldspar. Later intrusion of the Pine Creek Stock thermally metamorphosed the northernmost exposures of the sill and produced a diopside granofels.

Table 3. Major oxide concentrations and CIPW normative analyses for the amphibolite and related rocks.

	PC-237	Hawaiite[a]	Trachyandesite[b]
SiO_2	51.2	50.4	50.5
TiO_2	2.4	2.23	1.7
Al_2O_3	18.9	16.32	18.0
FeO	7.9	6.35	5.5
Fe_2O_3	---	3.84	3.9
MgO	4.0	4.96	2.4
CaO	7.0	7.43	6.7
Na_2O	4.4	4.26	5.5
K_2O	3.95	1.84	2.8
MnO	---	0.17	0.1
P_2O_5	---	0.92	0.89
H_2O^-	---	---	2.5
H_2O^+	---	1.01	0.3
total	99.75	99.73	100.8
orth	22.2	10.87	16.7
alb	18.8	36.05	33.8
anor	22.2	19.98	16.1
neph	11.6	---	---
diop	11.6	8.76	9.8
hyp	---	5.57	---
oliv	11.3	5.51	4.1
ilm	4.5	4.24	3.2
mag	---	5.57	5.6
apa	---	2.18	2.0
total	100.2	98.73	98.0

a - from Abbott, 1969 in Carmichael and others, 1974 p. 494-5.

b - from Varne, 1968 in Carmichael and others, 1974, p.499

The absolute age of the amphibolite is uncertain. Large xenoliths of amphibolite in the leucocratic granitoid dikes indicate it is older than the dikes. Purcell Sills (750 to 850 m.y.), which are of a similar composition, intrude the Belt Supergroup in Montana and northern Idaho (Gabrielse and Reesor, 1964). The amphibolite is probably at least this old.

AUGEN GNEISS

Highly weathered exposures of augen gneiss are found along Forest Service Road 232 and typical outcrops are shown in Figure 11. Within the Pine Creek area the unit is intruded everywhere by finely crystalline to pegmatitic granitoid dikes. These dikes are more resistant to weathering than the augen gneiss. Because of this differential resistance to weathering, fragments of the granitoid dikes are much more common in float and this effect possibly masks the true areal extent of the augen gneiss.

The augen gneiss consists of large potassium feldspar "phenocrysts" in a medium to coarsely crystalline and strongly foliated matrix (Fig. 12). The constituents include potassium feldspar (45-60 percent; microcline greater than orthoclase), oligoclase (10-20 percent), biotite (10-20 percent), quartz (15-25 percent), with minor amounts of muscovite, magnetite, zircon apatite and sphene. Clays and white mica are common alteration products of plagioclase feldspar.

Phenocrysts of potassium feldspar are variegated from pink to white in color and frequently contain inclusions of biotite. They average 12 by 18 mm in dimensions, but some may exceed 25 mm in length. Many display overgrowths of sodic plagioclase, forming a rapakivi texture. The matrix of the augen gneiss consists of quartz, plagioclase feldspar,

Figure 11. A typical outcrop of augen gneiss. The joint set is parallel to the foliation. The bighorn sheep near the top of the outcrop provides the scale.

Figure 12. A close-up view of the augen gneiss showing a strongly foliated texture and aplitic to pegmatitic dikes. In addition, the potassium feldspar "crystals" appear to be broken phenocrysts rather than true augen.

biotite, and potassium feldspar. Crystal sizes range from 1 to 5 mm. Undulatory extinction in quartz and bent twin lamellae in plagioclase feldspar are common. Myrmekite is present where plagioclase feldspar and microcline have mutual crystal boundaries.

Geochemistry. Major oxide data for the augen gneiss and rapakivi granite (18954) and with CIPW normative analyses are shown in Table 4. These data indicate a strong chemical similarity between the augen gneiss and rapakivi granite. The major chemical differences are the higher Na_2O, total Fe, MgO, and Al_2O_3 for the augen gneiss, which suggests a less differentiated parent magma. In addition the augen gneiss and rapakivi granite are very similar to the Precambrian biotite rapakivi of Finland as illustrated in Table 4.

Origin and Age. The strongly foliated texture of the augen gneiss confused earlier workers as to whether it was derived from an igneous or sedimentary parent rock. Field evidence, in addition to chemical evidence, supports an igneous parent because the unit displays many characteristics of catazonal to mesozonal intrusions described by Buddington (1958). The augen gneiss intrudes medium to high-grade metasedimentary rocks, lacks chill contact zones and has a well-developed foliation. These features collectively suggest a catazonal environment. Characteristics typical of mesozonal intrusions include associated pegmatites and discordant contacts.

The strongly foliated texture of the augen gneiss, undulatory extinction of quartz, broken potassium feldspar phenocrysts with mortar zones and bent albite twin lamellae indicate a post-solidification deformational event. However, this cataclasis does not appear to have chemically changed the inferred primary igneous composition of the host.

Table 4. Major oxide concentrations and CIPW normative analyses for the augen gneiss and related rocks.

	Augen Gneiss[a]	18954	Biotite Rapakivi[b]
SiO_2	70.00	74.2	73.84
TiO_2	0.37	0.4	0.22
Al_2O_3	14.76	13.4	13.09
FeO	3.04	2.9	1.79
Fe_2O_3	0.84	---	0.87
MgO	1.23	0.5	0.23
CaO	0.98	1.0	1.12
Na_2O	4.06	2.7	2.32
K_2O	4.00	5.10	6.24
MnO	---	---	0.03
P_2O_5	---	---	0.05
F	---	---	0.17
H_2O^-	0.24	---	0.07
H_2O^+	0.56	---	0.45
total	100.08	100.2	100.49
qtz	25.43	33.97	33.61
cor	1.97	1.62	1.05
ortho	23.80	30.08	36.74
alb	35.58	22.85	19.74
anor	4.92	4.95	3.98
hyp	7.37	5.91	2.84
il	0.70	0.76	0.46
mag	1.23	---	1.16
apa	---	---	0.14
total	99.91	100.14	99.39

a - from Davidson, 1928, p. 21.
b - from Savolahti, 1956 in Carmichael and others, 1974, p. 591.

The augen gneiss is younger than the biotite gneiss that it intrudes, and is older than the cross-cutting Tertiary (Challis?) dikes. Potassium-argon analyses of biotites from the augen gneiss yielded dates ranging from 108±3 to 562±17 m.y. and represent minimum ages (Armstrong, 1975, p. 442). However, rubidium-strontium whole rock analyses have resulted in a controversial date of 1450 m.y. Supporting evidence for such an old age includes similarities between the augen gneiss near Shoup and near Elk City, Idaho; the latter has yielded a 1450 m.y. based on the U-Pb method from zircons (Reid and others, 1973).

LEUCOCRATIC GRANITOID DIKES

Closely associated with the augen gneiss and biotite gneiss in the northern part of the Pine Creek area are aplitic to pegmatitic leucocratic granitoid dikes. The best outcrops of the dikes are along Forest Service Road 242 between Pine Creek and Hot Springs Creek. Locally, the dikes and dikelets comprise more than 50 percent of the bedrock and range from less than 0.1 to 60 feet in width. Because of the complexly interfingered contacts between the augen gneiss, biotite gneiss and granitoid dikes, only generalized contacts are shown on Plate 1.

Field evidence indicates that at least two ages of dike emplacement are present (Fig. 9). Although there is a wide variation in the contents of quartz and feldspar of the dikes, a correlation between composition and age could not be made. Maley (1974), on the basis of cross cutting relationships, has also presented evidence for two ages of dikes in the Pine Creek area.

The leucocratic granitoid dikes are white (N 9) to grayish orange pink (5 YR 8/4) on fresh surfaces. This variation in color depends on the intensity of alteration. Weathered surfaces are generally a moderate reddish orange (10 R 6/6).

Petrography. The leucocratic granitoid dikes are allotriomorphic to hypidiomorphic granular. Primary minerals range from 1 to 3 mm in diameter, but small lenses and pods of more coarsely crystalline pegmatitic quartz and feldspar are common throughout. The major constituents are oligoclase (40-50 percent), quartz (20-30 percent), potassium feldspar (25-40 percent), biotite (2-5 percent), muscovite (1-2 percent), and magnetite (tr). Oligoclase, potassium feldspar, and biotite are partially altered to white mica. Compositionally, the dikes range from granite to granodiorite. In addition, these dikes near the Hot Springs Fault have undergone strong cataclasis as depicted in Figure 13.

Origin and Age. The origin and age of these dikes are uncertain. However, because there are at least two different ages of dikes in the Pine Creek area, more than one hypothesis might be valid. The first hypothesis suggests that the dikes formed primarily as a water-rich magmatic differentiate of the augen gneiss. The development of aplite and pegmatite dikes from a magma equivalent to the composition of the augen gneiss is clearly possible. A second hypothesis might suggest that some of the dikes have formed by metamorphic differentiation. Dikelets and segregations of quartz and feldspar shown in Figures 9 and 10 may have formed by partial melting of the biotite gneiss. Lastly, it is possible that some of the dikes could be genetically related to the Idaho batholith.

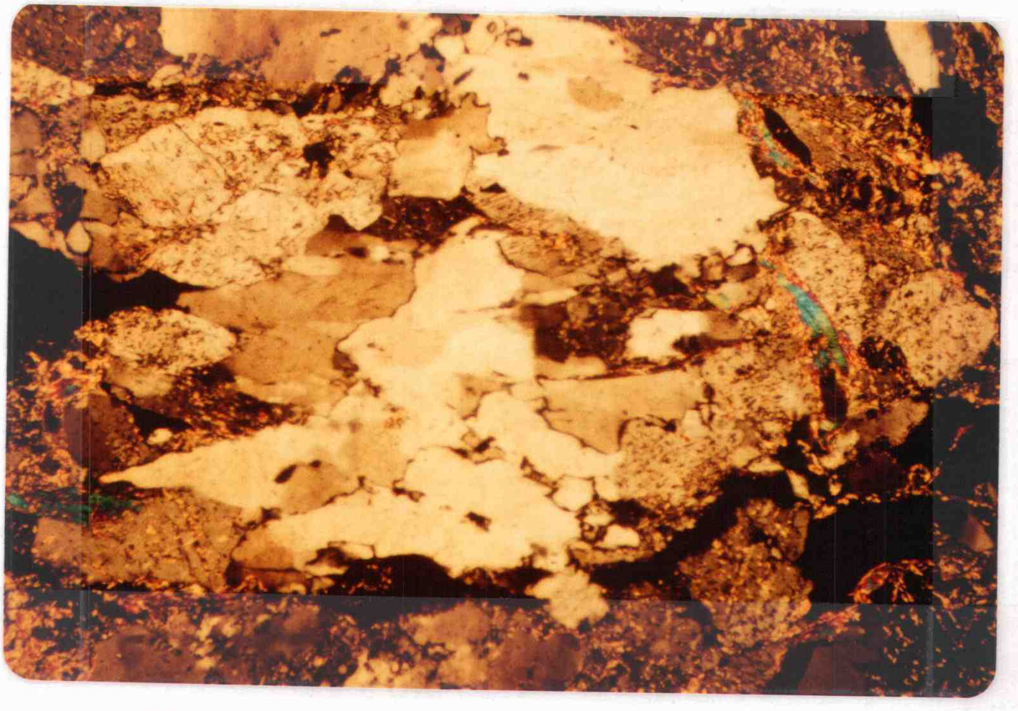


Figure 13. Photomicrograph of a leucocratic granitoid dike showing strong shearing of the quartz and feldspar in addition to the alteration of the feldspars (crossed nicols, field of view is 7 x 4.7 mm).

RAPAKIVI GRANITE

The rapakivi granite is excellently exposed on the slopes east of the Pine Creek Ranch (Plate 1). Outcrops display surfaces of spheroidal weathering that are typical of granitoid rocks. The color of this unit is generally light gray (N 6). The rapakivi granite is medium to coarsely crystalline, and porphyritic with phenocrysts of gray potassium feldspar. Some phenocrysts are rimmed with sodic plagioclase feldspar that produces a rapakivi texture. Numerous xenoliths of quartzite occur within the unit. Cross-cutting dikes of aplite and pegmatite (Fig. 14), with some containing tourmaline, are also fairly common.

Petrography. The rapakivi granite consists of quartz (15-20 percent), potassium feldspar (30-45 percent), oligoclase (15-25 percent), biotite (8-10 percent) muscovite (3-4 percent) with minor amounts of sphene (1 percent) and trace amounts of apatite, magnetite and zircon. Common alteration products of oligoclase and biotite are white mica, and epidote. The groundmass is hypidiomorphic granular, nonfoliated and the component minerals vary from 1 to 5 mm in diameter. Phenocrysts of orthoclase are blocky, subhedral and range from 10 to 30 mm in length (Fig. 14). Perthitic intergrowths are common in these phenocrysts and some are also rimmed with sodic plagioclase feldspar. Inclusions of biotite are also common. In addition to forming the larger phenocrysts, potassium feldspar is also present as small anhedral (1-2 mm) crystals in the groundmass.

Quartz is anhedral and displays embayed and sutured borders. Although individual grains average 0.5 to 1.0 mm in diameter, they also form much larger polycrystalline masses up to 5.0 mm in diameter. Small

Figure 14a. Aplite dike with small lenses of pegmatite. Note the post aplite stringers of tourmaline and the dilational offset of the quartzite xenolith. The rapakivi granite is the host. The pencil is 5.6 inches in length.

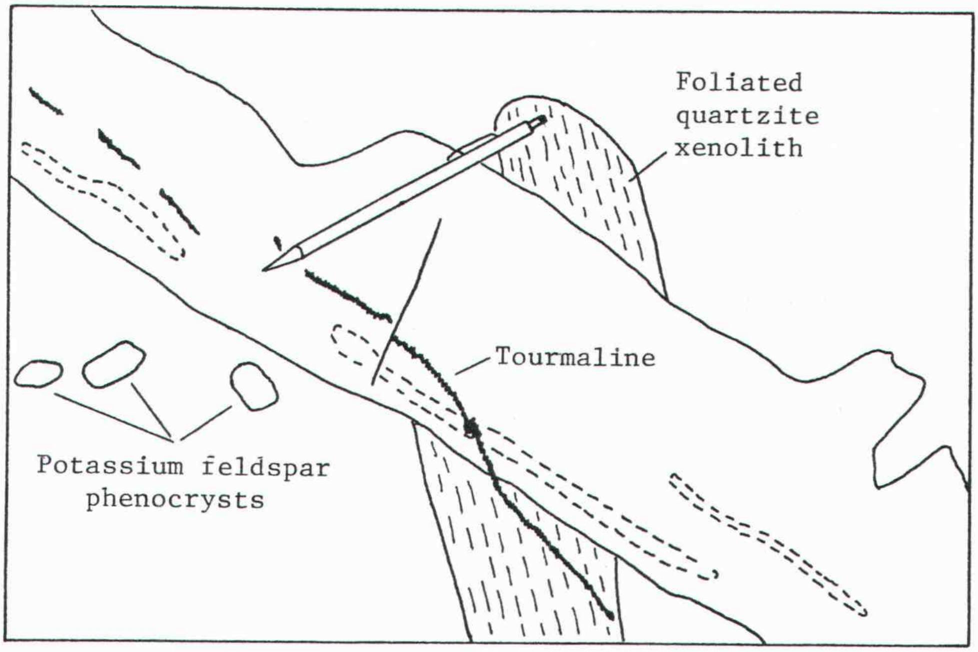


Figure 14b. A diagrammatic representation of the aplite dike and related features.

platelets of biotite (?) are present as inclusions in some crystals of quartz.

Crystals of oligoclase (An_{21-24}) are generally subhedral to euhedral and 2.0 to 5.0 mm long. They generally show weak to pervasive alteration with white mica being the most common replacement product. The presence of unusually large amounts of white mica along selective zones in the plagioclase host suggests a compositional zoning. Albite twins are rarely present and they may have been obliterated by subsequent alteration.

Biotite and muscovite are mutually associated in lepidoblastic masses that average 1.0 to 2.0 mm in length. Epidote is associated with biotite as a replacement product. The crystals of biotite contain inclusions of metamict zircon that have produced radiation halos in the adjacent mica.

Geochemistry. Major oxide concentrations and CIPW normative analyses for the rapakivi granite (18954) are shown in Table 4. The average compositions of 37 rapakivi granites (Tuttle and Bowen, 1958), the augen gneiss, and sample 18954 in terms of normative quartz, albite, and orthoclase are illustrated in Figure 15. In general, the rapakivi granites are more potassic than most plutonic rocks that contain more than 80 percent normative q-ab-or. The highly potassic composition of these rocks is probably important to the development of rapakivi texture.

Rapakivi granites and related potassic plutonic rocks (K_2O/Na_2O 2) are generally confined to stable cratonic provinces and most are Precambrian in age. In contrast, plutonic rocks of major orogenic belts are commonly granodioritic to quartz monzonitic in composition (Carmichael and others, 1974, p. 590).

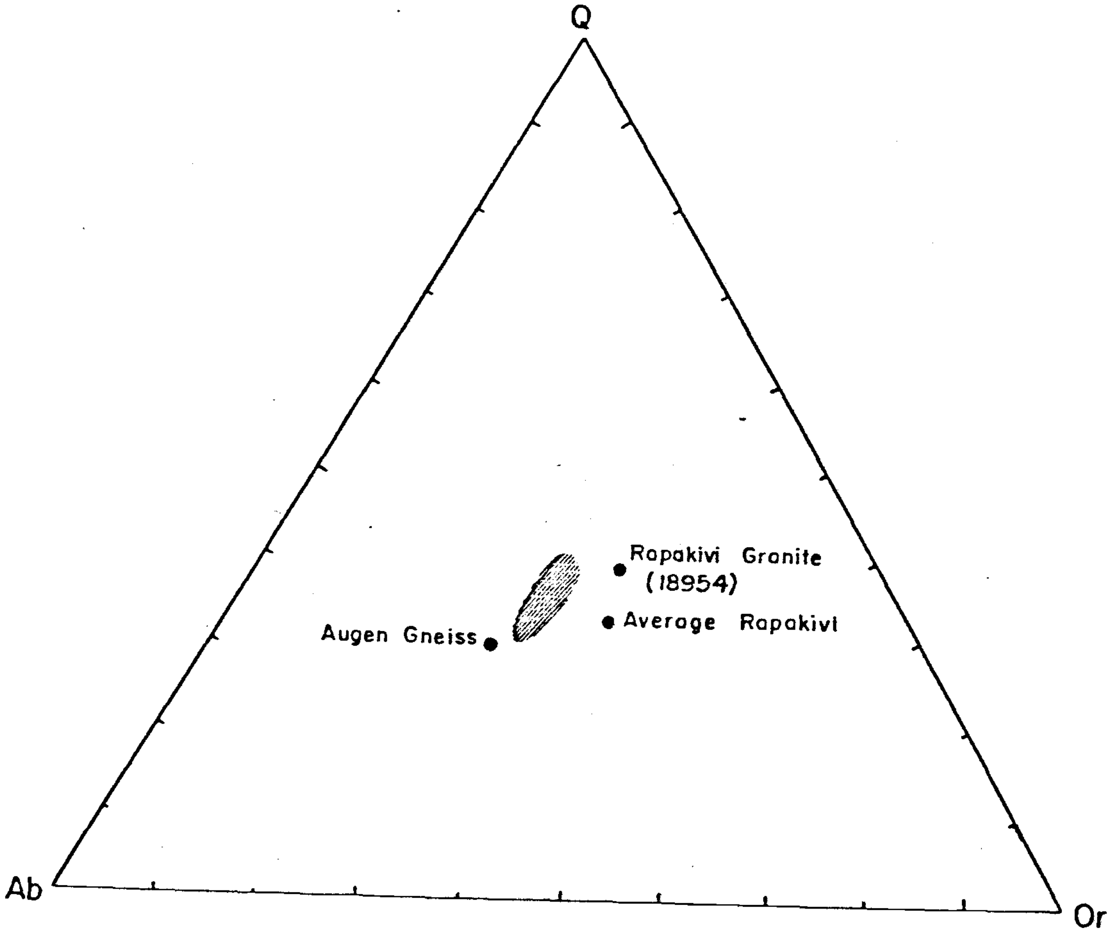


Figure 15. The distribution of normative quartz (Q), orthoclase (Or), and albite (Ab) in the rapakivi granite (18954), augen gneiss and other plutonic rocks. Shaded region shows the composition of most plutonic rocks with more than 80 percent normative Q + Or + Ab (after Tuttle and Bowen, 1958).

Origin. The rapakivi granite and augen gneiss have mineralogical and chemical similarities. Both rock types contain large phenocrysts of potassium feldspar, some of which are mantled with sodic plagioclase feldspar. In addition, the major oxide chemistry for both rock types shows affiliations with potassic granites. Because of these similarities, a common parental magma is suggested for the rapakivi granite and augen gneiss. However, the augen gneiss has a less differentiated chemistry and would therefore be more compositionally similar to that of the parental magma.

Experimental studies in the granite system (Tuttle and Bowen, 1958; von Platen, 1965) have helped to explain the crystallization histories of plutonic rocks. In particular, the studies of von Platen are applicable in understanding the crystallization history of the augen gneiss-rapakivi granite complex. Von Platen determined the sequence of crystallization for various compositions of melt and fluid phases, and his work can be summarized on a series of normative quartz-albite-orthoclase ternary diagrams. These diagrams (Figures 16, 17 and 18) are actually projections onto the q-ab-or plane from planes within the q-ab-or-an tetrahedron. His results showed that the normative proportion of Ab/An has the greatest influence on the sequence of crystallization of leucocratic minerals in granite melts. The composition(s) of the fluid phase(s) is (are) also important. However this sequence of crystallization of leucocratic minerals is independent of the biotite and magnetite components. The crystallization fields of quartz, albite, and orthoclase at 2 kb are shown in the ternary diagram depicted in Figure 16. These fields of crystallization for melts with Ab/An ratios of 1.8, 3.8, 5.2 and 7.8 are bounded by cotectic lines with end points at A, B,

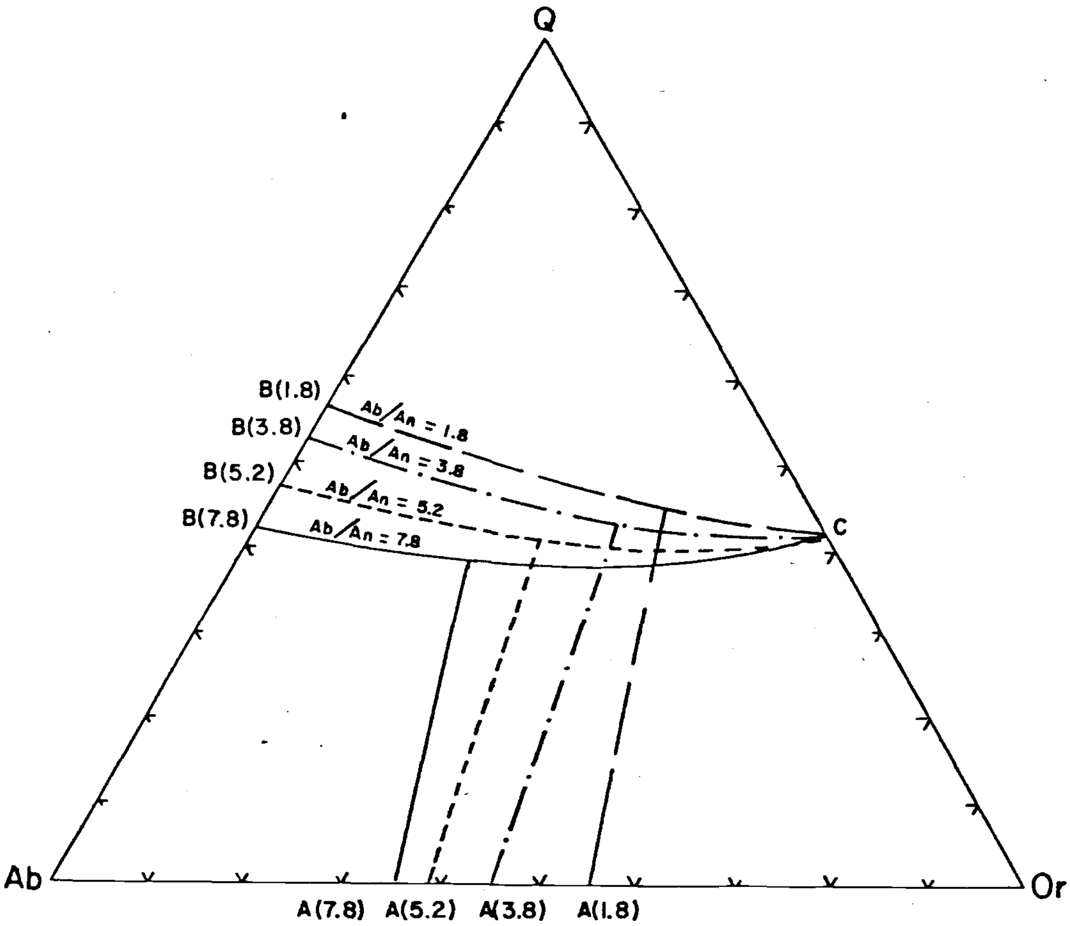


Figure 16. A Q-Ab-Or diagram showing the fields of crystallization of quartz, plagioclase feldspar and orthoclase for water saturated granitic melts at 2.0 kb confining pressure (after von Platen, 1965).

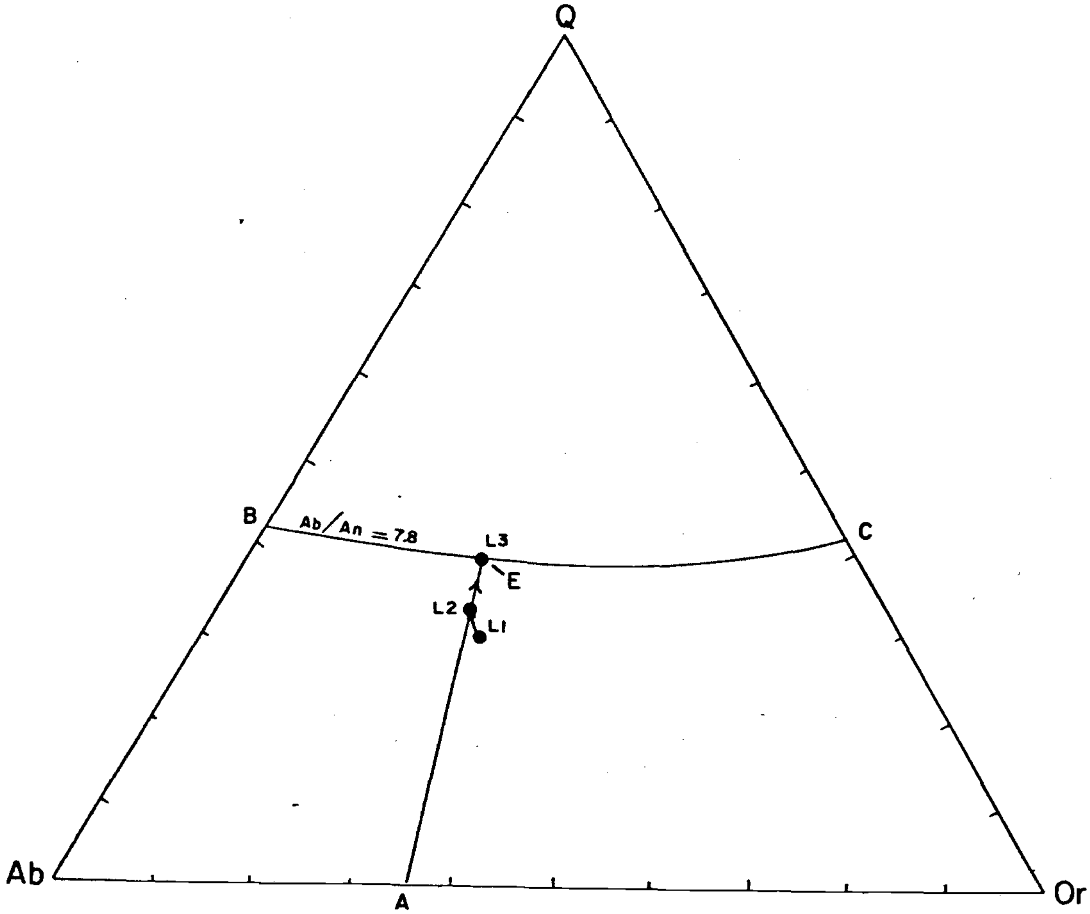


Figure 17. Approximate trend of the residual melt during the crystallization of the augen gneiss at 2.0 kb confining pressure and saturated with water. See text for futher elaboration.

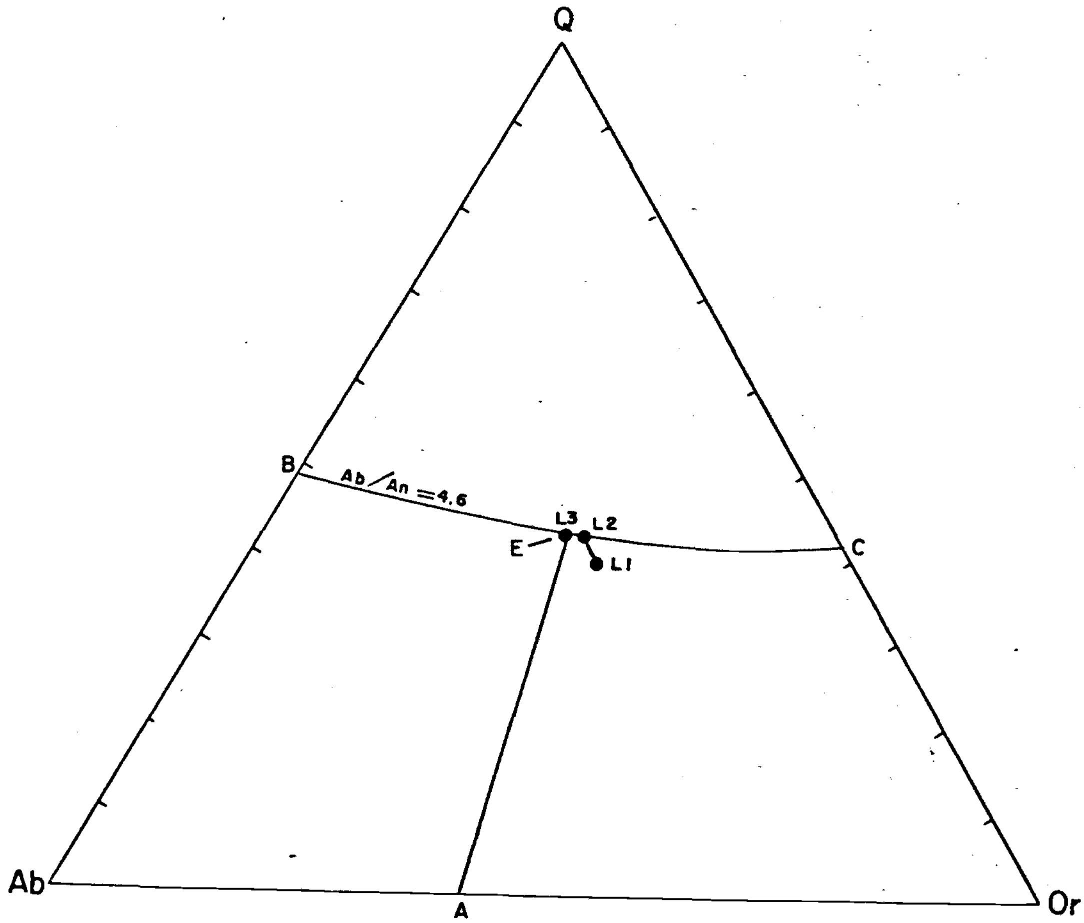


Figure 18. Approximate trend of the residual melt during the crystallization of the rapakivi granite (18954) at 2.0 kb confining pressure and saturated with water.

and C. The cotectic lines meet at the eutectic point (E) (Fig. 17 and 18). Because the positions of the cotectic lines are dependent on the Ab/An ratios, the size of the orthoclase field will increase with an increase in the Ab/An ratio. Note also that the eutectic points (E) are higher in quartz and orthoclase components when the original magmas have smaller Ab/An ratios. This trend indicates that plutonic rocks of granodiorite composition will produce aplites and pegmatites richer in quartz and potassium feldspar than those of granitic composition. This trend may also have analagous effects in hydrothermal systems derived from source rocks that are granodioritic to quartz monzonitic in composition.

The sequence of crystallization of leucocratic minerals for a melt of the composition of the augen gneiss (L1) (Ab/An = 7.0) at 2 kb and saturated with respect to water is shown in Figure 17. The point, L1, is within the crystallization field of alkali feldspar, so therefore this feldspar would be the first to precipitate. The alkali feldspar would contain appreciable amounts of sodium as indicated by the later formation of perthite. Moreover, the change in the composition of the residual liquid would be away from both the Or and Ab corners as illustrated in Figure 17 by the line from L1 to L2. Note also that during the crystallization of alkali feldspar (L1 to L2), that the Ab/An ratio of the residual magma would decrease until the precipitation of plagioclase feldspar begins. Plagioclase feldspar and alkali feldspar would crystallize concurrently from L2 to L3. At L3, crystallization would proceed with plagioclase feldspar, alkali feldspar and quartz until the residual melt is entirely crystalline.

The sequence of crystallization of leucocratic minerals for a melt equivalent to the composition of the rapakivi granite (18954) at 2kb and saturated with respect to water is shown by point L1 in Figure 21. Crystallization in this system would begin with alkali feldspar, during which time the change in the composition of the residual melt follows the line from L1 to L2. Upon reaching the cotectic line at L2, alkali feldspar and quartz would be co-precipitates. At L3, the eutectic, alkali feldspar, quartz, and plagioclase feldspar would crystallize until the melt has entirely solidified.

The trends in composition of the residual melts shown in the ternary diagrams of Figures 17 and 18 suggest the following:

1. if the major oxide data represent the compositions of the original melts, then it is not possible to derive a magma which has the composition of the rapakivi granite from a magma which has the composition of the augen gneiss, by differentiation alone; and

2. the formation of large phenocrysts of alkali feldspar in potassic plutonic rocks may likely be the result of early crystallization from a magma and not necessarily due to potassic metasomatization as has been suggested by other authors (Greenwood, 1967; Maley, 1974).

BIOTITE GRANITE

The biotite granite is similar in texture and composition to the rapakivi granite. It differs primarily by the lack of phenocrysts and slightly smaller size of crystals. The biotite granite forms a marginal zone to the rapakivi granite. and except for one roadcut on the west side of Pine Creek, all exposures are on the east side of Pine Creek. Although the contact between the biotite granite and rapakivi granite does not crop out, it appears to be partly gradational with potassium feldspar phenocrysts occasionally present in the eastern portion of the biotite granite.

The unit is mineralogically dominated by grayish pink (5 R 8/2) potassium feldspar which results in an overall light color on unweathered surfaces. Weathered surfaces are light brown (5 YR 5/6) to moderate reddish brown (10 R 5/4).

Petrography. The biotite granite consists of quartz (35-40 percent), microcline (40-50 percent), plagioclase feldspar (10-15 percent), biotite (0-9 percent), with trace amounts of sphene, zircon, apatite, and magnetite. White mica is a very common alteration product of plagioclase feldspar. Texturally, the biotite granite is medium to coarsely crystalline and hypidiomorphic granular.

Microcline is subhedral to anhedral and averages 3 to 5 mm in diameter, although many crystals are as large as 10 mm. Gridiron twinning is well-developed and exsolution of sodic plagioclase feldspar to form microperthite is fairly common. Micropegmatitic intergrowths (Figure 19) near the margins of large microcline crystals are ubiquitous.

Quartz is anhedral and varies from 1 to 2 mm in diameter. The smaller grains comprise polycrystalline aggregates that can be up to 7 mm in diameter. Small light brown plates (biotite?) are found as inclusions in the quartz.

Plagioclase feldspar is oligoclase that forms blocky subhedral to euhedral crystals up to white mica.

Origin. Evidence such as the occasional potassium feldspar phenocrysts, similarities in texture and spatial association suggest a close

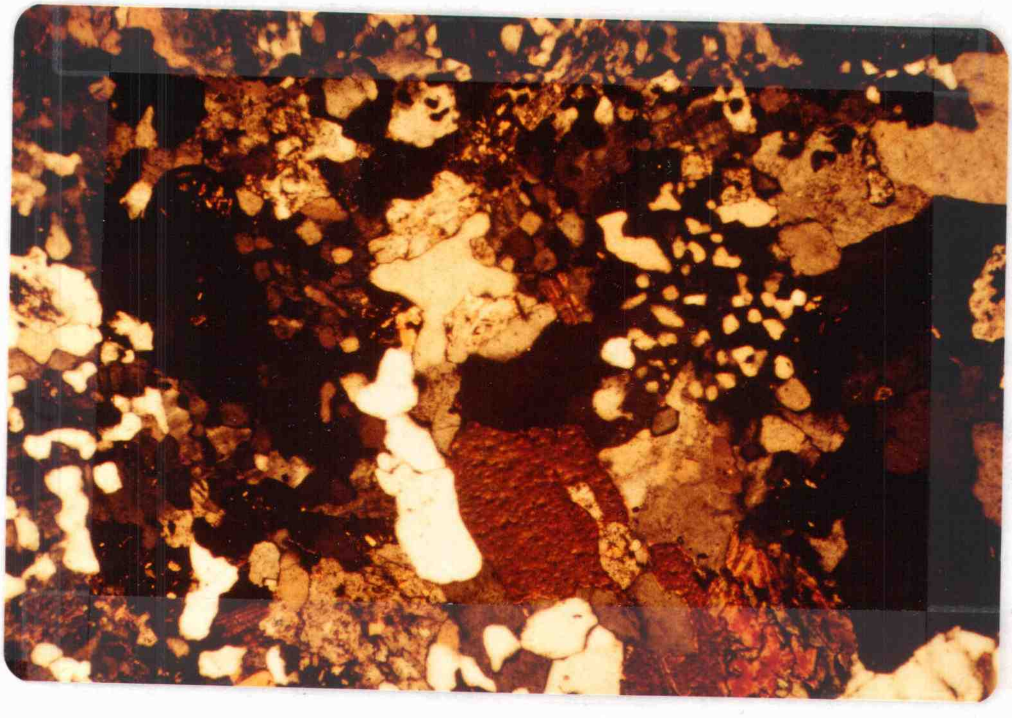


Figure 19. Photomicrograph of the biotite granite illustrating the numerous micropegmatitic intergrowths (crossed nicols, field of view is 4.7 x 7 mm).

genetic relationship between the biotite granite and rapakivi granite. Although the more highly differentiated composition of the biotite granite suggests that it is younger than the rapakivi granite, the necessary field relationships to provide this evidence are lacking.

CRETACEOUS TO TERTIARY IGNEOUS ROCKS

Igneous rocks of Cretaceous to Tertiary age are exposed in the northern part of the Pine Creek area. They vary from dioritic to rhyolitic in composition and from glassy aphanites to phanerites in texture. The Pine Creek stock is the only representative of this group that crops out south of the Hot Springs Fault. All other post-Precambrian igneous rocks are found north of the fault and include dikes of rhyolite, diorite, and porphyritic andesite (Plate 1).

PINE CREEK STOCK

Maley (1974) mapped a pink quartz monzonite stock in the lower Pine Creek area, and Bennett (1977) in a reconnaissance study included portions of the leucogranitoid unit north of the Hot Springs Fault as part of the intrusion. In addition, he informally named the intrusive body the Leesburg stock, which suggests a genetic relationship with the intrusion found eight miles to the southeast. The stock on lower Pine Creek has little resemblance to the Leesburg stock and a different name is warranted. The name Pine Creek stock will be used informally in this report.

The lower Pine Creek road (F.S. 32) has several excellent exposures of this stock. The road marks the easternmost margin of the intrusion. Slightly arcuate in plan (Plate 1), the stock trends and narrows to the northwest where it is eventually truncated by the Hot Springs fault. The ridges north and south of German Gulch also have fairly good exposures of the Pine Creek Stock, although the valley slopes in this area were mapped on the basis of the distribution of float.

Contacts of the stock with the host quartzite are sharp and discordant. Features common along the contact include an increase in the mica content of both the quartzite and the intrusion. The abundance of quartz vein within the intrusion also increases toward the contact. Dikes of similar lithology crop out to the south and west of the main stock.

The stock is a medium crystalline, equigranular, leucocratic granodiorite that consists essentially of feldspars and quartz. Muscovite and biotite are present in minor amounts but constitute less than 10 percent of the rock.

Unweathered surfaces of the granodiorite are very pale orange (10 YR 8/2) to pale yellowish orange (10 YR 8/6) in color. Weathered surfaces display moderately abundant stains of iron oxides which render outcrop dark yellowish orange (10 YR 6/6) to moderate reddish brown (10 R 4/6).

Petrography. Granodiorite of the Pine Creek stock displays a subhedral granular texture that is very slightly hiatal. Primary minerals include plagioclase feldspar, quartz, potassium feldspar, muscovite, biotite, and trace amounts of zircon and apatite. White mica and calcite are common alteration products of plagioclase feldspar. Modal analyses are shown in Table 5.

Phenocrysts of plagioclase feldspar (An_{25-33}) are euhedral to subhedral in shape and range from 1.0 to 1.5 mm in length. Albite, Carlsbad and pericline twins are present but not ubiquitous, and many of the crystals are untwinned. Certain zones of the phenocrysts are preferentially altered which suggest a compositional zoning.

Crystals of quartz are generally anhedral and display undulatory

Table 5. Modes, major oxide concentrations, and CIPW norms for samples of the Pine Creek Stock.

	PC-2	PC-3	PC-4
quartz	34	30	36
plagioclase	47	54	42
K-feldspar	13	12	18
biotite	1	1	1
muscovite	6	1	1
opaques	tr	1	tr
sericite	1	1	1
calcite	tr	1	tr
chlorite	tr	tr	tr
SiO_2	73.7	74.6	
TiO_2	0.5	0.05	
Al_2O_3	14.8	15.5	
FeO	1.9	0.9	
MgO	0.2	0.2	
CaO	1.0	1.3	
Na_2O	4.4	4.9	
K_2O	3.40	3.25	
Total	99.9	100.7	
quartz	31.5	29.7	
albite	37.2	41.3	
orthoclase	20.1	19.4	
anorthite	5.0	6.4	
hypersthene	3.2	2.0	
ilmenite	0.9	0.2	
corundum	2.0	1.5	
Total	99.9	100.5	

extinction. They range from 0.2 to 1.0 mm in diameter.

Phenocrysts of potassium feldspar are generally subhedral and range from 0.2 to 0.7 mm in length. These phenocrysts are most commonly unaltered; a characteristic that serves to distinguish untwinned potassium feldspar from untwinned plagioclase feldspar. Micropegmatitic intergrowths are common near adjacent quartz and potassium feldspar phenocrysts (Fig. 20).

Biotite and muscovite are subhedral to anhedral. They range from 0.06 to 0.6 mm in length. Hematite is commonly present near aggregates of biotite and muscovite. Cleavage lamallae of the micas are commonly bent.

Geochemistry. The major oxide concentrations and CIPW norms for PC2 and PC3 are given in Table 5. The Pine Creek stock shows gross similarities with other granitoid rocks. The primary differences include the very low concentrations of MgO and FeO and the probably low concentrations of CaO (Fig. 21). The former is probably real and reflects the paucity of mafic minerals in the rock. The low content of CaO may be an alteration effect because most phenocrysts of plagioclase feldspar display some effects of alteration. The rock is peraluminous, that is the molecular proportion of Al_2O_3 exceeds the molecular proportion of ($CaO + Na_2O + K_2O$), as indicated by the formation of magmatic muscovite. The lack of agreement between the norm and mode (Table 5) is probably a result of the formation of muscovite and the alteration of plagioclase feldspar phenocrysts.

Age and Origin. The absolute age of the Pine Creek stock is not known and field relationships provide very little additional evidence. The stock must be younger than the quartzite and amphibolite which it

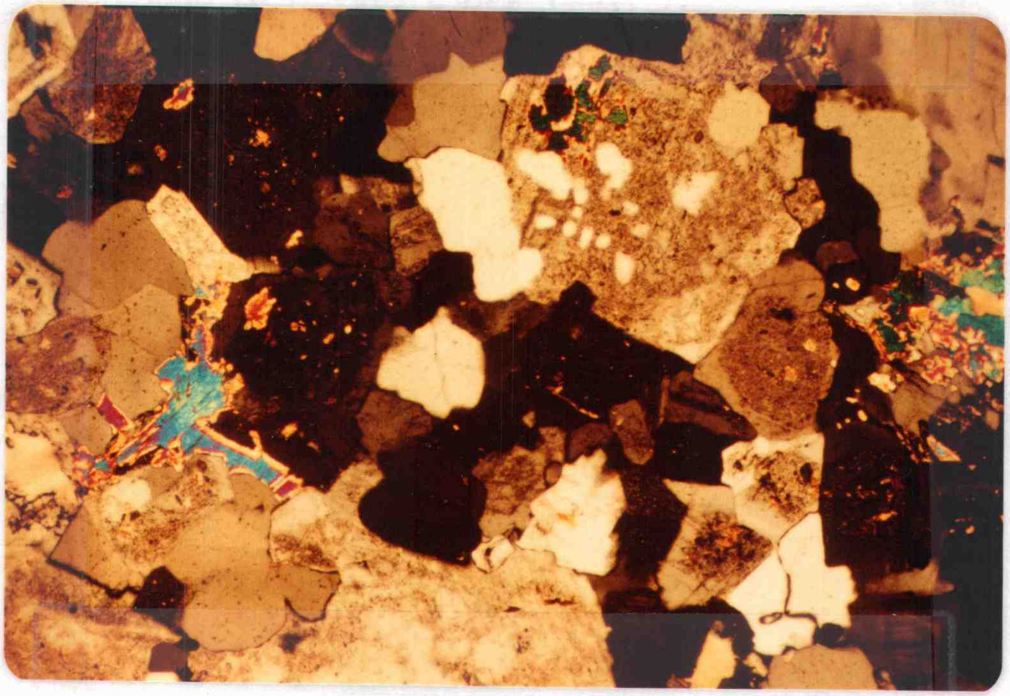


Figure 20. Photomicrograph of the Pine Creek Stock showing muscovite, the alteration of the feldspars and micropegmatitic intergrowths (crossed nicols, field of view is 0.8 x 1.2 mm).

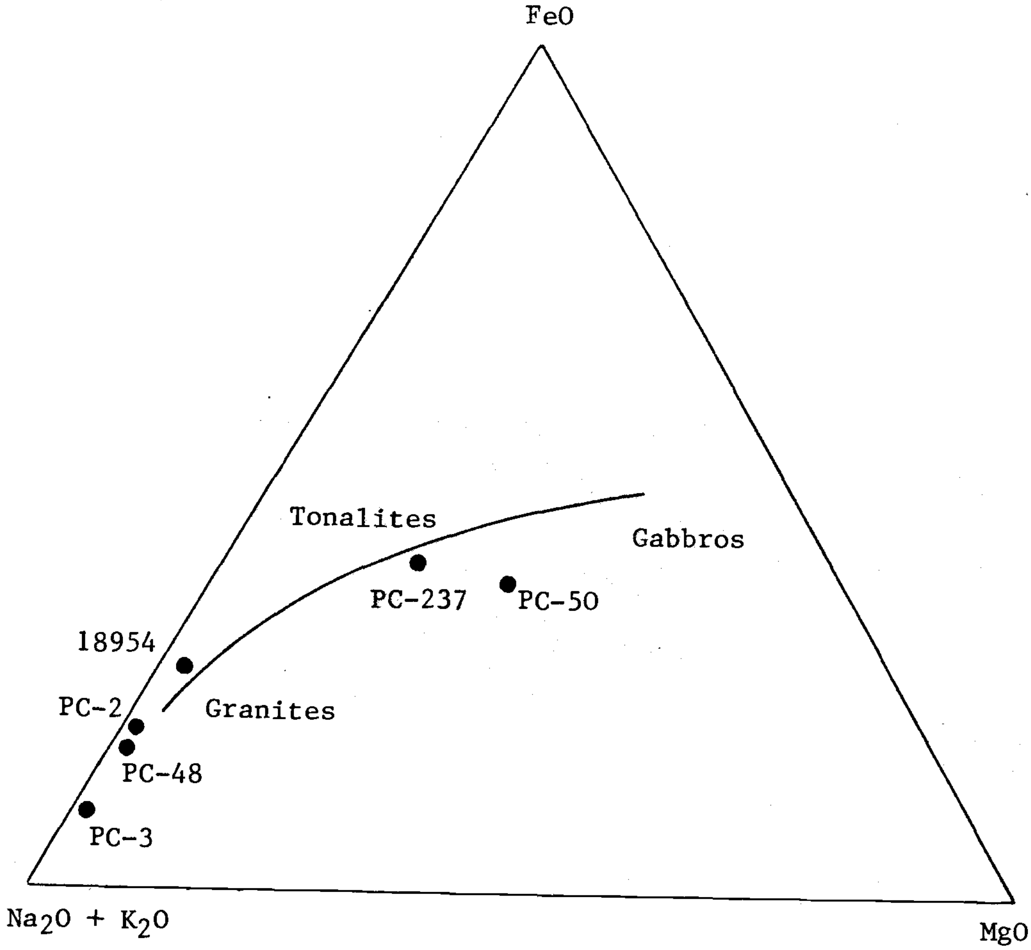


Figure 21. An AFM plot of the various igneous rocks from the Pine Creek area compared with the general trend from the lower California batholith shown in oxide proportions by weight (after Carmichael and others, 1974, p. 568).

intrudes (1.3 b.y.) and is probably as old or older than the latest magmatic event in this part of Idaho (40-50 m.y.). The texture and composition suggest that it may be related to the Idaho Batholith and therefore Cretaceous in age.

The Idaho Batholith crops out about three miles to the north, and Pine Creek stock may represent an apophysis of the batholith. The chemistry of the stock suggests a differentiation of the main body of Idaho Batholith. The Pine Creek stock, and/or other derivatives of the Idaho Batholith, are the most likely host rocks for Thompson Creek molybdenum deposits.

RHYOLITE DIKES

Dikes of rholitic composition crop out north of the Hot Springs Fault in the northern part of the Pine Creek area. The dikes display positive relief (Fig. 22) and range from 10 feet to 25 feet in thickness. They generally strike to the east or northeast and most dip vertically. Unweathered surfaces are yellowish gray (5 Y 7/2) and weathered surfaces are a pale yellowish brown (10 YR 6/2) in color.

These dikes are very finely holocrystalline to holohyaline, depending on the thickness of the dike and the location of the sample from within the dike. Excellent flow banding is preserved along the margins of several dikes. Megascopically identifiable minerals include biotite, feldspar and quartz. Phenocrysts comprise about 10 to 25 percent of the holocrystalline portion of the dikes.

Petrography. Primary mineral constituents include orthoclase (40-50 percent), quartz (20 percent), oligoclase (12-17 percent), biotite (4-7 percent), and opaques (tr-1 percent). White mica (12-15 percent)

Figure 22. A typical outcrop of a rhyolite dike that has intruded augen gneiss. The outcrop is 10 to 15 feet high.

is a common alteration product of oligoclase. The groundmass consists of anhedral plagioclase feldspar, quartz, biotite, and orthoclase which are less than 0.1 mm in diameter. Phenocrysts include anhedral quartz, euhedral plagioclase and orthoclase (?) and subhedral biotite. The phenocrysts are from 0.5 mm to about 1.5 mm in diameter.

Plagioclase phenocrysts lack albite twinning, although the large 2V (75-85) and positive sign suggest that it is albite or sodic oligoclase. In addition, the phenocrysts of plagioclase feldspar display pervasive alteration to white mica. In contrast, those of orthoclase are generally only slightly altered to white mica. Phenocrysts of quartz are embayed and appear to have undergone assimilation. Crystals of biotite are filled with numerous inclusions of opaques.

Geochemistry and Age. Major oxide concentrations and CIPW norms for sample PC-48 are listed in Table 6. The major oxide chemistry of PC-48 is similar to that of samples PC-2 and PC-3 of the Pine Creek stock. The most significant differences include lower concentrations of CaO and Na_2O and higher concentrations of K_2O in PC-48 relative to the Pine Creek stock. This sample (PC-48) is compositionally closely aligned with granite-rhyolite clan as illustrated in Figure 21.

Although the composition of the rhyolite dikes is similar to that of the Pine Creek stock they are probably not genetically related. There are major differences in the texture between these rhyolite dikes and those related to the Pine Creek stock which crop out west and south of the main body.

Because of these differences, it is speculated that the rhyolite dikes in the Pine Creek area are probably 40 to 50 m.y. in age and thus are related to the Challis magmatic event.

Table 6. Major oxide concentrations and CIPW norms for samples PC-48 and PC-50 with comparisons to other rhyolite and quartz diorite.

	PC-48	A	PC-50	B
SiO_2	73.5	73.2	58.3	62.2
TiO_2	0.25	0.24	0.95	0.7
Al_2O_3	15.3	14.0	16.3	16.6
Fe_2O	-	0.6	-	1.4
FeO	1.9	1.7	6.8	4.5
MgO	0.4	0.4	5.6	2.7
CaO	0.4	1.3	5.5	5.7
Na_2O	3.4	3.9	3.3	3.4
K_2O	5.55	4.1	3.15	1.6
P_2O_5	-	0.05	-	0.09
H_2O^+	-		-	-
H_2O^-	-		-	0.6
Total	100.70	99.49	99.90	99.55
quartz	29.6		3.4	12.9
albite	28.8		27.8	28.8
orthoclase	32.8		18.9	8.9
anorthite	1.9		20.3	28.9
diopside			5.7	2.1
hypersthene	3.9		22.0	13.5
magnetite			-	2.1
ilmenite	0.5		1.8	1.7
apatite			-	0.3
corundum	2.9		-	-
Total	100.4		99.9	99.2

A average Cascades rhyolite (after Carmichael, 1964, Table 8 in Carmichael and others, 1974).

B average Bonsall quartz diorite, southern California Batholith (after Carmichael and others, 1974, p. 568.

DIORITE DIKES

Three north-striking dikes of diorite crop out along the ridge between Pine and Hot Springs Creek (Plate 1). They are holocrystalline and slightly porphyritic. The dikes range from 60 feet to 120 feet in width. They weather from a variegated grayish olive green (5 GY 3/2) to a grayish yellow green (5 GY 7/2). Unweathered surfaces display a light (feldspar) to dark (hornblende and biotite) contrast, and are dusky green (5 G 3/2) to very light gray (N 8). Sparse phenocrysts of feldspar (2 percent) are present in the finely crystalline (1-2 mm) granular groundmass. In addition to feldspar and hornblende, quartz, chlorite, pyrite and magnetite are megascopically visible in most samples.

Petrography. The principal mineral constituents of the diorite include plagioclase feldspar (35 to 40 percent), hornblende (23 to 26 percent), myrmekite (8 percent), potassium feldspar (4 percent), quartz (7 percent), and chlorite (21 percent). In addition, trace amounts of pyrite, magnetite, zoisite, chabazite, sphene, and calcite are also present. The mineralogy suggests that these dikes should be more accurately named a quartz-bearing diorite.

Subhedral phenocrysts of plagioclase feldspar range from 0.5 to 2.0 mm in length. Carlsbad twins are very common, although albite twins are rare. Frequent alteration products of plagioclase feldspar include zoisite, calcite, and chabazite.

Hornblende is generally light brown, euhedral and up to 0.5 mm in length. Chlorite replaces the hornblende along the margins of the phenocrysts.

Quartz is present as small anhedral crystals (0.1 mm), and also as myrmekitic intergrowths with plagioclase feldspar, which are the most distinctive petrographic feature of the diorite.

Geochemistry and Age. Major oxide concentrations and CIPW norms for a diorite dike (sample PC-50) are shown in Table 6. Also listed is the average composition of the Bonsall quartz diorite (B) of the Southern California batholith (Carmichael and others, 1974, p. 568). Major chemical differences include lower concentrations of MgO and K_2O in the batholith rocks, and these differences are well displayed on the AFM plot given in Figure 21.

On the basis of texture and composition, the diorite dikes are probably related to the Challis magmatic event and thus may be 40-50 m.y. in age.

PORPHYRITIC ANDESITE DIKES

Dikes of andesitic composition are confined to the northwest portion of the Pine Creek area. They do not form prominent exposures and most exposures are limited to road cuts. They generally strike north or northeast, and vary from five feet to 25 feet in width.

Unweathered surfaces range from grayish green (10 GY 5/2) to grayish olive green (5 GY 3/2) in color. Weathered surfaces are a moderate yellowish brown (10 YR 5/4). White, euhedral prismatic phenocrysts of plagioclase feldspar up to 5 mm long constitute about five to ten percent of the host. Also conspicuous in hand specimen are frequent (1-2 percent) rounded and embayed xenocrysts of quartz.

Petrography. Phenocrysts of plagioclase feldspar, hornblende and xenocrysts of quartz make up 5 to 15 percent of the rock. The matrix consists of a finely crystalline (0.1 to 0.3 mm), anhedral felted plagioclase feldspar (30-35 percent), biotite (10-25 percent), and hornblende (15-25 percent) with minor amounts of quartz (6-8 percent), orthoclase (2-3 percent), and trace amounts of hypersthene, apatite, sphene and zircon. Alteration of biotite and hornblende to chlorite is ubiquitous. Plagioclase feldspar is commonly altered to epidote, chlorite, quartz, biotite, or white mica.

Zoned phenocrysts of plagioclase feldspar are the most characteristic petrographic feature of the rock (Figure 23). The zones consist of an unaltered core of sodic andesine (An_{32-36}) surrounded by a margin of clouded plagioclase. The clouding results from very minute inclusions of an unidentified mineral (clay?) in the phenocrysts. The altered feldspar is surrounded by a very thin, discontinuous rim of albite(?). In addition to the euhedral phenocrysts, subhedral prismatic plagioclase feldspar is also the dominant mineral of the groundmass.

Hornblende is generally brown, euhedral and from 0.05 to 1.0 mm in length. This amphibole alters to biotite, chlorite and opaques. In addition, white mica and calcite are also commonly associated with these ferromagnesian products of alteration.

Biotite is largely subhedral to anhedral, brown and less than 0.4 mm in length. It alters readily to chlorite.

Hypersthene is the only other primary mafic mineral present. It is present in small amounts (<1%) as phenocrysts that exhibit embayed and irregular outlines which suggest that this orthopyroxene was not stable in the later stages of crystallization.

Except for the xenocrysts, quartz is present as very small crystals (0.02 mm) that are dispersed throughout the groundmass. Potassium feldspar has a similar habit as the quartz, and is more abundant near the large xenocrysts of quartz.

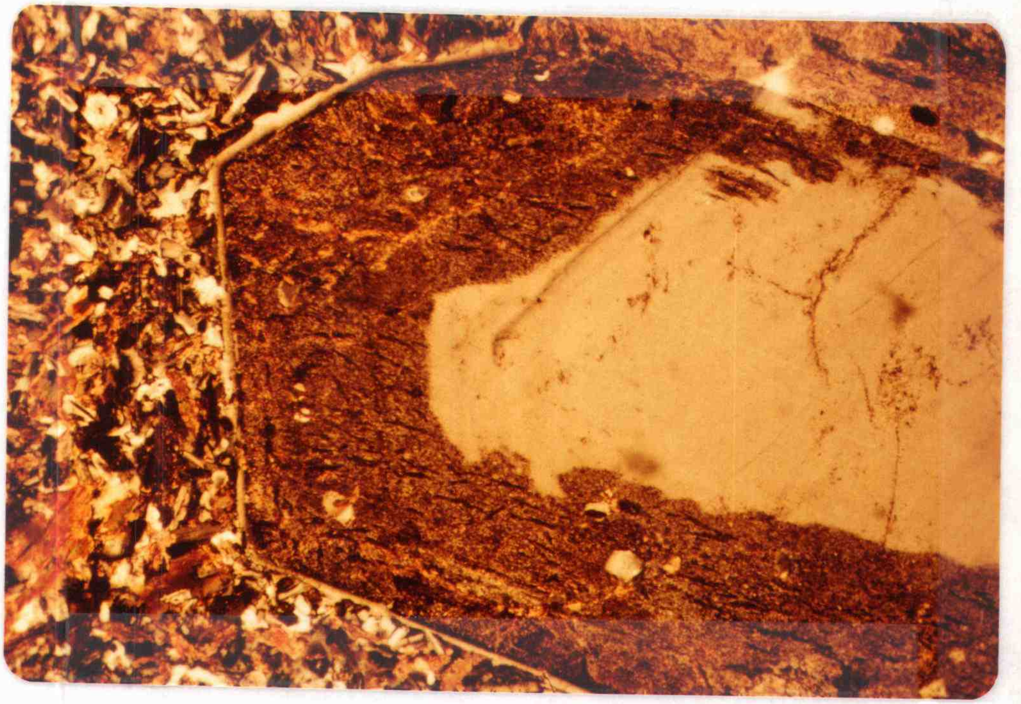


Figure 23. Photomicrograph of porphyritic andesite showing the large zoned phenocrysts of plagioclase feldspar (crossed nicols, field of view is 2 x 3 mm).

The dikes of porphyritic andesite are probably related to the Challis magmatic event (40-50 m.y.).

STRUCTURAL GEOLOGY

The Pine Creek area occupies a very structurally complex zone along the eastern margin of the Idaho Batholith. This area is bracketed on the north and west by augen and ellipsoidal gneiss, and on the east by rapakivi granite (Plate 1). The quartzites in this area probably have undergone repeated tectonic adjustments since late Precambrian (Y) time.

The prominent structural grain within the Pine Creek area has a northwest trend. Bedding and foliation of the Yellowjacket Formation have a northwest strike and generally a northeast dip. In addition, the Yellowjacket Formation is overturned with younger metasedimentary rocks to the southwest. Bedding-plane faults that exhibit minor displacement are common in the Yellowjacket Formation throughout the area.

The Leesburg Fault also has a northwest trend that can be traced from the Pine Creek area to the southeast for over 15 miles. The fault has juxtaposed younger rocks of the Hoodoo Formation on rocks of the Yellowjacket Formation. This fault is well-exposed on several ridge tops in the southwestern portion of the Pine Creek area. The Yellowjacket Formation near the fault is strongly sheared which imparts a "phyllitic" appearance. Bedding planes within the Yellowjacket Formation are not discernible near the fault. In addition, the Hoodoo Formation is more resistant to weathering than the Yellowjacket Formation. As a consequence, the first appearance of Hoodoo Formation is generally marked by a prominent outcrop. The present erosional surface has removed much of the fault and only klippen of the Hoodoo Formation remain.

Several large open folds are present in the northern part of the

Pine Creek area. The axial trace of these folds trends north-northwest. The folds probably formed as a result of the intrusion of the rapakivi granite. Wavelengths of these folds decrease with increasing proximity to this intrusive body.

The youngest structural trend within the Pine Creek area consists of several large high-angle faults that strike to the northeast. A similar trend is exhibited by most of the Tertiary dikes. The largest of these structures is the Hot Springs Fault, which forms the contact between the Yellowjacket Formation to the south and augen gneiss and higher grade metamorphic rocks to the north. This fault dips steeply to the southeast. Slickensides indicate that the latest movement has been primarily left-lateral slip with a minor component of normal slip. Although other faults are present within the quartzite terrain (Plate 1), actual fault surfaces were rarely observed. Zones of quartzite breccia and topographic depressions are the most common features near the inferred positions of these faults.

A poles-to-plane plot of joint surfaces did not reveal any dominant structural trend. The negative results of this exercise probably relate to an insufficient amount of data (70 poles) or to greater structural complexities that were not recognized in studies of the available outcrops.

ECONOMIC GEOLOGY

Past mineral production in the Pine Creek area was limited to three small mines: the Copper King mine at Copper Mountain, the Tramway prospect on Pine Creek and a small placer operation on Beaver Creek (Plate 1). Total production from these three mining ventures probably did not exceed $200,000 (1980 prices). In addition, four other small prospects, the PC prospect, the UBC prospect, the Red Dog prospect, and the Mother's Day prospect show past exploration activity (Plate 1).

Although mining activity has been very limited in the study area, several factors encouraged exploration for a Thompson Creek-Endako type of ore deposit in this region. They include:

1. the presence of hydrothermally altered rocks along the divide between Hot Springs Creek and Pine Creek, and also reports of weakly anomalous molybdenum values in the stream sediment of Hot Springs Creek (Bennett, 1977);
2. strongly anomalous concentrations of molybdenum in soil (96, 33, and 11 ppm) and stream sediment (13, 9, 9, 8, and 8 ppm) in the area of upper Beaver Creek as reported by Bennett (1977);
3. plutonic rocks similar in composition and texture to the host quartz monzonite stock at the Thompson Creek molybdenum deposit; and
4. a tectonic setting favorable for Cordilleran type molybdenum deposits that includes a location within the Idaho-Montana Porphyry Belt and along a northwest trending lineament as defined by a high altitude magnetic survey (Zietz and others, 1971).

MINERALIZATION AND ALTERATION

All occurrences of sulfide mineralization in the Pine Creek area are associated with quartz veins. Other gangue minerals within the veins include potassium feldspar, biotite, pyrite, magnetite, green muscovite/sericite, and iron hydroxides after pyrite and magnetite. In addition, sulfides and associated products of oxidation within the veins are divisible into two major groups. The first group has anomalous concentrations of copper, lead, silver, and manganese. Veins of this type are generally void of potassium bearing silicates, although green muscovite/sericite is sometimes found. The second group has anomalous concentrations of molybdenum and fluorine that are nearly always associated with potassium bearing silicates.

The quartz veins associated with both types of mineralization are generally not found in pervasively altered host rocks. Although the margins of the veins may display selvages of biotite or muscovite, the host rock beyond these selvages is neither altered nor bleached. However, whole rock alteration does occur near the headwaters of Hot Springs Creek and along the northern portion of upper Beaver Creek (Plate 1).

Copper Mineralization. There are four prospects or old mines where copper mineralization is abundantly exposed. Those workings include the Copper King mine, the PC prospect, the UBC prospect and the Mother's Day prospect. Other occurrences of copper that normally consist of malachite or chrysocolla are also found in the Pine Creek area and their locations are shown on Plate 1.

Host rocks at the Copper King mine consist of garnet bearing quartzite and garnet bearing schist which generally strike N. 40 W. and dip 45 NE. The portal of this mine was partially caved and the writer chose not to examine the underground workings. Umpleby (1913, p. 155) reported approximately 500 feet of subsurface development. Mineralization was reported to consist of a series of quartz veins which average two feet in width. The veins strike N. 45° E. and dip 75° NW. and form a zone about 40 feet wide. Malachite, chrysocolla, cuprite, and chalcocite (?) are common secondary copper minerals on the mine dump. According to Umpleby (1913) primary sulfides include pyrite and chalcopyrite. Vein quartz is clear to milky white and massive. Some veins have margins of coarsely crystalline muscovite. Quartzite in the vicinity of the mine lacks any visible expression of hydrothermal alteration.

The PC prospect is located on the east side of Pine Creek just outside the property boundary of the Pine Creek Ranch (Plate 1). It consists of a small collapsed adit which trends east-northeast. The small size of the dump indicates very minor development. The host rock is probably the lower laminated quartzite and mineralization consists of quartz veins that contain minor amounts of pyrite. The quartz is white and coarsely crystalline. Although primary sulfides were not observed, malachite and chrysocolla were present in some samples found at the mine dump.

The UBC prospect is located on the north side of upper Beaver Creek, in section 28 T. 23 N. R. 19 E. (Plate 1). Phyllitic quartzite striking N. 63° W. and dipping 31° NE. is the host rock. The metasedimentary host rocks are bleached and silicified, and much of the biotite is altered to chlorite. Mineralization is confined to a silicified zone composed of small subparallel quartz veins that is up to 20 feet wide and trends N. 10° W. The portal of the exploratory adit is now collapsed but the volume of excavated material suggests that the workings total less than 100 feet. Most of the mineralized material on the mine dump consists of oxidation products of iron and copper; pyrite was the only sulfide mineral observed. Muscovite is a minor accessory constituent of the quartz veins.

The Mother's Day prospect is located in Sec. 31, T. 23 N., R. 19 E. (Plate 1). At the prospect there are a series of small quartz veins, the largest of which is about two feet wide and strikes N. 31° E. and dips 51° SW. The host rock is the upper laminated quartzite which is generally unaltered except for minor bleaching along the margins of the veins. Development includes two small adits which are probably less than 100 feet in length. The quartz veins are coarsely crystalline and vuggy, and they contain minor amounts of pyrite, galena and magnetite as the other primary constituents.

The genesis of the mineralization in these copper prospects is uncertain. Those located in the southern part of the Pine Creek area are generally parallel to the strike of the Yellowjacket Formation. This structural relationship suggests that the metasedimentary rocks may have been the source of the copper and other base and precious metals. Mineralization may have occurred by remobilization of the metals and SiO_2 into veins as a consequence of regional or thermal metamorphism.

Molybdenum Mineralization. Veins containing anomalous concentrations of molybdenum ($\geq$50 ppm) occur throughout the Pine Creek area (Plate 1). Common constituents of these veins include quartz, potassium feldspar, biotite, green muscovite/sericite, iron hydroxides after pyrite and magnetite and rarely molybdenite. In addition, potassium feldspar and biotite are more common in veins from the northern part of the Pine Creek area whereas green muscovite is more common in the southern part. Veins in the north generally display a mineralogical zonation with a central zone of quartz and pyrite, an intermediate zone of potassium feldspar and an outer selvage of biotite. Molybdenite, when present, is found in the selvage of biotite. Veins in the southern part of the thesis area near Beaver Creek (Plate 1) also display a mineralogical zonation. This zonation is characterized by a central core of quartz and outer margins of green muscovite/sericite along with supergene iron hydroxides replacing magnetite and pyrite. Although several of these veins are strongly anomalous in molybdenum ($\geq$500 ppm), molybdenite was not visible in hand specimens. Veins in the upper Beaver Creek area generally consist of white quartz that is coarsely crystalline and vuggy. They range from less than 0.5 inches to more than 12 inches in width. Although white coarsely crystalline veins are present throughout much of the area underlain by the Yellowjacket Formation, the area where more abundant veins and veins with selvages of muscovite and pseudomorphs of pyrite and magnetite is shown in Plate 1.

Two prospects that have visible amounts of molybdenite are present in the northern part of the study area. One is the Tramway prospect (Plate 1) located near Pine Creek south of the biotite granite. At this prospect, a steel cable tramway about 500 feet long connected the mine with a small mill on Pine Creek. Underground development was minor, probably less than 200 feet. Although the portal to the workings has caved, mineralized rock on the mine dump was observed to consist of altered quartzite cut by numerous quartz veins. Abundant stains of limonite and jarosite are ubiquitous. The vein quartz is white and coarsely crystalline and is associated with pyrite and magnetite. Molybdenite was observed in a biotite-rich selvage next to the quartz veins. Other potassium-bearing silicates in addition to biotite were not present. Small amounts of secondary copper minerals (malachite and chrysocolla) are also found in rock from the mine dump.

The Red Dog prospect is located near the contact of the biotite granite and quartzite about 1700 feet north of the Tramway prospect. Development at this prospect consists of two small adits which follow a zone of gossan, or ledge, that strikes N. 60° E. and dips 30° NW. The entire mineralized zone, which is about 30 feet thick and 500 feet long, is in biotite granite. Mineralogical zonations are present within this showing. These consist of an inner zone, three to four feet thick, composed of finely crystalline potassium feldspar and biotite, and outer zones 10 to 14 feet thick of biotite granite in which the feldspars have been altered to sericite and clays. This argillized zone grades into more typically weathered biotite granite. The entire mineralized zone is strongly fractured and has been pervasively stained by abundant jarosite and limonite. Quartz veins are present within this zone and they decrease in abundance with increasing distance from this showing. Molybdenite is present in quartz veins on the west side of the ledge near the adits. Torbenite ($Cu(UO_2)_2(PO_4)_2$ 8-12 H_2O) was also identified along fractures at one locality. This observation is supported by the fact that the entire ledge displays anomalous counts of gamma radiation of two to four times background values.

Occurrences of molybdenite and its anomalously high concentrations in veins along the northern and southern parts of the Pine Creek area probably have separate modes of genesis. Those in the north are spatially associated with the Precambrian biotite granite, and therefore they are probably genetically related. The veins to the south, however, lack any clear association with igneous rocks. The biotite granite and rapakivi granite are nearly 12,000 feet to the north or west and the Leesburg stock is more than 10,000 feet to the south. These veins may represent a metamorphic remobilization that concentrated silica and various other metals and elements including molybdenum and fluorine. If this interpretation is correct, the source of the molybdenum might be the Yellowjacket Formation. Accordingly, it is unlikely that a pluton hosted deposit such as a Thompson Creek-Endako mineralized system would be found in this area. Nevertheless, it is possible that the veins in the upper Beaver Creek area represent a very high level expression of a plutonic molybdenum system such as the one nearby at Thompson Creek. Determination of the source of the molybdenum is the key to establishing which is the appropriate hypothesis.

Hot Springs Creek. Hydrothermal alteration in the upper Hot Springs Creek area consists of clay and minor white mica that replaces feldspars and small amounts of chlorite or white mica that replaces biotite. This alteration has produced outcrops that are very light gray (N 8) on unweathered surfaces and dark yellowish orange (10 YR 6/6) on weathered surfaces. It has formed most likely as a result of hot springs activity similar to that found 10,000 feet to the west on Hot Springs Creek.

Beaver Creek Area. In the upper part of Beaver Creek there is a small zone in which much of the biotite in the host quartzite has been altered to chlorite (Plate 1). This is the only zone within the terrain studied in which chlorite is an appreciable component of the quartzite. In addition, this zone of chlorite is coincident with abundant occurences of quartz-pyrite-magnetite veins. These associations suggest that the chlorite has been formed as a result of weak hydrothermal alteration, and not because of the effects of retrograde metamorphism. The source of the fluids is speculative because the nearest outcrops of the potential parental igneous rocks are 10,000 feet to the north and 10,000 feet to the south.

GEOCHEMISTRY

Five hundred samples of soil, stream sediment, and rock were collected for trace element analyses of copper, lead, zinc, molybdenum, silver, manganese and fluorine. The results of these analyses were a major factor in the identification and subsequent exploration of the Pine Creek area.

Soil Geochemistry. Soil profiles within the area of study are poorly developed and are generally less than two feet in thickness. Samples were collected from the C horizon usually at a depth of 1.5 to 2.0 feet. In addition, samples were also collected periodically from the A and B horizons in order to ascertain the variability of the trace elements within the soil profile.

In total, 392 samples of soil were collected and analyzed for copper, lead, zinc, molybdenum, silver, manganese, and fluorine. The range and geometric mean for each element is shown in Table 7. A statistical evaluation of the data was not performed to determine if two separate populations are present. Therefore, anomalous concentrations as used in this report are considered to be values larger than the

Table 7. Trace element concentrations in soil samples of the Pine Creek area, Lemhi County, Idaho.

Element	Range (ppm)	Geometric Mean (ppm)
Cu	1 to 382	15.8
Pb	2[a] to 105	7.3
Zn	5 to 190	44.2
Mo	1[b] to 180	2.0
Ag	0.2 to 0.9	0.2
Mn	25 to 3450	267
F[c]	95 to 4200	240

a - 2 considered 1.0 ppm for calculation of the log mean
b - 1 considered 0.5 ppm for calculation of the log mean
c - Only 372 samples were analyzed for fluorine.

geometric mean plus two standard deviations.

All copper anomalies in soil are confined to areas where the underlying bedrock is the Yellowjacket Formation. Moreover, the larger anomalies (60 ppm) are associated with soils derived from the phyllitic quartzite.

Lead concentrations are typically very low, although they are slightly anomalous (15 ppm) in soil that occupies a zone along the Hot Springs Fault. Concentrations in soil are lowest in the C horizon and highest in the organic-rich A horizon.

A large zone of zinc concentrations slightly above background values (80 ppm) occurs where the underlying bedrock is augen gneiss. Several small anomalies are defined by one or two samples collected from the upper Beaver Creek area.

Molybdenum concentrations in soil over the weakly altered rocks in the Hot Springs area and over the Pine Creek stock are at or below background levels (1 ppm). Anomalous molybdenum concentrations (10 ppm) in the upper Beaver Creek area coincide with the anomalous values reported by Bennett (1977). The area enclosed by molybdenum values which are greater than 10 ppm is approximately 6,000 feet by 3,000 feet with the long axis trending to the northwest. Manganese concentrations are highest in the A horizon (max. 3450 ppm) and lowest in the C horizon (max. 900 ppm). Most anomalous zones are found in soil overlying the Yellowjacket Formation and nearly all consisted of one-sample anomalies.

Silver concentrations in soil were consistently below detection levels (0.2 ppm) and thus failed to show any anomalous zones.

Anomalous concentrations of fluorine are found in soils south of the Pine Creek stock and they are coincident with the area underlain by the amphibolite. Fluorine exhibits a slight decrease in concentration from the C to A horizon (approximately 200 to 500 ppm). In addition, several one-sample anomalies are present in the area of upper Beaver Creek.

Stream Sediment Geochemistry. Samples of stream sediment were collected from all major streams and many of the tributaries in the study area. The sample was interval most closely spaced in areas where few soil samples were collected. All samples of stream sediment were collected from active (flowing) streams. The samples were dried and sieved and the -80 mesh fraction was used for the trace element analyses.

Fifty-two stream sediment samples were collected and most came from the northern part of the Pine Creek area. The samples were analyzed for copper, lead, zinc, molybdenum, silver, manganese, and fluorine. The range and geometric mean of each element is shown in Table 8. Anomalous concentrations of the elements in stream sediment are defined as values larger than the geometric mean plus two standard deviations.

Copper concentrations slightly above background values (20 ppm) are found in stream sediments from a north-flowing stream that is coincident with weakly altered rocks in the northern part of the study area. In addition, the concentrations of lead and zinc (Pb 10 ppm; Zn 35 ppm) are higher than the geometric mean in this region as well.

Anomalous concentrations of molybdenum (8 ppm) are confined to areas where the bedrock is the Yellowjacket Formation. The highest stream sediment concentrations (12 ppm) coincide with the anomalous soil values in the upper Beaver Creek area.

The upper part of Hot Springs Creek is slightly anomalous in manganese. The bedrock in this area is augen gneiss.

Table 8. Trace element concentrations in stream sediment of the Pine Creek area, Lemhi County, Idaho.

Element	Range (ppm)	Geometric Mean (ppm)
Cu	2 to 30	8.1
Pb	2[a] to 12	3.7
Zn	9 to 122	23.1
Mo	1[b] to 12	0.9
Ag	0.2	0.2
Mn	70 to 610	185
F	50 to 1800	350

a - 2 considered 1.0 ppm for calculation of the geometric mean
b - 1 considered 0.5 ppm for calculation of the geometric mean

Fluorine values do not reveal any zones of anomalous concentrations.

Rock Geochemistry. The results of fifty-six rock chip samples are shown in Table 9. In general, many of the soil and stream sediment anomalies correlate with a particular rock type or zone of mineralization/alteration.

Nearly all copper anomalies (soil 60 ppm; stream sediment 20 ppm) coincident with areas for which the underlying bedrock is the Yellowjacket Formation. In addition, most anomalies are specifically coincident with the phyllitic quartzite. These results are correlative with the anomalous values for copper in rocks; the highest copper concentrations (x = 27 ppm) for all rock types is in the phyllitic quartzite (Table 9).

Concentrations of lead are highest in soil and stream sediment north of the Hot Springs fault, and these are roughly coincident with the weak alteration zone in this area. Rock samples from the upper Hot Springs Creek region include those that contain the highest lead values (two samples of altered leucocratic granitoid dikes at 63 and 111 ppm, respectively).

Concentrations of zinc in soil, stream sediment and rock do not display well-defined correlations. Most anomalies delineated by the soil, rock, or stream sediment samples are the result of only one sample. In addition, more mafic rock types have the largest zinc values ($\geq$38 ppm).

Molybdenum concentrations in rock samples correlate reasonably well with anomalous zones previously defined by soil and stream sediment geochemistry. Altered rocks from within the Hot Springs alteration zone

Table 9. Trace element geochemistry for specific rock types from the Pine Creek area (n = number of samples, x = geometric mean, values in parts per million).

		Cu	Pb	Zn	Mo	Ag	Mn	F
Porphyritic Andesite (n=1)		9	3	54	1	0.2	430	380
Diorite (n=1)		16	9	59	1	0.2	470	410
Pine Creek stock	x =	6	7	4	1	0.2	96	150
(n=6)	range =	2-12	7-9	1-7	1	0.2	70-170	100-210
Biotite Granite	x =	18	5	8	1.2	0.2	115	851
(n=4)	range =	7-181	2-10	4-42	1-2	0.2	55-530	690-1050
Rapakivi Granite	x =	9	4	16	1.4	0.25	155	988
(n=4)	range =	3-75	2-10	13-22	1-2	0.2-0.5	130-190	690-1550
Granitoid Dikes	x =	2	5	4	1	0.25	67	95
(n=13)	range =	1-9	2-111	1-63	1	0.2-0.9	20-180	25-260
Augen Gneiss (n=1)		6	10	22	2	0.2	190	850
Amphibolite (n=1)		7	2	32	1	0.2	550	2200
Garnet Quartzite (n=1)		20	2	38	1	0.2	102	535
Phyllitic Quartzite	x =	27	3	22	6	0.2	65	470
(n=12)	range =	6-555	2-12	10-44	1-31	0.2	45-360	165-1350
Lower Laminated	x =	14	2	20	8	0.2	160	690
Quartzite (n=11)	range =	3-54	2	15-43	1-48	0.2	110-330	380-1500
Biotite Quartzite (n=1)		3	2	19	2	0.2	200	460

average one ppm molybdenum. In addition, the Pine Creek stock does not contain anomalous concentrations of molybdenum (Table 9). However, the quartzites which underlie the extensive molybdenum anomaly in soils of the upper Beaver Creek area, are highly enriched in Molybdenum.

Concentrations of silver in samples of both rock and stream sediment are very low. Only three rock samples contained silver above the limits of detection (0.2 ppm).

Manganese concentrations in rocks are largest within the mafic rock types, but these do not display a reliable correlation to anomalous zones previously defined by samples of stream sediment or soil.

Fluorine concentrations in the various igneous rock types are highest in the biotite granite (851 ppm), rapakivi granite (988 ppm), augen gneiss (850 ppm) and amphibolite (2200 ppm). In addition, they are low (100-210 ppm) in the Pine Creek stock.

The most significant result of the rock geochemistry survey is the delineation of anomalously high concentrations of molybdenum within the quartzite units of the upper Beaver Creek area. Also interesting are the larger copper values in samples of the phyllitic quartzite. There does not appear to be a zonal distribution of the anomalous copper and molybdenum values within this area. In this respect, the data as well as the geology suggest two separate modes of origin for the copper and molybdenum in rock samples. Anomalous concentrations of copper are associated with the phyllitic quartzite which suggests stratabound source for the copper. Anomalous concentrations of molybdenum in both samples of rock and soil cut across the units in the Yellowjacket Formation and are associated with abundant quartz veins. These features collectively suggest a hydrothermal source for the anomalous concentrations of molybdenum.

ECONOMIC POTENTIAL

The original exploration interest within the Pine Creek area was generated by the presence of hydrothermal alteration along the upper part of Hot Springs Creek and by published accounts of anomalous molybdenum concentrations in soils of the upper Beaver Creek area. In addition, geologic mapping disclosed the presence of numerous occurrences of molybdenite that are peripheral to the biotite granite, as well as many occurrences of copper within the Yellowjacket Formation. Subsequently, two genetically different types of exploration targets were generated by these results within the Pine Creek area. They include a pluton-hosted Thompson Creek-Endako molybdenum target and a sedimentary-hosted copper-silver stratabound target.

Thompson Creek-Endako Target. Portions of the study area are more favorable in terms of the potential development of specific targets, whereas the surrounding region has little potential and will not be considered further. Those areas with some potential include the upper Hot Springs Creek area, the Pine Creek stock, the biotite granite and the upper Beaver Creek area.

Geologic mapping in the upper Hot Springs Creek area has revealed weak clay type of alteration that is imprinted on various rocks of Precambrian age. The alteration appears to lack a mineralogical zonation and quartz veins are virtually absent. In addition to these negative features, the results of geochemistry indicate generally low concentrations of the important pathfinder elements. Particularly important are the low concentrations of molybdenum and fluorine. These results suggest that the alteration is not related to a high level hydrothermal Thompson Creek-Endako molybdenum system, but rather to possible hot spring activity 12,000 feet to the southwest.

The Pine Creek stock may be Cretaceous in age and thus part of the Idaho Batholith complex. If this speculation is correct, the pluton may therefore be similar in age to the plutonic host rock at the Thompson Creek molybdenum deposit. However, geologic mapping of the stock did not reveal any similarities to the host at Thompson Creek, particularly with respect to the style of alteration and the frequency of quartz veins. Analyses of rock chip samples have demonstrated consistently low concentrations of trace elements. Accordingly, it is unlikely that this pluton is host to a Cordilleran-type molybdenum system.

In contrast, the biotite granite is spatially associated with numerous small veins which contain quartz and molybdenite. These veins appear to be related to a potassic type of alteration and their genesis is probably related to that of associated pegmatites. In addition, the biotite granite and related showings of molybdenite are probably Precambrian in age.

The upper Beaver Creek area has the best potential for the discovery of a Thompson Creek molybdenum deposit in the Pine Creek area. Positive factors include the large size and frequency of molybdenum anomalies in soil and rock. These are associated with veins of quartz Thompson Creek veins. Negative factors include a lack of plutonic host rocks exposed at the surface and the possibility that the molybdenum anomalies of this area may be derived from quartzites rather than by leakage from a hydrothermal molybdenum system. Additional geologic and geochemical studies must be undertaken in an effort to determine the source of the molybdenum.

<u>Copper-Silver Stratabound Target</u>. Numerous copper-bearing ex-

posures are present within the Yellowjacket Formation (Plate 1). Although these occurrences are related to quartz veins rather than to stratabound disseminaions of copper minerals in the quartzites, they generally follow the strike of the metasedimentary rocks. The spatial configuration of these occurrences suggests the presence of a copper-rich stratigraphic interval within the quartzite sequence. Additional detailed geologic mapping and geochemical surveys should be implemented to test this hypothesis.

GEOLOGIC SUMMARY

The region is underlain by three major groups of rocks which include metasedimentary rocks of Precambrian age, Precambrian age rocks of igneous origin and stocks and dikes of Cretaceous to Tertiary age.

Metasedimentary rocks of Precambrian age include quartzites of the Yellowjacket and Hoodoo (Big Creek) Formations. The Yellowjacket Formation in the Pine Creek area is divisible into five units based on variations in the total mica content (10-45 percent), the biotite to muscovite ratio (4.0 to 0.25), the size of the quartz grains (0.04 to 0.1 mm), the presence of garnet, and the presence or lack of laminations, cross-laminations, ripple marks and graded bedding. The units are, from oldest to youngest, the biotite quartzite, the lower laminated quartzite, the phyllitic quartzite, and the upper laminated quartzite. In addition, the fifth unit, garnet-bearing quartzite, is found as a thick lense within the upper laminated quartzite unit. This sequence is at least 9,000 feet in thickness and is overturned. The Formation generally strikes to the northwest and dips to the northeast although there are exceptions.

The Hoodoo or Big Creek Formation is a white to light gray, fine-grained (0.1 to 1.0 mm) quartzite. It contains only minor amounts of muscovite and trace amounts of biotite in contrast to larger mica concentrations in the Yellowjacket Formation. The Hoodoo Formation is found in the far western portion of the area as klippen in thrust contact with the underlying Yellowjacket Formation.

Precambrian age rocks of igneous origin include the augen gneiss-rapakivi granite complex and amphibolite. The augen gneiss-rapakivi granite complex is an assemblage of potassic granitic plutons tentatively dated at 1.4 to 1.5 b.y. (Armstrong, 1975). Although the textures of the augen gneiss and rapakivi granite are different, the presence of rapakivi texture in both rock types and the similarities in major and trace element concentrations suggest a genetic relationship. The augen gneiss is associated with leucocratic granitoid dikes and has intruded biotite gneiss, schist and quartzite. These strongly foliated rocks of medium metamorphic grade have been juxtaposed lower-grade metamorphic rocks of the Yellowjacket Formation by the northeast-trending Hot Springs fault. The rapakivi granite, which is associated with tourmaline-bearing aplite/pegmatite dikes, has intruded the lower-grade metasedimentary rocks without major changes in texture or metamorphic grade of the host.

A small sill of amphibolite is present within the Yellowjacket Formation. This unit displays many chemical similarities to alkali basalts.

Stocks and dikes include the Pine Creek stock of probable late Cretaceous age and rhyolitic to andesitic dikes of Tertiary age. The Pine Creek stock is medium crystalline, leucocratic, two mica granodiorite. The stock has intruded the Yellowjacket Formation. Plutonic igneous rocks of this age and composition are the most likely host rocks for cordilleran-type molybdenum mineralization such as that found at Thompson Creek.

The Tertiary dikes have intruded augen gneiss and associated rocks north of the Hot Springs fault. These dikes generally strike to the north or northeast.

The prominent structural grain in the Pine Creek area is to the northwest as exemplified by the strike of bedding and foliation in the Yellowjacket Formation, the strike of bedding plane faults and the trend off the low-angle detachment surface (Leesburg Fault) between the Hoodoo and Yellowjacket Formations. In addition, in the northern part of the area there are several open folds within the quartzites with axial traces that trend northwest. The development of these folds may be attributed to the intrusion of the rapakivi granite. Numerous younger northeast or east-northeast striking high-angle faults which cut the older trends. The largest of these younger faults is the Hot Springs Fault. The latest movement along this fault has been primarily left-lateral slip.

Occurrences of molybdenite and copper-bearing minerals (malachite, chrysocolla) are found throughout the Pine Creek area. Molybdenite is most commonly found in quartz veins which contain potassium-bearing silicates (biotite, potassium feldspar and muscovite) while occurrences of copper are usually associated with veins without potassium-bearing silicates. Most of the molybdenite-bearing veins are found within 1000 feet of a late potassic phase of the rapakivi granite. The occurrences of copper in the southern part of the area generally form a line that parallels the strike of the Yellowjacket Formation.

Hydrothermal alteration has affected three different areas within this region. North of the Hot Springs fault a zone (2000 x 3000 feet) trends to the northeast in which some of the feldspars have been altered to clay. This alteration may have been a result of previous hot spring activity. Within the Yellowjacket sequence north of Beaver Creek chlorite has replaced biotite. Although this feature could have been caused by retrograde metamorphism, it was the only area observed where the micaceous quartzites contained chlorite. South of this chlorite zone is a large zone (6000 x 3000 feet) of anomalous quartz veins. Many of these quartz veins have selvages of muscovite and also geothite pseudomorphs of pyrite and magnetite. In addition, the biotite in the host quartzite near the veins is commonly altered to muscovite.

Five hundred samples of soil, stream sediment and rock were collected and analyzed for copper, lead, zinc, molybdenum, silver, manganese and fluorine. The results from these analyses did not reveal any significant anomalies in the northern part of the area including the area underlain by the Pine Creek stock and the zone of weak clay alteration. South of Beaver Creek is a large zone (6000 x 3000 feet) of anomalous concentrations of molybdenum (≥10 ppm) in soil. This area is also coincident with the zone of frequent quartz veins. In addition to the molybdenum anomalies there are numerous zones with anomalous copper concentrations (≥37 ppm) in soil. These zones generally follow the phyllitic quartzite unit of the Yellowjacket Formation.

There is the potential for two different types of economic mineralization in the Pine Creek area: molybdenum mineralization hosted in plutonic igneous rocks and stratabound copper mineralization. The area outlined by anomalous molybdenum concentrations in soil as well as frequent quartz veins offers the best potential for economically viable molybdenum mineralization. Portions of the Yellowjacket sequence may be hosts for stratabound copper mineralization.

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