AN ABSTRACT OF THE THESIS OF

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Title: GEOLOGY, MINERAL DEPOSITS, AND ALTERATION OF PARTS OF THE CUDDY MOUNTAIN DISTRICT, WESTERN IDAHO

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The area of study is located on the northern part of Cuddy Mountain in the Hornet and Copperfield quadrangles, Washington County, in western Idaho. Bedrock consists of a eugeosynclinal assemblage of northeast trending Triassic-Jurassic sedimentary and volcanic rocks that was intruded by a Jurassic plutonic complex and both of which were covered by plateau basalt flows in late Tertiary time. Basement rocks have been partly exhumed by post-Miocene uplift and subsequent glacial and stream erosion.

The oldest rocks in the area mapped are the Seven Devils Volcanics of Late Triassic age. This unit is a complex sequence of volcanic and volcaniclastic rocks with a minimum thickness of 3000 feet. It is overlain by the red conglomerate (about 300 feet thick) which is in turn overlain by the Lucile Series that consists of a sequence of

slates, phyllites, conglomerates, sandstones, and limestones at least 3000 feet in thickness. The units overlying the Seven Devils Volcanics are of Early Jurassic age. Angular unconformities separate the major stratigraphic units from each other. These, and the lithologies of the rocks attest to the mobile tectonic history of this geosynclinal terrain.

After deposition of the Lucile Series, the country rocks were intruded by a plutonic complex consisting of gabbro, quartz diorite, and porphyritic granodiorite in order of emplacement. Contact metasomatism of gabbro by quartz diorite and granodiorite produced a quartz-rich hybrid phase of the gabbro. The distribution of hybrid gabbro relative to other plutonic rocks, and the gently plunging lineations of the gabbro suggest that the members of this complex were intruded as gently dipping, sheet-like bodies. Geologic, chemical, and mineralogical data indicate that the three major plutonic rock types differentiated from a single basaltic parent magma of high-alumina affinities. Such magmas, with differentiation following the calc-alkaline trend, are characteristic of orogenic belts.

Although sedimentary rocks intruded by the complex are as young as Early Jurassic on the basis of paleontological evidence, K-Ar radiometric age determinations for the principal phases of the complex range from 180 to 216 m.y. and thus suggest an older age. This apparent conflict is resolved by moving the Triassic-Jurassic boundary back to a minimum of 210 m.y.

Hydrothermal alteration and mineralization are generally structurally controlled. They appear to be genetically related to the porphyritic granodiorite. Sulfur isotope data indicate that sulfide and sulfate minerals at Cuddy Mountain and nearby areas are of magmatic hydrothermal origin. The three most important types of deposits are (1) copper-molybdenum disseminations in the plutonic rocks, (2) contact metasomatic copper mineralization in calcareous sediments, and (3) fault controlled lead-zinc-silver metallization in the country rocks.

The high grade copper-molybdenum mineralization at the IXL mine is located in a fault breccia. A late-stage change in oxygen fugacity is suggested to explain the mineral assemblage molybdenite-chalcopyrite-pyrite-magnetite-hematite. The alteration assemblage quartz-sericite-kaolinite-chlorite is typical of Cuddy Mountain alteration.

The Kismet mine is located in a tourmaline granite breccia pipe. Intense potassic alteration resulted in complete replacement of plagioclase feldspar by orthoclase. This alteration type changes abruptly to a sericitic type immediately outside the pipe. The zoning is believed to be caused by a lower temperature and $K^+/H^+$ ratios away from the pipe.

The country and plutonic rocks were regionally metamorphosed during Middle to Late Jurassic time. The Mesozoic rocks are unconformably overlain by late Tertiary Columbia River Basalt flows of which a part may have been derived locally from plugs.

# Geology, Mineral Deposits, and Alteration of Parts of the Cuddy Mountain District, Western Idaho

by

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# GEOLOGY, MINERAL DEPOSITS, AND ALTERATION OF PARTS OF THE CUDDY MOUNTAIN DISTRICT, WESTERN IDAHO

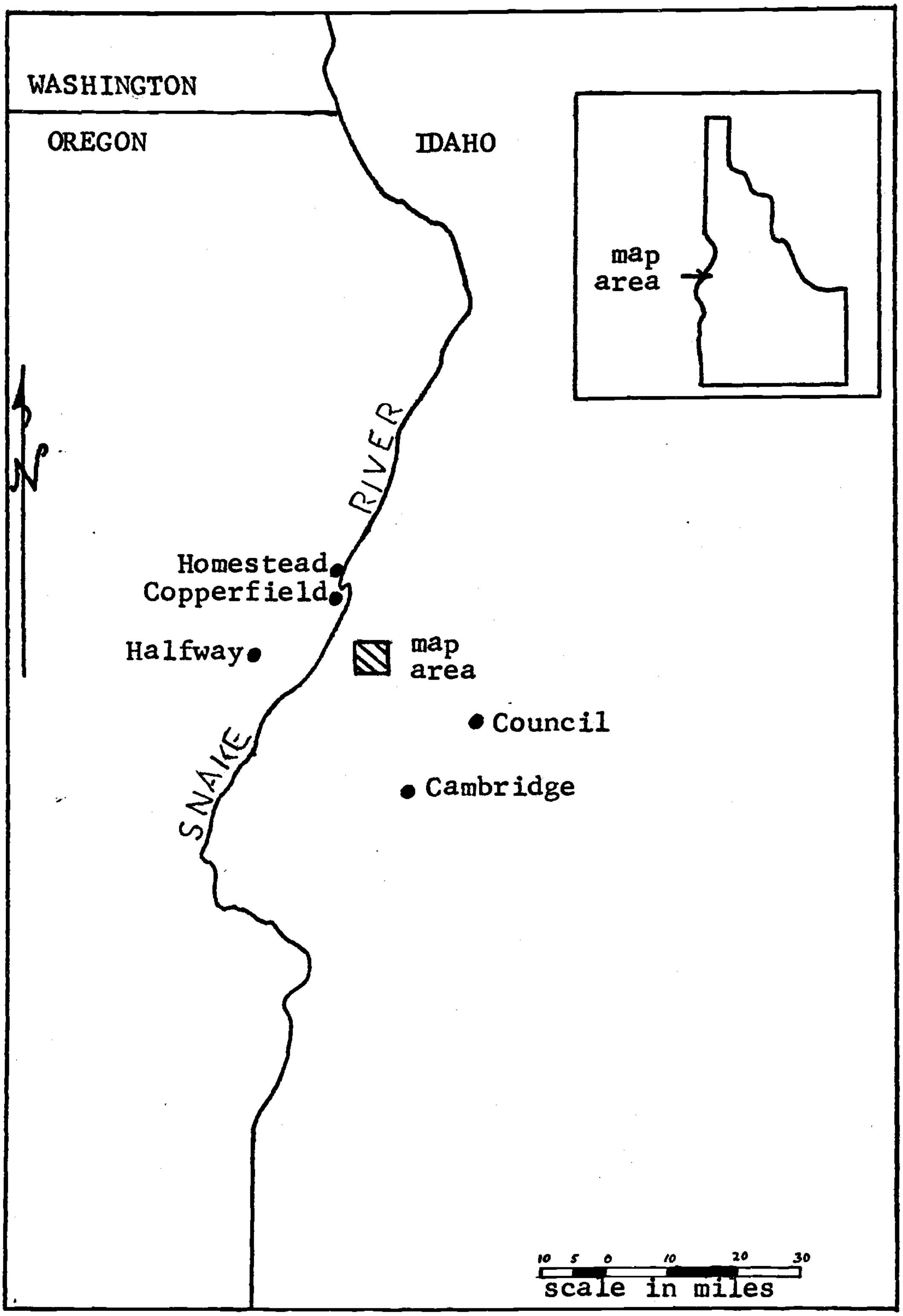
## INTRODUCTION

### Location and Accessibility

This thesis area is on the northern border of Washington County about 15 miles northwest of Council, Idaho (Figure 1). It lies mainly on the northeast flank of Cuddy Mountain but extends a few thousand feet west of the top of the crest. The area includes 25 square miles of T. 17 N., R. 3 W. and T. 17 N., R. 4 W. Its western edge is about seven miles east of the Snake River.

The area can be reached by automobile only from the east. Fifteen miles west of Council on the Cuprum Road a United States Forest Service road branches off to the west at the Hornet Creek Guard Station. This road proceeds up Hornet Creek, through the center of the area, and on to the top of Cuddy Mountain. There it branches, one road proceeding north, the other south along the western border of the map area. About three miles west of the guard station on the Hornet Creek Road, a secondary road branches off to the southwest. It provides access to much of the southern part of the map area. A short offshoot from this road leads to the Kismet Mine on the eastern border of the study area.

Figure 1. Index map of thesis area.



## Previous Work

In his paper "The Gold Belt of the Blue Mountains of Oregon," Lindgren (1901) made several references to the geology of the Cuddy Mountain area and included part of it on his general geologic map. Livingston (1920, 1923, 1932) described the mineral deposits, general geology, and thrust faulting in the Cuddy Mountain area. More recently, Cook (1954) published a report on the mining geology of the Seven Devils region which lies about 20 miles north of Cuddy Mountain. He included several mines of the Cuddy Mountain district in his property descriptions. The most recent work done in the area was by D. A. Wracher (Master's thesis, 1969), R. E. Fankhauser (Master's thesis, 1969), and M. Slater (Master's thesis, 1969). Wracher mapped an area a few miles northeast of Cuddy Mountain in the vicinity of Peck Mountain, Fankhauser mapped the southwest flank and Slater mapped the northwest flank of Cuddy Mountain. J. R. King is presently preparing a Master's thesis that describes the geology of the southeast flank of the mountain. Dr. Cyrus W. Field has spent parts of several field seasons mapping and collecting samples in the Mineral and Cuddy Mountain districts.

## Topography

The map area has about 2400 feet of relief. The maximum altitude is 7737 feet on top of Cuddy Mountain, and the minimum is about 5300 feet in Hornet Creek at the eastern border of the area. The top of Cuddy Mountain is almost 6000 feet above the Snake River, seven miles to the west.

A steep, north-trending scarp forms the western flank of Cuddy Mountain. The eastern flank is somewhat gentler in slope. Hornet Reservoir occupies a large cirque in the west-central part of the area. The valley of Hornet Creek is somewhat U-shaped. In general the topography is youthful. Most other valleys are steep-sided and V-shaped. The ridge tops are generally broad and often gently sloping. Drainage is poor and marshy areas are common.

Most of the ridges are underlain by intrusive igneous rocks, but some are capped by gently dipping layers of Columbia River Basalt.

## Climate and Vegetation

A United States Weather Bureau station is located at Council, 15 miles east of the thesis area. Although the altitude at Council is 3000 feet, appreciably less than that of Cuddy Mountain, the weather data from this station are the best available. Cuddy Mountain would have somewhat lower temperatures and higher precipitation than Council. July and August are the warmest months with temperatures above 100°F. quite common. Temperatures around -10°F. have been recorded in December and January. Precipitation averages about 27 inches annually. The maximum falls in January (about 5 inches), and the minimum in July (.37 inches). Much of the moisture on Cuddy Mountain falls as snow.

Slopes at lower altitudes in the thesis area are commonly heavily timbered. Englemann spruce, White and Douglas fir, and Ponderosa pine are common. At higher altitudes (about 6000 feet), Alpine fir is the dominant type. The top of Cuddy Mountain (above 7000 feet) is largely barren of timber, and broad, grassy meadows are widespread. Sagebrush flats are also common, especially on Columbia River Basalt.

## Purpose and Methods of the Research

The primary purpose of the study was to determine the types and distribution of mineralization and alteration and their relationships to plutonic intrusions in the area. Several methods were utilized in accomplishing these goals, one of which was the construction of a geologic map at a scale of 1:24,000. Host rocks, country rocks, and later products of alteration and mineralization were studied through the use of petrographic, polished section, X-ray diffraction, chemical, trace element, stable isotope, and radiogenic isotope age dating techniques. These studies have materially enhanced present knowledge concerning the (1) geologic and absolute ages of country rock, plutonic complex, and associated mineral deposits; (2) chemical and physical conditions that prevailed during emplacement and crystallization of the plutonic complex; (3) types of mineral deposits and associated alteration; (4) number of episodes of mineralization; (5) source of mineralizing fluids and their relationship to intrusive igneous activity; and (6) relationship of mineralization to structure.

A more detailed analysis of mineralization and alteration was achieved by selective investigation of several important prospects in the district.

## REGIONAL SETTING

The Cuddy Mountains are within the Columbia Arc of the Nevadian orogenic belt as defined by Taubeneck (1966) and the Columbia Plateau province described by Hamilton (1962).

Nearby plutons include the Idaho batholith 20 miles to the east, the Wallowa batholith 50 miles to the northwest, and intrusions of the Seven Devils Mountains 30 miles to the northeast.

Tectonic uplift and subsequent erosion of Tertiary volcanic rocks have exposed Triassic to Jurassic sedimentary, volcanic, and plutonic rocks. Gilluly (1965), Hamilton (1963), and other workers suggest that a eugeosyncline was present in western Idaho and eastern Oregon during much of the Mesozoic Period. The lithologies and thicknesses of the volcanic and sedimentary rocks at Cuddy Mountain are indicative of such an environment of deposition. The plutonic complex, which intrudes this eugeosynclinal assemblage, pre-dates Middle to Late Jurassic regional metamorphism. It is probably related to the Canyon Mountain Magma Series proposed by Thayer and Brown (1964) and to the "plutons of the mafic suite" described by White (1968) in the Seven Devils Mountains. Intrusions of similar age are present in the Klamath Mountains of southwestern Oregon and northwestern California, Sierra Nevada batholith of eastern California, northern Cascade Mountains of northwestern Washington, Coast Range of western British Columbia, and southeast Alaska.

The basement rocks of eastern Oregon and western Idaho were covered by flows of Columbia River Basalt during middle Miocene to early Pliocene time. They are now exposed as inliers in numerous small areas as a consequence of Quaternary erosion.

# ROCK UNITS

## Introduction

The country rocks of the thesis area consist of a thick sequence of Triassic-Jurassic metavolcanic and metasedimentary rocks that strike northeasterly and dip steeply (50° to 80°) to the west. They have been intruded by a plutonic complex that consists predominately of gabbroic, dioritic, and granodioritic phases. These older rocks are overlain by gently dipping (10° to 20°) flows of Miocene to Early Pliocene Columbia River Basalt.

## Seven Devils Volcanics

A thick sequence of interbedded metasedimentary and metavolcanic rocks constitute the oldest lithologies in the Cuddy Mountain district. On the basis of geographic location and lithologic and paleontological similarities, they are correlated with the Seven Devils Volcanics as originally defined by Lindgren (1900) and as later revised by Anderson (1930).

### Distribution and Field Description

The Seven Devils Volcanics crop out along the steep scarp on the western border of the thesis area and on the walls of Crooked

River canyon to the northwest.

The base of the Seven Devils Volcanics is not exposed in the Cuddy Mountains. The unit is unconformably overlain by red conglomerate, porphyritic rhyolite tuff, Lucile Series, and Columbia River Basalt. Both the thickness and stratigraphic sequence of component beds of the Seven Devils Volcanics are difficult to determine. Regional and contact metamorphism, truncation of beds by intrusive rocks, lack of fossils, structural deformation, absence of distinctive marker beds, and extensive cover of alluvium and Columbia River Basalt collectively make stratigraphic work difficult. Estimates of thickness range from several miles in the Riggins quadrangle to the north, according to Hamilton (1963), to more than 2000 feet at Cuddy Mountain according to Slater (1969). The latter estimate is a minimum for the thickness of this formation exposed at Cuddy Mountain.

The Seven Devils Volcanics are a complex series of interbedded metavolcanic and volcaniclastic metasediments. Reds, greens, and grays are the more common colors of fresh rocks, and many outcrops are blackened by secondary manganese oxide. The various lithologies exposed in the area are discussed as follows in their approximate order of stratigraphic succession.

## Lithology and Petrography

The oldest units in the Seven Devils Volcanics are exposed in the north-central part of the area (sec. 7 and 8). They consist of a thick sequence of medium-grained, poorly-sorted, volcaniclastic rocks. Much of the bedding has been obscurred by recrystallization and dislocation associated with regional and contact metamorphism.

Quartz is the most abundant mineral, and much of it is secondary. Grains of plagioclase feldspar have been partially to completely albitized. Other common minerals are epidote, chlorite, calcite, sericite, clay, biotite, and finely disseminated pyrite.

Overlying this unit is a series of conglomerate beds that range from 10 to 50 feet in thickness. They are interbedded with thin beds of silicified limestone, shale, and sandstone. The conglomerates are dark gray-green in color and have been highly silicified. Clasts range up to a foot in diameter. Nearly all have been derived from volcanic sources although clasts of sedimentary rock are also present.

An andesite flow or series of flows about 300 feet thick is poorly exposed near the head of Crooked River valley (SE1/4, sec. 7). The andesites are dense, dark gray, silicified, and contain abundant disseminated pyrite.

Overlying the andesite is dark gray to gray-green hornfels that crops out at the head of No Business Canyon near the southwest boundary (S1/2, sec. 24) of the area. Outcrops are massive in appearance. Several thin conglomeratic layers serve to delineate the otherwise obscure bedding of this unit. The hornfels is divided into two parts by a yellowish-gray (5Y 7/2) cherty unit about 300 feet thick. The combined thickness of the hornfels is estimated to be at least 300 to 400 feet, although its base is covered by Columbia River Basalt.

The mineralogy and texture of this unit has been modified by contact metamorphism that took place during emplacement of the nearby plutonic complex. The hornfels is highly siliceous as quartz comprises over 50 percent of the rock. The quartz is fine-grained and commonly forms overgrowths. Sillimanite is present as long, fine-grained, randomly oriented needles on the quartz. Relatively large plagioclase laths are scattered throughout the finer grained quartz matrix. Phyllosilicates (sericite and clay minerals) are common alteration products of the plagioclase. Magnetite is abundant and comprises up to 20 percent of the host. Much of the magnetite is finely disseminated, although larger blebs are also common. Chlorite usually rims the larger magnetite grains and is scattered elsewhere throughout the rock. Other secondary minerals include epidote, actinolite, calcite, muscovite, magnetite, pyrite, and pyrrhotite.

The cherty unit, previously mentioned as separating the hornfels into two parts, is a monotonous sequence of thinly-bedded, dense, siliceous rock. Iron and manganese oxides coat the outcrops at many locations.

Andesite breccias ranging from less than 300 feet to nearly 1000 feet in thickness crop out along the western edge of the map area.

No bedding is visible in the breccias, and contacts with adjacent units are normally concealed and/or faulted. Fresh andesite breccia ranges from greenish-gray (5GY 8/1) to dusky red (5R 3/4) to medium dark gray (N4) in color. It weathers to a dark reddish-brown color. Iron and manganese oxides are ubiquitous.

The breccia consists of plutonic, volcanic, and sedimentary rock fragments set in a dark, fine-grained matrix composed of plagioclase laths, quartz, and muscovite. The clasts are subangular to subrounded, up to several inches in diameter, and are highly fractured. Plagioclase laths make up the bulk of the fine-grained matrix, although minor quartz is also present. Larger plagioclase laths, andalusite crystals, and a few hornblende and quartz crystals are scattered throughout the finer grained part of the matrix. Tourmaline (schlorite) is abundant in some outcrops. It occurs as sunbursts, aggregates of elongate prisms, and as fracture fillings. Other minerals include calcite replacing plagioclase feldspar, fiberous zeolites lining small cavities, and chlorite. Some of the chlorite is finely fiberous, lines cavities, and rims zeolites and calcite grains. In other samples it is flaky and appears to replace biotite or magnetite. The large plagioclase crystals are sericitized. Finely disseminated pyrite is present throughout the breccia.

## Origin and Depositional Environment

Marine fossils found in the Seven Devils Volcanics by Fankhauser (1969) and others suggest that part of it, at least, is of marine origin. The great thickness of the formation, the abundance of conglomerates and other poorly sorted sediments, and the volcanic and volcaniclastic composition of the unit indicate that it was deposited in an eugeosynclinal environment. Moreover, Hamilton (1963) has suggested that the Seven Devils Volcanics are the product of island arc volcanism.

## Age and Regional Correlation

Metavolcanic and volcaniclastic metasediments of the Seven Devils Mountains were named the "Seven Devils Series" by Lindgren in 1900. Anderson (1930 revised the name to Seven Devils Volcanics from work on a similar sequence of rocks near Orofino, Idaho. The formation is also found in the Cuprum quadrangle (Hamilton, 1963), Riggins quadrangle (Hamilton, 1963), lower Salmon River Country, and on Cuddy Mountain (Fankhauser, 1969; Wracher, 1969; Slater, 1969). Cook (1954) correlated the Seven Devils Volcanics with the Clover Creek greenstone of northeastern Oregon.

Livingston (1923) postulated that the Seven Devils Volcanics ranges from Permian to Jurassic in age. Cannon (*in* Hamilton, 1963) found many invertebrate marine fossils of Permian to Late Triassic age in the Seven Devils Volcanics of the Cuprum quadrangle. Fossils found at Cuddy Mountain were dated by Dr. David A. Bostwick as probable Late Triassic, according to Fankhauser (1969).

Fankhauser's fossil evidence and the higher percentage of sedimentary material in these units than elsewhere suggest that only the upper part of the Seven Devils Volcanics is exposed in the Cuddy Mountain area.

## Red Conglomerate

A distinctive red and green conglomerate was described by Brooks (1967) near Mineral, Idaho, and Lime, Oregon. A conglomerate of similar color, lithology, thickness, and stratigraphic position is found at Cuddy Mountain. This unit is correlated with Brooks' conglomerate on the basis of the similarities listed above.

### Distribution and Field Description

The red conglomerate crops out along the steep scarp on the western boundary of the map area and on the walls of the Crooked River canyon to the northeast. It overlies the Seven Devils Volcanics unconformably and in turn is overlain unconformably by the porphyritic rhyolite tuff. The conglomerate, underlying Seven Devils Volcanics, and overlying porphyritic rhyolite tuff, are repeated along their northeast trend by reverse faulting.

On Cuddy Mountain the conglomerate apparently ranges from 100 to 300 feet in thickness. However, the estimate is imprecise because the unit is repeated by reverse faulting. Fankhauser (1969) has estimated the thickness at more than 400 feet, and Slater (1969) has indicated that it exceeds 1000 feet on the north wall of Grade Creek canyon. Therefore, structural complexities render estimates of thickness questionable for this formation at Cuddy Mountain. Nonetheless, Brooks (1967) has estimated the conglomerate to be about 360 feet thick near Lime, Oregon, almost 40 miles southwest of Cuddy Mountain.

Bedding in the red conglomerate is marked by sandy or phyllitic layers. Beds of massive red conglomerate up to 30 feet thick are also present. Most of the conglomerate is characteristically a maroon color (grayish red purple, 5RP 4/2), although locally irregular patches of light green conglomerate (light-green, 5C 7/4) are present. The red and green colors are the most distinctive feature of the unit.

## Lithology and Petrography

The conglomerate and associated sandstones are poorly sorted and are composed largely of volcanic fragments. The conglomerate is a petromict according to Pettijohn's classification (1957, p. 225). The associated sandstones are lithic wackes. Cobbles and boulders (up to three feet in diameter) of the conglomerate are subangular to subrounded, and the sand grains are largely angular to subangular. Thus, the unit can be described as immature.

Although the clasts of the conglomerate are largely volcanic, intrusive and sedimentary rocks are also represented. Andesites and basalts are the most common volcanic lithologies, and many of the clasts appear to have been derived from the underlying Seven Devils Volcanics.

Silica, hematite, and calcite are the principal cementing agents. The hematite, derived from the oxidation of magnetite, pyrite, and possibly ferromagnesian minerals by deuteric alteration and weathering, is responsible for the red color. The green color is caused by the presence of chlorite, epidote, and montmorillonite, which have formed by the alteration of ferromagnesian minerals. They appear to be closely associated with areas of shearing or faulting. Perhaps hydrothermal fluids passing through these secondary channelways altered the ferromagnesian and other iron-bearing minerals to products green in color. Other minerals of secondary origin include pyrite, chalcopyrite, and locally malachite. These minerals are almost certainly of hydrothermal origin. Gypsum is commonly related to the conglomerate, and deposits of some economic value are found elsewhere to the southwest in the Mineral district of Idaho and along the Snake River in Oregon (Wagner, 1946 and 1947).

## Origin and Depositional Environment

The poor sorting, thick bedding, variations in thickness, and angularity and large size of the clasts suggest that the conglomerate was deposited rapidly from a nearby source. The unit is correlated with the red and green conglomerate described by Brooks (1967). Thus, it has a linear extent of at least 40 miles to the southwest. The conglomerate was probably deposited adjacent to an area that was undergoing rapid uplift. Paleontological evidence, to be discussed in the next section, indicates that deposition of the conglomerate was in a marine environment.

## Age and Regional Correlation

The "red and green conglomerate" described by Brooks (1967) strikes north-northeast from Lime, Oregon, to Mineral, Idaho. He suggested that the conglomerate marked the Triassic-Jurassic boundary. The conglomerate at Cuddy Mountain is correlated with the "red and green conglomerate" because of (1) the distinctive coloration, (2) similar lithologies, (3) alignment along strike, and (4) similar stratigraphic positions.

Fossils were found in a silty lense of the red conglomerate at Cuddy Mountain in 1969 by Donald H. Adair of Curwood Mining Company. Representative specimens were obtained by the writer from

M. Adair in Salt Lake City and sent to Dr. N. J. Silberling of Stanford University for identification. He identified the bivalves Pinna sp., and Entolium sp., and a pentenacid resembling Lima sp. All three genera occur in Upper Triassic and younger rocks, but the Entolium sp. found at Cuddy Mountain has the distinctive morphological features of a form found in the Sunrise Formation of western Nevada of Late Sinemurian (Early Jurassic) age (Silberling, 1969, personal communication). Dr. Silberling also noted that he had seen the same distinctive species in the collection by Wagner, Brooks, and Imlay (1963) from the Juniper Mountain area of eastern Oregon. Thus, the Early Jurassic age of the red conglomerate is strongly indicated.

## Porphyritic Rhyolite Tuff

A porphyritic rhyolite tuff crops out along the northwest margin of the area mapped. It was originally described by Livingston (1923) who also noted a similar rock type in the Mineral district, Idaho, and Bayhorse district, Oregon, 15 and 22 miles respectively to the south-southwest. The results of this investigation, together with those of Fankhauser (1969) and Slater (1969), have provided details concerning the origin, mineralogy, and chemistry of this regionally important stratigraphic unit.

## Distribution and Field Description

The areal distribution of the porphyritic rhyolite tuff is similar to that of the underlying Seven Devils Volcanics and red conglomerate. The tuff crops out in the northwest part of the area, where it is repeated by reverse faulting. The tuff overlies the red conglomerate unconformably and is in turn unconformably overlain by the Lucile Series. On the southwest flank of Cuddy Mountain the tuff is 300 to 400 feet thick (Fankhauser, 1969), and in the Mineral district it thickens to 600 feet (Livingston, 1923).

Although the entire unit is called porphyritic rhyolite tuff, it is not homogeneous. The percentage of phenocrysts varies from 20 to less than 2 percent. The top of the unit is appreciably more mafic than the base and is accordingly somewhat darker in color. Lithic fragments are common in the upper mafic parts of the unit, whereas pumice is present in the lower silicic parts. Outcrops of the prophyritic rhyolite tuff are intensely fractured, and surfaces are characteristically dark colored because of manganese oxide stains.

## Lithology, Petrography, and Chemistry

On the basis of composition, the porphyritic rhyolite tuff can be subdivided into a lower rhyolite and an upper latite. Textural differences obtained from petrographic studies indicate the presence of both welded and non-welded vitric tuffs in the rhyolitic part, and a welded, crystal-rich lithic tuff in the upper mafic part. In the non-welded part of the lower rhyolite, glass shards and whole bubble walls are present. The shards are commonly curved and randomly oriented, and the bubble walls are nearly spherical. This texture is characteristic of the non-porphyritic portions of the lower division of the unit. In other samples of the rhyolitic part of the tuff, a well-developed eutaxitic texture characteristic of welded tuffs is well-developed. Glass shards and pumice fragments are flattened to give a banded appearance. Originally spherical bubble walls are flattened until their opposite sides are in contact. The banded texture bends around numerous phenocrysts and occasional lithic fragments. The two textures are "interbedded" and suggest that several eruptions took place. The texture of the upper andesitic rocks is characteristic of ash-flow tuffs of intermediate composition (Ross and Smith, 1961). The andesitic tuff is poorly sorted with a high percentage of lithic fragments and broken phenocrysts in a fine-grained matrix. Although occasional outlines of flattened glass shards are visible in the matrix, much of the original texture is obscured by devitrification and metamorphic effects.

The tuff ranges from rhyolitic to andesitic in composition. The rhyolitic and latitic rocks of the basal part of the unit is a microcrystalline aggregate of sanidine, tridymite, and plagioclase with or without feldspar phenocrysts. The composition of the groundmass was confirmed by X-ray diffraction analyses.

Phenocrysts of plagioclase feldspar, perthite, and sanidine range up to four millimeters in diameter and are generally anhedral. The plagioclase feldspar is sodic oligoclase ($An_{10}$ to $An_{15}$) as determined by the Mical-Levey method. Many phenocrysts have been partly to completely replaced by unzoned albite. The most abundant phenocrysts are perthites composed of sanidine and sodic plagioclase. The two feldspars are of subequal abundance. The evidence for both textures and abundance suggest an origin by exsolution rather than by replacement. If replacement had occurred, crystals displaying variable proportions of these minerals would be expected. An X-ray diffraction record was used to determine the composition of the two phases of the perthitic phenocrysts. A few scattered phenocrysts composed entirely of potassium feldspar were noted.

The upper part of the unit is andesitic in composition. The andesitic tuff consists of broken plagioclase phenocrysts and lithic fragments set in a fine-grained groundmass of feldspar, alteration minerals, and minor quartz. The plagioclase phenocrysts, which consist of sodic andesine ($An_{35}$), are commonly broken or highly fractured, characteristic of crystals in pyroclastic rocks. In some specimens the lithic fragments make up as much as 35 percent of the rock, but the average is closer to 15 percent. These fragments, almost entirely of volcanic rocks, are mostly silicic to intermediate in composition. Perhaps they were derived from earlier deposits of porphyritic rhyolite tuff. Other clasts appear to have been derived from the Seven Devils Volcanics (?).

The matrix is composed of fine-grained feldspar, minor quartz, chlorophaeite, magnetite, and alteration products. Textural evidence indicates that the feldspar and quartz were derived from the devitrification of glass shards. The alteration products include chlorite from clinopyroxene, and biotite (remanants of which are present), epidote, and brownish montmorillonite.

Chemical analyses of samples collected from near the base (267) and near the top (266) of the tuff confirm the change in composition noted in earlier discussions. The chemical composition and norms of these samples and of average andesite, latite, rhyodacite, and calc-alkali rhyolite (Nockolds, 1954) are given in Table 1. Sample (267) from the basal, more silicic part of the unit is intermediate between a rhyolite and a rhyodacite in composition. The sample is low in $SiO_2$ for a rhyolite, but very high in $K_2O$ for a rhyodacite. It is also extremely deficient in CaO compared with Nockolds' rhyolitic rocks. The norm of the Cuddy Mountain sample is similar to that of a rhyolite. Sample (266) from the andesitic part of the tuff is intermediate between a latite and an andesite. It is deficient in $K_2O$ compared to the average latite, but it is also deficient in CaO, MgO and iron oxides

Table 1. Comparison of chemical and normative analyses (weight percent) of samples from the bottom (65-59 and 267) and top (266) of the porphyritic rhyolite tuff with four average volcanic rocks (Nockolds, 1954).

| | 65-59 | 267 | 266 | av calc alkali rhyolite | av rhyo-dacite | av latite | av andesite |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 67.90 | 67.43 | 55.32 | 73.66 | 66.27 | 54.02 | 54.20 |
| $TiO_2$ | 0.51 | 0.55 | 0.68 | 0.22 | 0.66 | 1.18 | 1.31 |
| $Al_2O_3$ | 13.82 | 14.03 | 18.23 | 13.45 | 15.39 | 17.22 | 17.17 |
| $Fe_2O_3$ | 3.84 | 1.31 | 1.68 | 1.25 | 2.14 | 3.83 | 3.48 |
| FeO | 0.97 | 1.62 | 4.90 | 0.75 | 2.23 | 3.98 | 5.49 |
| MnO | 0.28 | 0.04 | 0.04 | 0.03 | 0.07 | 0.12 | 0.15 |
| MgO | 0.78 | 2.02 | 2.15 | 0.32 | 1.52 | 3.87 | 4.36 |
| CaO | 0.06 | 0.39 | 6.67 | 1.13 | 3.68 | 6.67 | 7.92 |
| $Na_2O$ | 1.92 | 2.68 | 5.35 | 2.99 | 4.13 | 3.32 | 3.67 |
| $K_2O$ | 8.41 | 6.08 | 0.98 | 5.35 | 3.01 | 4.43 | 1.11 |
| $H_2O+$ | 1.05 | 2.13 | 3.17 | 0.78 | 0.68 | 0.78 | 0.86 |
| $P_2O_5$ | 0.09 | 0.04 | 0.16 | 0.07 | 0.17 | 0.49 | 0.28 |
| qtz | 22.7 | 23.8 | 6.1 | 33.2 | 20.8 | 0.5 | 5.7 |
| or | 49.5 | 36.1 | 6.1 | 31.7 | 17.8 | 26.1 | 6.7 |
| ab | 16.2 | 23.1 | 45.6 | 25.1 | 35.1 | 27.8 | 30.9 |
| an | 1.7 | 2.0 | 22.0 | 5.0 | 14.5 | 19.2 | 27.2 |
| c | 1.0 | 2.1 | -- | 0.9 | -- | -- | -- |
| di | -- | -- | 9.5 | -- | 1.3 | 4.5 | 4.2 |
| hy | 1.9 | 5.9 | 7.0 | 0.1 | 0.3 | 7.4 | 8.0 |
| mt | 4.2 | 1.9 | 2.3 | 1.9 | 3.0 | 5.6 | 4.9 |
| il | 0.9 | 1.1 | 0.9 | 0.5 | 1.4 | 2.3 | 5.0 |
| hem | 1.0 | -- | -- | -- | -- | -- | -- |
| ap | -- | -- | -- | 0.2 | 0.3 | 1.2 | 1.1 |

compared to the average andesite. Sample (266) is somewhat enriched in $Al_2O_3$. The unusual chemistry of this rock may be partly related to contamination by foreign lithic clasts that are common to the upper part of this unit.

## Origin

The porphyritic rhyolite tuff was first described by Livingston (1920), who believed it to be a rhyolitic lava flow. Such an interpretation is understandable, as the effect of regional metamorphism and commonly hydrothermal alteration have destroyed most of the original texture. However, careful examination of thin sections reveals definite pyroclastic textures. The three textural types were described in the preceding section.

The basal rhyolitic part of the unit has textures characteristic of both air-fall and ash-flow tuffs. Air-fall tuffs have good sorting, and a random orientation of glass shards (non-welded). Ash-flow tuffs are poorly sorted and are welded. The two textures have no definite stratigraphic position; rather, they are "interbedded" which suggests a series of related air-fall and ash-flow events.

The upper andesitic part of the tuff has a texture characteristic of ash-flow tuffs of intermediate composition. No texture suggesting air-fall was observed. Perhaps the less viscous nature of the andesitic lava along with loss of volatiles in earlier eruptions caused the more mafic material to be erupted less violently.

The volcanic source of the formation was probably located near Mineral, Idaho, which is 15 miles to the southwest of Cuddy Mountain. Barring structural complications, the unit is thickest in that area. Dr. Cyrus W. Field and the writer observed this unit a few miles southwest of Mineral, on the Oregon side of the Snake River Canyon, and in that locality the thickness did not approach the 600 feet reported by Livingston (1920) in the Mineral district. As was noted earlier, the unit also appears to be thinner at Cuddy Mountain. The great lateral extent of the formation and its thickness suggest that it was probably erupted from a volcanic center. Volcanic centers are thought to be the source areas for widespread ash-flow deposits (Ross and Smith, 1961).

The change in composition of the unit from rhyolitic to andesitic has been described in other ash-flow tuff units. Smith and Bailey (1966), in describing the Bandelier Tuff, state that the successive changes from salic to mafic material as eruption progressed was probably evidence of a magma chamber undergoing differentiation. The ejecta first erupted would be the less mafic material from the top of the chamber.

## Age and Correlation

This unit is thought to be of Early Jurassic age by reason of its stratigraphic position and relationship to the plutonic complex. The unit overlies the red conglomerate which has been definitely established as Early Jurassic, and is intruded by the gabbro phase of the plutonic complex, which has been radiometrically dated at 180-216 m. y.

Livingston (1920) suggested that the rhyolite is present in the Mineral district and at the Bay Horse Mine in Oregon. The latter locality is about 22 miles southwest of Cuddy Mountain. Slater (1969) and Fankhauser (1969) both described the unit on Cuddy Mountain. In the Mineral district, the stratigraphic position of the tuff relative to the red conglomerate is reversed, but at the Bay Horse mine the sequence is the same as at Cuddy Mountain. Apparently the section at Mineral has been overturned or, as is more likely, repeated by faults as at Cuddy Mountain.

## Lucile Series

Wagner (1945) first used the name Lucile Series to describe a thick sequence of interbedded shales, slates, and sandstones in the Riggins area, Idaho. A unit with similar lithology and stratigraphic position at Cuddy Mountain is thought to be correlative with the Lucile Series of the Riggins area.

## Distribution and Field Description

The Lucile Series crops out in the northwest corner of the thesis area (sec. 1, 6, 12, and 13) where it overlies the porphyritic rhyolite tuff with angular unconformity and is overlain by the Columbia River Basal with extreme angular unconformity. The unit is estimated to be at least 3000 feet thick at Cuddy Mountain, although the top is not exposed.

Units of this formation range greatly in color, thickness of bedding, and lithology. Parts of the sequence are made up of thinnly laminated shales and slates in which successive laminae may be dark gray (N3), very pale orange (10YR 8/2), or yellowish brown (10YR 6/2). Other parts consist of thick, homogeneous sections of medium gray (N5) phyllite. Thin beds of light gray (N7) limestone, greenish-gray (5G 6/1) sandstone, and similar slaty conglomerates are also present.

## Lithology and Petrography

The shaly parts of this formation are composed largely of quartz, plagioclase feldspar, mica, calcite, clay, carbonaceous material, and iron oxides. Individual grains are angular to subangular and are moderately sorted.

The sandstones are arkosic or lithic wackes. They are poorly sorted, with coarse sand grains up to one millimeter in diameter and with occasional small pebbles. They are composed largely of quartz, feldspars, biotite, chlorite, and assorted lithic fragments (largely volcanic) set in a clay matrix and cemented with silica.

The slaty conglomerates are typically four or five feet thick, but some units may range up to 200 feet in thickness. The matrix commonly exhibits distinct cleavage or foliation, and the pebbles are stretched and aligned. Grains of feldspar and quartz are abundant in the matrix, whereas the clasts are normally quartz, chert, and volcanic pebbles.

### Origin and Depositional Environment

Gilluly (1965) and other investigators have demonstrated that geosynclinal conditions prevailed in the western Cordillera throughout most of the Paleozoic and Mesozoic eras. The thickness and lithologies of the Lucile Series suggests that is was deposited in a eugeosyncline. This formation also has features that indicate that special conditions may have existed at the time of its deposition. The delicate lamination and black color (due to organic material) of the shales suggest that they were deposited below wave base in a euxinic environment. Wave action and/or a benthonic fauna would have disrupted the fine laminations present in much of the shale. A benthonic fauna would also have consumed the organic matter. Thus the Lucile Series was probably deposited in an eugeosyncline, below wave base, and in a euxinic environment. The sandstones and conglomerates may represent episodes of uplift on adjacent land surfaces.

Age and Regional Relationships

Hamilton (1963) and Vallier (1967) have indicated that regional metamorphism in west-central Idaho and eastern Oregon occurred in Middle Jurassic time. Thayer and Brown (1964) and Lanphere and Irwin (1965) suggest a Late Jurassic age for this event. As the Lucile Series has been regionally metamorphosed, it is older than the Middle to Late Jurassic regional metamorphism. Slater (1969) suggested that the Lucile Series was deposited after the intrusion of the plutonic complex. He cited such features as lack of deformation, mineralization, and thermal effects in the Lucile Series near plutonic contacts. However, in the area studied by Slater (1969), only one small mass of plutonic rock crops out, and it is several thousand feet from outcrops of the Lucile Series. The present writer suggests that the Lucile Series antedates the intrusive complex because of the following evidence: (1) trace element (Cu, Mo, Pb, and Zn) anomalies are present in rocks of the Lucile Series near the Lead Zone mine; (2) mineralized shale was noted in the Lead Zone mine adit (subsequently closed) by Cook (1954); (3) several prospect pits in the Lucile Series rocks are mineralized; and (4) Fankhauser (1969) described quartz veins in the Lucile Series in the vicinity of the Belmont mines on the southwest flank of Cuddy Mountain. Thus, the Lucile Series is apparently older than the plutonic complex, which is K/Ar dated at about 200 m.y. The Lucile Series is younger than the Early Jurassic red conglomerate. No fossils have been found in rocks that can be definitely correlated with the Lucile Series. Imlay (1964) found Upper Jurassic ammonites in black shales near Mineral, Idaho, but local structural complications make the stratigraphic position of the shales uncertain. As it is hazardous to extrapolate these findings to the Cuddy Mountain area, all that can be said in dating the Lucile Series is that the rocks are probably between Early and Late Jurassic in age.

## Cuddy Mountain Complex

### Introduction

A plutonic complex of Late Triassic or Early Jurassic age forms the core of Cuddy Mountain. Outcrops exhibit an irregular distribution with respect to the entire mountain. Three major rock types are present: gabbro, quartz diorite, and porphyritic granodiorite. Closely related mafic and aplitic dikes and a tourmaline granite breccia pipe are also present. All component phases of this intrusive complex crop out over an area of about eight square miles in the central part of the thesis area.

## Gabbro

Field Description. Gabbro, the oldest and most widely distributed phase of the plutonic complex, occupies approximately six square miles of the exposed complex. The gabbro is dark greenish gray (5G 2/1), fine- to medium-grained, and outcrops form smooth, rounded slopes. It has two sets of widely spaced, near vertical joints that intersect at right angles. One set trends northwest and the other northeast. A third, less prominent set is commonly present. Quartz-epidote veinlets are common and in many cases follow the jointing pattern. Coarse, late stage mafic pegmatite veinlets and pods are also present. The gabbro locally exhibits linear or planar structures. Willow Lake-type layering (Poldervaart and Taubeneck, 1959) was observed in one outcrop (sec. 19).

Lithology and Petrography. In thin section the gabbro exhibits a hypidiomorphic granular, often poikilitic texture. Crystals average about 2 mm in length but range from 0. 25 to 5 mm. The most common minerals are plagioclase, quartz, augite, hypersthene, hornblende, biotite, and magnetite. Accessory minerals include sphene, zircon, pyrite, pyrrhotite, and apatite. Chlorite, epidote, actinolite, talc, sericite, clay minerals, and calcite are the usual alteration minerals.

Plagioclase feldspar as labradorite ($An_{50}$ to $An_{66}$, average $An_{58}$), comprising 50 to 70 percent of the rock, occurs as subhedral laths 0.5 to 5 mm in length. The laths commonly contain poikilitic inclusions of pyroxene and amphibole. In addition, the same specimens may have anhedral plagioclase, as well as hornblende and biotite, poikilitically included in pyroxene crystals. Normal and oscillatory zoning is common and the more calcic zones are selectively altered to sericite and clay (kaolinite, montmorillonite and/or a mixed layer chlorite-montmorillonite). Calcite and epidote are less common alteration products of the feldspar and mafic minerals as well.

Samples of gabbro contain up to 30 percent quartz. The quartz-rich varieties were collected from localities near contacts with quartz diorite or granodiorite. Evidence described later suggest that these rocks formed by contact metasomatism, and they were accordingly mapped as a distinct alteration phase of the gabbro (Plate 1). The gabbro is here defined by the composition of its plagioclase ($An_{50}$ or greater) and quartz content (less than 10 percent). Quartz generally constitutes 2 to 5 percent as an interstitial component of the gabbro, although in several samples it is totally lacking.

The gabbro contains two pyroxenes: augite and hypersthene. Augite ranging from 2 to 20 percent in abundance, occurs as crystals up to 3 mm in length that are commonly embayed by plagioclase feldspar. The feldspar is often poikilitically included in augite, and the reverse relationship also occurs. The augite crystals are occasionally twinned. Most of the augite has been at least partly altered to hornblende. This alteration effect ranges from incipient, where the hornblende forms a thin rim, through partial, wherein augite forms a residual core enveloped by hornblende, to complete replacement that is characterized by bleached cores and inclusions of quartz in the hornblende. The quartz was presumably formed by release of silica as the hornblende replaced the augite (Taubeneck, 1963). Biotite, chlorite, and actinolite are minor alteration products of the augite. This alteration is probably the result of both hydrothermal alteration and regional and contact metamorphism.

Hypersthene is present in most samples of the gabbro. Although it is generally subequal to augite in abundance, it is entirely lacking in a few samples. Orthopyroxene occurs as small, anhedral crystals about 1 mm long. Some crystals display the classical pink to green pleochroism, but most are colorless in thin section. The hypersthene was apparently more resistant to alteration than the augite. For example, in several samples the hypersthene is fresh whereas augite is almost completely replaced by hornblende. Where hypersthene has altered, the most common product is actinolite, and hornblende, biotite, chlorite, and talc are subordinate products.

Petrographic evidence suggests that both primary and secondary hornblende after pyroxene are present in the gabbro. The criteria for recognizing hornblende after augite (Taubeneck, 1963) were discussed above. Other crystals of hornblende are not related to augite, as they do not have bleached cores or inclusions of quartz, and their average length is greater than that of the augite. Thus, some primary hornblende is believed to be present, although in lesser amounts than secondary hornblende. Common alteration products are biotite and chlorite.

Biotite was noted in approximately one half of the thin sections of gabbro examined. A number of samples contain as much as 10 percent biotite, which is both primary and secondary. Primary biotite occurs as coarse (to 3 mm) books whose edges are corroded and embayed by plagioclase crystals. They exhibit well-defined cleavage and typical "birds-eye" extinction. In contrast, secondary biotite forms reddish-brown masses that do not have good cleavage and typical biotite extinction. It is present as alteration rims that envelop mafic minerals and magnetite. Although biotite usually alters to chlorite, small quantities of epidote were assumed to form replacement wedges along cleavage planes of the biotite.

Magnetite is the most abundant opaque mineral in the gabbro. It occurs as finely disseminated anhedra that comprise up to 8 percent of the host. Pyrite, pyrrhotite, and chalcopyrite are also common.

Modal analyses of 30 gabbro samples are given in Table 2. Plagioclase feldspar, augite, hypersthene, hornblende, and perhaps biotite are the essential minerals in the gabbro. Magnetite is the most abundant accessory. Other minerals, including part of the

Table 2. Modal analyses of 30 gabbro samples from Cuddy Mountain (volume percent).

| Sample | Qtz | Plag | Aug | Hyp | Hb | Biot | Mag | Chl | Act | Seric | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | -- | 27 | 10 | 3 | tr | -- | 14 | 2 | 6 | 37 | 6 |
| 72 | -- | 70 | 9 | 2 | tr | -- | 3 | 3 | 4 | 5 | 2 |
| 80 | 4 | 48 | -- | -- | 10 | tr | 6 | 11 | -- | 17 | tr |
| 86 | 8 | 65 | 2 | 5 | 6 | 9 | 3 | -- | -- | 1 | 1 |
| 87 | -- | 64 | 6 | 1 | 3 | -- | 5 | 6 | 9 | 4 | 1 |
| 89 | -- | 83 | 3 | 9 | tr | tr | tr | tr | -- | tr | tr |
| 97 | -- | 60 | 12 | 2 | 8 | -- | 7 | 6 | 2 | 2 | 2 |
| 111 | 1 | 78 | 2 | 6 | 3 | -- | 3 | -- | 5 | 2 | -- |
| 151 | 6 | 42 | tr | -- | 20 | -- | 5 | 4 | -- | 19 | 4 |
| 178 | tr | 60 | -- | 2 | 8 | -- | 3 | 4 | 9 | 7 | 6 |
| 184 | 2 | 45 | 1 | 1 | 12 | -- | 5 | 5 | 5 | 18 | 6 |
| 197 | 3 | 50 | 10 | 15 | 1 | 5 | 5 | 1 | -- | 6 | 4 |
| 211 | 5 | 64 | 3 | 5 | 1 | 6 | 4 | 8 | -- | 1 | 3 |
| 225 | tr | 40 | 20 | 5 | -- | -- | tr | -- | tr | 20 | 10 |
| 227 | -- | 41 | 11 | 18 | 1 | 3 | 9 | tr | 1 | tr | 16 |
| 241 | -- | 81 | 2 | 4 | tr | -- | 3 | 3 | 4 | 2 | tr |
| 269 | -- | 46 | 3 | -- | 7 | -- | 5 | 8 | 12 | 8 | 9 |
| 270 | -- | 58 | 14 | 15 | tr | -- | 4 | 2 | 1 | 3 | 3 |
| 271a | -- | 21 | -- | -- | 16 | tr | 7 | 10 | 1 | 9 | 32 |
| 271b | -- | 54 | 11 | 12 | 5 | -- | 4 | 5 | 2 | 1 | 6 |
| 272 | 5 | 50 | 4 | 1 | 9 | 13 | 2 | 6 | -- | 7 | 2 |
| 64-45 | 1 | 65 | 5 | 11 | 1 | -- | 3 | 2 | 10 | 1 | 1 |
| 64-67 | 6 | 72 | tr | -- | 8 | 1 | 2 | tr | 1 | 9 | tr |
| 65-69 | 3 | 76 | 2 | 6 | 1 | 8 | 3 | tr | -- | 1 | -- |
| 65-78 | 1 | 67 | 5 | 10 | 5 | 2 | 5 | tr | 2 | 3 | 1 |
| 65-84 | 5 | 52 | 4 | 7 | 7 | 4 | 3 | 4 | -- | 4 | 10 |
| 65-85 | tr | 57 | 11 | 20 | -- | tr | 4 | tr | 5 | 1 | 2 |
| 66-105 | 5 | 60 | 2 | 8 | 3 | 8 | 3 | 1 | -- | 4 | 6 |
| 66-118 | -- | 74 | 12 | 2 | 2 | tr | 4 | tr | tr | 1 | 3 |
| 66-132 | 3 | 65 | 2 | 9 | 4 | 3 | 4 | 2 | 2 | 4 | 2 |
| Mean | 2 | 57 | 6 | 6 | 5 | 2 | 4 | 3 | 3 | 7 | 5 |
| Standard deviation | 2 | 15 | 5 | 6 | 5 | 3 | 3 | 3 | 3 | 8 | 6 |

biotite and hornblende, are secondary in origin. The variable abundance of secondary minerals is responsible for the large standard deviations given in Table 2. Mineral effects related to hydrothermal alteration and contact metamorphism are particularly the cause of wide variations in modal analyses.

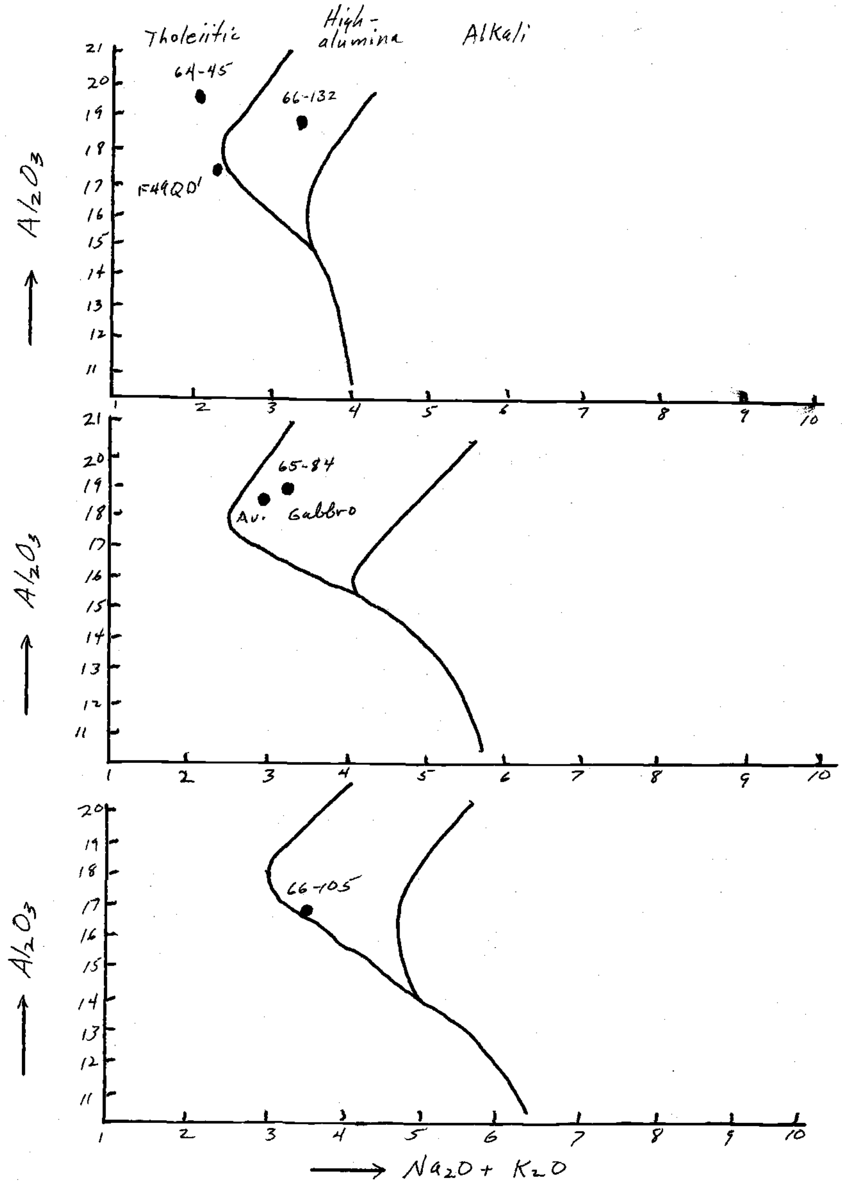
Chemistry. The chemical composition of gabbro from the Cuddy Mountain Complex is compared with values for average gabbro (Nockolds, 1954) and average high-alumina magma type of the Oregon plateaus and Cascade Range (Waters, 1962) in Table 3. The Cuddy Mountain average gabbro has higher $Al_2O_3$, $Fe_2O_3$, and $SiO_2$ contents than the average gabbro determined by Nockolds (1954). The average gabbro from the thesis area is comparable to the high-alumina magma described by Waters (1962). Four out of five of the Cuddy Mountain gabbros, as well as their average, plot in the high-alumina basalt region of an $Al_2O_3$ versus $Na_2O$+$K_2O$ diagram proposed by Kuno (1960), as shown in Figure 2. Kuno (1960) suggests that high-alumina basalt is generated at a depth in the mantle intermediate between alkali and tholeiitic basaltic magmas, and that such magma is common in orogenic belts of the world but rare in non-orogenic belts. Thus the Cuddy Mountain basaltic magma was probably generated and intruded during orogenic activity related to the destruction of the eugeosyncline (Nevadian orogeny) during the Jurassic Period.

Table 3. Comparison of chemical analyses (weight percent) of the Cuddy Mountain gabbro with average gabbro (Nockolds, 1954) and average high-alumina magma type of the Oregon plateaus and Cascade Range.

| | F49QD[1] | 65-45 | 65-84 | 66-105 | 66-132 | Average | Nockolds Average | Waters Average |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.60 | 47.99 | 51.98 | 53.06 | 48.92 | 50.49 | 48.36 | 49.15 |
| $TiO_2$ | 1.51 | 1.21 | 1.13 | 0.93 | 1.21 | 1.12 | 1.32 | 1.52 |
| $Al_2O_3$ | 16.90 | 19.69 | 18.67 | 16.48 | 19.04 | 18.47 | 16.84 | 17.73 |
| $Fe_2O_3$ | 5.08 | 4.39 | 3.98 | 2.25 | 4.12 | 3.68 | 2.55 | 2.76 |
| FeO | 6.94 | 5.24 | 5.51 | 6.10 | 6.23 | 5.77 | 7.92 | 7.20 |
| MnO | 0.17 | 0.16 | 0.18 | 0.19 | 0.26 | 0.20 | 0.18 | 0.14 |
| MgO | 5.74 | 5.44 | 4.28 | 5.61 | 4.98 | 5.33 | 8.06 | 6.91 |
| CaO | 8.48 | 11.45 | 8.92 | 8.43 | 9.76 | 9.64 | 11.07 | 9.91 |
| $Na_2O$ | 1.86 | 1.95 | 2.30 | .243 | 2.32 | 2.25 | 2.26 | 2.88 |
| $K_2O$ | 0.56 | 0.19 | 1.09 | 0.96 | 0.99 | 0.81 | 0.56 | 0.72 |
| $H_2O^+$ | 2.33 | 1.77 | 1.54 | 3.28 | 1.74 | 2.08 | 0.64 | 0.40 |
| $H_2O^-$ | 0.33 | 0.02 | 0.25 | 0.04 | 0.10 | 0.10 | --- | 0.25 |
| $P_2O_5$ | 0.10 | 0.17 | 0.07 | 0.14 | 0.25 | 0.14 | 0.24 | 0.26 |

[1] Fankhauser (1969), southwest flank of Cuddy Mountain.

Figure 2. Comparison of the $Al_2O_3$ and $Na_2O + K_2O$ contents of the Cuddy Mountain gabbro with the three basalt types from Japan (modified after Kuno, 1960).




1. Fankhauser, 1969.

"Hybrid" Gabbro

Field Description. Contacts between the gabbro and the later quartz diorite or porphyritic granodiorite are seldom sharp. In most localities, the contact is gradational. Contact metasomatism of the gabbro by the more silicic intrusions has produced a rock of intermediate character. This "hybrid" phase of the gabbro crops out as a band 300 to 2500 feet wide between the normal gabbro and younger quartz diorite or granodiorite and was mapped separately (Plate 1).

In hand specimen the rock is medium gray (N5) or dark greenish-gray (5G 2/1) and is intermediate in color between the quartz diorite and the gabbro. In contrast to the normal gabbro, a significant amount of quartz is visible. However, the character of its outcrops and jointing are similar to those of the gabbro.

Lithology and Petrography. The texture of the "hybrid" rock is hypidiomorphic granular. Like the gabbro, poikilitic relationships between plagioclase and mafic minerals are common. In thin sections examined the grains average about 2 mm in length, but individual plagioclase laths are up to 4 mm long.

The "hybrid" rock is classified as a quartz gabbro. The mineralogical boundaries of this rock type were set arbitrarily, plagioclase feldspar composition greater than $An_{49}$ and a quartz content greater than 9 percent. Nearly all samples within the "hybrid" zone conform to these mineralogical criteria.

Mineralogically, the "hybrid" rock is similar to the gabbro. However, the quartz content averages 14 percent. The quartz is entirely interstitital and occurs as irregular patches between other minerals. Nonetheless, the "hybrid" gabbro has a much lower quartz content than do the younger quartz diorite and granodiorite. In addition, the latter are nearly devoid of pyroxene.

Modal analyses of several samples of "hybrid" gabbro are given in Table 4. The ratio of pyroxene to hornblende or to biotite is much lower in "hybrid" than in normal gabbro. The following ratios for the average "hybrid" versus the average gabbro were determined: (1) pyroxene/hornblende ratio 0.4 versus 2.4, and (2) pyroxene/biotite ratio 0.6 versus 6.0. The standard deviations of mineral means for the "hybrid" gabbro are larger than for those of the normal gabbro. This apparent increase is probably related to the inferred metasomatic origin of the "hybrid" rock, which thereby imposed greater mineralogical variability.

Chemistry. Chemical analyses of four "hybrid" rock samples are presented in Table 5. The two varieties of gabbro are chemically similar. The principal difference is that the "hybrid" gabbro averages approximately 4 percent more $SiO_2$ than the normal gabbro. This difference, as expected, is correlative with the higher quartz content of the rock. Quartz diorite and granodiorite average approximately

Table 4. Modal analyses of 16 "hybrid" phase samples from Cuddy Mountain (volume percent).

| Sample | Qtz | Plag | Aug | Hyper | Hb | Biot | Chl | Seric | Clay | Mag |
|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 5 | 61 | 3 | 7 | tr | 6 | 7 | 4 | 4 | 3 |
| 108 | 17 | 50 | 1 | -- | 10 | 5 | 2 | 9 | 2 | 4 |
| 118 | 16 | 56 | 1 | 1 | 3 | 14 | 1 | 4 | 2 | 2 |
| 127 | 8 | 36 | 1 | -- | 3 | 23 | 8 | 17 | tr | 1 |
| 140 | 13 | 46 | -- | -- | 27 | 5 | 4 | 3 | 1 | 1 |
| 153 | 10 | 44 | 1 | -- | 14 | 3 | 8 | 5 | 3 | 2 |
| 209 | 17 | 50 | 3 | 2 | 4 | 6 | 4 | 6 | 2 | 3 |
| 210 | 15 | 56 | 4 | 3 | 2 | 3 | 6 | 6 | 1 | 3 |
| 230 | 12 | 52 | 3 | -- | 7 | 6 | 1 | 13 | 2 | 4 |
| 249 | 17 | 26 | 2 | 6 | 4 | 2 | 6 | 30 | 4 | 1 |
| 257 | 15 | 57 | 1 | 3 | 4 | 10 | 2 | 6 | 1 | 1 |
| 64-63 | 12 | 70 | 1 | tr | tr | -- | tr | 2 | tr | 1 |
| ×65-82 | 15 | 59 | 2 | 6 | 2 | 7 | tr | 3 | 4 | 2 |
| 66-123 | 20 | 45 | -- | -- | 8 | 3 | 4 | 14 | 2 | 2 |
| 66-124 | 15 | 48 | tr | tr | 10 | 3 | 5 | 12 | 3 | 2 |
| 66-128 | 12 | 54 | 1 | -- | 13 | 3 | 4 | 8 | 1 | 1 |
| Mean | 14 | 50 | 1.5 | 2 | 8 | 6 | 4 | 10 | 2 | 2 |
| Standard deviation | 4 | 10 | 1 | 2 | 7 | 5 | 3 | 7 | 1 | 1 |

5 and 16 percent more $SiO_2$, respectively, than the "hybrid" gabbro.

Table 5. Chemical analyses of four samples of "hybrid" gabbro from the Cuddy Mountain Complex (weight percent).

| | 65-82 | 66-128 | 153 | 257 |
|---|---|---|---|---|
| $SiO_2$ | 55.53 | 52.06 | 53.12 | 57.00 |
| $TiO_2$ | 0.82 | 1.08 | 0.71 | 0.77 |
| $Al_2O_3$ | 17.52 | 19.96 | 17.00 | 14.81 |
| $Fe_2O_3$ | 3.41 | 1.78 | 3.28 | 2.81 |
| FeO | 4.88 | 5.41 | 6.11 | 6.42 |
| MnO | 0.14 | 0.23 | 0.19 | 0.28 |
| MgO | 4.26 | 4.73 | 5.17 | 4.68 |
| CaO | 7.76 | 9.24 | 8.31 | 7.01 |
| $Na_2O$ | 2.56 | 1.95 | 2.66 | 2.98 |
| $K_2O$ | 1.32 | 1.51 | 1.29 | 1.40 |
| $H_2O$ | 1.24 | 1.55 | 1.53 | 1.33 |
| $P_2O_5$ | 0.11 | 0.09 | 0.13 | 0.06 |

Sufficient chemical and mineralogical data are not available to distinguish "hybrid" rocks adjacent to quartz diorite from those adjacent to porphyritic granodiorite. Proximity to the contact, regardless of intrusive phase, appears to be the most important factor governing the composition and distribution of the "hybrid" gabbro.

## Quartz Diorite

Field Description. Quartz diorite crops out in a zone up to 2000 feet wide near the western and southern margins of the plutonic complex and as a larger mass in the center of the complex as well. Where fresh, the rock is light gray (N7) in color. In contrast to the gabbro, jointing although present, is neither well-developed nor consistently oriented. Epidote-quartz veins commonly fill these joints. Lineation and foliation are largely absent.

Lithology and Petrography. Modal analyses of 14 samples are presented in Table 5. The quartz diorite exhibits a hypidiomorphic granular texture. Crystals average about 3 mm in diameter and range up to a maximum of 6 mm. Plagioclase, quartz, hornblende, biotite, orthoclase, and augite are the major minerals of this rock. Accessory minerals include magnetite, pyrite, sphene, zircon, and apatite. The alteration assemblage is sericite, clay minerals, chlorite, epidote, and carbonate. Standard deviations of the means for various minerals are high. As was the case for the gabbroic rocks, this large mineralogical variability is probably the result of non-uniform hydrothermal alteration and metamorphism.

Plagioclase feldspar, which constitutes approximately 50 percent of the rock, is calcic andesine ($An_{40}$ to $An_{48}$, average $An_{44}$). The plagioclase occurs as anhedral to subhedral laths. It may also be poikilitically included in hornblende and biotite. Normal and oscillatory zoning are observed in some crystals. The more calcic zones, especially the cores, are preferentially altered to sericite and clay minerals. Epidote and calcite have formed in part by the alteration of

Table 6. Modal analyses of 14 quartz diorite samples from Cuddy Mountain (volume percent).

| Sample | Qtz | Plag | Orth | Aug | Hb | Biot | Chl | Epid | Seric | Clay | Mag |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 28 | 34 | 1 | -- | 5 | 1 | 8 | 1 | 20 | tr | 1 |
| 49 | 14 | 50 | 2 | tr | 14 | 5 | 2 | 2 | 8 | 1 | 2 |
| 81 | 20 | 64 | 2 | -- | 2 | 4 | 2 | 1 | 4 | tr | 1 |
| 90 | 40 | 48 | 2 | tr | 2 | 3 | tr | tr | 2 | 1 | 2 |
| 105 | 28 | 47 | 1 | 1 | 4 | 11 | 2 | -- | 2 | tr | 1 |
| 107 | 14 | 64 | 1 | tr | 4 | 10 | 2 | -- | 3 | 1 | 1 |
| 132 | 13 | 52 | 1 | 4 | 5 | 11 | 4 | -- | 6 | tr | 2 |
| 150 | 26 | 27 | tr | -- | 15 | -- | 3 | -- | 19 | 6 | 4 |
| 185 | 11 | 45 | 1 | tr | 7 | 15 | 6 | -- | 10 | 5 | 1 |
| 64-65 | 19 | 54 | 2 | 1 | 10 | 5 | 3 | 1 | 3 | 1 | 1 |
| 65-80 | 22 | 45 | 2 | -- | 7 | 8 | 6 | 1 | 8 | tr | 1 |
| 65-86 | 19 | 52 | 1 | 1 | 8 | 4 | 3 | 1 | 5 | 1 | 3 |
| 65-88 | 26 | 43 | 5 | 1 | -- | 3 | 4 | 3 | 11 | 1 | 1 |
| 65-122 | 31 | 51 | tr | -- | 9 | 4 | tr | tr | 3 | tr | 1 |
| 66-129 | 15 | 52 | tr | -- | 13 | 3 | 1 | 1 | 10 | tr | 3 |
| 66-130 | 29 | 48 | tr | -- | 10 | 6 | 1 | tr | 4 | 1 | tr |
| 66-136 | 21 | 43 | 2 | tr | 10 | 9 | 6 | tr | 6 | 1 | 1 |
| Mean | 22 | 48 | 1.5 | 0.5 | 7 | 6 | 3 | 1 | 7 | 1 | 1.5 |
| Standard deviation | 7 | 9 | 1 | 1 | 4 | 4 | 2 | 1 | 5 | 2 | 1 |

plagioclase feldspar.

The quartz diorite contains an average of 22 percent quartz, which occurs as a late interstitial filling between crystals of earlier minerals. Undulatory extinction is common.

Hornblende averages about 7 percent in the quartz diorite. Many crystals have small patches of augite in their cores, or the cores are bleached, which suggests that at least part of the hornblende formed by replacement of augite (Taubeneck, 1964). Other crystals show no evidence of earlier pyroxene, and may be the result of direct primary crystallization of hornblende from the magma. Biotite and chlorite as reaction rims are the most common alteration products of the hornblende.

The average biotite content of the quartz diorite is about 6 percent. Both primary and secondary biotite are present. The primary biotite is more abundant and occurs as coarse "books" up to three inches in length. It displays typical "birds-eye" extinction and good cleavage. Epidote commonly replaces the biotite along cleavage planes as wedges that spread apart opposite sides of the host. Secondary biotite is found in irregular, reddish-brown masses that have neither extinction nor cleavage typical of biotite. It normally forms replacement rims around hornblende and less commonly around magnetite. The secondary biotite may be partly altered to chlorite.

Orthoclase constitutes as much as 5 percent of the quartz diorite, but the average value is approximately 1.5 percent. It commonly forms myrmekitic intergrowths with quartz at the boundaries between quartz and plagioclase crystals. Occasionally, the orthoclase is present as discrete, interstitial crystals. In all cases, the potassium feldspar crystallized late.

Augite, wherever present, is altered and occurs as remnant cores in the center of hornblende crystals. The average content, however is a mere 0.5 percent.

Chemistry. Chemical analyses of four samples of Cuddy Mountain quartz diorite, their average, and average hornblende-biotite tonalite (Nockolds, 1954) are compared in Table 7. Cuddy Mountain quartz diorite, with respect to this comparison, exhibits a relative deficiency in $SiO_2$ and $Na_2O$, and an excess of $Fe_2O_3$, FeO, MgO, and CaO. These differences are attributed to the relatively basic nature of the Cuddy Mountain quartz diorite, which is relatively rich in mafic minerals. Moreover, its plagioclase feldspar is calcic andesine. As discussed in a later section, the quartz diorite has a close genetic relationship to the gabbro.

## Porphyritic Granodiorite

Field Description. Porphyritic granodiorite constitutes the youngest major phase of the plutonic complex. It crops out over an area of about one-half square mile in the north-central part of the area

Table 7. Comparison of chemical analyses (weight percent) of the Cuddy Mountain quartz diorite with average hornblende-biotite tonalite (Nockolds, 1954).

| | 64-65 | 65-80 | 66-136 | 105 | Average | Average Nockolds |
|---|---|---|---|---|---|---|
| $SiO_2$ | 59.05 | 59.25 | 58.07 | 59.05 | 58.86 | 64.41 |
| $TiO_2$ | 0.76 | 0.99 | 1.20 | 0.66 | 0.90 | 0.62 |
| $Al_2O_3$ | 16.65 | 16.43 | 15.44 | 16.84 | 16.34 | 15.95 |
| $Fe_2O_3$ | 2.90 | 1.47 | 3.92 | 2.25 | 2.64 | 1.46 |
| FeO | 4.67 | 4.91 | 5.34 | 4.31 | 4.81 | 3.81 |
| MnO | 0.11 | 0.30 | 0.19 | 0.21 | 0.20 | 0.10 |
| MgO | 3.02 | 2.90 | 3.11 | 2.93 | 2.99 | 2.45 |
| CaO | 6.55 | 6.43 | 6.79 | 6.85 | 6.66 | 5.36 |
| $Na_2O$ | 3.03 | 2.80 | 2.53 | 3.10 | 2.86 | 3.39 |
| $K_2O$ | 1.39 | 1.68 | 1.40 | 1.49 | 1.49 | 1.45 |
| $H_2O^+$ | 1.34 | 0.84 | 1.67 | 0.48 | 1.08 | 0.80 |
| $H_2O^-$ | 0.22 | 1.47 | 0.05 | 1.11 | 0.71 | --- |
| $P_2O_5$ | 0.11 | 0.11 | 0.12 | 0.14 | 0.12 | 0.21 |

(sec. 8, 9, 16, and 17), and is found in three other localities (sec. 15, 16, and 22) where it forms small plug-like masses that intrude earlier plutonic phases of the complex. In two of these latter occurrences, the granodiorite has been brecciated.

The porphyritic granodiorite is light greenish-gray (5GY 8/1) in color and forms subdued, rounded outcrops. Its most distinctive feature is the presence of large, rounded "quartz eyes" that are readily apparent on weathered surfaces. Foliation and lineation are absent, and joint sets do not show any consistent orientation.

Lithology and Petrography. The granodiorite has a porphyritic texture with phenocrysts of quartz and plagioclase and occasionally hornblende, biotite, and orthoclase set in a fine-grained groundmass of plagioclase feldspar. The pehnocrysts range up to 10 mm in diameter. Magnetite, zircon, and apatite are the most common accessory minerals. Clay minerals (koalinite and montmorillonite or mixed-layer montmorillonite-chlorite) are typical alteration products of feldspar. Hornblende and biotite are almost completely altered to chlorite. Sericite, epidote, and carbonate are also present.

Fresh granodiorite contains approximately 58 percent plagioclase feldspar, which is sodic andesine ($An_{30}$-$An_{37}$, average $An_{36}$) that occurs both as large, anhedral to subhedral phenocrysts and small, anhedral crystals in the groundmass. The phenocrysts are commonly zoned. Throughout the area plagioclase is highly altered to clay minerals (average 10 percent) and sericite (average 6 percent).

The average quartz content of the granodiorite is 27 percent. The quartz occurs as large, rounded "eyes" up to 7 mm in diameter.

Hornblende and biotite occur largely as remnant cores in large masses of chlorite. However, Fankhauser (1969) described these minerals as large, subhedral phenocrysts in fresh porphyritic granodiorite on the southwest flank of Cuddy Mountain.

The granodiorite contains scarce phenocrysts of highly altered orthoclase. However, petrographic, staining, and X-ray diffraction studied indicate that very little orthoclase is in the groundmass. Orthoclase makes up approximately 4.5 percent of the average porphyritic granodiorite.

Mineralogically, this rock is intermediate between a granodiorite and a quartz diorite. Potassium feldspar averages approximately 9 percent of the total feldspar. Many of these samples should actually be classed as quartz diorites and others as granodiorites. Because Fankhauser (1969) and Slater (1969) referred to the rock as a granodiorite, their precedent is followed in this thesis.

Modal analyses of six granodiorite samples from the thesis area and one relatively unaltered sample from the area mapped by Fankhauser (1969) to the southwest are presented in Table 8. Because of the small number of samples, standard deviations for the numeral averages were not calculated. Inspection of the data, however,

Table 8. Modal analyses of eight porphyritic granodiorite samples from Cuddy Mountain (volume percent).

| Sample | Qtz | Plag | Orth | Hb | Biot | Chl | Seric | Clay | Mag |
|---|---|---|---|---|---|---|---|---|---|
| 31 | 29 | 33 | 3 | -- | 4 | -- | 5 | 22 | 4 |
| 32 | 20 | 40 | 10 | tr | 3 | tr | 5 | 20 | 2 |
| 35 | 28 | 37 | 3 | 5 | -- | 3 | 7 | 17 | tr |
| 134 | 29 | 40 | 3 | 5 | 1 | 6 | 9 | 1 | 4 |
| 274a | 23 | 40 | 3 | 9 | tr | 7 | 4 | 10 | 4 |
| F48G[1] | 23 | 55 | 6 | 1 | 2 | 3 | 3 | 3 | 1 |
| 74[2] | 35 | 48 | 3 | -- | 5 | -- | 7 | -- | 1 |
| A-1 | 31 | 43 | 2 | -- | 1 | 6 | 9 | 2 | 2 |
| Mean | 27 | 42 | 4.5 | 3 | 1 | 3.5 | 6 | 10 | 2 |

[1] Fankhauser, 1969.

[2] Slater, 1969.

reveals that the mineralogy of the granodiorite is variable, as was the case for the other plutonic phases. The high percentages of clay minerals, sericite, and chlorite support the hypothesis that this variability is caused by alteration and metamorphism.

Chemistry. Chemical analyses of four samples from widely separated localities are compared with average hornblende-biotite granodiorite of Nockolds (1954) in Table 9. With the exception of $K_2O$ content, the chemistry of the Cuddy Mountain granodiorite compares favorably with that of Nockolds (1954). Cuddy Mountain granodiorite averages approximately 1.9 percent $K_2O$ compared with 3.0 percent for average granodiorite. The apparent relative $K_2O$ deficiency of Cuddy Mountain granodiorites is presumably a function of low potassium feldspar content.

## Dikes, Plugs, and Breccia Pipes

Three types of dikes intrude all previously mentioned members of the igneous complex. They include: (1) mafic dikes, (2) aplite dikes, and (3) a tourmaline granite breccia pipe or dike. In addition to these dikes, which are genetically related to the intrusive complex, much younger dikes and plugs of Columbia River Basalt are also present. Of those observed, mafic dikes are the oldest. They are cut by aplite dikes. Fragments of both mafic and aplite dikes occur in the tourmaline granite breccia. All dikes have a northerly trend. The

Table 9. Comparison of chemical analyses (weight percent) of the Cuddy Mountain porphyritic granodiorite with average hornblende-biotite granodiorite (Nockolds, 1954).

| | 31 | 35 | 74[1] | F48G[2] | Average | Average Nockolds |
|---|---|---|---|---|---|---|
| $SiO_2$ | 70.97 | 70.70 | 68.82 | 67.20 | 69.42 | 65.50 |
| $TiO_2$ | 0.51 | 0.45 | 0.22 | 0.56 | 0.44 | 0.61 |
| $Al_2O_3$ | 14.46 | 14.19 | 14.92 | 15.97 | 14.88 | 15.65 |
| $Fe_2O_3$ | 1.49 | 0.74 | 0.20 | 1.04 | 0.87 | 1.63 |
| FeO | 1.13 | 2.16 | 3.27 | 2.66 | 2.30 | 2.79 |
| MnO | 0.02 | 0.12 | 0.15 | 0.10 | 0.10 | 0.09 |
| MgO | 0.24 | 0.76 | 1.63 | 1.07 | 0.92 | 1.86 |
| CaO | 1.78 | 4.44 | 1.68 | 3.99 | 2.97 | 4.10 |
| $Na_2O$ | 4.56 | 3.84 | 3.48 | 3.67 | 3.89 | 3.84 |
| $K_2O$ | 1.73 | 1.07 | 2.72 | 1.87 | 1.85 | 3.01 |
| $H_2O^+$ | 2.09 | 0.09 | 2.17 | 1.24 | 1.39 | 0.69 |
| $H_2O^-$ | 0.54 | 0.35 | 0.34 | 0.40 | 0.41 | --- |
| $P_2O_5$ | --- | 0.09 | 0.09 | 0.13 | 0.08 | 0.23 |

[1] Slater, 1969

[2] Fankhauser, 1969

mafic dikes are most variable in trend, whereas the aplite dikes generally trend north to north-northeast. Emplacement of the dikes was definitely controlled by fractures. The tourmaline granite breccia is also elongated to the north-northeast, as are the Columbia River Basalt intrusives. Three of the four types of dikes are discussed briefly below.

Mafic Dikes. The mafic dikes vary considerably in trend (as mentioned above) and size. Most of the dikes are only two or three feet thick, but a few are much larger (up to 30 feet in thickness). One dike, which intrudes the gabbro about 1000 feet north of Hornet Reservoir, displays what may be described as radial columnar jointing.

The dikes are medium dark gray (N4) and of andesitic to basaltic composition. Fine plagioclase laths, andesine to labradorite in composition, make up from 70 to 90 percent of the host. Other minerals include augite, chlorite, sericite, and finely disseminated magnetite. Many of the dikes have an aphanitic, equigranular texture, and others are porphyritic. The most common phenocrysts are plagioclase and/or augite. Primary mineral components of most of the mafic dikes are highly altered to sericite and chlorite.

Aplite Dikes. The aplite dikes seldom exceed 3 or 4 feet in width and can occasionally be traced more than 200 feet.

The dikes are fine-grained, with an allotriomorphic granular texture. Perthitic, micrographic, and myrmekitic textures are common. The most abundant minerals are quartz, sodic plagioclase feldspar, and orthoclase. A little biotite is commonly present. The common alteration minerals are sericite and chlorite. These rocks range in composition from quartz monzonite to granodiorite.

Tourmaline Granite Breccia. A tourmaline granite breccia pipe crops out on a ridge along the east central border of the map area (SW1/4 sec. 15 and NW1/4 sec. 22). It is about 1500 feet long and ranges from 200 to 400 feet wide. Another less well-developed tourmaline breccia crops out on the north side of the Hornet Creek canyon (SE1/4 sec. 16). Both occur closely associated with small masses of porphyritic granodiorite. As the four distinct masses of granodiorite in the thesis area crop out in a northwest trending line, their emplacement may have been structurally controlled.

The well-developed tourmaline granite breccia is located in a small patch of porphyritic granodiorite which was intruded along the gabbro-quartz diorite contact. Clasts of granodiorite comprise about 90 percent of the breccia, but fragments of gabbro, quartz diorite, and mafic and aplite dikes are also present. The clasts are up to 6 inches in diameter and are subrounded. The clasts have been highly altered. Orthoclase has completely replaced the original plagioclase feldspar and is itself partially altered to sericite and kaolinite. Small amounts of magnetite, hematite, chalcopyrite, and malachite are also present.

The matrix of the breccia is mineralogically simple. It contains quartz, orthoclase, and tourmaline (schlorite). The tourmaline occurs as phenocrysts (5 mm long), sunbursts, and fracture fillings. Hematite, magnetite, sericite, and kaolinite are minor constituents of the matrix.

Modal analyses of an average tourmaline granite breccia and of the less well-developed breccia in sec. 16 are presented in Table 10.

In terms of chemical composition the breccia differs appreciably from the porphyritic granodiorite of which it is largely comprised. The most drastic changes are in the $Na_2O:K_2O$ and $CaO:Na_2O$ ratios (see Table 16). The $Na_2O:K_2O$ ratio is 2:1 for the granodiorite and 1:66 for the breccia; the $CaO:Na_2O$ ratio is 1:1 for the granodiorite and 1:3 for the breccia. The $SiO_2$ content is little changed. Hence, the dominant mineralogical change is the replacement of plagioclase feldspar by orthoclase.

The low $Na_2O$ content (0.44 percent) of the breccia is somewhat anomalous, as it is a major constituent of tourmaline. However, tourmaline makes up a much lower percentage of the breccia than does plagioclase of the porphyritic granodiorite. The $Na_2O:CaO$ ratio increases from 1:1 in the granodiorite to 3:1 in the breccia. Thus, most of the CaO was leached out of the breccia, but some $Na_2O$ was retained, probably in the tourmaline.

Table 10. Modal analyses of six samples of tourmaline granite breccia in various stages of development and alteration. Five are from the Kismet mine and one (280a) is from SE1/4 sec. 16.

| Sample | Qtz | Plag | Orth | Tour | Chl | Seric | Clay | Mag | Cal | Hem |
|---|---|---|---|---|---|---|---|---|---|---|
| K-2 | 19 | -- | 47 | 14 | 6 | 2 | 6 | 2 | -- | 4 |
| K-3 | 48 | -- | 4 | -- | 6 | 34 | tr | 3 | 4 | 1 |
| K-5 | 30 | -- | 40 | 16 | 2 | 4 | 3 | tr | -- | 3 |
| K-6 | 21 | tr | 48 | 4 | 9 | 12 | 1 | 2 | 3 | -- |
| 65-76 | 62 | -- | 23 | 7 | 1 | 1 | -- | 1 | -- | 5 |
| 280a | 10 | 25 | 10 | 11 | 11 | 5 | 1 | 2 | 2 | -- |
| Mean | 32 | 4 | 29 | 9 | 6 | 10 | 2 | 2 | 15 | 2 |

| | Qtz | Plag | Orth | Hb | Biot | Chl | Seric | Clay | Mag |
|---|---|---|---|---|---|---|---|---|---|
| Average porphyritic granodiorite | 27 | 42 | 4.5 | 3 | 1 | 3.5 | 6 | 10 | 2 |

The Kismet copper-molybdenum property is located on the tourmaline granite breccia. The mineralogical and chemical changes that took place during the formation of the tourmaline granite will be discussed in greater detail under Economic Geology.

## Columbia River Basalt

Russel (1901) was the first to use the name Columbia River Basalt to describe the thick sequence of flows along the Yakima River. Waters (1961) divided the formation into two members: the lower Picture Gorge Basalt and the overlying Yakima Basalt. Both types are well exposed along the Imnaha River of northeastern Oregon. The basalt flows at Cuddy Mountain are correlated with the Columbia River Basalt on the basis of lateral continuity with Columbia River Basalt occurrences in adjacent areas and lithologic similarities.

### Distribution and Field Description

Columbia River Basalt flows completely surround the Cuddy Mountains and cap the plateau-like summit as well. Feeder dikes and a plug of this basalt intrude basalt flows, the plutonic complex, and the country rocks. The thesis area lies along the eastern edge of the Grand Rhonde-Cornucopia dike swarm described by Taubeneck (1966). The dikes and plugs of Cuddy Mountain were probably feeders for Columbia River Basalt flows.

The Columbia River Basalt unconformably overlies all the rock units at Cuddy Mountain. That Cuddy Mountain stood as a topographic high at the time of basalt eruptions is shown by the fact that the flows lap up against the western flank of the mountain. On top of Cuddy Mountain, where small and thin erosional remnants of basalt rest directly on rocks of the plutonic complex, it is the younger Yakima Basalt that is represented. The older Picture Gorge Basalt crops out several hundred feet down the western flank of the mountain, beyond the map area. The contact between the two members is marked by an abrupt change in slope. Yakima Basalt forms a steep scarp that gives way to more gentle, rubbly slopes of the underlying Picture Gorge Basalt. Waters (1961) noted a similar relationship in outcrops of the two basalts.

Fankhauser (1969) estimated a maximum thickness of approximately 1000 feet for these basalts on the western flank of Cuddy Mountain.

As discussed above, only the Yakima Basalt is found in area mapped. Yakima Basalt is characteristically medium gray, fine-grained, and nonporphyritic (Waters, 1961). Individual flows vary considerably from this generalization. Some are dark and dense, others are light gray and amygdaloidal. In the latter type, hyaline opal fills the amygdules. Finely-porphyritic flows are also present. Columnar jointing is well displayed in several localities, especially along the steep western scarp (sec. 23 and 24).

Lithology, Petrography, and Chemistry

The basalt samples examined in thin section are hemicrystalline and equigranular to finely porphyritic. Intersertal textures are characteristic. The samples display several mineralogical features characteristic of Yakima type Columbia River Basalt (Waters, 1961), including (1) lack of olivine, (2) high tachylyte content (averages about 25 percent), (3) plagioclase feldspar composition of about $An_{50}$, (4) presence of opal in vesicles, and (5) scarcity of large phenocrysts. The dominate constituents of the rocks are plagioclase feldspar, clinopyroxene (pigeonite?), tachylyte, and magnetite. Chlorophaeite is present in small amounts and is commonly partly altered to celadonite or nontronite. Other minerals include montmorillonite and chlorite, the latter commonly rimming magnetite crystals.

In Table 11 Cuddy Mountain basalt is compared with typical Picture Gorge and Yakima Basalts described by Waters (1961) and also with parental tholeiitic magma of Hawaii (Kuno and others, 1957). Chemically, the rock is a typical tholeiitic basalt. The $SiO_2$ content of the Cuddy Mountain sample is somewhat lower than that of the typical Yakima Basalt, but otherwise the compositions are similar. Chemical analyses of basalts by King (1970) at the southern end of Cuddy Mountain indicate that both members occur in the area, as was previously inferred from geologic considerations.

Table 11. Chemical analyses of average Yakima and Picture Gorge basalt (waters, 1961), average parental tholeiite of Hawaii (Kuno and others, 1957), and Columbia River basalt from the top of Cuddy Mountain.

| | Picture Gorge | Yakima | Hawaiian Tholeiite | 275 |
|---|---|---|---|---|
| $SiO_2$ | 49.3 | 53.8 | 50.9 | 50.5 |
| $TiO_2$ | 1.6 | 2.0 | 2.8 | 2.3 |
| $Al_2O_3$ | 15.6 | 13.9 | 13.2 | 14.1 |
| $Fe_2O_3$ | 3.5 | 2.6 | 2.0 | 3.7 |
| FeO | 7.8 | 9.3 | 9.1 | 9.2 |
| MnO | 0.2 | 0.2 | 0.1 | 0.1 |
| MgO | 6.5 | 4.1 | 8.0 | 4.0 |
| CaO | 10.3 | 7.9 | 10.6 | 7.3 |
| $Na_2O$ | 2.7 | 3.0 | 2.2 | 2.9 |
| $K_2O$ | 0.5 | 1.5 | 0.4 | 1.8 |
| $P_2O_5$ | 0.3 | 0.4 | 0.3 | 0.3 |
| $H_2O^+$ | 1.8 | 1.2 | 0.3 | 2.3 |
| $H_2O^-$ | | | 0.1 | 1.6 |

## Origin

Although basalt at Cuddy Mountain may have come in part from local feeders, much of it was derived from sources to the west, as is indicated by their onlapping relationship to the western flank of the mountain. Cuddy Mountain is within the boundaries of the Grande Ronde-Cornucopia dike swarm (Taubeneck, 1966), but the greatest concentration of dikes is in northeastern Oregon and southeastern Washington. Therefore, much of the Columbia River Basalt at Cuddy Mountain may have been derived from more distant sources to the northwest.

## Age and Regional Correlation

According to Waters (1961) the Columbia River Basalt ranges from middle Miocene to early Pliocene in age.

Lithologic and chemical comparisons suggest that both the Picture Gorge and Yakima types of Columbia River Basalt are present at Cuddy Mountain. Only the Yakima member crops out in the area mapped, and it caps the topographically highest parts of the mountain.

## Columbia River Basalt Dikes and Plugs

One plug and three dikes of Columbia River Basalt were found in the thesis area. The plug is about 1000 feet long by 500 feet wide and is located northeast of the Lead Zone mine tunnel (sec. 7). The plug is on a contact between porphyritic rhyolite tuff and Columbia River Basalt flows. The basalt plug displays good, vertical columnar jointing as well as nearly horizontal platy jointing. The intersection of these joint sets causes the rock to break off in fist-sized polygons. The dikes have platy jointing only. Small dikes of Columbia River Basalt intrude quartz diorite east of Rush Lake (sec. 29), Seven

Devils Volcanics (sec. 13), and Columbia River Basalt flows (NW1/4 sec. 15). In each case, the basalt intrusives now stand as topographic highs.

In contrast to earlier mafic and aplite dikes, those of Columbia River Basalt are relatively unaltered. They are dark gray (N7) in color. The rocks are usually aphanitic, equigranular, and have intersertal textures. Small (2 mm) phenocrysts of plagioclase are occasionally present. The most common minerals are plagioclase, clinopyroxene, and magnetite. Olivine is rarely present. Minor hypersthene and chlorophaeite are also present, and the latter commonly is altered to celadonite. Tachylyte occurs in amounts up to 20 percent. The lack of olivine, the abundance of tachylyte, and the fine-grained texture of these dikes indicates a Yakima-type parent magma.

# EMPLACEMENT AND CRYSTALLIZATION OF THE PLUTONIC COMPLEX

## Mode and Depth of Emplacement of the Plutonic Rocks

From the evidence listed by Buddington (1959), it is postulated here that the Cuddy Mountain Complex was forcefully intruded into the upper mesozone at a depth of approximately 10 km. Geologic evidence suggests that the intrusive body may be sheet-like rather than stock-like in shape.

Distorted country rocks near contacts with the complex indicate forceful intrusion. At one contact between country rocks and the plutonic complex, the dip of the rhyolite tuff is steepened from about 65° to almost vertical near its contact with the gabbro. Immediately adjacent to the contact, the tuff is highly fractured parallel to the contact. Slater (1969) and Fankhauser (1969) found similar relationships between plutonic and country rocks. Slater (1969, p. 55) mentions "contorted country rocks" near such contacts, and Fankhauser (1969, p. 80) described "severed, tilted, or otherwise deformed beds in the Seven Devils Volcanics" adjacent to plutonic rocks. Inclusions of country rock and of earlier plutonic phases are common. The contact between the rhyolite tuff and the gabbro is very sharp, the country rock being literally cut-off or torn out of the path of the intruding body.

Features suggestive of the mesozone after Buddington (1959) include: (1) intrusion into country rocks of the greenschist facies; (2) early Mesozoic age of the stock; (3) presence of a good contact-metamorphic aureole; (4) intrusion into a eugeosynclinal belt; (5) lack of chilled margins; (6) composite intrusions of intermediate composition, with quartz diorite making up an appreciable percentage of the rock; (7) abundance of aplite dikes; and (8) no evidence of a direct relationship between plutonic and volcanic activity. The comparative lack of foliation and the discordant nature of the contacts between intrusive and country rocks are features more characteristic of epizonal plutons.

Two features suggest that the plutonic rocks, at least in the northern part of Cuddy Mountain, may have been intruded as sheet-like bodies. Both in the Cuddy Mountain Complex and in Slater's area (1969, Plate 1), outcrop patterns of several plutonic phases suggest flat-lying, tabular bodies. Lineations in the rocks of the plutonic complex are often poorly developed and sparse. However, sufficient data, as shown in Figure 3, were obtained to define the general trend of the lineations. All are gently plunging (less than 29°), and most plunge to the south. Probably the main body of the complex lies to the south under Columbia River Basalt flows and north of the areas mapped by Fankhauser (1969) and King (1971, M.S. thesis in preparation). Plutonic rocks on the north flank of Cuddy Mountain may be sill-like or peripheral offshoots from the main complex. Intervening

Figure 3. Lineations in the rocks of the plutonic complex; all lineations plunge less than 25°.

Plunging Lineation

Horizontal Lineation

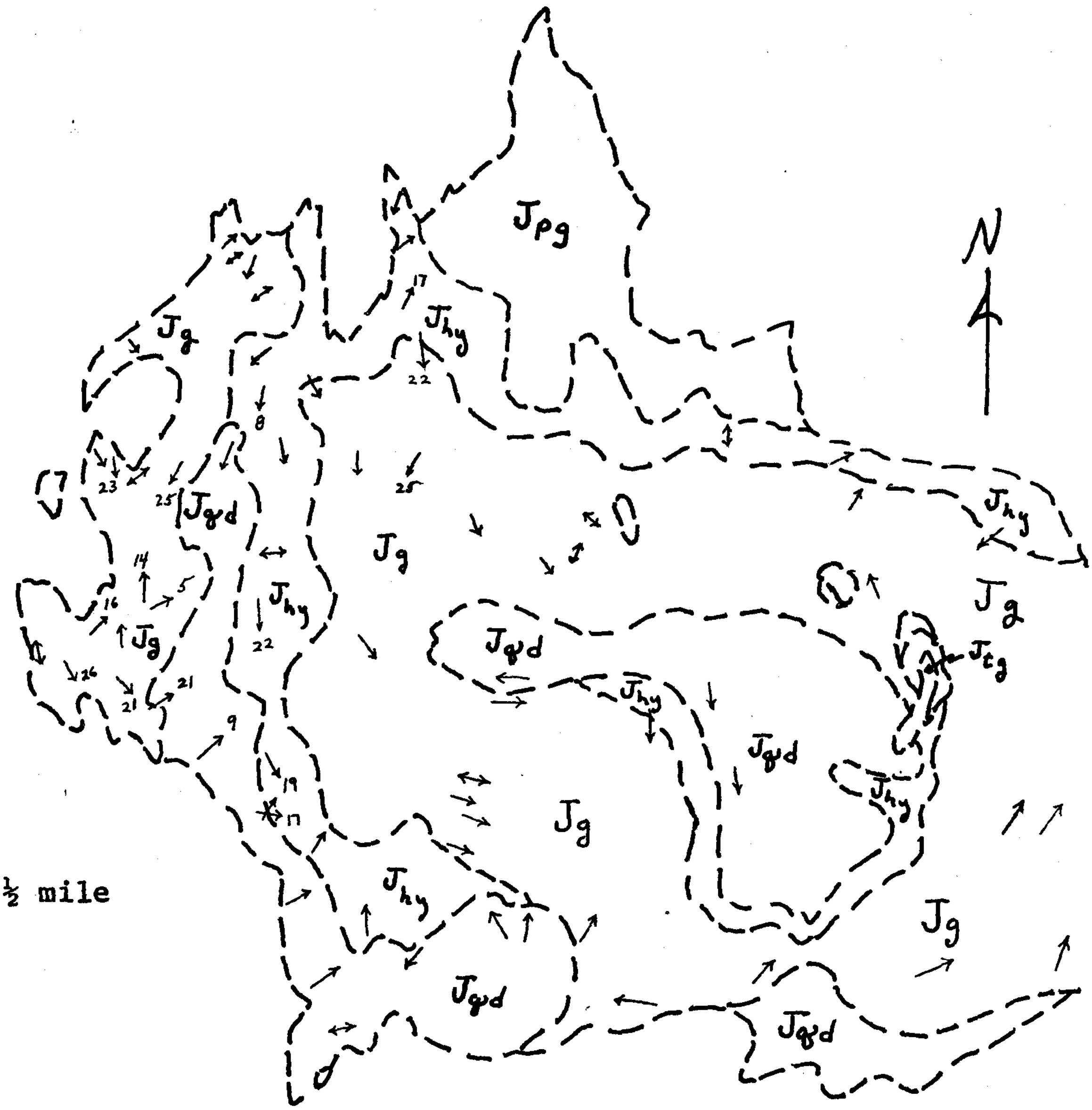
Jg Gabbro

Jhy Hybrid Phase

Jqd Quartz Diorite

Jpg Porphyritic Granodiorite

Jtg Tourmaline Granite Breccia




½ mile

basalt cover and lack of other evidence make further speculations conjectural, at best.

## Physical Condition of the Magmas at Time of Emplacement

The absence of phenocrysts at gabbro-country rock contacts, the scarcity of foliation, and the presence of Willow Lake-type layering (Taubeneck, 1967) collectively suggest that crystals were sparse or absent at the time the gabbro was intruded. Hence, gabbro and quartz diorite were largely or completely liquid at the time of their emplacement. Phenocrysts are formed by the quenching of a magma that contains pre-existing early formed crystals. However, the absence of phenocrysts and the scarcity of planar structures in the gabbro, even near contacts, indicate early formed crystals were rare and that the magma was essentially liquid. Finally, Willow Lake-type layering is present along the western border of the plutonic complex (sec. 19) in a body (apparently an autolith) 40 feet wide and 200 feet long. The layering strikes northwest and dips steeply to the northeast. The layers range from less than one-tenth to slightly more than one inch in thickness. A few are composed of long (to 4 mm) pyroxene crystals arranged perpendicular to the layering. Most layers consist of alternating plagioclase-rich and plagioclase-poor layers. The former consist of small (less than 1 mm), anhedral plagioclase laths that are oriented at high angles to the banding. The laths are commonly poikilically enclosed in large hypersthene crystals that are at low angles to the layering. Subordinate clinozoisite and magnetite are also present. The plagioclase-poor layers are composed largely of clinozoisite and magnetite with lesser amounts of hypersthene and plagioclase. The composition of plagioclase in both types of layers is approximately $An_{63}$. Taubeneck (1967a) stated that Willow Lake-type layering forms by undercooling of a mafic magma along contacts with wall rocks, xenoliths, or autoliths. He further stated that such layering could develop only in magmas that were esssentially crystal free, since any crystals present would act as nuclei for further crystallization as undercooling started. Thus, banded rocks could not form.

The almost complete lack of flow structure in the quartz diorite suggests that few crystals were present at the time it was intruded (Taubeneck, 1967b). Moreover, dikes of quartz diorite in adjacent gabbro are finer-grained than the main intrusion, yet the dike-rocks are equigranular.

The porphyritic grandiorite was 25 to 40 percent crystalline at the time it was intruded. This interpretation is based on the presence of large phenocrysts of quartz and feldspar that obviously crystallized earlier than similar minerals of the fine-grained groundmass in which they occur.

## Sequence of Emplacement of the Several Plutonic Phases

The gabbro is clearly the oldest member of the intrusive complex. Along the western margin of the complex, veins and dikes of quartz diorite cut the gabbro, and inclusions of gabbro occur in the quartz diorite. In sec. 8, xenoliths of gabbro were found in porphyritic granodiorite, and narrow dikelets of granodiorite are present in the adjacent gabbro outcrop. Thus the gabbro is the oldest of the three major plutonic phases.

It is possible that more than one surge of gabbroic magma occurred. Gabbro somewhat finer-grained than usual crops out in scattered localities. In one area (sec. 20), a vein of slightly coarser-grained gabbro was found in the finer-grained rock. The two rocks are identical mineralogically. The apparent autolith of banded gabbro described in the preceding section also suggests successive influxes of gabbroic magma.

Nowhere on Cuddy Mountain has a contact between quartz diorite and porphyritic granodiorite been observed. Their relative ages must be determined from indirect evidence. The normal sequence of intrusion is from early mafic, through intermediate, to late silicic members. The logical sequence, then, is gabbro to quartz diorite to porphyritic granodiorite. A late relative age for the granodiorite is supported by data of alteration and mineralization. All major ore deposits in the intrusive complex are closely associated with the granodiorite. Quartz diorite is appreciably mineralized and/or altered only where it is in close proximity to granodiorite. Thus hydrothermal alteration and mineralization post-date the emplacement and consolidation of the quartz diorite. Three small areas of granodiorite (as well as a large one in the northwest part of the area) occur in the area. The granodiorite appears to intrude gabbro at two of these localities and occupies an apparent gabbro-quartz diorite contact zone at the third (Kismet mine). This relationship suggests that the granodiorite is younger than the other major intrusive lithologies.

Both mafic and aplite dikes occur in all three major plutonic phases and thus post-date them. Near the Kismet mine, an aplite dike cuts a mafic dike. Because clasts of each type occur in the breccia, all of the above-mentioned intrusive rocks appear to pre-date the tourmaline granite breccia.

## Variations in Mineralogy and Chemistry of Plutonic Rocks

The gabbro and its associated "hybrid" phase compose approximately one half of the Cuddy Mountain Complex that is exposed in this area. Because the gabbro is the most widely distributed and quantitatively important plutonic phase of the complex, it should have the greatest compositional variation. Available mineralogical and chemical data indicate this assumption to be correct, since no meaningful trends were observed for the other intrusive phases. The mineralogical and chemical variations of the gabbro are related to contacts with and proximity to the younger quartz diorite or granodiorite phases, and not to location within the complex.

Mineralogical parameters such as quartz content, plagioclase composition, ratios of pyroxene (hypersthene and augite) to hornblende and biotite, and others have been plotted on a geologic map of the complex. The following trends can be observed: (1) quartz content increases with increasing proximity to contacts with quartz diorite or granodiorite, (2) anorthite content of plagioclase decreases with increasing nearness to these contacts, and (3) pyroxene:hornblende and pyroxene:biotite ratios decrease markedly in gabbro near these contacts. These mineralogical effects are found only in gabbro located south or east of quartz diorite or granodiorite. Thus, the zone of mineralogical changes in the gabbro is restricted to the area mapped as "hybrid" gabbro. Mineralogical comparisons between normal gabbro and "hybrid" gabbro given in Table 12 illustrate these changes.

Comparison of the average chemical composition of the gabbro (Tables 3 and 5) to that of the "hybrid" gabbro provides a quantitative compositional index of the mineralogical differences between the two rock-types. The "hybrid" phase averages about 4.5 percent more silica, 0.3 percent more $Na_2O$, and 0.6 percent more $K_2O$. It has approximately 1.2 percent less $Al_2O_3$ and 1.6 percent less CaO. The other oxides apparently do not change significantly. The increase in $SiO_2$ in the "hybrid" gabbro is due largely to the addition of quartz. The increase in $Na_2O$ and decrease in $Al_2O_3$ and CaO in the "hybrid" phase are related to the more sodic plagioclase feldspar. The lower CaO content of the "hybrid" gabbro may be related, also, to the low pyroxene:hornblende ratio, because augite contains about 30 percent CaO as compared with 12 percent for hornblende. The higher $K_2O$ content of the "hybrid" gabbro is related to its low ratio of pyroxene:biotite. Thus, the mineralogical and chemical data are in mutual agreement with respect to differences between gabbro and its hybrid equivalent adjacent to later intrusions of quartz diorite or porphyritic granodiorite.

Table 12. Mineralogical variations in the gabbroic rocks of the Cuddy Mountain Complex.

| | Gabbro | "Hybrid" Phase |
|---|---|---|
| Average quartz content | 2% | 14% |
| Average An content of plagioclase | $An_{58}$ | $An_{54}$ |
| Average pyroxene/Hb+biotite ratio | 6.1 | 0.4 |

| Quartz Content | Average An Content of Plagioclase |
|---|---|
| Quartz $\leq$ 2% (18 samples) | $An_{59.7}$ |
| 2% < Quartz < 10% (11 samples) | $An_{55.0}$ |
| Quartz $\geq$ 10% (13 samples) | $An_{53.6}$ |

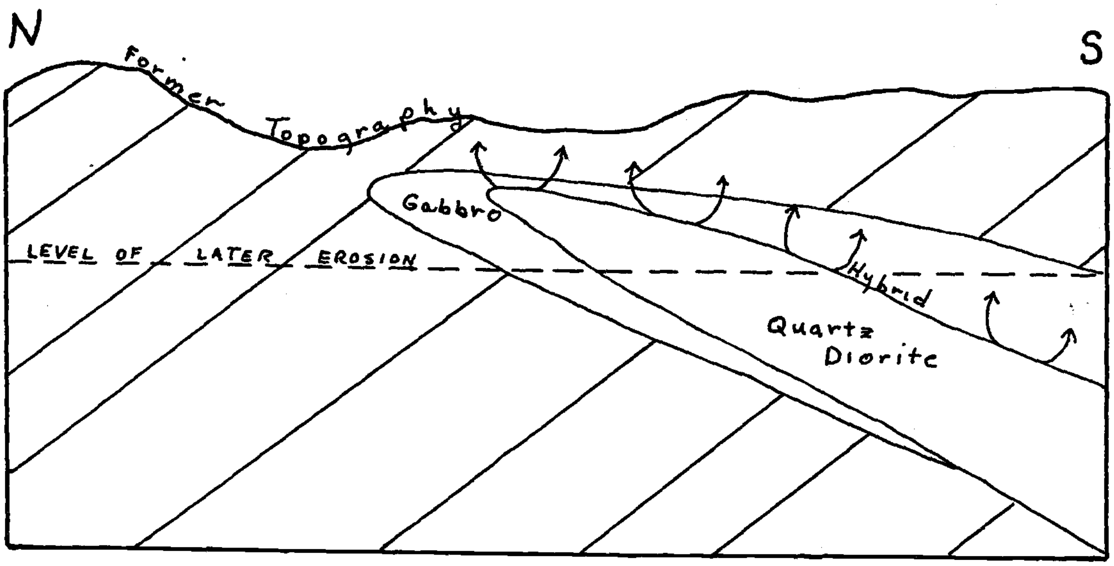
It has previously been noted that silicic intrusions of the northern part of Cuddy Mountain were possibly emplaced as gently dipping, sheet-like bodies from the south (or southeast). Metasomatizing fluids derived from such sheets intruded into the gabbro probably would have emanated upward and outward more easily than downward in response to pressure and temperature gradients. The fact that gabbro west and north of bodies of quartz diorite or granodiorite is essentially mineralogically unchanged suggests that contacts between the gabbro and later silicic intrusions dip gently to the south or east.

Thus, the overlying rocks would be affected more readily than the underlying rocks for an intrusive body dipping gently to the south as portrayed in Figure 4. The most intensely metasomatized rocks would then crop out south of the intrusion when later exposed by erosion.

## The Role of Water in the History of the Complex

Water became increasingly important as the plutonic complex proceeded through the early magmatic, late magmatic, and deuteric phases of its history. The following evidence suggests that volatiles (chiefly water) were present in the plutonic complex: (1) a zone of contact metamorphism that is wide in some localities; (2) common occurrence of quartz veins and both mafic and silicic pegmatites; (3) associated alteration and mineral deposits of hydrothermal origin;

Figure 4. Emplacement of a sheet-like body of quartz diorite into gabbro and metasomatism of the gabbro.



and (4) the breccia pipe, probably a product of fluidization (Reynolds, 1954).

## Early Magmatic Water

Although the gabbro was fluid at the time of its emplacement, and volatiles were undoubtedly present, its water content apparently never became high during crystallization. This inference is supported by the mineralogical composition of the gabbro, the narrowness of its zone of contact metamorphism in the porphyritic rhyolite tuff adjacent to the gabbro (less than 200 feet), and the paucity of associated hydrothermal effects in adjacent country rock.

Development of the "hybrid" gabbro adjacent to the quartz diorite indicates that the latter had a volatile content sufficient to cause metasomatism of a substantial volume of gabbro. However, the absence of extensive hydrothermal activity related to this phase suggests that an excess of water again was not present.

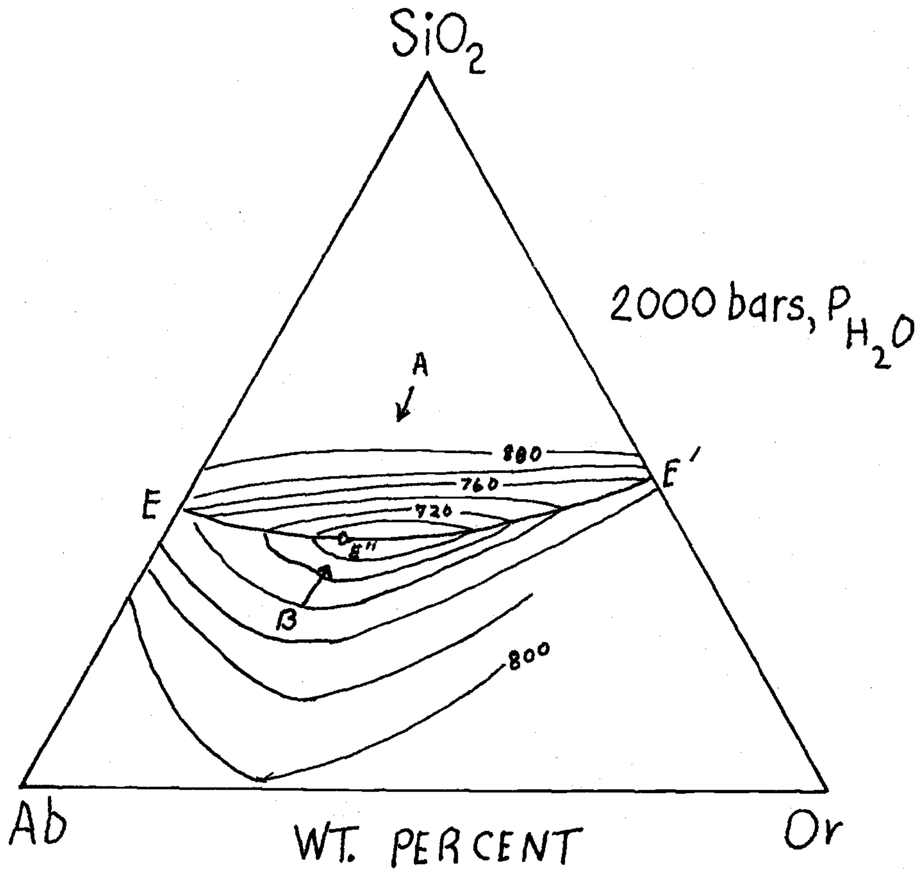
In contrast, the porphyritic granodiorite magma was water-rich. Extensive contact metasomatism is found in both gabbro and country rocks adjacent to the granodiorite. Hydrothermal alteration and mineralization at Cuddy Mountain are invariably associated with this phase, and the Kismet property is localized within a tourmaline-bearing breccia pipe partly within granodiorite. In addition, the formation of a quartz porphyry may relate to high water content in the parent magma.

The development of a quartz prophyry can be explained in at least two ways. Figure 5 is the ternary diagram for the system quartz-albite-orthoclase (Q-Ab-Or) after Tuttle and Bowen (1958). The line E-E' is a eutectic trough with E'' the low point in the trough.

Point A represents a magma with an $SiO_2$ content greater than 75 percent. As the magma cools, quartz will crystallize first and the composition of the magma will move toward the eutectic (E-E'). When the eutectic composition is reached, feldspars and quartz will crystallize. Rapid cooling at this late stage would yield a quartz porphyry. However, few magmas, including the porphyritic granodiorite, are sufficiently rich in silica for this model to be common.

Another possible process involves an increase in the amount of water or $P_{H_2O}$ of a magma whose composition plots below the eutectic trough (point B in Figure 5). This increase may come about by the collection of water in the upper part of the chamber as the magma crystallizes, by the incorporation of water from the country rocks, by crystallization of anhydrous phases, or by decreasing the total pressure, which causes ebullience of water and an increase in $P_{H_2O}$. Taylor (1969) has shown through oxygen and hydrogen isotope studies that at least in some intrusions large amounts of non-magmatic and presumably meteoric water were incorporated by hot, liquid magmas. Moreover, this contamination was characteristic of most porphyritic

Figure 5. Ternary eutectic diagram (modified after Tuttle and Bowen, 1958).



intrusions of intermediate to silicic composition. The effect of the addition of water to the system is to lower the eutectic trough towards Ab-Or. Thus, as magma B begins to crystallize feldspar, the composition of the magma is driven up toward the trough. Addition of water to the system would cause the eutectic trough to simultaneously migrate down toward point B. If sufficient water were added, the trough could be displaced below the composition of the remaining magma and assisted up to that point by the concomitant precipitation of feldspars. The result might then be resorption of feldspars and eventually the precipitation of quartz with further cooling. The composition of the magma would then move back down to the eutectic where quartz and feldspar would form simultaneously. Rapid cooling at that point would result in the formation of a quartz porphyry, or a quartz-feldspar porphyry if the original feldspar crystals were not completely resorbed. If enough water were available through sudden influx of meteoric waters, the liquidus might be sufficiently depressed to cause resorption of the quartz crystals. Such a process might account for the corroded appearance of "quartz eyes" in the porphyritic granodiorite.

Geologic evidence indicates that the porphyritic granodiorite magma was rich in water. The above discussion presents a generalized model for the possible formation of quartz phenocrysts in this rock.

## Late Magmatic Water

All three phases of the plutonic complex underwent a late stage increase in $P_{H_2O}$. This effect is shown by the precipitation of hydrous minerals (hornblende and biotite), and especially by the replacement of pyroxene by hornblende. That the hornblende is late magmatic rather than deuteric in origin is indicated by its subhedral (Best, 1963), massive (Herz, 1951) form.

## Deuteric Effects

Deuteric effects in the complex are difficult to separate from those of regional metamorphism and hydrothermal alteration. The following changes may reflect combinations of three processes: (1) the replacement of pyroxene by fiberous amphiboles (actinolite) and talc, (2) the alteration of hornblende to biotite, (3) the formation of chlorite and epidote from pyroxene, hornblende, and biotite, and (4) the replacement of plagioclase feldspar by clay minerals and sericite. However, formation of the clays and mica of (4) appears to be correlative with late hydrothermal processes.

# The Differentiation History of the Plutonic Complex

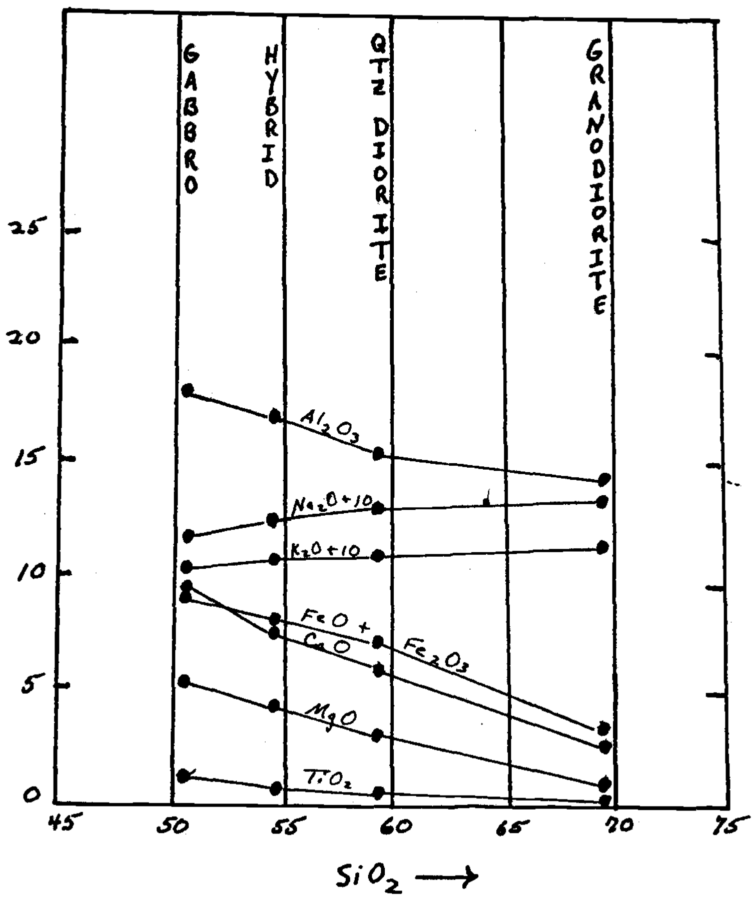
## Evidence of Differentiation

A number of features of the Cuddy Mountain Complex suggest that its several phases are differentiates of a common parent magma. Sharp contacts between different members of the complex are the exception rather than the rule. Contacts are generally gradational over tens or even hundreds of feet. This relationship suggests that the earlier phase was hot or partially liquid at the time of emplacement of the later intrusion. The K/Ar dates (Table 13) for the three phases are grouped within the limits of accuracy of the dating method. Thus, if the ages are accepted as valid, they were all intruded within a short period of time. This relationship cannot be relied on, however, because regional metamorphism subsequent to the crystallization of the complex would tend to redistribute, and possibly expel, the radioactive and radiogenic isotopes.

A technique that is often employed to support differentiation is the use of variation diagrams. Chemical data representing average compositions of normal gabbro, "hybrid" gabbro, quartz diorite, and porphyritic granodiorite are plotted on the Harker diagram in Figure 6. The systematic distribution of chemical data is consistent with the hypothesis that the various igneous phases are differentiates of the same magma. Curves for the various oxides are gently sloping and generally smooth. With decreasing age and increasing silica content, $K_2O$ and $Na_2O$ increase and $Al_2O_3$, $Fe_2O_3$+FeO, CaO, MgO, and $TiO_2$ decrease.

The chemical data suggest that all the phases of the plutonic

Figure 6. Harker variation diagram of the Cuddy Mountain plutonic rocks based on the average compositions of gabbro (4), hybrid (4), quartz diorite (4), and porphyritic granodiorite (4).



complex are differentiates of a single magma. The original magma may have been more mafic than the phases exposed at Cuddy Mountain. Possibly the intrusive phases represent fractions of the residual liquid that were periodically injected into the overlying country rock by a mechanism such as filter pressing (Daly, 1933) as the parent magma crystallized at depth. Periodic tectonism, as is common to mobile eugeosynclinal area, could facilitate such a process.

Trend of the Differentiation

It has previously been stated that the chemistry of the gabbro is similar to that of high-alumina basalts. Comparisons of silica and alkali contents of the alkali rock series, the high-alumina rock series, and the tholeiitic rock series after Kuno (1964) are presented in Figure 7. Four samples of each of the major divisions of the plutonic complex are plotted, and all but one falls in the high-alumina field. This strong association indicates that effects of regional metamorphism and hydrothermal alteration are not responsible for the apparent high-alumina affinities of the Cuddy Mountain suite.

In Figures 8 and 9, the differentiation trend of the Cuddy Mountain Complex is compared with those of the high-alumina basalt parent magma of the Skaergaard Complex (Wager and Brown, 1967), the British and Icelandic Tertiary tholeiitic rocks, and the calc-alkali rocks from the Southern California Batholith (Nockolds and Allen,

Figure 7. Chemical affinities of the Cuddy Mountain plutonic rocks (modified from Kuno, 1964).

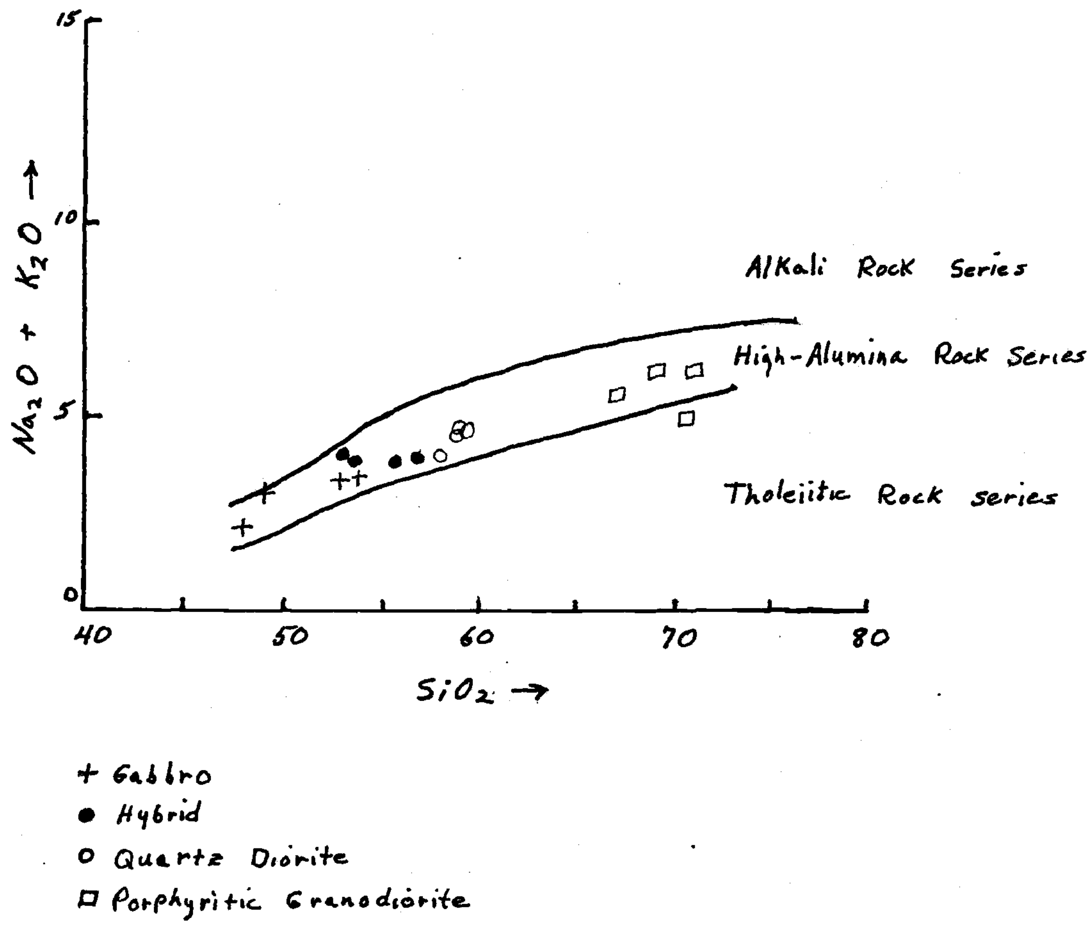


Figure 8. Ternary differentiation diagram.

——— Cuddy Mountain rocks

- - - - Skaergaard trend (Wager and Brown, 1967)

. . . . . . Hawaiian Alkali Suite (MacDonald and Katsura, 1964)

1. Av. porphyritic granodiorite
2. Av. quartz diorite
3. Av. hybrid gabbro
4. Av. gabbro

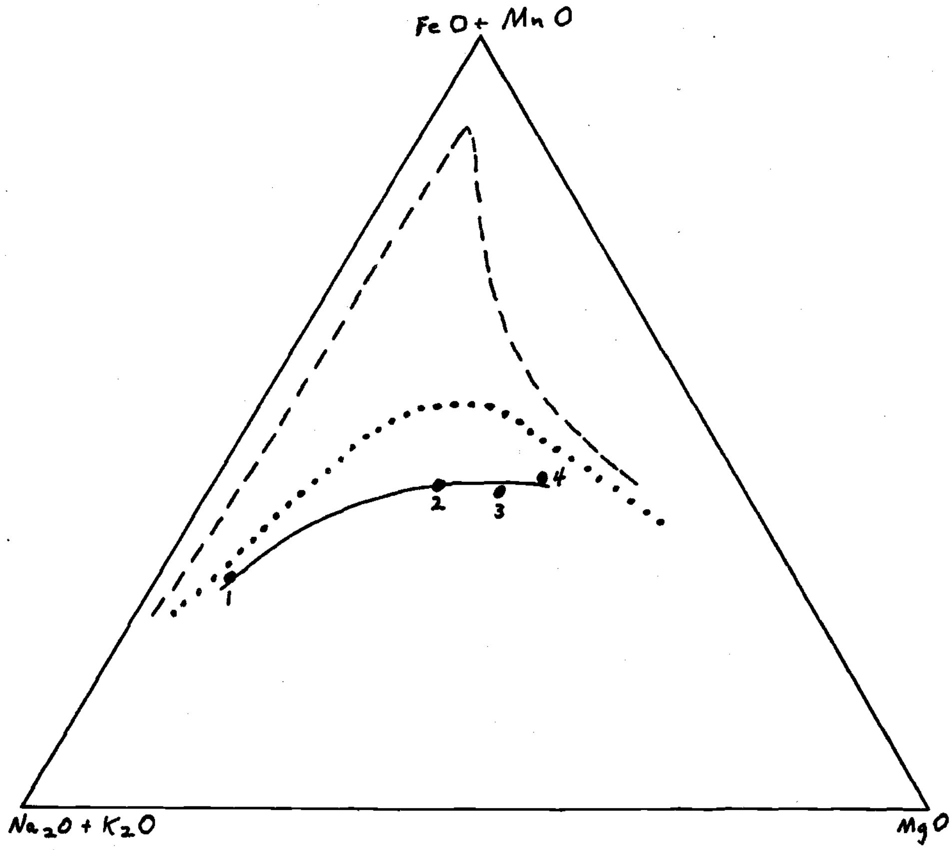
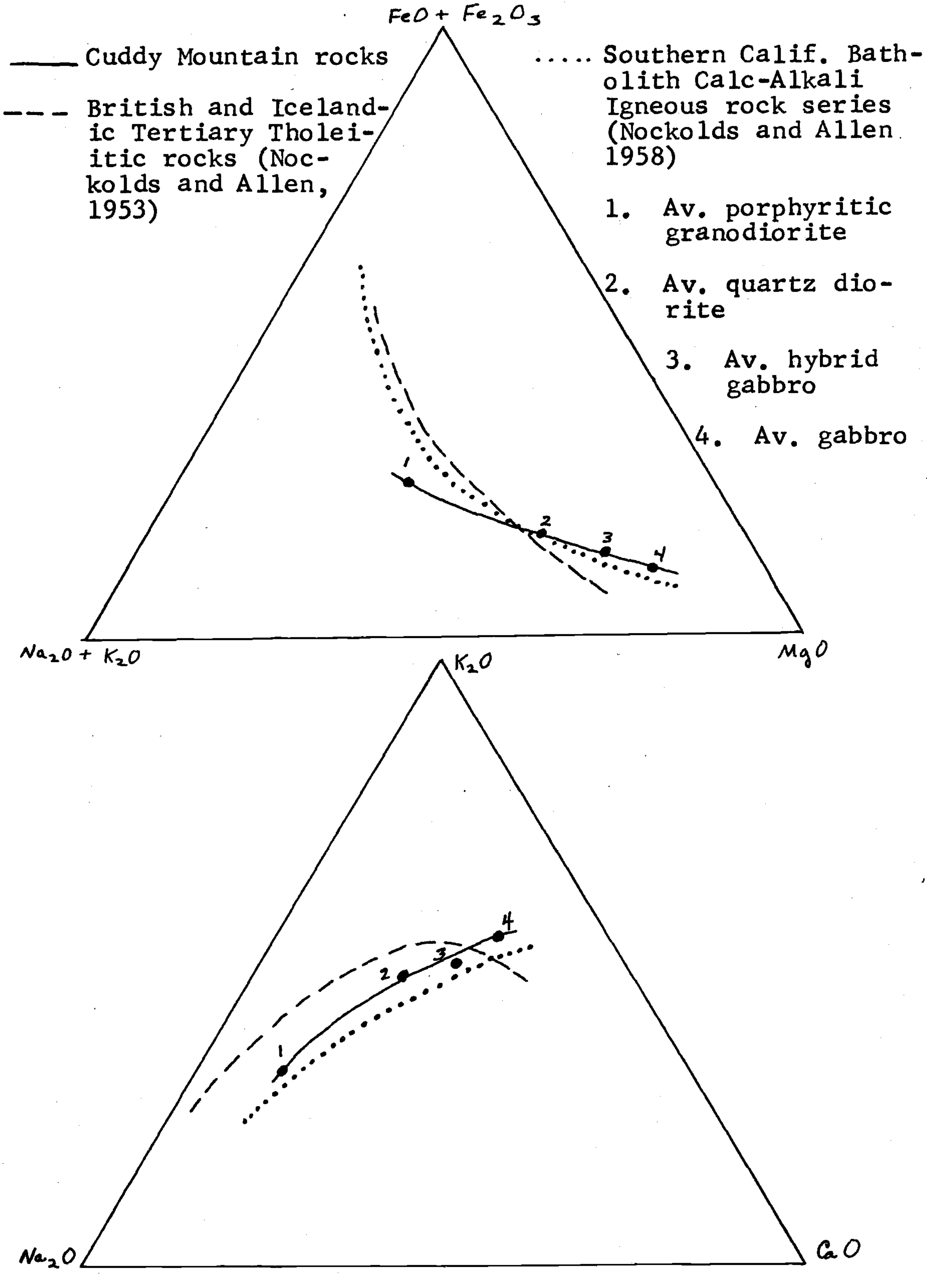


Figure 9. Ternary differentiation diagrams.



1953). The trend of the Cuddy Mountain rocks is not that of the high-alumina series, but rather that of the calc-alkaline series.

Kuno (1966, 1968) believes that the calc-alkaline rock series could be derived from basaltic parent magma of the alkali, tholeiitic, or high-alumina types, but that the last named is the most reasonable parent magma. He and other investigators such as MacDonald and Katsura (1964), suggest that time and rate of magnetic crystallization is the most important factor in determining which rock series will develop from a given parent magma. The crystallization of magnetite is dependent upon the $P_{O_2}$ which is in turn dependent upon the $P_{H_2O}$. A low $P_{O_2}$ would cause magnetite to crystallize late. Late crystallization of magnetite causes the characteristic "hump" in the differentiation curves of the tholeiitic and high-alumina series on AMF diagrams. Relatively high $P_{O_2}$ effects early separation of magnetite and gradual tapering of the magnetite content that results in the alkali or calc-alkaline trends. The gradual decrease in magnetite from the gabbro to porphyritic granodiorite intrusive phases suggests that early separation occurred in the Cuddy Mountain Complex.

Kuno (1966, 1968) lists the following features, all of which are displayed by the rocks of the Cuddy Mountain Complex, as characteristic of the calc-alkaline rock series: (1) relatively high $Al_2O_3$ content, (2) presence of hypersthene, (3) lack of iron concentration during crystallization, and (4) appearance of hydrous silicate minerals.

Thus, intrusive phases of the Cuddy Mountain Complex belong to the calc-alkaline rock series and their parental magma had a composition similar to that of high-alumina basalt.

# AGE RELATIONSHIPS

## Age Relationships Within the Plutonic Complex

Field evidence indicates that the sequence of emplacement for members of the plutonic complex was gabbro, quartz diorite, and finally porphyritic granodiorite. K/Ar age determinations for the three phases do not agree with their geologic order of emplacement; gabbro (178 m.y.), quartz diorite (207 m.y.), and porphyritic granodiorite (190 m.y.). Relevant analytical and computational data for the age determinations are listed in Table 13.

Table 13. K/Ar radiometric age determinations for three major phases of the plutonic complex.

| Sample Number | Rock Type | Age (m.y.) Hornblende | Age (m.y.) Biotite | Analyst |
|---|---|---|---|---|
| 66-105 | Gabbro | 171 ± 5 | | Armstrong |
| WB-86 | Gabbro | | 184 ± 5 | Armstrong |
| 66-136 | Qtz. diorite | | 216 ± 5 | Isotopes, Inc. |
| 66-136 | Qtz. diorite | 206 ± 5 | 200 ± 5 | Armstrong |
| F48G | Ppy. Gd. [1] | 200 ± 5 | 180 ± 5 | Armstrong |

[1] Porphyritic Granodiorite (Fankhauser, 1969)

Relative ages of the quartz diorite and porphyritic granodiorite as derived from radiometric data are consistent with those deduced from field relationships. Although field relations show conclusively that gabbro is the oldest member of the complex, the K/Ar date is younger than those of the other two rock types. This seemingly contradictory age relationship is tentatively explained in terms of location of the dated samples with respect to the edge of the plutonic complex. Regional metamorphism may cause degassing and loss of radiogenic $Ar^{40}$. Micas will lose argon at temperatures as low as 200°C (Armstrong, 1966). Thus, regional metamorphism that affected the terrain in Middle or Late Jurassic time undoubtedly caused partial loss of $Ar^{40}$ from the rocks of the plutonic complex. Accordingly, the ages listed in Table 13 are minimum dates. In some cases the amount of $Ar^{40}$ lost by a rock is determined by its position relative to other rock types. Armstrong (1966) has described approaches that can be used to circumvent the problems in K/Ar dating caused by metamorphism. He suggests dating rocks from "asylums"; defined as isolated patches of rock, such as the central area of a mass of mafic igneous rock, that are shielded from the effects of regional metamorphism. Perhaps the gabbro of the Cuddy Mountain Complex would qualify as an asylum. The quartz diorite sample (66-136; NW1/4 SE1/4 sec. 19) dated has a body of gabbro at least one-half mile wide between it and regionally metamorphosed country rocks. The porphyritic granodiorite (F48G; NW1/4 SE1/4 sec 15, T. 16 N; R. 4 W.) from Fankhauser's area was dated because no unaltered samples were discovered within the writer's thesis area. A wide expanse of

Columbia River Basalt lies between this sample location and the country rock to the west, and no gabbro crops out in the intervening area. However, the trend of the gabbro-porphyritic granodiorite contact southeast of the sample locality suggests that a band of protective gabbro could very possibly be present.

When the opportunity and funds were available for K/Ar dating the plutonic complex, the areal extent of the gabbro was unknown, and samples from known outcrops along the western border of the complex were chosen. Sample 66-105 (SE1/4 NW1/4 sec. 17) and sample WB-86 (NE1/4 NW1/4 sec. 19) are both from localities relatively near gabbro-country rock contacts and were consequently vulnerable to the effects of regional metamorphism. This band of gabbro that crops out along the western border of the complex was originally mapped as metagabbro because of its fine-grained and somewhat hornfelsic texture. It was later found to grade inward into fresher grabbo. Regardless of possible effects of contact metamorphism, dates for the gabbro should be no younger than those of the later quartz diorite and granodiorite. The cause of apparent K/Ar age determination anomalies may relate to effects of regional metamorphism. The "older" quartz diorite and granodiorite ages are provisionally attributed to the occurrence of these samples in protected local "asylums."

## Country Rock-Plutonic Complex Age Relationships

Field evidence indicates that all country rock units except the Columbia River Basalt were intruded by the plutonic complex. Near the head of Crooked River (SW1/4 sec. 7) pyroxene hornfels is well-developed in porphyritic rhyolite tuff outward from its contact with gabbro. Seven Devils Volcanics were subjected to contact metamorphism by gabbro in the SE1/4 sec. 23. The attitudes of the country rocks are commonly disrupted adjacent to the complex, and xenoliths of country rock are found in the intrusive rocks. Slater (1969) and Fankhauser (1969) have reported similar relationships.

Fankhauser (1969) collected fossils from the Seven Devils Volcanics on the southwest flank of Cuddy Mountain. These were dated as probably Late Triassic in age. As discussed earlier, fossils in the red conglomerate are Early Jurassic (Sinemurian) in age. Thus, the plutonic complex is no older than Early Jurassic according to both field and paleontological evidence.

As previously discussed, minimum K/Ar dates as old as 216 ± 5 m.y. were obtained for rocks of the plutonic complex. The commonly accepted date for the Triassic-Jurassic boundary is about 180 m.y. Thus, a sharp conflict exists between the paleontological ages and the radiometric ages. Armstrong (personal communication, 1970) believes, on the basis of extensive K/Ar work, that the

Triassic-Jurassic boundary should be moved back at least as far as 210 m.y. He has obtained K/Ar dates as old as 245 m.y. in the northeastern U.S.A. from volcanic beds in sedimentary sequences (Newark Group) dated paleontologically as Late Triassic. Similarly, the Guichon Batholith of British Columbia has been radiometrically dated as 200 m.y. and it intrudes well-established Late Triassic beds (Erickson and White, 1966). Thus, because the plutonic rocks definitely intrude the country rocks, the most reasonable explanation for the age discrepancy is that the Jurassic boundary is older than presently assumed. Other possible explanations are that the dated minerals had an original excess of $Ar^{40}$, or that contamination occurred during the dating process. Examples of hornblende containing an excess of $Ar^{40}$ have been reported, but significant excesses have not been noted for biotite (Armstrong, 1966). Because both biotite and hornblende were dated, and the dates are reasonably concordant, the anomalous ages are not the result of an excess of $Ar^{40}$. Laboratory contamination is unlikely because sample 66-136 was cross-checked by different analyses. The internal consistency of these dates and to those for the Guichon Batholith, approximately 200 m.y., indicate that contamination or other errors are not likely factors. Therefore, the best reationale to the present dilemma is to lower the age of the Triassic-Jurassic boundary to at least 210 m.y.

## Regional Age Relationships of the Plutonic Complex

The Idaho Batholith of western Idaho and the Wallowa Batholith of eastern Oregon are the two major plutonic bodies nearest the Cuddy Mountain Complex. The western border of the Idaho Batholith is about 20 miles east of Cuddy Mountain and the Wallowa Batholith is approximately 50 miles to the west. In addition, several smaller stocks of intermediate composition occur in the Seven Devils Mountains 30 miles north-northwest of Cuddy Mountain (White, 1968), in the Riggins quadrangle about 30 miles to the north, and in a small plutonic complex that crops out in the Mineral district 15 miles to the south. The first three bodies have been dated. They are much younger than the plutonic rocks at Cuddy Mountain. The age of the Idaho Batholith ranges from 38 to 156 m.y. (McDowell and Kulp, 1969), and that of the Wallowa Batholith from 95 to 149 m.y. (Taubeneck, 1962). The Deep Creek Stock in the Seven Devils Mountains was dated at 127 years (Field, 1969, personal communication). These dates indicate that the Cuddy Mountain Complex is much older than other major plutonic episodes of the region.

Few plutons in western North America have absolute ages between 190 and 250 m.y. As stated earlier, the Guichon Batholith of British Columbia was dated as 200 ± 5 m.y. (Erickson and White, 1966). In addition, the eastern part of the Sierra Nevada Batholith gives dates ranging from 170 to 210 m.y. (Bateman and Eaton, 1967), the Pit River Stock in the Klamath Mountains on the Oregon-California border has been dated at 246 m.y. (Lanphere, Irwin, and Hotz, 1968), and a few plutons in southeastern Alaska range from about 200 to 260 m.y. in age (Loney, Brew, and Lanphere, 1968). The writer believes that plutonic rocks in the Mineral district may be similar in age to those at Cuddy Mountain. This inference is based on geographic proximity and similarities in lithology and geologic setting.

Thus, intrusion of the Cuddy Mountain Complex occurred during a period of limited and widely scattered intrusive activity. The major plutonism in western North America took place from Middle Jurassic to Early Tertiary time (Gilluly, 1965).

# METAMORPHISM

Both regional and contact metamorphism have affected the rocks at Cuddy Mountain. The country rocks, with the exception of the Columbia River Basalt, underwent contact metamorphism by intrusion of the complex. The intrusive rocks as well as the older country rocks were subjected to regional metamorphism during Middle or Late Jurassic time (Hamilton, 1963; Thayer and Brown, 1964; Lanphere and Irwin, 1965; Vallier, 1967). Regional metamorphism has partly obscurred the effects of contact metamorphism, especially in country rocks.

## Contact Metamorphism

The development of the "hybrid" phase from the gabbro is an effect of contact metamorphism. The mineralogical and chemical changes of the gabbro have been previously discussed.

The best example of contact metamorphism is found at the gabbro-porphyritic rhyolite tuff contact near the headwaters of the Crooked River (SE1/4 sec. 7). At the contact, the original pyroclastic texture of the tuff has been completely destroyed and a hornfelsic texture developed. Fine-grained anhedral quartz and subordinate anhedral augite crystals compose up to 25 percent of the metamorphosed host. Lesser amounts of hypersthene and magnetite are also present. With increasing distance from the contact, these minerals rapidly decrease in abundance, and the original pyroclastic texture of the host gradually reappears. The mineralogic components, and their occurrence immediately adjacent to the plutonic complex, indicate that host rocks belong to the pyroxene-hornfels facies of contact metamorphism. Turner (1968, p. 225) states that development of this facies is favored by shallow depths and high temperatures immediately adjacent to intrusive rocks of mafic or intermediate composition.

Hornfels was also developed in the Seven Devils Volcanics that crop out at the head of No Business canyon (S1/2 sec. 24 and N1/2 sec. 25, T. 17 N., R. 4 W.). Here the mineralogy, as previously described, consists largely of quartz (about 50 percent), sillimanite, albitic plagioclase, chlorite, epidote, actinolite, and magnetite. The presence of sillimanite indicates that the rock was at one time metamorphosed to the hornblende-hornfels or even pyroxene-hornfels facies, but later regional metamorphism has imposed retrograde effects to an assemblage that is characteristic of the greenschist facies. With increasing distance from the contact the mineralogy of the facies changes to assemblages dominated by andalusite, plagioclase (albitic), and tourmaline (schlorite). Although regional metamorphism has obscurred much of the original mineralogy, these rocks originally belonged to the hornblende-hornfels facies prior to that event.

These two occurrences are the only localities where effects of contact metamorphism are readily distinguishable. Both examples are adjacent to gabbro contacts, and the reasons for this relationship are twofold: (1) much of the complex is surrounded by gabbro; and (2) the relatively higher temperatures of gabbro in contrast to other phases, would develop mineral assemblages of a higher metamorphic grade. Although these assemblages were not stable during lower grade regional metamorphism, metastable remnants make it possible to recognize the prior effects of contact metamorphism. Low grade contact metamorphic facies such as the albite-epidote-hornfels facies have mineral assemblages that are essentially indistinguishable from those of the greenschist facies of regional metamorphism and propylitic hydrothermal alteration. Thus low grade contact metamorphism, if present, cannot be defined with precision at Cuddy Mountain.

## Regional Metamorphism

Regional metamorphism of pre-Tertiary rocks at Cuddy Mountain is evident from minerals that are characteristic of the chlorite zone of the greenschist facies as defined by Turner (1968). Mineral assemblages that contain chlorite, epidote, actinolite, and albite are stable over temperatures of 300° to 500° C. and pressures ($P_{H_2O}$) of 3 to 8 kb according to Turner and Verhoogen (1960).

The most abundant metamorphic minerals include quartz, albite, chlorite, actinolite, and epidote. Others commonly present are muscovite, biotite, montmorillonite, andalusite, and calcite, as well as metastable remnants of hornblende, plagioclase feldspar (more calcic than albite), pyroxene, and sillimanite. The assemblage of metamorphic minerals present varies from unit to unit, and these differences appear to be caused by primary compositional variations of the host and not by changes in the physical conditions of metamorphism. Comparison with the work of Slater (1969), Fankhauser (1969), and Wratcher (1969) suggests that the grade of regional metamorphism is uniform over the entire area. Because of their distribution about the plutonic complex, sillimanite and andalusite are thought to be products of contact metamorphism. Andalusite was probably stable during later regional metamorphism, as its stability range overlaps that of minerals of the greenschist facies. The continued presence of sillimanite, hornblende, plagioclase, and pyroxene on the other hand, suggests that equilibrium was not achieved during metamorphism, as these minerals are not stable under conditions of greenschist metamorphism.

The effects of regional metamorphism on plutonic rocks are difficult to separate from those of contact metamorphism, hydrothermal alteration, and deuteric proceeses. Minerals that may have been produced by regional metamorphism include chlorite, actinolite, epidote, and talc. The gabbro was the most strongly affected phase in the northern part of Cuddy Mountain. In contrast, Fankhauser (1969) reported that porphyritic granodiorite was most intensely metamorphosed on the southwest flank of the mountain. The degree of metamorphism varies with respect to location in the plutonic complex. For example, gabbro along the western border was originally mapped as "meta-gabbro," but the same rock type in the interior was termed "gabbro." The difference in the two types is merely one of degree of metamorphism, and the change is gradational.

# STRUCTURAL GEOLOGY

## Regional Setting

The Cuddy Mountains, Hitt Mountains, and Seven Devils Mountains form a line of north-northeast trending, doubly plunging anticlines that are separated by broad synclinal portions of the Columbia River Plateau (Livingston, 1923; Cook, 1954). Because Columbia River Basalt was included in the folding, the anticlines are thought to be of post-Middle Miocene age. Other structures of similar age, such as the Blue Mountains uplift and the Snake River downwarp, trend eastward (Cook, 1954). Cook (1954) suggested that the anomalous trend of the anticlines in western Idaho might be caused by renewed movement along pre-basalt, northeast-trending faults that are common in the region. Stresses involved in the post-basalt deformation may have caused renewed movement on pre-existing faults. Similarly, Hamilton (1962) has suggested that Cuddy Mountain lies within the Columbia Plateau province, which is characterized by north-trending normal faults and irregular domal or anticlinal uplifts. These structures are superimposed upon northeast-trending, regionally metamorphosed basement rocks that have been intruded by semiconcordant stocks and batholiths associated with a Late Jurassic orogeny (Hamilton, 1962).

## Folding

The Cuddy Mountain Plutonic Complex is located in the core of a north-northeast trending anticline. Mesozoic country rocks dip steeply to the northwest and strike northeasterly on the western flank of the anticline. The eastern flank is not exposed. Folding in the Cuddy Mountain region has taken place during four or possibly five periods of tectonism since Late Triassic time. Three of these periods of deformation are marked by angular unconformities between the following stratigraphic units: (1) Seven Devils Volcanics and red conglomerate, (2) porphyritic rhyolite tuff and Lucile Series, and (3) Lucile Series and Columbia River Basalt. A fourth period of deformation is represented by the folding of the Columbia River Basalt. An unconformity may also exist between the red conglomerate and porphyritic rhyolite tuff, but no direct evidence for such a relationship was found.

From paleontological evidence, the time of uplift and erosion of the Seven Devils Volcanics (dated as Late Triassic by Fankhauser, 1969) can be bracketed between Late Triassic and Early Jurassic. The latter date is that obtained for the red conglomerate that overlies with angular unconformity the Triassic Seven Devils Volcanics. Abundant clasts of Seven Devils Volcanics found in the red conglomerate are further evidence of the unconformity. Dickinson (1964) describes a major Early Jurassic orogeny in rocks of central Oregon, and the tectonism at Cuddy Mountain may be a manifestation of the same event.

The Lucile Series overlies porphyritic rhyolite tuff and all older units with angular unconformity. Dips of the underlying units average approximately 65° NW and those of the Lucile Series average about 50° NW. Because the age of the Lucile Series is unknown, the age of pre-Lucile deformation cannot be closely bracketed. According to Hamilton (1962), several episodes of tectonism occurred in the area during Jurassic time, of which the one described and dated by Dickinson is only one of several.

Another major angular unconformity in the area exists between the Triassic-Jurassic metamorphics and Miocene to early Pliocene Columbia River Basalt. Hamilton (1962) has suggested that the major Mesozoic tectonism in the area took place in Middle to Late Jurassic time. This even, which included folding and uplift, metamorphism, and the intrusion of major plutonic bodies, probably represented the destruction of the geosyncline that was present in the area during much of Late Paleozoic, Triassic, and Jurassic time. This orogeny may have been accompanied by the intrusion of the plutonic complex.

After early Pliocene time, the flows of the Columbia River Basalt were warped into broad folds. At Cuddy Mountain, they dip away from the topographic high in all directions. This relationship and their distribution indicate that they lapped up against and flowed over the top of the mountain.

## Faulting

### Reverse Faulting

Livingston (1932) demonstrated the presence of a major thrust fault in western Oregon and northeastern Idaho. He indicated that it extended northeast from the Bay Horse mine in Oregon to Grade Creek at Cuddy Mountain and possibly farther north into the Bitterroot area. According to him, the fault dips variably from 20° to 60° to the northwest and has a possible vertical displacement of 1500 feet near Lime, Oregon.

At Cuddy Mountain, Slater (1969) mapped a high angle reverse fault that can be traced northeast into the thesis area, where it trends northeasterly along Ellie May Creek on the western flank of the mountain, crosses over the divide just south of the Lead Zone mine, and parallels the Crooked River to a point where it crosses the north-central border of the map area in sec. 3.

Evidence for the fault includes: (1) repetition of the stratigraphic sequence of the Seven Devils Volcanics, red conglomerate, and porphyritic rhyolite tuff; (2) a steeply dipping fault scarp in Ellie May Creek; and (3) the presence of highly sheared rock, breccia, slickensides, and fault gouge.

Generally, the fault is localized in the red conglomerate. Both the conglomerate and porphyritic rhyolite tuff are repeated. In some localities, however, the fault crosses the stratigraphic boundary and traverses units of the Seven Devils Volcanics as well. Thus, the vertical displacement of the fault is variable, ranging from about 400 feet to almost 1000 feet where thick sections of Seven Devils Volcanics are included in the fault block.

At the Yellowjacket mine near Mineral, Idaho, a similar lithologic sequence displays shears, drag folds, and slickensides. Moreover, the stratigraphic sequence appears to be repeated, although the evidence was not examined in detail. Accordingly, the writer agrees with Livingston (1932) that this fault may be continuous into the Mineral district.

## Normal Faulting

At least two, and possibly three, periods of normal faulting can be recognized at Cuddy Mountain. The older faults strike northeast and more or less parallel the trend of the pre-Tertiary country rocks. These faults do not displace Columbia River Basalt flows but disappear beneath them. The second group of normal faults strike northwest and displace Columbia River Basalt. However, some of these faults were apparently active during both Mesozoic and Cenozoic Eras.

The trends of these two fault groups agree with those described by Hamilton (1962) for pre-Tertiary and Tertiary faults of the region.

The older faults are found in the country rocks along the western scarp of Cuddy Mountain. They are recognized by the presence of slickensides and narrow breccia zones, by the repetition of beds, and by abrupt changes in the dip of the wall rocks (which suggests that the movement had a rotational component).

Several faults can be traced northwest across the thesis area on aerial photographs. These faults displace pre-Tertiary country rocks, members of the plutonic complex, and Columbia River Basalt, and thus appear to be Tertiary in age. However, the following features suggest that movement occurred on these faults both in Mesozoic and Cenozoic time: (1) several faults are mineralized (the Kismet mine and breccia to the northwest, the Cuddy mine, and gold mineralization north of the Cuddy mine); (2) hydrothermal alteration is concentrated about the fault zones in some localities; and (3) the brecciated porphyritic granodiorite at the Kismet mine and nearby in the SE1/4 sec. 16 appears to have been emplaced along one of these faults.

An interesting geomorphic feature of the area, the Devils Slide located in the SW1/4 sec. 21, is actually a fault scarp produced by one of these steeply dipping normal faults.

Two northwest trending faults in the thesis area show no evidence of pre-Tertiary movement. (However, no evidence discounting earlier movement was found.) One occurs along the west-northwest trending Placer Creek (sec. 16 and 17). Gabbro south of the fault is displaced upward into contact with overlying Columbia River Basalt. Sheared gabbro in the stream bed is further evidence of faulting. A second fault that trends northwest in Ellie May Creek can be traced on aerial photographs through the Columbia River Basalt at the top of Cuddy Mountain (SE1/4 sec. 13 and NW1/4 sec. 19), and into the plutonic complex where it disappears. John King (1971, M. S. thesis in preparation) describes a fault farther to the southeast that is on strike with this fault.

According to Fankhauser (1969), the lower Picture Gorge member of the Columbia River Basalt near the top of Cuddy Mountain is evidence for post-Miocene uplift, perhaps in the form of block faulting. The writer suggests that this relationship may have formed by a combination of block faulting (perhaps along pre-existing fault zones) and onlap of basalt against a topographic high.

# ECONOMIC GEOLOGY

## Mining History

Numerous prospect pits, adits, and waste dumps on Cuddy Mountain attest to the long and largely unsuccessful mining history of the district. Major development has taken place at the Lead Zone (lead, zinc, and silver), Belmont (lead, zinc, and silver), Railroad (copper), IXL (copper and molybedenum), and Cuddy (gold and copper) mines. Although mineralization is widespread and varied at Cuddy Mountain, production to date has been small. Mineral exploration continues at the present time with prospectors, small mining companies, and corporate giants all working in the area. The possibility is very real that a major deposit will be discovered in the district; especially if exploration methods become available that "penetrate" beneath the wide-spread cover of Columbia River Basalt.

## Classification of Mineral Deposits

The mineral deposits at Cuddy Mountain may be defined as magmatic concentrations, contact metasomatic deposits, and hydrothermal deposits according to the genetic classification of Bateman (1950). All mineralization is believed to be genetically related to the plutonic complex.

Apparent magmatic concentrations of pyrite and chalcopyrite occur locally in the gabbro of the plutonic complex. Evidence of their magmatic origin includes: (1) occurrence in the most mafic (gabbroic) phase of the complex; (2) lack of discernable structural control for the mineralization; (3) the "bleb-like" form of the sulfide grains; (4) lack of alteration and replacement features; and (5) textural similarity to the normal gabbro (Fankhauser, 1969). Similar deposits elsewhere are thought to have formed by the separation of an immiscible sulfide melt during crystallization of a gabbroic magma (Hawley, 1962).

Contact metasomatic deposits of copper-iron sulfides and iron oxides are common on the southwestern flank of Cuddy Mountain as replacements of limestone beds in the Seven Devils Volcanics. The principal minerals of these deposits are pyrite, chalcopyrite, magnetite, and hematite. They are localized in tactites of garnet, actinolite, and epidote (Fankhauser, 1969). The largest of these deposits is that of the Railroad mine which is presently being mined for copper. However, contact metasomatic deposits are not present in the area mapped because calcareous sediments are lacking.

On the basis of the mineralogy and textures, the hydrothermal deposits of the district may be subdivided into epithermal types (largely cavity or vein fillings) and mesothermal types (combined cavity filling and replacement) according to the classifications of

Lindgren (1933) and Bateman (1950). Examples of epithermal deposits, in which cavity filling was the dominant process, include lead-zinc-silver deposits, such as the Lead Zone and Belmont mines, which are localized in shear zones in the country rock. These and many similar prospects are localized at distances up to 4000 feet from the plutonic complex. Also, gold deposits of the Cuddy mine as gold-quartz veins and cavity fillings of fault zones occur in porphyritic granodiorite and gabbro that have been intensely argillized. The mineralogy, textures, and distance from inferred sources collectively suggest that these deposits are of epithermal origin.

Examples of mesothermal deposits in which both cavity filling and replacement occurred include the disseminated copper-molybdenum deposits at the IXL and Kismet mines. Mineralization occurs both in breccia zones and disseminated in adjacent plutonic host rocks. These two deposits have been studied in appreciable detail.

## The IXL Mine

### Introduction

The IXL mine is located on the southwest flank of Cuddy Mountain near the head of the western fork of Little Pine Creek (NE1/4 sec. 11, T. 16 N., R. 4 W.). The deposit was discovered at least 50 years ago, and several major mining companies have attempted to develop it. The major development consists of an adit 900 feet long. Mineralization occurs both in the intrusive rocks (quartz diorite and porphyritic granodiorite) and in large xenoliths of the Seven Devils Volcanics.

## General Geology

A detailed geologic map of the IXL mine area is given in Figure 10. The mine is situated near the contact between quartz diorite and porphyritic granodiorite. These rocks appear to be closely equivalent in age, chemistry, and mineralogy to those of the plutonic complex in the principal area mapped to the north. However, another intrusive rock type, described by Fankhauser (1969) as an altered porphyritic granodiorite or albite granite occurs in the area. He suggested that it formed by albitization and silicification of the porphyritic granodiorite and noted its similarity to rock types from eastern Oregon reported by Gilluly (1933).

Several large blocks of Seven Devils Volcanics were found in the intrusive rocks. They are generally located near the contacts between two or more plutonic phases.

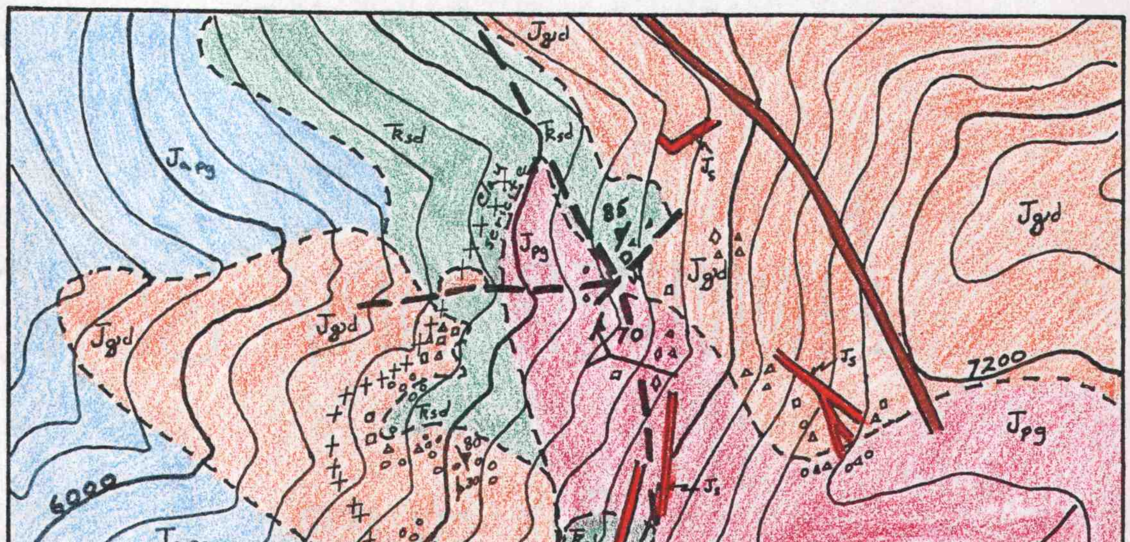
Two distinctive types of dikes occur in the vicinity of the mine. The older, silicic dikes are commonly altered and mineralized. They are generally aplitic in texture. A northwest trending, post-

Figure 10. Geology, mineralization, and alteration at the IXL Mine.

| | | | |
|---|---|---|---|
| - - - - - - | Geologic contact | ▲ | Fracture altitude |
| ▬ ▬ ▬ | Fault | Tib | Intrusive Columbia River Basalt |
| sericite + + + + + clay | Approximate boundary between argillic and potassic alteration | Js | Silicic Dike |
| | | Japg | Altered porphyritic granodiorite (albite granite) |
| ◊ ◊ ◊ | Molybdenite | Jpg | Porphyritic granodiorite |
| △ △ △ | Chalcopyrite | Jqd | Quartz diorite |
| □ □ □ | Pyrite | Ꞧ sd | Seven Devils Volcanics |
| ○ ○ ○ | Malachite | | |
| ≻— | Adit | | |

0 250 500 1000

1000 Feet



mineralization lamphrophyre is exposed over a length of more than 1500 feet. It is fresh in appearance and may be genetically related to the Columbia River Basalt.

Faults are common in the area. A major northwest-trending fault can be traced for several miles on aerial photographs and is seen as a wide shear zone in the IXL mine adit. Several other high angle faults are present, and most have northwest or northeast trends. In addition, a fault with a significant strike-slip component can be seen in the adit. Zones of intense fracturing and brecciation are associated with these faults, and the sulfides are most commonly localized along these zones.

## Mineralogical Effects

Ore Mineralogy. The IXL mine is an example of a porphyry-type copper deposit in that a porphyritic rock of intermediate composition is intimately associated with mineralization that consists in part of sulfides disseminated in the host rock. However, the IXL mine differs from the classical disseminated deposit in that the most significant mineralization occurs in shear and breccia zones. The host rocks become structurally similar to stockworks in areas of intense fracturing (Fankhauser, 1969).

Important ore minerals are chalcopyrite, molybdenite, and minor bornite. Pyrite and minor pyrrhotite are also present.

Secondary magnetite is abundant, especially in breccias, where it forms a large part of the matrix. It is partially oxidized to hematite. The paragenetic sequence, as determined from hand specimen and polished section study, is molbydenite, chalcopyrite, pyrite, and magnetite.

The crudely zoned mineralization is depicted in Figure 10. The sulfide mineralogy changes progressively outward from the center of the deposit (near the adit) from chalcopyrite-molybdenite to chalcopyrite-pyrite to pyrite. As shown in Figure 11, a somewhat similar zonation occurs on a larger scale in the adit. The most intense mineralization is found in a breccia zone about 500 feet from the portal to the adit. Crosscuts from the main tunnel follow the zone for a few tens of feet to the northeast and southwest. Magnetite, chalcopyrite, molybdenite, and quartz form the matrix of the breccia. Away from this zone, the molybdenite content decreases abruptly, chalcopyrite decreases gradually, and pyrite increases. The distribution of metals in rocks of the adit, as shown in Figure 12, confirms this trend. Copper values (370 to >1000 ppm) are high for nearly the entire length of the tunnel, but appear to diminish near either end. Molybdenum is definitely concentrated about the breccia zone (19 to >300 ppm) and even zinc (90 to 225 ppm) and lead (40 to 140 ppm) values are relatively high in this structural zone.

The zone of brecciation was probably formed by the major

Figure 11. Geology, mineralization, and alteration of the IXL Mine adit.

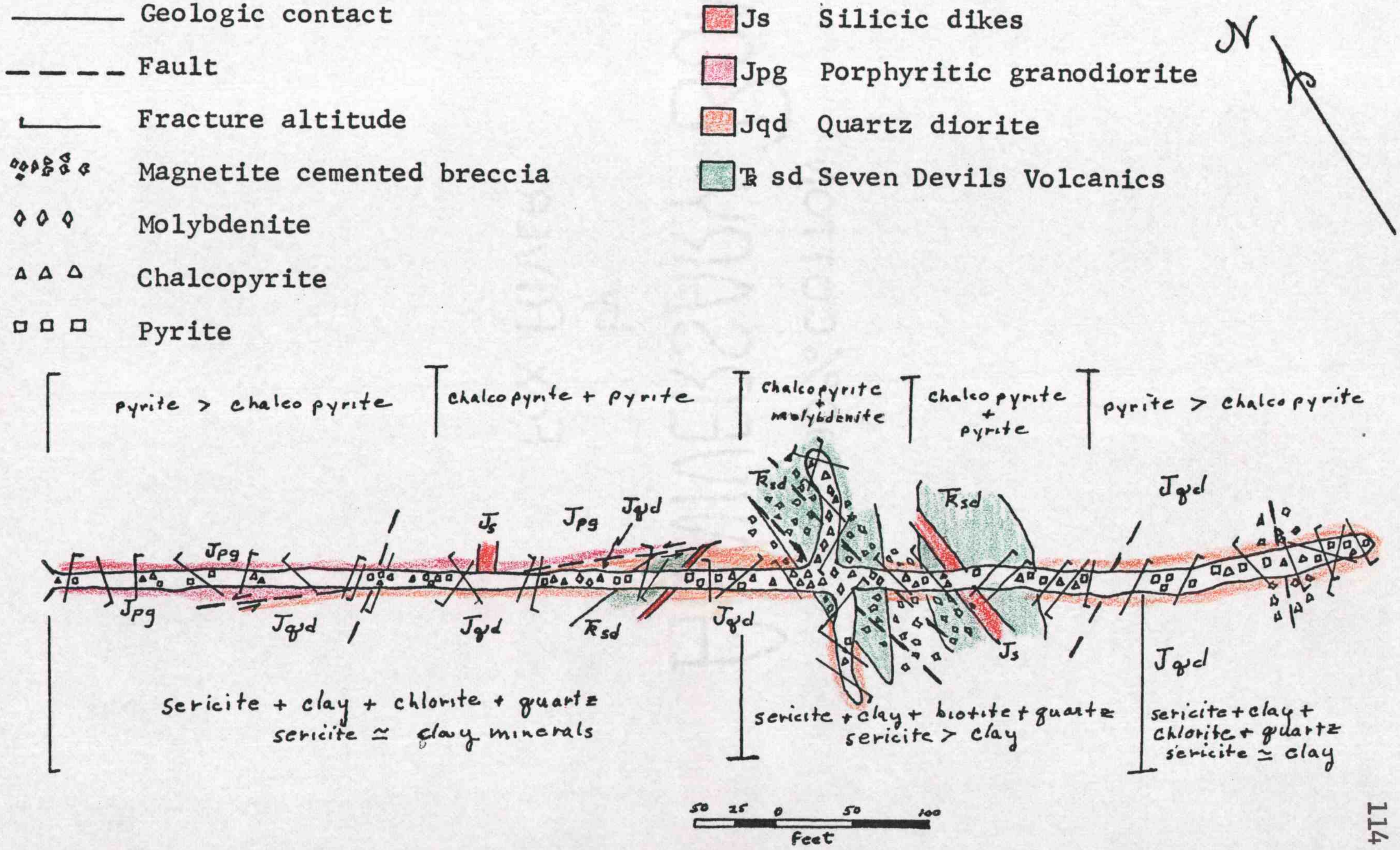
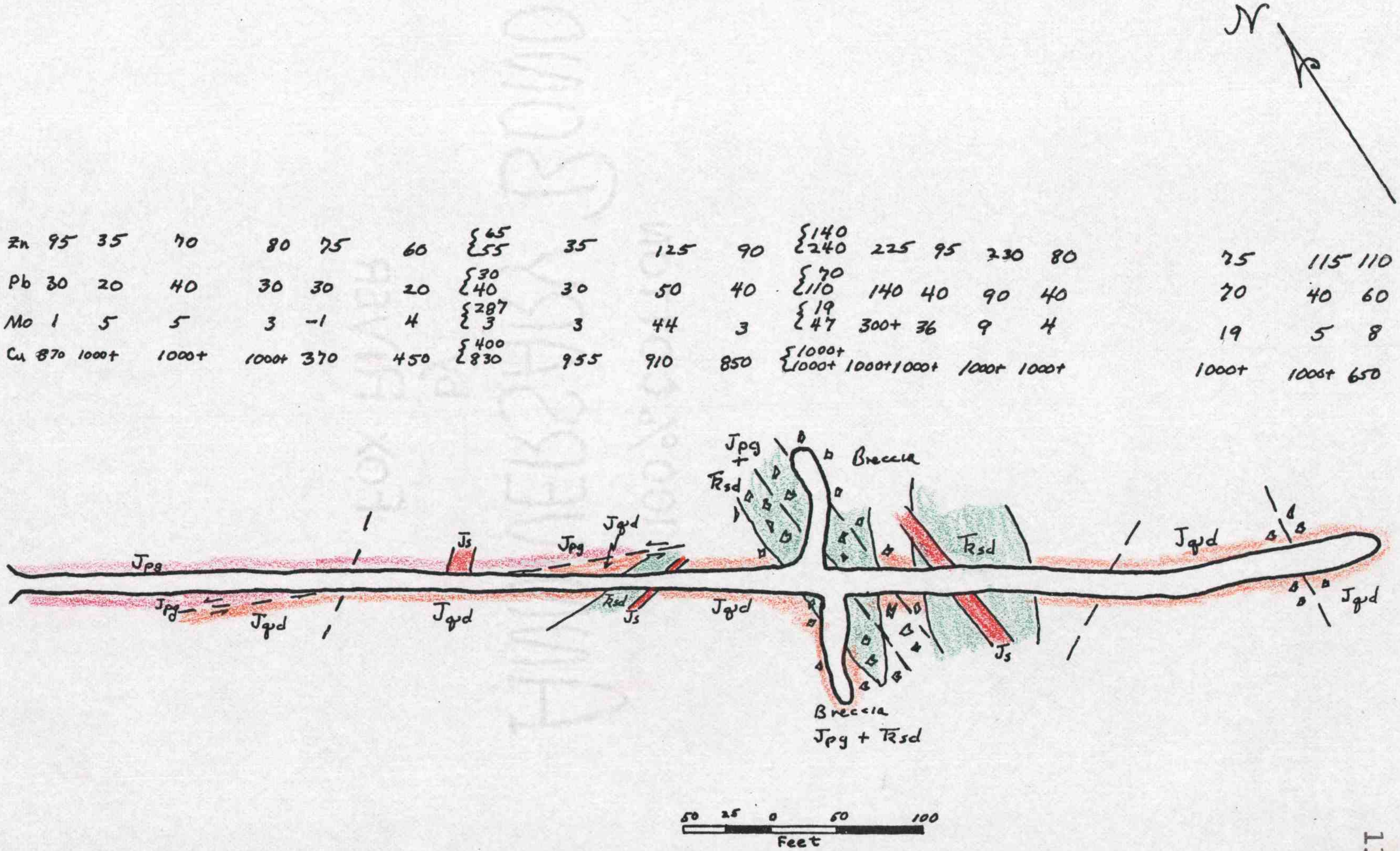


Figure 12. Trace element distribution in the IXL Mine adit (ppm).



northwest-trending fault described previously (see Figure 11). This fault zone crosses the adit at a moderate angle, thus making the shear zone, and consequently the zone of intense mineralization, appear several feet wider than its actual width. With the exception of one hole, diamond drilling from the surface has failed to locate this zone or any other significant mineralization. The hole that penetrated mineralization was drilled from above the adit and intersected the sulfide zone at approximately the altitude of the adit. Ten feet of core averaged about 2.75 percent copper, the next 30 feet averaged 1 percent, and the following 170 feet averaged 0.4 percent. The actual width of the mineralized zone is small. The hole was drilled vertically into the steeply dipping fault zone. Further drilling failed to intersect the mineralized zone which is apparently displaced by the east-striking fault that is present about 200 feet northwest of the adit. This possible structural offset should be considered in subsequent exploration drilling at the IXL property.

Alteration Mineralogy. Hydrothermally altered rocks at the IXL mine belong to either the potassic or argillic groups of the classification proposed by Creasy (1966). Potassic alteration is concentrated in the central part of the area. The typical assemblage is quartz-sericite-chlorite ± biotite. Hydrothermal biotite was found only in or near the breccia zone at the IXL mine adit where ore sulfides are the most abundant. Assemblages that contain this whispy, green mica represent the highest grade of hydrothermal alteration found in the vicinity of the mine. Mineralogical changes involved in potassic alteration can be seen by comparing the modal analyses of sample A-14 and F48G (Table 14). The altered sample (A-14) is much richer in quartz, sericite, iron oxides, and chalcopyrite. The secondary quartz occurs in small veinlets. The amount of hydrothermal biotite in the altered sample is approximately equal to the amount of primary biotite in the fresh sample (2 percent).

Rocks altered to the argillic group (sample X-24, Table 14) fringe those of the potassic group as shown in Figure 11. The assemblage typical of the argillic group is quartz-kaolinite-sericite-chlorite. Kaolinite is much more abundant than sericite, and both minerals replace feldspars. With the exception of chlorite, mafic minerals are essentially absent in this zone.

The potassic and argillic groups grade into one another. For example, petrographic and X-ray diffraction analyses of several samples revealed the presence of kaolinite, sericite, montmorillonite-chlorite, and chlorite in subequal amounts along with quartz.

A general zonation of this alteration occurs in the IXL mine adit as is shown in Figure 12. The potassic assemblage of hydrothermal biotite-sericite-chlorite-quartz occurs in the breccia zone about 500 feet from the portal. Away from this zone, in either direction, an assemblage of quartz-sericite-montmorillonite-chlorite is

Table 14. Chemical (weight percent) and modal (volume percent) analyses of two altered porphyritic granodiorite samples from the IXL mine and of one fresh sample.

| | F48G (fresh) | X-24 (argillic) | A-14 (potassic) |
|---|---|---|---|
| $SiO_2$ | 67.20 | 73.77 | 62.40 |
| $TiO_2$ | 0.56 | 0.20 | 0.67 |
| $Al_2O_3$ | 15.97 | 13.22 | 12.24 |
| $Fe_2O_3$ | 1.04 | 1.24 | 6.15 |
| FeO | 2.66 | 0.98 | 3.33 |
| MnO | 0.10 | 0.20 | 0.09 |
| MgO | 1.07 | 0.50 | 1.78 |
| CaO | 3.99 | 2.25 | 2.40 |
| $Na_2O$ | 3.67 | 4.69 | 3.13 |
| $K_2O$ | 1.87 | 1.11 | 1.45 |
| $H_2O^+$ | 1.21 | 1.08 | 2.72 |
| $H_2O^-$ | 0.40 | 0.58 | 0.53 |
| $P_2O_5$ | 0.13 | 0.09 | 0.11 |
| Total | 99.87 | 99.73 | 97.00 |
| Qtz. | 29 | 28 | 35 |
| Plag. | 54 | 46 | 22 |
| Orth. | 4 | 6 | tr |
| Hb. | 1 | -- | -- |
| Biot. | 2 | 1 | 2 |
| Chl. | 2 | 4 | 2 |
| Seric. | 3 | 4 | 10 |
| Clay | 3 | 11 | 2 |
| Epid. | 1 | tr | 1 |
| Mag. | 1 | tr | 10 |
| Hem. | -- | tr | 10 |
| Cpy. | -- | -- | 5 |
| Py. | -- | tr | tr |
| Ap. | tr | tr | tr |

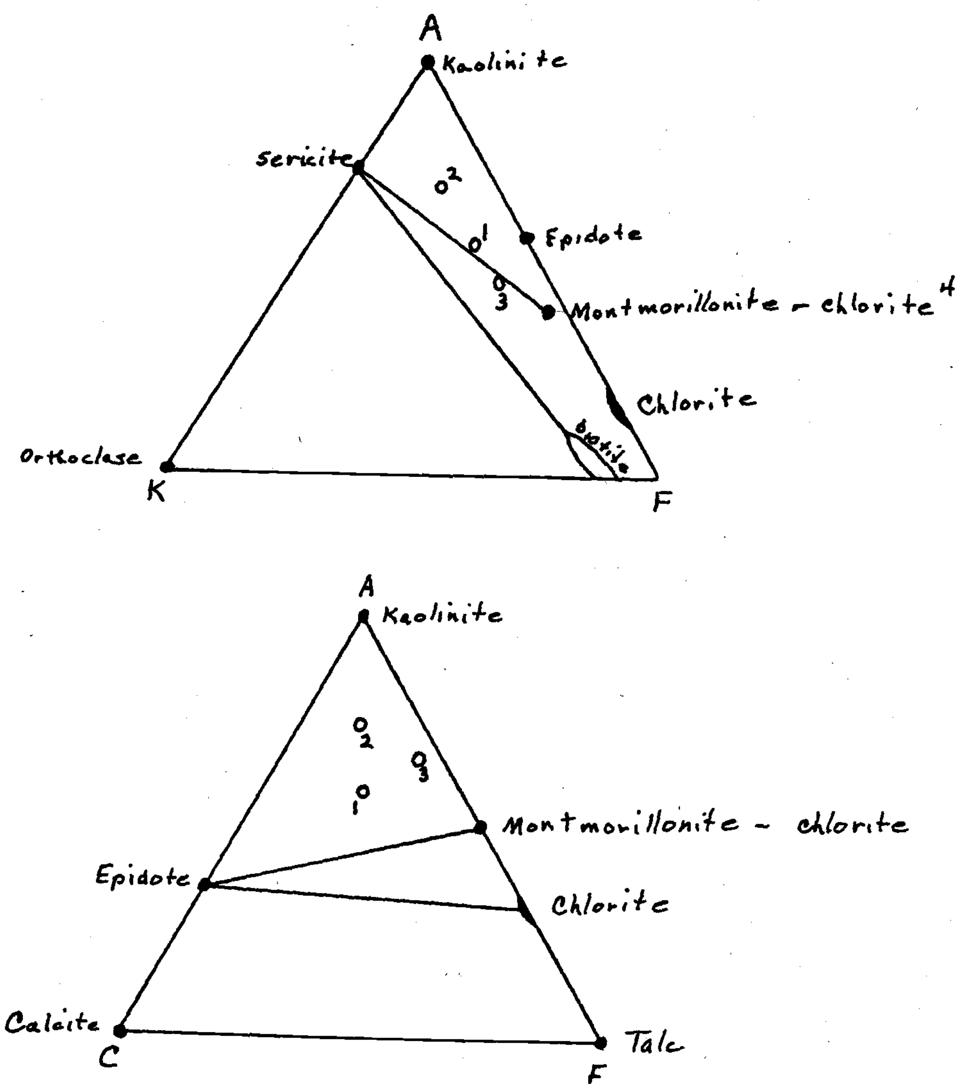
encountered, grading into an assemblage of quartz-sericite-montmorillonite-chlorite-kaolinite.

The AKF and ACF diagrams present in Figure 13 indicate that samples containing kaolinite, montmorillonite-chlorite, and chlorite are disequilibrium assemblages. This association, present in many of the rocks of the area, may have arisen from later regional metamorphism.

## Chemical Effects

The mineralogical changes that were affected by hydrothermal alteration of the porphyritic granodiorite are indicated by the differences in chemistry between the fresh (F48G) and two altered samples (X-24 and A-14) given in Table 14. Although sample A-14 contains secondary quartz, the $SiO_2$ content is lower than that of the fresh granodiorite. However, approximately 25 percent of the altered rock is made up of oxides and sulfides, whereas only two percent of the fresh rock is composed of non-silicate minerals. Because the oxides and sulfides take the place of silicate minerals, especially aluminum silicates, low $Al_2O_3$ and $SiO_2$ values for sample A-14 are understandable. The high FeO and $Fe_2O_3$ contents of sample A-14 are indicative of abundant iron oxides and sulfides. This iron enrichment is also shown on the AKF and ACF diagrams of Figure 13, where sample A-14 plots on the F side of sample F48G. A part of the iron may have

Figure 13. AKF and ACF alteration diagrams of porphyritic granodiorite from the IXL Mine area.




1. F48G Relatively fresh porphyritic granodiorite

2. X-24 Argillic facies (clay sericite, kaolinite montmorillonite chlorite)

3. A-14 Phyllitic facies, magnetite cemented breccia (sericite clay, montmorillonite-chlorite kaolinite)

4. Montmorillonite-chlorite composition from Earley and others (1956)

been derived from the leaching or replacement of mafic minerals in the argillic zone. The alteration of plagioclase feldspar to sericite (and possibly partial albitization of the plagioclase) is shown by the lower CaO content of sample A-14.

The chemical analysis of sample X-24 from the argillic zone shows an increase of about 6.5 percent in silica content relative to fresh granodiorite. This effect is caused by silicification during hydrothermal alteration. The chemical effect of the kaolinization of plagioclase feldspar is not readily apparent in the chemistry of the rocks, as the fresh sample has nearly three percent more $Al_2O_3$ than does the altered sample. However, the alumina content of the altered rock (X-24) has increased relative to all other major oxide components in the AKF and ACF diagrams of Figure 13, where X-24 plots on the A (alumina) side of sample F48G. The alteration of plagioclase to kaolinite is also revealed by a decrease in CaO in altered rock. Nearly complete alteration of mafic minerals is shown by the low FeO, MgO, and MnO values for sample X-24.

## Physical and Chemical Conditions of Alteration and Mineralization

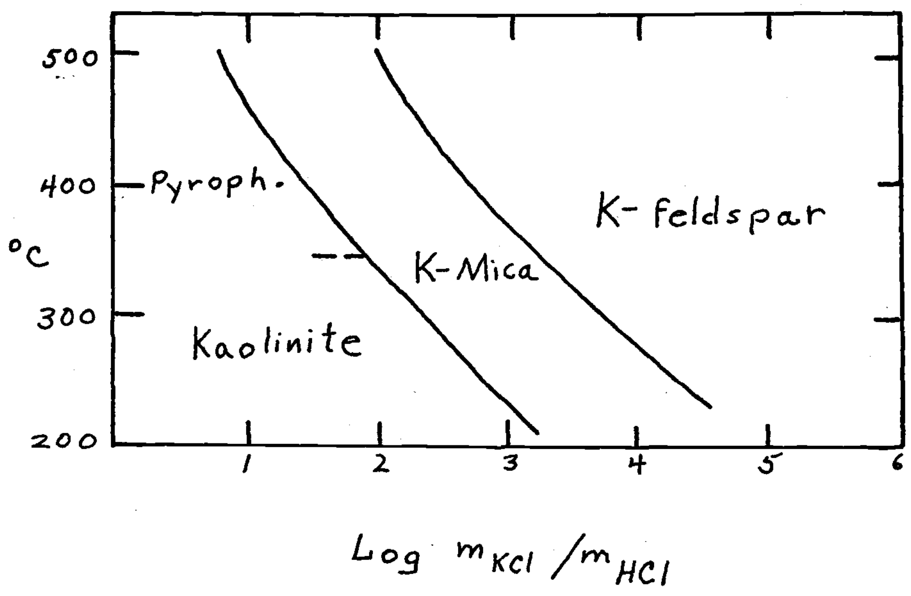
According to Meyer and Hemley (1967), the major physical and chemical factors controlling hydrothermal ore and gangue mineral assemblages include: (1) pH, particularly the ratio of the activities of

$K^+$ and $Na^+$ to that of $H^+$; (2) oxygen fugacity; and (3) sulfur fugacity. The absence of hydrothermal potassium feldspar at the IXL mine, including areas of molybdenite mineralization, is unusual for a porphyry copper deposit and may indicate a relatively low temperature of alteration. However, Meyer and Hemley (1967) suggest that the $K^+/H^+$ ratio is equally or more important (see Figure 14), and the generally potassium-deficient character of the Cuddy Mountain plutonism indicates that $K^+$ deficiency may be the major reason for the lack of hydrothermal orthoclase. Such an environment might seem ideal for the formation of paragonite rather than sericite, but Hemley (1970, personal communication) indicates that, because of the narrow stability field of paragonite, sericitic white mica will form even at very low concentrations of potassium.

Intense base-leaching is indicated by the absence of mafic minerals and the kaolinization of feldspars in rocks that have been argillized. Argillic alteration is favored by low temperatures and low $K^+/H^+$ ratios, as shown in Figure 14 after Meyer and Hemley (1967).

According to Hemley and Meyer (1967) the formation of the ore mineral assemblage (chalcopyrite-molybdenite-pyrite-magnetite-hematite) and the alteration assemblage (quartz sericite-biotite-chlorite) is largely dependent upon the pH, oxygen fugacity, and sulfur fugacity at the site of deposition. They indicate that at 250°C. such alteration and sulfide mineral groups would develop in hydrothermal

Figure 14. Equilibrium relationships in the system $K_2O$-$Al_2O_3$-$SiO_2$-$H_2O$ in a chloride electrolyte environment at 15,000 psi total pressure. Taken from Meyer and Hemley, 1967, p.212.



environments that have a pH of approximately seven, an oxygen fugacity of about $10^{-33}$ atm., and a sulfur fugacity of approximately $10^{-14}$ atm. Assuming that deposition took place at 350° C., the pH would be about 4, the oxygen fugacity around $10^{-32}$ or $10^{-31}$ atm., and the sulfur fugacity approximately $10^{-9}$ atm.

## The Kismet Mine

### Introduction

The Kismet mine is located on a knoll overlooking Hornet Creek (NW1/4 sec. 22 and SW1/4 sec. 15). Although the property is called "Kismet mine," it was discovered in 1964 and has yielded no mineral production to date. The prospect is heavily trenched and has been explored at depth by several diamond drill holes.

### General Geology

Mineralization at the Kismet mine is associated with a tourmaline granite breccia pipe (Figure 15). The pipe is localized in porphyritic granodiorite that was intruded where a gabbro-quartz diorite contact intersects a northwest trending fault. A smaller, less well-developed tourmaline breccia crops out along this same fault approximately one-half mile northwest of the Kismet mine. Movement along this fault may have been responsible for the initial brecciation of the

Figure 15. Geology of the Kismet Mine.

- - - - - Geologic Contact

— — Fault

o Sample Location

Jtg Tourmaline Granite Breccia

Js Silicic Dike

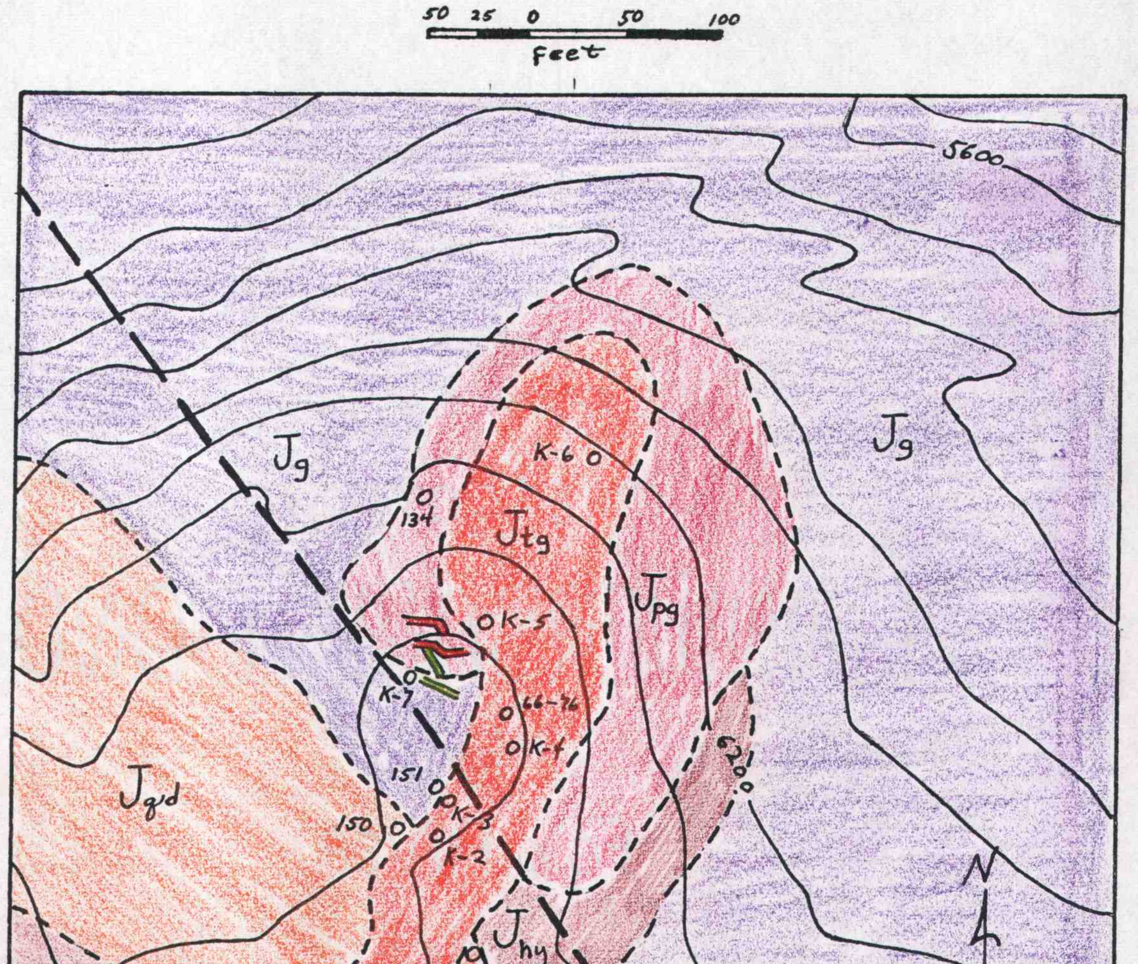
Jm Mafic Dike

Jpg Porphyritic Granodiorite

Jqd Quartz Diorite

Jhy Hybrid Gabbro

Jg Gabbro



porphyritic granodiorite, but fluidization processes (Reynolds, 1954) were also important, as indicated by the rounded fragments of the breccia. The lithology, petrography, and chemistry of the tourmaline granite breccia have been previously discussed and are considered here only in terms of alteration processes.

## Mineralogical Effects

Ore Mineralogy. In general, the bulk of the mineralization appears to be associated with the matrix of the breccia or is fracture controlled. Copper and molybdenum are the major base metals of the Kismet mine, as shown in Table 17. Because of intense weathering, copper sulfide minerals (chalcopyrite) are very rare in weathered outcrops of the Kismet mine. Poor exposures at and around the mine make the lateral distribution of the mineralization impossible to determine. Likewise a zonation of the metallization could not be established.

Examination of diamond drill cores showed that to depths of 500 feet, as at the surface, the sulfide minerals are oxidized and that the abundance of copper and molybdenum minerals is low. The oxidized state of the copper bearing minerals, the lack of supergene enrichment, and the apparently limited lateral and vertical extent of the mineralization make the chances of production from the Kismet mine rather unlikely.

Alteration Mineralogy. Modal analyses of several different rock types from the area of the Kismet mine are listed in Table 15, and the sample locations are plotted on the geologic map in Figure 15. Although contacts between the breccia and the surrounding rocks are not exposed, the abrupt change from intense potassic (potassium feldspar) to quartz-sericite alteration (as between samples K-2 and 150 in Figure 15) indicates that the hydrothermal effects are closely controlled by structure. Thus, the alteration at the Kismet mine is zoned about the breccia pipe. An assemblage of quartz-orthoclase-tourmaline occurs in the pipe itself. This assemblage is rimmed, with little gradation, by a quartz-sericite assemblage that grades outward into a quartz-sericite-kaolinite assemblage. Chlorite and epidote are present in all three assemblages but may be the result of later regional metamorphism.

Clasts in the tourmaline granite breccia are largely of porphyritic granodiorite. The mineralogical changes between the breccia and the granodiorite are (1) nearly complete replacement of plagioclase by orthoclase (sample K-6 displays orthoclase rimming plagioclase cores); (2) addition of tourmaline; (3) addition of secondary quartz; and (4) the replacement of mafic minerals by chlorite.

Chemical Effects

Chemical analyses of a tourmaline granite breccia sample

Table 15. Modal analyses of eleven samples from the Kismet mine and of a relatively fresh porphyritic granodiorite, and an average Cuddy Mountain gabbro and quartz diorite.

| | Rock Type | Qtz | Plag | Orth | Hb | Biot | Seric | Clay | Tour | Fe Ox[1] | Chl | Epid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65-76 | tour. breccia | 55 | -- | 30 | -- | -- | 1 | -- | 11 | 3 | -- | -- |
| K-1a | qtz. diorite (?) | 28 | 15[2] | | -- | -- | 42 | 2 | -- | 3 | 8 | 2 |
| K-2 | tour. breccia | 19 | -- | 47 | -- | -- | 2 | 6 | 14 | 6 | 6 | -- |
| K-3 | breccia | 48 | 4 | | -- | tr | 38 | -- | -- | 4 | 6 | -- |
| K-5 | tour. breccia | 30 | -- | 40 | -- | -- | 4 | 3 | 16 | 3 | 2 | 1 |
| K-6 | tour. breccia | 21 | tr | 48 | -- | -- | 13 | -- | 4 | 2 | 9 | tr |
| K-7 | gabbro | 10 | 41 | tr | 10 | 2 | 9 | 12 | -- | 8 | 7 | 1 |
| 134 | ppy. gd. | 29 | 40 | 3 | 5 | 1 | 10 | -- | -- | 4 | 6 | tr |
| 150 | qtz. diorite | 26 | 27 | tr | 15 | -- | 19 | 6 | -- | 4 | 3 | tr |
| 151 | gabbro | 6 | 42 | -- | 20 | -- | 19 | 4 | -- | 5 | 4 | tr |
| F48G[3] | ppy. gd. | 23 | 55 | 6 | 1 | 2 | 3 | 3 | -- | 1 | 3 | -- |
| Av. | gabbro[4] | 2 | 57 | -- | 5 | 2 | 7 | 5 | -- | 4 | 3 | -- |
| Av. | qtz. diorite | 22 | 48 | 15 | 7 | 6 | 7 | 1 | -- | 1.5 | 3 | 1 |

[1] Magnetite + hematite.

[2] Feldspar too altered to distinguish plagioclase and orthoclase.

[3] Fankhauser, 1969.

[4] Also 6 percent augite and 6 percent hypersthene.

(65-76) and a relatively fresh porphyritic granodiorite sample (F48G) are tabulated in Table 16. The breccia, relative to the fresh granodiorite, is depleted in CaO, $Na_2O$, and $Al_2O_3$ and enriched in $K_2O$. These chemical differences reflect the replacement of plagioclase feldspar by orthoclase. The breccia has a lower MgO, FeO, and MnO content (caused by alteration of mafic minerals) and a higher $Fe_2O_3$ content (caused by oxidation of iron from mafic minerals, magnetite, and iron sulfides) than fresh granodiorite. In addition, the breccia has a relatively high $B_2O_3$ content (1.67 percent) because of the high percentage of tourmaline.

The chemical composition of oxide components added to granodiorite to form the tourmaline granite breccia suggests that the fluids may have represented the final expression of hydrothermal activity associated with the Cuddy Mountain Complex. Potassium, silicon, and boron are elements that normally accumulate in the residual liquid of a differentiating magma. The fluids may have accumulated under pressure in the cupola of a magma chamber. When later suddenly released, possibly by faulting, the fluids migrated rapidly upward altering the host rocks. The most intense alteration (potassic) is confined to the breccia zone. The major alteration mineral changes abruptly from orthoclase to sericite outward from the breccia.

The trace element contents (Cu, Mo, Pb, and Zn) in the rocks of the Kismet mine are shown in Table 17. No zonation of the

Table 16. Comparison of the chemistry of tourmaline granite breccia sample 65-76 with porphyritic granodiorite sample F48G.[1]

| | 66-76 | F48G |
|---|---|---|
| $SiO_2$ | 66.39 | 67.20 |
| $TiO_2$ | 0.35 | 0.56 |
| $Al_2O_3$ | 13.60 | 15.97 |
| $Fe_2O_3$ | 5.10 | 1.04 |
| FeO | 0.74 | 2.66 |
| MnO | 0.04 | 0.19 |
| MgO | 0.52 | 1.07 |
| CaO | 0.14 | 3.99 |
| $Na_2O$ | 0.44 | 3.67 |
| $K_2O$ | 9.20 | 1.87 |
| $H_2O^+$ | 1.72 | 1.24 |
| $H_2O^-$ | 0.29 | 0.40 |
| $P_2O_5$ | 0.02 | 0.13 |
| $B_2O_3$ | 1.67 | --- |

Table 17. Trace element distribution in the rocks of the Kismet mine (ppm).

| | Cu | Mo | Pb | Zn |
|---|---|---|---|---|
| 66-76 | 130 | 26 | 5 | 20 |
| K-1a | 1000+ | 12 | 60 | 140 |
| K-2 | 515 | 7 | 40 | 70 |
| K-3 | 1000+ | 8 | 60 | 80 |
| K-4 | 185 | 13 | 40 | 75 |
| K-5 | 1000+ | 4 | 20 | 90 |
| K-7[1] | 335 | 3 | 40 | 40 |
| K-7[1] | 190 | 1 | 10 | 45 |

[1]Separate analyses of the same sample.

mineralization can be determined because of poor exposures. High copper values are represented in rocks of both the potassic (K-5) and sericitic (K-1a) alteration groups.

Physical and Chemical Conditions of Alteration

Meyer and Hemley (1967) have indicated that temperature and the $K^+/H^+$ ratio are the most important factors in determining the formation of alteration minerals in hydrothermal environments (see Figure 14). Intense potassic alteration at the Kismet mine is favored by a high temperature and a high $K^+/H^+$ ratio. The abrupt change to sericitic alteration implies a sharp decrease in temperature and/or $K^+/H^+$ ratio. With greater distance from the breccia, kaolinite may have formed at yet lower temperatures and $K^+/H^+$ ratios.

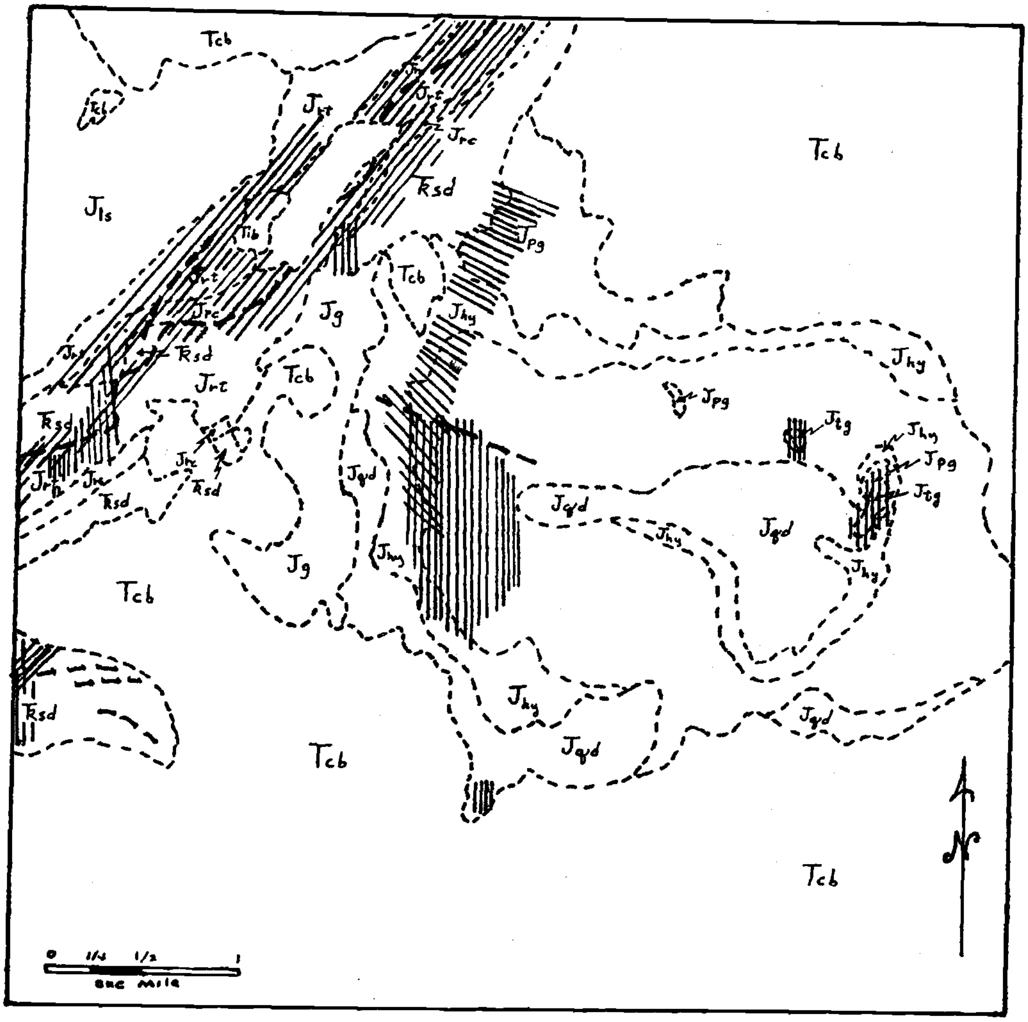
## Distribution of Metals

The distribution of common metals in the area mapped, based on field examination, trace element data, and published reports of mineralization, is shown in Figure 16. Moreover, the entire district exhibits two scales of zonation: (1) large scale zonation with lead, zinc, silver, and gold concentrated around the edges, and copper and molybdenum concentrated toward the center of the complex; and (2) small scale zonation around individual mineral deposits.

Figure 16. Distribution of types of mineralization in the thesis area.

| | |
|---|---|
| (vertical hatching) | Copper |
| (cross hatching) | Gold |
| (diagonal hatching) | Lead-Zinc-Silver |
| ------ | Geologic Contact |
| — — — | Fault |

| | |
|---|---|
| Tcb | Columbia River Basalt |
| Tib | Basalt Dikes and Plugs |
| Jls | Lucile Series |
| Jtg | Tourmaline Granite Breccia |
| Jpg | Porphyritic Granodiorite |
| Jqd | Quartz Diorite |
| Jhy | Hybrid Phase |
| Jg | Gabbro |
| Jrt | Porphyritic Rhyolite Tuff |
| Jrc | Red Conglomerate |
| Tsd | Seven Devils Volcanics |



## Distribution of Hydrothermal Alteration

Over much of the area, and particularly in country rocks, the mineralogical effects imposed by hydrothermal alteration have been obscurred by later regional metamorphism. However, hydrothermal minerals and textures are still discernible throughout most parts of the plutonic complex. Nonetheless propylitic alteration minerals are largely indistinguishable from those of regional metamorphism (chlorite, epidote, talc, and possibly actinolite).

Petrographic studies have revealed three mineral assemblages of hydrothermal alteration according to the classification of Creasy (1966). These include sericitic alteration (a subtype of the potassic group according to Creasy, 1966), argillic alteration, and propylitic alteration. Their distributions are recorded in Figures 17, 18, and 19. The intense potassic alteration at the Kismet mine is ignored in this discussion.

In general, sericitic alteration is concentrated in the central part of the complex (sec. 20), where sericite makes up more than 15 percent of the rock (Figure 17). Argillic alteration is most intense in the gabbro near the Cuddy mine (sec. 17 and 18) and in the porphyritic granodiorite north of the Cuddy mine (Figure 18). Clay mineral contents greater than 20 percent are common. The distribution of propylitic alteration is similar to that of the other two types, but

Figure 17. Contour map of sericitic hydrothermal alteration in the Cuddy Mountain Complex.

| | |
|---|---|
| ☐ 5 - 10% | Jg Gabbro |
| ☐ 10 - 15% | Jhy Hybrid Phase |
| ☐ > 20% | Jqd Quartz Diorite |
| ___Geologic Contact | Jpq Porphyritic Granodiorite |
| ---Contour (% Sericite) | Jtg Tourmaline Granite Breccia |

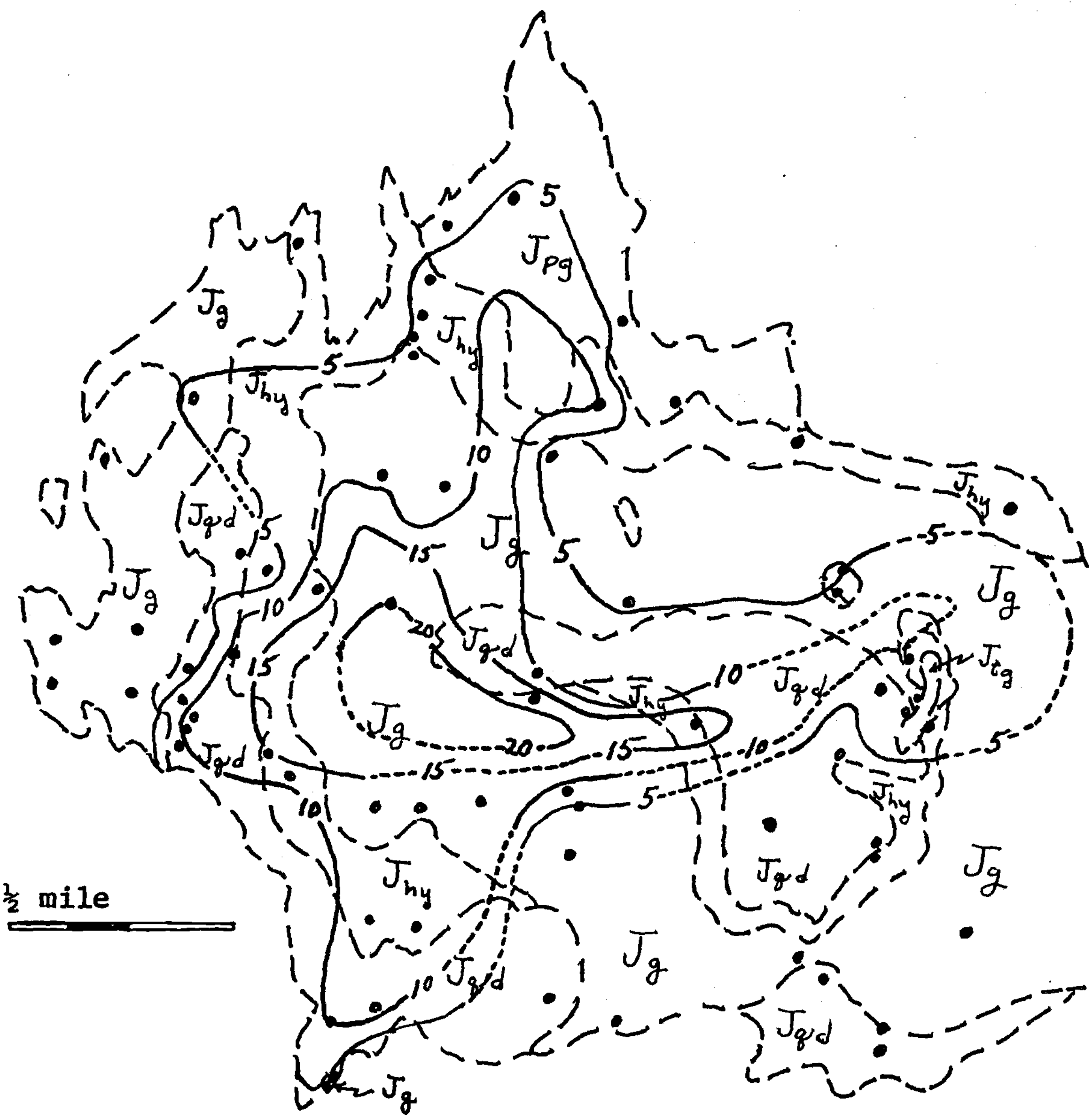
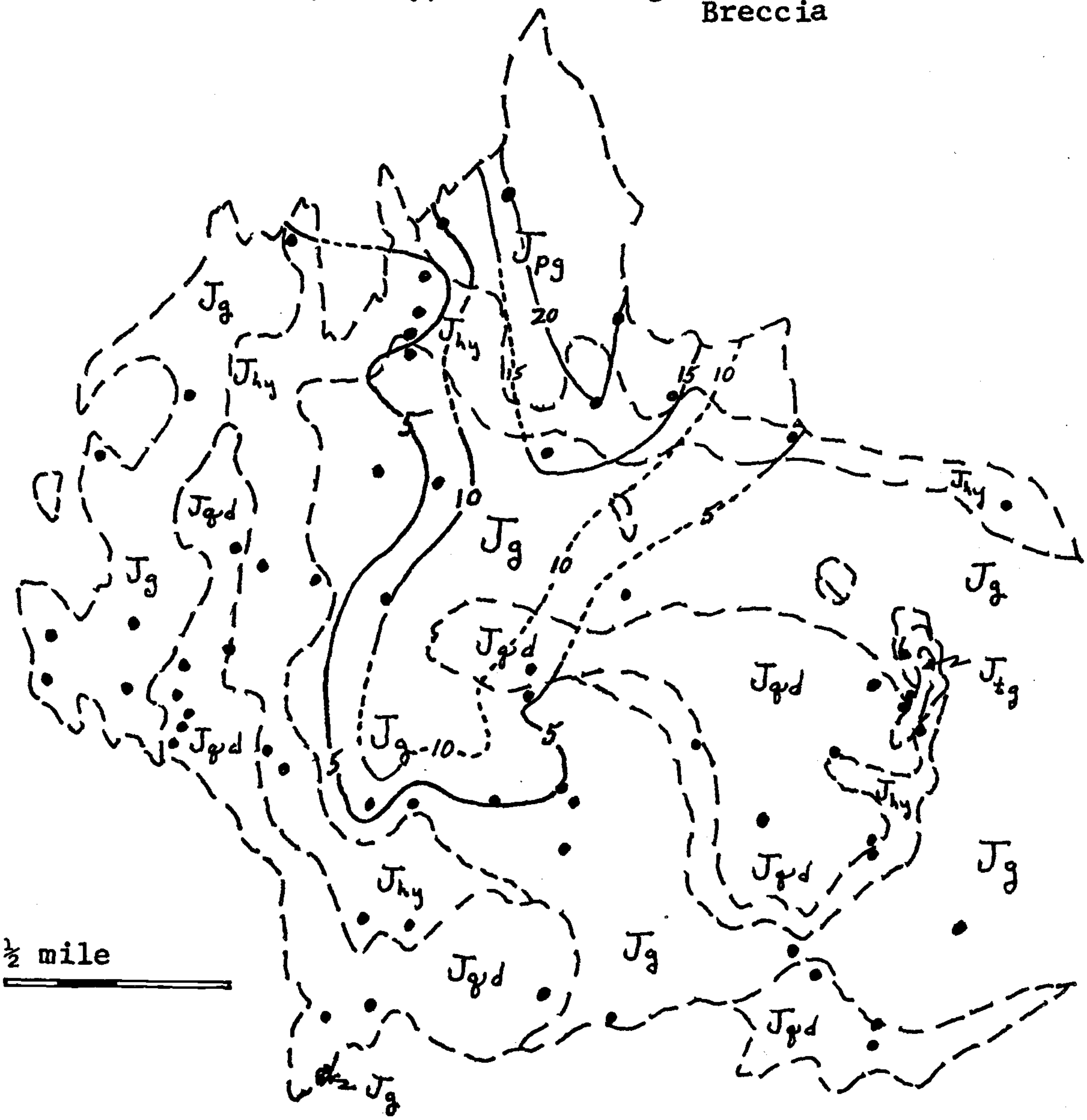


Figure 18. Contour map of argillic (mixed layer chlorite-montmorillonite + montmorillonite + kaolinite) hydrothermal alteration in the Cuddy Mountain Complex.

| | |
|---|---|
| ☐ 5 - 10% | Jg Gabbro |
| ☐ 10 - 15% | Jhy Hybrid Phase |
| ☐ > 20% | Jqd Quartz Diorite |
| — — — Geologic Contact | Jpg Porphyritic Granodiorite |
| ——---- Contour (% Clay) | Jtg Tourmaline Granite Breccia |



the alteration is less intense (Figure 19).

The distributions of alteration are controlled by rock type and structure. Intense argillic alteration is closely related to the porphyritic granodiorite, but effects are observed in the gabbro as well near the Cuddy mine area. This northerly trending zone of alteration is apparently controlled by the northwest trending fault in that vicinity (see Plate 1). The sericitic alteration is most intense (up to 20 percent) in the gabbro, located between two masses of quartz diorite (sec. 20). As shown in Figure 16, copper mineralization occurs in the area of strong sericitic alteration, whereas gold and minor copper occur in the argillized rocks. This distribution is consistent with the assumed T-P differences that lead to the classical partitioning of gold and copper between epithermal and mesothermal types of mineralization.

The chemical changes that were imposed on host rocks of the plutonic complex as they underwent strong sericitic or argillic alteration can be understood from comparisons of the chemical data listed in Table 18. As the intensity of sericitization increases, $K_2O$ increases and iron decreases (the latter possibly caused by the alteration of magnetite to chlorite). Iron released by the breakdown of ferromagnesian minerals may have been re-deposited in part as copper-iron sulfides in fractures and joints of the gabbro. Sulfides are common throughout most of the sericitized gabbro.

Figure 19. Contour map of prophyllitic (chlorite + talc + epidote + actinolite) hydrothermal alteration in the Cuddy Mountain Complex.

☐ 5 - 10%

☐ 10 - 15%

☐ > 20%

———Geologic Contact

——------ Contour (%Alteration)

Jg Gabbro

Jhy Hybrid Phase

Jqd Quartz Diorite

Jpg Porphyritic Granodiorite

Jtg Tourmaline Granite Breccia

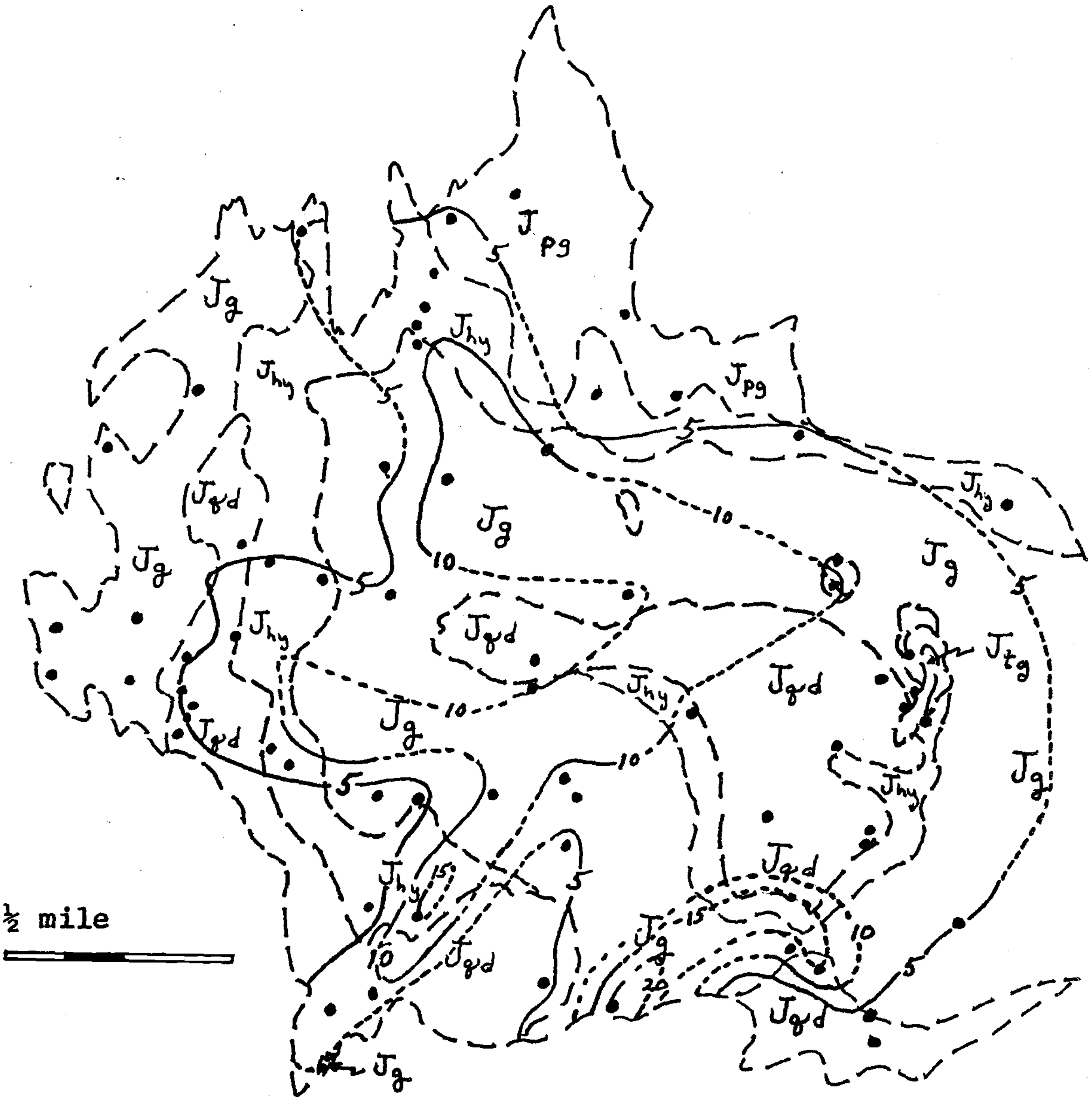


Table 18. Chemical changes in the zones of intense sericitic (gabbro samples) and argillic (granodiorite samples) alteration in the Cuddy Mountain complex (weight percent).

| Oxide | Weak | Moderate | Strong |
|---|---|---|---|
| | | Sericitic Alteration | |
| $SiO_2$ | 47.99 | 53.06 | 52.35 |
| $FeO + Fe_2O_3$ | 9.63 | 8.35 | 8.69 |
| MnO | 0.16 | 0.19 | 0.20 |
| MgO | 5.44 | 5.61 | 4.73 |
| CaO | 11.45 | 8.43 | 8.82 |
| $Na_2O$ | 1.95 | 2.43 | 2.30 |
| $K_2O$ | 0.19 | 0.96 | 1.30 |
| | | Argillic Alteration | |
| $SiO_2$ | 67.20 | 70.70 | 70.97 |
| $FeO + Fe_2O_3$ | 3.70 | 2.90 | 2.62 |
| MnO | 0.10 | 0.12 | 0.02 |
| MgO | 1.07 | 0.76 | 0.24 |
| CaO | 3.99 | 4.44 | 1.78 |
| $Na_2O$ | 3.67 | 3.84 | 4.56 |
| $K_2O$ | 1.87 | 1.07 | 1.73 |

The minerals included in the argillization are kaolinite, montmorillonite-chlorite mixed layer clays or montmorillonite, and chlorite. Chemical changes related to the argillic alteration include small increases in $SiO_2$ and $Na_2O$, and decreases in FeO, $Fe_2O_3$, MnO, and CaO. The replacement of mafic minerals by clay minerals and chlorite and of plagioclase by clay minerals and sericite accounts for the decreases of $Fe_2O_3$, FeO, MgO, and CaO in the altered rocks. The small (approximately one percent) increase in soda content may have been caused by incipient albitization of plagioclase feldspar. The potash content of the rock remains approximately constant.

## Sulfur Isotopes

Sulfur isotope abundance data have been obtained for a number of sulfate and sulfide minerals in samples collected from the Cuddy Mountain and nearby districts. The data are listed in Table 19. Results are expressed as deviations of $S^{34}$ in permil ($\delta S^{34}$‰) between sample and the meteoritic troilite sulfur standard (zero permil by definition). The analyses were undertaken to obtain the isotopic compositions of older Mesozoic, and presumably hydrothermal, sulfides for which little data are available, and to determine the presence and extent of possible systematic variations among associated sulfide-sulfide and sulfate-sulfide mineral groups.

With the exception of two chalcocite concentrates that will be

Table 19. $\delta S^{34}$ contents of sulfur bearing minerals from Cuddy Mountain and surrounding areas (values listed as $\delta S^{34}$ relative to standard meteoritic troilite, 0 permil).

| Sample | Location | Mineral | $S^{34}$(%) |
|---|---|---|---|
| 67-152 | Iron Prospect, SW Cuddy Mtn. | Barite | 11.6 |
| 76-153 | Same Prospect, Near 67-152 | Pyrite | 2.6 |
| 67-157 | IXL Mine, Cuddy Mtn. | Barite | 12.0 |
| | | Pyrite | 2.4 |
| 67-158 | IXL Mine, Cuddy Mtn. | Pyrite | 0.8 |
| | | Chalcopyrite | 0.7 |
| A-15 | IXL Mine, Cuddy Mtn. | Molybdenite | 1.2 |
| | | Chalcopyrite | 1.2 |
| A-20 | IXL Mine, Cuddy Mtn. | Pyrite | 3.3 |
| | | Chalcopyrite | 2.1 |
| 68-59 | Railroad Mine, Cuddy Mtn. | Chalcopyrite | 1.6 |
| K-6 | Kismet Mine, Cuddy Mtn. | Chalcopyrite | 4.3 |
| Bh-1 | Bay Horse Mine, Oregon | Gypsum | 14.6 |
| Bh-3 | | Gypsum | 14.9 |
| M-4 | Yellowjacket Mine, | Gypsum | 14.6 |
| M-6 | Mineral, Idaho | Gypsum | 14.4 |
| M-7 | Mineral, Idaho | Pyrite | 0.9 |
| | | Chalcopyrite | 0.9 |
| M-8 | Mineral, Idaho | Pyrite | -1.4 |
| Nor-1 | Near Cuprum, Idaho | Chalcocite | -42.9 |
| Nor-3 | | Chalcocite | -43.7 |
| Sd-2 | South Peacock Mine, Seven | Bornite | -5.8 |
| Sd-3 | Devils district, Idaho | Bornite | -5.7 |

discussed later, the $\delta S^{34}$ contents for all other sulfides range from -5.8 to +4.3 permil. This relatively small total isotopic variation (10.1 permil) derived from $\delta S^{34}$ values for sulfide-sulfur narrowly clustered about the zero permil value of meteoritic sulfur, is consistent with the assumed hydrothermal origin of these sulfides (Ault, 1959; Field, 1966a; Jensen, 1967). Moreover, the isotopic similarity to meteoritic sulfur is suggestive, although not completely diagnostic for reasons elaborated by Gross and Thode (1965), of a deep-seated source within the lower crust or upper mantle. The sulfide-bearing samples were collected from contact metasomatic (Railroad and South Peacock mines) and hydrothermal (IXL and Kismet mines and Iron and Mineral prospects) deposits that are localized within or closely adjacent to plutonic igneous rocks that served as sources of the fluids. The isotopic compositions of these sulfides are exactly similar to those of magmatic hydrothermal sulfides associated with younger Laramide intrusions of the eastern Cordillera (Ault, 1959; Field, 1966a; Jensen, 1967).

Two analyses of disseminated chalcocite in keratophyre from the Cuprum area south of the Seven Devils district yielded $S^{34}$ contents of -43.7 and -42.9 permil respectively. The samples constitute extraordinary sulfur isotopic anomalies because of the extreme $S^{34}$ depletion exhibited by hypogene chalcocite of presumed magmatic or somewhat later hydrothermal origin. Isotopically light sulfides are formed only by low temperature biochemical processes (Ault, 1959). However, such an interpretation is unreasonable on the basis of local and regional geologic evidence. The data suggest a crustal source of both sulfide-sulfur and host rock, possibly by the anatectic fusion of sedimentary rocks within the mobile eugeosyncline, but further speculations are unwarranted at this time.

$\delta S^{34}$ compositions of barite and gypsum range from +11.6 to +14.9 permil (Table 19) and thus comprise a distinct isotopic population relative to the sulfides. This contrast, between sulfates enriched in $S^{34}$ and sulfides relatively depleted in $S^{34}$, is consistent with fractionation effects for equilibrium isotope exchange reactions as determined from theory and experiment (Ault, 1959). Barite from the Iron prospect and IXL mine (+11.6 and +12.0 permil respectively) of the Cuddy Mountain district is clearly of hypogene origin, since it is localized in veins and is enriched in $S^{34}$ relative to unoxidized pyrite (+2.6 and +2.4 permil) with which it is associated (Field, 1966b). However, the origin of gypsum in massive stratiform deposits of the Mineral and Bay Horse districts is less certain. Geologic and textural evidence suggests that they are local replacements of conglomerates and mudstones along the Bay Horse thrust zone proposed by Livingston (1932). Additionally, many of the gypsum deposits, as in the Mineral district and elsewhere, appear to be localized in close proximity to centers of plutonic and hydrothermal activity. Isotopic compositions of gypsum range narrowly from +14.4 to +14.9 permil. Although this narrow range could be diagnostic of marine evaporites, the absolute values are depleted in $S^{34}$ relative to contemporary marine sulfate (+20.0 permil) and are within the lighter end of the spectrum of values for Cambrian to Jurassic evaporite sulfates (+7.0 to +35.0 permil) according to Ault and Kulp (1959) and Holser and Kaplan (1966). Because of local and regional geologic evidence that includes stratigraphic, structural, and textural considerations, the massive, bedded gypsum deposits are interpreted as having originated as secondary hydrothermal replacements of pre-existing sedimentary rocks. The isotopic data do not conflict with this hypothesis.

The $\delta S^{34}$ values for sulfide minerals exhibit gross systematic variations among the different sulfide species. In general they show an imperfect trend of progressive $S^{34}$ depletion in the mineralogical order pyrite, molybdenite, chalcopyrite, and bornite. This trend is in agreement with those measured by Tatsumi (1965) and Field (1966a) and predicted from bond-strength theory by Bachinsky (1969). They demonstrate increasing $S^{34}$ depletion in the order molybdenite, pyrite, sphalerite, pyrrhotite, chalcopyrite, bornite, chalcocite, and galena for common sulfides. The gross similarity of fractionation trends, which is indicative of equilibrium exchange reactions, provides additional evidence in support of the magmatic hydrothermal origin of sulfides at Cuddy Mountain and nearby districts.

The magnitude of isotopic fractionation between coexisting minerals formed by equilibrium reactions varies inversely with temperature. Delta values ($\Delta$), the isotopic separation between two minerals (A and B) stated by the equation ($\Delta_{AB} = \delta S^{34}_{A} - \delta S^{34}_{B}$), calculated from the measured $\delta S^{34}$ values provide an index to the extent of fractionation. As fractionation is temperature dependent, the delta values may serve as a geothermometer when interpreted on an experimental or theoretical working curve (plot of fractionation versus temperature) and provided the two minerals constitute an equilibrium pair. Delta values based on $\delta S^{34}$ data for sulfate and sulfide minerals of samples 67-152 and 153 and 67-157 from the Cuddy Mountain district and averaged sulfate and sulfide data for all samples of the Mineral district are 9.0, 9.6, and 14.4 permil respectively. Interpolation of these delta values to theoretical values calculated from data presented by Ault (1957) yields estimated isotopic temperature ranges of 750-850°, 710-820°, and 475-575° C. respectively. The temperature range for each sample group arises from the choice of sulfur-sulfide precursor ($H_2S$ or $S^{-2}$ as determined by pH). At best these temperatures are maxima, since conditions of contemporaniety and equilibrium are not fulfilled and the theoretical data are subject to errors. Moreover, both $\delta S^{34}$ and derived delta values collectively suggest a secondary and possibly hypogene origin for the bedded sulfate deposits.

In conclusion, this limited study has indicated that (1) the isotopic composition of Mesozoic sulfides is similar to their Laramide counterparts in the western U. S., (2) different sulfide minerals exhibit a generally consistent order of fractionation, (3) non-contemporaneous barite is of hypogene origin, and (4) massive gypsum deposits from the nearby Mineral and Bay Horse districts are probably of hydrothermal origin.

## Source(s) of the Mineralization

Mineralization at Cuddy Mountain is believed to be genetically related to Early Jurassic plutonic activity. More specifically, the intrusive complex is composed of three major, primary phases, and the bulk of the hydrothermal and contact metasomatic deposits appear to be more closely related to the late prophyritic granodiorite than to the earlier phases. The evidence for this relationship is largely indirect. However, there is a close spatial relationship between granodiorite and mineralization. Four separate bodies of porphyritic granodiorite were mapped (see Plate 1). Significant hydrothermal alteration and mineralization were found to be associated with three of these occurrences (including the Cuddy and Kismet mines). Although both the quartz diorite and nearby gabbro are commonly mineralized, the apparent intensity is highest in granodiorite. Also, apart from the magmatic concentrations in the gabbro, no significant mineralization occurs in the plutonic rocks except near porphyritic granodiorite. This distribution is significant because granodiorite forms less than 10 percent of all plutonic rock that crops out in the map area. Moreover, it provides convincing evidence that earlier intrusive phases, and their magmas, were deficient in water, because hydrothermal alteration associated with mineral deposits and the transport of metals would require a large supply of water. A similar relationship is present on the southwest flank of Cuddy Mountain where porphyritic granodiorite is present at both the Railroad and the IXL mines.

The source of the mineralization in country rocks of the thesis area is more difficult to determine. This is because the mineralized rocks are generally at considerable distances from the plutonic rocks, contacts are generally covered by alluvium or Columbia River Basalt, and of the three major rock types that crop out along the western border of the complex no one type can be defined as the most likely source on the basis of proximity to country rocks. In Fankhauser's (1969) thesis area, however, significant mineralization in country rock occurs in the western part of the area that is nearest a large mass of porphyritic granodiorite.

Another line of evidence, however, suggests that at least part of the country rock mineralization may be from the gabbro. Trace metal concentrations in porphyritic rhyolite tuff at a tuff-gabbro contact near the head of the Crooked River is contrasted to distance from the gabbro in Table 20. Contents of copper, molybdenum, lead, and zinc decrease with increasing distance from the contact. Although the copper values are anomalous for the tuff, the lead, zinc, and molybednum values are close to background for rhyolite in that area.

Table 20. Metal content (ppm) of the porphyritic rhyolite tuff with increasing distance from the gabbro.

| Distance from Gabbro (ft.) | Cu | Pb | Zn | Mo |
|---|---|---|---|---|
| 0 | 215 | 80 | 180 | -1 |
| 40 | 40 | 70 | 115 | -1 |
| 150 | 145 | 40 | 90 | 3 |

Geologic evidence has definitely established the gabbro as the oldest phase. Radiometric age dating and indirect geologic evidence indicate that the porphyritic granodiorite is younger than the quartz diorite. Because the granodiorite is mineralized, the ore-bearing fluids must have been derived from a genetically related residual liquid or source at depth. Moreover, it is a common fact that most hydrothermal base-metal deposits are associated with porphyritic intrusive rocks of intermediate composition (Titley, 1966, p. ix). Conversely, few hydrothermal deposits are known to be genetically related to equigranular quartz diorites or gabbros.

Trace element concentrations of copper, lead, zinc, silver, and molbydenum in the three plutonic phases of the complex are listed together with averages given by Turekian and Wedepohl (1961) in Table 21. With the exception of molybdenum and a few anomalous silver values, concentrations of these metals in the Cuddy Mountain Complex are generally lower than the average. The data, as such, do not imply a unique source among the three dominant intrusive phases. However, the data suggest possible contamination or insensitive analytical techniques for samples on which the published average contents are based.

The preceding discussion has described several features that suggest that the bulk of the mineralization at Cuddy Mountain is related to the granodiorite. The classical approach is to assume that both the hydrothermal fluids and the base-metals were derived directly from the magma. However, recent work by a number of investigators inclusing Garlick and Epstein (1966), Taylor (1967), White (1968), and Sheppard and others (1969) suggests that most of the water involved in hydrothermal processes may be derived from non-magmatic sources; either meteoritic or connate waters. Similarly, Skinner and others (1967), Jackson and Beales (1967), and Chrismas and others (1969) have suggested that the metallic constituents of many deposits were derived from adjacent country rocks. Because the granodiorite at Cuddy Mountain is porphyritic, it probably crystallized (or completed crystallization) at a relatively shallow (hypabyssal) depth where meteoritic contamination of the hydrothermal fluid could have occurred.

Table 21. Comparison of the trace element contents (ppm) of the three primary phases of the Cuddy Mountain Complex with the average content for a given rock type from Turekian and Wedepohl (1961).

| | Ag | Cu | Mo | Pb | Zn | Ni |
|---|---|---|---|---|---|---|
| Ppy. Granodiorite | | | | | | |
| F48G | -1.0 | 40 | 7 | 30 | 25 | n. a. |
| 35 | -0.2 | 15 | 1 | 10 | 60 | n. a. |
| 74 | 0.1 | 20 | 1 | 10 | 25 | n. a. |
| T. and W. Average[1] | 0.05 | 30 | 1.0 | 15 | 60 | 15 |
| Quartz Diorite | | | | | | |
| 64-65 | -1.0 | 75 | 3 | 10 | 40 | n. a. |
| 65-80 | 1.0 | 60 | 3 | 10 | 50 | 95 |
| 66-136 | -1.0 | 90 | 2 | 10 | 55 | n. a. |
| 105 | -0.2 | 90 | 1 | 20 | 80 | n. a. |
| T. and W. Average[2] | 0.08 | 58 | 1.2 | 10 | 82 | 72 |
| Gabbro and Hybrid* | | | | | | |
| 64-45 | 3.0 | 35 | 1 | 10 | 35 | n. a. |
| 65-82* | -1.0 | 30 | 2 | 15 | 55 | 85 |
| 65-84 | -1.0 | 55 | 4 | 20 | 40 | 110 |
| 66-218* | -1.0 | 45 | 4 | 5 | 45 | 50 |
| 66-132 | 1.0 | 105 | 3 | 15 | 170 | n. a. |
| 153* | 1.2 | 50 | 1 | 10 | 75 | n. a. |
| 257* | -0.2 | 35 | 1 | 10 | 90 | n. a. |
| T. and W. Average[3] | 0.1 | 87 | 1.5 | 6 | 105 | 130 |

[1]High calcium granitic rocks.

[2](High calcium + basaltic)/2.

[3]Basaltic rocks.

In conclusion, the mineralization at Cuddy Mountain is believed to be genetically related to the plutonic complex. Evidence includes: (1) presence of sulfides in plutonic rocks; (2) close proximity of mineral deposits in country rocks to the plutonic complex; (3) zonation of mineralization about plutonic rocks; (4) association of metallization with zones of intense hydrothermal activity; (5) predominance of cavity filling and replacement textures; (6) importance of structure in controlling mineralization; and (7) isotopic similarity of sulfide $\delta S^{34}$ values to those of undoubted magmatic hydrothermal origin. The bulk of the evidence indicates that the porphyritic granodiorite was the major source for the essential components of hydrothermal alteration and mineralization at Cuddy Mountain.

# GEOLOGIC SUMMARY

The Cuddy Mountains of western Idaho consist of a thick sequence of eugeosynclinal metasedimentary and metavolcanic rocks of Late Triassic and Early Jurassic age. A Jurassic plutonic complex forms the core. These older rocks are unconformably overlain by late Miocene to early Pliocene Columbia River Basalt that caps and flanks the mountains.

The oldest unit is the Seven Devils Volcanics of Late Triassic age. It is a thick (3000 feet minimum) sequence of interbedded volcaniclastic and volcanic rocks. The Seven Devils Volcanics were uplifted, eroded, and then downwarped before the deposition of the red conglomerate as indicated by the angular unconformity between the two units. The red conglomerate is a relatively thin (200-400 feet), pebble to boulder conglomerate of Early Jurassic age. Clasts are largely of volcanic rocks, and conglomeratic beds are interlayered with thin beds of sandstone and phyllitic shale. The porphyritic rhyolite tuff overlies the red conglomerate with apparent angular conformity. The composition of the tuff changes from rhyolitic near the base to latitic near the top of the unit. Both air-fall and ash-flow textures are present. The porphyritic rhyolite tuff and overlying Lucile Series pre-date Middle to Late Jurassic regional metamorphism and emplacement of the plutonic complex (about 200 m. y. ) and are thought to be of Early Jurassic age. The Lucile Series overlies the porphyritic rhyolite tuff with an angular unconformity that records another period of uplift, erosion, subsidence, and deposition. The Lucile Series consists of a thick (3000 feet minimum) sequence of interbedded slates and phyllites and lesser amounts of conglomerate, sandstone, and limestone.

The Triassic-Jurassic eugeosynclinal sequence was intruded by rocks of the Cuddy Mountain Plutonic Complex. The complex is made up of three major phases: gabbro, quartz diorite, and porphyritic granodiorite. Contact metasomatism of gabbro by quartz diorite and granodiorite produced a quartz-rich, hybrid phase of the gabbro. The three major members of the complex were apparently intruded as sheet-like rather than stock-like bodies. Geologic evidence shows that the sequence of intrusion was gabbro, quartz diorite, and finally porphyritic granodiorite. K/Ar dates on all three phases indicate, however, that gabbro is the youngest member of the complex. This contradiction may have arisen because dated samples of quartz diorite and granodiorite were shielded by gabbro from the homogenizing effects of later regional metamorphism. The plutonic rocks have been radiometrically dated by the K/Ar method as approximately 200 m.y. old. This conflict in ages between the country rocks and intruding plutonic rocks is resolved by moving the Triassic-Jurassic boundary back at least as far as 210 m.y.

Chemical data suggest that the various phases of the plutonic complex were the result of differentiation from a parent magma with high-alumina basalt affinities. Such magmas are characteristic of orogenic belts, and the hypothesis that the plutonic complex was intruded during the destruction of the eugeosyncline (Nevadian orogeny) is strengthened by the high-alumina affinities of the magma. The differentiation of the magma followed the trend of the calc-alkaline rock series.

During or immediately after intrusion of the plutonic complex (Middle to Late Jurassic time), the rocks of the Cuddy Mountain area were regionally metamorphosed to the greenschist facies, as indicated by the presence of minerals such as chlorite, actinolite, talc, epidote, and albite in both country and plutonic rocks.

Mineralization and alteration at Cuddy Mountain are genetically related to the plutonic complex and are generally structurally controlled. Copper-molybdenum deposits (such as the Kismet and IXL mines) are located within rocks of the plutonic complex. Although the mineralization is in part disseminated, the greatest concentration is found in brecciated zones. Such deposits are generally associated with quartz-sericite or potassic alteration which is surrounded by argillic alteration. Massive, tactite-type copper and iron deposits present in calcareous country rocks immediately adjacent to plutonic rocks were formed by contact metasomatism. Gold mineralization as gold-quartz veins and shear-zone fillings is present near the edge of the plutonic complex and is associated with intense argillic alteration. Deposits of lead-zinc-silver are found localized in fault zones in country rocks.

The types and distribution of alteration at Cuddy Mountain suggest that the $K^+/H^+$ ratio and temperature gradient were the major factors in determining mineral assemblages and zonations. The relatively small amount of potassic-type alteration is related to the generally potassium-deficient character of intrusive members of the complex. Geologic and chemical evidence suggest that the porphyritic granodiorite was the source of the mineralization and alteration. Moreover, sulfur isotopic data indicate that sulfides and sulfates from mineral deposits in and adjacent to the Cuddy Mountains are of magmatic hydrothermal origin.

The geologic history of the Cuddy Mountain region is unknown from Late Jurassic to middle Miocene time because no rocks representing that time interval are recognized in the area. During late Miocene and early Pliocene time, large volumes of Columbia River Basalt were extruded, in part from nearby fissures and plugs. These flows lapped up against and finally covered Cuddy Mountain. The present configuration of the mountain is due to Pliocene-Pleistocene uplift, Pleistocene glaciation, and recent stream erosion.

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# APPENDIX

# APPENDIX I

## Laboratory Techniques

Modal analyses of approximately 191 thin sections were obtained. Thirty samples, including all those chemically analyzed, were point counted (500 points) using a mechanical stage. Visual analyses were made on the other 161 thin sections by estimating mineral percentages at 10 to 20 randomly selected sites per slide. Cross-checks were made by using both methods on several slides. Plagioclase feldspar compositions were determined using extinction angles on Carlsbad-albite twins normal to (101) where possible. A few specimens required oil immersion techniques to determine feldspar composition.

Potassium-bearing minerals were detected by staining rock slabs with potassium cobaltinitrate.

X-ray diffraction studies of feldspars and phyllosilicates were performed on a Norelco diffractometer at the Department of Geology, Oregon State University. $Cu_{K\alpha}$ radiation was used, data was recorded on strip charts, and the mineral types were determined by comparing results obtained in the laboratory with data listed in the ASTM X-ray diffraction data card file. Physical separation of phyllosilicate alteration products from feldspar hosts was difficult because of the generally low percentages of alteration minerals. Because of the poor quality of the diffraction records caused by impure samples, X-ray determinations of phyllosilicates were used largely as support for hand-sample and microscopic identification of alteration products. Sericite was identified as fine-grained white mica; kaolinite was identified as a colorless, low-relief, weakly birefringent, clay-sized mineral; montmorillonite was recognized on the basis of its brown to green color, low relief, moderate birefringence, and clay-sized particles; and mixed layer chlorite-montmorillonite was distinquished from montmorillonite by the coarser grain-size of the former. X-ray diffraction results (referring to the 001 peak in particular) did not contradict mineral identifications based on the criteria listed above.

Both sulfate and sulfide minerals were analyzed to determine their sulfur isotopic compositions. Sulfate-sulfur was reduced to hydrogen sulfide by boiling in a mixture of $H_3PO_2$, HI, and HCl according to the method of Thode and others (1961). The sulfide was collected as CdS and reprecipitated as $Ag_2S$. Both sulfide minerals and $Ag_2S$ prepared from sulfates were converted to $SO_2$ for analysis using the high temperature $N_2$-$O_2$ combination technique described by Sakai and Yamamoto (1966). Isotopic analyses of sulfur in the prepared $SO_2$ samples were performed on a modified C. E. C. Model 21-401 mass spectrometer in the Laboratory of Isotope Geology at the University of Utah under the direction of Professor M. L. Jensen.

Major oxide chemical analyses were performed by Dr. Kenichiro Aoki of Tohoku University, Japan, using standard wet chemical methods. Trace element analyses were done by Rocky Mountain Geochemical Corporation. Copper, lead, sinz, and silver were determined by atomic absorption, and molybdenum was determined colorimentrically.

Potassium-argon age determinations were carried out by Dr. Richard L. Armstrong of Yale University and by Isotopes, Incorporated of Westwood, New Jersey.