AN ABSTRACT OF THE THESIS OF

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Title: GEOLOGY AND TACTITE MINERALIZATION OF THE SOUTH MOUNTAIN MINING DISTRICT, OWYHEE COUNTY, SOUTHWEST IDAHO

Abstract approved: Redacted for privacy
Dr. William H. Taubeneck

Basement rocks occurring near South Mountain comprise the most complex and one of the largest exposures of metamorphic and plutonic rocks in the Owyhee Mountains of southwest Idaho. Crystalline rocks are concealed by voluminous Neogene volcanic and sedimentary rocks in most of the region. Tactite and vein mineralization in marble host rocks near South Mountain have been exploited since 1871; over 11.5 million dollars worth of metals have been produced.

Schists, marbles, amphibolites, and diopside granofels comprise the oldest rocks in the mining district. Only the marbles were subdivided. The age of the rocks is unknown. However, they may have been regionally metamorphosed to the staurolite zone during the Cretaceous. Subsequent thermal metamorphism during the Eocene recrystallized schist and produced varied calcsilicate mineral assemblages. Isoclinal folding occurred prior to or was concurrent with regional metamorphism, whereas open folds postdate regional metamorphism and predate thermal metamorphism.

Five major plutonic units were distinguished during field and petrographic studies. They range in composition from melanocratic

hornblende diorite to leucocratic granite. The age of catazonal quartz diorite sills is Cretaceous. They are similar in mineralogy to western satellites of the Idaho batholith north of the Snake River Plain. Eocene plutons were emplaced in the mesozone to epizone. Intrusive breccias are associated with the youngest pluton.

Zinc rich hedenbergite tactite, copper-bearing andradite-diopside tactite, and unmineralized diopside-grossularite and wollastonite tactites were identified. Zinc rich, polymetallic sulfide replacement bodies in hedenbergite tactites have the best economic potential in the district. The hedenbergite tactite and polymetallic mineralization formed at temperatures exceeding 400°C and at a relatively low oxygen fugacity. The replacement bodies are localized in marble host rock along fractures which may be related to open folds. Late argentiferous galena veins may fill the same fractures. Minor alteration of tactite has occurred along post ore faults and dikes.

Significant amounts of mineralized hedenbergite tactite may be present as down dip extensions of exploited ore bodies. It may be possible that additional mineralized tactite has not yet been discovered.

GEOLOGY AND TACTITE MINERALIZATION OF THE SOUTH MOUNTAIN MINING DISTRICT, OWYHEE COUNTY, SOUTHWEST IDAHO

by

Lawrence K. Freeman

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INTRODUCTION

Purpose of the Investigation

The exposure of metamorphic and plutonic rocks at South Mountain is intriguing because of the location and the large variety of rock types that occur. Except for a few localities, metamorphic and plutonic rocks are concealed by Neogene volcanic and sedimentary rocks in southwest Idaho and southeast Oregon. None of these localities display such a diverse suite of basement lithologies as the area of this investigation. Consequently, a thorough descriptive study of the geology at South Mountain has provided data for a more accurate interpretation of the basement rocks of the region.

Since 1871, over 11.5 million dollars (present prices) worth of base and precious metals have been extracted from metasomatic ore deposits in pre-Tertiary host rocks at South Mountain. The success of future exploration in the district depends on accurate geological interpretation of the exposed mineralization.

The district-wide geological study that was undertaken as part of this investigation had two goals. The first was to suggest some possible relations of the geology at South Mountain to the geology of other exposures of basement rocks in the region. The second was to ascertain the general geologic environment of the economic mineralization. The purpose of the detailed work in this investigation was to define the structural, chemical, and lithological controls of the ore bodies. Ultimately, it is hoped that this study will provide information that will be helpful in outlining future exploration targets at South Mountain. It is also hoped that this study will be an aid to future geologic investigations concerned with the interpretation of the regional geologic history.

Previous Work

Mineralization at South Mountain was discovered in 1868 with the recognition of oxidized veins in outcrops (Raymond, 1873). Since that time there has been periodic exploration, development, and production by assorted private corporations. The mining history has been recorded in annual reports by the Idaho Bureau of Mines and Geology, the Idaho State Inspector of Mines, and the United States Bureau of Mines. The History of the district is summarized in a later section of this report.

Brief descriptions and early interpretations of the geology and mineralization at South Mountain were published by Lindgren (1900) and Bell (1907a). The only detailed description of the geology and mineralization that has been published is by Sorenson (1927). Shannon (1918, 1926) described and analyzed samples of the mineral ilvaite from South Mountain.

Some reconnaissance work at South Mountain was discussed by Taubeneck (1971) as part of a regional investigation of plutonic rocks associated with the Idaho batholith. Samples collected from South Mountain for that study were later included in regional isotopic examinations of igneous rocks in the Pacific Northwest (Armstrong, 1974, Armstrong and others, 1977). In more local reconnaissance work, Bennett and Galbraith (1975) and Bennett (1976) published state reports concerning the stream sediment geochemistry and the geology of the Owyhee Mountains.

Methods of Investigation

This study is principally a field investigation which is supported with petrographic and geochemical data. Three months were spent at South Mountain during the summer of 1979. Geologic mapping was done at three different scales, a 1:12,000 scale map covering 47 km^2 (18 mi^2), a 1:2,400 scale map covering the area directly adjacent to the major mineralization, and 1:600 scale maps of the economically more interesting features in the underground mine workings.

Most modal analyses of plutonic rocks represent counts of 1200 points each from two 600 mm^2 (0.9 in^2) petrographic slides. These particular figures were determined to be the most practical for this study according to statistical guidelines of Chayes (1956). The igneous rock classification used in this study has been recommended by the IUGS Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1973, 1979, and Schmid, 1981).

Location and Access

South Mountain is in western Owyhee County, Idaho; approximately 8 km (6 mi) east of the Idaho-Oregon state line and 113 km (70 mi) south-southwest of Boise (Fig. 1). This study includes an area approximately 8 km (6 mi) long in a north-south direction and 4 km (3 mi) wide; the summit of South Mountain is centered in the South half of the study area. The area includes parts of T. 7 S and T. 8 S., R. 5 E., Boise Principal Meridian.

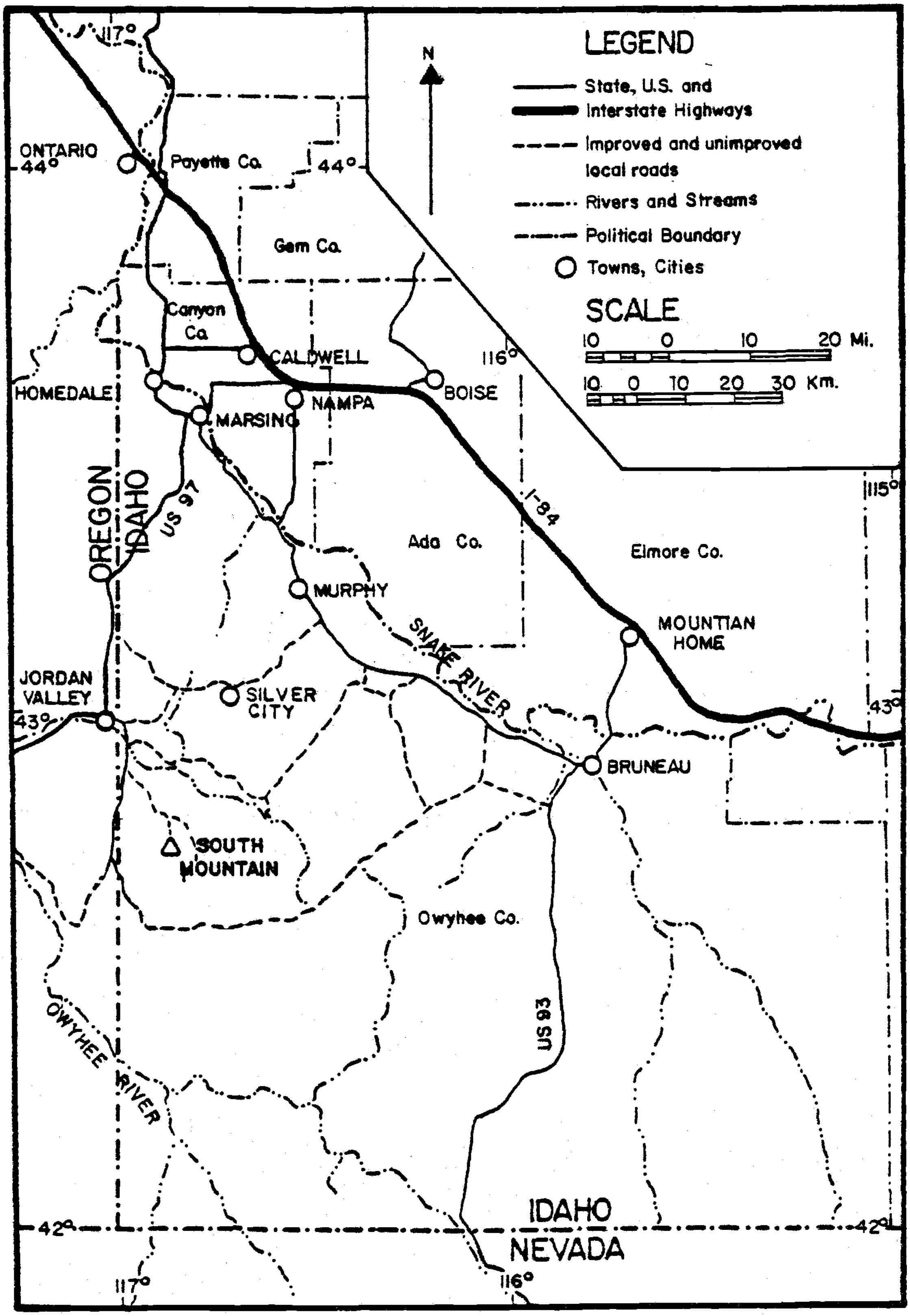


Figure 1: Map of southwest Idaho showing the location of South Mountain with respect to selected cultural features.

The closest town to South Mountain is Jordan Valley, Oregon, located on U.S. Highway 97, 80 km (50 mi) south of Homedale, Idaho (Fig. 1). Access to South Mountain from Jordan Valley is by approximately 40 km (25 mi) of improved and unimproved gravel and dirt roads. During the summer the U.S. Bureau of Land Management maintains a road to the fire lookout on the crest of South Mountain. Many dirt roads in the region may be impassable to conventional vehicles during the winter and early spring because of snow or poor drainage.

Travel within the study area is by the B.L.M. road, poorly maintained ranch roads, and jeep trails. Any part of the study area may be reached in less than one hour by hiking cross-country from the B.L.M. road.

Topography and Exposure

The Owyhee Mountain Range, to which South Mountain belongs, forms a highland in southwest Idaho and southeast Oregon. South Mountain itself is separated from the main Owyhee range by a broad, northeast trending valley occupied by Jordan, Boulder, and Cow Creeks.

South Mountain is a broad, dome shaped uplift which is deeply disected by several small creeks. The creeks drain the uplift in a radial pattern. There is an area of approximately 10 km^2 (4 mi^2) on South Mountain that is greater than 2130 m (7000 ft) in elevation, with a maximum elevation of 2378 m (7801 ft). The area of this study includes all of the higher part of the mountain, and extends to the north edge of the uplift at a minimum elevation of 1585 m (5200 ft).

Relief in the area is moderately rugged except for the Iron Mine and Rail Creek valleys in the northeast corner. The major topographic feature in the study area is Williams Creek valley (Fig. 2) which has its head in the south-central part of the area and extends north into Boulder Creek.

Annual precipitation varies with elevation on South Mountain; the higher portions of the mountain receive as much as 50 cm (20 in) per year whereas the lower parts may receive less than 25 cm (10 in). Most precipitation falls as snow in the winter with accumulations of up to 250 cm (100 in) near the mine workings. Isolated snow banks persist through early July.

Vegetation in the area is variable depending on elevation, aspect, and proximity to springs or creeks. The flora changes from sparse sagebrush and grasses at lower elevations through lush stands of Douglas Fir or Aspen to sub-alpine meadows near the summit of the mountain.

The area has numerous small outcrops. Commonly, the rock is moderately weathered and partially covered with lichen. The soils that are developed on several types of bedrock are distinctive and facilitate geologic mapping.

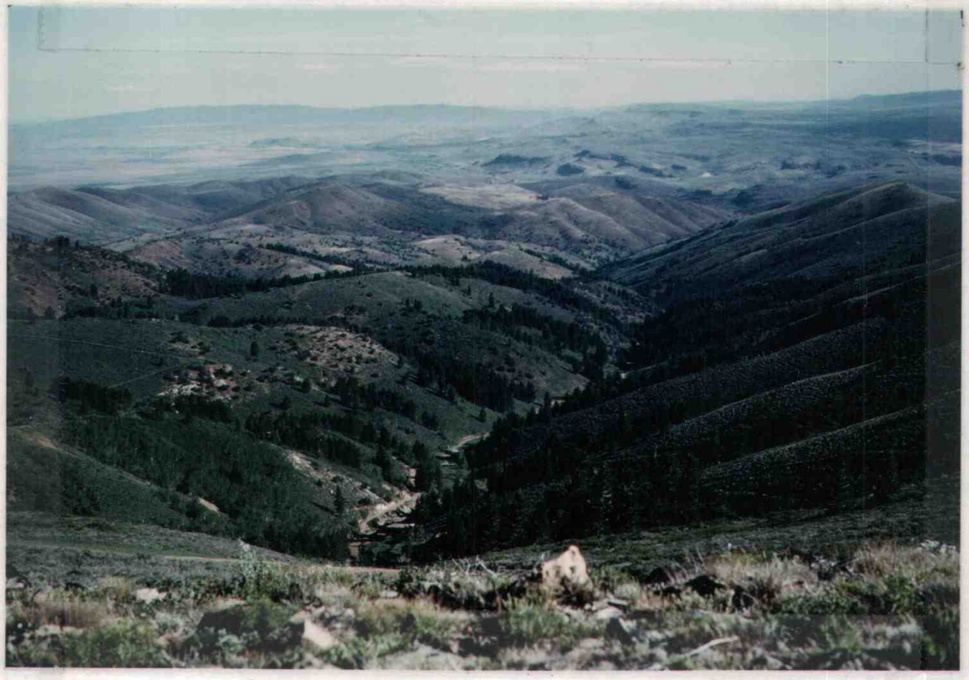


Figure 2: View of Williams Creek from the summit of South Mountain. The northwest part of the Owyhee Mountains is in the distance. The photograph shows typical topography and vegetation in the study area.

REGIONAL GEOLOGY

The Owyhee volcanic field of Pansze (1975) occupies most of southwest Idaho. Isolated exposures of basement plutonic and metamorphic rocks occur in the Owyhee Mountains and at South Mountain (Bond, 1978). Volcanic rocks of the Owyhee Volcanic field and Snake River Plain range in age from Miocene to Pleistocene (Malde and Powers, 1962, Pansze, 1975); however, a few Eocene volcanic rocks are exposed in the Owyhee Mountains (Neill, 1975). The distribution of rocks by age is shown in Figure 3.

Basement Rocks

Several areas in the Owyhee Mountains have extensive exposures of granitic rocks ranging in composition from granodiorite to quartz monzonite (Neill, 1975, Pansze, 1975). They are typically medium-grained, equigranular rocks with biotite as the dominant mafic mineral (Neill, 1975, Pansze, 1975). Muscovite K/Ar radiometric dates of 62.1 ± 1.2 m.y., 65.6 ± 2.0 m.y., and 66.8 ± 1.3 m.y. have been published by Pansze (1975). Taubeneck (1971) has suggested that these intrusions lie within an extension of the Idaho Batholith south of the Snake River Plain. Country rocks in the Owyhee Mountains are exposed only locally as small roof pendants and xenoliths of quartz-mica schist (Bennett and Galbraith, 1975).

Basement rocks at South Mountain are more varied than in the Owyhee Mountains to the north (Bennett and Galbraith, 1975). Plutonic rocks are more variable in composition (Taubeneck, 1971) and have a larger range of age (Armstrong, 1974, 1975). South Mountain also has

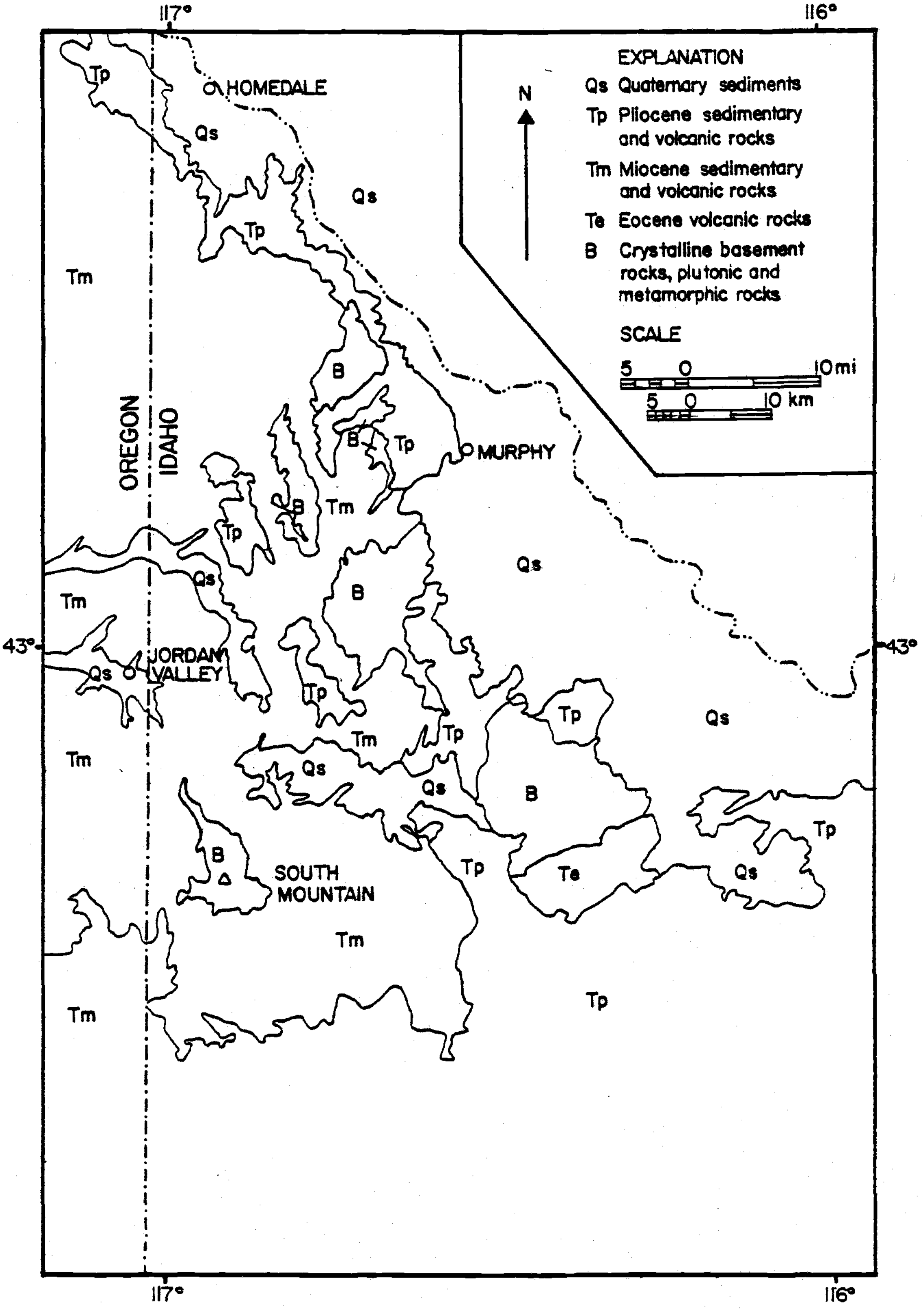


Figure 3: Regional geologic map of southwest Idaho. Redrawn from Walker, 1977, and Bond, 1978. The study area is centered on South Mountain.

a more extensive distribution of metamorphic country rocks (Bennett, 1976). The age of the country rocks is unknown but may be Paleozoic as suggested by Sorenson (1927).

Eocene Volcanic Rocks

In the southeast Owyhee Mountains, Neill (1975) has mapped a relatively large area underlain by Eocene volcanic rocks. These consist mainly of porphyritic andesite to dacite flows and dikes which are mixed with lithic-crystal tuffs. Based on a biotite K/Ar radiometric date of 43.6 ± 0.8 m.y., as well as similar lithologies, Neill (1975) has suggested that these extrusives are similar in age and genesis to the Challis volcanics of central Idaho.

Miocene Volcanic and Sedimentary Rocks

A major proportion of rocks in the Owyhee Mountains consist of a complex sequence of interfingering Miocene basalts, silicic volcanic rocks, andesites, and sediments (Malde and Powers, 1962). Bennett and Galbraith (1975) and Bennett (1976) have attempted to construct a regional correlation of the Miocene rocks in the area. Bennett (1976) incorrectly included Miocene silicic tuffs of the southern Owyhee Mountains in the Pliocene Idavada Group of Malde and Powers (1962).

The oldest Miocene rocks in most of southwest Idaho are a thick sequence of alkali basalt flows, which rests disconformably on granitic and metamorphic basement rocks (Bennett and Galbraith, 1975, Bennett, 1976). In the Owyhee region of Oregon the Owyhee Basalt of Kittleman and others (1965), which is similar to Miocene basalts in Idaho (Neill, 1975), overlies the Sucker Creek Formation and crystalline basement rocks are not exposed. Kittleman, and others (1965), and subsequent authors have pointed out that the Miocene basalts of southwest Idaho and Southeast Oregon are chemically and geographically distinct from the Columbia River Basalts.

Miocene felsic flows, flow breccias, and tuffs with minor volcaniclastic sediments overlie the basalts in the Owyhee Mountains (Bennett and Galbraith, 1975), Bennett, 1976). Several rhyolitic vents have been identified by Pansze (1975) near Silver City, Idaho, in the Owyhee Mountains. Epithermal silver, gold, and base metal veins exploited near Silver City are a result of hydrothermal activity near these vents (Asher, 1968, Pansze, 1975).

Pliocene Volcanic and Sedimentary Rocks

Miocene volcanic and sedimentary rocks are unconformably overlain by the Pliocene Idavada Volcanics of Malde and Powers (1962). The Idavada Volcanics consist of unmineralized silicic welded tuffs and vitric tuffs. The sequence locally reaches a thickness of more than 900 m (3000 ft) (Malde and Powers, 1962).

The Idaho Group comprises the remainder of Pliocene rocks in southwest Idaho and is, in part, Pleistocene (Malde and Powers, 1962). Sedimentary rocks and basalts equivalent to the Poison Creek Formation and Banbury Basalt of the Idaho Group have been mapped near South Mountain (Bennett and Galbraith, 1975, Bennett, 1976).

Tectonic History

Most previous geologic investigations in southwest Idaho have highlighted the Neogene tectonics and geology of the region. The only investigations concerning the older rocks have concentrated on the late Mesozoic plutonic environment. The pre-Cretaceous geologic record is very poorly preserved in southwest Idaho; thus, the pre-Idaho batholith history can only be extrapolated from surrounding regions.

According to paleogeographic reconstructions of Stokes (1979), the region was probably the site of eugeosynclinal sedimentation through the Paleozoic, and may have been involved in the Antler Orogeny. However, isotopic evidence suggests that the Owyhee Mountains overlie the boundary of Pre-cambrian crust and lie at the edge of the Phanerozoic eugeosycline to the west (Armstrong, and others, 1977). During the latest Paleozoic and early Mesozoic, the region may have been the site of clastic deposition (Stokes, 1979).

Taubeneck (1971) has suggested that the Idaho batholith extends south of the Snake River Plain. Granitic outcrops north of the study area are within the southern extension of the batholith. Plutonic rocks near South Mountain are probably satellite plutons west of the concealed margin of the batholith (Taubeneck, 1971). From Jurassic through early Tertiary, the region was within, or immediately east of, a sinuous magmatic arc which extended along the North American Cordillera (Dickinson, 1975).

The region was the site of high angle faulting with dominant northwest fault trends during the Neogene (Malde and Powers, 1962). Voluminous eruptions of a bimodal volcanic suite (Pansze, 1975) have nearly buried all earlier rocks.

The north-northwest fault orientation and weaker east-west and northeast trends are represented by aerial photograph linears (Bennett and Galbraith, 1975, Bennett, 1976), and by fractures and mineralized fissure fillings near Silver City, Idaho (Pansze, 1975). Normal faulting and fissure eruptions along the north-northwest trends have separated the Owyhee uplands from the uplands north of the Snake River Plain (Hill, 1963). Hill and Pakiser (1967) have proposed that the Snake River Plain is underlain by eruptive volcanics and basaltic crust, whereas the flanking highlands are underlain by granitic crust.

Pansze (1975) has suggested that the Owyhee Mountains region is at the boundary of the Snake River Plain and the Basin and Range Province. He has presented evidence that faulting and volcanism in the region have been equally affected by rifting in the Snake River Plain and crustal extension in the Basin and Range Province.

METAMORPHIC ROCKS

Medium grade metasediments and possibly metavolcanic rocks comprise a complex suite of lithologies in the vicinity of South Mountain. The metamorphic rocks are exposed along a continuous belt from 5 km (3 mi) northwest of the study area to the southern border of the area.

The lithologic map units used in this study include undivided metamorphic rocks (pTsc), undivided marbles (pTm), and Laxey marble (pTlm).

Undivided Metamorphic Rocks (pTsc)

In order of relative abundance the undivided metamorphic rocks include quartz-biotite schists, amphibolites, diopside granofels, graphitic schists, and muscovite-quartz schist. Thin, discontinuous lenses of marble and quartzite are intercalated with the major lithologies. These lithologies were not subdivided because the map scale was too small to show lithologic units clearly. Also, it was felt that such lithologic subdivision would have slowed the progress of field work and probably would not have aided in the search for future mineral exploration targets. Generally rocks of this map unit form poor outcrops and underlie moderately steep grass and sagebrush covered slopes. However, some areas are covered by thick forest and brush, with virtually no exposure of rocks.

The predominant lithology is a schistose and commonly banded rock composed of quartz, feldspar, biotite, and muscovite in variable proportions. The schist generally forms low outcrops. Where the schist is quartzose it forms more prominant, resistant outcrops. The rock is well foliated and breaks easily along the schistosity. Foliation may be planar or strongly crenulated. In quartzose varieties a thin, conspicuous, unevenly spaced banding of quartz and mica rich layers occurs. The banding is commonly parallel to foliation but may locally be tightly folded. It is presumed that this banding represents original sedimentary bedding. The schists have a variable color from light to dark brown depending on the relative abundance of biotite to other minerals. The more micaceous schists have a thin hematite stain on foliation surfaces whereas more quartz-rich schists are slightly bleached with exposure. Spotted schists are locally common. The spotting reflects the presence of 1 to 3 mm garnets. Only in very limited areas were larger (1 cm) porphyroblasts of garnet or kyanite observed.

The schists are composed of biotite, muscovite, quartz, and plagioclase. Garnet, kyanite, staurolite, and tourmaline are common in some rocks. Biotite and muscovite occur as thin isolated plates in quartzose bands and as scaly, foliated layers. Biotite may also form porphyroblastic crystals which have grown across foliation. Quartz and plagioclase are anhedral and granoblastic with straight or slightly curved grain boundaries. Crystals of micas, plagioclase and quartz show no evidence of deformation. Garnets occur as severely embayed remnants of porphyroblasts that were up to 1 cm in diameter. Some garnets have been totally replaced by pseudomorphic aggregates of quartz, green biotite, sericite, and orthoclase. Quartz strain shadows and curved foliation are preserved around the margins of most pseudomorphs and remnant garnets. Kyanite and staurolite occur in one location in a highly porphyroblastic schist which contains as much as 30 percent of 1 cm long kyanite porphyroblasts. The kyanite appears euhedral in hand specimen, but in this section it is strongly embayed by quartz and muscovite. Staurolite occurs as very fine, rounded irregular grains. Adjacent staurolite grains have identical optical orientations which suggests that they are remnants of larger porphyroblasts. Possible pseudomorphs of staurolite occur in other rocks.

Lineated amphibolites comprise the second most abundant lithology in the undivided metamorphic rocks. The amphibolites mostly occur in the southern part of the study area where they comprise a large proportion of the metamorphic sequence. Elsewhere, amphibolites occur as small lenses.

Outcrops of amphibolite may be found only in stream gullies. Typically, the rock was seen as cobbles or smaller pieces of float mixed with the soil cover. Weathered surfaces of the amphibolite are brown to tan and fresh surfaces are dark green to grey. Foliation reflects the parallel arrangement of elongate mineral grains. The rock has alternating laminations of plagioclase, epidote, and hornblende which are parallel to the lineation. Grain size ranges from fine (less than 1 mm) in most rocks to medium (1 to 3 mm).

Hornblende and plagioclase comprise the major minerals of the amphibolite. Varying amounts of quartz, biotite, epidote, and opaques may be present. Weak retrograde reactions to chlorite have occurred locally.

Relations of the amphibolites with other metamorphic rocks are poorly known. However, the amphibolites appear to occur in bodies concordant to bedding and other lithologic contacts. The amphibolites may be the metamorphic product of basic to intermediate volcanic or volcaniclastic rocks.

Diopside granofels is another of the more common lithologies in this map unit. It typically forms cliffs or rocky peaks making it one of the more conspicuous metamorphic lithologies. Generally the outcrops of diopside granofels are large and blocky. The rock is alternately banded green and grey. Bands can vary in width from 3 cm to fine laminations. Weathered surfaces are dull orange and very rough textured. Diopside and plagioclase rich bands weather with positive relief in contrast to carbonate rich bands. Weathered specimens of very fine grained, laminated granofels may have a cellular appearance resulting from the dissolution of carbonate. The rock is very hard, and breaks with great difficulty.

The granofels can be composed of two rather distinct mineral assemblages which may only be recognized in thin section. The more widespread assemblage consists of diopside, plagioclase, calcite, and sphene. The second assemblage, only identified in rocks from the extreme east part of the field area, consists of diopside, scapolite, plagioclase and sphene. Diopside can occur as large poikioblastic grains or fine granoblastic grains which are light green in hand specimen and colorless in thin section. Diopside content ranges from 30 to 60 volume percent. Plagioclase occurs as allotrioblastic grains in aggregates or as inclusions in diopside. Albite twinning is undeformed and common. The composition of the plagioclase is estimated to be andesine. Scapolite occurs as partial to total replacement of plagioclase and forms dusty looking, irregular grains. Sphene may commonly be seen in hand specimens as wedges up to 2 mm long, and was often observed in thin sections as smaller subhedral wedges. Calcite occurs in granoblastic bands and as an irregular alteration product of other minerals.

Graphite is a minor component in many metasedimentary rocks. Local graphite rich horizons are intercalated throughout the sequence. Near the saddle in north central sec. 10, T. 8 S., R. 5 E. (Plate 1) graphite-muscovite-quartz schists comprise a prominent lithology. Outcrops of the graphitic schists are typically low and broken. They are stained with limonite on interior fractures. Weathered samples contain abundant small, cubic pits with occasional remnant limonite or pyrite. Fresh and unstained surfaces are dull grey, except for foliation surfaces which have a silky luster from graphite and muscovite. Bedding may commonly be observed and is typically tightly folded. Cleavage crenulations are prominent in this rock.

Minor lenses of muscovite-quartz schist occur in the valley of Williams Creek. The muscovite schists are prominent in the field because of their light color and resistance to weathering. These schists form blocky rubble outcrops. The rock is white or slightly stained with iron oxides, fine grained, and massively foliated with widely spaced micaceous partings. Microscopic examination reveals that the rock is composed mainly of granoblastic, fine grained quartz and sodic plagioclase. Muscovite occurs as fine isolated flakes and planar concentrations which together comprise approximately 10 percent of the rock. Fine, strongly embayed or amoeboidal, colorless garnet grains are disseminated throughout the rock. Pyrite occurs as streaks and elongate pods up to 4 mm long which are parallel to foliation. The mineralogy of this rock suggests that it may have been metamorphosed from a felsic volcanic or volcanisclastic rock.

Small lenses of marble and grey, banded quartzite are intercalated throughout the biotite schists. The marbles are similar in description to mappable beds of marble. The quartzites are grey banded rocks with weakly iron stained surfaces and occur as thin lenses less than 1 m (3 ft) thick. They form blocky outcrops where other lithologies have been reduced to soil.

Undivided Marbles (pTm)

Several discontinuous beds, up to 45 m (150 ft) thick, of impure and pure marbles were mapped throughout most of the metasedimentary sequence. The discontinuity of the beds may be partly due to changes in the original composition of the sediments or to tectonic activity. Outcrops of these marbles are typically low and rounded but may stand 1 to 2 m (3 to 6 ft) in height. Marble bedrock commonly is covered by a distinctive, light colored soil with abundant cobbles of marble and a characteristic paucity of vegetation. Mountain Mahogany (*Cercocarpus intricatus*) typically grows in soil underlain by marble.

Marbles mapped in this unit are typically impure, although minor beds and local areas of pure marble occur. These marbles are strongly banded with siliceous, dark greyish-blue, micaceous, and iron stained bands alternating with light grey to white bands. Impurities including calcsilicate minerals, micas, graphite, and pyrite are concentrated in the bands. The banding is usually strongly contorted but may be planar. The impure bands probably represent original beds and laminations of impurities in limestone. Siliceous bands contain quartz, diopside, and tremolite. Tremolite was observed in several hand specimens as clusters of radiating needle-shaped crystals up to

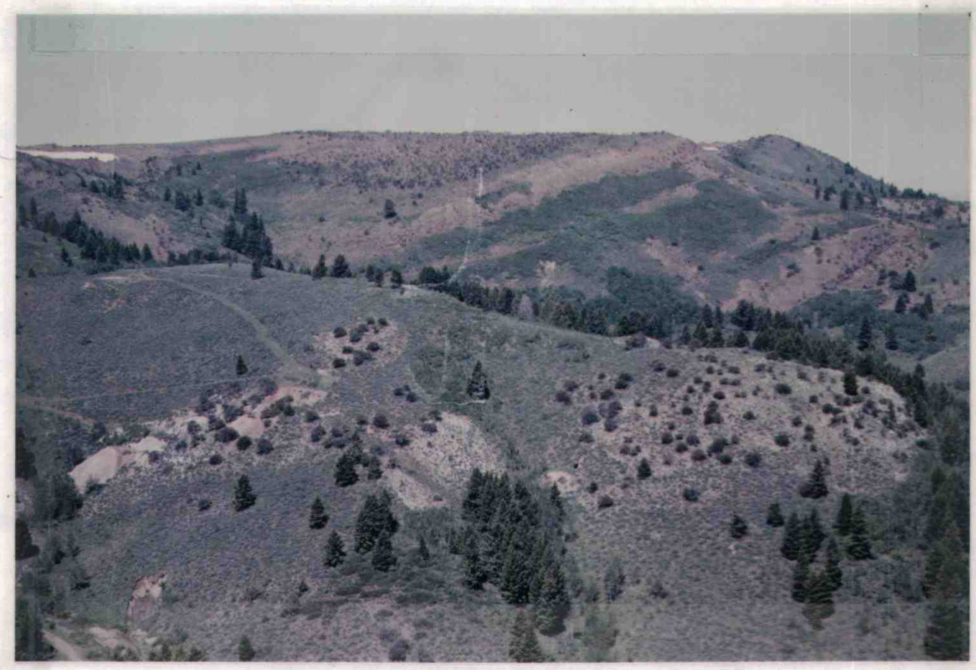


Figure 4: View of a representative exposure of marble. The white rocks and light colored soil on the foreground ridge is an exposure of Laxey marble near the Bay State Workings.

3 cm long. Diopside and quartz occur in thin section as sparsely disseminated, very fine rounded grains which are virtually always located at carbonate grain boundaries. Quartz and diopside also occur as granoblastic aggregates in the siliceous bands. Graphite and micas occur in narrow, commonly contorted laminations which may contain other noncarbonate minerals. Graphite also occurs as very fine, disseminated crystals in the grey or greyish blue bands. Calcite in the marble is granoblastic, and grain boundaries are typically straight or slightly curved. Microscopic lamellar twinning was observed in nearly every carbonate grain. Calcite grain size is affected by the purity of the rock. Pure carbonate bands may have grain sizes of up to 4 mm. Siliceous or graphitic bands contain much smaller calcite crystals.

Laxey Marble (pTlm)

Mine geologists at South Mountain have used the informal name of Laxey marble to designate the unit which serves as the host for the exploited mineralization. This unit is distinctive from the other marble units because of its greater thickness, purity, and continuity. The Laxey marble is exposed for approximately 5 km (3.1 mi) along strike in the central part of the study area. The maximum thickness of the marble is approximately 120 m (430 ft) and the minimum is 35 m (110 ft). Exposures of Laxey marble are similar in appearance to the undivided marbles except that they are more prominent because of greater thickness and lighter color.

The Laxey marble is typically a white to light gray, massive to weakly banded, medium-grained rock. It contains much less graphite and silicate minerals than the other marbles. Throughout most of its length and thickness it is primarily composed of granoblastic calcite, with an average grain size of 1 to 4 mm. Where silicates are present in the Laxey marble they are similar to those in the other marble units.

Metamorphism

Evidence for two distinct periods of metamorphism may be observed in the metamorphic rocks at South Mountain. The first period consisted of prograde regional metamorphism to medium grade of Winkler (1976) or amphibolite facies of Turner (1981). A thermal event followed, nearly destroying index minerals of the regional metamorphism and strongly recrystallizing impure, magnesium-rich carbonate rocks.

Typical index minerals of medium grade metamorphism occur in some rocks. Porphyroblasts of garnet, possibly almandine, are present in many schists. Staurolite, kyanite, and retrograde pseudomorphs of both minerals occur in more micaceous schists. Sillimanite was not observed in the field or in petrographic examination of several pelitic rocks. Metamorphic textures including strain shadows around garnet suggest that regional metamorphism occurred during or prior to the earliest recorded deformation. Pressure and temperature limits of the stability of kyanite and staurolite are given in Figure 5. Prograde metamorphism reached temperatures of approximately 550°C at pressures greater than 4.5 Kbars to produce the assemblage of kyanite and staurolite. Because sillimanite was not observed, it may be assumed that metamorphic temperatures did not exceed the sillimanite isograd.

Metamorphic country rocks in and adjacent to the western margin of the Idaho batholith show a progressive eastward increase in metamorphic grade to a maximum of the sillimanite zone in inclusions

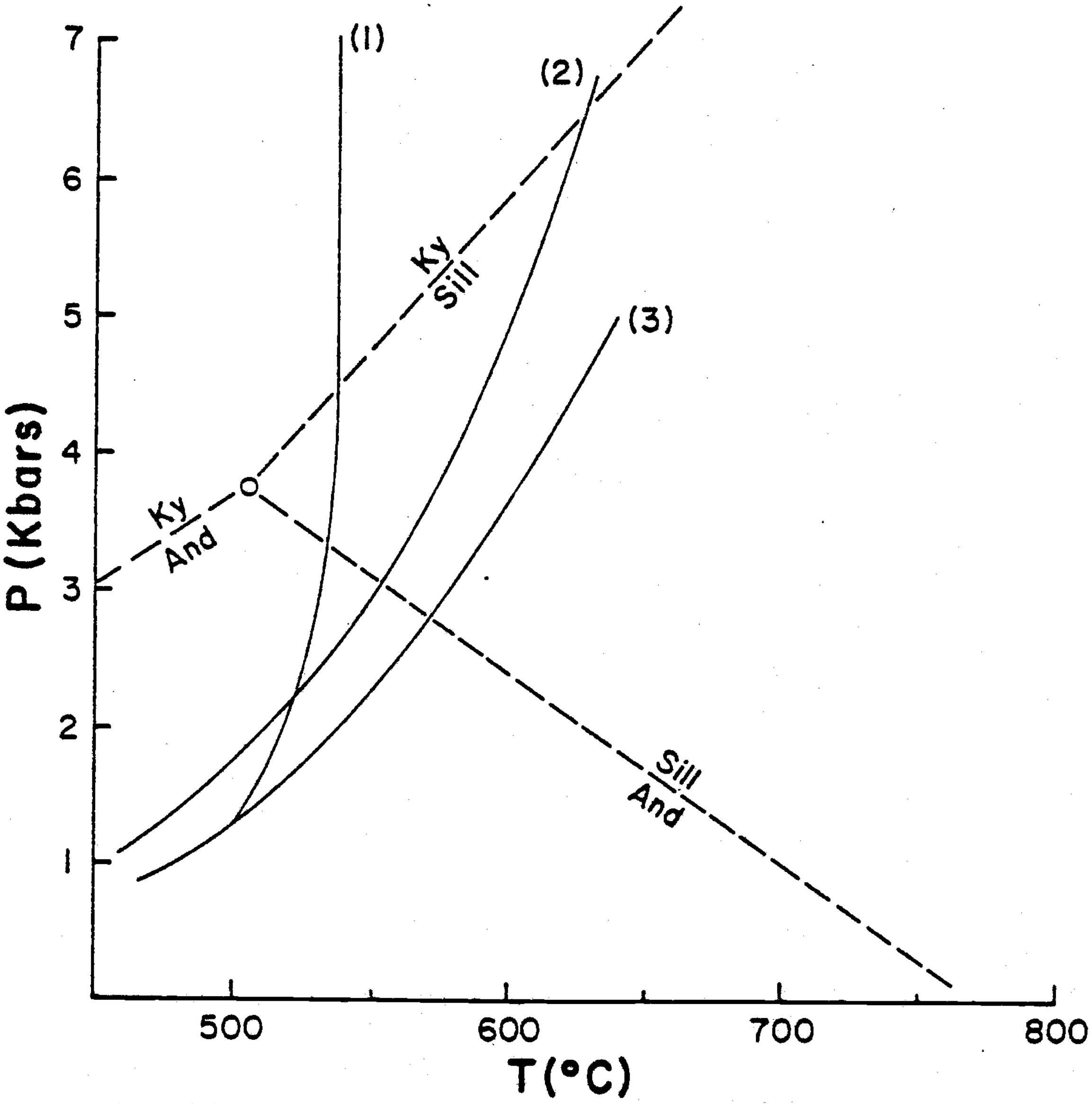


Figure 5: Pressure and temperature equilibrium conditions for selected minerals under medium grade metamorphic conditions. $P_t = P_{H_2O}$. Abbreviations: And, andalusite; Ky, kyanite; Sill, sillimenite.

Dashed curves are Al_2O_5 equilibrium from Turner, 1981.

Curve (1): 8 chloritoid + 10 sillimanite ⇌ 2 staurolite + 3 quartz + $4H_2O$ (from Turner, 1981)

Curve (2): isobaric invariant point where dolomite, quartz, talc, calcite, and tremolite comprise an equilibrium assemblage (from Winkler, 1975).

Curve (3): tremolite + 3 calcite + 2 quartz ⇌ 5 diopside + $3CO_2$ + H_2O (from Turner, 1981).

within the batholith (Schmidt, 1964). Schmidt (1964) located prograde staurolite schists near granitic rocks that Taubeneck (1975) later recognized as satellites west of the batholith. Hamilton (1963) and Schmidt (1976) have suggested that the synkinematic, medium to high grade metamorphism in country rocks west of the Idaho batholith occurred during the middle to late Cretaceous emplacement of the batholith. Similar metamorphism probably occurred near South Mountain during the emplacement of the batholith which may lie concealed to the east (Taubeneck, 1971).

Evidence of at least one thermal event subsequent to regional metamorphism includes the variable mineral assemblages in impure marbles, diopside granofels, and tactites. The tactites will be described later. Three mineral assemblages in impure marbles and two in diopside granofels were observed. Quartz, dolomite and calcite comprise some impure marbles west of Williams Creek. Course tremolite needles or granoblastic diopside may occur in other impure marbles. Diopside granofels are composed of either scapolite or plagioclase with diopside, calcite, and sphene. Scapolite occurs in rocks which may be roof pendants in granodiorite whereas the plagioclase assemblage is present west of the granodiorite pluton. Experimental and field evidence summarized by Winkler (1976) and Turner (1981) shows that neither diopside nor tremolite are stable in regional metamorphic conditions at temperatures below the sillimanite isograd (Figure 4). It is probable that tremolite and diopside were produced during contact metamorphism of impure, dolomitic marbles near the granodiorite pluton. The presence of quartz, dolomite, and calcite in some impure marble and the variable calcsilicate mineral assemblages suggest that the rocks have not been subjected to equal intensities of metamorphism.

Other evidence supporting a thermal event subsequent to regional metamorphism may be observed in pelitic schist. Garnet commonly occurs as fine remnant grains or strongly embayed porphyroblasts in pseudomorphic clots of fine grained quartz, micas, and orthoclase. Chlorite was rarely observed. Kyanite and staurolite apparently have been partially replaced by poorly foliated micas and quartz. In crenulated schists, micas are undeformed. Instead, they have been recrystallized to individual grains oriented in a herringbone pattern.

Armstrong (1974) has provided evidence for an Eocene thermal event which included widespread volcanism, plutonism, and associated metamorphism throughout Idaho (Armstrong, 1974). Granodiorite, leucocratic granite and quartz monzodiorite plutons were emplaced in the South Mountain area during this time. The post kinematic metamorphism described above probably occurred during the Eocene thermal event.

Origin

Sorenson (1927) suggested that the country rocks at South Mountain are of Paleozoic age, but no substantiating or contradicting evidence has been reported. The metasediments, including the carbonate rocks, are barren of fossil material. Long range stratigraphic and lithologic correlations from South Mountain to similar, but unmetamorphosed sequences in adjacent regions, may not be dependable. However, such long range correlations are the only alternative for proposing a possible age of the metasediments.

The metamorphism, deformation, and lithology of the metasediments at South Mountain are similar to country rocks west of the Idaho batholith near McCall, Idaho (Ross, 1933, Hamilton, 1963, and Schmidt, 1964). These authors have presumed that medium to high grade metamorphic rocks near McCall are Precambrian.

Pre-Tertiary sedimentary rocks of approximately known age have been mapped by Coats (1964) in the Jarbridge quadrangle in north Elko County, Nevada. A poorly preserved trilobite of probable Cambrian or early Ordivician age was found in a sequence of low grade, predominantly carbonate metasediments (Coats, 1964).

Possible ages of the metasediments in the study area may be implied by extrapolation from paleogeographic reconstructions of Stokes (1975). The region surrounding South Mountain was probably the site of eugeosynclinal sedimentation, or transitional between equeosynclinal and miogeosynclinal sedimentation during much of the Phanerozoic until late Devonian. During the late Devonian, the study area was near the north end of the Antler uplift. Deposition resumed in the region during the Permian period and continued until large scale orogeny commenced during the Cretaceous. Sedimentation subsequent to the Antler Orogeny was dominantly clastic. The mixed suite of pelitic, psammitic, and carbonate rocks along with possible volcanically derived rocks at South Mountain were probably deposited in the late Precambrian or Paleozoic prior to the Antler Orogeny. However, the possibility that these rocks may be Permian or Mesozoic in age cannot be excluded.

PLUTONIC ROCKS

Most exposures at South Mountain are of plutonic rocks. Ages of these rocks range from Cretaceous to Eocene; minor dikes may be significantly younger. Five major plutonic units were distinguished on the basis of mineralogic composition, textures, contact relations and geographic continuity. In addition, three types of dike rocks were recognized on the basis of texture and color index. Within each unit there is some variation in texture and mineral content. However, hand specimens from each are easily identified.

Quartz Diorite (Kqd)

Outcrops of quartz diorite are present near the south edge of the study area in sections 9, 14, 15 and 16, T. 8 S., R. 5 E. Rocks of this plutonic unit range in composition from melanocratic diorite to gniessic tonalite. Outcrops are typically small, rarely over 2 m (6 ft) high and 7 m (20 ft) long. The appearance of the outcrops is variable as is the texture and composition of this unit. The outcrops are well rounded from chemical weathering.

The textures of the quartz diorite vary from coarse grained, cumulate-textured melanocratic rocks to well-foliated, medium to fine grained, leucocratic gneisses. The cumulate textured variety consists of blocky euhedral prisms of hornblende ranging from 6 mm to 15 mm in length. The intercumulus minerals are medium to fine grained and are usually anhedral, and include orthoclase, quartz, plagioclase, and epidote. Augite may be present as euhedral grains up to 0.5 mm in diameter. The gneissic rocks have a secondary foliation which results

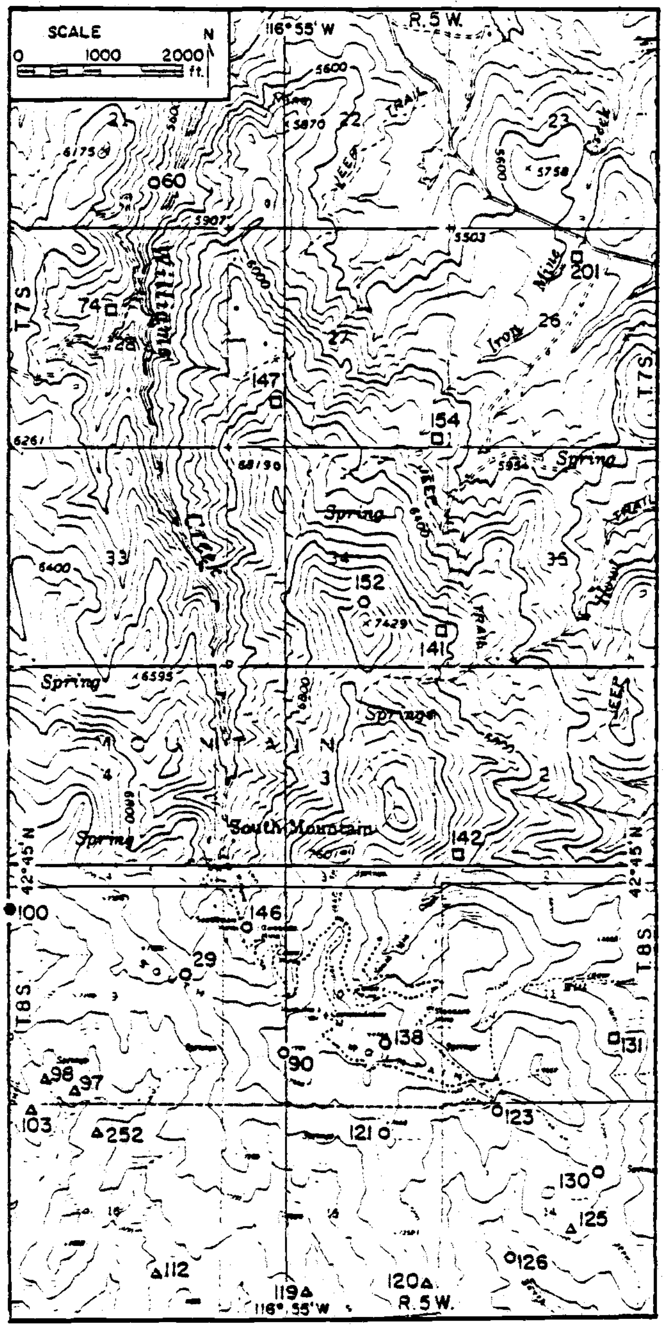


Figure 6: Map of study area showing the location of samples used for modal analysis. Symbols are: triangles, Kqd; solid hexagons, KTmg; squares, Tgd; open hexagons, Tlg; and circles, Tgm.

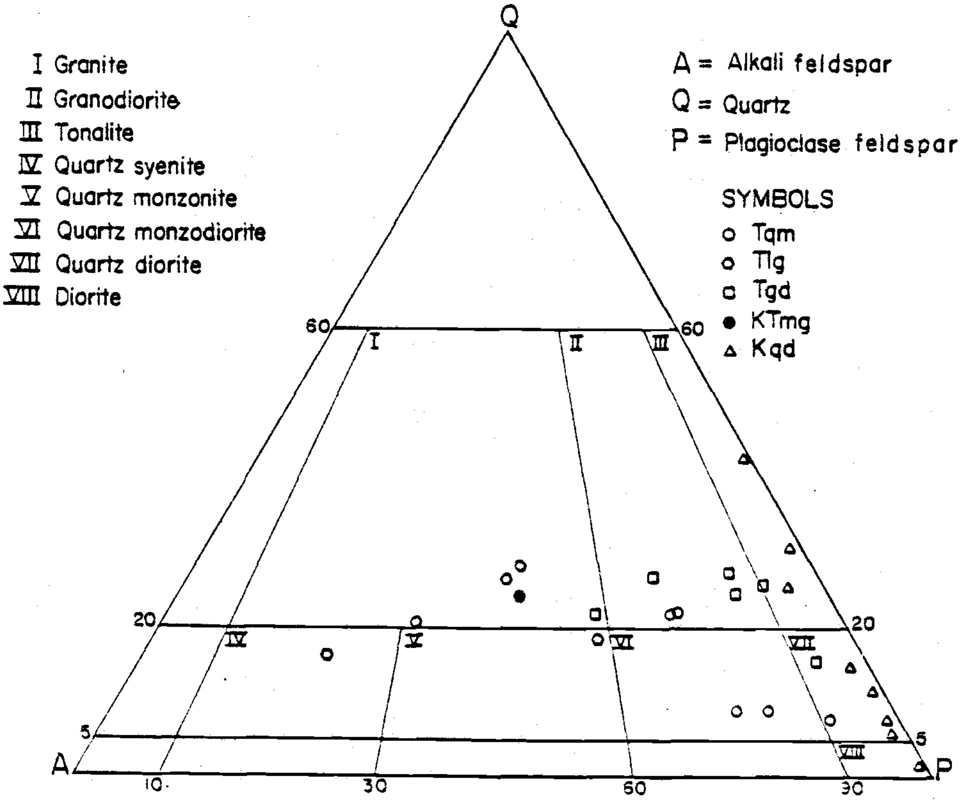


Figure 7: Modal composition of granitic rocks from South Mountain. Compositions are plotted on quartz, alkali feldspar, plagioclase ternary classification diagram of Streckeisen (1973).

Figure 8: Three hand specimens of quartz diorite. Samples, clockwise from upper left are: weakly gneissic, tonalites, 98, hypidiomorphic quartz diorite, 97, and melanocratic quartz diorite, 120. Scale is in centimeters.

TABLE 1: MODAL ANALYSES OF QUARTZ DIORITE FROM SOUTH MOUNTAIN.

Mineral	Sample Number							
	97	98	103	112	119	120	125	252
Orthoclase	1.5	1.2	0.8	1.0	0.1	-	1.0	0.6
Quartz	9.0	23.0	4.5	8.0	0.5	1.6	3.3	30.9
Plagioclase	49.6	51.1	12.5	61.1	6.1	23.0	56.9	41.9
Biotite	8.4	19.2	tr	9.4	-	-	-	18.3
Hornblende	26.3	1.1	66.4	18.3	81.0	56.5	38.1	2.2
Augite	-	1.6	8.5	tr	11.1	3.7	-	-
Epidote	0.4	2.0	5.9	0.2	0.9	5.9	tr	5.8
Alternation products	3.1	0.4	0.1	0.8	-	7.8	0.1	-
Opaque accessories	0.5	tr	0.5	1.1	0.2	0.1	0.7	0.2
Non opague accessoreis	1.2	0.4	0.8	0.1	0.1	1.4	tr	0.1
Color Index	38.9	24.7	82.2	29.9	93.3	75.4	38.9	26.6

from the parallel arrangement of biotite flakes, and a weak segregation of felsic and mafic minerals. Foliation is very weak to absent in mesocratic rocks that form the bulk of this plutonic unit. The mesocratic rocks typically have a medium-grained, equigranular, hypidiomorphic texture. Where biotite is present it usually occurs as conspicuous thin flakes up to 10 mm (0.4 in) wide. Modal analyses are given in Table 1. Rocks in Table 1 range from diorite to tonalite.

Minor alteration occurs adjacent to fractures in the quartz dioritic rocks, especially in the melanocratic rocks. Alteration minerals consist of clinozoisite, cummingtonite, calcite and chlorite. The alteration minerals partially replace the primary minerals in irregular zones along some fractures. Locally, coarsely crystalline epidote and calcite occur as fracture fillings.

The quartz diorite forms several lens shaped plutons which intrude pre-Tertiary amphibolites. The gross form of the plutons is conformable to foliation in the country rocks. Basal contacts of the sill-like bodies were not observed. However, many good exposures of the roofs of the sills were observed. The upper contacts are zones of intrusion breccia or migmatite displaying ptygmatic apophyses, lit-par-lit injections and large areas of unrotated xenoliths. Migmatite is in greater abundance where the quartz diorite sills are thicker. Melanocratic rocks, including hornblende meladiorite and hornblendite occur near the basal contacts of the sills. As was stated earlier, the melanocratic rocks are cumulate textured; thus, they may result from magmatic differentiation by crystal settling in individual magma chambers.

The quartz-diorite represents the earliest plutonic episode that has been documented in the Owyhee Mountains region. A K/Ar radiometric date of 87 ± 3 m.y., was obtained on hornblende from this plutonic unit (Armstrong, 1975). This plutonic unit was intruded at a much deeper level than the other units exposed at South Mountain.

Gneissic diorites intruded in the catazone are characteristic of the border facies of the Idaho batholith north of the Snake River Plain (Anderson, 1951, Buddington, 1959). However, Taubeneck (1971) has noted that epidote bearing rocks at South Mountain are similar to rocks occurring as satellites west of the batholith. Taubeneck has also suggested that epidote-bearing quartz diorites at South Mountain probably represent a satellite of the Idaho batholith, and that the margin of the batholith lies to the east of the study area.

Microcline Granite (KTmg)

Coarse grained granite occurs as a small isolated pluton near the west margin of the area in sections 8, and 9, T. 8 S., R. 5 E. The granite forms low, rounded, brownish yellow outcrops. All specimens collected were strongly weathered, moderately stained with limonite and friable. The rock consists of microcline feldspar, quartz, plagioclase, and small amounts of muscovite. Texturally the rock is very similar to the leucogranite. It is a coarse- to medium-crystalline allotriomorphic-granular, with serrated grain boundaries and abundant myrmekite. A modal analysis is tabulated with the orthoclase leucogranite in Table 3.

The relation of this rock type to the other plutonic rocks at South Mountain is unknown. It has intruded amphibolites and is disconformably overlain by basalt flows. Its composition and texture is similar to the leucogranite (described in a later section). However, the distinction of this unit from the leucogranite is based on the presence of microcline instead of orthoclase. The only possible field distinction is that outcrops of microcline granite are significantly more fractured, friable, and stained with limonite than are outcrops of orthoclase bearing leucogranite.

Granodiorite (Tgd)

Granodiorite occurs in the northern part and along the eastern edge of the area. This granitic intrusion is the most voluminous in the area. The granodiorite underlies a rolling terrain with steep valley sides and rounded ridges. The terrain is covered with abundant, scattered outcrops which have closely spaced joints, commonly along only one or two prominent directions. Outcrop blocks are rounded due to chemical weathering.

The granodiorite is light grey to light pinkish-grey in hand specimen. It weathers to a pale yellowish-brown. The rock is medium-grained, hypidiomorphic-equigranular in texture. In the central portions of the pluton the granodiorite may contain up to 5 percent orthoclase megacrysts ranging from 1 to 3 cm in diameter. Biotite and hornblende, the major mafic minerals, are generally of equal abundance.

The mineralogy of the granodiorite consists of orthoclase, quartz, plagioclase, biotite, hornblende, chlorite, magnetite and possibly other opaques, apatite, zircon, sphene, and minor secondary minerals. Normally orthoclase and quartz occur as anhedral

Figure 9: Outcrop of typical granodiorite on the ridge east of Williams Creek at an elevation of 1830 m (5000 ft). The outcrop is approximately 5 m (15 ft) in height.

TABLE 2: MODAL ANALYSES OF GRANODIORITE FROM SOUTH MOUNTAIN

Mineral	Sample Number					
	74	131	141	147	154	201
Orthoclase	4.5	8.6	9.1	6.0	15.5	27.0
Quartz	11.4	22.7	19.9	21.1	24.2	21.9
Plagioclase	58.5	52.2	52.5	55.2	51.3	38.2
Biotite	10.3	11.1	10.9	10.0	6.8	7.8
Hornblende	13.7	5.0	6.3	7.2	0.2	4.7
Chlorite	0.6	0.1	0.3	0.3	1.6	-
Opaque accessories	0.9	0.2	0.8	0.1	0.3	0.1
Non opaque accessories	0.1	0.1	0.2	0.1	0.1	0.3
Color Index	25.6	16.5	18.5	17.7	9.0	12.9

interstitial minerals between plagioclase and the mafic minerals. Orthoclase is more coarse-grained and perthitic where it is more abundant. Orthoclase megacrysts are subhedral, contain abundant inclusions, display carlsbad twinning, and are strongly perthitic. Myrmekite is common in the more potassic rocks, but is rare in the more plagioclase rich varieties. Orthoclase is typically cloudy in appearance because of weak alteration to kaolinite. Plagioclase forms subhedral, blocky prisms ranging from 1 to 4 mm (0.04 to 0.16 in) in length. Oscillatory zoning is present in the plagioclase. The composition ranges from An_{40} to An_{25}. Carlsbad, albite and pericline twinning are typical. Biotite and hornblende comprise the mafic mineral phases in the granodiorite and are commonly intergrown. Hornblende forms rare euhedral prisms but more commonly subhedral grains which are rimmed or partially replaced by biotite. Biotite also occurs as subhedral crystals and commonly is partially replaced by chlorite and anhedral sphene. Opaques occur as euhedral to subhedral inclusions in the mafics. The primary nonopaque accessory minerals include apatite, sphene, and zircon, listed in relative order of abundance.

Modal analyses of six rocks which are representative are listed in Table 2. The modal composition of each of these is plotted in Figure 7; the range is from tonalite to granite. This range in composition is roughly correlative with distance from the contact of the intrusive; the most potassic rocks are near the center of the pluton.

In general, the texture of the granodiorite is holocrystalline, hypidiomorphic, equigranular, and medium grained. Except where orthoclase megacrysts occur, the grain size ranges from 0.5 to 4 mm.

The myrmekitic textures and the replacement of biotite by chlorite and sphene can be attributed to late magmatic processes. Evidence of weak, post-magmatic deuteric alteration is abundant and includes minor dusty alteration of orthoclase to kaolinite, and alteration of plagioclase along cleavage and selected oscillatory zones to very fine grained clinozoisite.

Two types of strong alteration of the granodiorite were observed. The first type occurs in an area approximately 70 m (250 ft) in diameter in the southwest corner of section 22, T. 7 S., R. 5 E., where the granodiorite has undergone strong phyllic alteration. The altered rock is reddish brown. Pseudomorphs of montmorillinite after plagioclase feldspar can be seen in hand specimen and thin section. From petrographic observation the alteration assemblage includes montmorillinite, kaolinite and hematite. Quartz is the only primary mineral that is not obliterated. The second alteration type occurs in several scattered localities. Mafic minerals have been totally replaced by actinolite and epidote. In addition, the plagioclase is slightly more calcic, sausserizitation of plagioclase is more complete, and myrmekite is much more abundant than in fresh granodiorite. This alteration type probably occurs in areas where carbonate country rocks have been assimilated.

Although the granodiorite pluton is discordant, some contacts appear to be locally concordant. Contacts with the country rocks were observed in only two outcrops. One outcrop is on the west side of Williams Creek in the southeast quarter of section 28, T. 7 S., R. 5 E. This contact is concordant, extremely sharp, has no chilled margin, and contains a few partially digested xenoliths. The country rock has been recrystallized to a biotite-quartz hornfels for a short distance from the contact. The other outcrop is at the portal of a small caved adit in the north half of section 28, T. 7 S., R. 5 E. The country rock is a small pendant or large xenolith of tactite and schist. Surrounding the pendant is a densely packed intrusion breccia consisting of fine to medium grained, recrystallized fragments of biotite-quartz schist in a coarsely crystalline matrix of biotite and plagioclase. Biotite, plagioclase and quartz have recrystallized and become coarser grained in the fragments. The presence of up to one percent granular hercynite in some fragments indicates a realtively high temperature of recrystallization. The matrix is granodioritic material but is much richer in biotite than the normal granodiorite, which suggests that the fragments have been partially assimilated.

Hornblende and biotite K/Ar dates from a sample from this pluton are 49.7 ± 1.3 m.y., and 45.2 ± 1.3 m.y., respectively (Armstrong, 1976). These dates show that this pluton is significantly younger than the quartz diorite.

The characteristics of this pluton are mostly similar to those described by Buddington (1959) for plutons of the mesozone. The lack of chilled margins, the overall metamorphic grade of the country rocks, partial assimilation of xenoliths, zoning, both discordant and concordant contacts in the granodiorite are characteristic of plutons of the mesozone. However, a few features are not characteristic of mesozonal plutons. The absence of foliations parallel to the contact in both the country rock and pluton, and the hornfels-like metamorphism of country rock near the contact are atypical of mesozonal plutons. The granodorite was probably intruded at a more shallow depth than the quartz diorite sills. Significant uplift of the region must have occurred in late Cretaceous and Eocene time.

Leucocratic Granite (Tlg)

The prominent high peaks and ridges of South Mountain are composed of leucocratic granite. The white color and relatively vegetation-free nature of these ridges may be easily seen on aerial photographs and from a distance on the ground. Leucogranite outcrops in two north to northwest trending belts which originate beyond the southeast corner of the area. The major belt trends across the Mill and South Mountain Creek valleys and continues north, forming the eastern divide of Williams Creek. The second, smaller belt trends along the divide between Boulder Creek and Mill and South Mountain creeks, across the summit of South Mountain and descends into the Williams Creek drainage. The more prominent eastern belt marks the contact of the granodiorite with the metamorphic rocks exposed in the valley of Williams Creek.

Outcrops of the leucogranite are very fresh, blocky and angular. Frost wedging comprises the predominant weathering phenomenon and results in many large talus slopes on the ridges underlain by the leucogranite.

The leucogranite is typically a white, coarse-grained, allotriomorphic granular rock composed chiefly of orthoclase, quartz and plagioclase, with minor muscovite and light green micas. Virtually no mafic minerals are present. Commonly, the rock is weakly stained by iron oxides. Small, irregular patches of pegmatite are common throughout, whereas aplitic textured patches are common only locally. Generally, the western belt has a weak, coarse-grained, planar fabric

TABLE 3: MODAL ANALYSES OF LEUCOCRATIC GRANITE FROM SOUTH MOUNTAIN
(Stained slabs were used for analysis)

Mineral	Sample Number						
	29	60*	100**	130	138	142	152
Microcline	-	-	36.0	-	-	-	-
Orthoclase	32.7	46.6	-	48.3	35.8	32.9	61.5
Quartz	28.5	31.0	24.2	19.6	26.5	17.5	16.2
Plagioclase	37.7	20.7	39.5	28.9	36.5	45.7	20.9
Other (includes muscovite, biotite, and chlorite)	0.1	1.7	0.3	3.2	1.2	3.9	1.2

* Sample of pegmatite dike

** Sample of microcline granite

of irregular, alternating bands of quartz and feldspar approximately 1 cm wide. Bleached inclusions of the metamorphic rocks occur throughout the leucogranite. Elongate inclusions composed of a garnet-clinopyroxene tactite are common. The tactites are often weakly mineralized with chalcopyrite.

In thin section, the texture of the leucogranite is typically allotriomorphic and inequigranular. Crystal boundaries are serrated. No twinning was observed in the orthoclase, but microperthite occurs as strings and bands. Quartz has interpenetrating grain boundaries with other minerals. The composition of plagioclase was not determined because of the inconspicuous nature of the albite twinning, but antiperthite is common, suggesting that the composition is probably oligoclase or albite. Myrmekite and micrographic textures are well-developed.

The mafic minerals never exceed five percent, and include greenish biotite, chlorite and muscovite. Pink garnet occurs as a common accessory in the pegmatitic patches.

The plutonic unit is classified as a leucogranite based on modal analyses of five stained slabs. This method was used because of the difficulty of distinguishing the microperthitic potassium feldspar from poorly twinned, altered plagioclase. The rock is not classified as an alaskite, as the plagioclase is not definitely albite.

The intrusive contact with the granodiorite is sharp, but highly irregular, with rounded inclusions of granodiorite up to 1 m in leucogranite with abnormally abundant pegmatite. Locally, the contact with the granodiorite seems gradational because the biotite content of the leucogranite is greater near the granodiorite. Trenches near the lookout tower expose both leucogranite and country rock. The nature of the contact in these trenches is indistinguishable due to intense fracturing, strong oxidation, and heavy iron staining.

The leucogranite is younger than the granodiorite, but is probably of approximately the same age. Many contact relations and textural characteristics suggest that late magmatic fluids played an important role in the genesis of the leucogranite. Such a fluid could have been evolved during the late stages of crystallization of the adjacent granodiorite.

Quartz Monzodiorite (Tqm)

The youngest of the major plutonic units in the South Mountain district has an average composition of quartz monzodiorite. This unit is exposed on the Juniper and Williams Creek divide, on the small plateau southeast of the lookout tower on South Mountain and in the valley of Boulder Creek. A small stock of similar rock occurs near the portal of the Sonneman Tunnel and is also exposed in the tunnel; informally named the Sonneman Stock by mine geologists.

Outcrops of the quartz monzodiorite are generally small and well-fractured. Frost wedging has broken the rocks into heaps of rubble. Weathered surfaces are yellowish tan whereas fresh surfaces are light olive grey to medium grey. The rock is typically medium-grained and equigranular, but may range to a fine-grained porphyry, with an aphanitic groundmass. Euhedral crystals or phenocrysts of plagioclase about 3 mm in diameter are characteristic of this plutonic unit. Rare euhedral megacrysts of pyroxene up to 2 cm in diameter are also characteristic.

TABLE 4: MODAL ANALYSES OF QUARTZ MONZODIORITE FROM SOUTH MOUNTAIN

Mineral	Sample Number				
	90	121	123	126	146*
Orthoclase	16.6	16.1	5.0	12.3	13.3
Quartz	18.2	18.7	4.5	9.6	9.1
Plagioclase	49.4	50.1	50.3	47.8	63.8
Biotite	8.2	3.2	0.7	7.7	3.2
Hornblende	1.8	1.6	0.8	-	9.9
Orthopyroxene	-	-	6.6	-	-
Matrix	-	-	28.8	16.1	-
Alteration products	4.7	8.1	2.6	6.3	0.4
Opaque accessories	0.4	0.6	0.6	0.1	0.1
Non opaque accessories	0.7	1.6	0.1	0.1	0.2
Color Index	15.8	15.1	11.4	14.2	13.8

* Sample from Sonneman stock

Microscopically, the texture of the quartz monzodiorite is very distinctive. The texture ranges from porphyritic, with a very fine-grained matrix, to seriate with a fine to medium matrix. The matrix consists of allotriomorphic orthoclase, quartz, plagioclase and biotite.

The essential minerals of this rock include orthoclase, quartz, plagioclase, and biotite. Hornblende and orthopyroxene are present locally, but, typically, are altered beyond recognition. Orthoclase occurs in the matrix of the rock and may be microcrystalline to 0.5 mm in diameter. Quartz typically occurs along with orthoclase as an interstitial mineral; phenocrysts of quartz are rare. Plagioclase occurs as euhedral to subhedral phenocrysts from 0.5 to 3 mm in diameter. Rims of albite or orthoclase are common. Most plagioclase has prominent, tightly-spaced oscillatory zones which commonly make determination of composition difficult. Biotite occurs as fine discrete flakes, or as granular aggregates. Unaltered hornblende and orthopyroxene form euhedral phenocrysts, but more commonly they are partially to completely replaced by rough pseudomorphs of felty-textured calcite, chlorite, cummingtonite and epidote. Hornblende is usually less altered than orthopyroxene and, therefore, is more abundant in modal analyses. The orthopyroxene has a composition of hypersthene to ferro-hypersthene as determined by optical sign and the 2V angle. Sparse large phenocrysts of pyroxene are altered by a two-stage process, as follows: (1) development of a fibrous reaction rim of cummingtonite, and (2) alteration of the core to calcite, chlorite and epidote.

Mafic minerals are locally altered to clinopyroxene and epidote. The clinopyroxene is typically anhedral, and fine-grained, replacing the mafic minerals in an otherwise normal appearing quartz monzodiorite. Clinopyroxene may be intergrown with sphene or rimmed by epidote. In one location, densely-spaced, parallel veinlets contain subhedral clinopyroxene. According to Zarikov (1970), endoskarns with such a mineralogy are the result of late magmatic diffusion reactions between granitic rocks and dolomitic rocks, but such reactions occur only on a limited basis.

Weak to moderately strong alteration characterized by fine-grained chlorite, calcite, epidote, and minor sericite is ubiquitous in the quartz monzodiorite. Where this propylitic alteration is strongest, the rock contains as much as one percent disseminated pyrite. Much of the Sonneman Stock is extensively altered to a propylitic assemblage.

Intrusive contacts were observed only near, and in, the Sonneman Tunnel. The contact is very sharp where the quartz monzodiorite intrudes marble which is extensively recrystallized to an extremely coarse granoblastic texture. An extensive chilled zone is present along some margins of the intrusion. Schist in contact with this intrusive phase is recrystallized to hornfels. The contact between chilled quartz monzodiorite and the recrystallized schist is gradational over 0.3 to 0.6 m. Elsewhere, the contacts were not observed; however, the prevalence of fine-grained matrix near most contacts indicates rapid crystallization and shallow level of emplacement. The discordant nature of the stocks and the association of intrusive breccias with the quartz monzodiorite is consistent with epizonal emplacement (Buddington, 1959).

An absolute age of the quartz monzodiorite stocks has not been determined; however, both stocks were intruded at much shallower levels than the other intrusions, and one cross cuts quartz diorite and leucocratic granite.

Intrusive Breccia (Tib)

Several exposures of brecciated igneous and metamorphic rocks occur in the southern half of the field area. Most breccia occurs as irregular discontinuous zones along the southern contact of the main quartz monzodiorite stock. The main breccia zone, at least 900 m (3000 ft) long, and as wide as 450 m (1500 ft), is exposed over a vertical distance of 200 m (700 ft). A small, poorly-exposed breccia body is located on the low ridge in the southwest corner of section 4, T. 8 5., R. 5 E. This igneous breccia is the only one that is not directly associated with the quartz monzodiorite.

The intrusive breccia is variable in appearance because of different types of fragments and an inconsistent intensity of alteration in the matrix. It forms highly irregular shaped, light-colored outcrops that, locally, have weak limonite stains. The fragments consist of angular to sub-angular blocks of country rock, and rarely fine-grained quartz monzonitic rocks. Fragments range from less than 1 cm to as much as 2 m in diameter. The breccia matrix consists of variably altered, comminuted rock material. Several orientations of quartz veinlets cut matrix and fragments.

In thin section, the fragment boundaries are very distinct except where alteration is strong. The matrix consists of fine- to very fine-grained rock chips or flour. Alteration to finely granular epidote, sericite, actinolite and quartz is common. Locally, the alteration effects are strong enough to nearly obliterate the gross fragmental

Figure 10: Hand specimen of intrusive breccia. Collected approximately 500 m (1600ft.) southwest of the summit of South Mountain. Several fragment lithologies may be observed in this specimen. Note the small amount of matrix material. Scale is in centimeters.

texture. Irregular actinolite veins cut both fragment and matrix in the strongly altered rock. Trace amounts of pyrite are ubiquitous.

Preferred orientation of fragments, planar fabric in the matrix, and major fault and joint surfaces were not observed in any of the breccias. Neither were any contacts between breccia and country rocks or quartz monzodiorite observed. The heterogenous mixture of fragment types, the rounding of some fragments, and the comminuted matrix suggest that the breccia has been transported. However, none of the lithologies represented by the fragments are exotic to the South Mountain area. The proportion of some fragment types is locally higher where a particular lithology is predominant in the adjacent country rock. The direction of fragment transportation cannot be determined, although there has been some downward component. Fragments of hornblendite were found at least 70 m (200 ft) structurally below the updip projection of the lowest known dioritic lens.

Possible mechanisms for the formation of intrusive or intrusion breccias have been outlined by Bryant (1968). The mechanisms include tectonic activity (fault breccias), solution and replacement, brecciation during intrusion of a viscous magma (protoclastic breccias), gaseous explosion breccias (diatremes), fluid intrusion (includes pebble dikes), and magmatic or mineralization stopping. Field evidence for the mechanism which formed the breccias at South Mountain is inconclusive. However, it suggests that some collapse or stopping of chilled quartz monzodiorite and a portion of the country rocks has occurred. A cavity created by release of exsolved hydrothermal fluid or by removal of magma might have precipitated such a collapse. Similar processes have been envisioned by Locke (1926) and

Sillitoe and Sawkins (1971). Normally such breccias are strongly altered to either a quartz-sericite assemblage or quartz-tourmaline-muscovite assemblage, and contain significant amounts of metallic mineralization (Sillitoe and Sawkins, 1971). However, mineralization is not associated with breccias and only propylytic alteration occurs in the breccias near South Mountain. To better understand the intrusive breccias at South Mountain, detailed studies are needed of contact relations with country rocks and the quartz monzodiorite host and structures within the breccia and along the margins of the breccia.

Pegmatite Dikes (Tip)

Pegmatite occurs in several discrete dikes or veins throughout the area. The dikes or veins range from 1 cm (0.4 in) to about 30 m (100 ft) in width. Typically they form white, irregular, angular outcrops. Commonly, the pegmatite is composed of graphic intergrowths of quartz and orthoclase with coarse flakes of muscovite and fine disseminated red garnets. Contacts of the pegmatite are extremely sharp and planar. Some contacts of the longest dike, exposed in the Sonneman and Laxey tunnels, are marked by gouge zones. Where these gouge zones occur, the pegmatite is locally mylonitized.

Although some of the dikes are similar in texture and composition to the leucocratic granite, the genesis of the dikes is unknown. Most of the dikes are probably Cretaceous to Eocene in age, and are probably related to the intrusion of the quartz diorite, granodiorite or leucocratic granite.

Intermediate Dikes (Tid)

Several dikes with intermediate color indexes were mapped during this study. Many others were observed, but were too small to map at the map scales used. These dikes are greyish-green to green porphyritic rocks with a fine to aphanitic matrix. Phenocrysts include plagioclase and hornblende. Some dikes contain phenocrysts of basaltic hornblende and rare quartz. In most of the dikes the matrix is fine-grained and altered to a felty mass of chlorite, calcite and epidote or to clays. Hornblende phenocrysts are often partially or completely altered to chlorite whereas plagioclase is weakly altered to calcite and clinozoisite.

The dikes are mostly northeast trending and locally occur as small lenses along some of the major faults. Where the dikes are exposed by mine workings (Plate 2 b,c) they strike east-northeast and dip steeply to the northwest. The contacts with the country rocks are commonly bounded by gouge zones, and sometimes there is observable offset across the dikes. Where the dikes have been observed in diamond drill core, they typically contain abundant clay-rich fault gouge.

The dikes intrude all the major plutonic rocks, including the intrusive breccia, but have not been observed to intrude the Miocene basalts or tuffs. Pansze (1975) has published a 26.6 ± 0.5 m.y. K/Ar age date for similar dikes in the Silver City area. The intermediate dikes at South Mountain may be any age between Eocene and Miocene, and as a group may span that time interval.

Felsic Dikes (Tir)

A small number of light-colored, porphyritic and aphanitic dikes were mapped in the study area. Typically, the felsic dikes are white to light greenish-grey, and may be slightly to strongly iron stained when weathered. The porphyritic varities contain phenocrysts of plagioclase, quartz, biotite and alkali feldspar. The matrix of all felsic dikes is aphanitic.

The felsic dikes appear to be of the same age and have similar structural control as the intermediate dikes.

TERTIARY VOLCANIC ROCKS

Three Tertiary volcanic and one sedimentary rock units were mapped. The units include a lower (Eocene) rhyolitic tuff, Miocene basalt, siltstones, and an upper (Miocene) rhyolitic tuff. All the Tertiary rocks disconformably overlie the plutonic and metamorphic rocks that are described in the previous sections of this thesis.

Eocene Rhyolitic Tuff (Tl)

Outcrops of rhyolitic tuff occur on two small hills in the valley of an unnamed tributary of Williams Creek (section 28, T. 7 S., R. 5 E, Plate 1) in the northwest portion of the thesis area. This lower tuff forms an unconformity bounded unit below Miocene basalt and above the pre-Tertiary metamorphic rocks. Outcrops of the tuff are small, highly-fractured, deeply-weathered, and strongly iron stained.

Fresh specimens of the tuff are light greenish-grey, and are composed of a heterogenous mixture of fine ash, and coarse ash to lapilli-sized fragments of rocks, pumice, and crystals. The tuff is poorly sorted and the coarser tephra is suspended in a matrix of very fine grey ash. Lithic fragments consist of quartzites, schists, and granitic rocks (including microcline granite). Crystal fragments include embayed and broken quartz, subhedral biotite, and altered albitic feldspars.

The lower tuff unit can be tentatively correlated with Eocene volcanic rocks that have been mapped by Neill (1975) near Poison Creek in the southeast Owyhee Mountains. This correlation is based on

Figure 11: Photograph of three hand specimens of Eocene rhyolitic tuff. A geochemical analysis of the lower sample included a zinc value of 1000 ppm. Note strongly oxidized character of all the samples.

lithologic similarity, identical stratigraphic position, and relative proximity (32 km, 20 mi). Neill has reported a K/Ar radiometric date of 43.6 ± 0.8 m.y., for biotite rhyodacite from Poison Creek. Armstrong (1974) has suggested that scattered exposures of Eocene volcanic rocks throughout Idaho, including the Challis volcanics, are erosional remnants of a large volcanic field that covered most of the region during Eocene time. The very limited exposure of possible Eocene age volcanic rocks at South Mountain may be such an erosional remnant.

Miocene Basalt (Tb)

The Tertiary basalts at South Mountain comprise a 120 m (390 ft) to at least 300 m (980 ft) thick unit. Individual flows range from 5 m (15 ft) to 20 m (65 ft) in thickness. The basalts occur along the north, east, and south margins of the study area (Plate 1).

The flows have poorly-developed massive columnar jointing which is cut at right angles by a set of platy horizontal joints. The joint pattern produces rounded blocky outcrops. The basalt is typically a dark grey aphanitic rock which weathers to a moderate yellowish-brown. The weathered surfaces commonly have a fine, knobby texture which results from differential weathering of the glassy groundmass. Amygdaloidal basalts and scoracious basalts are abundant locally, and basaltic flow-breccia occurs in a few outcrops. Local outcrops of diabase probably represent dikes or sills; however, field relations were not determined.

Aphanitic, ophitic-intersertal textures predominate in the basalts, but porphyritic-intersertal and diktytaxitic textures were also observed. The mineralogy of the basalts is consistent despite the moderate textural variation. The basalts are composed of 35 to 50 percent (estimated abundance) labradorite microlites or bladed phenocrysts, 20 to 30 percent ophitic to intergranular augite, 2 to 5 percent euhedral to skeletal magnetite, and 1 to 15 percent discrete olivine phenocrysts. Where interstitial glass is fresh, it is grey in color, but more commonly the glass has undergone some degree of devitrification to a yellowish-brown clay. Amygdaloidal cavities are filled with a dirty, crystalline calcite. The observed mineralogy of the basalts at South Mountain is consistent with the mineralogy that Kuno (1968) has described for alkali-olivine basalts.

Basalts near South Mountain are petrographically similar to Miocene basalts of southeast Oregon (Walker and Repenning, 1966), the Silver City Range (Pansze, 1975), and the southeast Owyhee Mountains (Neill, 1975). Pansze (1975) has reported a K/Ar radiometric date of 16.6 ± 4.3 m.y., from basalts in the Silver City Range that are identical to basalts described in this thesis. It should be noted that the Miocene basalts of southwest Idaho, and southeast Oregon are petrographically, chemically, and probably genetically distinct from the coeval Columbia River Basalts of west central Idaho, northern Oregon, and southeast Washington (Walker, 1970, Pansze, 1975).

Miocene Sediments (Ts)

Locally the basalts are overlain by as much as 30 m (100 ft) of white, thinly-bedded siltstones. This rock type was found only in the lower part of the Iron Mine Creek drainage (section 23, T. 7 S., R. 5 E., Plate 1). The siltstones form outcrops in gullies where the soil cover has been eroded. However, the soil above the siltstones has a distinctive white color that facilitates mapping. These sediments were mapped by Bennett and Galbraith (1975) as interflow lenses in the Miocene basalts. Field relations indicate that at least this lens of white siltstones overlies the basalt and underlies the upper rhyolitic tuff.

The sediments are fine-grained and poorly-indurated. They contain no carbonaceous material, and, in hand specimen, appear to be rich in volcanic ash. The siltstones were probably deposited in a Miocene lake which had been dammed by basalt flows. The basalt flow breccia mentioned in the previous section of this thesis, is closely associated with these sediments.

Miocene Rhyolitic Tuff (Tt)

Rhyolitic tuffs overlie the white siltstones and the basalt on the south and east slopes of Iron Mine Creek (section 23, T. 7 S, R. 5 E., Plate 1). These tuffs form typically small, but moderately good, outcrops. Jointing in the tuffs is random and produces outcrops and talus that are irregular in shape and size.

Two textural varieties of the upper tuff were identified. The first is poorly-indurated, and overlain by the second variety which is a welded tuff. The former is light grey in color and weathers to a dark yellowish-brown. It contains approximately 20 percent obsidian, pumice, lithic, and crystal fragments which range from 0.5 mm to 10 mm in diameter. In thin section, the grey matrix of the un-welded tuff consists of fresh glass shards, pumice, and fine ash. The welded variety is medium to dark grey and weathered surfaces are a light olive-grey. The welded tuff contains fewer and smaller fragments than the un-welded variety, and has a weak parallel orientation of the fragments. The glassy groundmass of the welded tuff is eutaxitic.

The crystal fragments of both types of tuff include sanidine, albitic plagioclase, and quartz. Most crystal fragments are broken, but a few crystal faces have been preserved. Quartz crystals are commonly embayed. The composition of tuffs is dacite to rhyolite.

Although Bennett and Galbraith (1975) did not map any rhyolitic tuffs within the area of this study, this unit could be representative of the unit they mapped as Welded Tuff 1. This correlation has an element of uncertainty because there are several similar Miocene tuffs that have been described in adjoining areas. For a more complete treatment of Miocene volcanic stratigraphy, petrology and history of the Owyhee Mountains, the reader should consult studies by Neill (1975), Pansze (1975), Bennett and Galbraith (1975) and Bennett (1976).

STRUCTURAL GEOLOGY

There is evidence for at least three periods and styles of deformation, including two distinct folding episodes, and at least one period of faulting in rocks near South Mountain. Neither of the fold sets visibly affect Eocene plutonic rocks. Much of the observed faulting and fracturing can be related to the Neogene tectonic history of the region.

Folds

Evidence for two distinct ages and styles of folding is present in the metamorphosed sediments at South Mountain. The older of the two folding styles is characterized by tight isoclinal folds and a penetrative axial plane foliation. The isoclinal folds have been refolded by more open, symmetric to slightly asymmetric folds. There is no foliation parallel to the axial plane of the open folds.

Small scale isoclinal folds were observed in hand specimens and in outcrops of the marbles and mica schists. No large scale isoclinal folds were observed or mapped in the study area. The most obvious effect of this deformation is the penetrative axial plane foliation in the schists and amphibolites. Virtually all bedding, compositional layering, and lithologic contacts are parallel to the foliation except for the hinge areas of isoclinal folds. The foliation is expressed as a parallel alignment of platy or elongate minerals and possibly some compositional segregation of mica and quartz. Foliation is consistently parallel to axial planes through all parts of the isoclinal folds.

Small scale isoclinal folds with vertical axes are common in schistose country rocks and inclusions near the western margin of the Idaho batholith north of the Snake River Plain (Schmidt, 1964). Schmidt (1964) and Hamilton (1963) have suggested that metamorphism and deformation in metamorphic rocks immediately west of the batholith occurred during emplacement of the batholith in the mid-Cretaceous. Evidence that the batholith continues south of the Snake River has been provided by Taubeneck (1971). It is possible that the observed isoclinal folding and associated foliation are related to the emplacement of the batholith which is concealed east of South Mountain.

Isoclinal folds, foliation, bedding, and lithologic contacts have been refolded by a later deformation. The later deformation is characterized by small scale west-plunging symmetric to slightly asymmetric open folds and a large west-plunging antiform. Measured plunges of small scale folds and cleavage crenulations roughly coincide with the axis of folding that is crudely defined in a Pi diagram of foliation and bedding planes from the study area (Fig. 12). Petrographic evidence suggests that recrystallization of muscovite and biotite occurred subsequent to this folding episode. Undeformed mica occurs in a herringbone pattern in crenulated schists. The recrystallization probably occurred during a thermal metamorphic episode that was synchronous with the Eocene emplacement of granodioritic intrusions in the area. The metamorphic rocks at South Mountain are exposed in a broad, west-plunging antiformal structure with an ill-defined axis. The granodiorite and leucogranite plutons are in the center of this structure. The strike of foliation and bedding is generally northeast in the north part of the study area, and northwest in the south. In

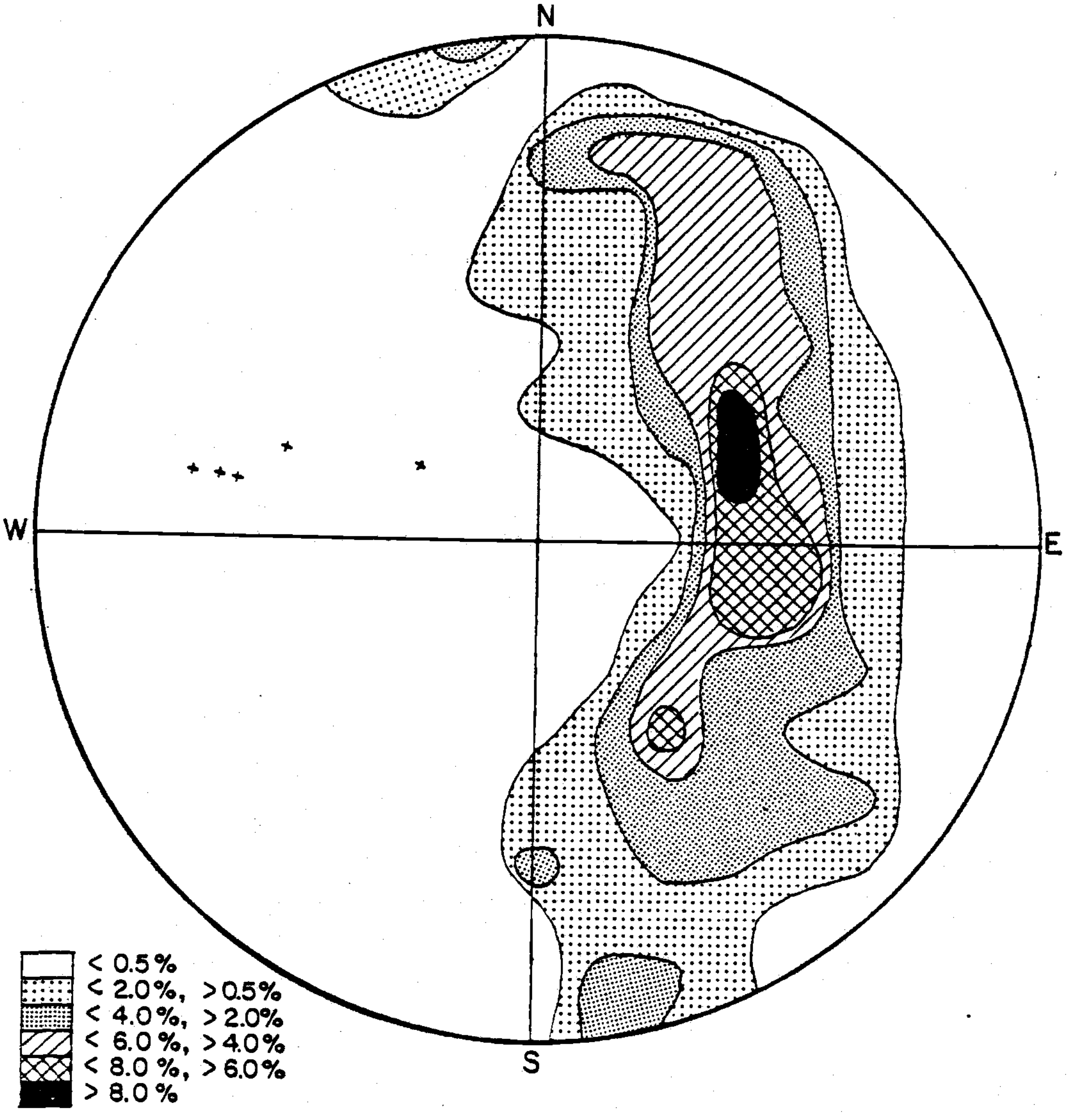


Figure 12: Contour pi diagram of 107 bedding and foliation planes in pre-Tertiary metamorphic rocks near South Mountain. Crosses represent the plunge of small scale open folds or cleavage crenalations measured in the field. The contouring method that was used is from Billings (1972).

the central part of the area the strike is variable, but roughly averages north. The antiform, crenulations, and small-scale folds may be the result of doming over the granodiorite and leucogranite plutons. Unequivocal evidence supporting this conclusion was not collected during field investigations.

Faults

Several high-angle normal and reverse faults of minor regional displacement were mapped during this study. The prominent strikes of the faults are north to northeast and northwest. These faults offset Miocene basalts and postdate any observed intrusive activity, including Tertiary dikes.

Miocene basalt flows and felsic tuffs on the flanks of South Mountain dip moderately away from the central portion of the study area. Some basalt flows appear to lap up against the older rocks, and some apparently filled in old topographic lows in the underlying Eocene volcanics.

A Pi diagram of all measured joints in intrusive rocks (Fig. 13) shows a weak concentration of northwest trending, near-vertical fractures. A strong northeast lineament on aerial photographs is apparent in the eastern part of the study area. Tertiary dikes near South Mountain have predominantly northeast strikes.

Uplift and subsequent exposure of basement rocks at South Mountain is a result of block faulting and slight doming. Bennett (1976) recognized three prominent regional trends of lineaments which are parallel to the trends of faults, joints, and aerial photograph linears found in this study. The northwest striking structures are

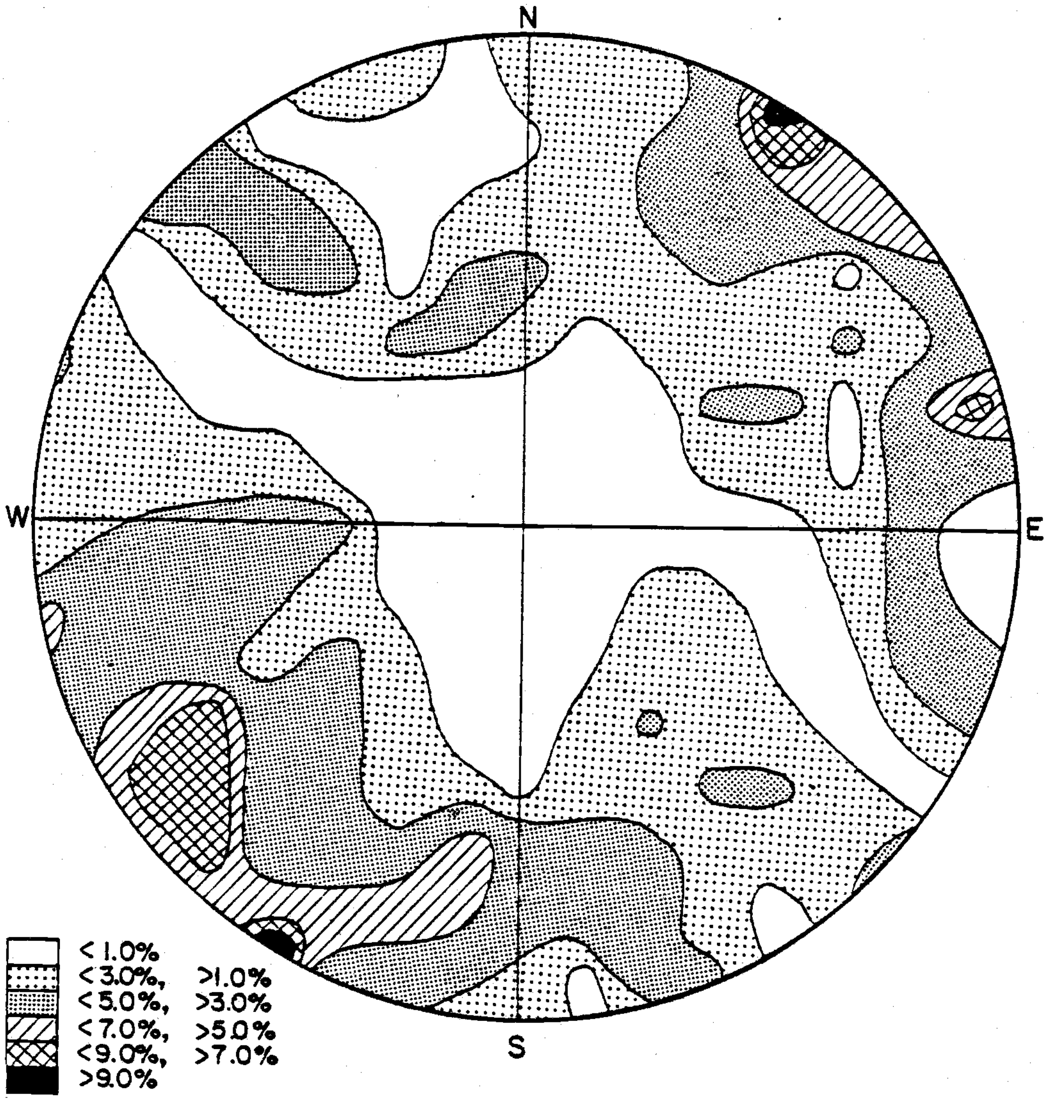


Figure 13: Contour pi diagram of 65 joints in granitic rocks near South Mountain. The contouring method that was used is from Billings (1972).

the most prominent regional trend. The prominent northwest joints, faults, and linears near South Mountain are parallel to the axis of the western Snake River Plain. Rifting in the western Snake River Plain commenced during the Miocene and probably continued through the Pleistocene (Hill and Pakiser, 1967); the uplift of South Mountain may have been synchronous. Relations of northeast trending structures to the regional tectonic regime are unclear.

MINERALIZATION AND TACTITES

Mineralization was discovered in the valley of Williams Creek in 1869 by prospectors from Silver City, Idaho (Raymond, 1873). Several productive lead-silver veins had been discovered and developed by 1871. Near-surface ore, consisting of argentiferous lead carbonate, was mined and smelted in a crude charcoal-fired furnace near Williams Creek during 1871, 1872, and 1874 (Raymond, 1875, 1876). Reported production figures from this early period of mining are inconsistent, but apparently at least 250,000 dollars (1870 prices) worth of gold and silver were recovered (Bell, 1907b). As many as 1000 miners, prospectors, and other workers lived at South Mountain during the peak of the early mining activity (Bell, 1907a). However, by 1875, the South Mountain mining district was nearly abandoned as a consequence of improper management, lack of transportation, and a general decline of mining activity in the surrounding region (Raymond, 1976).

Production during this period came mainly from the oxidized portions of argentiferous galena veins in marble host rocks (Bell, 1907b). The workings that had given access to these ores included the Golconda surface stope, the Bay State shaft and tunnel, and the Mexican Hat Shaft (referred to by Sorenson, 1927, and earlier authors, as the Grant incline shaft), which are shown on Figure 14.

Activity after 1875 in the area was not reported until 1906, when development work was renewed on the Golconda workings by the newly-formed South Mountain Mining Company (Bell, 1907b). During the following few years, the development work concentrated on the Golconda vein and the oxidized portions of the tactites occurring between the Laxey

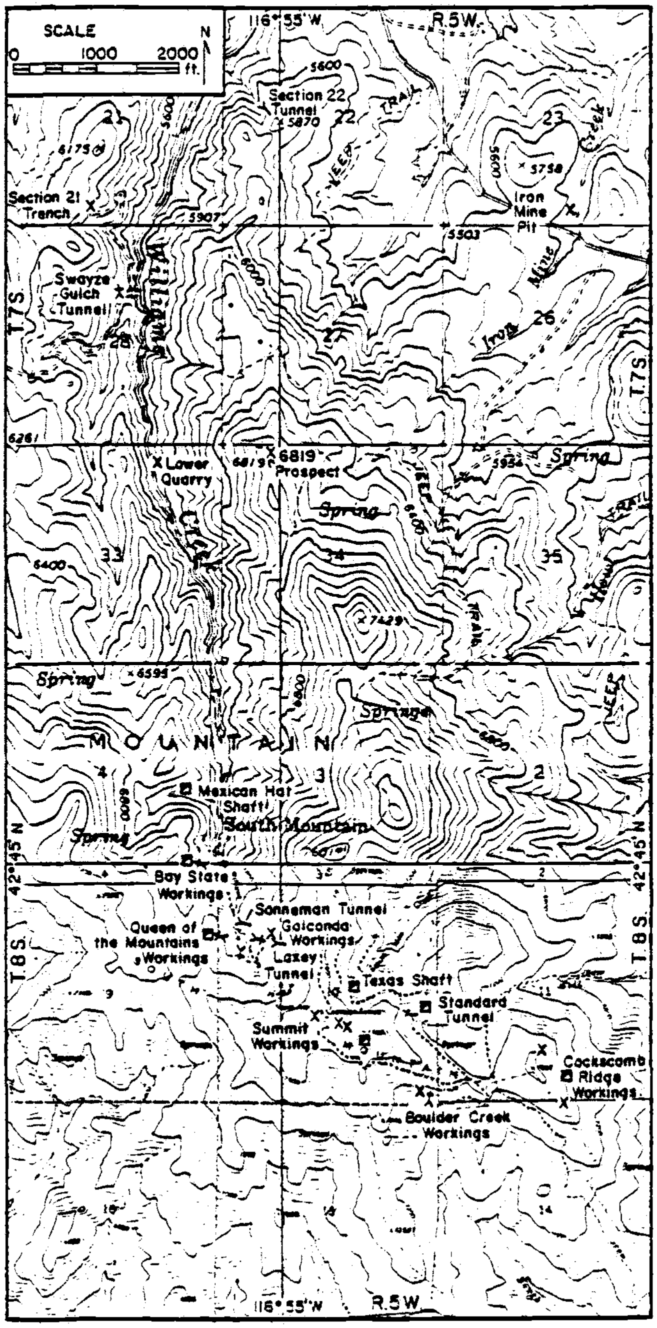


Figure 14: Mine and prospect locations in the South Mountain Mining District. Standard symbols are used for mine workings.

TABLE 5: METAL PRODUCTION FROM THE SOUTH MOUNTAIN MINE, IDAHO

Gross Value is in U.S. Dollars of the Year in which Production Occurred

Year	Au(oz)	Ag(oz)	Cu(lbs)	Pb(lbs)	Zn(lbs)	Tonnage (in short tons)	Gross value of shipments (in U.S. dollars of that period		Source of Data
1873							250,000	Golconda, Bay State, Mexican Hat & others	Bell, 1906
1907		908		13,645		14	868	Standard	Bell, 1908
1940	251	63,194	57,000	225,860	1,080,000	4,961	139,497	Galconda, Laxey 113 & 111 zones	Woodward & Luff, 1941
1941	376	199,838	246,000	287,000	4,402,000	16,663	530,804	" "	Woodward & Luff, 1943a
1942	212	122,355	193,200	124,700	2,970,000	11,188	402,370	" "	Woodward & Luff, 1943b
1943	55	42,407	63,800	78,000	1,266,000	4,706	182,953	" "	Woodward & Luff, 1945
1944	84	33,279	94,000	64,000	1,392,000	6,721	203,103	" "	Woodward & Luff, 1946
1945	58	41,054	93,600	48,000	1,355,600	7,523	203,882	" "	Needham & Luff, 1947
1950	6	11,301	47,100	1,400		464	20,424	Laxey, Texas, DMEA	Robertson & Halverson, 1953
1951	4	1,191		6,000	26,000	120	6,988	" " "	Dettman, 1954
1952	1	1,366	10,000	2,000	100,000	324	20,613	" " "	Kauffman & others, 1955
1953	30	19.210	58,000	54,000	14,000	976	43,766	" " "	Baber & others, 1956
1954	5	*5,993	16,000	4,000		267	10,867	" " "	Baber & others, 1957
1955	96	29,405	98,000	38,000	18,000	4,552	74,403	" " "	Baber & others, 1958

* No detailed production figures, ore was possibly smelted on site. In other years direct shipping ore was sent to custom mills and smelters in Utah.

Tunnel and the Texas Shaft (Bell, 1907b). According to Bell (1907b), work by the American Standard Mining Company on claims southeast of the Texas Shaft commenced in 1906. American Standard developed the Standard Tunnel, and prospected in the Cockscomb Peak and the Boulder workings (Bell, 1907b). They shipped 14 tons of ore before terminating operations in 1907 (Bell, 1908).

During 1929, 1930 and 1931, the Exploration Company of California completed major development work on the Sonneman, Golconda, and Laxey Tunnels (Cambell, 1930, 1931; Cambell and Mahan, 1932). However, the company failed to ship any ore before low metal prices and depleted capital forced them to close the mines (Cambell and Mahan, 1932).

Metal production from the Laxey zone (Plate 2) began in 1940. During the period from 1940 to 1946, the South Mountain Mining Company grossed nearly 1.5 million dollars (1940 prices) from direct shipping ore (Table 5). Production was terminated in late 1946 (Needham and Luff, 1952). In 1950, production was renewed from leases and subleases on the Laxey, Texas, 111, 113, DMEA 2, and DMEA 3 zones, but ended again in 1955 (Table 5). A mill was completed near the entrance to the Sonneman Tunnel in 1955 (Needham and Luff, 1957). However, figures on the productivity of the mill have not been published.

Since 1955, no production from the district has been recorded, but several companies have done exploration work. In 1971, William A. Bowes and Associates gained control of most claims in the district and have continued exploration up to the present time.

Most ore that has been produced from the Sonneman, Laxey, Standard, and Texas workings has been from irregular, high-grade, zinc-rich, polymetallic sulfide replacement bodies in hedenbergite tactite. Mineralization in the Golconda, Queen of the Mountains, Bay State, and Mexican Hat workings consists of partially-oxidized argentiferous galena "replacement veins" in marble (Sorenson, 1927). Other prospects and workings which are shown in Figure 14 are mostly in copper or zinc-bearing tactites. Many older and less important tunnels, shafts, and prospects are not shown in Figure 14 for the sake of clarity.

Hedenbergite Tactite

Zinc-rich, polymetallic massive sulfide replacement bodies in hedenbergite tactite have been the source for most mineral production in the South Mountain Mining District. Hedenbergite tactite and the associated mineralization form several replacement bodies in the Laxey marble near the head of Williams Creek. The tactite replaces the Laxey Marble east of the summit of South Mountain in the areas of the Texas and Standard workings. Smaller bodies of tactite occur in thinner beds of marble above the Laxey marble. Surface exposures of tactite are strongly weathered and heavily stained with dark brown oxides of iron and manganese. Gossan is present on the surface where sulfide minerals are abundant in the tactite. Copper, lead, and zinc carbonate minerals may locally be abundant in the gossan.

The tactite replacement bodies form irregular, anastomising pipes which plunge roughly 40° to the west. Locally, the entire thickness of marble may be replaced. The tactite is mostly located along the hangingwall contact of the Laxey marble, but may occur in any part of the marble. The Laxey zone (Plate 2) is concentrated near the footwall contact of the marble. Sulfides occur throughout

Figure 15: Photograph of a typical specimen of hedenbergite tactite. The top of the specimen shows a typical vug filled with crystalline ilvaite, quartz and calcite. The bottom of the specimen shows replacement sulfides with pyrrhotite, sphalerite, chalcopyrite and galena. Scale is in centimeters.

the tactite as small pods and stringers, but may be concentrated into semimassive to massive irregular replacement pipes up to 15 m (50 ft) in diameter. The mineralized pipes roughly mimic the shape and orientation of the enclosing tactite. Minor stringers of sphalerite may occur in marble.

Four mineral assemblages were recognized in the hedenbergite tactites of the South Mountain Mine. The assemblages, which are listed in Table 8, are (1) unmineralized tactite which is composed chiefly of hedenbergite, garnet, ilvaite, quartz, and calite; (2) mineralized tactite which is composed of pyrrhotite, sphalerite, chalcopyrite and galena with clays, actinolite, and remnant clinopyroxe; (3) argentiferous galena veins that are open space fracture fillings of pyrrhotite, arsenopyrite, sphalerite, galena, pyrite, quartz and calcite (the veins will be described under a separate heading); and (4) altered tactite which is composed of fine-grained alteration products of tactite. Each mineral assemblage occurs in several distinct zones, but no systematic arrangement of zones was observed. Every tactite body contains the unmineralized tactite assemblage but may not include all, or any of the other assemblages.

The tactite is chiefly composed of interlocking bundles of radiating clinopyroxene blades. Individual blades may be up to 13 cm long and 1 cm wide. Rosettes are convex outward at the marble contact, which has a scalloped edge. Euhedral, 1 to 4 mm grains of honey-colored garnet, probably andradite, are disseminated throughout the tactite. Locally, the garnet is concentrated into irregular granular masses which may be up to 0.5 m in diameter. Irregular cavities in the tactite, 5 to 30 cm in diameter, are filled with

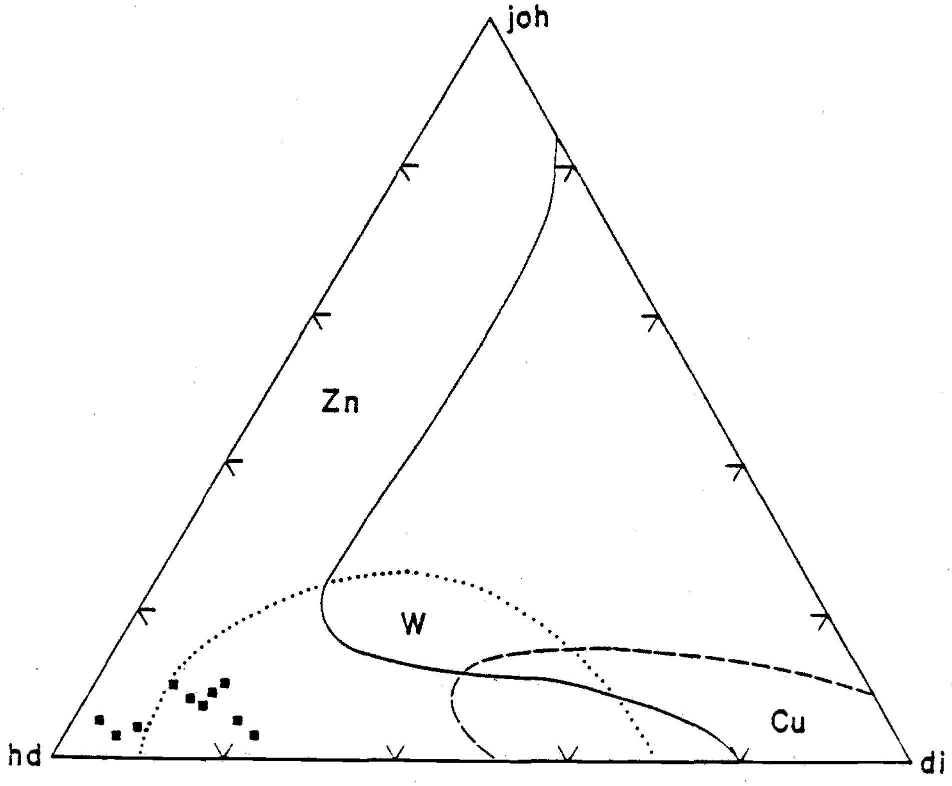


Figure 16: Ternary diagram showing the molar composition of clinopyroxenes from the South Mountain Mine. End members are hd, hedenbergite, $CaFeSi_2O_6$; joh, johansenite, $CaMnSi_2O_6$; and di, diopside, $CaMgSi_2O_6$. Filled squares represent molar compositions of clinopyroxenes from South Mountain from Burton (1978). The three fields enclose compositions of clinopyroxenes from tactites which have been classified by the contained metals. Copper (Cu) tactite clinopyroxenes are enclosed by a dashed line; tungsten, W, by a dotted line; and zinc (Zn) by a solid line. The fields are from Meinhert and others (1981).

crystalline ilvaite ($CaFe_2Fe_3(SiO_4)_2 \cdot OH$), quartz, and calcite. Ilvaite, quartz, and calcite also occur as anhedral grains interstitial to clinopyroxene and garnet. Ilvaite may occur as anhedral replacements of hedenbergite. The ends of clinopyroxene blades which are adjacent to the filled cavities have been pseudomorphically replaced by quartz and calcite. Magnetite is occasionally present as partial replacements of ilvaite. Pyrite occurs as rare euhedral cubes in some unmineralized tactite zones.

Mineralized tactite typically contains fresh remnants of garnet and clinopyroxene, except where the sulfides comprise large, massive replacement bodies. The mineralized zones may range from small pockets and stringers less than 2 cm in width to large massive replacement bodies up to 2 m wide. Where several of the small stringers and larger pipes are concentrated, they constitute semimassive ore bodies. Many sulfide stringers are located near the base of radiating clinopyroxene blades. Particular growth zones of andradite are commonly preferentially replaced by sulfide minerals. Occasionally, sulfide stringers and cavities filled by ilvaite, quartz, and calcite occur on the opposite sides of clusters of clinopyroxene (Figure 15). However, relations between the sulfides and the ilvaite, quartz, and calcite were not observed.

The sulfide minerals in mineralized tactite are pyrrhotite, chalcopyrite, sphalerite, and galena. All the minerals are closely intergrown. Large inclusions of pyrrhotite and chalcopyrite are present in sphalerite. However, many crystals of sphalerite contain veinlets of pyrrhotite and chalcopyrite. Rims of chalcopyrite may occur around sphalerite. Trains of microscopic beads of chalcopyrite in sphalerite are ubiquitous and suggest that exsolution of chalcopyrite has occurred. The sphalerite is metallic, dark grey marmotite, which has a high iron content. Galena was identified in only a few sulfide replacement bodies and appears to have replaced the other sulfide minerals. Pyrrhotite and sphalerite may be disseminated in the unmineralized tactite. A reddish-brown, highly birefringent clay replaces hedenbergite adjacent to sulfide minerals. The clay is probably an iron and manganese-rich variety of montmorillinite. The clay may occur as very fine, felty aggregates replacing hedenbergite, or as botryoidal aggregates interstitial to calcsilicate minerals. Actinolite and epidote occur as finely-granular alteration products of hedenbergite in massive sulfide replacement pipes.

Zones of altered tactite may locally occur adjacent to igneous dikes and some faults. Alteration of tactite is also present in calcite stringer zones. The products of alteration are fine-grained, and have a felty texture in thin section. The original tactite minerals have been mylonitized and then altered adjacent to faults. Alteration adjacent to dikes is characterized by actinolite, clays, calcite and pyrite. Alteration minerals adjacent to faults and in mylonitic zones consist of calcite, clays, magnetite, hematite, and talc. Remnant pods of fresh tactite may occur in either type of alteration. Ghosts and remnant grains of hedenbergite were recognized in thin section.

Argentiferous Galena Veins

Mineralization in veins which have been prospected and mined for lead and silver occurs in marble host rocks between the Laxey Tunnel and the Mexican Hat Shaft. Similar veins were observed in tactite and mineralized tactite in the Laxey and Sonneman Tunnels. Other scattered occurrences of argentiferous galena veins in marble host rocks are in the valley of Williams Creek. Any marble beds may serve as a host for the veins, but the largest ones occur in the Laxey marble. The major veins which have yielded lead, silver, and gold include a vein exposed in the Texas zone at the Laxey Tunnel level, the Golconda vein, the Queen of the Mountains vein, several veins in the Bay State Shaft area, and the Mexican Hat vein. The workings that expose most of these veins are inaccessible. Thus, most descriptive data that follows is taken from earlier publications.

The veins range from fine stringers to 2.5 m in width and follow steeply dipping fractures that strike N35°E to N75°E (Sorenson, 1927). The veins are only present in carbonate rocks, and may terminate abruptly against the schist (Raymond, 1874). Although the veins are, in part, fracture fillings, some carbonate wall rock has been replaced along preferred beds and cross-fractures resulting in a tabular vein with highly irregular margins (Sorenson, 1927).

The major hypogene ore minerals of the veins are arsenopyrite, galena, sphalerite, pyrrhotite, and pyrite. Tetrahedrite occurs as fine beads in galena (Sorenson, 1927), as does chalcopyrite in sphalerite. Quartz and calcite comprise the gangue minerals. A variety of minerals which result from the oxidation of the sulfide have been identified by Shannon (1926). Much metal that was produced during the nineteenth century came from the zone of oxidation (Bell, 1907a).

Copper-Bearing Tactites

Several small workings and prospects which expose chalcopyrite-bearing tactites are located in small pendants and country rocks adjacent to the contact of the granodiorite and the leucocratic granite. Copper prospects of this group include the Cockscomb Ridge workings, 6819 prospect, Swayze Gulch Tunnel, Section 22 Tunnel, and the Iron Mine pit (Figure 14). Surface exposures in all of these prospects, except the one in the Section 22 Tunnel, are highly oxidized. The tactite is strongly fractured and crumbly at the surface, and fresh tactite specimens were difficult to obtain. Fractures and exposed surfaces are coated with a dark brown oxide. Azurite or malachite may be common in many fractures. The tactite typically does not form outcrops and has been exposed only by digging. The chalcopyrite-bearing rocks in and adjacent to the Section 22 Tunnel are only slightly oxidized, and are not strongly fractured. However, the rocks at this location are different from the other copper-bearing tactites.

These tactites occur as small replacement bodies in marble, diopside granofels, or diopside grossularite country rocks adjacent to granodiorite, as pendants in the leucogranite. Because the copper-bearing tactites are poorly-exposed, their shape, structure, and relations to host rock have not been determined.

The mineralogy of these tactites is variable, but includes essential andraditic garnet, clinopyroxene, quartz, calcite, chalcopyrite and pyrrhotite. Greenish to yellow garnet is typically medium-grained, and may constitute up to 50 percent of the rock. Some coarse, discrete grains of red garnet may be present locally.

The clinopyroxene is medium green, and may have a composition intermediate between hedenbergite and diopside. It forms aggregates of medium- to fine-grained subhedral prisms, or may locally be granoblastic. Quartz and calcite occur interstitial to garnet and clinopyroxene and locally replace the calcsilicate minerals. Chlorite and epidote with calcite comprise fine-grained alteration products of garnet and clinopyroxene. Locally, pyrrhotite or pyrite may accompany this alteration. Chalcopyrite and pyrrhotite may occur as coarse replacements of the calcsilicate minerals, as fine-disseminated grains, or as thin coatings on fractures. Where the sulfides replace garnet they may replace only certain growth zones. Rocks containing chalcopyrite near the Section 22 Tunnel are strongly banded and composed of calcite, grossular garnet, diopside, and tremolite. The banding probably reflects the replacement of selected beds by garnet, diopside or tremolite. Chalcopyrite is the only sulfide mineral present and occurs as irregular, coarse to medium elongate grains which are parallel to the banding.

Other Prospects

Three prospect areas which have not yet been described are the sphalerite-bearing tactites of the Boulder and Summit workings and the oxidized vein material in the Section 21 Trench.

The workings on the summit ridge of South Mountain and near the head of Boulder Creek expose strongly oxidized and fractured hornfels and tactite. These rocks form pendants in the quartz monzodiorite and a partial screen between the quartz monzodiorite and the leucocratic granite. The attitude of bedding in these inclusions is consistent with that in nearby country rocks. The hornfels is a very fine-grained rock, composed of bands of clinopyroxene alternating with bands of quartz and calcite. The tactite is generally medium-grained and composed of radial growths of clinopyroxene. Dark red garnet locally occurs as coarse granular masses. Sulfides were not observed except in the dump at the Boulder Tunnel. Pyrrhotite and traces of chalcopyrite occur in clinopyroxene tactite. Sphalerite, and minor galena were observed in tactite which has been strongly altered to calcite, quartz, and yellow clay.

The Section 21 Trench exposes strongly oxidized, clay-rich material in a vein that crosscuts foliation in altered schist. The maximum width of the vein is 0.3 m. Oxidized and altered biotite schist flanks the vein for approximately 3 m. This occurrence is significant as it is the only vein in schist and the only strongly altered biotite schist that was observed.

Unmineralized Diopside-Garnet Tactite

Several occurrences of unmineralized tactite composed of diopside and garnet are scattered throughout the study area. Most are located where marble beds are in contact with granodiorite, but there is a minor bed of garnet-diopside tactite in marble at the surface (Sorenson, 1927), and at the Laxey Tunnel level near the Texas zone. This tactite forms low, slightly oxidized outcrops. It is composed of coarse-grained subhedral garnet and medium-grained, granoblastic diopside. In general, diopside appears to have replaced the garnet. Pockets and veins of coarsely crystalline calcite and epidote occur in the tactite at several localities. The diopside-garnet tactite has been crosscut and replaced by the hedenbergite and copper-bearing tactites.

Wollastonite Tactite

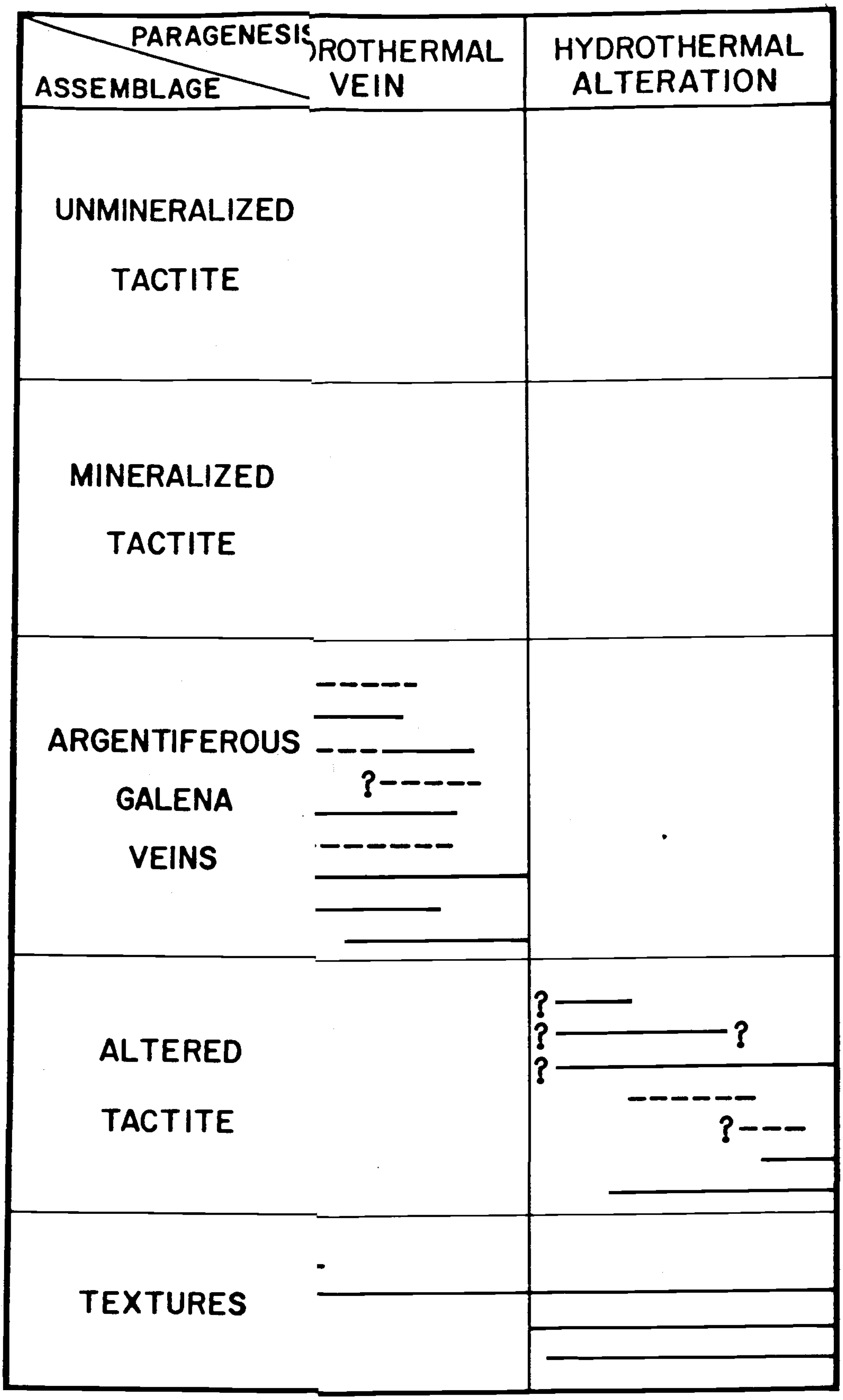
Small outcrops of wollastonite tactite were identified in the central part of the study area. In many locations, the coarse-grained wollastonite is accompanied by acicular growths of tremolite and actinolite. Many wollastonite tactites form envelopes where bull quartz veins cross marble beds. A small pod of wollastonite tactite was found on the surface above the entrance of the Laxey Tunnel. At this location it has been replaced by hedenbergite tactite. The significance of wollastonite to the genesis of tactite mineralization in the South Mountain area has not been determined.

Paragenesis of Mineralized Tactite

The paragenetic sequence of the hedenbergite tactite is understood better than that of the other tactites because of more complete exposure in the accessible mine workings. The zinc-rich polymetallic sulfide mineralization in this tactite has more potential for future expoitation than the other types of mineralization in the area. Knowledge of the paragenesis may aid in locating more mineralization.

The paragenesis of the hedenbergite tactite shown in Table 6 may be separated into four major stages, as follows: (1) a prograde tactite stage, in which initial replacement of the marble by anhydrous calcsilicate minerals occurred; (2) a sulfide replacement stage; (3) a sulfide vein stage characterized by crystallization of sulfide and gangue minerals in open fissures in marble and tactite; and (4) a

TABLE 6: MINERAL PARAG



tactite alteration stage which accompanied faulting and the intrusion of porphyritic and aphanitic dikes. A fifth stage of vug filling has been identified, and is shown in Table 6, but the timing of this event relative to the two sulfide stages is unknown.

Hedenbergite was the first mineral of the mineralized tactite to replace marble, and in some areas, it comprises a monomineralic rock. Hedenbergite also replaces minor pods of earlier-formed wollastonite and diopside-garnet tactite. Textures suggest that individual clinopyroxene blades grew progressively outward into the marble. Andraditic garnet replaces hedenbergite, but may have been accompanied by continued crystallization of hedenbergite. Garnet may have formed from hedenbergite by an increase in sulfur fugacity by the reaction:

$$6\ CaFeSi_2O_6 + S_2 \rightleftarrows 2\ FeS + 6\ SiO_2 + 2Ca_3Fe_2Si_3O_{12}$$

While garnet and pyrrhotite were in equilibrium with hedenbergite, this reaction would have served as a buffer of sulfur fugacity (Burton, 1978).

During the sulfide replacement stage, garnet no longer continued to form from the reaction of sulfur with hedenbergite. Instead, an iron- and manganese-rich montmorillinite with minor actinolite and epidote were the alteration products of clinopyroxene. All three major sulfide minerals appear to have grown simultaneously. The deposition of galena probably occurred late in this stage.

Ilvaite, quartz, and calcite replace the original calcsilicate minerals and fill pore spaces in the tactite. Minor amounts of pyrrhotite are associated with the ilvaite, quartz and calcite. The reaction:

$$4\ CaFeSi_2O_6 + Ca_3Fe_2(SiO_4)_3 + H_2O + 3\ CO_3 \rightleftharpoons 2\ CaFe_2Fe(SiO_4)_2 \cdot OH$$

$$+ 5\ CaCo_3 + 7SiO_2$$

shows that the breakdown of hedenbergite and garnet could have been in response to an increase of the partial pressure of carbon dioxide. The relationship of this stage to the sulfide replacement or the sulfide vein stage has not been determined.

Argentiferous galena veins are more widespread than the hedenbergite tactite. They crosscut marble and tactite. The veins partially formed by fissure filling and replacement along the sides of filled fractures.

Alteration of tactite along dikes and faults probably occurred subsequent to the two stages of mineralization, but no direct evidence has been observed.

Geochemistry

Emission spectrographic analyses, which have been used in this study, provide rapid, inexpensive, qualitative data on the concentration of several elements. Because the analyses do not provide precise determinations, only qualitative treatment of the data has been undertaken. Atomic absorption and assay analyses of selected elements and samples are used as a check of the emission spectrographic analyses. Results of all analyses are listed in Tables 7 and 8.

The hedenbergite tactite is significantly enriched in manganese relative to marbles and other types of tactite. It also has significantly higher concentrations of iron, copper, lead, zinc, and silver than any of the marbles which were sampled. Silica values in tactite

TABLE 7: GEOCHEMICAL ANALYSES OF HEDENBERGITE TACTITE

Constituent	Concentration in sample (Oxides in weight percent, metals in ppm)								
	169a	169b	171a	173a	182a	188a	188b	191a	191b
SiO_2	53.	-	53.	64.	64.	64.	-	11.	-
Al_2O_3	2.	-	2.	2.	6.	2.	-	2.	-
FeO	19.	-	26.	19.	19.	9.	-	26.	-
MnO	0.6	2.06	0.6	0.6	0.6	0.6	2.84	0.05	0.10
MgO	0.5	-	1.2	1.2	1.2	1.2	-	0.3	-
CaO	21.	-	14.	21.	21.	14.	-	0.4	-
Na_2O	ND	-	ND	0.7	ND	0.4	-	ND	-
K_2O	ND	-	ND	ND	ND	ND	-	ND	-
P_2O_5	0.2	-	ND	0.2	ND	0.2	-	0.2	-
Total	96.1	-	96.8	108.7	111.8	91.4	-	40.0	-
Cu	15,000	-	5,000	70	300	50	-	10,000	-
Pb	500	520	300	200	700	50	60	700	1,800
Zn	10,000	28,400	10,000	1,000	2,000	500	340	10,000	127,400
Ag	150	156	200	ND	70	ND	4.0	200	1,069
Au	ND	-	ND	ND	ND	ND	-	ND	-

169 - Mineralized hedenbergite tactite; 6.1 m chip sample from DMEA-3 zone, Laxey Tunnel

171 - Mineralized hedenbergite tactite; 4.6 m chip sample from 111 zone, Laxey Tunnel

173 - Unmineralized hedenbergite tactite; 9.2 m chip sample from 113 zone, Laxey Tunnel

182 - Unmineralized hedenbergite tactite; 7.6 m chip sample from 111 zone, Sonneman Tunnel

188 - Altered hedenbergite tactite, 10.7 m chip sample from unnamed zone northwest of 113 zone, Sonneman Tunnel

191 - Massive replacement sulfides in tactite, grab sample from Texas zone, Laxey Tunnel

Source of data: samples with postscript "a" are emission spectrographic analyses from Specomp Labs, samples with postscrip "b" were provided by John King of Anaconda Copper Co.

ND means not detected

TABLE 8: GEOCHEMICAL ANALYSES OF TACTITES AND MARBLES

Constituent	Concentration in sample (Oxides in weight percent, metals in ppm)								
	205a	224a	228a	228b	230a	230b	184a	194a	231a
SiO_2	64.	53.	53.	-	53.	-	32.	43.	54.
Al_2O_3	2.	13.	13.	-	9.	--	0.9	2.	4.
FeO	6.	19.	13.	-	9.	--	0.6	0.6	1.3
MnO	0.3	0.3	0.4	0.53	0.3	0.36	0.09	0.09	0.09
MgO	17.	1.7	1.2	-	3.3	-	1.7	3.3	1.7
CaO	28.	21.	28.	-	28.	-	28.	28.	28.
Na_2O	0.7	1.4	0.7	-	0.9	-	0.3	0.4	0.7
K_2O	0.6	0.6	0.6	-	0.6	-	0.6	0.6	0.6
P_2O_5	0.2	ND	ND	-	0.2	-	ND	ND	ND
Total	118.8	111.0	110.9	-	105.3	-	64.2	77.4	90.4
Cu	70.	15.	30.	-	10,000	-	15.	7.	15.
Pb	150.	10.	10.	40.	30.	40.	30.	10.	30.
Zn	2000.	500.	ND	120	300.	280.	ND	ND	ND
Ag	10.	ND	0.5	4.0	70	39.8	1.0	ND	ND
Au	ND	ND	ND	-	15	-	ND	ND	ND.

205 - Wollastonite tactite; 1.8 m chip sample from outcrop 150 m south of Laxey tunnel portal.

224 - Diopside - grossularite tactite; 3.1 m chip sample from outcrop 30 m north of lower quarry.

228 - Diopside - grossularite tactite; 6.1 m chip sample from outcrop 50 m south of 6819 prospect.

230 - Andradite diopside tactite with chalcopyrite; grab sample from 6819 prospect.

184 - White Laxey marble; 10.8 m chip sample from 113 crosscut, Sonneman Tunnel.

190 - Siliceous Laxey marble, 15.3 m chip sample from outcrop 300 m south of lower quarry.

231 - Siliceous marble; 4.6 m chip sample from outcrop 400 m southwest of Swayze Gulch Tunnel.

Source of data: Samples with postsript "a" are emission spectrographic analyses from Specomp Labs, samples with postscript "b" were provided by John King of Anaconda Copper Co.

ND means not detected

are also higher than in marble, but this difference may be less significant when the analytical error of the analyses is considered. The decrease in weight percent of calcium in marble to that in hedenbergite is notable. However, if the change in density during the formation of tactite is considered, the loss of calcium may be negligible. Rigorous calculations of the exchange of elements during tactite formation, such as those of Lindgren (1927), are not feasible because of the imprecise geochemical data and because no important data such as the carbon dioxide content or specific gravity values were obtained for this study. However, approximate calculations, using assumed specific gravities for tactite and marble, were performed on manganese, iron and calcium. These calculations verify the qualitative observations that have been listed above.

Structural Control

Mineralized tactite pipes exploited at the South Mountain Mine have roughly consistent plunges of 40° to the west. The intersection of argentiferous galena veins and bedding planes in the marble also have a west plunge of roughly 40°. The plunge of axes of open folds which are of probably Eocene age is similar to that of the mineralized pipes. It may be a fortuitous coincidence that open folds and both types of mineralization have similar orientations. However, it is very possible that localization of the metal deposits could have been controlled by structures associated with Eocene folding. The significant mineral deposits may either be in the axes of minor anticlines or may be controlled by radial joints related to the Eocene folding. The second possibility is favored in this study. Meinhert, and others

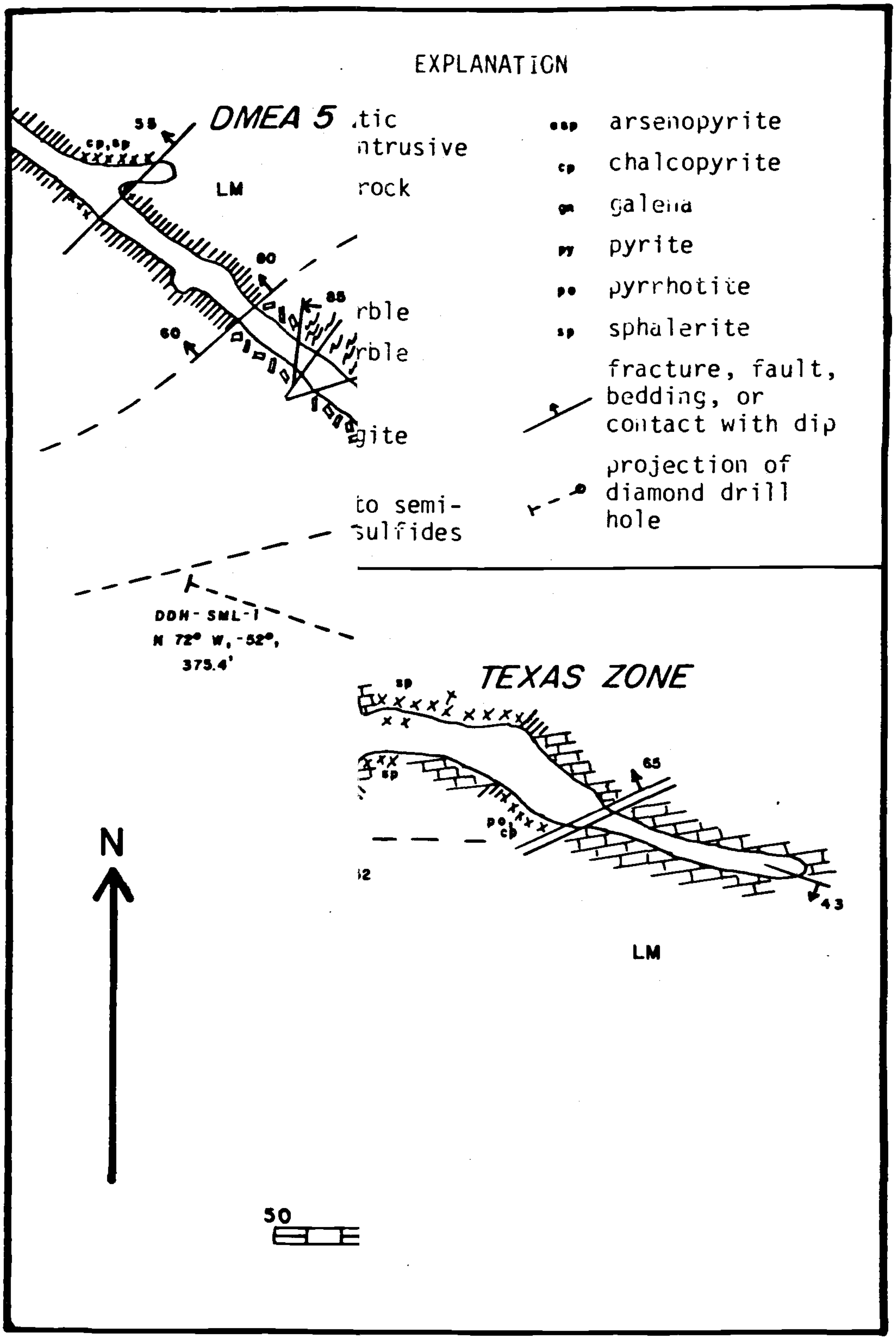
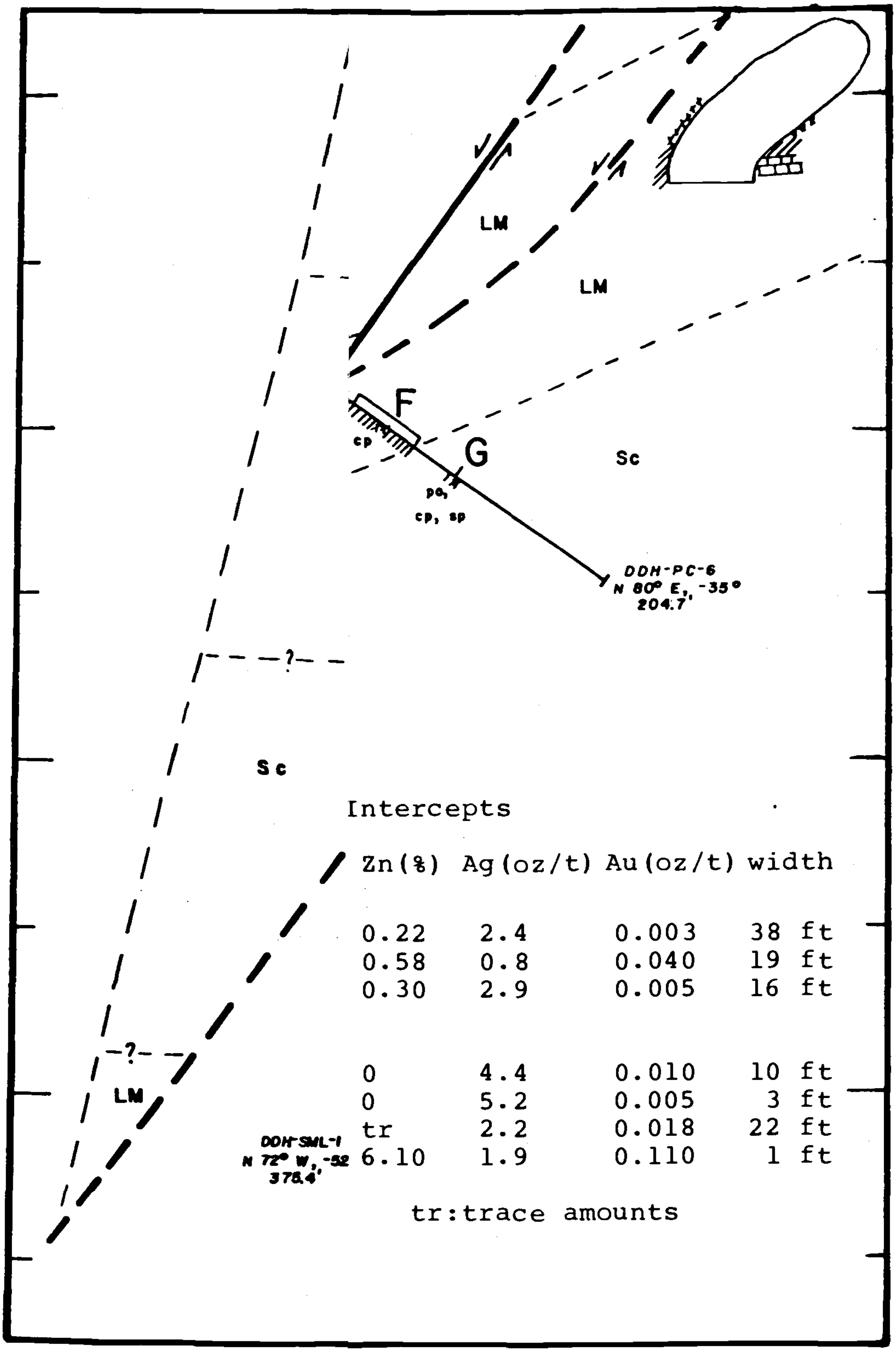


Figure 17: Geologic map (



Intercepts

Zn(%)	Ag(oz/t)	Au(oz/t)	width
0.22	2.4	0.003	38 ft
0.58	0.8	0.040	19 ft
0.30	2.9	0.005	16 ft
0	4.4	0.010	10 ft
0	5.2	0.005	3 ft
tr	2.2	0.018	22 ft
6.10	1.9	0.110	1 ft

tr:trace amounts

Figure 18: Geologic cr
the Laxey T
in Figure 1

(1981), have found that zinc-rich tactites are commonly localized along faults, fractures or other structural pathways which allow metasomatic fluids access to the carbonate host. The vein mineralization, such as that in the Bay State and Golconda workings, are definitely localized along fractures, most of which strike northeast and dip steeply to the north (Sorenson, 1927). This vein attitude is similar to the expected attitude of radial joints on the southern limb of a west-plunging fold. It is also highly probable that the fractures which localized the vein mineralization were the major fractures which which allowed metasomatic fluids access to the part of the Laxey Marble which is host to tactite mineralization.

Several normal and reverse faults with north to northeast strikes and west to northwest dips crosscut and displace the Laxey Marble and intrusive dikes (Plate 2). At least in the Texas zone, mineralization is also offset by these faults (Figures 17 and 18). The post-ore faulting has complicated the prediction of drill targets in the Texas zone. Neither diamond drill hold DDH-PL-6 nor DDH-SML-1 intersected mineralization with ore grade or width similar to that of the Texas zone. The displacement of mineralization by the normal faults had not been considered before either of the holes were drilled. The mineralization has probably been displaced down and to the southwest on the hanging-wall side of the fault.

Generalized Model of Tactite Mineralization

Meinhert, and others (1981), have summarized the characteristics of several occurrences of tactites in western North America. Characteristics of zinc-rich tactites are: (1) small size, less than five million tons, and elongate shape parallel to structural pathways in the host rock; (2) iron- or manganese-rich pyroxene (Figure 16) is the dominant calcsilicate mineral with a lesser amount of andraditic garnet; (3) sphalerite is the dominant sulfide mineral, but may be accompanied by pyrrhotite, chalcopyrite, pyrite, and galena; (4) minor amounts of retrograde alteration which mostly consists of actinolite, ilvaite, and chlorite; (5) very small metamorphic aureoles, no mineralogic zoning such as in tungsten or copper skarns is evident; and (6) distally located from intrusive source rocks along faults, lithologic contacts or dike contacts.

Titley (1961) has pointed out that iron sulfides may not be abundant in zinc-rich tactites, and magnetite is common (Meinhert, and others, 1981). The tactite described in this study contains only minor amounts of magnetite whereas pyrrhotite is fairly abundant. This may suggest that the tactites near South Mountain formed at lower oxygen fugacities than most zinc-rich tactites.

It can be shown from thermodynamic relations presented by Burt (1972) that the reaction:

$$6\ CaFeSi_2O_6 + S_2 \rightleftharpoons 2FeS + 6\ SiO_2 + 2\ Ca_3Fe_2Si_3O_{12}$$

is replaced by the reaction:

$$3\ CaFeSi_2O_6 + S_2 \rightleftharpoons 1\ FeS_2 + Ca_3Fe_2Si_3O_{12}$$

at temperatures below approximately 400°C. The lack of pyrite and the relative abundance of pyrrhotite replacing hedenbergite during the sulfide replacement stage suggests that temperatures exceeded 400°C until at least the sulfide vein stage. This conclusion is consistent with temperatures of tactite formation in general that have been suggested by Rose and Burt (1979).

CONCLUSIONS

Metasedimentary rocks of possible early Paleozoic age near South Mountain were strongly deformed and regionally metamorphosed to the staurolite zone during late Cretaceous emplacement of the Idaho batholith. A subsequent deformation folded the metamorphic sequence into a broad, west-plunging antiform. Cleavage crenulations and small-scale folds which refold isoclinal folds of the earlier deformation are associated with the large antiform. This folding may represent doming over a granodiorite pluton. At least one period of post-kinematic thermal metamorphism recrystallized the metamorphic rocks and nearly destroyed the porphyblastic minerals of regional metamorphism. A variety of tactites, including ones containing mineralization were produced during thermal metamorphism.

Plutonic rocks ranging in composition from hornblendite to leucocratic granite comprise five major plutonic map units. They range in age from Cretaceous to Eocene. The oldest pluton was emplaced at a depth transitional between the mesozone and catazone whereas the youngest pluton was emplaced in the epizone. Significant amounts of intrusive breccias are associated with the epizonal pluton. Three types of dike rocks mapped in this study may range in age from Eocene to Miocene. Cretaceous quartz diorite sills may be satellites of the Idaho batholith which is concealed east of South Mountain.

Minor Eocene rhyolitic lithic tuffs near South Mountain may have been locally derived. They probably are an erosional remnant of part of a volcanic field that covered most of Idaho during the Eocene (Armstrong, 1975).

Miocene basalt and felsic tuffs that overlie basement rocks near South Mountain are the oldest of voluminous Miocene and Pliocene volcanic rocks in the Owyhee Mountains. These rocks were erupted during the onset of Neogene rifting in the Snake River Plain. Many Tertiary structures, including faults, joints, and the relative uplift of basement rocks in the Owyhee Mountains may also be associated with the Neogene tectonic regime of the Snake River Plain.

Several types of tactite were identified in the pre-Tertiary marble host rocks in the study area. Andradite-diopside tactites, which contain chalcopyrite, sphalerite-bearing grossular clinopyroxene tactites and diopside-grossularite tactites are located at the contact of carbonate rocks with granodiorite, leucogranite, and quartz monzodiorite. In the central part of the study area, minor amounts of wollastonite tactite and diopside-grossularite tactite occur in carbonate rocks away from exposed granite contacts.

Economic concentrations of sphalerite, chalcopyrite, and galena are present in irregular shaped replacement pipes of hedenbergite tactite. The location of these pipes is probably controlled by fractures which have a similar attitude to argentiferous galena veins and the expected attitude of radial fractures of open folds in the metamorphic rocks. The hedenbergite tactite pipes have a consistent west plunge of 40°.

Minerals in the hedenbergite tactite are grouped into four mineral assemblages which are unmineralized tactite, mineralized tactite, argentiferous galena veins, and altered tactite. Neither regular distribution nor zoning were observed, except that argentiferous galena veins are more widespread than tactite and may occur in marble host rock. Hedenbergite and andraditic garnet, the prograde tactite minerals, were replaced by pyrrhotite, sphalerite, chalcopyrite, and galena. These replacement sulfides have been the source for most of the metal production. Temperatures during prograde tactite formation and sulfide replacement were probably in excess of 400°C. The hedenbergite tactite near South Mountain was formed in less oxidizing conditions than most zinc-rich tactites. Argentiferous galena veins fill fissures that strike northeast and have steep dips in tactite and marble host rocks. Minor alteration of tactite is associated with post-ore dike emplacement and faulting.

The hedenbergite tactites formed along structural pathways at locations distal from an igneous source of metasomatic fluids. The source of these fluids has not been identified.

Significant mineral resources in tactite may remain near South Mountain. Exploration targets include the down-plunge extensions of ore bodies which have already been exploited in the Laxey and Sonneman Tunnels. It is also possible that zinc-rich tactites may occur at depth down-dip from argentiferous galena veins such as those exposed in the Golconda, Queen of the Mountains, Bay State, and Mexican Hat Workings. A thorough detailed geologic mapping program should be completed before these targets are tested by drilling. This program would define the location, attitude and relative movement of Tertiary post-ore faults.

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