

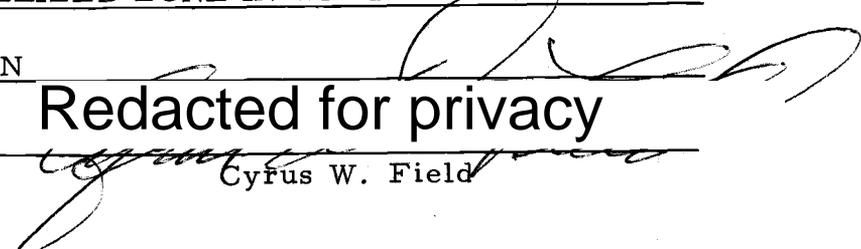
AN ABSTRACT OF THE THESIS OF

THOMAS ALVA HENRICKSEN for the DOCTOR OF PHILOSOPHY  
(Name of student) (Degree)

in GEOLOGY presented on May 30, 1974  
(Major department) (Date)

Title: GEOLOGY AND MINERAL DEPOSITS OF THE MINERAL-  
IRON MOUNTAIN DISTRICT, WASHINGTON COUNTY, IDAHO,  
AND OF A METALLIZED ZONE IN WESTERN IDAHO AND  
EASTERN OREGON

Abstract approved:

  
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Cyrus W. Field

The Mineral-Iron Mountain District is located in the west part of the Hitt Mountains, Washington County, Idaho. Bedrock consists principally of a eugeosynclinal sequence of northeast trending Triassic-Jurassic sedimentary and volcanic rocks that have been intruded by plutons of several ages.

The oldest rocks in the area are the Seven Devils Volcanics of Late Triassic age. This unit comprises as much as several thousand feet of mostly volcanic and volcanoclastic rocks.

The Triassic sequence was intruded by the Iron Mountain Complex consisting mainly of gabbro, quartz diorite, granodiorite (trondhjemite) and aplite in order of emplacement. The complex was emplaced as a stock-size pluton; however, the original shape is

difficult to determine because of post-complex reverse faulting, pre-Tertiary erosion and tilting of the complex, and later flows of Columbia River basalt. A K-Ar radiometric age determination for the quartz diorite phase suggests a minimum age of 200 m. y. Geologic and geochemical data suggest that the plutonic complex was the result of magmatic differentiation from one or several mantle or lower crustal sources. Differentiation apparently followed the trondhjemite trend and may have been influenced by high water contents.

The Seven Devils Volcanics and plutonic complex were uplifted, eroded, and downwarped before deposition of the Early Jurassic Cuddy Mountain red conglomerate (maximum thickness 100 feet). Well-rounded boulders of quartz diorite are present at the base of the unit and are interpreted as having been derived by erosion of the underlying plutonic complex. The conglomerate is overlain by the rhyodacite porphyry and Mineral porphyritic rhyolite tuffs that together are up to 650 feet thick. These rocks are overlain by the Thorsen formation (maximum thickness 320 feet), consisting of arenites and conglomerates, and Tate shale (maximum thickness 300 feet) of Middle Jurassic age. An allochthonous section, consisting of parts of the Brooks red and green conglomerate, and all of the Dennett Creek limestone and Big Hill formation, was emplaced via late Mesozoic(?) reverse faulting.

Types of mineral deposits include: (1) gypsum and silica, (2) copper-molybdenum-zinc metallization (Iron Mountain and Thorn Spring Prospects, Mortimer Mine) related to the Iron Mountain Complex, and (3) vein-type metallization (lead-zinc-silver-copper) of regional importance.

Copper-zinc (chalcopyrite-sphalerite) metallization at the Iron Mountain Prospect is primarily disseminated in hornfelsed and hydrothermally altered metasedimentary and metavolcanic lithologies adjacent to the aplite-pegmatite dikes of the Iron Mountain Complex. The alteration assemblages include quartz-sericite+kaolinite+chlorite+andalusite.

Copper-molybdenum metallization at the Thorn Spring Prospect is fracture-controlled and located within an aplite. Mineralization is associated with orthoclase veinlets and quartz-sericite alteration. Zonation of alteration, from potassic through sericitic to argillic types, is attributed to decreasing temperatures and  $K^+ / H^+$  ratios of the hydrothermal fluids with increasing distances from the aplite.

Vein-type metallization of regional importance is stratabound in silicic volcanics of Early Jurassic age. The mineralization is characterized by a carbonate gangue and is attributed to hydrothermal activity that occurred shortly after deposition of the volcanics.

Geologic and geochemical evidence, including proximity to major prospects, pegmatitic segregations of quartz and tourmaline, concordant magmatic and hydrothermal events at approximately 200 m. y., and sulfur isotope studies (0 permil, "magmatic" sulfur), collectively suggest that granodiorite and aplites were the sources of the porphyry-type and skarn-type metallization. The regional vein-type deposits are slightly younger, but also have a magmatic hydrothermal origin, as evidenced by the wide variation (+14.7 to -26.2 permil) of mostly negative  $S^{34}$  permil values in the sulfides.

Some of the pre-Tertiary lithologies were subjected to regional metamorphism during Jurassic time. The Mesozoic rocks are unconformably overlain by late Tertiary basalts of the Columbia River Group. Basement rocks have been exhumed by post-Miocene uplift and erosion.

Geology and Mineral Deposits of the Mineral-Iron  
Mountain District, Washington County, Idaho,  
and of a Metallized Zone in Western  
Idaho and Eastern Oregon

by

Thomas Alva Henricksen

A THESIS

submitted to

Oregon State University

in partial fulfillment of  
the requirements for the  
degree of

Doctor of Philosophy

June 1975

APPROVED:

Redacted for privacy

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Associate Professor of Geology  
in charge of major

Redacted for privacy

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Chairman of Department of Geology

Redacted for privacy

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Dean of Graduate School

Date thesis is presented May 30, 1974

Typed by Velda Mullins for Thomas Alva Henricksen

## ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to his major professor, Cyrus W. Field, for his guidance, field and laboratory assistance, and critical reading of the manuscript. Gratitude is also expressed to Drs. R. L. Lawrence, W. H. Taubeneck, and E. M. Taylor for advice and criticism of the manuscript. Discussions with Mr. Howard Brooks of the Oregon Department of Geology and Mineral Industries and Dr. George Williams from the University of Idaho were extremely helpful. A special thank you is extended to Joseph Worthington of Cyprus Mines, Inc., for allowing me to examine and sample diamond drill core from the Mineral-Iron Mountain District. The writer also wishes to thank Drs. Richard L. Armstrong and Donald J. Parker for several K-Ar radiometric age-determinations performed at Yale University.

Fellow graduate students, including Gregory M. Cox, Roney L. Long, and Stephen J. Skurla, deserve special mention for many hours of geological discussion concerning the Idaho-Oregon boundary area. Discussions with Joseph A. Briskey, Jr., and Michael B. Jones were also helpful. Robert A. Schmuck is acknowledged for suggestions on the manuscript.

Financial support, in the form of a three-year National Science Foundation Traineeship and a one-year appointment as a Teaching Assistant, was deeply appreciated. Financial aid including a Field Research Grant by Bear Creek Mining Company for general expenses, geochemical analyses, and thin-section preparations is also acknowledged.

The writer is indebted to Mr. and Mrs. Lee Thorsen, Weiser, Idaho, for their hospitality and permission to use their private land as a base camp.

Finally, my wife, Christine, deserves credit as camp guard, cook, and companion throughout my graduate studies. Her patience has been outstanding.

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GEOLOGY AND MINERAL DEPOSITS OF THE MINERAL-IRON  
MOUNTAIN DISTRICT, WASHINGTON COUNTY, IDAHO,  
AND OF A METALLIZED ZONE IN WESTERN IDAHO  
AND EASTERN OREGON

INTRODUCTION

The Mineral-Iron Mountain Mining District is located in the western part of the Hitt Mountains of western Idaho, about 22 miles north of Weiser, Idaho (Fig. 1). The district is best known for its past production of silver from vein-type deposits. Host veins for the silver metallization occupy part of a stratigraphically thin zone of pre-Tertiary volcanic rocks that extends 42 miles north-northeast from the Bayhorse Mining District in Oregon adjacent to the Snake River, through the Mineral-Iron Mountain District, to north of the Cuddy Mountain Mining District in Idaho. Pre-Tertiary plutons and associated porphyry-type deposits are also present in the Mineral-Iron Mountain District. The area of study is within the Columbia Arc of the Nevadan orogenic belt as defined by Taubeneck (1966).

Location and Accessibility

The area of detailed mapping includes 16 square miles of T. 14 N., R. 6 W., in the Mineral 15-minute quadrangle, Oregon-Idaho. The western edge of the map area is approximately two miles east of the Snake River. Roads of the U.S. Forest Service and of the

KEY

- B - Baker, Ore.
- C - Cuddy Mts.
- E - Elkhorn Mts.
- H - Hitt Mts.
- L - Lookout Mt.
- S - Seven Devils Mts.
- SR - Snake River
- WA - Wallowa Mts.
- WE - Weiser, Ida.

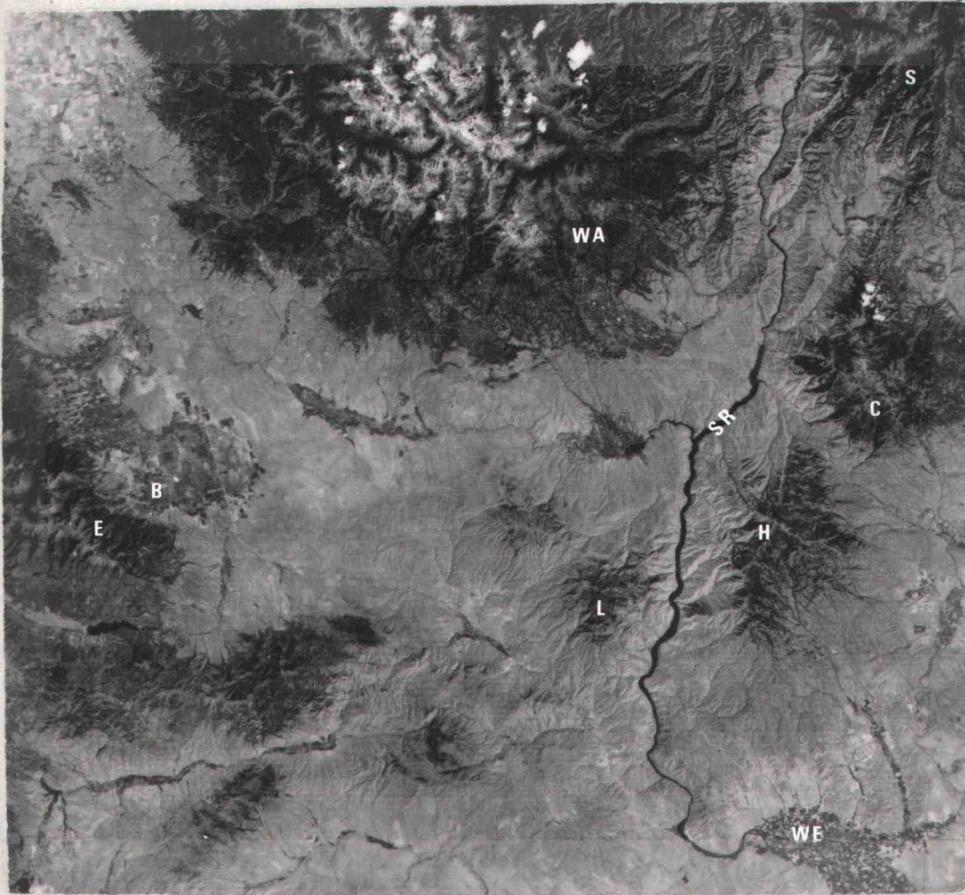
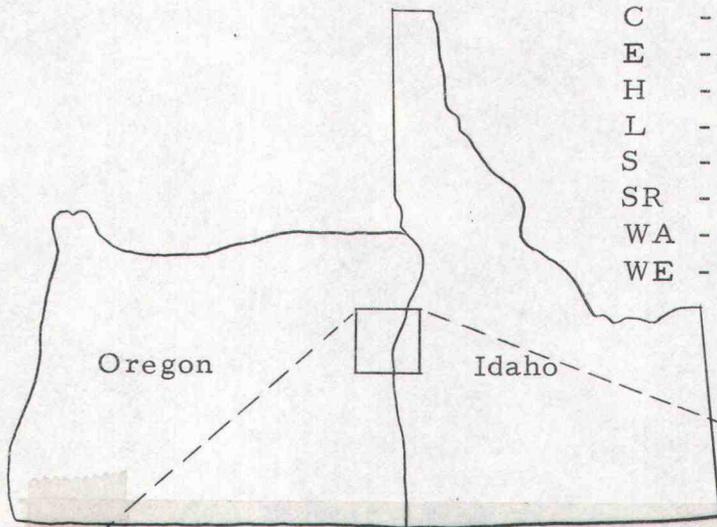


Figure 1. ERTS photograph - western Idaho and eastern Oregon.

Bureau of Land Management through the Payette National Forest provide excellent local and regional access to most of the areas studied. The Mineral-Iron Mountain District is best reached by driving 13 miles north from Weiser on U.S. Highway 95, turning left onto the improved gravel Mann Creek Road for eight miles, turning left again onto the packed clay Fourth of July Creek road for nine miles to a saddle which is the divide between Fourth of July and Dennett Creeks. Here, within the detailed map area, the road again bifurcates, but further access is generally restricted to four-wheel drive vehicles. The district may also be reached from the west and south via several gravel roads that begin north of Weiser; the Henley Basin road eventually follows the Snake River and approaches the Mineral-Iron Mountain District from the west along Dennett Creek, whereas the Jenkins Creek road approaches the area via Monroe Butte. In addition, many jeep trails not located on more recent maps were utilized during the field studies. Because of heavy snow and slippery clay-based road surfaces, much of the area is not accessible during the winter months.

#### Topography

The area of detailed mapping has approximately 3,500 feet of relief. The maximum altitude is 6,492 feet on Iron Mountain and the minimum is approximately 3,000 feet in Dennett Creek at

the west end of the area. In comparison, the top of Cuddy Mountain, 18 miles north-northeast of the Mineral-Iron Mountain District, is 7,737 feet, whereas the altitude of the Bayhorse District adjacent to the Snake River, 12 miles south-southwest of the Mineral-Iron Mountain District, is approximately 1,970 feet.

In general, the topography of this region is youthful and the valley of Dennett Creek is markedly V-shaped. Drainage is good and numerous springs are located at even the highest altitudes, principally along the contact zones between Columbia River Basalt flows and the pre-Tertiary rocks.

The most prominent ridges within the Mineral-Iron Mountain District are formed by silicic volcanic units whereas intrusive igneous rocks, generally form more subdued outcrops in the topographically lower areas.

#### Climate, Flora, and Fauna

Temperature data for the summer of 1971 was provided by Douglas and Nancy Laird, U.S. Forest Service personnel at the Payette National Forest Mann Creek Guard Station, elevation 3,800 feet:

	<u>June</u>		<u>July</u>		<u>Aug.</u>		<u>Sept.</u>	
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>
Average	78	44	90	53	97	51	78	37

Very little precipitation falls during the summer except for an occasional thunderstorm. Snow covers the slopes of Iron Mountain in the winter, but lower altitudes, such as the old mining camp of Mineral, get little or no snow.

The vegetation is varied. Many types of fir, Englemann spruce, and Ponderosa pine are found at higher altitudes and support an active logging industry. Ponderosa pine commonly grows on south-facing slopes, whereas the fir and spruce favor north-facing slopes and higher terrain. Sage and juniper are found at lower altitudes. The density of vegetation, either tree or sage, is not anomalously high or low over zones of disseminated sulfide metallization. However, juniper trees seem to take root well on the fractured silicic volcanic units which host the vein-type deposits.

Major fauna observed during field work included bear, bobcats, coyotes, deer, elk, and rattlesnakes.

#### Previous Studies

The first detailed geologic studies of the region were conducted by Lindgren (1901) who made several references to the Mineral District as well as to the Cuddy Mountain District and Bayhorse Mine area nearby to the north and south, respectively. A brief discussion of the ore deposits in the Mineral District was

published by Turner (1908). Livingston (1923, 1932) mapped in detail parts of all the districts and also noted the unusual stratigraphic control for part of the mineralization in the area. Reconnaissance mapping south and west of Iron Mountain by Kirkham (1931) revealed plutons in the Trail Creek area. Detailed mapping of the formerly productive vein-type silver deposits was conducted by Anderson and Wagner (1952) who spent several weeks in the Mineral District, whereas Mackin (1953) mapped and described in detail the skarn-type iron deposits of the Iron Mountain area several miles east of the old town of Mineral. The mining geology of the Seven Devils region, including the Cuddy and Mineral areas, was discussed by Cook (1954) who also mentioned the economic potential of the region. Dr. George Williams, professor of geology at the University of Idaho, published an abstract (1964) on the geology of the Mineral quadrangle. He is presently mapping the Idaho part of that quadrangle. An important observation from an economic standpoint was made by Howard Brooks (Thayer and Brown, 1964) who first mentioned the possibility that the entire Jurassic stratigraphic section, which contains the vein-type silver mineralization, post-dated the major plutonic complex that itself contains disseminated and vein-type copper-zinc-molybdenum mineralization. Anderson (1963) concluded from a study of the microscopy of silver ores at Mineral that the primary silver-bearing mineral is

tetrahedrite and that much of the ore mined in the past was from zones of supergene enrichment. Imlay (1964) collected and described marine Jurassic ammonites and oysters in the black shale of the Mineral District. Later, the distinctive Early Jurassic red and green conglomerate of the Bayhorse-Mineral area was studied by Brooks (1967). More recently, Paris (1969) completed a detailed study of the pre-Tertiary stratigraphy in part of the Mineral quadrangle mostly to the north of the writer's area of investigation. The volcanic stratigraphy of part of the Olds Ferry quadrangle south of the Mineral-Iron Mountain District was mapped by Juras (1972) who noted a major pre-Tertiary reverse fault that is correlated with a similar reverse fault in the Iron Mountain area. Mesozoic plutonism and mineralization of the Snake River boundary area, including the Mineral-Iron Mountain District, was briefly described by Field, Bruce, and Henricksen (1972). Henricksen, Skurla, and Field (1972) discussed several radiometric ages of plutonism (200 m. y. and 120 m. y.) in the Hitt Mountains. Preliminary stratigraphic and structural relationships along the metallized zone that extends through the Mineral-Iron Mountain District were described in an abstract by Henricksen and others (1973). Steven J. Skurla recently completed an M. S. thesis (1974) at Oregon State University on the geology of the Sturgill Peak area, located several miles northeast of the Mineral-Iron Mountain

District.

Important references to theses on or near Cuddy Mountain, about 18 miles to the north, include D. A. Wracher (M.S. Oregon State University, 1969), R. E. Fankhauser (M.S. Oregon State University, 1969), M. N. Slater (M.S. Oregon State University, 1969), J. R. King (M.S. Oregon State University, 1971), and W. R. Bruce (Ph. D. Oregon State University, 1971).

Professor Cyrus W. Field has spent parts of several field seasons mapping, collecting samples, and conducting the Oregon State University field camp in and near parts of the Cuddy Mountain, Mineral-Iron Mountain, and Seven Devils mining districts.

#### Methods and Purpose of Investigation

Previous geologic studies of this district have been generalized and superficial. The primary purpose of this investigation was to genetically relate the multitude of mineral deposits and alteration zones to one or more geologic features of the complex Mineral-Iron Mountain District. This was accomplished in part by detailed field studies of the deposits, rock types and their interrelationships, structures, and distribution of important primary and secondary minerals. Interpretations were supported by appropriate chemical, mineralogic, and petrographic studies of samples collected during the field work. A secondary purpose of this investigation was to

determine the origin of unusual stratigraphically controlled vein-type deposits that are confined to a zone less than 1,000 feet thick and regionally continuous for a distance of at least 42 miles.

Several methods were utilized in achieving these goals. A detailed geologic map (1:15,400) and accompanying overlays for sample locations, economic geology, and mafic dikes were prepared for the Mineral-Iron Mountain District. In addition, several regional maps were prepared from both my own field work and that of others. Host rocks, country rocks, and both hypogene and supergene products of wall rock alteration and vein fillings, were studied through the use of thin section, polish section, X-ray, major oxide, trace element, stable isotope, and radiogenic isotope age-dating techniques (see Appendix I - Laboratory Techniques). These studies contributed information relating to: (1) the geologic and absolute ages of the country rock, plutons, and mineral deposits; (2) chemical and physical conditions that prevailed during emplacement and crystallization of the plutons; (3) types of mineral deposits and associated alteration within the Mineral-Iron Mountain District and along the stratigraphically controlled zone of metallization; (4) number of episodes of mineralization; (5) source of mineralizing fluids; and (6) structural and stratigraphic controls of metal deposition.

## GEOLOGIC SETTING

The Mineral-Iron Mountain District is within the Columbia Arc of the Nevadan orogenic belt as defined by Taubeneck (1966) and the Columbia Plateau province described by Hamilton (1962). This region is characterized by numerous plutons that have intruded the pre-Tertiary basement.

Major plutonic masses nearby include the Idaho Batholith some 35 miles to the east, the Wallowa Batholith 30 miles to the north, and the Bald Mountain Batholith nearly 45 miles to the west. Smaller stock-sized plutons include those of the Seven Devils Mountains 40 miles to the north-northeast, the Cuddy and Peck Mountain areas 18-30 miles to the north-northeast, Sturgill Peak seven miles to the northeast, Lookout Mountain ten miles to the west-northwest, Pedro Mountain 25 miles to the west-southwest, and intrusions of the Trail and Rock Creek drainages, six and eight miles to the south, respectively.

Tectonic uplift and subsequent erosion of Tertiary volcanic rocks have exposed the Triassic-Jurassic stratigraphy and plutonic rocks ranging from 120 to 216 m. y. in age. Hamilton (1963) suggested that a eugeosyncline was present in western Idaho and eastern Oregon during much of the Mesozoic Period. The lithologies, thicknesses, and trend of the volcanic and sedimentary rocks

are indicative of an island arc-trench environment as defined by modern plate tectonic theory. The Iron Mountain Complex pre-dates Middle to Late Jurassic regional metamorphism and also pre-dates regional reverse faulting. Intrusions of a similar age are present in the Sierra Nevada Mountains of eastern California, the Klamath Mountains of southwestern Oregon and northwestern California, the Cuddy Mountains of western Idaho, the Northern Cascade Mountains of Washington, the Coast Range and Intermontaine provinces of British Columbia, and southeast Alaska. Plutons of these ages serve as host rocks to important porphyry copper-molybdenum mineral deposits in British Columbia and possibly California (age uncertain).

The pre-Tertiary basement rocks of eastern Oregon and western Idaho were covered by flows of Columbia River basalt during Miocene and Early Pliocene time. Subsequent erosion formed many pre-Tertiary windows; especially in and adjacent to the Snake River Canyon. The Mineral-Iron Mountain District is in one of these windows.

## STRATIGRAPHIC UNITS

The pre-Tertiary stratigraphy of the Mineral-Iron Mountain District consists of a thick section of Upper Triassic to Upper Middle Jurassic volcanic and sedimentary rocks that are in part incipiently metamorphosed. In general, they strike north-northeast and dip to the northwest. Part of the Jurassic stratigraphy lies above a major reverse fault of regional importance (see Structural Geology). It has been designated the allochthonous section whereas Triassic-Jurassic stratigraphy below the reverse fault has been designated the autochthonous section. A columnar section showing typical thicknesses of autochthonous and allochthonous pre-Tertiary stratigraphic units is portrayed in Figure 2. The pre-Tertiary section and plutonic rocks are unconformably overlain by Columbia River basalt flows of Tertiary age.

The autochthonous and allochthonous sections are discussed separately. In order of diminishing age the autochthonous units include the Seven Devils Volcanics, the Cuddy Mountain red conglomerate, the rhyodacite porphyry, the Mineral porphyritic rhyolite tuffs, the Thorsen formation, and the Tate shale. The allochthonous section includes the Brooks red and green conglomerate, the Dennett Creek limestone, and the Big Hill wacke. The rather detailed discussion that follows is necessary because of the

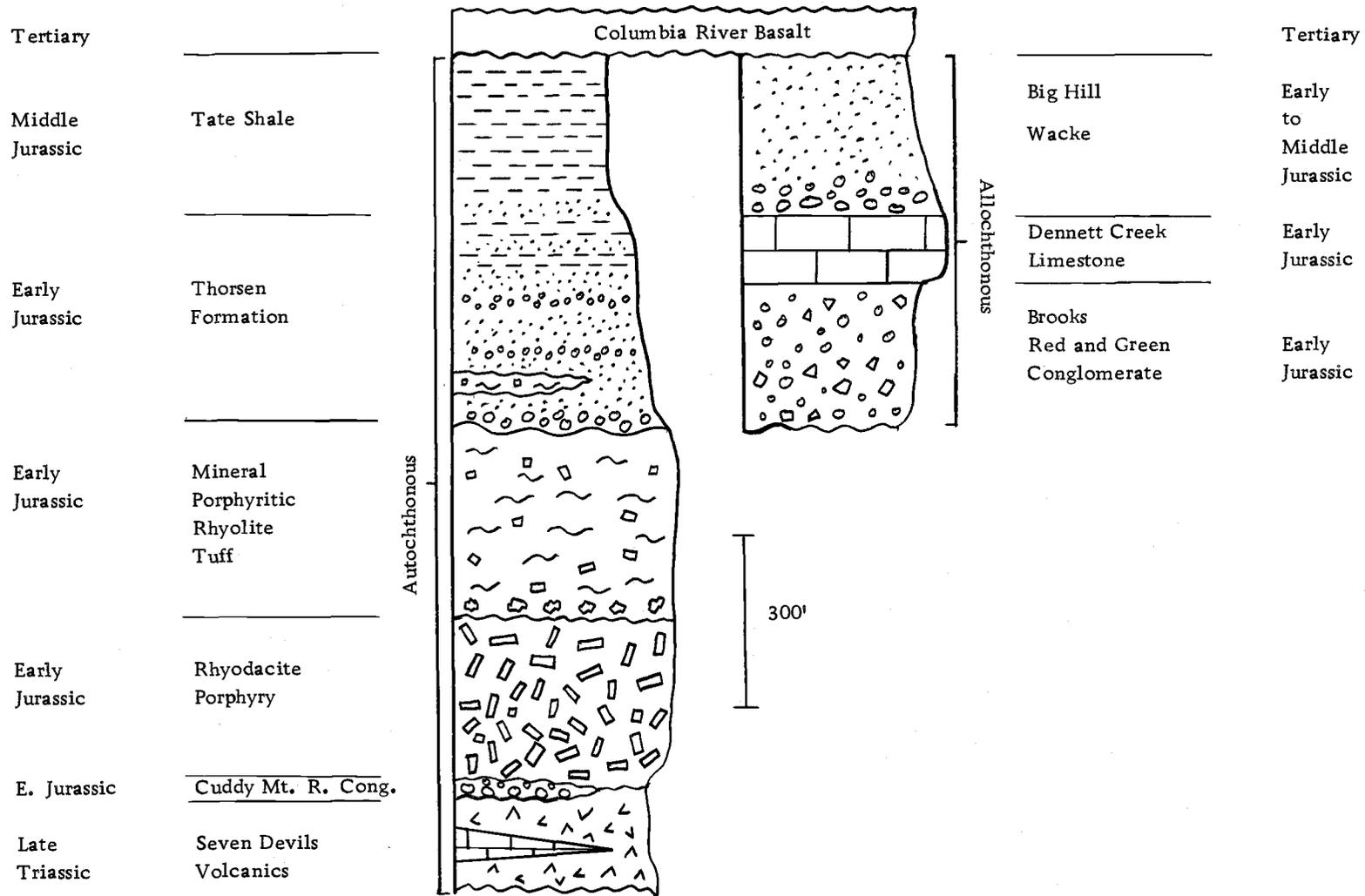


Figure 2. Columnar section - typical thicknesses of autochthonous and allochthonous pre-Tertiary stratigraphic units and Columbia River basalt.

apparent stratigraphic control for part of the metallization.

### Autochthonous Pre-Tertiary Section

Rocks beneath the reverse fault include Late Triassic to late Middle Jurassic volcanic and sedimentary lithologies that in part have undergone incipient regional metamorphism.

### Seven Devils Volcanics

A heterogeneous assemblage of metavolcanic and metasedimentary rocks of probable Late Triassic age is exposed in the east and southwest parts of the Mineral-Iron Mountain District. On the basis of lithic similarities and geographic location, this assemblage is correlated with the Seven Devils Volcanics named by Lindgren (1901) and revised by Anderson (1930).

Field Description. The Seven Devils Volcanics are well exposed along Fourth of July Creek road in the  $W\frac{1}{2}$  sec. 12. The metavolcanics are light to dark gray-green, massive, with foliation rarely developed. Minor dark green lapilli tuffs and volcanic quartz porphyries are also present in float adjacent to the Fourth of July Creek drainage. Coarsely crystalline white marble is confined to the nearly uppermost stratigraphic part of the Seven Devils Volcanics. Conglomeratic lithologies, consisting of well-rounded andesitic fragments, and quartz-feldspar arenites, are present in diamond drill core

from the Iron Mountain prospect.

On the basis of data collected in underground iron mines (now inaccessible) from the vicinity of Iron Mountain, Mackin (1953) reported that dips of the marble were variable and ranged from  $30^{\circ}\text{E}$ . through vertical to  $30^{\circ}\text{W}$ . The outcrop pattern of the marble pods indicate, however, that a north-northeast trend and northwest dip predominates.

Neither the original stratigraphic base nor the top of this formation is exposed, and much of the sequence crops out as a large screen between phases of the plutonic complex. Tertiary Columbia River basalt covers a significant part of the Seven Devils Volcanics, and at least several thousand feet of thickness may be obscured beneath basalt cover east of Iron Mountain.

Lithology and Petrography. The oldest lithologies in the Seven Devils Volcanics are exposed in the eastern part of the Mineral-Iron Mountain District. They consist of finely crystalline silicic meta-volcanic flow rocks that are characterized by abundant phenocrysts of quartz and plagioclase feldspar ( $\text{An}_{31-37}$ ) in a groundmass of similar mineralogy. The phenocrysts of quartz average 1.5 mm in diameter and are embayed by the groundmass. In contrast, those of plagioclase feldspar average 2 mm in diameter and are cloudy because of moderate to complete replacement by sericite or albite. Other common minerals are actinolite, biotite, calcite,

clays, epidote, magnetite, tourmaline, and finely disseminated pyrite. Younger flow rocks in the  $W\frac{1}{2}$  sec. 12 exhibit randomly oriented laths of plagioclase feldspar ( $An_{28-32}$ ) that are partly to completely altered to sericite and rimmed with albite. The ground-mass contains clusters of pyroxene, actinolite, quartz, magnetite, and traces of chlorite, garnet, and sphene. Trachytic textures that are common to andesites and keratophyres of the Seven Devils Volcanics in the Cuprum area to the north, according to Morganti (1972), were not observed in the Mineral-Iron Mountain District. The marble is composed of coarsely crystalline calcite. As discussed in a later section, the marble is replaced by assemblages of skarn minerals near contacts with the plutonic complex.

#### Age, Depositional Environment, and Regional Correlation.

Fossils were not found in the Seven Devils Volcanics of the Iron Mountain area. Upper Triassic marine fossils were reported by Fankhauser (1969) for a lithically similar and stratigraphically contiguous assemblage of metasedimentary and metavolcanic rocks approximately 18 miles to the north-northeast on Cuddy Mountain. Marine fossils of Late Triassic (Norian and Karnian) age have been reported by Brooks (1973) for a similar assemblage 12 miles to the south-southwest in the Bayhorse Mine area (Plate 4).

Hamilton (1963a) has suggested that the Seven Devils Volcanics of the Riggins and Cuprum quadrangles are the product of

Permo-Triassic island arc volcanism. The lack of pillow features that are common to many greenstone belts may be related to the silicic composition of the volcanic rocks. The Upper Triassic stratigraphy in the Mineral-Iron Mountain District, the Cuddy Mountain District, and the Huntington area of eastern Oregon is probably near the top of the volcanic section and in the two latter areas contains a high proportion of sedimentary lithologies. However, the only recognizable sedimentary lithologies in the Upper Triassic section of the Mineral-Iron Mountain District include minor conglomeratic to arenitic interbeds and marble. This relationship may be more apparent than real as hydrothermal alteration has rendered the recognition of many lithologies impossible. Intercalated beds of marble near the top of the Seven Devils Volcanics indicate that periods of volcanic quiescence probably occurred.

Cook (1954) correlated the Seven Devils Volcanics with the Clover Creek greenstone of northeast Oregon. The Seven Devils Volcanics may have once been nearly contiguous with the Karmutsen volcanics of western British Columbia and/or the Nicola greenstone of south-central British Columbia. Both formations are compositionally similar to the Seven Devils Volcanics and of a similar late Triassic age.

### Cuddy Mountain Red Conglomerate

A red conglomerate crops out near the common boundary between secs. 10 and 11 and also in the north-central part of sec. 9. On the basis of stratigraphic position and lithology, this conglomerate is correlated with the red conglomerate of Cuddy Mountain and a red conglomerate beneath the rhyolite tuff in the Bayhorse District (Bruce, 1971).

Field Description. The Cuddy Mountain red conglomerate is composed largely of subangular to subrounded volcanic fragments of porphyritic andesite and minor amounts of dark green basalt and gray chert. In the north-central part of sec. 9, several well-rounded boulders of equigranular quartz diorite, one to three feet in diameter, are present in the conglomerate. The fragments are locally cemented by calcite, epidote, and hematite. The hematite, derived from oxidation of magnetite and other ferromagnesian minerals, provides the distinct red coloration of this unit.

The Cuddy Mountain red conglomerate is less than 100 feet thick and is lithically identical to much of the younger and thicker Brooks red and green conglomerate which it underlies. Bedding in the Cuddy Mountain red conglomerate is poorly developed. However, it is discernible from thin sandy interbeds in places such as the NW $\frac{1}{4}$  sec. 13. The conglomerate is assumed to overlie the

Seven Devils Volcanics unconformably on the basis of faunal age differences and inferred structural interpretations in the Cuddy Mountain area.

Age, Depositional Environment, and Regional Correlation.

Although fossils were not found in the Cuddy Mountain red conglomerate of the Mineral-Iron Mountain District, Brooks (1972, oral communication) believes that the conglomerate is correlative with several lithically similar Upper Triassic (?) conglomerates in the Bayhorse Mine area. However, Bruce (1970) reports Early Jurassic (Sinemurian) fossils in the stratigraphically and lithically equivalent conglomerate on Cuddy Mountain. Thus, a tentative Early Jurassic age is assigned to the Cuddy Mountain red conglomerate.

The volcanic fragments were derived by erosion of the underlying Seven Devils Volcanics. The large plutonic clasts (1-3 feet in diameter) near the base of the Cuddy Mountain red conglomerate were apparently derived from erosion of the Iron Mountain Complex. The contact between the Cuddy Mountain red conglomerate and the Gabbro phase of the Iron Mountain Complex is exposed in a roadcut in the SE $\frac{1}{4}$  NW $\frac{1}{4}$  sec.9 (Fig. 3), and also in diamond drill core. This contact is interpreted as erosional because of the following evidence: (1) the plutonic clasts in the conglomerate are large, indicating a nearby source, and they resemble the quartz



Figure 3. Cuddy Mountain Red Conglomerate. Note the large light-colored plutonic clast. The contact between the conglomerate and the underlying gabbro phase of the Iron Mountain Complex is dashed.

diorite phase of the Iron Mountain Complex; (2) the contact is flat-lying as deduced from surface and diamond drill core information; (3) effects of contact metamorphism are not present in the conglomerate; and (4) the underlying gabbro apparently lacks a chill phase along the contact zone.

On the basis of these relationships, it is concluded that the Cuddy Mountain red conglomerate and probably all Jurassic stratigraphy of the Mineral-Iron Mountain District post-date the Iron Mountain Complex.

#### Rhyodacite Porphyry and Mineral Porphyritic Rhyolite Tuff.

The Cuddy Mountain red conglomerate is overlain by silicic porphyritic volcanic rocks that are subdivided into several cooling units on the basis of field relationships, petrography, and whole-rock chemistry. The oldest lithology is the rhyodacite porphyry and it is overlain by the Mineral porphyritic tuff(s). The two units are discussed under a single heading because of their similar mineralogy and whole-rock chemistry.

Field Description. The rhyodacite porphyry, a distinctive red to purple porphyritic volcanic flow unit, caps Iron Mountain and Chinaman Hat and forms much of the dip slope in secs. 9, 15, and 16 south of Dennett Creek. Overlying the red to purple porphyry are several cooling units of Mineral porphyritic rhyolite

tuff (Jmr1 and Jmr2 on Plate 1), gray to black in color. The upper porphyritic tuffs (Jmr2) are intercalated with the overlying Thorsen formation and Brooks red and green conglomerate. The rhyodacite porphyry and the lower Mineral porphyritic rhyolite tuff collectively form the prominent cliffs on the north side of Dennett Creek. These silicic volcanic rocks are dense, brittle, and highly fractured and they serve as host rocks to the Pb-Zn-Ag-Cu vein-type metallization in the Mineral-Iron Mountain District and along the metallized zone. Typical exposures of these volcanics are bleached and/or heavily stained by manganese oxides and silicates and jarosite.

The rhyodacite porphyry is distinguished from the overlying Mineral porphyritic rhyolite tuffs on the basis of abundant phenocrysts of plagioclase feldspar, a distinctive reddish-purple groundmass, and lack of fragmental and eutaxitic textures that are characteristic of the younger Mineral porphyritic rhyolite tuff(s).

The rhyodacite porphyry exhibits a maximum thickness of at least 300 feet along the Fourth of July Creek drainage and pinches out at the west end of McChord Butte. The overlying lower Mineral porphyritic rhyolite tuff (Jmr1) ranges up to 350 feet in thickness, as deduced from field relationships and the study of diamond drill core and it, too, pinches out in the west end of the

district. Younger and thinner (50-100 feet thick) porphyritic rhyolite tuffs (Jmr2) are intercalated with the overlying Jurassic Thorsen formation and Brooks red and green conglomerate. Bedding is marked by subtle flow banding in the rhyodacite porphyry and eutaxitic structures in the Mineral porphyritic rhyolite tuffs. Attitudes are variable. These units range from northeast to nearly east-west in strike and dips vary between  $15^{\circ}$  and  $50^{\circ}$ N. and they average about  $30^{\circ}$ N.

Lithology, Petrography, and Chemistry. The rhyodacite porphyry contains phenocrysts of plagioclase feldspar and minor sanidine, altered hornblende, microperthitic orthoclase, and quartz set in a microcrystalline groundmass of potassium feldspar and quartz. The groundmass also contains dusty ilmenite, magnetite, hematite, and pyrite in amounts up to four percent. The phenocrysts comprise 35 to 55 percent of rhyodacite porphyry and the plagioclase feldspar ( $An_{12-31}$ ) laths range up to 3.2 mm in length. Alteration minerals as replacement products of the primary constituents include carbonate after plagioclase, chlorite and clays after hornblende, and moderate to abundant sericite-clay after plagioclase. In addition, gangue minerals such as carbonate and minor potassium feldspar and quartz occupy veins and veinlets traversing the host.

The Mineral porphyritic rhyolite tuffs contain phenocrysts of

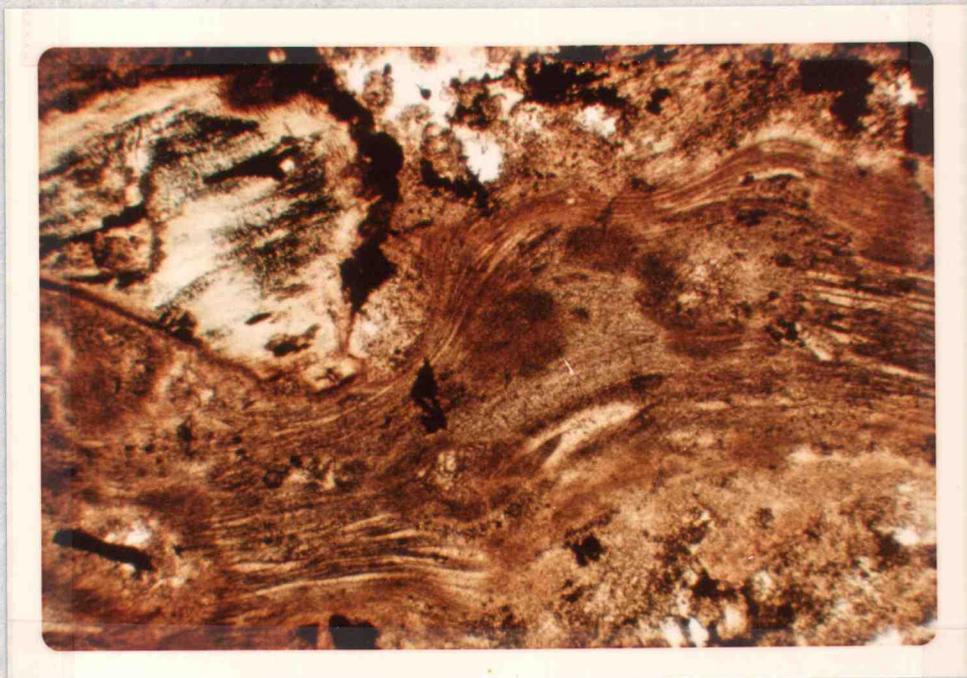


Figure 4. Photomicrograph, Mineral porphyritic rhyolite tuff. Flattened fragment of devitrified pumice occupies central portion of photograph. (crossed nicols, 100x)

sanidine, plagioclase feldspar, microperthitic orthoclase, and quartz, occurring with minor amounts of lithic fragments, and flattened (welded) fragments of devitrified pumice that are set in a felsic microcrystalline groundmass (Fig. 4). Phenocrysts comprise 5 to 15 percent of the unit, with the quartz being subordinate to the feldspars. Plagioclase feldspar ( $An_{8-12}$ ) exhibits excellent polysynthetic twinning and is present in laths that approach 1.5 mm in length. Groundmass and pumice are devitrified to finely crystalline mosaics of quartz, feldspars, biotite, and magnetite. Angular fragments of volcanic origin are concentrated within a zone 10 to 20 feet in thickness near the base of the lower tuff (Jmr1). Secondary mineral assemblages formed by hydrothermal alteration of the tuffs are similar to those previously described in the rhyodacite porphyry.

Modal and chemical analyses of the rhyodacite porphyry and the Mineral porphyritic rhyolite tuff are listed in Table 1. The terms "rhyodacite" and "rhyolite" used for lithologies in the Mineral-Iron Mountain District are from Nockolds' (1954) chemical classification scheme. On the basis of this classification, most rhyolites contain greater than 70 percent  $SiO_2$ , whereas rhyodacites contain slightly less than 70 percent  $SiO_2$ .

Age, Origin, and Regional Correlation. Livingston (1923) assigned a Triassic age to the "rhyolite flow" of the Cuddy, Mineral,

Table 1. Modal and Chemical Analyses of the Rhyodacite Porphyry (Jrp) and Porphyritic Rhyolite Tuffs (Jmr).

	I-36 (Jrp)	B-5-540 (Jmr)	MDD6-240 (Jmr)
Phenocrysts			
Quartz	5	4	15
K-fld.	6	10	10
P-fld.	27 (An <sub>15</sub> )	tr	tr
Groundmass	50	81	73
Accessories	tr	tr	tr
Opagues	3	2	2
Clay	6	tr	tr
Calcite	3	3	tr
	100.0	100.0	100.0
SiO <sub>2</sub>	67.5	72.5	69.0
TiO <sub>2</sub>	0.85	0.40	0.45
Al <sub>2</sub> O <sub>3</sub>	17.0	13.8	15.6
FeO	3.6	1.5	1.7
MgO	0.3	-	0.4
CaO	1.8	3.6	0.7
Na <sub>2</sub> O	4.2	1.7	0.9
K <sub>2</sub> O	4.5	6.5	9.54
	99.8	100.0	98.3

and Bayhorse Mining Districts. Anderson and Wagner (1952) reclassified Livingston's "rhyolite" to "latite" or "trachyte" and suggested a Permian age for this unit. The stratigraphically contiguous lithology(ies) on Iron Mountain was (were) visually described as a single "andesite flow" by Mackin (1953) who also correlated the "flow" with Miocene (?) andesites described by Gilluly (1937) in the Baker quadrangle of Oregon. Mackin (1953) also discussed a swarm of "andesite dikes" southeast of Chinaman Hat and claimed that these dikes were feeders to the "andesite". However, the "andesite dikes" which he considered feeders to the "andesite flow" are equigranular, not porphyritic, and are probably Columbia River basalt dikes. A more recent interpretation of the origin and age of the rhyodacite porphyry and the Mineral porphyritic rhyolite tuff was provided by Paris (1969), who called the entire unit a post-Upper Jurassic "andesite-quartz latite" composite dike. However, the latter interpretation is untenable because boulders of the "andesite-quartz latite" are present in an overlying basal conglomerate of Early Jurassic age.

These phenocryst-bearing silicic volcanic rocks are thought to be Early Jurassic in age on the basis of their stratigraphic position. They overlie the Lower Jurassic Cuddy Mountain red conglomerate and underlie, or are intercalated with, the overlying Lower Jurassic Brooks red and green conglomerate and Thorsen

formation.

Slater (1969) and Bruce (1971) were the first to note the fragmental and eutaxitic textures of the rhyolitic volcanic rocks on Cuddy Mountain. Skurla (1974) has mapped a similar porphyritic tuff on Sturgill Peak. Moreover, the writer found discontinuous exposures of rhyolitic rocks over a distance of 42 miles north-northeast from the Bayhorse Mine area, Oregon, to north of Cuddy Mountain on the Crooked River in Idaho (Plate 4). Field and chemical evidence indicate that more than one cooling unit is contained in the silicic volcanic rocks of this horizon. Rock slabs of various porphyritic silicic volcanics from vein-type prospects along the metallized zone (Plate 4) are shown in Figure 5. The differences in potassium feldspar content, as defined by the yellow sodium cobaltinitrate staining, and textures of the various cooling units are well exhibited. Whole-rock chemical analyses from the top and bottom parts of tuffs in the Mineral and Cuddy Mountain Districts are listed in Table 2. The differences in chemistry, especially that of silica, preclude any possibility that only one cooling unit is involved in the silicic volcanism.

Rhyolite welded tuffs are most commonly found in subaerial terrains (Ross and Smith, 1960). However, the Triassic-Jurassic marine fossils found above and below the welded tuffs of western Idaho indicate a possible subaqueous origin. Rankin (1960) has



Figure 5. Porphyritic silicic volcanics, metallized zone. Left sample of each pair is stained for potassium feldspar.

Table 2. Chemical Comparison of Ash Flow Tuffs Along Metallized Zone.

Cuddy Mountain (after Bruce, 1971)		Mineral District		
Top (266)	Base (64-59)		Top (MDD6-240)	Base (B-5-540)
55.32	67.90	SiO <sub>2</sub>	69.0	72.5
18.23	13.82	Al <sub>2</sub> O <sub>3</sub>	15.6	13.8
6.58	4.81	FeO	1.7	1.50
6.67	0.06	CaO	0.7	3.6
2.15	0.78	MgO	0.4	0.0
0.98	8.41	K <sub>2</sub> O	9.54	6.50
5.35	1.92	Na <sub>2</sub> O	0.9	1.7
0.68	0.51	TiO <sub>2</sub>	0.45	0.40
95.96	98.21		98.3	100.0

suggested that hot ash flows, especially those of rhyolitic composition, may have specific gravities of less than 1.0. Therefore, a hot ash flow having a density less than water would be dispersed upward, lose its volatiles, and produce a water-deposited tuff. In addition, Fiske and Matsuda (1964) have noted the absence of welding features from subaqueous pyroclastic flows of Japan. Excellent examples of this texture and crude vertical jointing in the Mineral porphyritic rhyolite tuffs indicate that high temperatures were maintained and that they presumably originated by subaerial, not submarine, ash flow volcanism. Moreover, the large clasts volcanic and plutonic rock, one to three feet in diameter, in part of the underlying Cuddy Mountain red conglomerate indicate that a nearby landmass was present, and possibly rising, prior to silicic volcanism marked both by the rhyodacite porphyry flow and the ash flow tuffs. Therefore, it is proposed that the sedimentary-volcanic pile, as well as the Iron Mountain Complex, was locally emergent above sea level prior to ignimbritic eruption in Early Jurassic time.

Bruce (1970) predicted that the Mineral-Iron Mountain area provided the feeder for the regionally important silicic volcanic rocks. However, the writer has demonstrated from field and whole-rock chemical evidence that more than one cooling unit, and at least several chemical types, were involved in the silicic

volcanism. Therefore, it is possible, that the ash flow tuffs originated from more than one feeder vent or fissure. Although source vents or fissures for these volcanics have not been positively identified, pre-Tertiary porphyritic rhyolite dikes were observed in the Burnt River canyon near Huntington, Oregon, south of the Bayhorse Mine.

### Thorsen Formation

The Thorsen formation is a sedimentary sequence consisting mainly of arenites and conglomerates of Jurassic age. It is characterized by subdued outcrops above the ridge-forming silicic volcanic units on both sides of Dennett Creek and near the top of Iron Mountain. Field relationships in the NW $\frac{1}{4}$  sec. 16 suggest that the Brooks red and green conglomerate may be a time-stratigraphic equivalent of the Thorsen formation.

Field Description. The base of the Thorsen formation consists of a distinctive conglomerate composed of well-rounded and gray colored boulders of Mineral porphyritic rhyolite tuff that are up to several feet in diameter. This basal conglomerate is well-exposed in road cuts adjacent to several of the Cyprus Mines, Inc., drill sites south of Dennett Creek in sec. 9 and near the top of the ridge north of the Mineral townsite in sec. 9. A small exposure of this basal conglomerate is also present in a

saddle near the top of Iron Mountain. This outcrop was previously interpreted as a spheroidally weathered basalt plug by Mackin (1953). Attitudes of this formation, determined by the three-point method, indicate that dips (northwest) and strikes (northeast) do not differ appreciably from those of the underlying Jurassic stratigraphy.

Conglomerates and lithic arenites, with minor limy interbeds containing fossil debris, overlie the basal conglomerate. Clasts are typically of porphyritic volcanics that exhibit various shades of grays, reds, browns, and greens. Poorly developed graded bedding is locally present in the fine-grained interbeds of sandstone, but cross-bedding is absent. Maximum thickness of the Thorsen formation is 320 feet.

Bleached and jarosite-stained outcrops, characteristic of the underlying silicic volcanic rocks, are also present and controlled by fractures in the Thorsen formation. These effects are attributed to the weathering of sulfide-bearing lithologies. A similar bleaching is locally found along and near the contact between the underlying silicic volcanic rocks and the overlying boulder conglomerate.

Lithology and Petrography. In addition to conglomerates, other dominant lithologies are lithic (ignimbritic) and quartz-feldspar arenites according to the classification of Williams,

Turner, and Gilbert (1954). In the lower part of the Thorsen formation, most lithic arenites consist (75 percent or more) of unsorted, loosely packed, and angular fragments of monolithic rhyolitic welded tuff in a matrix of quartz, sanidine, and sodic plagioclase feldspar. Higher in the section, lithic arenites contain abundant andesitic volcanic fragments. In the quartz-feldspar arenites, the volcanic fragments are subordinate to the crystals. Some detrital grains are locally cemented and replaced by calcite and silica. Argillaceous matrix, pumice fragments, and glass shards were not observed in this formation.

Age, Depositional Environment, and Regional Correlation.

Limy conglomeritic beds in the NW $\frac{1}{4}$  sec. 10 (Plate 1, fossil locality 1) contain poorly preserved marine pelecypods that Imlay (1972, written communication) provisionally labeled *Eopecten*. Their distribution ranges from Early Jurassic to Early Cretaceous. Fossils of the Jurassic *Gryphea* (oysters) have been reported by Brooks (1972, written communication) in the NE $\frac{1}{4}$  sec 16 and by Imlay (1964) in the NE $\frac{1}{4}$  NW $\frac{1}{4}$  sec 9. These *Gryphea* are identical to those observed by the writer in the overlying upper Middle Jurassic Tate shale. Field relationships in the W $\frac{1}{2}$  sec. 16, however, indicate that the Thorsen formation is intercalated with and is time-stratigraphically equivalent to the well-dated Lower Jurassic Brooks red and green conglomerate. Thus, an Early Jurassic age is tentatively

assigned to the Thorsen formation.

The well-rounded pebbles in conglomerate beds and the lack of pumice and preserved shards indicate reworking of mostly ignimbritic volcanics in relatively shallow water.

### Tate Shale

A black shale of Jurassic age is the youngest pre-Tertiary stratigraphic unit that has been faunally dated in the Mineral-Iron Mountain District. It crops out on the hillsides of the middle and north forks of Dennett Creek in secs. 4 and 9 and also south of Dennett Creek in sec. 9. The Tate shale forms topographically subdued outcrops that weather to fragments having chunky to conchoidal fracture surfaces. As a consequence, access roads to drill sites recently constructed by Cyprus Mines, Inc., provide the only good exposures.

Field Description. The lower part of the Tate shale is transitional with the upper part of the Thorsen formation. This transition zone is marked by alternating beds of shale and quartz-feldspar arenite that are several tens of feet in thickness. However, most Tate shale is characteristically homogeneous; fossil-bearing calcareous concretions near the top are the only textural variations observed in the thinly laminated unit. Maximum thickness of the shale is approximately 300 feet. It strikes northeast and dips range

between 30° and 40° NW.

The stratigraphic top of the Tate shale is locally (secs. 3, 4, 8, 9, and 10) the sole for a major reverse fault in the district. The shale is extremely fractured in the vicinity of this fault.

Lithology and Petrography. The Tate shale contains 90 percent argillaceous material, 7 percent white mica, and 3 percent quartz. Quartz grains are angular and are as much as 0.05 mm in diameter. The white mica occurs as finely crystalline flakes averaging 0.03 mm in length. A foliation is exhibited by platy minerals that are aligned along the bedding and envelope undeformed fragments. Dynamic pressures coincident with reverse faulting have caused the upper parts of the unit to be converted to slate.

Age, Depositional Environment, and Regional Correlation.

Undeformed ammonites and pelecypods were collected from black calcareous concretions in the Tate shale (Plate 1, F<sub>1</sub>, NW<sub>4</sub><sup>1</sup> NW<sub>4</sub><sup>1</sup> sec. 10). A suite of these fossils was sent to Dr. Ralph W. Imlay of the U.S. Geological Survey for identification. According to Imlay (1972, written communication), the ammonites included Xenocephalites vicarius Imlay, Lilloettia spp. and Kepplerites sp. These are characteristic of the lower part of the Callovian stage of the Pacific Coast states. The Callovian stage is tentatively placed at the top of the Middle Jurassic (Paris, 1969). Imlay also identified one specimen of the pelecypod Bositra buchii (Romer) which

ranges from late Early Jurassic (Toarcian) to middle Late Jurassic (Kimmeridgian). Imlay (1964) had previously found Callovian stage ammonites in the Tate shale from the NW $\frac{1}{4}$  sec. 9. Gryphea culebra Imlay, which is similar to oysters found in the upper part of the underlying Thorsen formation, was also reported from the shale by Imlay (1964).

The lithology of the Tate shale clearly indicates that it was deposited during a period of volcanic and tectonic quiescence. Abundant organic carbon and partial replacement of the ammonites by pyrite indicate that reducing conditions prevailed. Moreover, the finely laminated character of this sedimentary rock and the presence of locally thick oyster beds suggest deposition in a near shore estuarine environment.

Similar black shales of the Jurassic Callovian stage have been described by others for this region. These include the Coon Rapids Formation (Morrison, 1964) in the Snake River canyon and the Trowbridge Formation (Lupher, 1941) in the Izee area of central Oregon.

#### Allochthonous Pre-Tertiary Section

Rocks above the reverse fault are Jurassic in age. They include parts of the Brooks red and green conglomerate and all of the Dennett Creek limestone and Big Hill wacke.

### Brooks Red and Green Conglomerate

A red and green conglomerate of regional importance trends through the Mineral-Iron Mountain District. It was originally described by Brooks (1967). The best exposures are found on McChord Butte and also in the NW $\frac{1}{4}$  sec. 12. The conglomerate is in part located above the major reverse fault of the district and thus it is in part allochthonous.

Field Description. More than 90 percent of the clasts in the Brooks red and green conglomerate are of porphyritic volcanics. The clasts display a variety of colors including reds, purples, and greens inherited from a volcanic source that was presumably the Seven Devils Volcanics. Clasts of vein quartz and chert are locally abundant and help to differentiate this conglomerate from the older and thinner Cuddy Mountain red conglomerate. The fragments range in size from fine sand to pebbles two inches in diameter. They may be well-rounded, as on McChord Butte, or angular, as in the NW $\frac{1}{4}$  sec. 12.

The conglomerate trends approximately N. 50° E. and dips 15° to 40° NW as determined from thin sandy interbeds. Thicknesses are variable and exceed 1,000 feet in the vicinity of McChord Butte and Big Hill. However, bedding plane faults may have duplicated parts of this formation. The Brooks red and green

conglomerate is found structurally above the younger Tate shale, in secs. 3, 4, 8, 9, and 10, and this provides evidence for a reverse movement along the fault. Other evidence of possible structural complications includes a phyllitic sheen that is imparted to the conglomerate and a northwest-southeast elongation of pebbles in and near the fault zone.

Lithology and Petrography. The principal cementing minerals are hematite, calcite, and minor silica. Calcite veins are locally common.

In thin-section the sheared parts of this formation exhibit cataclastic features such as broken and/or bent fragments of crystals and rock. Feldspars and ferromagnesian minerals in the fragments are commonly altered to wispy sericite and chlorite.

The abundance of volcanic clasts renders the Brooks red and green conglomerate a volcanic conglomerate according to the classification proposed by Williams, Turner, and Gilbert (1954).

Age, Depositional Environment, and Regional Correlation.

Brooks (1967) was the first to define and describe the red and green conglomerate. He concluded, on the basis of paleontological evidence, that this formation marked the Triassic-Jurassic boundary in the region between Lime, Oregon, and Mineral, Idaho. Bruce (1971) reported marine fossils of similar age in the Cuddy Mountain red conglomerate which he correlated with the red and green

conglomerate as defined by Brooks (1967). However, the writer suggests that the Cuddy Mountain red conglomerate and the Brooks red and green conglomerate are two distinct Lower Jurassic conglomerates. Evidence to support this interpretation comes from both the Mineral and Bayhorse areas, where the conglomerates occur as two distinct stratigraphic units that are separated by a horizon of silicic volcanic rocks.

It was previously stated that this conglomerate and the Thorsen formation may be time-stratigraphic equivalents. Evidence for this interpretation includes a gradational contact zone in the NW $\frac{1}{4}$  sec. 16. The gradational zone occurs between the Thorsen formation, which consists mainly of reworked welded tuff fragments, and the Brooks red and green conglomerate, which consists mainly of andesitic flow rock debris.

#### Dennett Creek Limestone

The Dennett Creek limestone of Jurassic age is a prominent marker bed and it crops out near the base of Big Hill in the northwest part of the Mineral-Iron Mountain District. The limestone stratigraphically overlies the Brooks red and green conglomerate.

Field Description. The limestone, finely crystalline and light-gray in color, is predominantly massive although fine laminations are locally present. Dips and strikes are not dissimilar from other Jurassic units that trend northeast and dip northwest. The

limestone has a maximum thickness of nearly 100 feet in the SW $\frac{1}{4}$  sec. 4. However, it thins to the east and pinches out a short distance east of the Gypsum Mine (NW  $\frac{1}{4}$  sec. 11), where it has been largely replaced by gypsum (see Economic Geology).

Lithology and Petrography. The Dennett Creek limestone is composed predominantly (95-98 percent) of interlocking anhedral carbonate crystals. Clastic quartz and lithic fragments comprise five percent or less of the host. Minor brown organic material is recognized, but fossils were not observed.

Average grain size for all constituents is less than 0.1 mm. Quartz occurs largely as detrital fragments that are concentrated in distinct layers.

Age, Depositional Environment, and Regional Correlation.

The Dennett Creek limestone is assumed to be Jurassic in age based on its stratigraphic position above the well-dated Lower Jurassic Brooks red and green conglomerate and below the Big Hill wacke of Jurassic age.

Composition and texture are not indicative of a particular environment of deposition. The limestone is pure (less than five percent quartz and lithic fragments) and may have resulted from deposition in relatively shallow waters that did not receive a significant influx of detrital or volcanic material.

The "Cuddy Mountain Limestone", from the Cuddy Mountains

18 miles to the north, was first described by Fankhauser (1969).

"The Cuddy Mountain Limestone" is believed to be equivalent in stratigraphic position, lithology, and thickness to the Dennett Creek Limestone. A Jurassic limestone is located southwest of the thesis area in the drainages of Wolf and Trail Creeks (Juras, 1973) and is also equivalent to the Dennett Creek Limestone. The limestone being quarried near Lime, Oregon, 15 miles southwest of the Mineral-Iron Mountain District, is possibly an equivalent. However, structural and stratigraphic complexities in the Lime area (Brooks, 1972, oral communication) make this a tentative correlation at best. The Nelson Marble (Prostka, 1967) and the Martin Bridge Formation (Ross, 1938) of northeast Oregon are not stratigraphic equivalents of the Dennett Creek limestone because they are much thicker and older, Late Triassic according to Vallier (1967), than the Dennett Creek Limestone.

#### Big Hill Wacke

An undifferentiated assemblage of wackes and minor arenites crops out along the northern border of the Mineral-Iron Mountain District. This unit characteristically forms subdued outcrops and has been designated the Big Hill wacke because of its type-occurrence on Big Hill in the northwest corner of the district.

Field Description. Conglomerate beds containing clasts of gray-green chert, black shale, green porphyritic volcanics, and light-gray limestone mark the base of the wacke unit. The Big Hill wacke overlies the Dennett Creek limestone in the northwest part of the district. However, the limestone is largely absent in the northeast part of the district. In this area, the Brooks red and green conglomerate, composed primarily of andesitic volcanic fragments, grades directly upward into the gray-green lithologies of the Big Hill wacke. The upper parts of the Big Hill wacke are characterized by gray-green to gray-brown silty and sandy lithologies. Measured strikes and dips indicate a general northeast trend and northwest dip that are similar to other units of Jurassic stratigraphy. The Big Hill wacke has a total thickness of at least several thousand feet in the district. However, the stratigraphic top of the unit is north of the district, where Paris (1969) has described many thousands of feet of wacke (his "Unit 1").

Fine-grained schistosity is the most dominating feature of the Big Hill wacke. This foliation has developed parallel to bedding and is recognized as a phyllitic sheen in most of the fine-grained lithologies. In addition, pebbles, cobbles, and boulders near the base of the unit are elongated in the northwest-southeast direction within the bedding plane. The magnitude of this deformation is well illustrated by a limestone clast, less than three inches thick

and more than three feet long, observed in the NW $\frac{1}{4}$  sec. 12.

Tension fractures filled with quartz and calcite traverse the chert pebbles along directions that are normal to the principal axis of elongation. In addition, minor folds, overturned to the southeast, characterize deformation of this unit in the vicinity of the Gypsum Mine.

Lithology and Petrography. The Big Hill wacke is a sequence of mostly poorly sorted wackes having fragments up to 1.0 mm in diameter. Fragments consist of minerals such as anhedral quartz, plagioclase feldspar, and pyroxene, and assorted lithic fragments that include shale, chert, volcanics, and limestone. All clasts are set in an argillaceous matrix.

Clay minerals of the matrix are frequently aligned and envelope undeformed clastic particles (Fig. 6). This texture is interpreted as slaty cleavage that is defined by a penetrative surface resulting from the alignment of phyllosilicate grains normal to the direction of maximum finite compressive strain direction (Ramsay, 1967). The slaty cleavage (rotation) probably formed during de-watering and compaction with lithification as discussed most recently by Alterman (1973). Evidence for such an origin of slaty cleavage in the Big Hill wacke is the undeformed nature of the detritus, including fresh pyroxene and plagioclase feldspar. The elongation of fragments in the conglomeratic units is attributed to secondary stresses

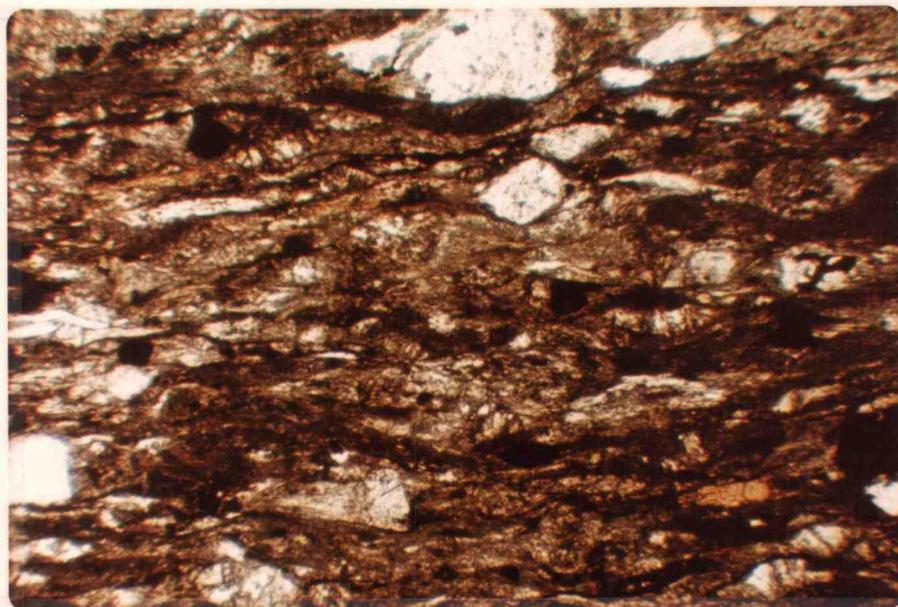


Figure 6. Photomicrograph, Big Hill wacke. Slaty cleavage exhibited by argillaceous material enveloping undeformed clastic fragments (plane light, 100x).

imposed by reverse faulting that probably post-dated the formation of slaty cleavage.

Age, Depositional Environment, and Regional Correlation.

Stretched fossils were found by Dr. A. J. Wright in a silty interbed of the chert-dominated conglomerate in the NW $\frac{1}{4}$  NE $\frac{1}{4}$  sec. 11 (Plate 1, F<sub>2</sub>). These fossils were provisionally identified by Dr. N. J. Silberling (1971, written communication) as marine Ammusium-like pecnids of post-Triassic age. On the basis of similar lithologies and geographic location, the Big Hill wacke is correlated with a wacke unit described by Brooks and Vallier (1967), Lawrence (1971), and Brooks (1973) that crops out in the nearby Snake River Canyon. This formation is well-dated and contains marine fossils of Jurassic (Sinemurian to Callovian) age. Thus, a similar Jurassic age is suggested for the Big Hill wacke. The Lucile series (Wagner, 1945) of the Riggins, Idaho, region may also be correlative with the Big Hill wacke on the basis of similar lithologies and stratigraphic position. The large thickness of the Big Hill wacke, and that of its correlatives nearby and elsewhere, indicate that the entire assemblage may have formed in an island arc - trench environment. Hamilton (1963a) has postulated that such an environment probably characterized this region during much of Mesozoic time. However, the absence of turbidite features, such as graded bedding, and the presence of conglomerates are more indicative of deposition in

shallow water than in a trench. Accordingly, the Big Hill wacke may have been deposited in the arc-trench gap as defined by Dickinson (1971), to be further discussed under Structural Geology. Detritus that comprises the wacke was probably derived from erosion of the underlying stratigraphic units of Triassic and Jurassic age.

### Cenozoic Section

Basalt flows of Tertiary age and unconsolidated deposits of Quaternary age cover parts of the pre-Tertiary basement terrain of the Mineral-Iron Mountain District.

#### Columbia River Basalt

Basalt flows of the Columbia River Group (Waters, 1961) unconformably overlie all pre-Tertiary rock types of the district. Their distribution is primarily confined to the drainages of Fourth of July, Stacy, Adams, and Thorn Spring Creeks. Basalt dikes of the Columbia River Group (Plate 2) are present in swarm-like proportions and they intrude all stratigraphic and plutonic rocks of the district. Several lithically and chemically distinct basalt types are recognized in the Mineral-Iron Mountain area.

Field Description. Basalt flow rocks exhibiting finely crystalline, equigranular to porphyritic textures are present on Monroe Butte (sec. 26) and in the drainages of Fourth of July, Stacy, and

Adams Creeks. Well-developed columnar jointing is characteristic of several flows. On Monroe Butte, individual flow tops are locally marked by scoriaceous zones, whereas the bases are defined by hematite-stained rubble zones. Basalt flow rocks exhibiting coarsely crystalline and porphyritic textures crop out at higher altitudes, primarily in secs. 11 and 14 near Iron Mountain proper.

Attitudes obtained on the basaltic flows indicate that most are nearly flat-lying. The basalts in lower drainages from the eastern part of the district appear to have flowed around the Iron Mountain Complex. Accordingly, their distribution indicates a pre-basalt topographic high. Basalt flows from the drainage of Thorn Spring Creek in the extreme southwest corner of the district are steeply dipping. These steep dips are the result of post-basalt fault movements in that area (see Structural Geology).

The basalt flows may exceed a total thickness of 600 feet in the vicinity of Monroe Butte. Flow thicknesses increase in the Mann Creek drainage to the east, and Skurla (1974) reports at least 1,800 feet of basalt for the Columbia River Group in the Sturgill Peak area to the northeast.

Basalt dikes (Plate 2) are widespread and exhibit mostly finely crystalline equigranular textures. They are commonly vertical and trend N.  $10^{\circ}$  to  $25^{\circ}$  W. with several obvious exceptions. The basalt dikes range from 2 to 40 feet in width. Traces of disseminated pyrite

and local bleaching, caused by deuteric activity as in the SE $\frac{1}{4}$  sec. 10, are common to the basalt dikes. Zeolite-lined vesicles may also be present. Spheroidal weathering is well-developed in exposures along the steep jeep trail leading from the Gypsum Mine down into Mineral.

Lithology and Petrography. The basalt dikes and flows exhibit hemicrystalline to holocrystalline and equigranular to porphyritic (phenocrysts of plagioclase feldspar) textures. Modal analyses of both flow and dike rocks are listed in Table 3. The dominant minerals, in addition to tachylyte, include plagioclase feldspar (An<sub>51-65</sub>), clinopyroxene, olivine, and opaques. Disseminated pyrite and magnetite are found as intergrown aggregates and as individual crystals. Apatite needles are abundantly associated with micropegmatite in the dikes. Products of deuteric alteration and weathering include brown chlorophaeite in cavities and gold-brown saponite (?) after glass. Calcite and white mica are incipient alteration products after plagioclase.

Modal analyses of basalts from the Mineral-Iron Mountain District are compared to those of other basalts of the Columbia River Plateau in Table 3. Sample M-95, a flow near Iron Mountain in sec. 11, mineralogically resembles the average Imnaha (Waters, 1961) and average Rock Creek (Hooper, 1974) basalts as evidenced by the high contents of olivine (five percent) and plagioclase (49 percent). In addition, large plagioclase feldspar phenocrysts (as much

Table 3. Modal Analyses of Basalt Flows and Dikes from the Mineral-Iron Mountain District Compared to Average Modal Analyses for Picture Gorge (Imnaha) and Yakima Flows (Waters, 1961) and Average Rock Creek Flow (Hooper, 1974) and Columbia River Basalt Dikes in Pre-Tertiary Rocks (Taubeneck, 1970).

Mineral	Flows					Ave. Picture Gorge <sup>11/</sup>	Ave. Yakima <sup>12/</sup>	
	M-95 <sup>1/</sup>	N-3 <sup>2/</sup>	Ave. Imnaha <sup>3/</sup>	Ave. Yakima <sup>4/</sup>	Ave. Rock Creek <sup>5/</sup>			
Plagioclase	49	43	46.5	31	49.16			
Clinopyroxene	30	17	29.5	28	14.06			
Olivine	5	-	6.7	0.03	11.40			
Glass	tr	35	7.0	29.8	15.91			
Alteration prod.	12	1	2.6	2.7	0.69			
Opagues	4	4	7.2	8.2	5.46			
	Dikes							
	N-25-b <sup>6/</sup>	N-13 <sup>7/</sup>	N-20 <sup>8/</sup>	N-22 <sup>9/</sup>	N-31 <sup>10/</sup>			
Plagioclase	41	56	45	58	54	51.0	55.8	
Pyroxene	21	29	19	29	31	30.4	28.0	
Glass	27	tr	tr	tr	tr	2.8	tr	
Alteration prod.	4	10	25	4	8	2.9	3.5	
Opagues	7	5	8	8	7	5.2	7.3	
Quartz	tr	tr	tr	tr	tr	.2	1.5	
Micropegmatite	-	-	2	-	-	-	-	
Apatite	-	tr	1	1	tr	tr	.1	
Olivine	-	-	-	-	-	5.1	-	

<sup>1/</sup> NE 1/4 SE 1/4 sec. 11.

<sup>2/</sup> SE 1/4 SW 1/4 sec. 13.

<sup>3/</sup> Average of Picture Gorge Basalts from the Imhaha Canyon as given by Waters (1961).

<sup>4/</sup> Average of the Yakima Basalts from the Crescent Bar section as given by Waters (1961).

<sup>5/</sup> Average of Rock Creek Basalt flow of Idaho as given by Hooper (1974).

<sup>6/</sup> SE 1/4 NW 1/4 sec. 23.

<sup>7/</sup> NE 1/4 SE 1/4 sec. 14.

<sup>8/</sup> NW 1/4 SE 1/4 sec. 10.

<sup>9/</sup> SW 1/4 NW 1/4 sec. 11.

<sup>10/</sup> NW 1/4 NW 1/4 sec. 10.

<sup>11/</sup> Average of Picture Gorge Basalt dikes from Chief Joseph Dike swarm (after Taubeneck, 1970).

<sup>12/</sup> Average of Yakima Basalt dikes from Chief Joseph Dike swarm (after Taubeneck, 1970).

as 3.1 cm in length) in sample M-95 are characteristic of both Imnaha (Waters, 1961) and Rock Creek (Hooper, 1974) basalts. Moreover, the absence of olivine, high glass content (35 percent), and finely crystalline texture of flow N-3 (from the Adams Creek drainage) are features characteristic of the Yakima basalt (Waters, 1961). Most basalt dikes were presumably derived from magmas of Yakima basalt because they lack olivine and generally are finely crystalline.

Chemistry. The Columbia River basalt has been grouped into a four-unit informal stratigraphic classification based upon 11 distinct chemical types by Wright, Grolier, and Swanson (1973). Whole-rock chemical analyses of basalt flows and a dike from the Mineral-Iron Mountain District are compared to those for the lower basalt (Rock Creek) and lower Yakima basalt chemical-stratigraphic types as defined by Wright, Grolier, and Swanson (1973) in Table 4. The finely crystalline flow rock (N-3) and dike (N-20) chemically resemble the lower Yakima basalt that is characteristically high in  $\text{SiO}_2$  and  $\text{K}_2\text{O}$ . However, the coarsely crystalline flow rock (M-95) compositionally resembles the lower basalt (Rock Creek) chemical-stratigraphic type because of similar major oxide contents, except  $\text{TiO}_2$  which is slightly deficient.

Age, Origin, and Regional Correlation. The thick sequence of Columbia River basalts along the Grande Ronde River in northeast

Table 4. Chemical Analyses of Basalt Flows and Dikes from the Mineral-Iron Mountain District Compared to Chemical Analyses of Columbia River Basalt (Wright, Grolier, and Swanson, 1973).

	M-95 <sup>1/</sup> (flow)	N-3 <sup>2/</sup> (flow)	N-20 <sup>3/</sup> (dike)	Lower <sup>4/</sup> Basalt	Lower <sup>5/</sup> Yakima Basalt
SiO <sub>2</sub>	49.6	55.0	55.5	49.36	54.98
Al <sub>2</sub> O <sub>3</sub>	17.0	13.9	13.7	16.41	13.76
FeO	11.2	12.0	12.4	11.82	12.30
MgO	6.4	3.1	2.6	5.95	3.38
CaO	10.2	6.3	5.7	9.69	7.11
K <sub>2</sub> O	0.62	1.64	1.68	0.71	1.78
Na <sub>2</sub> O	3.2	3.0	3.3	3.11	3.27
TiO <sub>2</sub>	1.75	1.72	1.67	2.25	2.20
	100.0	96.7	96.6	99.30	98.78

<sup>1/</sup> NE 1/4 SE 1/4 sec. 11.

<sup>2/</sup> SE 1/4 SW 1/4 sec. 13

<sup>3/</sup> NW 1/4 SE 1/4 sec 10.

<sup>4/</sup> Rock Creek flow of lower basalts of Wright *et al.* (1973).

<sup>5/</sup> Low-Mg lower Yakima basalt of Wright *et al.* (1973).

Oregon is of late Miocene to early Pliocene age (Waters, 1961). According to Field (1973, oral communication), Yakima basalt from the top of Cuddy Mountain has been dated at 16.3 m. y. Geographic proximity, as well as lithic and chemical similarities, suggest a correlation and thus a similar age for the basalts of the Mineral-Iron Mountain District.

The district is near the southern end of the huge Chief Joseph (Grande-Ronde-Cornucopia) dike swarm described by Taubeneck (1966, 1967, 1970) for southeast Washington, northeast Oregon, and western Idaho. The many basalt dikes of this district are probably part of this swarm.

#### Quaternary Deposits

Unconsolidated deposits of Quaternary age post-date the Columbia River basalt and are present as terrace deposits, alluvium, and landslide material.

A terrace deposit, approximately 50 feet in thickness, is located south of the junction of Dennett Creek and the north fork of Dennett Creek in sec. 9. The terrace is the result of lowering of the local base level of erosion.

Unconsolidated alluvium fills the major stream channels of the Mineral-Iron Mountain District. These deposits were formed by weathering and transport of lithologies from within the district.

Evidence of glaciation, common to the Seven Devils and Cuddy Mountains nearby to the north was not observed.

Landslide material is located in secs. 4, 8 and 9 northwest of the middle fork of Dennett Creek. Such deposits are common at the limestone-gypsum horizon and within the overlying incompetent Big Hill wacke and its lithic equivalents in western Idaho and eastern Oregon.

## PLUTONIC UNITS

Radiometric age determinations, in combination with geological and faunal evidence, indicate that composite Iron Mountain Complex of Late Triassic or Early Jurassic age was the major plutonic event in the Mineral-Iron Mountain District. Younger plutonism is recognized in the form of andesine porphyry sills and plugs that intrude the Tate shale of late Middle Jurassic age. Intrusions, probably pre-Tertiary in age, in the drainages of Trail and Rock Creeks, six and eight miles to the south, respectively, from the Mineral-Iron Mountain District (Plate 4) were recognized during regional reconnaissance mapping and are discussed for comparative purposes.

Chemical classifications are after Nockolds (1954), except where noted.

Iron Mountain Complex

The Mineral-Iron Mountain District contains the Late Triassic or Early Jurassic Iron Mountain Complex that intrudes the Late Triassic Seven Devils Volcanics. Four major and distinct phases of the Iron Mountain Complex are recognized; gabbro, quartz diorite, porphyritic granodiorite (trondhjemite), and aplite. Genetically associated mafic and porphyritic dikes and plugs are also recognized

and they pre-date late-stage hydrothermal activity. The plutonic phases of the complex crop out over an area of approximately six square miles. To the east and south, parts of the composite intrusion are covered by basalts of the Columbia River Group of Tertiary age. ✓

### Gabbro

The gabbro is the oldest phase of the Iron Mountain Complex. Its total areal coverage approximates about one square mile near the north, east and west margins of the exposed complex (Plate 1). The gabbro is greenish-gray to dark-gray, medium crystalline, and forms rounded and subdued outcrops. Several sets of northeast and northwest trending vertical joints are present. Neither primary foliation nor lineation of minerals were recognized. The gabbro phase is strongly magnetic. ✓

Lithology and Petrography. A hypidiomorphic-granular texture is displayed by minerals in the gabbro. Component minerals range from 0.5 to 3.0 mm in diameter. Modal analyses for selected gabbro samples (Table 5) indicate the dominant minerals to be quartz, plagioclase feldspar, clinopyroxene, orthopyroxene, hornblende, and ilmenite-magnetite. Accessory minerals include trace amounts of apatite, sphene, and zircon. Alteration products include actinolite, biotite, calcite, chlorite, clays, epidote, and sericite. Veinlets of ✓

Table 5. Modal and Chemical Analyses of Gabbros of the Iron Mountain Complex.

Data	I-93 <sup>1/</sup>	N-54 <sup>2/</sup>	N-55 <sup>3/</sup>	B-5-886 <sup>3/</sup>
Qtz.	2	7	11	21
K-fld.	-	tr	4	1
P-fld.	63	47	49	44
Clino-pyx.	tr	2	1	-
Ortho-pyx.	-	6	tr	-
Hbl.	17	10	-	-
Bio.	-	7	4	-
Acc.	tr	tr	tr	tr
Opq.	5	2	5	5
Ser.	tr	14	6	10
Clay	13	tr	tr	4
Chl.	tr	5	20	12
Epi.	tr	-	tr	-
Carb.	tr	-	-	3
SiO <sub>2</sub>	54.0	52.00	55.8	63.9
TiO <sub>2</sub>	0.50	0.94	0.73	0.95
Al <sub>2</sub> O <sub>3</sub>	21.2	16.81	17.0	18.0
Fe <sub>2</sub> O <sub>3</sub>	4.50	3.93		
FeO	1.87	5.80	10.63 <sup>1/</sup>	8.10 <sup>1/</sup>
MnO		0.25		
MgO	3.1	4.55	3.6	1.4
CaO	10.2	7.88	6.0	0.9
Na <sub>2</sub> O	3.4	2.13	2.0	0.9
K <sub>2</sub> O	0.50	1.95	2.12	5.00
H <sub>2</sub> O <sup>+</sup>	0.30	3.19		
H <sub>2</sub> O <sup>-</sup>	0.01	0.18		
P <sub>2</sub> O <sub>5</sub>		0.11		
	99.6	99.72	97.9	99.2
Specific gravity	2.83	2.81	2.79	2.77

<sup>1/</sup> Fe<sub>2</sub>O<sub>3</sub>, FeO, H<sub>2</sub>O<sup>+</sup>, H<sub>2</sub>O<sup>-</sup> analyzed by Chemical and Mineralogical Services, Salt Lake City, Utah.

<sup>2/</sup> Chemical analysis by Dr. K. Aoki, Tohoku University, Japan.

<sup>3/</sup> Total iron reported as FeO.

quartz-tourmaline and calcite-epidote-potassium feldspar are locally present.

Interstitial anhedral quartz (tr-six percent) exhibits undulatory extinction. Quartz is also present in myrmekite and quartz veinlets. It is most abundant near the contacts with younger phases of the Iron Mountain Complex.

Potassium feldspar (orthoclase) is recognized only as hydrothermal veinlets in secs. 9 and 10.

The plagioclase feldspar is labradorite ( $An_{51-57}$ ) and it is present in amounts ranging from 44 to 63 percent. It occurs as lath-shaped subhedra to euhedra that range from 1.5 to 3.0 mm in length. In addition to polysynthetic twinning, the plagioclase feldspar exhibits normal and oscillatory zoning. Near the cloudy cores of some plagioclase are poikilitic inclusions of randomly oriented biotite, chlorite, epidote, and magnetite. Small amounts of myrmekite are present in the gabbro of Barton Gulch (sec. 13). Because cloudy plagioclase crystals are associated with myrmekite, they may have formed as the result of hydrothermal alteration, metamorphism, or both (Barker, 1970). Plagioclase is partly to completely altered to calcite, clays, and sericite.

Up to six percent hypersthene, locally pink and pleochroic, is observed as anhedral crystals averaging one millimeter in length. However, hypersthene is absent, or present in only trace amounts,

in most specimens of gabbro.

Hornblende typically forms pleochroic pale-green anhedral that exhibit bleached cores of augite. Moreover, it commonly contains inclusions of quartz that formed by the release of silica as hornblende replaced clinopyroxene (Taubeneck, 1964).

Primary tabular crystals of biotite, pleochroic dark-brown to pale-brown, are present ranging from trace amounts to as much as seven percent. Biotite occurs as discrete individual crystals and as rims on hornblende, pyroxene, and magnetite.

Chemistry. Whole-rock chemical analyses were obtained for hydrothermally altered gabbro samples from the Iron Mountain Complex (Table 5). Compared with average gabbro defined by Nockolds (1954), all samples analyzed contain significantly more  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{SiO}_2$ . The higher silica contents (52.0 to 63.9 percent) relative to Nockolds' average (48.36 percent) are clearly attributable to variable amounts of introduced quartz. The anomalously large concentrations of  $\text{Fe}_2\text{O}_3$  (3.93 and 4.50 percent) compared to Nockolds' average (2.55 percent) are attributed to the presence of hematite. This oxide occurs both as an introduced phase in veinlets and as a hydrothermal alteration product of primary magnetite. The larger alumina content (16.8 to 21.2 percent) as contrasted to Nockold's average of 16.84 percent, may be inherited from an alumina-rich primary magma source,

as discussed later, or possibly in part a result of base leaching that accompanied hydrothermal alteration of host minerals to clay and sericite.

### Quartz Diorite

A quartz diorite (Travis, 1955), which includes some granodiorite, is exposed over an area of nearly four square miles. It is the most widely distributed phase of the Iron Mountain Complex. The steep north slope of Iron Mountain is composed primarily of this plutonic unit.

The quartz diorite is medium to coarsely crystalline and exhibits a "salt and pepper" appearance. It is largely unaltered although a thin grus is common to surficial exposures. Jointing and primary foliation are poorly developed in the quartz diorite. Where formed, the joints crudely parallel contacts with the Seven Devils Volcanics. Primary foliation of biotite was observed in quartz diorite from diamond drill core within several centimeters of contacts with the Seven Devils Volcanics. Xenoliths of dark-gray gabbro are also present. The quartz diorite is weakly to moderately magnetic.

Lithology and Petrography. The quartz diorite exhibits hypidiomorphic - granular to porphyritic (phenocrysts of quartz) textures. Crystals range from 0.5 mm to 4.0 mm in diameter.

The principal minerals (Table 6) include quartz, potassium feldspar, plagioclase feldspar, clinopyroxene, hornblende, and biotite. Alteration products are calcite, chlorite, clays, epidote, hematite, leucoxene, and sericite. Hydrothermal veinlets of carbonate, potassium feldspar, and quartz locally pervade the host.

Quartz is present both as interstitial anhedral crystals and locally as anhedral phenocrysts. It generally comprises 20 percent or more of the host rock.

Magmatic interstitial orthoclase (tr to eight percent) is the predominate potassium feldspar. Staining techniques (Bailey and Stevens, 1960) best reveal its presence. Traces of microcline are also present as crystals exhibiting gridiron twins. The potassium feldspars commonly exhibit partial alteration to kaolin group minerals.

Plagioclase feldspar is andesine ( $An_{33-44}$ ) that occurs as lath-shaped anhedra and euhedra that are up to four millimeters in length and comprise 46 to 61 percent of the quartz diorite. Polysynthetic twinning, as well as normal and oscillatory zoning, are exhibited by the plagioclase. Sericite and calcite are ubiquitous but minor alteration products of the feldspar.

Clinopyroxene anhedra, as augite, occur in trace amounts. Orthopyroxene was not identified in any of the samples. Euhedral green hornblende (1 to 13 percent) is a primary mineral and not

Table 6. Modal Analyses of Unaltered 1/ Quartz Diorite-Granodiorite Samples of the Iron Mountain Complex.

	Qtz.	K-fld.	P-fld.	Pyx.	Hbld.	Bio.	Acc. <u>2/</u>	Opq.	Alt. prod. <u>3/</u>
M-342	20	7	54 (An <sub>41</sub> )	-	3	12	tr	1	3
M-406	23	8	50 (An <sub>36</sub> )	-	8	3	tr	1	7
M-459-b	24	4	51 (An <sub>40</sub> )	-	6	8	tr	1	6
M-467	29	4	50 (An <sub>44</sub> )	tr	5	6	tr	tr	6
M-506	27	8	53 (An <sub>44</sub> )	-	6	5	tr	2	3
M-511	20	4	61 (An <sub>41</sub> )	tr	5	8	tr	1	1
M-520	18	4	56 (An <sub>38</sub> )	-	11	1	tr	2	8
I-13	21	5	53 (An <sub>33</sub> )	-	5	8	tr	tr	8
I-21	26	3	49 (An <sub>42</sub> )	-	10	10	tr	tr	2
I-23	25	3	55 (An <sub>37</sub> )	-	4	9	tr	tr	4
I-24	21	7	57 (An <sub>40</sub> )	-	6	9	tr	tr	tr
I-27-a	27	4	51 (An <sub>42</sub> )	-	1	7	tr	1	9
I-104	30	7	42 (An <sub>33</sub> )	-	9	6	tr	1	5
I-161	27	4	46 (An <sub>40</sub> )	-	6	10	tr	1	7
N-4	25	4	55 (An <sub>38</sub> )	-	1	4	tr	1	10
N-5	31	tr	46 (An <sub>40</sub> )	-	10	9	tr	2	2
N-25-a	27	tr	48 (An <sub>41</sub> )	-	13	8	tr	1	3
N-36	27	7	47 (An <sub>45</sub> )	-	7	5	tr	1	6
N-47	24	7	60 (An <sub>46</sub> )	-	5	5	tr	1	tr
Mean	25.3	4.7	51.8	tr	6.4	7.0	tr	0.9	4.7

1/ Less than 10% alteration minerals.

2/ Includes sphene, zircon, and apatite.

3/ Includes hydrothermal, metamorphic, and weathering products.

an alteration product of earlier pyroxene.

Primary biotite forms tabular crystals, is pleochroic dark-brown to pale-brown color, and is present in amounts ranging from 1 to 12 percent. Trace amounts of magnetite, sulfides, and zircon are associated with the biotite. Chlorite is ubiquitous as an alteration product that partly to completely replaces biotite.

Chemistry. Whole-rock chemical analyses of unaltered samples (less than 10 percent alteration minerals) of quartz diorite-granodiorite are listed with Nockolds' (1954) diorite (tonalite) in Table 7. Potash is generally more abundant (1.28 to 3.15 percent) in quartz diorite-granodiorite of the Mineral-Iron Mountain District as compared to the average value (1.42 percent) reported by Nockolds (1954). These values reflect the original magmatic concentrations, not secondary additions of hydrothermal potassium feldspar, biotite, or sericite.

#### Porphyritic Granodiorite

The porphyritic granodiorite phase crops out in the south and east parts of the Mineral-Iron Mountain District. Contact relationships in sec. 27 indicate that it intruded the quartz diorite. The porphyritic granodiorite is medium to coarsely crystalline and contains phenocrysts of quartz and plagioclase feldspar in a groundmass of identical mineralogy plus biotite and minor potassium

Table 7. Chemical Analyses of Unaltered <sup>1/</sup> Quartz Diorite-Granodiorite Samples of the Iron Mountain Complex Compared to Nockolds (1954) Average.

	M-506 <sup>2/</sup>	I-161 <sup>3/</sup>	N-4 <sup>4/</sup>	N-36 <sup>2/</sup>	N-47 <sup>2/</sup>	Ave. Qtz. Diorite
SiO <sub>2</sub>	66.5	65.7	67.19	68.3	68.2	66.15
TiO <sub>2</sub>	0.42	0.44	0.52	0.39	0.41	0.42
Al <sub>2</sub> O <sub>3</sub>	15.6	15.6	16.01	15.6	15.4	15.56
Fe <sub>2</sub> O <sub>3</sub>		2.43	1.83			1.36
FeO	5.1	2.06	2.20	4.7	4.6	3.42
M <sub>n</sub> O			0.06			
MgO	0.9	2.1	1.91	1.0	1.1	1.94
CaO	3.7	4.6	3.21	3.1	3.5	4.65
Na <sub>2</sub> O	3.0	3.5	3.54	2.8	3.1	3.40
K <sub>2</sub> O	2.93	2.50	1.28	3.15	2.91	1.42
H <sub>2</sub> O <sup>+</sup>		0.70	1.49			0.69
H <sub>2</sub> O <sup>-</sup>		0.01	0.17			
P <sub>2</sub> O <sub>5</sub>			0.10			
	98.1	99.6	99.51	99.0	99.2	99.51
Specific gravity	2.68	2.70	2.64	2.70	2.61	

<sup>1/</sup> Less than 10% alteration minerals.

<sup>2/</sup> Total iron reported as FeO.

<sup>3/</sup> Fe<sub>2</sub>O<sub>3</sub>, FeO, H<sub>2</sub>O<sup>+</sup>, H<sub>2</sub>O<sup>-</sup> analyzed by Chemical and Mineralogical Services, Salt Lake City, Utah.

<sup>4/</sup> Chemical analysis by Dr. K. Aoki, Tohoku University, Japan.

feldspar. The border zone adjacent to the Seven Devils Volcanics is locally chilled and often contains pegmatitic segregations of quartz, tourmaline, biotite, and potassium feldspar. The chilled border zone of the porphyritic granodiorite resembles many quartz and plagioclase feldspar porphyry dikes and plugs in the district. Thus, a genetic relationship between the two lithologies may be inferred. The leucocratic appearance of the porphyritic granodiorite is primarily caused by an original deficiency of mafic minerals, but hydrothermal alteration and weathering have also bleached the phase. East-west vertical jointing is conspicuous at the Thorn Spring Prospect, and weathered outcrops of the granodiorite appear as standing ribs. Outcrops are devoid of primary foliation and lineation. The phase is weakly magnetic.

Lithology and Petrography. Penocrysts of anhedral quartz (up to seven millimeters in diameter) and euhedral to subhedral laths of plagioclase (up to five millimeters in length) are set in a somewhat more finely crystalline groundmass of quartz, potassium feldspar, plagioclase feldspar, and biotite. Much of the rock is essentially non-porphyritic. Unaltered samples of the porphyritic granodiorite were not observed. Modal analyses are listed in Table 8 (and in Table 16, Economic Geology). Principal minerals of the porphyritic granodiorite include quartz, orthoclase, plagioclase feldspar, and biotite. Opaques are present in trace amounts

Table 8. Modal and Chemical Analyses of Porphyritic Granodiorite (Trondhjemite) of the Iron Mountain Complex.

Data	I-135-a <sup>1/</sup>	I-170 <sup>1/</sup>
Qtz.	35	32
K-flid.	-	-
P-flid.	16	22
Pyx.	-	-
Hblid.	-	-
Bio.	tr	3
Acc.	tr	tr
Opq.	1	tr
Ser.	20	5
Clay	23	32
Chl.	5	6
Epi.	-	-
Carb.	-	-
SiO <sub>2</sub>	75.4	74.6
TiO <sub>2</sub>	0.27	0.30
Al <sub>2</sub> O <sub>3</sub>	14.8	15.3
Fe <sub>2</sub> O <sub>3</sub>	1.50	2.43
FeO	.19	0.13
MgO	0.9	1.1
CaO	0.4	1.6
Na <sub>2</sub> O	4.6	4.9
K <sub>2</sub> O	1.45	1.00
H <sub>2</sub> O <sup>+</sup>	0.80	1.40
H <sub>2</sub> O <sup>-</sup>	0.01	0.0
	100.4	102.8
Specific gravity	2.63	2.59

<sup>1/</sup> Fe<sub>2</sub>O<sub>3</sub>, FeO; H<sub>2</sub>O<sup>+</sup>, H<sub>2</sub>O<sup>-</sup> analyzed by Chemical and Mineralogical Services, Salt Lake City, Utah.

as are the accessory constituents apatite, sphene, and zircon. Alteration products include biotite, calcite, clays, chlorite, and sericite.

In addition to early magmatic phenocrysts of quartz, late-stage pegmatitic quartz locally replaced plagioclase feldspar. Total quartz in individual specimens ranges from 31 to 39 percent.

Primary orthoclase is interstitial and is generally present in only trace amounts. Up to six percent interstitial orthoclase is contained in the border phases of the porphyritic granodiorite (e.g., the Thorn Spring Prospect). However, much of this potassium feldspar may be hydrothermal or pegmatitic in origin.

Plagioclase feldspar is oligoclase-andesine ( $An_{27-35}$ ) and comprises 11 to 31 percent of individual specimens. Polysynthetic twinning is recognized only with difficulty because of the effects of hydrothermal alteration. Kaolin group minerals, sericite, and minor calcite are alteration products that partly to completely replace the feldspar.

Biotite occurs both as tabular, dark-brown primary crystals and as felty, pale-brown to reddish-brown hydrothermal aggregates. The primary variety is most abundant. Primary biotite has been altered to both chlorite and hydrothermal biotite.

Chemistry. Selected modal and chemical analyses of hydrothermally altered porphyritic granodiorite are listed in Table 8

(and in Table 16, Economic Geology). Low percentages of mafics (tr-six percent) and potassium feldspar (tr-six percent) and abundant quartz (31-39 percent) and oligoclase-andesine (47-62 percent) are significant. The chemical characteristics of the porphyritic granodiorite such as large silica and soda concentrations and small potassium values are characteristic of trondhjemites that are allied to granodiorites (Turner and Verhoogen, 1960). A trondhjemite is defined as a light-colored plutonic rock primarily composed of sodic plagioclase (especially oligoclase), quartz, sparse biotite, and little or no alkali feldspar and this term could be applied to these rocks. The term porphyritic granodiorite, however, is retained in order to emphasize the similarity between these rocks and rocks of similar petrography and chemistry on Cuddy Mountain, where previous authors (Fankhauser, 1969; Slater, 1969; King, 1970; and Bruce, 1971) have used this rock name.

### Aplite

Finely crystalline intrusions of aplite are the youngest major phase of the Iron Mountain Complex. They are spatially, and probably genetically, associated with the porphyritic granodiorite. The aplites are important because of their spatial association with Cu-Mo-Zn metallization in the Mineral-Iron Mountain District.

Aplite intrusions, white to pink in color, exhibit a sugary texture. They range in size from several inches in width to several thousand feet across (Thorn Spring Prospect), and they are found within or near the margins of the porphyritic granodiorite. Aplites are also present in dike-swarm proportions within the Seven Devils Volcanics on the Iron Mountain Prospect (Plates 1 and 3). Pegmatitic segregations of biotite (up to 2.2 cm in diameter), muscovite, quartz, and tourmaline occur in the internal parts of many aplite dikes on the Iron Mountain Prospect. Thus, the term "aplite-pegmatite" is reserved for these dikes. The aplites exhibit primary foliation of biotite in surface exposures and diamond drill core from the Iron Mountain Prospect. However, they have neither a distinctive topographic expression nor recognizable joints.

Lithology and Petrography. The aplites consist principally of finely crystalline, equigranular to porphyritic, allotriomorphic mosaics that include quartz, potassium feldspar, plagioclase feldspar, biotite, and muscovite (Table 9). Crystals range in diameter from less than 0.5 mm to more than 3.0 mm. Opaque ilmenite-magnetite intergrowths are present in trace amounts as are the accessory minerals apatite, sphene, and zircon. Disseminated chalcopyrite and pyrite are associated with aplites at the Iron Mountain Prospect (see Economic Geology).

Table 9. Modal Analyses and a Chemical Analysis of an Aplite of the Iron Mountain Complex.

	Modal analysis				Chemical analysis	
	M-181	I-81	I-107-b	N-41-c		I-81
Quartz	38	47	48	36	SiO <sub>2</sub>	78.6
K-feldspar	37	19	6	21	TiO <sub>2</sub>	0.09
Plagioclase	19 (An <sub>9</sub> )	26 (An <sub>12</sub> )	2 (An <sub>26</sub> )	23 (An <sub>9</sub> )	Al <sub>2</sub> O <sub>3</sub>	12.6
Biotite	tr	-	4	-	FeO <u>1/</u>	0.7
Moscovite	4	tr	23	tr	MgO	0.6
Accessories	tr	tr	tr	tr	CaO	0.04
Opaques	tr	tr	tr	tr	Na <sub>2</sub> O	5.0
Clay	tr	8	9	20	K <sub>2</sub> O	2.45
Chlorite	tr	-	8	-		100.1
Carbonate	tr	-	tr	-		
Tourmaline	2	-	-	-		

1/ Total iron reported as FeO.

The potassium feldspar is orthoclase and it is present both as individual anhedral and as perthitic intergrowths with plagioclase feldspar. The orthoclase is partly replaced by dusty kaolin group minerals and sericite.

Plagioclase feldspar ( $An_{9-26}$ ) is unzoned and exhibits excellent polysynthetic twinning. This feldspar is rarely unaltered and is partly to completely replaced by sericite and kaolin group minerals.

Chemistry. A single whole-rock chemical analysis of unaltered aplite (sample I-81) is listed in Table 9. The aplite is siliceous (78.6 percent  $SiO_2$ ) and probably represents the end stage of magma crystallization in the Iron Mountain Complex.

#### Porphyritic Plugs and Dikes

Hydrothermally altered porphyritic dikes and plugs of varying composition occur within earlier phases (except the aplite) of the Iron Mountain Complex. Plugs and dikes are all less than 500 feet in diameter or width, respectively. They are probably late-stage phases of the Iron Mountain Complex.

Quartz-Feldspar Porphyries. Quartz-feldspar porphyries (Jpd), that have been subjected to pervasive hydrothermal alteration, occur within the quartz diorite near the Thorn Spring Prospect and also in secs. 10 and 11. Modal analyses for several

porphyries, containing phenocrysts of oligoclase ( $An_{25-27}$ ) and quartz in a microcrystalline groundmass, are listed in Table 10. As previously noted, textural and mineralogical similarities, such as phenocrysts of quartz and hydrothermally altered oligoclase, between the porphyries and the chilled margin of the porphyritic granodiorite suggest a common origin.

In addition to pervasive clay-sericite replacement products of plagioclase feldspars, the feldspar porphyry plugs in secs. 10 and 11 contain traces of disseminated and fracture-controlled pyrite and chalcopyrite.

Lamprophyres. Two melanocratic plugs are located in the southwest part of the Mineral-Iron Mountain District. Modal analyses of two samples collected from the plugs are listed in Table 11.

Phenocrysts, as much as 2.5 mm in diameter, of andesine ( $An_{34-46}$ ), biotite, hornblende, and clinopyroxene are set in a microcrystalline groundmass of similar mineralogy and quartz. By Knopf's definition (1936), all feldspars are confined to the groundmass in lamprophyres. However, Williams, Turner, and Gilbert (1954) discuss specific lamprophyres (kersanite and camptonite) that also contain plagioclase feldspar as phenocrysts. Thus, the term lamprophyre is applied to both melanocratic plugs of the Mineral-Iron Mountain District.

Table 10. Modal Analyses of Hydrothermally Altered Quartz-Feldspar Porphyries of the Iron Mountain Complex.

	M-160-d	M-281-a	M-297-a
Quartz	31	19	27
Plagioclase	22 (An <sub>25</sub> )	28 (An <sub>27</sub> )	24 (An <sub>27</sub> )
K-feldspar	tr	tr	tr
Hornblende	-	-	-
Accessories	tr	tr	tr
Opaques	1	2	tr
Sericite	10	2	3
Clay	21	23	32
Chlorite	14	13	14
Epidote	1	12	tr
Carbonate	-	1	-
Tourmaline	tr	-	-

Table 11. Modal Analyses of Two Lamprophyre Plugs of the Iron Mountain Complex.

	I-77	N-56
Quartz	tr	5
Plagioclase	54 (An <sub>34</sub> )	31 (An <sub>46</sub> )
Clinopyroxene	14	-
Hornblende	26	26
Biotite	-	3
Accessories	-	1
Opaques	6	2
Sericite	tr	32
Chlorite	tr	tr

Sample N-56, from the Thorn Spring Prospect, is pervasively hydrothermally altered. Sericite has replaced about 75 percent of the plagioclase feldspar. Abundant apatite needles are also present. Pyrite, up to three percent, and traces of chalcopyrite are disseminated in this lamprophyre.

Because pyroxene (augite) is abundant (14 percent) in sample I-77 and is totally lacking in sample N-56, derivation from separate magmas in two distinct intrusive events is suggested.

#### Andesine Porphyry Sills

Distinctive porphyritic sills containing phenocrysts of plagioclase feldspar, as much as 2.5 cm in diameter, and sub-aligned hornblende in an aphanitic groundmass crop out at or near the base of the allochthonous plate in the Mineral-Iron Mountain District (Plate 1). Modal analyses for several of the sills, and a single chemical analysis, are listed in Table 12.

The term andesine porphyry is derived from the abundant (21-31 percent) and obvious phenocrysts of plagioclase feldspar ( $An_{31-40}$ ) that characterize this rock type. The phenocrysts are euhedral to anhedral and commonly show evidence of resorption by the microcrystalline groundmass.

Phenocrysts of euhedral green hornblende, as much as 1.5 mm in length, comprise 31 to 51 percent of this host. Lineation

Table 12. Modal Analyses and a Chemical Analysis of Andesine Porphyry Intrusions in the Mineral-Iron Mountain District.

	Modal Analyses					Chemical Analysis	
	And. P-2	M-150	M-388	M-403	M-404	And. P-2	
Phenocrysts							
Quartz	tr	tr	tr	tr	tr	SiO <sub>2</sub>	65.5
Plagioclase	21 (An <sub>31</sub> )	22 (An <sub>37</sub> )	21 (An <sub>34</sub> )	31 (An <sub>38</sub> )	25 (An <sub>40</sub> )	TiO <sub>2</sub>	0.39
Hornblende	37	51	31	30	36	Al <sub>2</sub> O <sub>3</sub>	16.8
Groundmass <sup>1/</sup>	40	22	41	38	37	FeO <sup>2/</sup>	3.8
Accessories	tr	tr	tr	tr	tr	MgO	3.1
Opakes	1	2	2	1	1	CaO	4.3
Sericite	tr	tr	tr	tr	tr	Na <sub>2</sub> O	4.7
Chlorite	tr	tr	3	tr	tr	K <sub>2</sub> O	<u>2.35</u>
Carbonate	1	1	2	tr	1		100.9
Sphene	tr	2	tr	tr	tr		

<sup>1/</sup> Mostly plagioclase, quartz, and potassium feldspar.

<sup>2/</sup> Total iron reported as FeO.

defined by the alignment of phenocrysts of hornblende is sub-parallel to the dip of the enclosing sedimentary country rocks, as well as to the dip of the reverse fault at the base of the allochthonous plate.

The microcrystalline groundmass consists primarily of a mosaic of intermediate plagioclase feldspar, sanidine, and quartz. Accessory minerals include apatite, sphene, and zircon in the groundmass in trace amounts. Although the opaque iron oxides are up to two percent in abundance, sulfides were not observed.

Products of hydrothermal alteration include calcite and chlorite that have partly to completely replaced hornblende. Calcite and sphene occur as partial to complete replacement products of plagioclase feldspar.

Because the andesine porphyry sills intrude the upper Middle Jurassic Tate shale (NW $\frac{1}{4}$  sec. 10) and post-date, or are contemporaneous with, post-late Middle Jurassic reverse faulting, the sills cannot be part of the Late Triassic-Early Jurassic Iron Mountain Complex. The sills are possibly related to 120 m. y. plutonism reported for the Sturgill Peak area, seven miles to the northeast (Henricksen, Skurla, and Field, 1972). A similar andesine porphyry intrudes the Jurassic strata on the Oregon side of the Snake River across from the mouth of Dennett Creek (Cox, oral communication, 1973).

### Intrusions of Trail and Rock Creeks

During regional reconnaissance examination of the strata-bound vein-type metallization, stock-sized plutons of intermediate to silicic composition, and probably pre-Tertiary in age, were recognized in the drainages of Trail and Rock Creeks, six and eight miles south, respectively, of the Mineral-Iron Mountain District (Plate 4).

The Trail Creek pluton is located between Trail and Little Rock Creeks. It occupies an area of approximately one square mile in parts of secs. 11, 12, 13, 14, and 24, T. 13 N., R. 7 W. in the 15-minute Olds Ferry quadrangle. This pluton is elongate northwest-southeast and has intruded the Seven Devils Volcanics, that locally consist of metasedimentary and metavolcanic lithologies. Skarn deposits, containing structurally controlled assemblages of magnetite-pyrite-chalcopyrite-bornite, are found on the flanks of the Trail Creek pluton and are associated with quartz porphyry dikes that are as much as ten feet in width.

Modal and chemical analyses (sample I-152) of the Trail Creek pluton are listed in Table 13. The pluton exhibits graphic intergrowths of albite ( $An_5$ ) and quartz (Fig. 7). The plagioclase feldspar exhibits excellent polysynthetic twinning, and is partly altered to clay, sericite, and epidote. The original mafics, amounting to less than ten percent, were hornblende and biotite. However, they have been almost

Table 13. Modal and Chemical Analyses of Intrusions in the Trail and Rock Creek Areas.

	I-142 (Diorite) <sup>2/</sup>	I-144(Quartz Porph)	I-152 <sup>2/</sup>
Quartz	7	19 (phenocrysts)	40
K-feldspar	tr	-	-
Plagioclase	46 (An <sub>48</sub> )	26 (An <sub>11</sub> )(phenocrysts)	41 (An <sub>5</sub> )
Pyroxene	tr	-	-
Hornblende	27	-	tr
Biotite	3	-	tr
Groundmass <sup>1/</sup>	-	46	-
Opakes	4	1	tr
Alteration products	13	8	19
SiO <sub>2</sub>	55.4		76.6
TiO <sub>2</sub>	1.00		0.20
Al <sub>2</sub> O <sub>3</sub>	18.1		15.3
Fe <sub>2</sub> O <sub>3</sub>	3.79		1.14
FeO	5.68		.19
MgO	4.5		0.8
CaO	9.1		0.4
Na <sub>2</sub> O	3.2		4.6
K <sub>2</sub> O	0.85		1.70
H <sub>2</sub> O <sup>+</sup>	1.40		1.00
H <sub>2</sub> O <sup>-</sup>	.01		.01
	103.0		101.9

<sup>1/</sup> Mostly quartz and plagioclase feldspar.

<sup>2/</sup> Fe<sub>2</sub>O<sub>3</sub>, FeO, H<sub>2</sub>O<sup>+</sup>, H<sub>2</sub>O<sup>-</sup> analyzed by Chemical and Mineralogical Services, Salt Lake City, Utah.

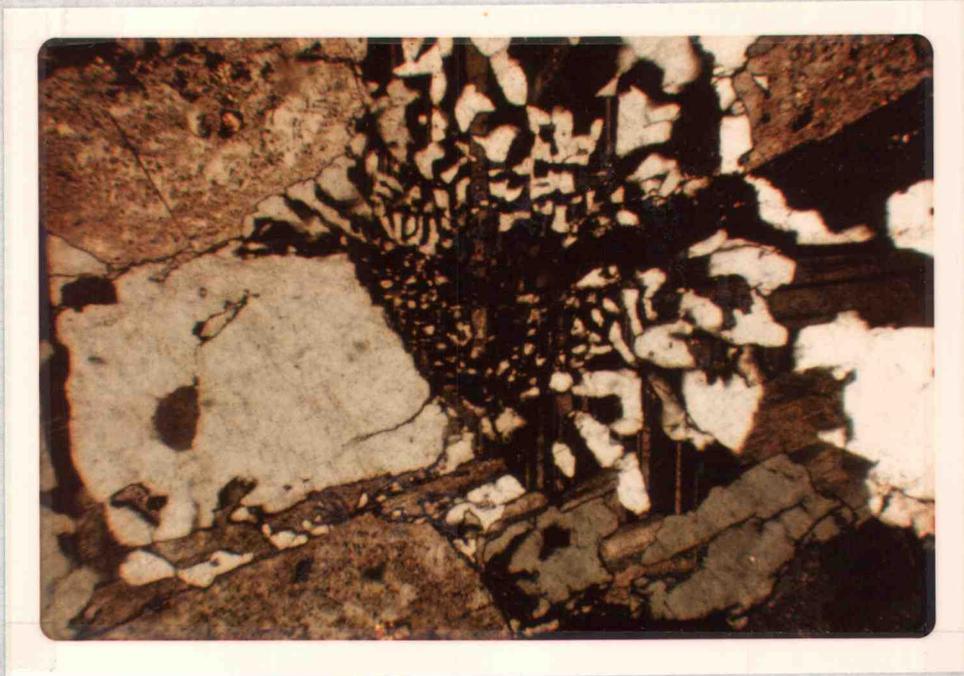


Figure 7. Photomicrograph, Trail Creek pluton. Cloudy plagioclase ( $An_5$ ) and graphic intergrowths are portrayed (crossed nicols, 50x).

completely replaced by epidote and chlorite.

The intrusion has undergone minor cataclastic deformation as defined by broken crystals of quartz and plagioclase feldspar.

The Trail Creek pluton is mineralogically, texturally, and chemically similar to the Sparta Granite of northeast Oregon. These similarities include high silica content (76.6 percent), cloudy crystals of albite ( $An_5$ ), low total mafics, graphic intergrowths of quartz and plagioclase feldspar, and cataclastic deformation features. Gilluly (1933), who first described the Sparta Granite, suggested an origin for the "albite granite" by replacement (hydrothermal) of primary diorite. However, more petrographic and whole-rock chemical data are needed before any definitive statements can be made concerning the origin of the Trail Creek pluton.

A window in the Columbia River basalt of Tertiary age in the Rock Creek drainage exposes a medium to coarsely crystalline diorite that has been intruded by several hydrothermally altered porphyry dikes up to 20 feet in width. The diorite-quartz porphyry complex comprises approximately one square mile in parts of secs. 25, 26, 35, and 36, T. 13 N., R. 7 W. of the Olds Ferry 15-minute quadrangle (Plate 4).

Modal and whole-rock chemical analyses of the diorite (I-142) and quartz porphyry (I-144) are given in Table 13. The diorite exhibits a hypidiomorphic-granular texture and crystals average 2.5 mm in

diameter. Andesine ( $An_{48}$ ) and green primary hornblende are the dominant minerals. The plagioclase feldspar exhibits excellent oscillatory zoning and the hornblende is commonly rimmed with late magmatic biotite. Alteration products of the diorite include sericite and clays after plagioclase feldspar and chlorite after hornblende.

The quartz porphyry dikes contain phenocrysts of sodic oligoclase ( $An_{11}$ ) and quartz that are as much as 1.2 mm in diameter. The phenocrysts are set in a microcrystalline groundmass of sodic plagioclase feldspar and quartz. Phenocrysts of oligoclase are characterized by oscillatory zoning, whereas those of quartz are embayed by the microcrystalline groundmass. The plagioclase feldspar is weakly altered to sericite. Infrequent veinlets of sericite and biotite traverse the host and they contain traces of pyrite and chalcopyrite.

## PETROGENESIS AND EMPLACEMENT OF THE IRON MOUNTAIN COMPLEX

A study of petrogenesis and emplacement of the Iron Mountain Complex is necessary to understand the origin of related mineral deposits of the Mineral-Iron Mountain District. Thus, topics such as mode and depth of emplacement, age relationships, physical condition of the complex at the time of emplacement, mineralogical variations, chemical variations, and the role of water warrant discussion.

### Mode and Depth of Emplacement

Field relationships of the plutonic complex to its country rocks suggest that the Iron Mountain Complex may have been passively emplaced into the Upper Triassic Seven Devils Volcanics. Evidence for this conclusion includes the absence of: (1) extensive deformation in the Seven Devils Volcanics adjacent to the complex, (2) breccias along the contact zones and elsewhere, and (3) xenoliths of Seven Devils Volcanics in the complex.

The Iron Mountain Complex was apparently intruded as a stock-size pluton into the Seven Devils Volcanics. The country rocks appear to be truncated by the complex in the west and south parts of the district. The dip of primary foliation of biotite in the quartz

diorite and aplite phases ranges from  $60^{\circ}$  to vertical. This foliation is found only in diamond drill core of the Iron Mountain Prospect (Plate 3) and within several centimeters of contacts with the Seven Devils Volcanics. The preferred location and weak development of foliation suggest that the complex may have been vertically emplaced into the Late Triassic stratigraphic units. However, the original shape of the composite pluton has been modified by several post-pluton events. As previously noted, uplift and erosion of the Seven Devils Volcanics and Iron Mountain Complex probably occurred in Early Jurassic time and was followed by deposition of the Jurassic strata. Later regional tilting of the Triassic-Jurassic sequence, including the Iron Mountain Complex, by as much as  $50^{\circ}$  NW is suggested from dips in the pre-Tertiary stratigraphic section. Furthermore, post-late Middle Jurassic reverse faulting (see Structural Geology) may have altered the original shape of the complex. Columbia River basalt flows of Tertiary age may cover more than 50 percent of the stock to the south and east of the district, as evidenced by plutonic lithologies recognized in windows through the basalt veneer of that area. Thus, the shape and absolute size of the plutonic complex are difficult to estimate.

Features of the Iron Mountain Complex that are characteristic of Buddington's (1959) mesozonal plutons include: (1) greenschist metamorphism in the Seven Devils Volcanics country rocks (see

Metamorphism), (2) an apparent lack of a direct relationship between the plutonic complex and the host volcanic lithologies, (3) pegmatitic segregations in the border zone of the granodiorite phase, (4) an excellent contact zone of hornfels developed in the Seven Devils Volcanics adjacent to the complex, (5) an early Mesozoic age for the plutonic complex (200 m. y. ), and (6) the absence of extensive chill zones in plutonic phases adjacent to the country rocks. In contrast, the absence of well-developed primary mineral foliations and lineations are features typical of epizonal plutons. The presence of several distinct plutonic phases is characteristic of both mesozonal and epizonal plutons.

The above evidence suggests that the complex was passively emplaced into either the lower part of the epizone or the upper part of the mesozone as defined by Buddington (1959). Greenschist metamorphism commences at depths ranging from less than five kilometers (White, 1963) to more than 10 kilometers (Turner, 1968). Accordingly, a similar possible range of depths is suggested for the emplacement of the Iron Mountain Complex.

#### Age Relationships

The sequence of emplacement for the major phases of the Iron Mountain Complex has been determined to be: gabbro, quartz diorite, porphyritic granodiorite (trondhjemite), and aplite. On

the basis of radiometric age determinations, minimum age of emplacement was 200 m. y.

### Emplacement Sequence

From geologic evidence the gabbro is clearly the oldest of the major phases. In sec. 10 it is highly silicified where it is the host for numerous quartz-tourmaline-sulfide veins near the contact with the younger quartz diorite. Furthermore, abundant gabbro xenoliths are locally observed in the quartz diorite. The gabbro samples collected from near the head of Barton Gulch (sec. 13) contain ubiquitous myrmekite, whereas myrmekite is absent in samples of gabbro from sec. 9 at the west end of the district. Thus, more than one pulse of gabbro may have occurred. However, the myrmekite may also be a contact effect from younger plutonic phases in sec. 13.

The porphyritic granodiorite has intruded the quartz diorite in the NW $\frac{1}{4}$  sec. 27 north of Wolf Creek. The hydrothermally altered and mineralized porphyry dikes and plugs, as well as the aplites, are lithically similar to the porphyritic granodiorite. They were probably emplaced at about the same time, or slightly later. However, the lamprophyre plugs post-date the porphyritic granodiorite as evidenced by field relations at the Thorn Spring Prospect.

### Radiometric Age Determinations

Radiometric K-Ar age determinations for the Iron Mountain Complex and other plutons of western Idaho are listed in Table 14. Because micas will lose radiogenic Ar<sup>40</sup> at temperatures as low as 200°C (Armstrong, 1966), Middle or Late Jurassic metamorphism of the region (Hamilton, 1962) may have caused partial loss of argon. The Iron Mountain Complex cooled at a minimum age of 200±4 m. y. on the basis of dating magmatic biotite from the quartz diorite phase (NW<sup>1</sup>/<sub>4</sub> SW<sup>1</sup>/<sub>4</sub> sec. 23). A later hydrothermal event occurred at a minimum age of 197±7 m. y., as determined by dating hydrothermal sericite from the porphyritic granodiorite (SW<sup>1</sup>/<sub>4</sub> NW<sup>1</sup>/<sub>4</sub> sec. 28). The magmatic-hydrothermal event at approximately 200 m. y. in western Idaho is markedly older than the 28 to 156 m. y. age of major Idaho Batholith plutonism to the east reported by McDowell and Kulp (1969). The U.S. Geological Survey (1972) has suggested an absolute age of 190-195 m. y. for the Triassic-Jurassic boundary. However, Armstrong and Besancon (1970) propose that the boundary is approximately 210 m. y. for western Idaho. Thus, the 200 m. y. event related to the Iron Mountain Complex may be either late Triassic or Early Jurassic in age.

The radiometric age determinations (Table 14) indicate a span of nearly 100 million years for the emplacement (or crystallization)

Table 14. K-Ar Radiometric Age Determinations for the Iron Mountain Complex and Other Plutons of Western Idaho.

Location	Sample No.	Mineral	Rock Type	Age (m. y. )	Analyst
Min. - I. M. <sup>1/</sup>	I-161	Mag. Biotite	Qtz. Diorite	200 $\pm$ 4	Armstrong
Min. - I. M. <sup>2/</sup>	N-57	Hyd. Sericite	Porph. Granodiorite	197 $\pm$ 7	Geochron
Sturgill Pk. <sup>1/</sup>	SS-60-A	Mag. Biotite	Porph. Granodiorite	120 $\pm$ 2.4	Armstrong
Cuddy Mt. <sup>3/</sup>	66-105	Mag. Biotite	Gabbro	187 $\pm$ 5	Armstrong
Cuddy Mt. <sup>3/</sup>	WB-86	Mag. Biotite	Gabbro	192 $\pm$ 5	Armstrong
Cuddy Mt. <sup>3/</sup>	66-136	Mag. Biotite	Qtz. Diorite	216 $\pm$ 5	Isotopes, Inc.
		Mag. Biotite	Qtz. Diorite	200 $\pm$ 4	Armstrong
		Mag. Hornblende	Qtz. Diorite	217 $\pm$ 8	Armstrong
Cuddy Mt. <sup>3/</sup>	F. 48 G	Mag. Biotite	Porph. Granodiorite	181 $\pm$ 4	Armstrong
		Mag. Hornblende	Porph. Granodiorite	201 $\pm$ 8	Armstrong
Peck Mt. <sup>2/</sup>	-	Mag. Hornblende	Qtz. Diorite	161 $\pm$ 11	Geochron
Seven Devils Mt. <sup>4/</sup>	-	Mag. Hornblende	Qtz. Diorite	127	Armstrong
(Deep Cr. stock)		Mag. Biotite	Qtz. Diorite	121	Armstrong
Red Ledge Mine <sup>2/</sup>	-	Hyd. Sericite	Rhyolite Plug	125	Geochron

<sup>1/</sup> Data from Henricksen, Skurla, and Field (1972).

<sup>2/</sup> Data from Field, Bruce, and Henricksen (1972).

<sup>3/</sup> Unpublished data from Field (1974).

<sup>4/</sup> Data from White (1973).

of plutons located between Iron Mountain on the south and Peck Mountain on the north, a distance of 26 miles. Plutons representative of the 200 m. y. event are found scattered from northern British Columbia south to California within the Western Cordillera according to Field, Jones, and Bruce (1973). Major metal deposits or prospects which are known to be genetically related to these older plutons are at Galore Creek, the Highland Valley District, in the Guichon Creek Batholith, and Ingerbelle-Copper Mountain, all in British Columbia; Cuddy Mountain and Mineral-Iron Mountain Districts, Idaho; and possibly part of the Shasta District, California.

#### Physical Condition of the Complex at the Time of Emplacement

Mackin (1953) suggested the possibility that the Iron Mountain Complex originated by in situ recrystallization-replacement (granitization) of the country rock. This interpretation was based on the presence of an apparent hybrid zone between the complex and Seven Devils Volcanics and the absence of directional flow features in the complex. This interpretation does not agree with the following evidence for an introduced magma: (1) narrow contact aureoles, generally less than several hundred feet in width, of hornblende hornfels are recognized within the Seven Devils Volcanics that were regionally metamorphosed under greenschist

conditions, (2) country rocks of mainly andesitic volcanic and volcanoclastic lithologies are chemically dissimilar from the more siliceous plutonic complex, and (3) areas mapped as "granitized greenstone" by Mackin (1953) actually consist of metavolcanic and metasedimentary lithologies that have been intruded by a stockwork of aplite and aplite-pegmatite dikes.

The absence of phenocrysts, lack of deformed or broken crystals, and weak or absent internal foliation of minerals indicate that the quartz diorite and gabbro phases were mainly liquid at the time of their emplacement. Crystal sizes of the quartz diorite are reduced five to ten percent near the contacts with the Seven Devils Volcanics. Although much granodiorite is coarsely crystalline and equigranular, it locally exhibits exaggerated phenocrysts of quartz and plagioclase. This is a characteristic textural feature of the granodiorite at Cuddy Mountain. Thus, parts of the porphyritic granodiorite magma may have contained more than 50 percent early-formed quartz and plagioclase crystals at the time of intrusion.

High fluid pressures in the late magmas are indicated by the presence of aplites and phenocrysts of quartz (see p. 101), as well as by fluid inclusions recognized in quartz of an aplite dike of the Iron Mountain Prospect.

### Mineralogical Variations

Various mineralogical parameters of the Iron Mountain Complex were plotted on a geologic map of the pluton. The principal trends, although not illustrated, are summarized as follows:

(1) Hornblende:biotite ratios in the quartz diorite phase range from 0:13 to 11:1, but apparently do not exhibit systematic variations. Most samples contain subequal amounts of the mafics and their total quantity does not change significantly within the phase.

(2) Total quartz is five to seven percent higher in the border phase of the quartz diorite phase than in the core. The gabbro contains up to 22 percent quartz near its contact with the quartz diorite in sec. 10. However, most of this quartz is hydrothermal in origin.

(3) Magmatic potassium feldspar shows no systematic variation in the quartz diorite. It is locally (Thorn Spring Prospect) concentrated by hydrothermal and pegmatitic fluids in amounts up to six percent near the outer borders of the porphyritic granodiorite.

(4) Apatite, observed both as needles and as euhedral to anhedral crystals, is locally concentrated in the porphyritic granodiorite and quartz diorite phases in and near contact zones with the Seven Devils Volcanics (e.g., the Mortimer Mine area, sec. 23). The distribution of apatite indicates concentration of volatiles at the borders of both the quartz diorite and granodiorite.

### Chemical Variations

Many theories have been advanced to explain the chemical variations of plutonic complexes; particularly the mafic border zones and the increasing silica content of younger phases of the plutons. The principal theories are: (1) diffusion of silica and alkalis toward the center of the plutonic mass and diffusion of calcium, magnesium, and iron toward the contacts, (2) crystal settling in place, (3) granitization of inhomogeneous metamorphic rock, (4) assimilation of wall rocks, (5) mixing of magmas from different sources, and (6) differentiation of magma at depth and subsequent intrusion of increasingly more differentiated magma.

Large-scale diffusion does not explain the generally distinct contacts between major phases of the Iron Mountain Complex. Early crystal accumulation of quartz and plagioclase is documented in the porphyritic granodiorite and late-stage porphyritic dikes, but crystal settling in place cannot be the only process to cause chemical variations as evidenced by the absence of other cumulate minerals. Field relationships previously discussed eliminate the possibility of large scale in place granitization or assimilation of country rock for the Iron Mountain Complex. Therefore, the principal explanations for chemical variations in the stock are intrusions of magma from different sources and/or magmatic differentiation.

### Magmatic Differentiation

A technique that is often employed to support differentiation from a single parent liquid is the use of variation diagrams (Harker, 1909). Major oxides from phases of the Iron Mountain Complex and from plutons of the Rock and Trail Creek drainages to the south are plotted versus silica in Figure 8. With diminishing age of emplacement, the  $\text{Al}_2\text{O}_3$ , FeO (total iron), CaO, and MgO contents all decrease, whereas  $\text{Na}_2\text{O}$  increases and  $\text{K}_2\text{O}$  remains nearly constant with increasing silica content.

Major oxides are plotted on AFM and NKC ternary diagrams in Figures 9 and 10, respectively, for the Iron Mountain Complex, the Cuddy-Peck Mountain plutons to the north, and the Guichon Creek Batholith of British Columbia. All three areas contain composite intrusions of Triassic-Jurassic age that intrude Upper Triassic eugeosynclinal metavolcanic and metasedimentary lithologies. The scatter of points for each region on the AFM diagram (Fig. 9) crudely follows the calc-alkaline line of descent of the Southern California Batholith as suggested by Nockolds and Allen (1953). Because  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  are at separate corners on the NKC diagram (Fig. 10), the potassium-deficient nature of the late major plutonic phases in all three areas is shown to be in marked contrast to the typical calc-alkaline trend. Although additional whole-rock chemical analyses

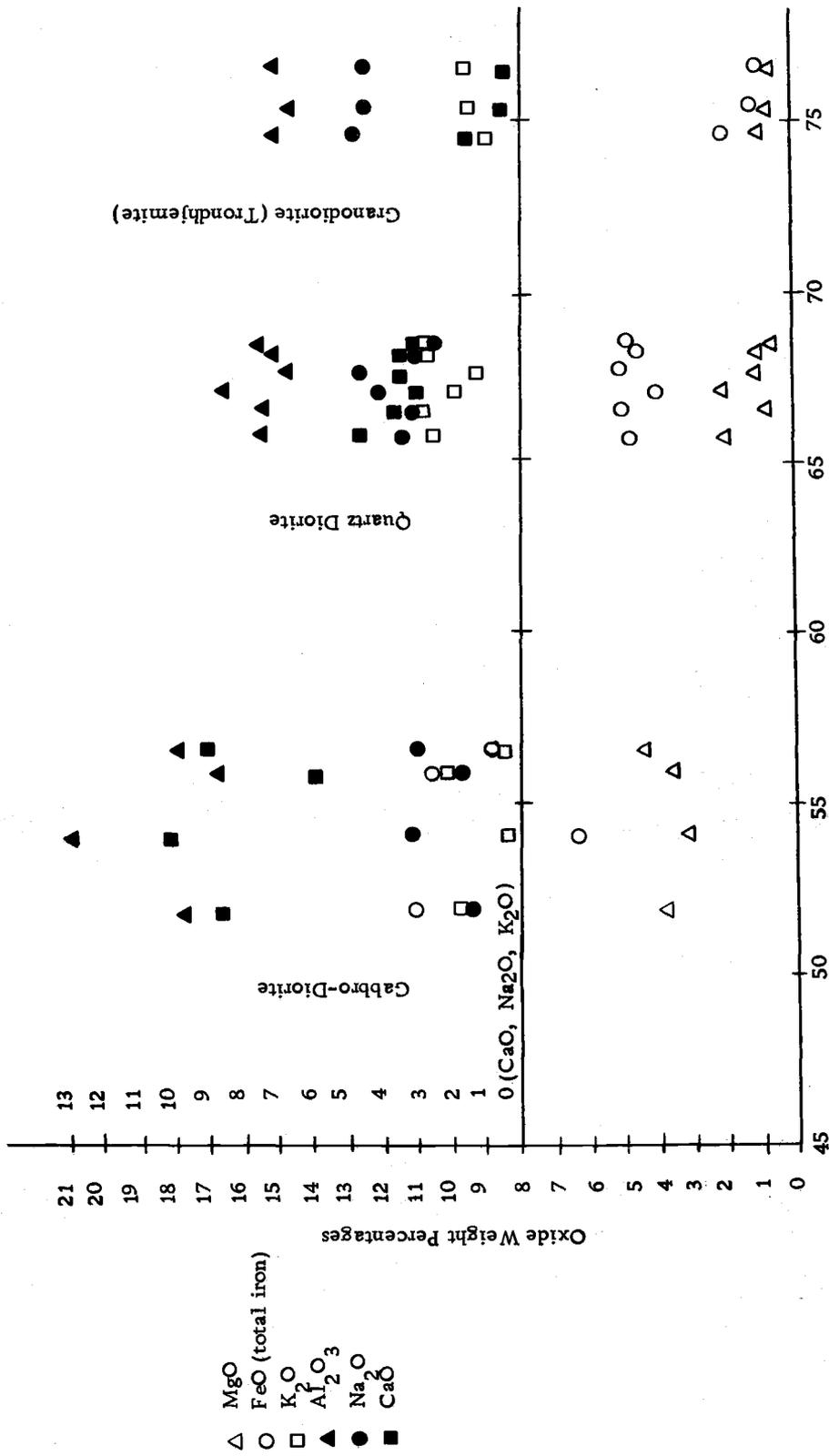


Figure 8. Variation diagram for the Iron Mountain Complex.

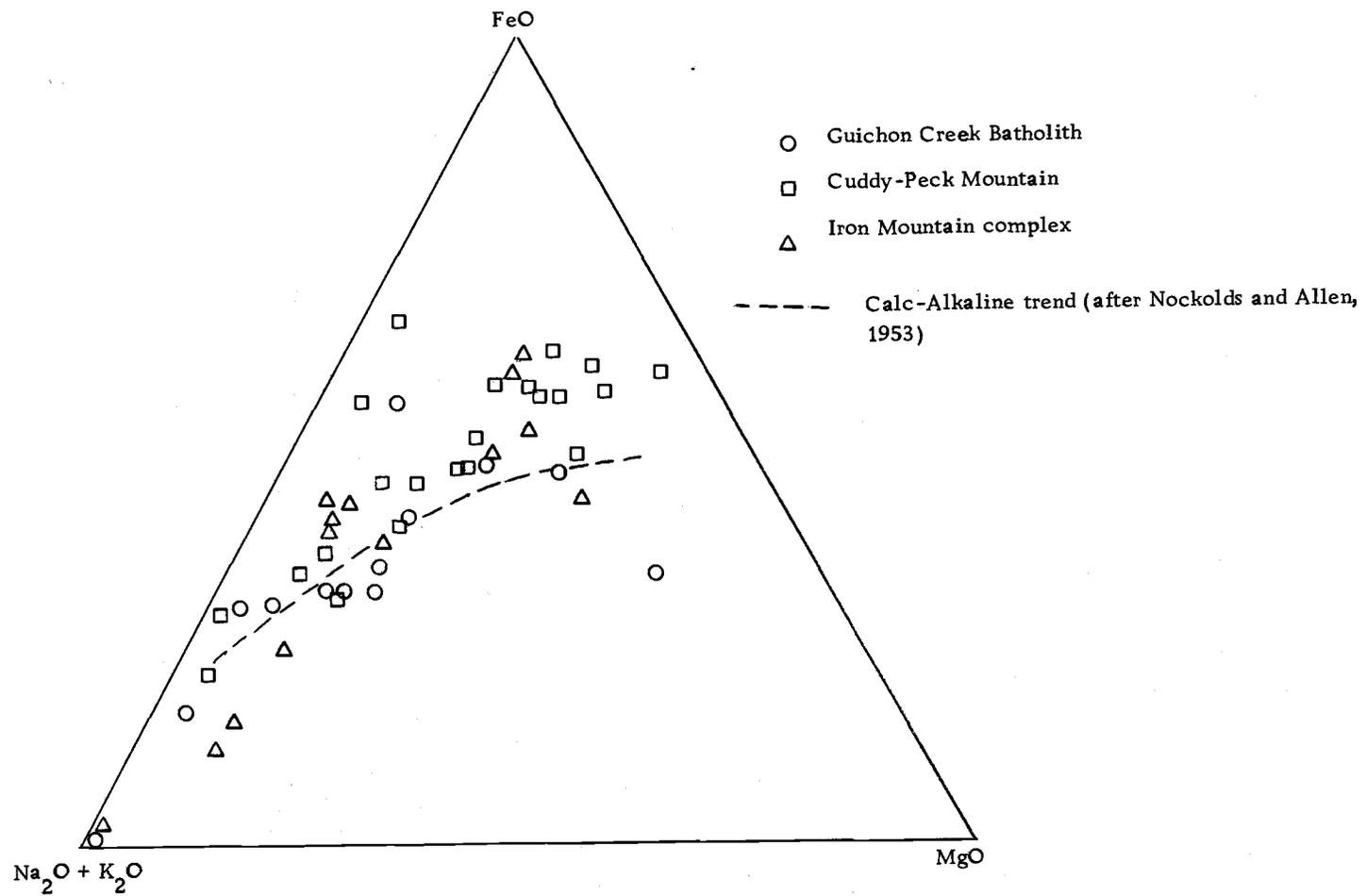


Figure 9. AFM diagram for plutonic phases of the Iron Mountain complex, Cuddy-Peck Mountain area, and Guichon Creek Batholith (modified after Field, Jones, and Bruce, 1973).

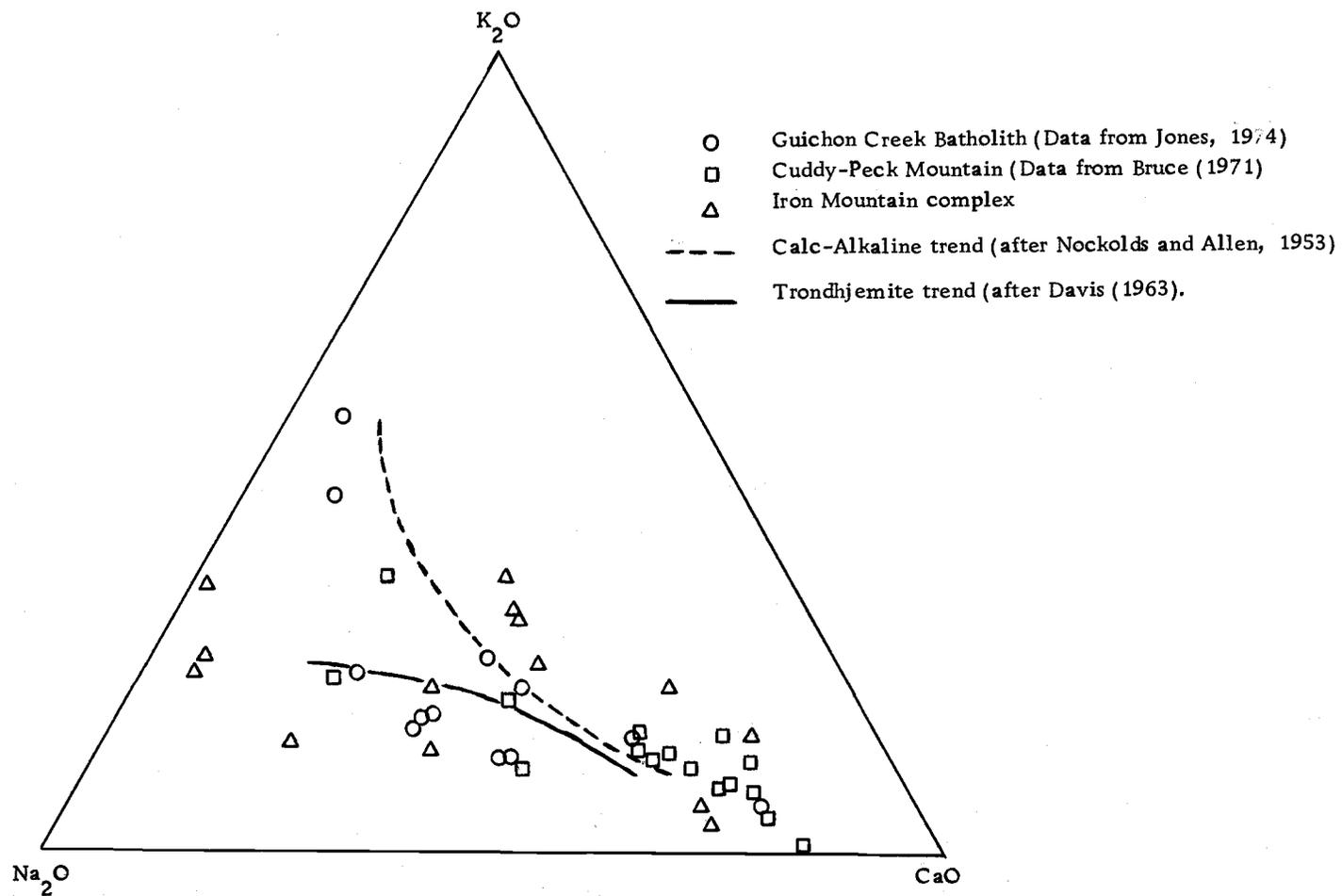


Figure 10. NKC diagram for plutonic phases of the Iron Mountain complex, Cuddy-Peck Mountain area, and Guichon Creek Batholith.

of unaltered specimens would be helpful, these data suggest that at least part of the magmatism of Late Triassic-Early Jurassic age in western Idaho and British Columbia more closely followed the trondhjemite magma trend (Fig. 10), postulated by Davis (1963) for plutons of Jurassic -Cretaceous age in the Klamath Mountains and Sierran foothills of California. Taubeneck (1967) reports both trondhjemite and calc-alkaline magma trends in plutons of Jurassic-Cretaceous age in the Wallowa Mountains of northeastern Oregon. Tilling (1973) has described a sodic series, in addition to a main (more  $K_2O$ -rich) series of magmatism for the Boulder Batholith of Montana. According to Tilling (1973), metalization is weak in plutons related to the sodic series in comparison to plutons of the main series of the Boulder Batholith.

A relationship between the Iron Mountain Complex and typical island arc volcanic calc-alkaline trend is suggested in Figure 11 (after Yoder, 1969) in which  $MgO$  is plotted versus  $(FeO + Fe_2O_3)$  contents for the complex. Three samples on the alkalic series line of descent have an anomalously high content of magnetite.

The Peacock index (Peacock, 1931) has been determined for plutonic rock samples of the Iron Mountain and Cuddy Mountain Complexes of Idaho and Guichon Creek Batholith of British Columbia. The index is obtained from the silica content at that point where the respective curves for  $CaO$  and  $(K_2O + Na_2O)$  cross on a variation

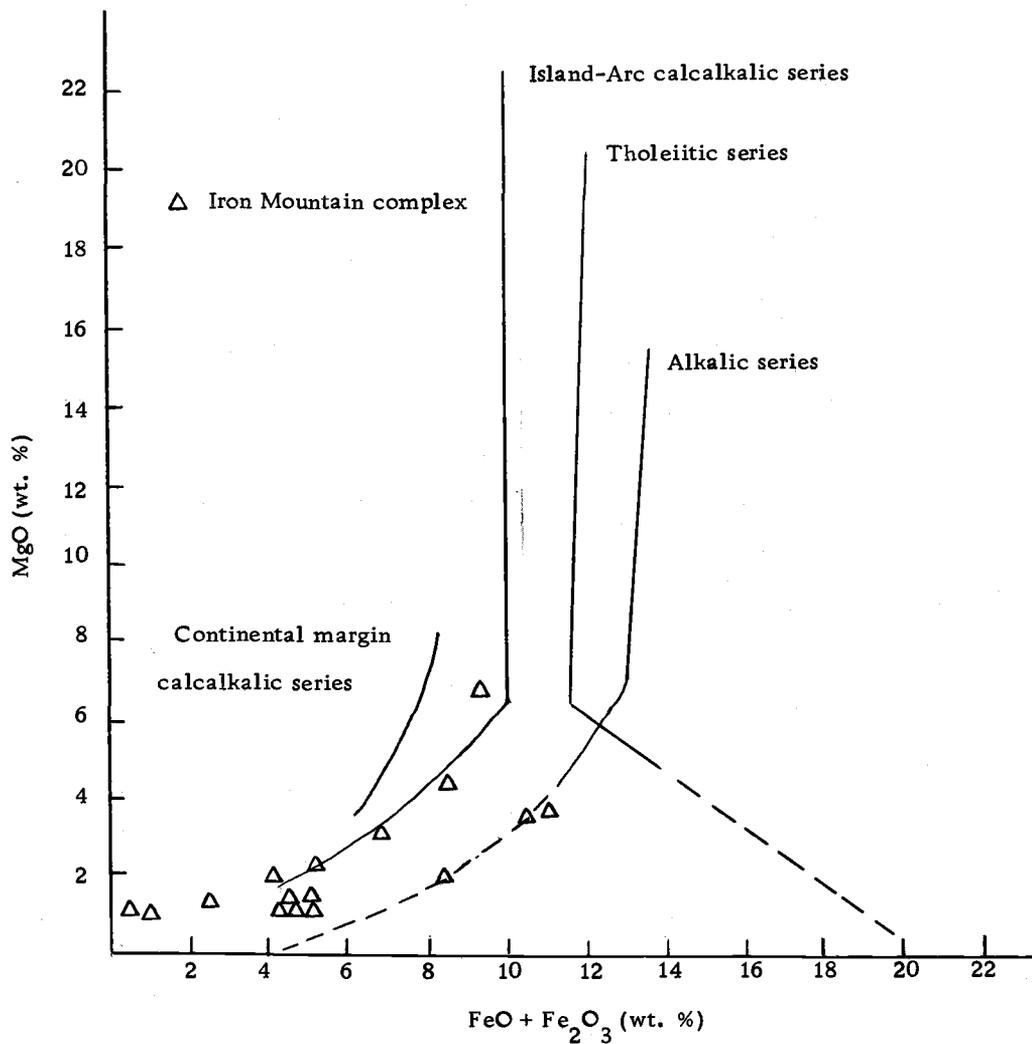


Figure 11. Plots of MgO versus (FeO + Fe<sub>2</sub>O<sub>3</sub>) for plutonic phases of the Iron Mountain complex (curves after Yoder, 1969).

diagram. Indices of 56 to 61 are indicative of calc-alkaline suites, whereas a magma series exhibiting an index of 61 or higher is designated calcic. The following indices were observed:

Iron Mountain Complex - 62, Cuddy Mountain Complex - 63, and the Guichon Creek Batholith - 61. The calcic chemical classification (Peacock, 1931) in all three areas is caused by the low  $K_2O$  content of late major phases. Enrichment in  $K_2O$  is found in the late, but quantitatively small, aplitic, pegmatitic, and hydrothermal phases of all three areas.

#### Origin of the Chemical Trends

Dickinson (1967) suggested that the potassium-rich and potassium-poor magma series, of continental arc and island arc environments, respectively, may reflect variable source materials or conditions at the sites of melting, rather than separate trends of magmatic differentiation or contamination. According to Dickinson (1967), magma generation of potassium-deficient plutons is favored at shallow depths (100 km or less) along inclined Benioff (seismic) zones. However, Stern and Wyllie (1973) and Huang and Wyllie (1973) conducted high pressure-temperature studies that suggest  $K_2O$  variation recorded in plutonic complexes transverse to island arcs is probably not caused by depth of magma generation. Furthermore, the range of  $K_2O$  contents in recent andesitic lavas

has been shown to be statistically different in different island arcs by Nielson and Stoiber (1973) who concluded that  $K_2O$  contents are probably not accurate indices of depth of magma generation. Thus, the 124 km depth for magma generation, as reported by Field, Jones, and Bruce (1973) for the Cuddy Mountain Complex on the basis of  $K_2O$  contents, is probably not a valid estimate for the potassium-deficient Cuddy Mountain or Iron Mountain Complexes.

As suggested by Kuno (1967), the basalt-andesite-rhyolite volcanic suites may be generated by fractional crystallization of mantle-derived high alumina basalt. The early gabbro phase in the Iron Mountain Complex suggests that this mechanism of origin is possible. However, simple differentiation of a high alumina basalt, as suggested by Bruce (1971) for the Cuddy Mountain Plutonic Complex to the north, does not appear to be a mechanism for the Iron Mountain Complex because gabbro comprises less than 10 percent of the entire intrusion.

Green and Ringwood (1968) discussed several possible models that are capable of producing potassium-deficient trends. One model involves the partial melting of subducted oceanic basalt that has been transformed into the high pressure equivalent, eclogite. At depths of 100 to 150 km, partial melting of eclogite under anhydrous (dry) conditions initially produces melts of diorite or quartz diorite compositions, whereas melting under hydrous (wet) conditions

produces initial melts of granodiorite or quartz monzonite. Burnham (1967) has demonstrated that melts of granodiorite that form anatectically under wet conditions have a small interval of crystallization and they will be completely crystallized prior to reaching 12 km below the surface. Therefore, the shallow depth (possibly less than 10 km) of emplacement for the Iron Mountain Complex, deduced from geologic evidence, indicates that early partial melt(s) may have been essentially dry. According to the experimental data of Green and Ringwood (1968) for eclogites, dry partial melting conditions promote more mafic (less potassic) partial melts. Thus, the water content of the original melt(s) of the Iron Mountain Complex may have been an important determinant of the final  $K_2O$  contents of the plutonic phases. Compositionally similar magma can be produced from the partial melting of amphibolite at the base of the oceanic or continental crust, according to Green and Ringwood (1968).

Possible contamination by sedimentary lithologies in the genesis of island arc magmas has been suggested by Dickinson (1970) from geologic evidence, and by Armstrong (1972) from radiogenic isotopic data. Both authors suggest that subducted oceanic sediments are partially to completely melted to form magmas. Strontium isotope data, cited by Armstrong (1974), suggests that plutons of western Idaho and eastern Oregon were intruded west of the

Mesozoic boundary between continental and oceanic crust. The data also indicate that only minor contamination by continental crust was involved in the plutonism. However, the data do not preclude contamination by potash-deficient oceanic sediments in the genesis of plutons of western Idaho.

### The Role of Water

Pressure quenching (Fournier, 1968) of a water-rich silicate melt may account for the finely crystalline textures of the aplites in the Mineral-Iron Mountain District. The porphyritic granodiorite grades northward imperceptibly into the aplite of the Thorn Spring Prospect (Plate 3) in sec. 28. The writer tentatively considers this textural change to: (1) migration and concentration of water and other volatiles, silica, and  $K_2O$  in the granodiorite toward the contact with the older quartz diorite, and (2) a pressure quench gradient caused by a local decrease in pressure at the contact. The local pressure gradient caused the separation of an aqueous phase from the granodiorite, elevated the solidus temperatures, and triggered rapid nucleation in the viscous silicate melt. According to this explanation, aplite of the Thorn Spring Prospect may not be a separate phase of the complex, but rather the result of a water-rich contact zone in the porphyritic granodiorite. Fluid inclusions, observed in an aplite dike on the Iron Mountain Prospect, provide the best

direct evidence for high water pressures in late magmatic phases. These inclusions contain both liquid and gas phases; a solid phase was not recognized. Thus, a salinity of less than 23 weight percent NaCl, which is the solubility of halite in water, can be estimated for the fluids (Nash and Theodore, 1971). Other evidence for high water pressures in aplite dikes of the district includes locally abundant microperthite, and occasional large pegmatitic crystals of quartz, biotite, muscovite, and tourmaline. The pegmatitic crystals formed by protracted crystallization in fluids expelled from the aplite melts.

Locally abundant phenocrysts of quartz in the porphyritic granodiorite, and related plugs and dikes, may have formed because of elevated water pressures at the magmatic stage. Water pressures in magma may increase by either crystallization of anhydrous phases or by diffusion of water from the country rocks. The effect of additions of water to the granite system ( $\text{NaAlSi}_3\text{O}_8 - \text{KAlSi}_3\text{O}_8 - \text{SiO}_2 - \text{H}_2\text{O}$ ) is to lower the isobaric minimum-eutectic (Fig. 12 after Luth, Jahns, and Tuttle, 1964). Thus, the area of the quartz field in the granite system is increased by higher water pressures. The normative orthoclase-albite-quartz content of an unaltered aplite (sample I-81), plotted on Figure 12, indicates that late phases of the complex may have been siliceous enough for quartz to crystallize directly from a relatively dry magma.

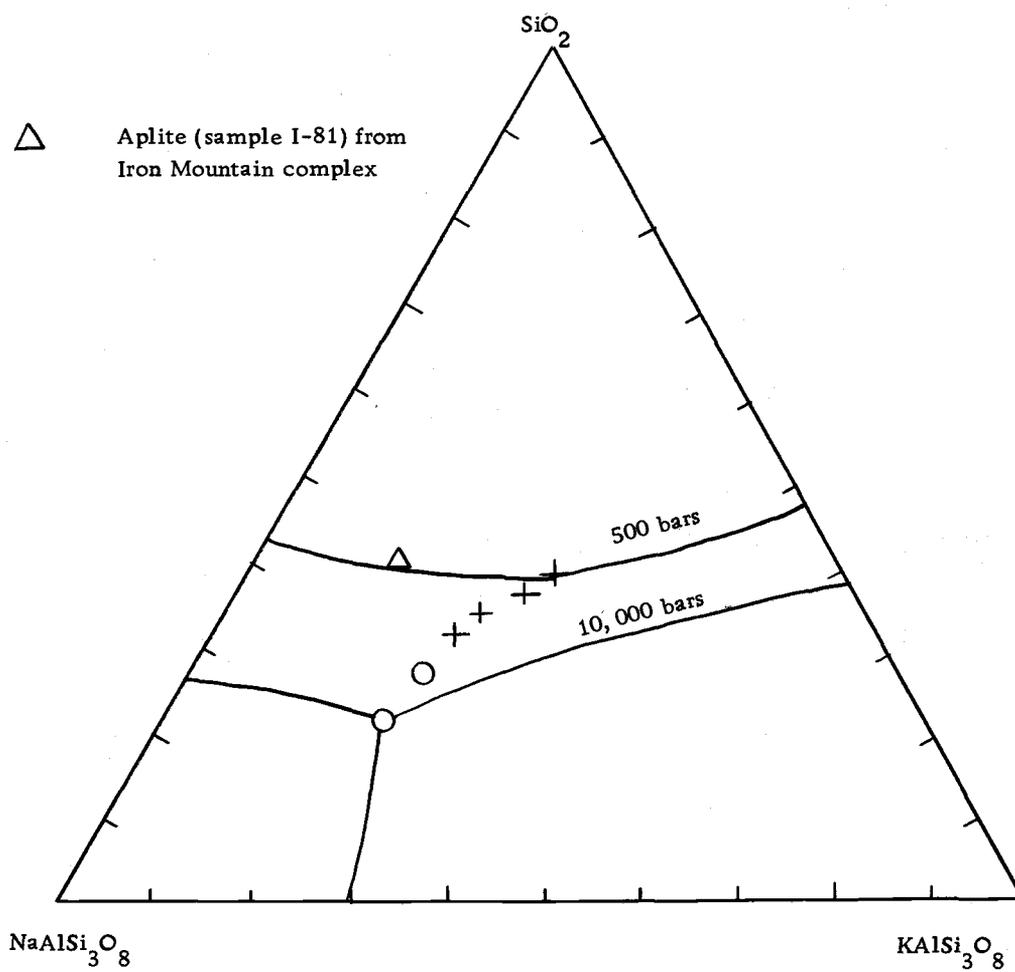


Figure 12. Progressive shift of the isobaric minimum (pluses) - eutectic (circles) with increasing water pressure (after Luth, Jahns, and Tuttle, 1964).

Finally, high water pressures in late phases of the Iron Mountain Complex may have been responsible for the trondhjemite trend of differentiation. As indicated by Figure 12, high water pressures promote high Na/K ratios in the granite system. Thus, the late granodiorite (trondhjemite) phase of the complex may have crystallized from a water saturated magma. This interpretation, however, does not eliminate the possibility of a potash-deficient source in the generation of magma to form the Iron Mountain Complex.

The source of water in the granodiorite magma can be predicted from the study of stable isotope distributions. A single  $^{18}\text{O}/^{16}\text{O}$  isotope determination was obtained from quartz phenocrysts in a sample of the porphyritic granodiorite (sec. 13). All oxygen isotope data are reported in permil ( $^{\circ}/\text{oo}$ ) values. The measured value of +8.4 permil, relative to the  $^{18}\text{O}$  content of standard mean ocean water, is statistically within the range (8.5 to 10.5 permil) of normal plutonic igneous quartz (Taylor, 1967). Thus, a magmatic source for water in the granodiorite melt is suggested by this single determination, and is supported by values of +9.1 and +9.0 permil for quartz phenocrysts in the granodiorite of the nearby Cuddy Mountains.

## METAMORPHISM

A narrow contact metamorphic aureole is recognized in the Seven Devils Volcanics adjacent to the Late Triassic-Early Jurassic Iron Mountain Complex. Following contact metamorphism, the pre-Cretaceous lithologies of western Idaho and eastern Oregon were subjected to low-grade regional metamorphism during Middle or Late Jurassic time, according to Hamilton (1963a). Because of mineralogical similarities, it is often difficult to separate effects of low-grade regional metamorphism from those of contact metamorphism and hydrothermal alteration in the Mineral-Iron Mountain District.

Contact Metamorphism

Excellent hornfels occur in sedimentary units of the Seven Devils Volcanics for several hundred feet outward from the contact with quartz diorite of the plutonic complex southeast of Iron Mountain. The hornfels exhibits a sugary texture and is difficult to distinguish from aplites at the Iron Mountain Prospect (Plate 3). Near the Mortimer Mine (SE $\frac{1}{4}$  NW $\frac{1}{4}$  sec. 23) the mineralogy of this aureole includes abundant biotite, minor muscovite, plagioclase feldspar (An<sub>11</sub>), quartz, and pink andalusite that is replaced by later needles of sillimanite. Apatite and magnetite are minor constituents and

small amounts of chlorite partly replace biotite. With the exception of chlorite, this assemblage is diagnostic of the hornblende facies as defined by Turner (1968). The presence of andalusite-sillimanite is a temperature-pressure field indicator (Turner, 1968). This assemblage limits the depth of formation of the hornfels to less than about 12 km (3 kb pressure) and temperatures to the approximate interval between 425 and 700°C. Small amounts of chlorite, as incipient replacements of biotite, are the result of either late-stage hydrothermal alteration related to the complex, or younger low-grade regional metamorphism. Limestone (marble) beds in the Seven Devils Volcanics are locally altered to assemblages of skarn consisting of garnet-epidote-idocrase-calcite-biotite (chlorite). Skarns are closely associated with contact metasomatic deposits of iron oxides that contain minor sulfides (e.g., Mortimer Mine).

### Regional Metamorphism

The effects of regional metamorphism are weak or absent because most lithologies in the Seven Devils Volcanics have the superimposed imprints of contact metamorphism and/or hydrothermal alteration. Exposures of the Seven Devils Volcanics that possibly exhibit the effects of regional greenschist metamorphism are near Fourth of July Creek in sec. 12. Cloudy plagioclase feldspar (An<sub>28-32</sub>) is commonly rimmed with clear albite. Actinolite

needles and chlorite, as well as biotite, calcite, epidote, magnetite, quartz, and white mica are minor constituents. The Iron Mountain Complex, itself, locally exhibits chloritized biotite and hornblende that can be explained either as products of hydrothermal alteration or as the result of younger regional metamorphism.

Hamilton (1963a) suggested that regional metamorphism occurred in Middle or Late Jurassic time for western Idaho. The K-Ar radiometric age of 200 m. y., on magmatic biotite from the quartz diorite phase of the Iron Mountain Complex, places some constraints on the time of regional metamorphism. If the metamorphic event occurred in Middle or Late Jurassic time, the temperatures of metamorphism were probably 200°C or less because at higher temperatures the micas would begin to lose their radiogenic argon (Armstrong, 1966), and this loss would be manifested in proportionately younger radiometric ages for the dated plutons.

## STRUCTURAL GEOLOGY

The Cuddy, Hitt, and Seven Devils Mountains form a line of north-northeast trending, doubly plunging anticlines that are separated by broad synclinal parts of the Columbia River Plateau, according to Livingston (1932) and 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 in the region. The Hitt and Cuddy Mountains lie within the Columbia Plateau Province which is characterized by north-northwest trending normal faults and irregular domal or anticlinal uplifts (Hamilton, 1962). These structures are superimposed on regionally metamorphosed basement rocks that have been intruded by stock-size plutons in western Idaho.

Major reverse faulting of pre-Tertiary age in western Idaho was first suggested by Livingston (1932) and evidence for such a fault in the Mineral-Iron Mountain District is presented in this chapter.

Folds

The Iron Mountain Complex may be located in the core, or on the northwest flank, of a northeast-trending anticline, probably of pre-Tertiary age. The Jurassic strata of western Idaho, including

those of the Mineral-Iron Mountain District, generally dip  $25^{\circ}$  to  $40^{\circ}$  NW and strike northeast. However, because evidence for a southeast flank to this postulated anticline is absent, this structure is herein termed a homocline.

Unconformities are recognized between the following rock units of the district: (1) Seven Devils Volcanics-Iron Mountain Complex and Cuddy Mountain red conglomerate, (2) Cuddy Mountain red conglomerate and rhyodacite porphyry, (3) mineral porphyritic rhyolite tuffs and Thorsen formation-Brooks red and green conglomerate, (4) Big Hill wacke-Tate shale and Columbia River basalt, and (5) Columbia River basalt and unconsolidated deposits of Quaternary age.

From paleontological evidence, the timing of the uplift and erosion of the Seven Devils Volcanics-Iron Mountain Complex can be bracketed between Late Triassic (Norian) and Early Jurassic (Sinemurian), the probable age of the Cuddy Mountain red conglomerate. Dickinson and Vigrass (1964) described a major orogeny of Early Jurassic age in rocks of central Oregon. Tectonism of a similar age is indicated by the volcanic and conglomerate-dominated lithologies of the Mineral-Iron Mountain District and others nearby. Major folding in western Idaho may have also occurred contemporaneously with Middle to Late Jurassic metamorphism (Hamilton, 1962).

### Reverse Faults

The possibility of a major thrust fault in western Idaho and eastern Oregon was suggested by Livingston (1932). This fault is exposed near the Bayhorse Mine (Plates 4 and 5), for which it is named, and crops out intermittently along a north-northeast direction from the mine, through the Mineral-Iron Mountain District to Grade Creek on Cuddy Mountain, a distance of nearly 40 miles. According to Livingston, the fault dips  $20^{\circ}$  to  $60^{\circ}$  NW. The apparent direction of tectonic transport is to the southeast, and often is parallel to the Triassic-Jurassic bedding. Both Slater (1969) and Bruce (1971) have mapped in detail a high angle reverse fault with these characteristics on Cuddy Mountain.

In the Mineral-Iron Mountain District, the reverse fault trends northward from near McChord Butte (NW $\frac{1}{4}$  sec. 20) to Dennett Creek, and then trends east through and out of the district. Stratigraphic units of Jurassic age on the allochthonous plate include parts of the Brooks red and green conglomerate, and all of the Dennett Creek limestone and the Big Hill wacke. Evidence for the fault includes: (1) repetition of similar Jurassic stratigraphic units (Brooks red and green conglomerate-Thorsen Formation), (2) the presence of highly sheared rock, stretched pebbles, slickensides, and fault gouge in the vicinity of the inferred fault, (3) drag folding of the conglomerate at the Gypsum Mine (NW $\frac{1}{4}$  sec. 11)

near the base of the allochthonous plate that indicates overturning to the southeast, (4) veins of quartz and carbonate that are found intermittently along the base of allochthonous plate, (5) andesine porphyry sills found at the base of the plate and probably localized by the fault, and (6) the structural location (sec. 9) of the Brooks red and green conglomerate of Early Jurassic age above the Tate shale of late Middle Jurassic age. Thus, the reverse fault is post-late Middle Jurassic in age. Unfortunately, the oldest rocks to regionally cover parts of the fault are basalts of the Columbia River group, supplying only a pre-Miocene minimum age for it.

The writer estimates approximately 750 feet of vertical separation along the fault in the Mineral-Iron Mountain District, as determined from repetition of the upper Mineral porphyritic rhyolite tuff (Jmr2) (see Geologic section A-A', Page 1). The total amount of movement of allochthonous material to the southeast is difficult to estimate. Brooks (1973), from geologic mapping in the Huntington quadrangle of Oregon, has suggested that the total amount of movement was small. On the basis of evidence such as vertical separation of beds in the Mineral-Iron Mountain District, movement of a thousand feet or more is possible.

Vallier (1973) has reported strike-slip movement along northeast-trending shear zones in the Seven Devils Mountains to the north. In the Mineral-Iron Mountain District, there is no

evidence, such as slickensides, folding, or offsets of stratigraphic units, for strike-slip movement along the shear zone.

Another major northeast-trending reverse fault is located north and west of the Mineral-Iron Mountain District (Plate 4) as mapped by Paris (1969), Cox (1974), and Skurla (1974). Perhaps both reverse faults had a common origin during Late Jurassic-Early Cretaceous time when the batholiths of the Elkhorn and Wallowa Mountains were emplaced. Hamilton (1963a) has postulated a similar origin for the Rapid River Thrust, which he attributed to the rising and expanding Idaho Batholith of the Riggins area.

In terms of plate tectonics, the allochthonous units may represent sedimentary lithologies that were deposited in the arc-trench gap, as defined by Dickinson (1971), during Jurassic time. Subsequently these lithologies may have been obducted (Coleman, 1971) over the island arc volcanics by thrust faulting associated with compressional tectonics. However, there does appear to have been enough motion to substantiate such a hypothesis.

The Bayhorse overthrust fault (Livingston, 1932) and the Rapid River Thrust (Hamilton, 1963a) are on strike with one another, but dips and movement are opposite in direction. Perhaps a major transverse structural zone lies between Council, Idaho, and Cuprum, Idaho, and beneath Columbia River basalt which conceals the possible continuity of these two major structures.

### Normal Faults

Major northeast-trending and northwest-trending block faults, both of which post-date Columbia River basalt, are recognized in the Cuddy Mountains (King, 1970) and in the Sturgill Peak area of the Hitt Mountains (Skurla, 1974). The writer has mapped similar northwest-trending normal faults along the metallized zone, including the Wolf Creek Fault (Fig. 13) south of the Mineral-Iron Mountain District (Plate 4).

Two major northwest-trending faults, which form a horst, are located near the northeast and southwest borders of the Iron Mountain Complex. The fault to the northeast crops out along a drill site access road in the NE $\frac{1}{4}$  sec 10 west of the Gypsum Mine. The northeast side of the vertical fault has been down-dropped, as evidenced by offsets in the Dennett Creek limestone and pre-Tertiary volcanic sequence. Vertical displacement of 1,000 to 2,000 feet is indicated. On the north side of Stacy Creek in sec. 13 the Columbia River basalt has been down-dropped along the fault. In the southwest corner of the district another major fault is topographically expressed by saddles. It is exposed as a near vertical gouge zone in a road cut in the NW $\frac{1}{4}$  sec. 29, T. 14 N., R. 6 W. west of the area portrayed on Plate 1. As evidenced by the position of Columbia River basalt and offsets in the pre-Tertiary strata, the southwest side

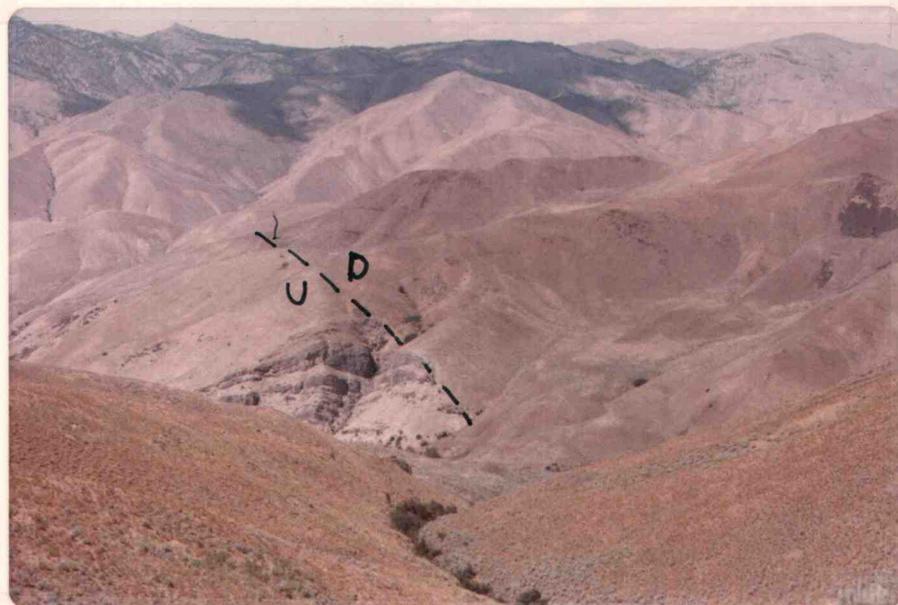


Figure 13. Wolf Creek fault. View northwest along the trace of the fault.

of the fault has been down-dropped by as much as several thousand feet, provided there was no strike-slip component. Steeply dipping Columbia River basalt adjacent to the fault (sec. 29) indicates post-basalt movement. Minor normal faults, exhibiting a northwest trend, are indicated by offsets in the Dennett Creek limestone in secs. 4, 8, and 9. Small-scale northeast and northwest-trending faults are also present in the NE $\frac{1}{4}$  SW $\frac{1}{4}$  sec 11 and the NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec. 10.

Evidence for normal faults south of Dennett Creek in secs. 9, 15 and 16 include: (1) local offsets of several tens of feet in the silicic volcanic units, and (2) the large area of silicic volcanic float as compared to its inferred thickness as measured from north-westerly dips. The exact locations of the faults are not known because of the absence of outcrops. Thus, the faults as portrayed on Plate 1 are largely diagrammatic.

A major fault is believed to be present in part of the Dennett Creek drainage (Plate 1). The plutonic complex and pre-Tertiary strata have been down-dropped south of the creek, as indicated by offsets in the Thorsen formation and Tate shale in secs. 8 and 9. However, fault offsets are not present in the allochthonous Dennett Creek limestone marker bed that crosses Dennett Creek just west of the map area. Thus, the normal fault of the Dennett Creek drainage apparently pre-dates reverse faulting.

## ECONOMIC GEOLOGY

Mining in the Mineral-Iron Mountain District has been sporadic since the 1870's (Dudgeon, 1967). Prospecting and mine development in the past resulted in minor production of copper (340,000 lbs.), lead (100,000 lbs.), and silver (1,000,000 oz.) from vein-type deposits in the old Mineral District (Anderson and Wagner, 1952). Skarn-type deposits, near Iron Mountain proper, have produced small amounts of iron, but no base or precious metals (Mackin, 1953). Deposits of gypsum, magnetite, and silica have been mined in the last several years, and exploration for large-tonnage, low-grade porphyry-type deposits has been conducted most recently in the area.

Previous investigators have described the strata-bound vein-type copper-lead-silver deposits of the Mineral District (Anderson and Wagner, 1952) and skarn-type iron deposits of Iron Mountain (Mackin, 1953). These and other deposits, such as the skarn-type Iron Mountain Prospect and the Thorn Spring porphyry-type deposit, as well as strata-bound vein-type deposits of regional importance and nonmetallic minerals, have been subjected to detailed and/or regional study in this investigation. In addition to mapping of lithologies, structure, and products of hydrothermal alteration, geochemical data for oxides, trace elements, and stable isotopes, and

mineralogical data have been obtained. Sample locations, trace element concentrations in stream sediment, soil, and rock samples, and hydrothermal alteration mineral assemblages are summarized on an overlay for the district (Plate 3). These data collectively provide a more detailed knowledge of the distribution and genesis of the several types of ores that occur both locally and regionally within the Snake River boundary area of western Idaho and eastern Oregon.

Products of hydrothermal alteration are discussed according to the classification scheme proposed by Meyer and Hemley (1967). On the basis of mineralogical and chemical effects, they subdivide alteration assemblages into potassium silicate, propylitic, and intermediate argillic, sericitic, and advanced argillic types that are defined by the presence of one or more critical minerals. Potassium feldspars and micas are the essential minerals of the potassium silicate alteration type; clay minerals are absent. Propylitic assemblages are characterized by epidote, albite, chlorite, and carbonate; less commonly with sericite and clays. Intermediate argillic alteration is characterized by kaolin and montmorillonite group minerals that occur principally as alteration products of plagioclase feldspar. Sericite, quartz, and pyrite are the prominent phases in sericitic alteration. The advanced argillic assemblage contains dickite, kaolinite, pyrophyllite, usually with

sericite and quartz.

### Nonmetallic Minerals

In the past several years, including 1971, 1972, and 1973, gypsum and silica have been mined by the open-pit method in the Mineral-Iron Mountain District. The gypsum deposit is leased by the Weiser Co-operative, and the ore is used solely for local agricultural purposes. The silica mine is owned jointly by H. F. Anderson, Tacoma, Washington, and L. Thorsen, Weiser, Idaho, and is presently leased by the Bristol Northwest Silica Corporation. Approximately 10,000 tons of gypsum and 34,000 tons of silica ore (99.7+ percent silica) were mined from the district during 1973 (H. F. Anderson, oral communication, 1974).

#### Gypsum Mine

The commercial gypsum deposit (Fig. 14) is located within a sheared conglomerate at the top of the divide between the main and middle forks of Dennett Creek in the NW $\frac{1}{4}$  sec. 11. The mine is located near the base of the allochthonous plate (see Structural Geology) and the gypsum is found at the stratigraphic interval occupied by the Dennett Creek limestone where it locally contains interbeds of phyllite. The deposit occurs over a stratigraphic thickness of approximately 100 feet and dips 30°NW into the hill.



Figure 14. Gypsum Mine. View east toward the Snake River canyon.

Three varieties of gypsum are recognized: (1) massive white (nearly pure), (2) phyllitic (gypsum mixed with phyllite), and (3) silicified brown gypsum. The host rock is locally overturned to the southeast as indicated by small drag folds in the sheared conglomerate that is exposed in the open pit.

Several hypotheses may account for the origin of the gypsum. One mechanism is by evaporite deposition. According to Krumbein and Sloss (1963), anhydrite is the normal calcium sulfate of evaporite deposits formed at temperatures above 30°C. However, it is commonly surficially altered to gypsum. Moore (1937) has reported that gypsum grades downward into massive anhydrite at the now abandoned gypsum mine on the Oregon side of the Brownlee Reservoir near the Bayhorse Mine. Therefore, it is likely that the gypsum deposits of the Mineral-Iron Mountain District, and elsewhere along the Dennett Creek limestone horizon, represent surficial hydration of a deeper subsurface anhydrite bed.

However, the anhydrite may not be sedimentary and thus not of an evaporite origin. Hydrothermal replacement of limestone by anhydrite is another possible origin because, as first mentioned by McDevitt (1952), the only major occurrences of gypsum (anhydrite) are located in the Bayhorse and Mineral-Iron Mountain Districts, approximately 12 miles apart. Although neither crosscutting relationships nor replacement textures for the gypsum were

recognized, iron staining, probably after pyrite, is present in the gypsum deposit of the Mineral-Iron Mountain District and provides evidence of a hydrothermal origin. Trace metal concentrations in various types of gypsum from the Mineral-Iron Mountain District are listed in Table 15 and are compared with those for evaporate gypsum, sold commercially by the Simplot Corporation, Utah. The evaporite gypsum from Utah generally contains smaller concentrations of trace metals than does the gypsum from western Idaho. Thus, the exclusive association of gypsum with deposits of sulfides in or near known mining districts, and the relatively high trace metal contents of gypsum collectively suggest a hydrothermal origin. Sulfur isotope abundance data, discussed in a later section, are consistent with either a hydrothermal or evaporate origin.

### Silica Mine

The silica mine is located in the SW $\frac{1}{4}$  sec. 18, T. 14 N., R. 5W., approximately two miles east of Iron Mountain. The deposit occurs as a vein-like pegmatitic segregation of quartz. The segregation is at least 100 feet wide and vertically (?) oriented in a hydrothermally altered trondhjemite. Basalts of the Columbia River Group surround this pre-Tertiary window.

Although impurities in the quartz segregation are rare, tourmaline inclusions are locally present and are as much as one foot in

Table 15. Trace Metal Contents (ppm)<sup>1/</sup> of Gypsum Samples from the Mineral-Iron Mountain District Compared to Evaporite Gypsum (Simplot Corporation, Utah).

Sample No.	Copper	Lead	Zinc	Molybdenum	Silver
N-15 <sup>3/</sup>	15	40	25	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
N-16 <sup>4/</sup>	15	30	30	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
N-17 <sup>5/</sup>	30	70	35	-1 <sup>2/</sup>	.2 <sup>2/</sup>
Simp-1 <sup>6/</sup>	-5 <sup>2/</sup>	40	10	-1 <sup>2/</sup>	-.1 <sup>2/</sup>

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation, Midvale, Utah.

<sup>2/</sup> Below detection.

<sup>3/</sup> Massive white gypsum.

<sup>4/</sup> Phyllitic gypsum.

<sup>5/</sup> Silicified brown gypsum.

<sup>6/</sup> Simplot evaporite gypsum.

diameter. Pegmatitic segregations of quartz and tourmaline are common in the porphyritic granodiorite (trondhjemite) of the Iron Mountain Complex. Thus, a genetic relationship between formation of the silica deposit and late phases of the Iron Mountain Complex is evident.

#### Metallization Associated With the Iron Mountain Complex

Base metal deposits are spatially associated with hydrothermally altered porphyritic, aplitic, and pegmatitic phases of the Iron Mountain Complex. These deposits include the Iron Mountain and Thorn Spring Prospects, as well as abundant sulfide-bearing quartz-tourmaline veins and local zones of skarn (e.g., Mortimer Mine) in

carbonate host rocks adjacent to the intrusions. Although small tonnages of magnetite have recently been extracted from several skarn deposits, there has been no significant production of base metals from any of these deposits.

### Iron Mountain Prospect

The Iron Mountain Prospect is located in parts of secs. 12, 13, 14, and 23 (Plate 3). The area of economic interest is surficially at least two miles long and as much as several thousand feet wide. Copper-zinc metallization is locally present near the surface. This examination was greatly facilitated by studies of diamond drill core because outcrops are generally sparse as a consequence of cover by soils and vegetation.

Geology. The Iron Mountain Prospect occupies a screen of hornfelsed metavolcanic and metasedimentary host rocks that have been intruded by a swarm of aplites and pegmatites. The porphyritic granodiorite locally exhibits pegmatitic segregations of quartz, biotite (mostly altered to chlorite), and tourmaline. The aplite-pegmatite dikes range from several inches to tens of feet in width. In zones where the dikes appear to be more numerous, there is a marked increase in the sulfide content of the host rocks. Because of textural and mineralogical similarities, the aplite and hornfels assemblages are commonly difficult to distinguish. Finely

crystalline dikes of Columbia River basalt are abundant at the prospect as are related basalt flows that cover nearby areas of possible exploration interest.

Alteration and Mineralization. Several distinct types of wall rock alteration and mineralization are recognized on the Iron Mountain Prospect. Mosaics of quartz, sericite, chlorite, and kaolinite have completely replaced and/or recrystallized after the original constituents of the metasedimentary and metavolcanic lithologies. Associated with these assemblages are unusually large concentrations of sulfides including pyrite (as much as 15 percent), sphalerite (up to 5 percent), and chalcopyrite (as much as 3 percent) that occur both as disseminated crystals in the host and as structurally controlled veinlets. Locally, the chalcopyrite and sphalerite are intergrown to form schistose blebs that range up to 5.2 mm in length (Fig. 15). Examination of polished sections indicate that chalcopyrite has, in part, exsolved from sphalerite. A thin film of sericite commonly envelopes the sulfides. Andalusite is present as disseminations and as local envelopes surrounding individual sulfide grains (Fig. 16). Its abundance exceeds 10 percent in areas of high copper-zinc metallization. The andalusite may be the result of contact metamorphism of aluminum-rich metasedimentary host rocks by the Iron Mountain Complex. Alternatively, the andalusite may have formed by high-temperature alteration of early-formed

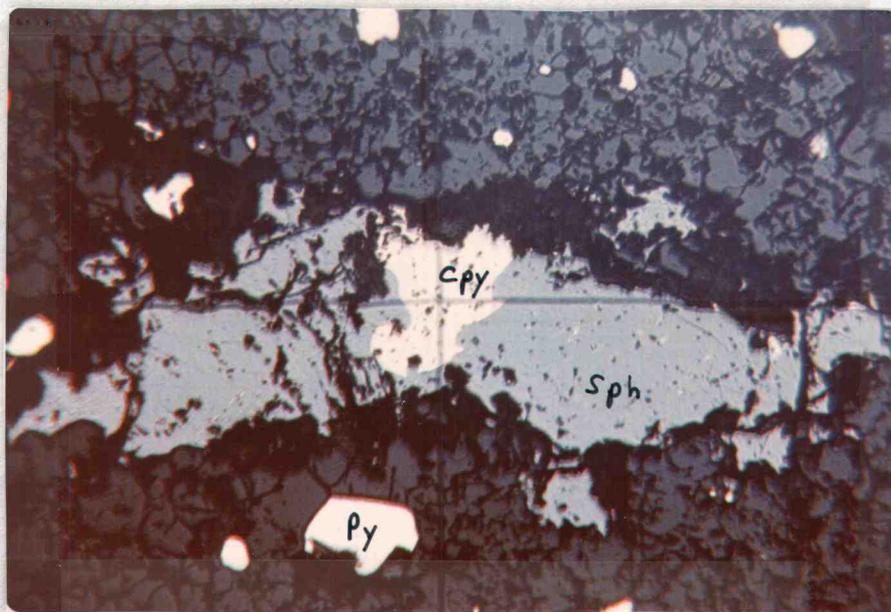


Figure 15. Photomicrograph, schistose chalcopyrite-sphalerite at the Iron Mountain Prospect. Host rock is altered metasedimentary unit (polished section, 28x).

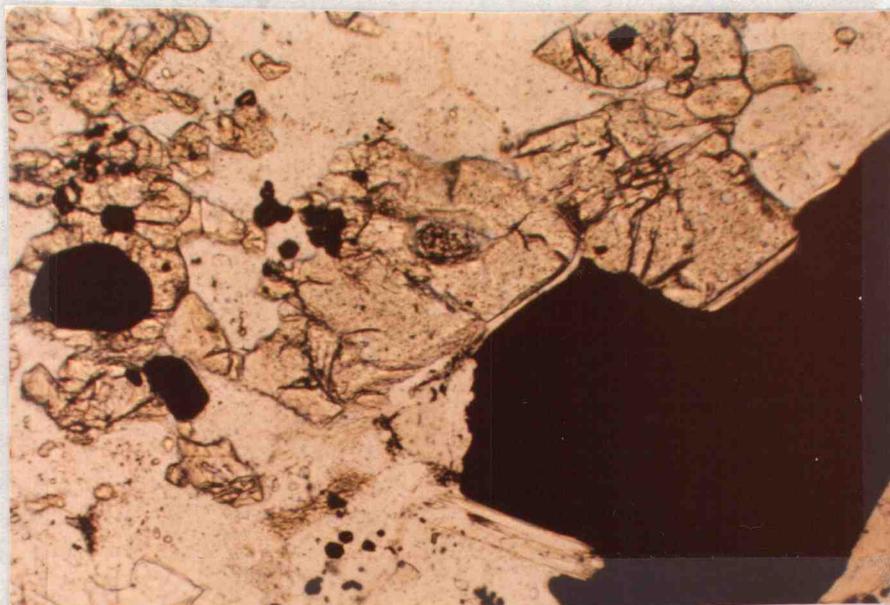


Figure 16. Photomicrograph, andalusite-sulfides at the Iron Mountain Prospect. Andalusite crystals (high relief) envelope pyrite and chalcopyrite blebs in altered metasedimentary host (plane light, 100x).

hydrothermal kaolinite (Meyer, 1974, oral communication). Veinlets of quartz-tourmaline-biotite-orthoclase, containing traces of pyrite and chalcopyrite, crosscut early pervasive quartz-sericite+chlorite+kaolinite assemblages. These veinlets, although lacking the sulfide components, are also present within the border zone of the porphyritic granodiorite at the Iron Mountain Prospect. The metavolcanic and metasedimentary host rocks contain infrequent veinlets of sericite or barren quartz. Late-stage veinlets of calcite, containing vugs and traces of pyrite, represent the youngest event of hydrothermal mineralization at the Iron Mountain Prospect.

Trace Element Geochemistry. Stream sediment samples TH-13 to TH-21 were collected from major drainages at the Iron Mountain Prospect and analyzed for copper, lead, molybdenum, and zinc (Table 16 and Plate 3). Threshold values (background, in ppm) for stream sediments of the Pacific Northwest have been estimated (Field, Jones and Bruce, 1973) for silver (<1), copper (50), molybdenum (<1), lead (30), and zinc (100). Significant anomalies are normally two to three times the threshold value provided that variations imposed by drainage patterns lithology, and contributions from known deposits are taken into account. The copper contents of samples TH-18 (195 ppm) and TH-19 (335 ppm) of Fourth of July Creek are anomalous but presumably are attributable to mine dumps of abandoned skarn-type deposits that contain minor amounts of

Table 16. Trace Metal Contents (ppm)<sup>1/</sup> of Stream Sediment and Rock Chip Samples from the Iron Mountain Prospect.

Sample No.	Copper	Lead	Zinc	Molybdenum	Silver
<u>Stream Sediment:</u>					
TH-13	115	30	125	1	
TH-14	45	20	305	-1 <sup>2/</sup>	
TH-15	85	30	300	-1 <sup>2/</sup>	
TH-16	70	30	165	-1 <sup>2/</sup>	
TH-17	40	30	145	-1 <sup>2/</sup>	
TH-18	195	40	375	-1 <sup>2/</sup>	
TH-19	335	30	450	-1 <sup>2/</sup>	
TH-20	75	20	440	-1 <sup>2/</sup>	
TH-21	75	20	225	-1 <sup>2/</sup>	
<u>Rock Chip:</u>					
CS-1	25	20	55	1	-1
CS-2	90	30	65	-1 <sup>2/</sup>	4.7
CS-3	45	20	210	-1 <sup>2/</sup>	4.8
CS-4	590	10	135	19	1.5
CS-5	175	10	60	-1 <sup>2/</sup>	1.5
CS-6	400	30	70	5	2.6
CS-7	30	10	20	1	-.1 <sup>2/</sup>
CS-8	20	20	15	1	.4
CS-9	45	10	10	-1	.8
IM-1	1,700	6	33,500	3	2.0
15553 A	1,000				3.6

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation, Midvale, Utah.

<sup>2/</sup> Below detection.

chalcopyrite. However, anomalous zinc values in stream sediments (e.g., TH-20, Barton Gulch, 440 ppm) may be a good pathfinder for copper-zinc metallization. Hawkes and Webb (1962) predict a high mobility for zinc in deposits characterized by a siliceous gangue. Thus, the mobility for zinc and the high zinc contents of stream sediments at the Iron Mountain Prospect may be caused in part by the presence of sphalerite as disseminations and fracture-fillings

in a silica-rich gangue assemblage. However, the iron-rich system, as evidenced by magnetite, hematite and pyrite in these skarn-type deposits, favors the co-precipitation of zinc with limonite that is observed as coatings on the coarser particles of stream sediment.

Rock chip samples (CS-1 to CS-9, Table 16) were collected from exposures, including float, of hydrothermally altered and hornfelsed matavolcanic and metasedimentary lithologies. Abundant hematite and jarosite (see Oxidation and Secondary Enrichment) are locally present in the leached capping and indicate the former presence of various sulfides. Background values (in ppm) for rock samples of the Pacific Northwest have been estimated for copper (50), lead (20), zinc (60), molybdenum (less than 1), and silver (less than .1 ppm) by Field, Jones, and Bruce (1973). However, these values vary by as much as a factor of two with differences in lithology. Trace metal concentrations are generally higher in plutons and volcanic lithologies with a mafic composition, relative to background values in more silicic rocks. As much as seven percent pyrite and traces of chalcopyrite, both as disseminations and minor veinlets, are present in samples CS-5 (175 ppm copper) and CS-6 (400 ppm copper). Pervasive hydrothermal quartz and sericite, as well as supergene (?) clays, have replaced the original metasedimentary components. A sample (IM-1) of hornfelsed and hydrothermally altered metasediment was collected from diamond

drill core on the prospect and contains significant copper (1, 700 ppm) and zinc (33, 500 ppm). Schistose blebs of chalcopyrite and sphalerite, associated with 11 percent disseminated pyrite, are present in an assemblage of primarily quartz-sericite-andalusite gangue.

Oxidation and Secondary Enrichment. Both jarosite and hematite are present on fractures and in disseminated casts after pyrite that pervade leached outcrops of the Iron Mountain Prospect. However, transported hematite, formed by the breakdown of pyrite and ferromagnesian minerals, is ubiquitous and more common than jarosite. From observations in an adit (now inaccessible) on the Abundance Red Hematite property (Plate 3), Mackin (1953) described a plane surface of earthy red hematite that formed on a post-Seven Devils Volcanics, pre-Rhyodacite porphyry (his andesite) erosion surface. He also reported secondary enrichment of copper (24 percent) in an adit of the Abundance property. A cellular, earthy hematite-rich zone forms a capping on the Seven Devils Volcanics and contains 590 ppm copper and 19 ppm molybdenum (sample CS-4, Table 16) at the Montana Red Hematite property (Plate 3), several thousand feet south of the Abundance property, but occupying the same stratigraphic horizon. This massive red hematite zone is not continuous between the two properties and, thus, may have formed by the oxidation of two distinct skarn

deposits. Fragments of float from the Seven Devils Volcanics contain up to four percent disseminated steel-gray chalcocite, one percent pyrite, and traces of red hematite at this same stratigraphic horizon near the north end of Thorsen Lake (NE $\frac{1}{4}$  sec. 12, T. 14 N., R. 6 W.) east of the detailed map. Composite rock sample 15553A (Table 16) is from this float and contains 1,000+ ppm copper and 3.6 ppm silver. However, it is unlikely that any steel-gray variety of chalcocite is of supergene origin. Moreover, Long (1974) has described disseminated chalcocite of probable primary origin in flows from the Seven Devils Volcanics. This type of disseminated deposit, the Silver King Mine near Cuprum, Idaho, is presently in production.

Conclusions. Copper-zinc metallization on the Iron Mountain Prospect is present as disseminations and veinlets of chalcopyrite and sphalerite in host rocks of metavolcanic and metasedimentary lithologies. These rocks have been hydrothermally altered and hornfelsed to finely crystalline assemblages of quartz, sericite, and variable amounts of andalusite and chlorite. Thus, the metallization is skarn-type. Adjacent to the metallized country rocks, the porphyritic granodiorite and quartz diorite phases of the Iron Mountain Prospect are essentially barren of mineralization. However, aplite-pegmatite dikes, containing traces of pyrite and chalcopyrite, are ubiquitous in the areas of highest copper-zinc metallization.

Thus, a genetic relationship between the Iron Mountain Complex and the skarn-type deposits is suggested. The presence of pegmatitic segregations within the aplites, as well as in the border phases of the nearby porphyritic granodiorite, suggest a possible deep hydrothermal system relative to normal porphyry-type deposits (Guilbert and Lowell, 1974). Evidence of secondary enrichment of copper on the present erosion surface was not observed. However, supergene chalcocite may have formed on the erosion surface between the Seven Devils Volcanics and rhyodacite porphyry in Early Jurassic time.

#### Thorn Spring Prospect

The Thorn Spring Prospect (Fig. 17), containing copper-molybdenum metallization, is located in the southwest part of the Mineral-Iron Mountain District in sec. 28 (Plate 3). The prospect may be reached from the west via four-wheel drive vehicle on a private road that begins in the NW $\frac{1}{4}$  sec 23, T. 14 N., R. 7 W., adjacent to the Snake River. The prospect is mostly covered by soil and contains few outcrops.

Geology. Aplite serves as the principal host rock for metallization at the Thorn Spring Prospect. It is located along and near contacts between hydrothermally altered porphyritic granodiorite (on the south) and quartz diorite (on the north) phases of the Iron



Figure 17. Thorn Spring Prospect. View of the south from McChord Butte.

Mountain Complex. Minor aplite intrusions crop out north and south of the prospect and feldspar porphyries (Jpd) crop out to the north (SE $\frac{1}{4}$  sec. 21). A lamprophyre plug and several dikes of Columbia River basalt (less than 15 feet in width) are also recognized.

Alteration and Mineralization. The effects of hydrothermal alteration are intense at the Thorn Spring Prospect (Plate 3). Modal and chemical analyses of hydrothermally altered host rocks are listed in Table 17 together with that of typically unaltered porphyritic granodiorite from Cuddy Mountain. Unaltered porphyritic granodiorite was not recognized in the Mineral-Iron Mountain District. Chemical analyses (in weight percent) of both unaltered and altered samples have been recalculated as molecular proportions and are also plotted on an ACF-AKF diagram (Fig. 18) as proposed by Creasey (1959).

The potassium silicate alteration assemblage of orthoclase-sericite-chlorite is recognized in the quartz diorite (sample N-48, Table 17) adjacent to the aplite and feldspar porphyries. In this alteration zone, plagioclase feldspar is partly to completely replaced by orthoclase and sericite, and the primary ferromagnesian minerals are completely replaced by chlorite. Veinlets of orthoclase, locally accompanied by as much as two percent pyrite and traces of chalcopyrite, are present within the quartz

Table 17. Model and Chemical Analyses of Hydrothermally Altered Lithologies at the Thorn Spring Prospect compared to Unaltered Quartz Diorite and Average Unaltered Porphyritic Granodiorite from Cuddy Mountain.

Data	Quartz Diorite			Porphyritic Granodiorite		
	I-161 <u>2/</u> (unaltered)	N-48 <u>1/</u> (Potassic)	N-61 (Prop.)	Ave. C.M. Grano. <u>3/</u>	N-57 (Sericitic)	N-58-c <u>1/</u> (Int. Argillic)
Qtz.	27	30	30	30.6	60	49
K-fld.	3	53	6	3.9	-	4
P-fld.	46	tr	32	45.1	-	10
Pyx.	-	-	-	-	-	-
Hbld.	6	-	4	1.7	-	-
Bio.	9	2	5	2.0	-	6
Acc.	tr	tr	tr	tr	tr	tr
Opq.	2	3	2	1.3	tr	1
Ser.	3	6	6	3.3	30	3
Clay	4	tr	7	5.9	8	25
Chl.	tr	2	5	3.1	2	2
Epi.	tr	tr	3	3.5	-	-
Carbo.	tr	4	tr	tr	-	-
SiO <sub>2</sub>	65.7	67.71	68.0	68.8	79.45	73.57
TiO <sub>2</sub>	0.44	0.46	0.41	0.5	0.39	0.30
Al <sub>2</sub> O <sub>3</sub>	15.6	14.01	15.2	14.1	12.54	14.42
Fe <sub>2</sub> O <sub>3</sub>	2.43	2.06	-	1.4	0.82	0.74
FeO	2.06	0.78	4.81 <u>4/</u>	3.6	0.16	1.24
MnO	-	0.17	-	0.1	tr	0.08
MgO	2.1	0.63	0.7	0.9	0.18	0.90
CaO	4.6	1.74	2.5	3.1	0.10	1.45
Na <sub>2</sub> O	3.5	0.73	3.0	3.7	0.22	4.20
K <sub>2</sub> O	2.50	8.82	3.77	1.8	3.62	1.67
H <sub>2</sub> O <sup>+</sup>	.70	2.65	-	1.1	2.14	1.47
H <sub>2</sub> O <sup>-</sup>	.01	0.10	-	0.4	-	0.11
P <sub>2</sub> O <sub>5</sub>	-	0.04	-	0.1	tr	tr
	99.6	98.4	99.4	99.6	99.6	100.1
Specific gravity	2.70	2.73	2.70	2.68	2.57	2.60

1/ Wet chemical analysis by Dr. K. Aoki, Tohoku University, Japan.

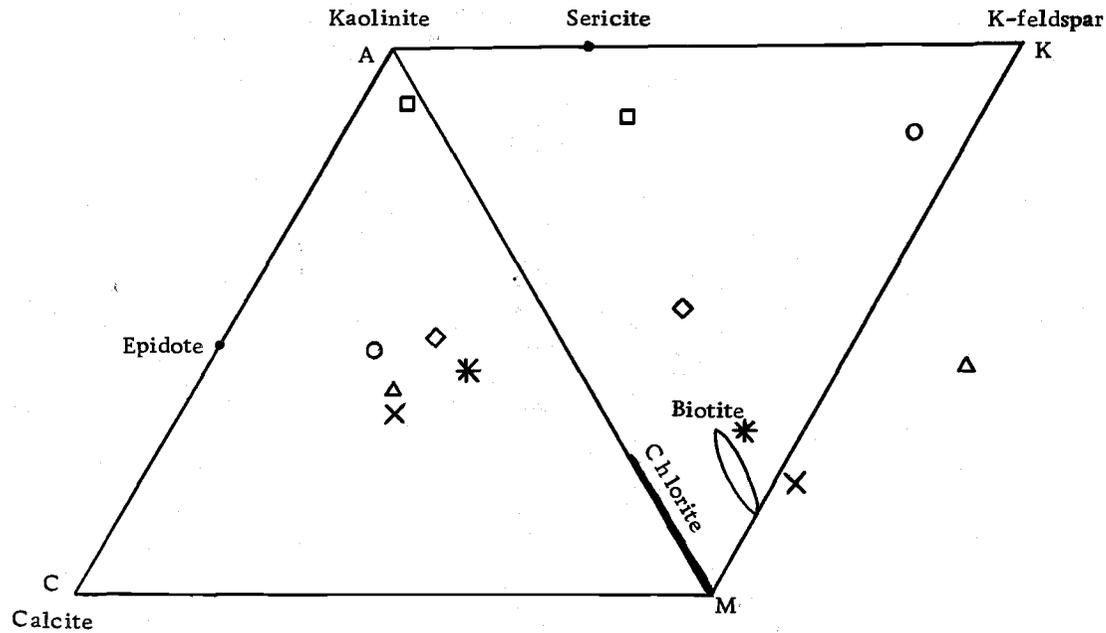
2/ H<sub>2</sub>O<sup>-</sup>, H<sub>2</sub>O<sup>+</sup>, Fe<sub>2</sub>O<sub>3</sub>, FeO analyzed by Chemical and Mineralogical Services, Salt Lake City, Utah.

3/ Average porphyritic granodiorite from Cuddy Mountain (after Field *et al.*, 1973).

4/ Total iron reported as FeO.

diorite and aplite. Mineralogical changes in sample N-48 are reflected by the high contents of  $K_2O$  (8.82 percent) and  $H_2O$  (2.65 percent) and low contents of  $CaO$  (1.74 percent) and  $Na_2O$  (0.73 percent), relative to the values of these oxides in the unaltered quartz diorite (sample I-161). Components such as  $Fe_2O_3$ ,  $FeO$ , and  $MgO$  were also removed during potassium silicate alteration. The addition of  $K_2O$  and depletion of  $Fe_2O_3$ ,  $FeO$ , and  $MgO$  is well-illustrated in the AKF part of Figure 18.

Sericitic alteration is represented by the quartz-sericite-pyrite assemblage (sample N-57, Table 17) in the gradational contact zone between the aplite and the porphyritic granodiorite. Hydrothermal sericite, radiometrically dated by K-Ar method at 197±7 m.y., and kaolin group minerals, believed to have formed by supergene effects, have completely replaced plagioclase feldspar of the host rock. Pyrite and associated pyrite casts are present in amounts up to six percent in fracture-fillings and as disseminations, in the sericitic alteration type. The intense sericitization has caused major changes in chemistry (Table 17). Compared with the average unaltered porphyritic granodiorite from Cuddy Mountain, sample N-57 contains higher  $SiO_2$ ,  $K_2O$ , and  $H_2O^+$  whereas  $Fe_2O_3$ ,  $FeO$ ,  $MgO$ ,  $CaO$ , and  $Na_2O$  are all depleted. Extreme base leaching of the porphyritic granodiorite during sericitic alteration is shown by the ACF-AKF diagram (Fig. 18).



<u>Rock Type</u>	<u>Sample Number</u>	<u>Alteration Type</u>	<u>Symbol</u>
Porphyritic Granodiorite	Ave. Cuddy Mt. (Field, <i>et al.</i> , 1973)	Fresh	*
Quartz Diorite	I-161	Fresh	x
Quartz Diorite	N-48	Potassic	o
Porphyritic Granodiorite	N-57	Sericitic	□
Porphyritic Granodiorite	N-58-c	Int. Argillic	◇
Quartz Diorite	N-61	Propylitic	△

Figure 18. ACF-AKF alteration diagram for lithologies from the Thorn Spring Prospect and the average porphyritic granodiorite from Cuddy Mountain.

Sample N-58-c (Table 17) represents an alteration assemblage that contains sericite-kaolin group minerals, that have partly to completely replaced plagioclase feldspar, and felty washed-brown hydrothermal biotite and chlorite, that completely replaced magmatic biotite (Fig. 19). This assemblage is defined as an intermediate argillic type of alteration and is recognized only in the porphyritic granodiorite. Granodiorite that has been altered to this assemblage contains abundant quartz and tourmaline as segregations, but only traces of sulfides. The chemistry of the altered sample (N-58-c, Table 17) does not differ appreciably from the unaltered porphyritic granodiorite from Cuddy Mountain. Only  $\text{SiO}_2$  is slightly enriched in the thesis specimen, whereas  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ , and  $\text{FeO}$  are all depleted relative to unaltered granodiorite.

Propylitic alteration, consisting of a chlorite-epidote+sericite assemblage, is widely developed in the quartz diorite north of the prospect (sample N-61, Table 17). In this alteration type, chlorite and epidote have partly replaced the mafics, whereas sericite has partly replaced plagioclase feldspar of the host. Minor veinlets of carbonate are present in the quartz diorite adjacent to the feldspar porphyries and also in the porphyritic granodiorite. Chemical differences are small between unaltered and propylitically altered quartz diorite as shown by data listed in Table 17.

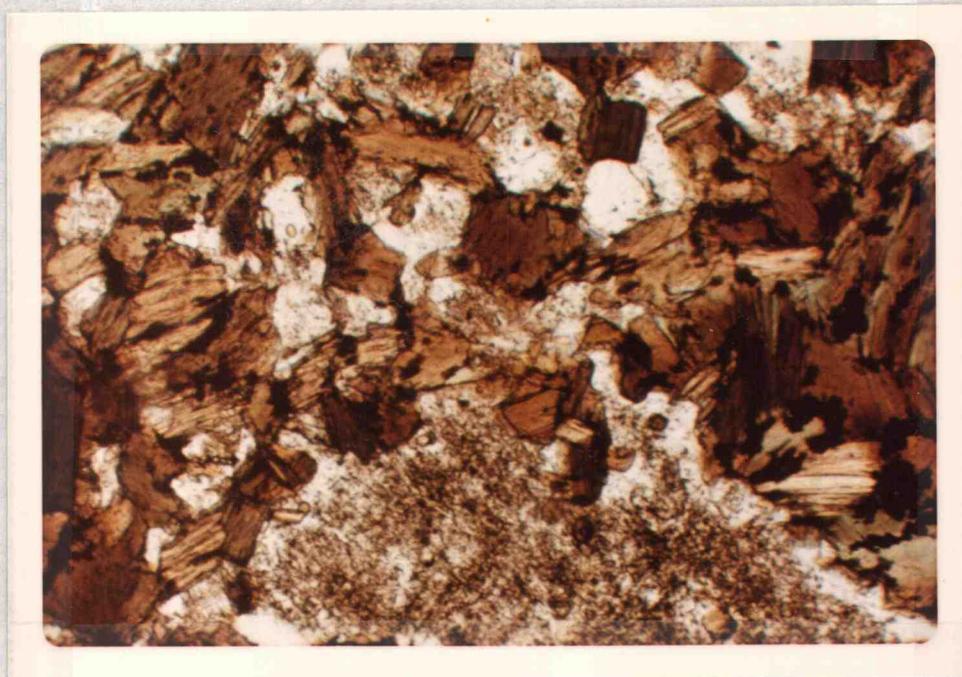
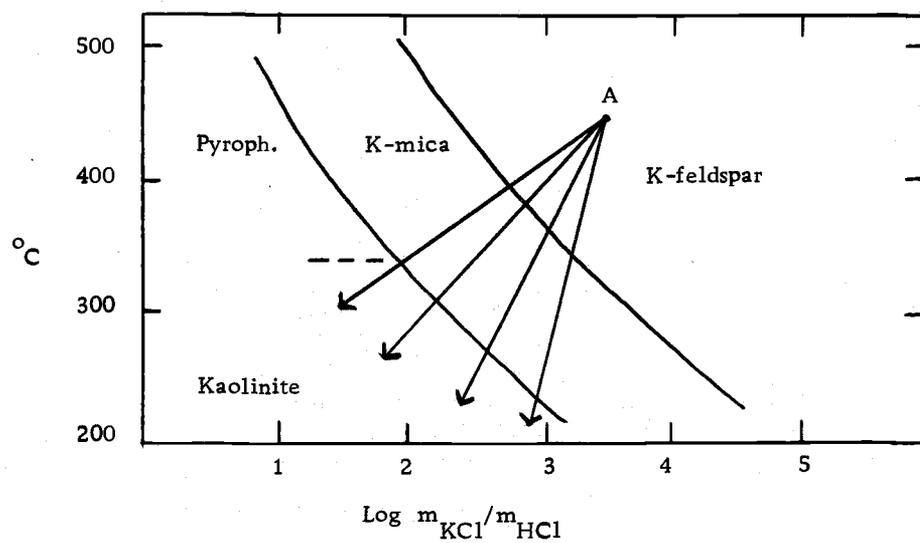


Figure 19. Photomicrograph, hydrothermal biotite-sericite-kaolinite-chlorite in granodiorite at the Thorn Spring Prospect (crossed nicols, 100x).

The assemblages of hydrothermal alteration are zoned as shown on Plate 3. An assemblage of orthoclase-sericite-chlorite occurs in the north-central part of sec. 28. Away from this zone to the south, an assemblage of quartz-sericite-pyrite is encountered first, and this grades into the intermediate argillic assemblage of kaolinite-sericite-biotite-chlorite that characterizes the granodiorite. The orthoclase-sericite-chlorite assemblage grades north from sec. 28 into propylitic alteration that characterizes the quartz diorite. According to Meyer and Hemley (1967), the ratio of the activities of  $K^+$  and  $Na^+$  to that of  $H^+$  is an important control of ore and gangue mineral assemblages deposited from chloride-rich hydrothermal systems (Fig. 20). The zonation of hydrothermal alteration may be caused by chemical changes in the hydrothermal fluids that cooled as they migrated away from the aplite; the arrows on Figure 20 represent possible chemical changes. The presence of an assemblage of orthoclase-sericite-chlorite and absence of salt crystals (halite, sylvite) in fluid inclusions from minerals of this assemblage suggest that the initial fluids ranged in temperature from  $400^{\circ}$  to  $600^{\circ}$  C and had relatively low  $K^+/H^+$  ratios (Roedder, 1971). Acids, such as HCl, are stable and do not have base leaching capabilities at such elevated temperatures (Meyer and Hemley, 1967). Thus, point A (Fig. 20) may approximate the important initial chemical and physical conditions of the



Arrows represent possible compositional paths for hydrothermal fluids at the Thorn Spring Prospect.

Figure 20. 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 (Meyer and Hemley, 1967).

hydrothermal fluid. The absence of pyrophyllite as a hydrothermal alteration product suggests that temperatures probably diminished as the later and/or peripheral sericitic and intermediate argillic assemblages were formed. Alteration zones are not well-developed in the quartz diorite north of the prospect (Plate 3). Their absence may be attributed to any one or a combination of the following parameters. The older quartz diorite may have been much cooler than the aplite at the time of hydrothermal alteration. Thus, the hydrothermal fluids may have cooled more rapidly in their northward migration, concomitantly effecting rapid deposition of dissolved constituents with consequent loss of base leaching capabilities. Differences in fracture intensity (permeability) may have been important in localizing hydrothermal fluids and the minerals deposited therefrom. Such differences, however, were not readily evident between the different host rocks.

Trace Element Geochemistry. Stream sediment samples collected from major drainages at the Thorn Spring Prospect were analyzed for copper, lead, molybdenum, and zinc (Table 18 and Plate 3). Sample TH-29, not on Plate 3, is from an ephemeral stream in the SW $\frac{1}{4}$  sec. 28. Low trace metal values in these stream sediment samples are interpreted to reflect the absence of a major drainage crossing the principal areas of hydrothermal alteration and mineralization. Rock chip samples were also collected from

Table 18. Trace Metal Contents (ppm)<sup>1/</sup> of Stream Sediment and Rock Chip Samples from the Thorn Spring Prospect.

Sample No.	Copper	Lead	Zinc	Molybdenum	Silver
<u>Stream Sediment:</u>					
TH-26	130	30	300	-1 <sup>2/</sup>	
TH-27	120	20	245	-1 <sup>2/</sup>	
TH-28	95	30	160	-1 <sup>2/</sup>	
TH-29	60	30	105	-1 <sup>2/</sup>	
<u>Rock Chip:</u>					
I-62	1, 100	20	95	44	.7 <sup>2/</sup>
N-48	5	10	75	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
N-49	1, 100	20	50	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
N-56	110	20	60	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
N-57	5	-10 <sup>2/</sup>	10	-1 <sup>2/</sup>	-1 <sup>2/</sup>
N-58-B	10	10	25	-1 <sup>2/</sup>	-.1 <sup>2/</sup>

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation, Midvale, Utah.

<sup>2/</sup> Below detection.

outcrops on and near the prospect. These samples were analyzed for silver as well as for copper, molybdenum, lead, and zinc.

Rock sample N-49 (1, 100 ppm Cu) is from quartz diorite containing traces of chalcopyrite in association with veinlets of orthoclase in fracture-fillings.

Because the Thorn Spring Prospect is characterized by few outcrops, soil samples provide the best exploration method for quantitatively estimating the trace metal content of underlying bed-rock. Trace element (copper-molybdenum) data for soil samples collected from the B-horizon were provided by the American Smelting and Refining Company (Jerry Aiken, written communication,

1971). Several anomalously high (500-1,000 ppm copper; 10-30 ppm molybdenum) values are plotted on Plate 3. The anomalous values do not show any preference for specific rock types or alteration assemblages and, therefore, they suggest a possible structural control for metallization.

Oxidation and Secondary Enrichment. Jarosite and the hydrous ferric oxide, goethite, are the principal limonite present in the leached capping. The abundance of jarosite suggests an acidic environment caused by the chemical decomposition of pyrite. The acidic environment may have caused substantial leaching of copper from surficial outcrops. Although malachite and azurite locally stain fractures, evidence for the former presence of secondary copper minerals, such as a cellular limonite boxwork, is generally absent. However, rock sample I-62 (1,100 ppm copper; 44 ppm molybdenum) is from a cellular goethitic limonite. This occurrence of limonite, in association with a quartz-sericite gangue and anomalously high concentrations of metals, suggests that secondary enrichment of copper may be present in minor amounts at depth.

Conclusions. The Thorn Spring Prospect contains porphyry-type copper-molybdenum mineralization that is believed to be related to a magmatic-hydrothermal event at approximately 200 m. y. along the southwest flank of the Iron Mountain Complex. Local

pegmatitic segregations of quartz and tourmaline in the granodiorite suggest a possible deep hydrothermal system relative to normal porphyry-type deposits (Guilbert and Lowell, 1974), similar to the Iron Mountain Prospect. Mineralization appears to be controlled mainly by fractures and is associated with potassium feldspar veinlets, as well as with assemblages of quartz-sericite-pyrite. A nonsymmetrical zonation of alteration types (Plate 3) is present and is probably in part the result of diminishing temperature and  $K^+/H^+$  ratios in the hydrothermal fluids. Differences in fracture intensity and composition of the host rocks may have also been important. Possible secondary enrichment of copper at depth is suggested by the jarositic and goethitic leached capping that is present on parts of the prospect.

#### Quartz-Tourmaline Veins

Veins containing quartz, tourmaline, and minor potassium feldspar are abundant in all phases, except aplite, of the Iron Mountain Complex. These veins, which are often continuous for only several tens of feet, and vary from two inches to several feet in width, are also locally present in the adjacent Seven Devils Volcanics. Tourmaline is commonly present as black suns, whereas potassium feldspar locally floods the wallrock immediately adjacent to the veins. Pyrite, chalcopyrite, and minor sphalerite

are disseminated in the quartz and are present in amounts up to three percent. Individual sulfide crystals are as much as 1.5 cm in diameter. Magnetite is commonly associated with the sulfides. Later carbonate stringers, accompanied by red hematite, are present in some of the veins.

Vein azimuths, measured in 48 locations throughout the district, have been plotted on a rose diagram (not illustrated). Their distribution indicates a preferred northeast trend which contrasts markedly with the preferred northwest trend of the silver-bearing veins in the overlying silicic volcanic country rocks.

Abundant quartz-tourmaline veins and several hydrothermally altered dikes and plugs of quartz-feldspar porphyry, exhibiting fractures that contain as much as three percent pyrite and two percent chalcopyrite, are present within the quartz diorite of parts of secs. 10 and 11. The quartz diorite is well-fractured and has been hydrothermally altered to an assemblage of sericite-kaolinite-calcite-chlorite+epidote. A general outline of the altered area is shown in Plate 3. Modal and chemical analyses for samples of quartz diorite collected from diamond drill core are listed by hole number and depth in Table 19. A typical unaltered quartz diorite (less than 10 percent alteration minerals) is listed for comparison. Plagioclase feldspar in the altered samples has been partly to completely replaced by kaolin group minerals, sericite, and epidote.

Table 19. Modal and Chemical Analyses of Argillic Alteration Assemblages in the Quartz<sup>1/</sup> Diorite from Diamond Drill Core in Sec. 10 Compared to Typical Unaltered Quartz Diorite.

	MDD1-930	MDD2-207	MDD2-635	MDD2-1390	U. Qdi (I-161)
Qtz.	36	40	35	46	27
K-fld.	tr	-	-	-	4
P-fld.	20	tr	14	12	46
Pyx.	-	-	-	-	-
Hbl.	-	-	tr	-	6
Bio.	-	-	tr	-	10
Acc.	tr	tr	tr	tr	tr
Opq.	1	3	1	1	1
Ser.	14	29	18	16	3
Clay	9	16	19	14	3
Chl.	1	8	1	10	tr
Epi.	-	tr	10	tr	tr
Carb.	19	4	2	1	tr
SiO <sub>2</sub>	68.0	65.2	67.2	70.6	65.7
TiO <sub>2</sub>	0.41	0.39	0.47	0.32	0.44
Al <sub>2</sub> O <sub>3</sub>	14.7	14.9	15.6	13.8	15.6
FeO	4.28 <sup>2/</sup>	9.32 <sup>2/</sup>	6.15 <sup>2/</sup>	3.18 <sup>2/</sup>	4.22 <sup>2/</sup>
MgO	0.7	1.3	1.2	0.7	2.1
CaO	2.5	-	2.8	3.1	4.6
Na <sub>2</sub> O	2.1	-	1.0	3.6	3.5
K <sub>2</sub> O	2.96	3.70	2.48	1.53	2.50
	95.6	94.8	97.9	96.8	98.7
Specific gravity	2.79	2.76	2.66	2.71	2.70

<sup>1/</sup> Less than 10% alteration minerals.

<sup>2/</sup> Total iron reported as FeO.

Chlorite, epidote, and calcite completely replace the primary mafic minerals. Hairline fractures filled with quartz are common and locally form stockworks. Late veinlets of carbonate are ubiquitous and they crosscut and brecciate the earlier quartz veinlets. Chemical data for the oxides indicate that intense base leaching occurred during the formation of the sericite-kaolinite-calcite-chlorite+epidote assemblage. Measurable amounts of  $\text{Na}_2\text{O}$  and  $\text{CaO}$  are not present in sample MDD2-207. However, their strong depletion may relate to intense acid leaching by supergene fluids caused in part by the surficial decomposition of sulfides. Weight percentages of major oxides do not total up to 100 percent for the argillically altered samples. These low oxide abundances (94.8-97.9 weight percent) are the result of volatilization and loss of sulfides, carbonates, and water by heating during sample preparation for whole-rock chemical analyses by the X-ray fluorescence method.

The quartz-tourmaline veins and related hydrothermal alteration are believed to be genetically related to the porphyritic granodiorite. This interpretation is geologically enhanced by pegmatitic segregations of quartz and tourmaline that are present in outcrops of the porphyritic granodiorite to the south and southeast, and which may underlie the entire district. This genetic link is additionally supported by the sulfides chalcopyrite and sphalerite that provide a copper-zinc metal association which is characteristic of

metallization related to the Iron Mountain Complex.

### Mortimer Mine

The Mortimer iron deposit is located within an erosional remnant of marble that is surrounded by the quartz diorite phase of the Iron Mountain Complex (Plate 1, NW $\frac{1}{4}$  sec. 23). The deposit is one of several magnetite and/or specularite-bearing skarns that are replacements of calcareous horizons in the Seven Devils Volcanics of the Iron Mountain area (Mackin, 1953). The property is mined seasonally by the open-pit method for iron that is used in the making of cement at Lime, Oregon.

A geologic cross-section of the deposit is portrayed in Figure 21. Near the contact with the quartz diorite, the coarsely crystalline marble has been replaced by an assemblage of skarn minerals that include garnet, epidote, idocrase and calcite. The magnetite occurs as a massive replacement body 20 to 40 feet in thickness, in the south end of the open-pit. The magnetite pod strikes northeast, dips 45° SE, and contains traces of disseminated chalcopryite and pyrite. Magnetite and calc-silicates are crosscut by younger large crystals of hydrothermal biotite, as books as much as one foot in diameter, that has partly retrograded to chlorite. Tourmaline is locally associated with the mica.

The formation of this oxide-sulfide deposit is believed to be

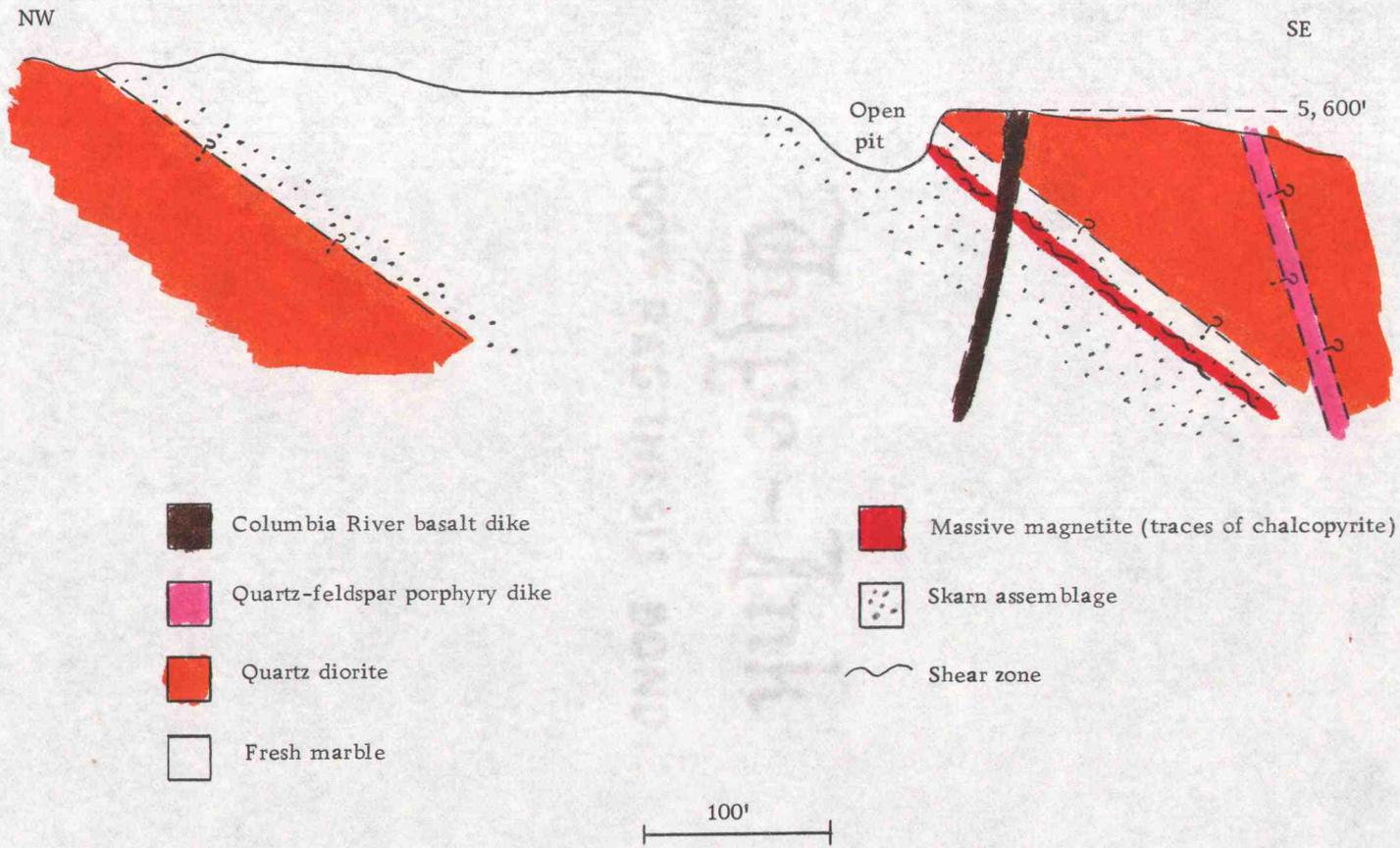


Figure 21. Geologic cross-section of the Mortimer Mine area.

genetically related to hydrothermal activity associated with emplacement and cooling of a quartz-feldspar porphyry dike in the southeast part of the mine area (Fig. 21). Evidence that supports this interpretation includes: (1) the crosscutting relationship of the biotite-tourmaline-magnetite-sulfides to the earlier calc-silicates of the skarn, and (2) the spatial relationship of biotite (chlorite) and tourmaline in the skarn to hydrothermally altered dikes of quartz-feldspar porphyry that contain pegmatitic segregations of quartz, tourmaline and biotite. In addition, a magnetite-chalcopyrite sample, approximately five pounds in weight, was analyzed for trace concentrations of metals. It contained anomalous amounts of copper (1,800 ppm) and zinc (415 ppm) which, as previously mentioned, are characteristic of the Cu-Zn metallization that is spatially related to the Iron Mountain Complex.

#### Regional Vein-Type Strata-Bound Metallization

Epithermal vein-type deposits, containing a copper-lead-zinc silver metal association, are present within a zone that is less than 1,000 feet thick and yet is stratigraphically continuous over a distance of at least 42 miles in western Idaho and eastern Oregon (Plate 4). The Mineral District (Plate 3), located approximately midway along this zone, has been the most productive mining locality and with silver as the most important metal (Table 20).

Table 20. Base and Precious Metal Production Records <sup>1/</sup> Along Metallized Zone in Western Idaho and Eastern Oregon.

CUDDY MOUNTAIN (1946-1952)		MINERAL DISTRICT (1889-1950)		BAYHORSE DISTRICT (1891-1925)	
All reported production is from the Lead Zone Mine near the top of Cuddy Mountain.		Many small, formerly producing mines near the junctions of the north and main forks of Dennett Creek.		One formerly producing mine on the Oregon side of the Brownlee Reservoir.	
Metal	Production (129 tons ore)	Metal	Production (unknown tonnage)	Metal	Production (unknown tonnage)
Ag	465 oz.	Ag	1, 000, 000 oz.	Ag	171, 880 oz.
Cu	86 lb.	Cu	340, 000 lb.	Cu	10, 440 lb.
Pb	76, 460 lb.	Pb	100, 000 lb.	Pb	156, 000 lb.
Zn	1, 416 lb.	Zn	-	Zn	76, 000 lb.
Au	2. 83 oz.	Au	Trace	Au	Trace

<sup>1/</sup> Data from Minerals Yearbooks, published by the U. S. Bureau of Mines, Livingston (1923), Anderson and Wagner (1952), and Cook (1954).

Livingston (1923) originally mentioned the unusual stratigraphic control for this metallization. The principal host rocks for these vein-type deposits are the dominantly brittle and silicic volcanic rocks which include the Mineral porphyritic rhyolite tuff(s) and rhyodacite porphyry of Early Jurassic age. The major problem concerning the genesis of these strata-bound deposits is determining whether or not they are related to hydrothermal fluids generated from nearby plutons, or are representative of a separate and distinct episode of mineralization that was possibly contemporaneous with volcanism. Beginning with the Mineral-Iron Mountain District, districts and prospects along the regional zone are described by the writer on an individual basis. Conclusions and possible origins for the metallized zone in western Idaho and eastern Oregon are suggested at the end of the section.

#### Mineral-Iron Mountain District

The Mineral-Iron Mountain District, located approximately midway along the metallized zone, is 18 miles south-southwest of the Cuddy Mountain District (Plate 4). The general geologic relationships and porphyry-type metallization have already been discussed. The copper-lead-silver deposits are chiefly found adjacent to and on both sides of Dennett Creek. Locations of the formerly productive mines are plotted on Plate 3.

Stratigraphic and Structural Controls. Vein-type deposits of the district are restricted to a maximum stratigraphic thickness of 900 feet within fractured portions of the rhyodacite porphyry, Mineral porphyritic rhyolite tuff(s), and the Thorsen formation, which collectively are all of Early Jurassic age. Most of the past metal production has come from deposits that formed in near vertical zones of fracturing and brecciation, that are as much as several tens of feet in width. Minor stratiform hydrothermal mineralization is present along the stratigraphic contact between the porphyritic rhyolite tuffs and the Thorsen formation.

The host rocks are bleached and stained by jarosite in the vicinity of the veins. Black manganese oxides are present but are not as abundant as in the Cuddy Mountain District to the north. Sulfide minerals identifiable macroscopically include finely crystalline chalcopyrite, galena, pyrite, sphalerite, and tetrahedrite. In addition, small amounts of boulangerite, bournonite, cylindrite, marcasite, stannite, and wurtzite have been identified by Anderson (1963) in polished sections of the ores. The sulfides commonly exhibit banding, framboidal, and colloform textures (Fig. 22). They are exclusively associated with a carbonate gangue. Mottled calcite and minor smectite partly to completely replace plagioclase feldspar and mafics, respectively, in the silicic volcanic rocks. Fragments of fault breccia in the volcanic units and clasts in the Thorsen

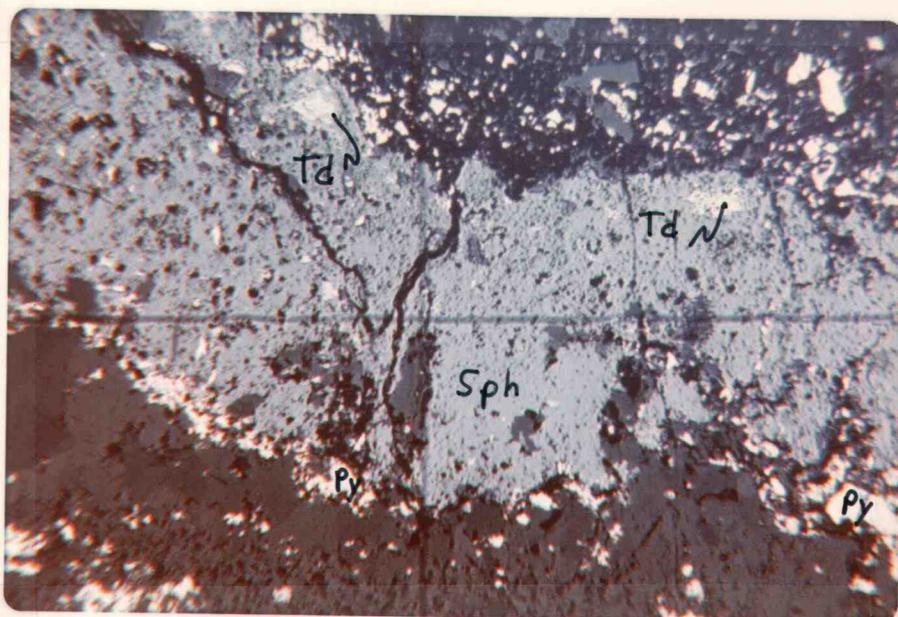


Figure 22. Photomicrograph, band of sphalerite-pyrite-tetrahedrite (?) in carbonate vein, Mineral District (polished section, 28x).

formation are variably replaced by the sulfides and carbonate gangue. Barite veins, as much as 10 cm in width, accompany several of the fissure deposits in the vicinity of the Boone property (NW $\frac{1}{4}$  sec. 9).

Azimuths of 32 sulfide-bearing veins traversing the Jurassic host rocks have been plotted on a rose diagram (not illustrated). They show a preferred northwest trend which contrasts markedly with the pronounced northeast trend for the quartz-tourmaline veins of the Iron Mountain Complex.

Because metallization does not occur above the major reverse fault of post-late Middle Jurassic age (see Structural Geology), the allochthonous plate forms a structural capping to these deposits. This structural relationship, therefore, suggests a pre-late Middle Jurassic age for the vein-type metallization. At least part of the metallization is Early Jurassic in age as evidenced by well-rounded clasts of rhyolite tuff in the Thorsen formation that locally contain disseminated pyrite. Dikes of Columbia River basalt post-date the hypogene sulfide deposition and are most common in areas of high-grade silver mineralization (Turner, 1908). These mafic dikes may have possibly imposed a further concentration of metals at the time of dike injection, or they may have acted as an impermeable barrier during a period of supergene enrichment. Because past ore production has come from deposits that bottomed at depths less than

200 feet, and because recent diamond drilling has indicated that the highest grades of silver are in the zone of oxidation, secondary enrichment of silver would appear to be the more geologically reasonable process for these near-surface concentrations.

Trace Element Geochemistry. Concentrations of trace elements in stream sediment and rock chip samples from the vicinity of the strata-bound vein-type deposits are listed in Table 21 and most are plotted on Plate 3. Anomalous copper and zinc values in the stream sediment samples can all be attributed to contamination from mine dumps at the dormant properties (Plate 3). Rock chip sample R-3-b (2,000 ppm lead, 2,800 ppm zinc; 26 ppm silver) is from a fractured rhyolite tuff (Jmr2) in the SE $\frac{1}{4}$  sec. 19, T. 14 N., R. 6 W., west of the map area, where the tuff pinches out. Traces of finely crystalline tetrahedrite (?), as well as small amounts of galena and pyrite, were observed on fractures in the sample.

In addition to the data reported in Table 21, copper-silver assay values from diamond drill core were provided by Cyprus Mines, Inc. The highest values (703 ppm silver; 35,000 ppm copper) were recorded in the oxidized zone (interval 320-340 feet) of a fault breccia from porphyritic rhyolite tuff near the Boone property (NW $\frac{1}{4}$  sec. 9, Plate 3). Mineralogically, the breccia zone contains manganese oxides and jarosite, as well as bands of pyrite and chalcopyrite in which tetrahedrite was apparently lacking. Copper assay

Table 21. Trace Metal Contents (ppm)<sup>1/</sup> of Stream Sediment and Rock Chip Samples from the Vicinity of the Porphyritic Rhyolite Tuff(s) in the Mineral-Iron Mountain District

Sample No.	Copper	Lead	Zinc	Molybdenum	Silver
<u>Stream Sediment:</u>					
TH-1	95	70	320	1	
TH-2	85	60	300	1	
TH-3	45	40	185	-1 <sup>2/</sup>	
TH-4	235	150	365	1	
TH-5	185	70	215	1	
TH-6	180	50	260	-1 <sup>2/</sup>	
TH-7	65	30	150	-1 <sup>2/</sup>	
TH-8	45	30	195	1	
TH-9	65	20	280	-1 <sup>2/</sup>	
TH-10	55	30	220	1	
TH-11	70	50	245	3	
<u>Rock Chip:</u>					
N-11	15	20	15	1	-.1 <sup>2/</sup>
R-3-b	5	2,000	2,800	1 <sup>2/</sup>	26
R-3-c	5	10	30	-1 <sup>2/</sup>	.1
R-30	10	30	105	-1 <sup>2/</sup>	-.1 <sup>2/</sup>

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation.

<sup>2/</sup> Below detection.

values are also discussed later as part of statistical study.

### Cuddy Mountain District

The Cuddy Mountain District is located near the north end of the metallized zone (Plate 4) and is cored by a plutonic complex of Late Triassic-Early Jurassic age that intruded the Upper Triassic and possibly the Jurassic stratigraphic units (Bruce, 1971). In addition to strata-bound vein-type deposits in the northwest part of the district, porphyry-type (IXL and Kismet) and skarn-type

(Railroad) mineralization is also present. All reported production (Table 20) from the vein-type mineralization is the Lead Zone Mine (Plate 4) near the top of Cuddy Mountain.

Stratigraphic and Structural Controls. The oldest rocks in the Cuddy Mountain District are several thousand feet of metavolcanic and metasedimentary rocks of Late Triassic age (Fankhauser, 1969). These rocks are overlain by several hundred feet of red conglomerate of Early Jurassic age. Porphyritic rhyolite tuff that is fractured and metallized overlies the red conglomerate. Both the red conglomerate and rhyolite tuff are repeated by a high angle reverse fault (Slater, 1969; Bruce, 1971) that is correlated with the overthrust of Livingston (1932) in the Mineral-Iron Mountain and Bayhorse Districts to the south.

Field observations by the writer and diamond drill core data for the Grade Creek Prospect (Plate 4) provided by Donald H. Adair (1972, written communication) indicate that sulfide mineralization is structurally localized in fracture and breccia zones within the lower rhyolite tuff. These zones are less than ten feet wide and the vein systems are generally vertical and trend northwest. Hypogene silver metallization within the lower rhyolite tuff is present as finely crystalline tetrahedrite that is accompanied by a manganese ferrous carbonate and minor quartz gangue. Other sulfides present at the Grade Creek Prospect are chalcopyrite, galena, pyrite, and

sphalerite. Manganese oxides, that are abundantly localized along fractures and thoroughly stain surficial exposures of the porphyritic rhyolite tuff, bottom at depths of approximately 100 feet in the core from diamond drill holes.

According to Adair (written communication, 1972), the best silver metallization may be localized on the axis of an anticline that plunges steeply to the northwest. Part of the hydrothermal mineralization may have been localized near the upper and lower contacts of the porphyritic rhyolite tuff. Base and precious metal-bearing veins are absent from the upper repeated rhyolite tuff near Grade Creek. However, near the top of Cuddy Mountain (Plate 4, Lead Zone Prospect), veins are found in both upper and lower tuff units.

Trace Element Geochemistry. The concentrations of trace elements in stream sediment from Cuddy Mountain are listed in Table 22. These samples were collected downstream from the porphyritic rhyolite tuff along drainages that included the Crooked River (TH-24 and TH-25), Brownlee Creek (TH-30 and TH-31) and Grade Creek (SS-1). With the exception of two samples, TH-24 (315 ppm zinc) and TH-25 (405 ppm zinc), collected in the Crooked River drainage that crosses the Lead Zone and Crooked River Prospects (Plate 4), the stream sediment values are not anomalous in comparison to background values for the Pacific Northwest

Table 22. Trace Metal Contents (ppm)<sup>1/</sup> of Stream Sediment and Rock Chip Samples from the Porphyritic Rhyolite Tuff of Cuddy Mountain.

Sample No.	Copper	Lead	Zinc	Molybdenum	Silver
<u>Stream Sediment:</u>					
TH-24 <sup>3/</sup> <sub>4/</sub>	60	40	315	1 <sub>2/</sub>	
TH-25 <sup>5/</sup> <sub>6/</sub>	45	100	405	-1 <sub>2/</sub>	
TH-30 <sup>6/</sup> <sub>7/</sub>	105	20	155	1 <sub>2/</sub>	
TH-31 <sup>7/</sup> <sub>8/</sub>	90	30	130	-1 <sub>2/</sub>	
SS-1	70	25	140	4	
<u>Rock Chip:</u>					
R-18-A <sup>8/</sup> <sub>9/</sub>	15	50	240	1 <sub>2/</sub>	-.1 <sub>2/</sub>
R-18-B <sup>9/</sup> <sub>10/</sub>	20	60	190	-1 <sub>2/</sub>	-.1 <sub>2/</sub>
MO-5-100 <sup>10/</sup> <sub>11/</sub>	700	14,600	10,800	-1 <sub>2/</sub>	31
MO-6-40 <sup>10/</sup> <sub>12/</sub>	20	110	2,600	-1 <sub>2/</sub>	2.0
MO-8-55 <sup>10/</sup> <sub>13/</sub>	690	460	1,100	-1 <sub>2/</sub>	20

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation, Midvale, Utah.

<sup>2/</sup> Below detection.

<sup>3/</sup> SW 1/4 sec. 15, T. 18 N, R. 3 W.

<sup>4/</sup> SW 1/4 sec. 5, T. 17 N, R. 3 W.

<sup>5/</sup> SE 1/4 sec. 7, T. 16 N, R. 4 W.

<sup>6/</sup> SW 1/4 sec. 8, T. 16 N, R. 4 W.

<sup>7/</sup> SE 1/4 sec. 26, T. 17 N., R. 5 W.

<sup>8/</sup> SW 1/4 sec. 8, T. 16 N., R. 4 W.

<sup>9/</sup> SW 1/4 sec 8, T. 16 N, R. 4 W.

<sup>10/</sup> Grade Creek Prospect.

(Field, Jones, and Bruce, 1973).

Rock chip samples (Table 22) with the prefix MO are from diamond drill core in the fractured rhyolite tuff that is intensely stained with manganese oxides at the Grade Creek Prospect. Although these samples contain as much as 700 ppm copper, 14,600 ppm lead, 10,800 ppm zinc, and 31 ppm silver, sulfides were not macroscopically recognized. Thus, it is believed that part of the metals may be complexed with the manganese oxides. Rhyolite tuff that is bleached and fractured adjacent to Brownlee Creek (samples R-18 and R-19) contains as much as 10 percent disseminated pyrite.

#### Bayhorse District

The Bayhorse District is at the southwest end of the metallized zone adjacent to the Brownlee Reservoir (Plates 4 and 5) in sec. 9, T. 13, S., R. 45 E., sec. 20, T. 13 N., R. 7W. of the Olds Ferry 15-minute quadrangle. Although inactive since the early 1920's, partly caved adits, into well-fractured host rocks stained by malachite and azurite, mark the location of the district on both sides of the reservoir. More than 170,000 oz. of silver (Table 20) have been mined from the district.

The metallized rock units are lithically similar to and stratigraphically continuous with those of the Mineral-Iron Mountain and Cuddy Mountain Districts. The rhyolite tuff in the Bayhorse District

has a highly fragmental base that is indicative of its ash flow origin. The nearest major pluton is an equigranular granodiorite that crops out along the reservoir approximately three miles south of the mine area.

The vein-type mineralization consists of finely crystalline chalcopyrite, pyrite, and tetrahedrite that is associated with a carbonate gangue. Livingston (1923) reported that the major ore body was localized along a shear zone that has a strike of N. 70° W. Several shear zones are portrayed on Plate 5. A wacke unit, exhibiting a stretched pebble conglomerate at its base, has been tectonically emplaced above the zone and forms a structural capping to metallization on both sides of the reservoir. Abundant malachite and azurite were noted adjacent to a dike of Columbia River basalt in one of the adits. This association suggests that the dike may have formed an impermeable barrier to descending supergene fluids that contained base and/or precious metals.

#### Other Prospects Along the Metallized Zone

The Wolf Creek Prospect (Plate 4) is located on a ridge between the Mineral-Iron Mountain and Bayhorse Districts in sec. 1, T. 13 N., R 7 W. of the Olds Ferry 15-minute quadrangle. Trenches and prospect pits are present at the prospect. A finely crystalline rhyolite, dark red in color, dips steeply northwest beneath the

regional reverse fault and is the host for the vein-type metallization. The nearest plutonic phase is the Trail Creek pluton (see Plutonic Units), approximately 1.5 miles to the south. Abundant fractures, locally containing azurite, chrysocolla, malachite, and tenorite, mostly trend N. 30°E. The manganese oxides todorokite and jacobsonite were identified by X-ray diffraction studies by the Geologic Research Division of Kennecott Copper Corporation, Salt Lake City, Utah. A single rock chip sample, collected from exposures stained by todorokite and jacobsonite, contained high concentrations of copper (860 ppm) and silver (248 ppm). However, sulfides were not macroscopically visible in this sample.

The Sturgill Peak Prospect (SE $\frac{1}{4}$ , sec. 28, T. 14 N., R. 5 W.) is located between the Mineral-Iron Mountain and Cuddy Mountain Districts (Plate 4). The prospect contains a bleached and fractured porphyritic rhyolite tuff that was intruded by a granodiorite at approximately 120 m.y. (Skurla, 1974). Sulfides were not observed in outcrop. A stream sediment sample, that was collected adjacent to this prospect in a tributary to Mann Creek, contained only background trace metal values.

The Crooked River and Cuprum-Council Road Prospects are at the north end of the metallized zone, where basalts of the Columbia River Group overlie and thus cover the metalliferous horizon. These two prospects contain fractured and bleached rhyolite tuff

that exhibits minor staining by malachite. White veins of bull quartz are present at the Crooked River Prospect and are accompanied by up to three percent pyrite.

### Conclusions

Geologic features that characterize the strata-bound, vein-type deposits of western Idaho and eastern Oregon include the following:

(1) Metallization occurs within a narrow stratigraphic horizon (less than 1,000 feet in thickness) for at least 42 miles.

(2) Brittle, silicic volcanic rocks of Early Jurassic age are ubiquitous along the zone.

(3) Metallization is more commonly localized by high angle faults and breccia zones rather than by stratigraphic contacts.

(4) The principal sulfide minerals include chalcopyrite, galena, pyrite, sphalerite, and tetrahedrite, whereas the gangue minerals are carbonate, locally manganiferous, and minor quartz.

(5) Although the Bayhorse District and some prospects (Wolf Creek, Crooked River, and Cuprum-Council Road) are distant from known plutons, metallization in the Mineral-Iron Mountain and Cuddy Mountain Districts appears to be localized around plutons of Late Triassic or Early Jurassic age.

(6) At least part of the metallization is Early Jurassic as evidenced by pyrite that is disseminated in sedimentary clasts of

the Thorsen formation in the Mineral-Iron Mountain District.

(7) A tectonically emplaced late Middle Jurassic unit forms a structural capping to hydrothermal metallization and alteration in all districts and prospects.

(8) Supergene enrichment of metals, principally silver, is common in the oxidized zone; dikes of Columbia River basalt locally acted as impermeable barriers during the enrichment process.

(9) Post-Miocene block faulting (Plate 4) offsets the metallized zone that is locally covered by flows of the Columbia River Group.

A definitive choice between the two likely but contrasting genetic models of origin, namely plutonic hydrothermal versus volcanogenic processes, for the vein-type deposits would be simplified if the age of the host rocks and of hydrothermal metallization could be independently determined. However, hydrothermal minerals, such as adularia, sericite, or biotite, are not sufficiently abundant for radiometric age determinations in the rocks of metallized zone. As previously noted, the entire Jurassic section which hosts the vein-type mineralization, may be younger than the Iron Mountain and Cuddy Mountain Plutonic Complexes of Late Triassic-Early Jurassic age. Although such an interpretation contrasts with contact effects between plutons and conglomeratic-rhyolitic country rocks at Cuddy Mountain (Bruce, 1971), the principal evidence in the Mineral-Iron Mountain District includes plutonic clasts of the

Iron Mountain Complex in the Cuddy Mountain red conglomerate.

The approximate age of 200 m. y. on magmatism and hydrothermal alteration associated with the Iron Mountain Complex appears to be too old for the deposits of the metallized zone. However, uplift and erosion of the plutonic complex containing porphyry-type metallization in Early Jurassic time, followed by outpouring of silicic volcanics and subsequent hydrothermal vein-type mineral deposition, may have occurred within a short interval of time (several million years) in an island arc environment. Bamford (1972) describes plutons and associated porphyry-type deposits, approximately one million years in age, that have been unroofed in the Philippines, an island arc environment. The best evidence for rapid uplift in western Idaho during Early Jurassic time is the abundance of conglomerates throughout much of the stratigraphic section. Thus, the oldest possible age for the regional vein-type deposits is Early Jurassic. Because fissure deposits in the Mineral-Iron Mountain District are not present in the overlying Tate shale of late Middle Jurassic age, this stratigraphic boundary provides a minimum age for the metallization along this zone.

On the basis of the foregoing geologic data, the writer has tentatively concluded that the regional vein-type deposits are the result of hydrothermal activity that may have occurred only several million years later than porphyry-type mineralization. The close

spatial relationship of metallization to silicic ash flow tuffs suggests that the mineralized fissures may have originated from fumarolic activity that occurred shortly after deposition of the volcanics.

#### Origin of Metals, Sulfur, and Hydrothermal Fluids

The role of high water pressures in the genesis of the Iron Mountain Complex, particularly the formation of aplites and pegmatites, has been discussed in the chapter on Petrogenesis. According to experimental data of Luth, Jahns, and Tuttle (1964), the potassium-deficient nature of the late phases of the complex can also, in part, be explained by high water pressures at the time of crystallization. In this section, the possible origin of metals, sulfur, and hydrothermal fluids in the Mineral-Iron Mountain District and in strata-bound deposits of the metallized zone are discussed on the basis of trace element and stable isotope abundance data.

#### Statistical Distribution of Copper, Lead, and Zinc in the Regional Vein-type Strata-Bound Deposits

A statistical study of available trace element data was undertaken to determine if one or more of the metals that characterize the vein-type deposits along the regional zone of metallization may be syngenetic, rather than epigenetic, with respect to the associated silicic volcanic host rocks. Trace element concentrations for

copper, lead, and zinc in the silicic volcanics, representative of unaltered host rocks to high-grade mineralization along the metalized zone, have been plotted on probability graph paper versus the cumulative frequencies of individual samples (Fig. 23). Tennant and White (1959) have shown from theoretical considerations that curves derived from the cumulative frequencies of multi-modal sample populations exhibit characteristic inflections that define each separate population. Because of the small number of samples available for this study, the cumulative frequencies of copper, lead, and zinc for individual samples are plotted in Figure 23, rather than sample group populations.

Well-defined inflections for the copper, lead, and zinc values that are portrayed in Figure 23 suggest the presence of at least two populations of metals in these samples. The lower populations probably represent the syngenetic (background) contribution of metals to the silicic volcanic rocks, whereas the upper populations are suggestive of an epigenetic contribution for these same metals. Four samples were not included in the statistical determination of zinc values. These samples, from surface outcrops, were bleached and contained anomalously low concentrations (10-40 ppm) of zinc. They probably represent a third population related to supergene weathering, whereby the original zinc content was leached to values less than normal background concentrations.

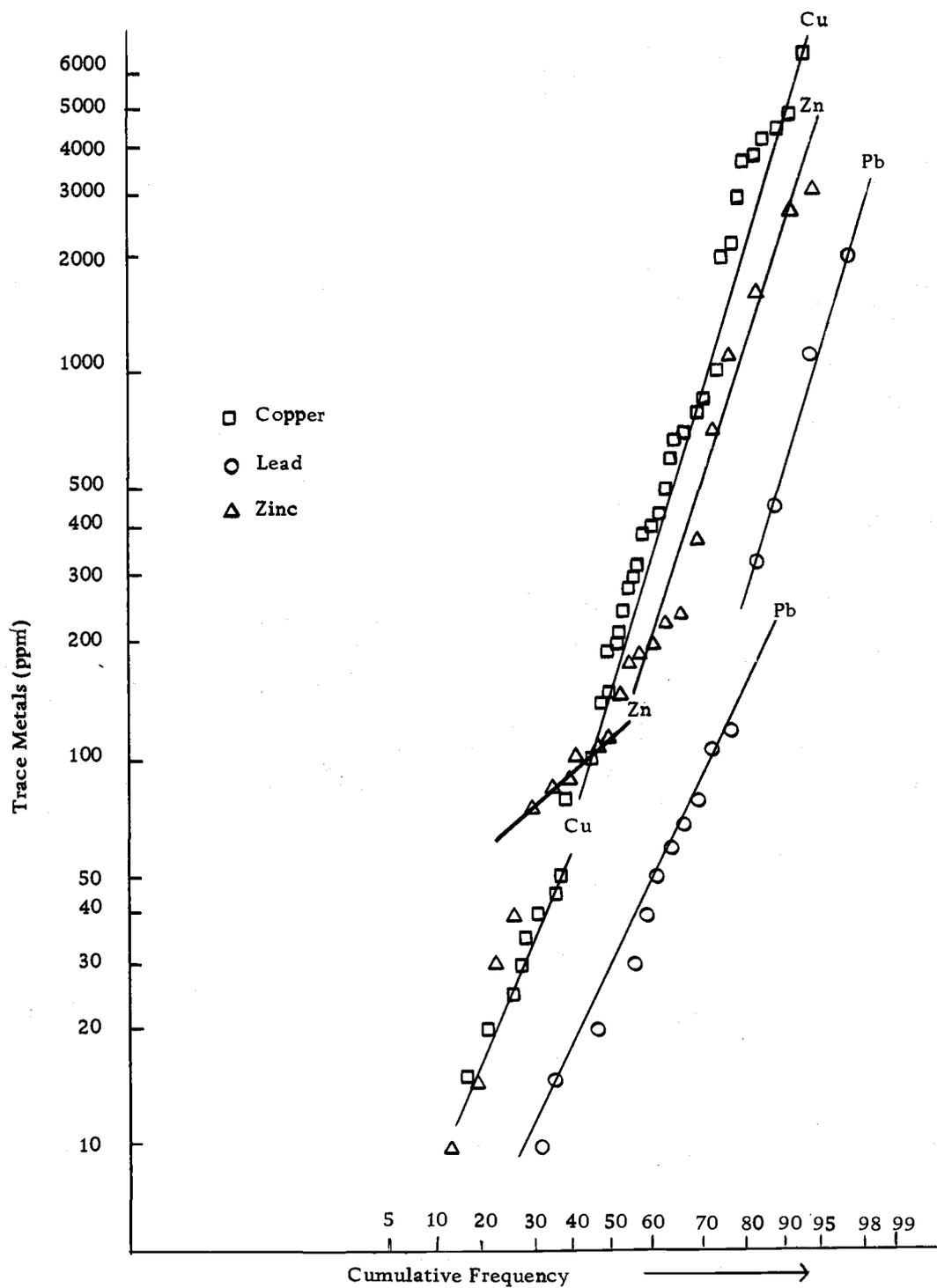


Figure 23. Statistical distribution of trace metals in the silicic volcanics of the metallized zone.

Thus, field evidence, including excellent crosscutting relationships for the veins, and statistical data, such as the curve inflections for trace elements plotted versus cumulative frequencies (Fig. 23) collectively suggest a later (epigenetic) episode of metallization to form the strata-bound deposits along the zone.

#### Sources of Metals in the Mineral-Iron Mountain District and Along the Metallized Zone

At least part of the metallization in the Mineral-Iron Mountain District is believed to be genetically related to Late Triassic-Early Jurassic magmatic-hydrothermal activity. The nearly contemporaneous igneous and hydrothermal events (Table 14) at approximately 200 m. y. provide the best evidence for such a conclusion. Furthermore, the spatial relationship of hydrothermally altered porphyritic granodiorite and related aplitic and porphyritic phases to copper-molybdenum-zinc metallization suggests a genetic relationship. Trace metal concentrations of silver, copper, molybdenum, lead, and zinc in the major plutonic phases of the complex are listed in Table 23, together with the average values for rock types given by Turekian and Wedepohl (1961). With the exception of a few anomalous values, concentrations of these metals in the Iron Mountain Complex are generally lower than the average values. Because all samples are at least incipiently hydrothermally altered, these low values may be the result of leaching of metals from early formed magmatic

Table 23. Trace Metal Contents (ppm) <sup>1/</sup> of the Major Phases of the Iron Mountain Complex Compared with Average Content for a Given Rock Type from Turekian and Wedepohl (1961).

	Ag	Cu	Mo	Pb	Zn
<b><u>Aplite</u></b>					
I-81	-1 <sup>2/</sup>	5	2	-1 <sup>2/</sup>	35
T. and W. Ave. <sup>3/</sup>	0.04	10	1.3	19	39
<b><u>Porphyritic Granodiorite:</u></b>					
N-57	-1 <sup>2/</sup>	5	-1 <sup>2/</sup>	-10 <sup>2/</sup>	10
I-135-a	.3	11	4	5	40
I-170	.3 <sup>2/</sup>	6	6	8	40
N-58-c	-1 <sup>2/</sup>	5	-1 <sup>2/</sup>	-10 <sup>2/</sup>	30
T. and W. Ave. <sup>3/</sup>	0.04	10	1.3	19	39
<b><u>Quartz Diorite:</u></b>					
I-161	0.5 <sup>2/</sup>	30	1 <sup>2/</sup>	11	45
N-48	-1 <sup>2/</sup>	35	-1 <sup>2/</sup>	10	35
T. and W. Ave. <sup>3/</sup>	0.05	30	1.0	15	60
<b><u>Gabbro:</u></b>					
I-93	1.0 <sup>2/</sup>	13	7 <sup>2/</sup>	16	25
N-54	-1 <sup>2/</sup>	55	-1 <sup>2/</sup>	20	65
N-55	0.2	325	-1 <sup>2/</sup>	30	125
T. and W. Ave. <sup>4/</sup>	0.11	87	1.5	6	105

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation, Midvale, Utah.

<sup>2/</sup> Below detection.

<sup>3/</sup> Calcic granite.

<sup>4/</sup> Basaltic rocks.

phases by late-stage hydrothermal fluids. However, normal magmatic differentiation processes also concentrate metals into hydrothermal fluids, as suggested by Graybeal (1973) for intrusive stocks of Laramide age in Arizona. In order to determine which process was primarily responsible for concentrating metals in the Iron Mountain Complex, a detailed trace element study of altered and unaltered phases, including concentrates of individual minerals, would have to be undertaken.

Because several of the vein-type deposits (e.g., the Bayhorse Mine and the Wolf Creek, Crooked River, and Cuprum-Council Road Prospects) of the metallized zone, are miles from outcrops of known plutons, the country rocks must be considered a potential source of metal for these deposits. Background concentrations of trace metals in the Seven Devils Volcanics are listed together with average background values for intermediate volcanic rocks (Turekian and Wedepohl, 1961) in Table 24. From the two samples listed, the Seven Devils Volcanics do not appear to be anomalous in trace metal content. Jensen (1971) has suggested that shales, a lithology that is well known to host particularly large concentrations of lead, zinc, and silver, may provide metals for hydrothermal systems. Concentrations of trace metals for three samples from the Tate shale of the Mineral-Iron Mountain District are listed in Table 24 and are moderately anomalous for zinc (115 ppm

Table 24. Background Trace Metal Contents (ppm)<sup>1/</sup> in Samples of the Seven Devils Volcanics and Tate Shale compared with average content of an intermediate igneous rock from Turekian and Wedepohl (1961).

Sample No.	Copper	Lead	Zinc	Molybdenum	Silver
<u>Seven Devils Volcanics:</u>					
N-32	65	10	110	1 <sup>2/</sup>	-.1 <sup>2/</sup>
N-35	70	20	105	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
T. and W. ave. <sup>3/</sup>	58	10	82	1.2	0.08
<u>Tate Shale:</u>					
B-4-50	50	50	135	-1 <sup>2/</sup>	-.1 <sup>2/</sup>
B-4-90	70	30	185	-1 <sup>2/</sup>	.1 <sup>2/</sup>
B-4-120	40	40	115	9	-.1 <sup>2/</sup>

<sup>1/</sup> Analyzed by Rocky Mountain Geochemical Corporation, Midvale, Utah.

<sup>2/</sup> Below detection.

<sup>3/</sup> (High calcium granite + basalt)/2.

to 185 ppm). Although providing a potential source of metals if leached by hydrothermal fluids, these vein-type deposits are located along the metallized zone regardless of whether or not the black shale is present. Furthermore, as previously mentioned, the fissures are apparently older than the Tate shale of late Middle Jurassic age.

Lead isotope data were obtained for a single sample of tetra-  
hedrite from a fracture-filling at the Grade Creek Prospect along  
the metallized zone on Cuddy Mountain. The  $^{206}\text{Pb}/^{204}\text{Pb}$ ,  $^{207}\text{Pb}/$   
 $^{204}\text{Pb}$ , and  $^{208}\text{Pb}/^{204}\text{Pb}$  ratios as reported by Zartman (1974, in  
press) are as follows:

	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{204}\text{Pb}}$
Ratios:	18.717	15.600	38.413

These ratios are representative of Zartman's (1974) "Area III" lead which is associated with eugeosynclinal plutonic, volcanic, and sedimentary rocks within several hundred kilometers of the Pacific Coast. Because igneous rock and ore lead from Area III exhibit relatively uniform ratios ( $^{206}\text{Pb}/^{204}\text{Pb} = 18.7-19.4$  and  $^{208}\text{Pb}/^{204}\text{Pb} = 38.2-39.1$ ) and generally contain little radiogenic lead ( $^{206}\text{Pb}/^{204}\text{Pb}$  more than 19.5), the source of lead may be the mantle or subducted oceanic crust. In addition, these ratios have been plotted on single stage growth curves for lead (Doe, 1970) and an age of separation from the mantle at approximately 200 m. y. is indicated. Thus, from available data, the lead, and possibly all the metals in the regional vein-type deposits, may have been derived by hydrothermal processes from nearby and possibly hidden plutons of mantle origin.

### Stable Isotopes

Recent studies (Jensen, 1967, 1971; Taylor, 1967; Field and Moore, 1971; Lange and Cheney, 1971; Campbell and Ethier, 1973; Field, 1974) of stable isotopes, especially those of carbon, hydrogen, oxygen, and sulfur, have provided important information concerning: (1) mantle or crustal origin for sulfur and metals, (2)

estimated temperatures of deposition for ore and gangue minerals, (3) roles of magmatic, meteoric, and sea waters in the deposition of ore and gangue minerals, and (4) physical-chemical conditions, such as Eh-pH, of the hydrothermal environment. Isotopic analyses, principally of sulfur, have been obtained for ore and gangue minerals from deposits of both the Mineral-Iron Mountain District and along the metallized zone. Interpretations of the sulfur isotope data listed in Table 25 are of both exploration and genetic significance. The analytical data for sulfur are expressed as deviations of  $S^{34}$  in permil ( $\delta S^{34} \text{ ‰}$ ) between sample and the meteorite standard (Canyon Diablo, troilite sulfide, 0 permil by definition). A single  $\delta C^{13}$  value (relative to the standard, PDB Chicago) and  $\delta O^{18}$  value (relative to standard mean ocean water, SMOW) were also obtained for vein carbonate of the Mineral-Iron Mountain District.

The outstanding features of the sulfur isotope abundance data (Table 25) are the wide range (+14.7 to -26.2 permil) and mostly negative  $\delta S^{34}$  values for sulfides of the strata-bound deposits as compared to the narrow range (-1.4 to +6.5 permil) and mostly positive  $\delta S^{34}$  values for sulfides associated with the Iron Mountain Complex. The wide variation of negative values, that is characteristic of sulfides of the regionally distributed pyrite-barite-calcite assemblages, may originate from a "magmatic" (0 permil) sulfur reservoir by the influence of relatively high fugacities of oxygen at

Table 25.  $\delta S^{34}$  Contents of Sulfur Bearing Minerals from the Mineral-Iron Mountain District and the Metallized Zone.

<u>Vein-type Strata-Bound Mineralization:</u>					
<u>Sample</u>	<u>Location</u>	<u>Host Rock</u>	<u>Gangue</u>	<u>Mineral</u>	$\delta S^{34} \text{ ‰}$
MO-5-330	Grade Creek, Cuddy Mt. Dist.	Rhyolite Tuff	Carbonate	Pyrite	-13.7
				Galena-Tetrahedrite	+14.7
B-27-322	NE 1/4 NW 1/4 sec. 9 Min. - I. M. Dist.	Thorsen Fm. (conglomerate)	Carbonate	Pyrite	-4.9
				Chalcopyrite	-3.4
MDD-4-315	NE 1/4 NW 1/4 sec. 9 Min. - I. M. Dist.	Rhyolite Tuff	Carbonate	Sphalerite	-0.3
M-359-C	NE 1/4 NW 1/4 sec. 9	Rhyolite Tuff	-	Barite	+11.0
DOGAMI-1	Bayhorse Mine, Oregon	Rhyolite Tuff	Carbonate	Tetrahedrite	-26.2
<u>Mineralization Associated with the Iron Mountain Complex:</u>					
M-7	SW 1/4 NW 1/4 sec. 11	Qtz. Diorite	Clay-Sericite (Tourmaline)	Pyrite	+0.9
				Chalcopyrite	+0.9
M-8	SW 1/4 NW 1/4 sec. 11	Qtz. Feldspar dike	Clay-Sericite (Tourmaline)	Pyrite	-1.4
B-16-181	NE 1/4 SE 1/4 sec. 9	Gabbro	Qtz. -Tourmaline	Pyrite	+2.2
				Chalcopyrite	+2.1
IM-1-165	Iron Mt. Prospect	Seven Devils Volc.	Chlorite-Sericite	Pyrite	+3.3
IM-3-122	Iron Mt. Prospect	Seven Devils Volc.	Qtz. -Sericite	Pyrite	+2.9
				Chalcopyrite	+1.8
IM-3-155	Iron Mt. Prospect	Seven Devils Volc.	Qtz. -Sericite	Pyrite	+6.5
				Sphalerite	+2.5
<u>Miscellaneous:</u>					
T-1	NW 1/4 NE 1/4 sec. 12 T. 14 N., R. 6 W	Seven Devils Volcanics		Chalcocite	+2.2
M-4	Gypsum Mine (Mineral)	Jurassic conglomerate	-	Gypsum	+14.6
M-6	Gypsum Mine (Mineral)	Jurassic conglomerate	-	Gypsum	+14.4
Bh-1	Gypsum Mine (Bayhorse)	Jurassic conglomerate	-	Gypsum	+14.6
Bh-3	Gypsum Mine (Bayhorse)	Jurassic conglomerate	-	Gypsum	+14.9

the time of hydrothermal mineral deposition (Ohmoto, 1972). Mineralogical evidence for such an oxidizing environment, in the strata-bound vein-type deposits at the time of sulfide deposition, includes local occurrences of red hematite and barite in the veins. Fractionation factors for sulfur as determined from theory, laboratory experiments, and actual measurements, preclude the formation of hydrothermal sulfates that are more depleted in  $S^{34}$  than that of total sulfur in the system (Field, 1974). Because barite (+11.0 permil) from the vein-type deposits (sample M-359-C, Table 25) contains less  $S^{34}$  than ocean water sulfate (+15.8 to 19.3 permil) for Jurassic to Early Tertiary time (Sangster, 1968), significant contributions of sea water sulfate were not incorporated in the strata-bound hydrothermal system. Moreover, because the host rocks for the vein-type deposits are subaerial ash flow tuffs, and because the metallization may have been nearly contemporaneous with volcanism, the apparent absence of sea water sulfate in the hydrothermal system is geologically reasonable. Permille values for pyrite (-13.7) and galena-tetrahedrite (+14.7) from sample MO-5-330 (Grade Creek Prospect, Cuddy Mountain) possibly suggest a second source of sulfur for pyrite in this vein deposit. Crosscutting relationships determined from polished section examination of the sample indicate that galena-tetrahedrite occupies a paragenetically younger veinlet than the pyrite. Thus, changing physical and chemical conditions

within the hydrothermal system between deposition of early pyrite and late galena-tetrahedrite may have resulted in this isotopic disequilibrium. Possible explanations (models) according to Field (1974, personal communication) for this isotopic disequilibrium include: (1) separate sources for sulfur; ocean sulfate (+20 permil) for the galena-tetrahedrite and magmatic sulfur (0 permil) for the pyrite; (2) splitting of the magmatic (0 permil) sulfur at approximately 250°C to sulfate (+15 permil) and sulfide (-15 permil) aqueous species and form early pyrite from the aqueous sulfide (-15 permil) fraction, and then later reduction (unidirectional) of sulfate to sulfide (+15 permil) to form the galena-tetrahedrite; or (3) deposition from hydrothermal fluids at approximately 200°C containing ocean water sulfate (+20 permil) under conditions of variable oxidation state with early pyrite (-13.7 permil) from fluids having  $\text{SO}_4^{2-}/\text{H}_2\text{S}$  ratios of 0.99/0.01 and late galena-tetrahedrite (+14.7 permil) from more reduced fluids having  $\text{SO}_4^{2-}/\text{H}_2\text{S}$  ratios of 0.25/0.75. Because 0 permil ("magmatic" sulfur) nearly splits the permil values for pyrite (-13.7) and galena-tetrahedrite (+14.7) the second explanation (model 2) is the most reasonable from the available data. Thus, the data suggest that the sulfur in the vein-type deposits of the metallized zone was derived primarily from a magmatic (0 permil) source.

A single  $\delta^{18}\text{O}$  value (+11.8 permil) was obtained from vein

carbonate (sample B-18-262) that contained traces of chalcopyrite, pyrite, and possibly tetrahedrite. Primary magmatic waters have  $\delta O^{18}$  values that range from approximately +7 to +9 permil (Taylor, 1967). However, carbonates tend to concentrate  $O^{18}$  relative to chlorite, hematite, and white mica during equilibrium exchange reactions, and these gangue minerals all are locally present in the vein-type and strata-bound hydrothermal deposits. From oxygen isotope calibration curves experimentally determined for calcite-water (Clayton, 1959; 1961) and assuming a depositional temperature of  $300^{\circ}C$  for the calcite, the original  $O^{18}$  content of the water is calculated to be +6.8 permil. This value is clearly within the acceptable range (+7 to +9 permil) for hydrothermal waters of a magmatic origin. Furthermore, the isotopic composition of carbon in calcite of this vein sample (B-18-262) was determined to be -11.1 permil. Although magmatic carbon normally has  $\delta C^{13}$  values of approximately -5 permil, more negative values may be expected under conditions of high oxygen fugacity (Ohmoto, 1972). Therefore, the isotopic data for carbon, sulfur, and oxygen, collectively suggest a magmatic origin for the hydrothermal fluids that formed the regional vein-type deposits.

A narrow range (-1.4 to 6.5 permil) of mostly positive  $\delta S^{34}$  values is characteristic of the sulfides in porphyry-type deposits, particularly the Iron Mountain Prospect associated with the plutonic

complex. Sulfides associated with the Cuddy Mountain and Peck Mountain plutons to the north also exhibit a narrow range (+0.0 to 4.3 permil) of positive  $\delta S^{34}$  values (Bruce, 1971; Field, Jones, and Bruce, 1973). The presence of pyrite in amounts up to 15 percent at the Iron Mountain Prospect, magnetite in the quartz-tourmaline veins, and apparent absence of sulfate minerals in rocks of the Thorn Spring and Iron Mountain Prospects suggest that the hydrothermal system was characterized by high total sulfur (greater than 0.01 moles/kg  $H_2O$ ), moderate to low oxidizing conditions, and low total sulfate according to the data of Ohmoto (1972). Under these constraints, the narrow range (-1.4 to 6.5 permil) of mostly positive values suggests that the sulfur in sulfides associated with the Iron, Cuddy, and Peck Mountain plutons was of a magmatic (0 permil  $S^{34}$ ) origin (Field, 1966, 1974; Ohmoto, 1972).

The isotopic composition of chalcocite (+2.2 permil) from sample T-1 of float in the Seven Devils Volcanics at the north end of Thorsen Lake ( $NE\frac{1}{4}$  sec. 12; see Iron Mountain Prospect) is similar to other values for sulfides at Iron Mountain Prospect. This compositional similarity suggests that the steel-gray chalcocite may have replaced primary pyrite by supergene processes. However, it was previously noted that primary chalcocite is common elsewhere in the Seven Devils Volcanics (Long, 1974). Because of the steel-gray color of the chalcocite, that contrasts with sooty

black supergene varieties, and the absence of replacement textures, the writer concludes that this minor occurrence is probably primary in origin.

Sulfates from the bedded gypsum deposits in the Mineral-Iron Mountain and Bayhorse Districts exhibit a narrow range (+14.4 to 14.9 permil) of  $\delta S^{34}$  values (Table 25). The isotopic values are within the lighter ( $S^{34}$ -depleted) end of the spectrum (+7.0 to +35.0 permil) for evaporite sulfates of Cambrian to Jurassic age according to Ault and Kulp (1959) and Holser and Kaplan (1966). However, regional geologic evidence that includes stratigraphic, structural, and textural considerations (see Nonmetallic Minerals) indicate an origin for the gypsum by surficial hydration of hydrothermal anhydrite that replaced pre-existing sedimentary rocks. Furthermore, permil values (+14.4 to +14.9) for gypsum along the metallized zone are coincident with the +14.7 permil value obtained for galena-tetrahedrite from the Grade Creek Prospect at Cuddy Mountain. Thus a genetic relationship between the gypsum (anhydrite) deposits and the regional vein-type metallization is possible. Except for complexities in timing (paragenesis, where necessary data are not known) this genetic relationship best fits model 2 (p. 178) by which a magmatic source has been suggested for sulfur in deposits at the Grade Creek Prospect.

The  $\delta S^{34}$  values for sulfide minerals theoretically exhibit

small systematic variations (fractionation) between different sulfide species (Sakai, 1968). Recent experimental sulfide equilibrations by Kajiwara and Krouse (1971) have established fractionation to be, in order of diminishing S<sup>34</sup> enrichment, pyrite, pyrrhotite = sphalerite, chalcopyrite, and galena, which is in agreement with the earlier theoretical predictions. The magnitude of isotopic fractionation between co-existing minerals formed by equilibrium reactions varies inversely with temperature. Delta ( $\Delta$ ) values, the isotopic separation between two minerals (A and B), given by the equation ( $\Delta_{AB} \approx \delta S_A^{34} - \delta S_B^{34}$ ), provide an index to the extent of fractionation. Because the fractionation is primarily temperature dependent, measurements of delta values for co-existing sulfate-sulfide or sulfide-sulfide equilibrium pairs may serve as a geothermometer when plotted on experimentally or theoretically determined working curves of the delta values versus temperature.

The delta value for co-existing sulfides ( $\Delta_{py-cp} = 1.06$ ) in sample IM-3-122 from metasedimentary host rocks at the Iron Mountain Prospect provides an isotopic temperature estimate of 372°C, based on the experimental pyrite-chalcopyrite curve determined by Kajiwara and Krouse (1971). The sulfides of this sample occur as intergrown blebs and stringers of pyrite and chalcopyrite that probably represent, from textural evidence, an equilibrium pair. Isotopic data for other sulfide pairs from the Iron Mountain

Prospect, and from veins along the metallized zone, represent disequilibrium assemblages and cannot be used for estimating temperatures.

In conclusion, sulfides of the vein-type deposits exhibit a wide range (+14.7 to -26.2 permil) of mostly negative  $\delta S^{34}$  values. These data, combined with  $C^{13}$  (-11.1 permil) and  $O^{18}$  (+11.8 permil) data for carbonate gangue of the veins, collectively suggest that the regionally distributed vein-type deposits formed under conditions of high oxygen fugacity and from fluids of primarily magmatic origin. These data support an epithermal, possibly fumarolic, origin for the metallization as suggested by their strata-bound occurrences. In contrast, the copper-molybdenum-zinc metallization associated with the Iron, Cuddy and Peck Mountain plutons and adjacent altered Seven Devils Volcanics, formed under conditions of lower oxidizing potential and from sulfate-deficient hydrothermal fluids of magmatic origin, as indicated by the narrow range (-1.4 to 6.5 permil) of mostly positive  $\delta S^{34}$  values. On the basis of plutonic-stratigraphic relationships (see Cuddy Mountain red conglomerate) and structural data (northeast-trending veins in the Iron Mountain Complex, but northwest-trending fissures in the silicic volcanics), the writer suggested in an earlier section that the regional vein-type deposits may be younger than the porphyry-type deposits associated with the Iron Mountain and Cuddy

Mountain Complexes. Nonetheless, the isotopic data do not contradict the possibility of a single source of sulfur, and perhaps a common origin, for these two types of mineral deposits. Moreover, the isotopic data do not suggest appreciable contributions of heavy sea water sulfate (+15.8 to +19.3 for the Jurassic) in sulfide deposits predominantly localized in volcanic and sedimentary host rocks (e.g., Iron Mountain Prospect, Peck Mountain, and regional vein-type deposits). Tupper (1960), Dechow (1960), and Lusk (1972) show that sulfides in volcanogenic deposits of the Bathurst-Newcastle area, New Brunswick, have mean  $\delta S^{34}$  values between +6.5 and +16.5 permil. Likewise, Campbell and Ethier (1973) report  $\delta S^{34}$  values that range from +10.6 to +25.3 permil for sulfides of the volcanogenic Anvil ore body, Yukon Territory, Canada. In both of these districts, metals are believed to have been deposited as sulfides at the sea water-sediment interface, and sea water sulfate has been suggested as the source of the heavy sulfide sulfur. The sulfur isotope data (Table 25) for sulfides, in the Mineral-Iron Mountain, Cuddy Mountain, and Peck Mountain Districts, as well as in strata-bound deposits of the metallized zone, preclude a classic volcanogenic origin that includes interaction with ocean water sulfate.

## GEOLOGIC SUMMARY

The Mineral-Iron Mountain District of western Idaho contains a thick sequence of Late Triassic to late Middle Jurassic volcanic and sedimentary lithologies that were probably deposited in an island arc environment. At least two episodes of plutonism are represented in the district that contains the Late Triassic or Early Jurassic Iron Mountain Complex. Stock-size plutons of probable pre-Tertiary age are recognized in the drainages of Trail and Rock Creeks, six and eight miles to the south, respectively, of the Mineral-Iron Mountain District. These older rocks are unconformably overlain by Tertiary Columbia River basalt.

The oldest stratigraphic unit is the Seven Devils Volcanics of Late Triassic age. It comprises as much as several thousand feet of interbedded volcanic and volcanoclastic rocks, as well as local limestone (marble). The original mineral constituents of this unit have been variably replaced by products of contact metamorphism and later hydrothermal alteration.

The Seven Devils Volcanics were intruded by the Iron Mountain Complex, a composite pluton consisting of four major phases. The sequence of emplacement was: gabbro, quartz diorite, porphyritic granodiorite (trondhjemite) and aplite. Related porphyritic plugs and dikes are also present. The complex was apparently emplaced as a

stock-size pluton, although the original shape and size of the intrusion is difficult to determine because of pre-Tertiary erosion and tilting of the complex, post-complex reverse faulting, and Columbia River basalt flows that cover parts of the pluton to the south and east. On the basis of a radiometric K-Ar age determination on magmatic biotite from the quartz diorite phase, the Iron Mountain Complex cooled at a minimum date of 200± m. y.

Chemical data suggest that the various phases of the plutonic complex were the result of magmatic differentiation. Possible sources and parent magmas for the complex include high alumina basalt from the mantle, subducted and partially melted oceanic crust, or partially melted amphibolite from the base of the oceanic or thin continental crust. Differentiation of the magma followed the trend of the trondhjemite (potassium-deficient) rock series. High water pressures in the late phases of the Iron Mountain Complex are believed to have been responsible for the formation of numerous aplite-pegmatites (by pressure quenching), and may account for both the quartz phenocrysts and potassium-deficient composition of porphyritic granodiorite (trondhjemite) and related dikes and plugs.

The Seven Devils Volcanics and Iron Mountain Complex were uplifted, eroded, and then downwarped before the deposition of the Cuddy Mountain red conglomerate. The red conglomerate is a relatively thin (100 feet maximum thickness) pebble to boulder

conglomerate of Early Jurassic age. Clasts are largely of volcanic rocks, but several well-rounded boulders, one to three feet in diameter, of quartz diorite are present at the base. These are interpreted to have been derived by erosion of the underlying and adjacent Iron Mountain Complex. The rhyodacite porphyry and Mineral porphyritic rhyolite tuff(s) overlie the red conglomerate with slight angular discordance. Welding textures, including flattened and devitrified punice, are present in the tuffs. The Thorsen formation (maximum thickness 320 feet), consisting mainly of arenites and conglomerates, and Tate shale (maximum thickness 300 feet), are Early and Middle Jurassic in age, respectively, as deduced from faunal evidence. Attitudes of these formations do not differ appreciably from those of the underlying Jurassic stratigraphic units. An allochthonous section, consisting of parts of the Brooks red and green conglomerate, and all of the Dennett Creek limestone and Big Hill wacke, was structurally emplaced by late Mesozoic (?) reverse faulting of regional importance. The Brooks red and green conglomerate of Early Jurassic age contains a variety of red, purple, and green colored volcanic clasts that were derived from a source presumably in the Seven Devils Volcanics. Clasts of vein quartz and chert are locally abundant and help to differentiate this thick conglomerate (maximum thickness more than 1,000 feet) from the older and thinner Cuddy Mountain red

conglomerate. Field relationships suggest that the Brooks red and green conglomerate may be a time-stratigraphic equivalent of the Thorsen formation. The Dennett Creek limestone is thin (maximum thickness 100 feet) and consists predominantly (95-98 percent) of interlocking and recrystallized carbonate anhedra. It overlies the Brooks red and green conglomerate and pinches out in the east part of the district. The Big Hill wacke is a thick (at least several thousand feet) assemblage of mostly wackes and arenites that overlie the limestone and is Early to Middle Jurassic in age.

The Late Triassic Seven Devils Volcanics and perhaps part of the Jurassic section were regionally metamorphosed to the greenschist grade during Jurassic time. Evidence for this metamorphism includes small amounts of minerals such as chlorite, actinolite, epidote, and albite in both country rocks and plutons.

At least part of the mineralization and alteration in the Mineral-Iron Mountain District is genetically related to the plutonic complex. Copper-molybdenum deposits (such as the Thorn Spring Prospect) are located within rocks of the plutonic complex and metallization is mainly fracture-controlled. Metallization on the Thorn Spring Prospect is associated sericite, dated at  $197 \pm$  m. y. by the K-Ar method, and potassium silicate alteration which is surrounded by argillic and propylitic alteration types. The types and zonal distribution of hydrothermal alteration assemblages are

related to changes in the  $K^+/H^+$  ratios and temperature gradients in the hydrothermal fluids. Skarn-type copper-zinc metallization (Iron Mountain Prospect) is confined to hornfelsed and hydrothermally altered metavolcanic and metavolcaniclastic lithologies adjacent to the plutonic complex. Massive, skarn-type deposits of iron oxides that contain traces of copper (Mortimer Mine) are present in calcareous country rocks. In contrast, pegmatitic segregations of quartz (Silica Mine) occur in the late-stage granodiorite (trondhjemite) phase of the pluton. Slightly younger epithermal deposits of lead-zinc-silver-copper are structurally localized by fractures and breccias, in silicic volcanic rocks, including ash flow tuffs, of Early Jurassic age in both the Mineral-Iron Mountain District and along a north-northeast trending, stratigraphically thin and near-continuous zone of metallization in western Idaho and eastern Oregon. Sulfide metallization along this zone is associated with a carbonate gangue. The strata-bound fissure-type mineralization is attributed to hydrothermal activity, probably fumarolic, that occurred shortly after deposition of the silicic volcanic rocks. Gypsum deposits in the Bayhorse and Mineral-Iron Mountain Districts are tentatively related to this hydrothermal event. They formed by replacement of limestone by anhydrite, with subsequent surficial hydration to form gypsum.

Geologic and geochemical evidence, including proximity to

major prospects, pegmatitic segregations of quartz and tourmaline, concordant magmatic and hydrothermal events at approximately 200 m. y., and sulfur isotope studies that indicate a "magmatic" (0 permil) source for the sulfur, collectively suggest that the porphyritic granodiorite and aplites were the source(s) of the porphyry-type and skarn-type metallization. The regional vein-type deposits are slightly younger, but also have a magmatic hydrothermal origin as evidenced by the wide variation (+14.7 to -26.2 permil) of mostly negative  $S^{34}$  values.

Little is known concerning the geologic history of the Mineral-Iron Mountain District from Late Jurassic to Middle Miocene because rocks representative of that time interval are not present in the area. Basalts of the Columbia River Group were extruded from numerous fissures during late Miocene through early Pliocene time and lapped up against and finally covered the Iron Mountain Complex that formed a topographic high. The present configuration of the Hitt Mountains, including the Mineral-Iron Mountain District, is attributable to Late Tertiary and possibly Quaternary block-faulting and recent erosion.

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## APPENDIX

## APPENDIX I

Laboratory Techniques

Modal analyses of approximately 246 thin sections were obtained. Selected samples, including all modal analyses listed in the text, were point counted (500 points) using a mechanical stage. Visual analyses were made on the other thin sections by estimating mineral percentages at approximately 15 selected sites per slide. Plagioclase feldspar compositions were determined using extinction angles on polysynthetic twins.

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

Studies of sulfide and gangue minerals were conducted on ten polish sections prepared by Mr. Ruperto Laniz, Stanford University.

X-ray diffraction studies of phyllosilicates were performed on a Norelco diffractometer at the Department of Geology, Oregon State University.  $\text{Cu}_{\text{K}\alpha}$  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. Clay samples were prepared as smears on glass slides. 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;

kaolin group minerals are clay-size, colorless, weakly birefringent and low in relief; chlorite was distinguished by its green color in plane light and anomalous blue interference colors. X-ray diffraction results did not contradict mineral identifications based on the criteria listed above.

Whole-rock chemical analyses for  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , FeO (total iron), CaO,  $\text{K}_2\text{O}$ , and  $\text{TiO}_2$  were mostly done by the X-ray fluorescence technique at Oregon State University. The rock powders were ignited and fused with anhydrous lithium tetraborate flux and cast into buttons. Polished faces of these buttons were analyzed using a Cr target X-ray source with appropriate analyzing crystals and detection systems. Most analyses for Mg and Na were done on a model 103 Perkin-Elmer atomic absorption spectrophotometer by Dr. E. M. Taylor. Analytical accuracy (1 $\sigma$ ) estimated for analyses on U.S. Geological Survey rock standards includes the following:

<u>Oxide</u>		<u>Accuracy</u>	
$\text{SiO}_2$	wt. %	$\pm 0.25$	wt. %
$\text{Al}_2\text{O}_3$	wt. %	0.25	wt. %
FeO	wt. %	0.05	wt. %
CaO	wt. %	0.05	wt. %
MgO	wt. %	0.1	wt. %
$\text{Na}_2\text{O}$	wt. %	0.1	wt. %

<u>Oxide</u>		<u>Accuracy</u>	
K <sub>2</sub> O	wt. %	0.025	wt. %
TiO <sub>2</sub>	wt. %	0.025	wt. %

Selected samples from the plutonic complex (samples N-4, N-48, N-54, N-57, and N-58-c) were analyzed for the 12 major oxides by the wet-chemical method by Dr. K. Aoki, Tohoku University, Japan. Trace element analyses were done by Rocky Mountain Geochemical Corporation. Copper, lead, zinc, and silver were determined by atomic absorption, and molybdenum was determined colorimetrically.

Specific gravities for samples from the plutonic complex were measured on a jolly balance (accuracy - 0.018 units - 10).

Stable isotope determinations, particularly those of sulfur, were performed in the Laboratory of Isotope Geology at the University of Utah under the direction of Professor M. L. Jensen. Several isotope determinations, including those of sulfur, oxygen, and carbon, were also performed in the Isotope Branch of the U. S. Geological Survey, Denver, Colorado.

K-Ar age determinations were carried out by Dr. Richard L. Armstrong and Dr. Donald J. Parker at Yale University and by the Geochron Laboratories Division of Krueger Enterprises, Inc., Cambridge, Massachusetts.