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Title: GEOLOGY AND MINERAL DEPOSITS OF THE BOHEMIA MINING DISTRICT, LANE COUNTY, OREGON

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The Bohemia District is located in the Western Cascade Range, Lane County, Oregon. Over one million dollars worth of metals have been produced from mines of this area since 1872, making it one of the most important districts of the Cascades.

Bedrock consists of a portion of the Oligocene-Miocene Little Butte Volcanic Series, and is composed principally of a thick section of pyroclastic tuffs overlain by massive interstratified flows of andesite and basalt. Other volcanic lithologies include flows of dacite porphyry and a multi-lithic breccia. Folds of small amplitudes and low angle unconformities of local distribution are widespread throughout the volcanic sequence and are interpreted to have formed by gentle deformation related to shallow subvolcanic magmatism.

Felsic plutons of probable Miocene age intrude the volcanic pile and there are over 40 small plugs in addition to the Champion Stock. The plugs are predominantly quartz diorites, whereas the composite Champion Stock contains granodiorite, quartz monzonite, and felsic aplite.

Vein-type mineralization is widespread in both the volcanic and plutonic rocks of the district. Although gold has been the most important metal, the deposits are dominated by zinc, lead and copper that occur in veins containing chiefly quartz, carbonates, sphalerite, galena, chalcopyrite and pyrite. The veins have two principal orientations; the dominant vein set trends N. 65° W. and the secondary cross-veins trend N. 20° E.

Contemporaneous with vein mineralization was the formation of at least eight breccia pipes. These bodies are roughly cylindrical in shape, vertically oriented, and vary from 3 m to over 100 m in diameter. The constituent clasts are derived from the nearby country rocks and range from 1 mm to 0.5 m in diameter. The breccia fragments and surrounding country rock have been intensely altered to a quartz-sericite$\pm$tourmaline assemblage. An admixture of quartz and tourmaline cements the breccias. Because the pipes grade upward into shatter breccias of highly fractured rock with little displacement, they are interpreted to have originated by collapse.

Low temperature propylitic alteration is widespread throughout the district and affects both volcanic and plutonic lithologies. Smaller zones of higher rank quartz-sericite and potassic alteration are localized in areas of structural weakness, such as breccias, and shear and fracture zones.

Geochemical abundances of trace elements in rock samples indicate that the district is zoned with respect to base metals. Anomalously high concentrations of copper, zinc, and lead are progressively encountered from east to west across the district. The molybdenum anomaly is coincident with that of copper, and these are roughly centered upon the zone of potassic alteration.

Hydrothermal alteration and mineralization of the district is related to the pluton. Evidence for such a genetic relationship includes the close association of all Cascades mineral districts with felsic intrusions, structural features related to these intrusions, and chemical and mineral zonations within the district. Geologic and geochemical evidence that includes alteration patterns, fluid inclusions, breccia pipes, and mineral and trace element zonations, collectively suggest that only the highest levels of the hydrothermal system are exposed, and that it is possible that porphyry-type mineralization is present at depth.

Geology and Mineral Deposits of the
Bohemia Mining District,
Lane County, Oregon

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF PLATES

GEOLOGY AND MINERAL DEPOSITS OF THE BOHEMIA MINING DISTRICT, LANE COUNTY, OREGON

INTRODUCTION

The Bohemia Mining District is located in the Western Cascade Range of Oregon, about 35 miles southeast of Cottage Grove. The district is one of the largest and most productive of the mining areas of the Western Cascades, and is best known for its production of gold from vein-type deposits. Although the district was discovered in the 1860's, significant production did not begin until the early 1890's. Mining activity has been erratic since World War II and at present is limited to a few "recreational" miners.

Location and Accessibility

The Bohemia Mining District is situated in the Umpqua National Forest. The most productive part of the district, in terms of metals, lies on the divide between the Willamette and Umpqua drainage systems. The thesis area comprises slightly less than nine square miles and includes secs. 1, 2, 11, 12, 13, and 14 of T. 23 S., R. 1 E. and secs. 6, 7, and 18 of T. 23 S., R. 2 E.

The area is readily accessible from Cottage Grove via the Row River road which is paved as far as Diston. Within the area,

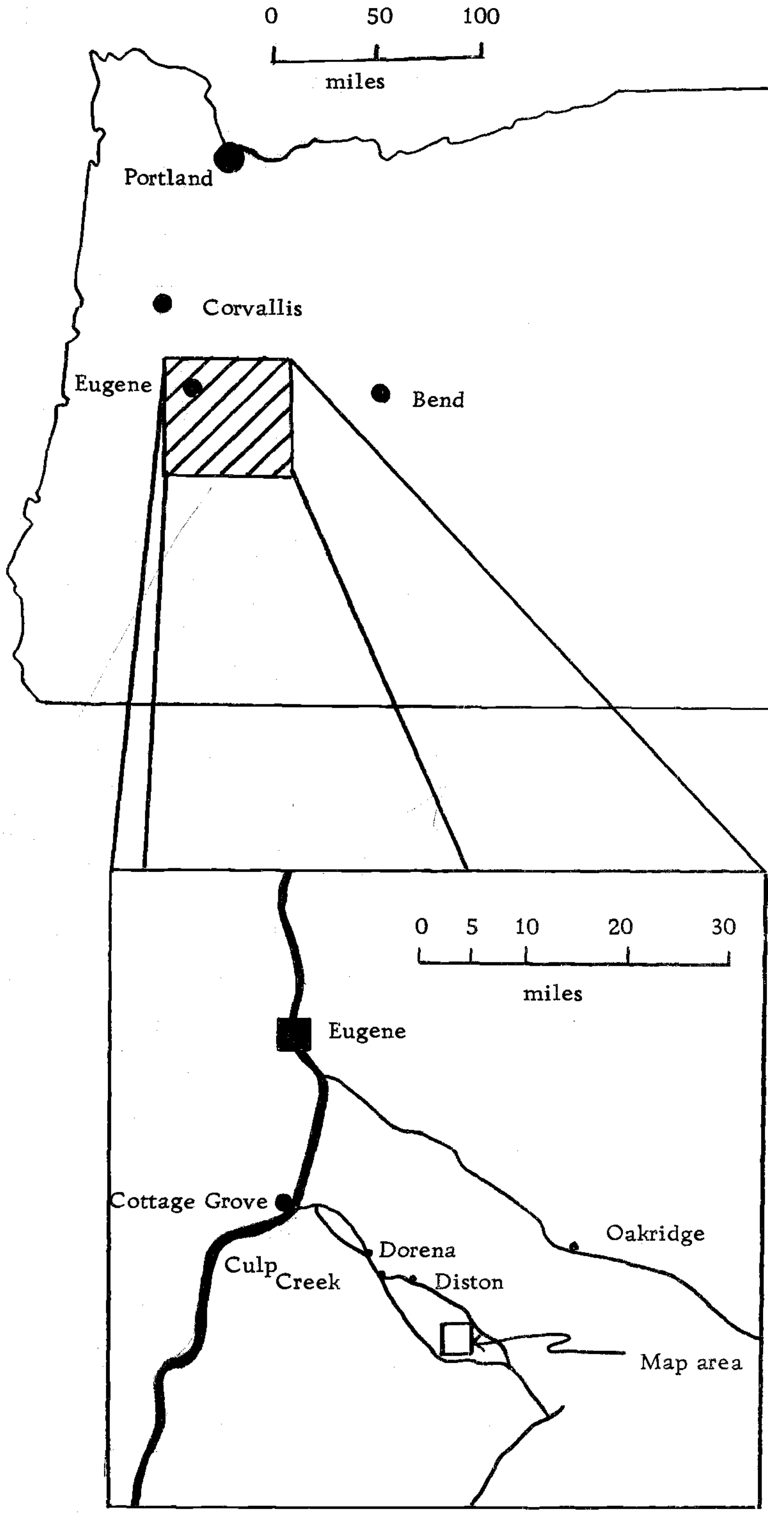

Figure 1. Index map of the thesis area.

movement is facilitated by a network of forest service roads, jeep trails and footpaths.

Topography, Climate and Vegetation

The Bohemia District is in a maturely dissected portion of the Western Cascade physiographic province. Narrow ridges and deep valleys radiate outward from the central part of the area, and steep forested slopes are characteristic. The peaks are the highest in the central part of the Western Cascades, altitudes ranging from 5987 ft. on Bohemia Mountain and 5450 ft. on Grizzly Mountain to less than 3500 ft. in the stream valleys of adjacent lowlands.

Precipitation averages 70 inches per year and considerable snowfall accumulates on the peaks and higher areas. Summer temperatures range from highs of 70-90^{o} F. to lows of 40-50^{o} F.

Coniferous forests cover much of the area, although the highest peaks are above the timberline. The forests are comprised of Douglas fir, true firs, Cedar, and Hemlock. In addition to these, rare individual stands of Sugar Pine occur in the southern portion of the area. Dense underbrush consists primarily of rhododendron, vine maple and alder.

Previous Geologic Investigations

The Bohemia district has been the most productive of the mining districts of the Cascades, and for this reason it has received much attention. Geologic literature concerning the district dates from Diller's work in the early 1900's to as recent as 1968. The most comprehensive reference is the U.S.G.S. Bulletin 893 by Callaghan and Buddington (1938). This work is an excellent source of background information concerning both the geology of the district and of the mines, but it is outdated in terms of modern concepts of metallogenesis.

The most recent work is by Brooks and Ramp (1968), a report that deals only briefly with the geology of the area, but which concentrates on the operations of the individual mines, their history and production. Although this is the most recent publication concerning the district, it presents little new information as it is for the most part a review and compilation of earlier work.

Two theses have been conducted in the area which are pertinent to this investigation. Bales (1951) did a reconnaissance study of the volcanic rocks to the northwest. Of more immediate interest is a study by Lutton (1962) of the geology and mineral deposits of the Bohemia district. His thesis covered an area of twenty-five square miles, which represents a major part of the district. Although no aspect of geology was neglected, much of Lutton's effort was directed to the volcanic stratigraphy and vein deposits. His work on the mineralization and hydrothermal alteration was of a broad scale and somewhat sketchy. In addition, the genesis of the mineral deposits was interpreted in terms of traditional concepts that have since become outmoded.

Purpose of the Investigation

The purpose of this investigation was primarily to relate the mineral deposits and alteration zones of the district to other geologic features such as faults, folds, and intrusives, and to determine the genesis of the mineralization. This broad goal was accomplished by: (1) mapping the lithologies and structures; (2) determining the relative ages and compositions of the intrusions and relating them to other features in the area; and (3) examining the types and distribution of alteration and mineralization in the area.

Methods

Eight weeks were spent during the summer of 1976 doing field work. Mapping was done on the U.S. Geological Survey, Fairview Peak, Oregon, quadrangle map enlarged to a scale of 1:6000. Fifty-two thin sections were examined and modal analyses of the representative samples were obtained with a mechanical stage and point counter. In addition, over 30 samples of intrusive and flow rocks were analyzed for trace elements and major oxide chemistry.

REGIONAL SETTING

The Cascade Range of Oregon consists primarily of Cenozoic volcanics, which may be divided into two major sequences of older and younger rocks (Figure 2). The younger sequence is late Pliocene to Recent in age, and forms the rocks of the High Cascade Range. This range is a linear plateau of undeformed and unaltered basalt and andesite flows capped by overlapping shield volcanoes, stratovolcanoes and cinder cones. Volcanics of the High Cascades occupy and fill a grabenlike structure (Taylor, 1976, personal communication), but some of the flows spill over into valleys of the Western Cascade Range, the eroded remnants of which form benches and mesas.

The older sequence is composed of mildly deformed and partially altered andesite and basalt flows of late Eocene to late Miocene age. All of the gold and base metal mining districts of the Cascades are located in this highly dissected north-trending terrain that lies to the west of the High Cascades. Bedrock of the Western Cascades has been divided into three major units which in order of decreasing age are the Colestin Formation, the Little Butte Volcanic Series and the Sardine Formation (Peck, 1960).

The Colestin Formation, of late Eocene age, is composed of clastic volcanic and andesitic flow rocks, which crop out

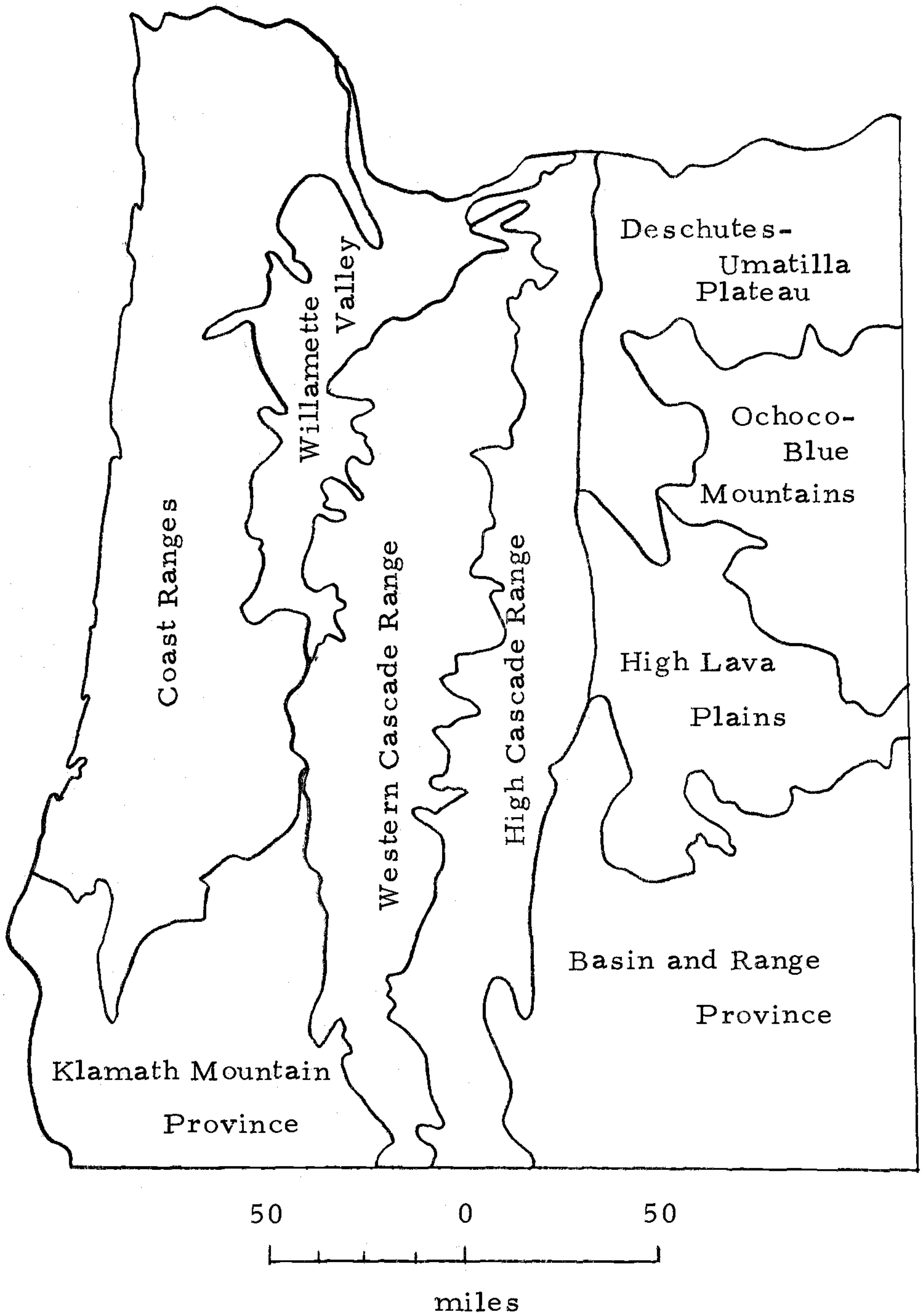

Figure 2. Physiographic regions in Western Oregon (after Peck and others, 1964).

discontinuously along the western margin of the Western Cascade Range. The Calapooyia and parts of the Fisher formations are also found in this area, and they are of similar age and lithology (Wells and Waters, 1934; Vokes and others, 1951).

The Little Butte Volcanic Series is composed of pyroclastics and flows of early or middle Oligocene to middle Miocene age. They unconformably overlie the Colestin formation. The series has a maximum thickness of 15,000 ft., but generally ranges between 5,000 to 10,000 ft. in thickness (Peck and others, 1964). These volcanics make up the bulk of the Western Cascade Range south of the McKenzie River. The Little Butte Volcanic Series typically consists of a lower sequence of pyroclastics, flows, flow breccias and coarse agglomerates, and of an upper sequence of predominantly fine-grained siliceous tuffs (Wells, 1956). The Mehama Volcanics and the lower portions of the Breitenbush and Sardine Series of Thayer (1939) are included in the upper Little Butte Volcanic Series, as are the Molalla and Eagle Creek Formations described by Peck (1960). The Fisher Formation of the foothills is probably gradational into the Little Butte Volcanic Series. It is believed to be a finer-grained fluvial equivalent, whereas the interfingering Eugene and Scappoose Formations of the southern Willamette Valley are the marine equivalents (Peck, 1960).

Radiometric age determinations have shown that at one locality, the uppermost Little Butte Volcanic Series and the lowermost Sardine Formation are essentially equivalent in age (McBirney and others, 1974). In addition, McBirney suggests that Cascade volcanism occurred as a series of pulses 1 to 2 m.y. in duration, that were separated by periods of relative magmatic quiescence up to 5 m.y. in duration. Should this interpretation be correct, the Little Butte Volcanic Series thus is comprised of a number of volcanic pulses.

The Sardine Formation is of middle to upper Miocene age. It has been defined as including the Fern Ridge Tuffs, the upper part of the Breitenbush Series, and most of the Sardine Series. All of these units consist predominantly of hypersthene andesite flows with minor amounts of associated tuffs and breccias (Peck, 1960).

The Sardine Formation overlies the Little Butte Volcanic Series with an angular unconformity over much of the Western Cascades. At one location a few miles south of the McKenzie River, the base of the Sardine has up to 1,000 ft. of relief. Moreover, it is estimated that as much as 5,000 ft. of the Little Butte Volcanic Series was eroded prior to deposition of the Sardine Formation in the Calapooyia Mountains (Peck and others, 1964).

Most of the Western Cascade Range north of the North Santiam River is covered by the Sardine Formation that averages about 3,000 ft. in thickness. Between the North Santiam and McKenzie Rivers, this formation is restricted to the axis of the Sardine Syncline. Farther to the south, the Sardine Formation is limited to discontinuous outcrops along the western margin of the High Cascades (Peck, 1960).

The Western Cascade Range is structurally dominated by four northwestward trending folds in the northern and central parts of the range. Folds in the southern part of this range are less prominent. The easterly dip of the strata in this part of the Western Cascades is reversed only locally across the crests of small folds (Peck, 1960). The folds were probably formed at several periods between late Eocene and late Miocene time. All formations older than Pliocene have been folded. At several localities the Sardine Formation has been less strongly deformed than the underlying Little Butte Volcanic Series, which indicates that deformation may have begun as early as Miocene time (Peck, 1960).

The major structural feature of the southern part of the Western Cascade Range is a series of northwest-trending faults. Only a few faults are known in the northern part of the range, but this feature may be caused by a lack of marker beds rather than to a lack of faults (Peck, 1960). In the mining districts of the Cascades, small mineralized faults and veins trend northwest with few exceptions (Callaghan and Buddington, 1938). The faults are possibly related to the northwest-trending strike slip fault zones of southeastern Oregon, which have been interpreted as being a result of the northward termination of Basin and Range extension in Oregon (Lawrence, 1976). The age of this structural event is not well known. The faults may be at least as young as Pliocene to Holocene in age because volcanic rocks of the High Cascades have been displaced. However, it is possible that the faults were formed as early as Miocene time (Peck, 1960; Lawrence, 1976).

Small intrusive bodies ranging from granite to basalt in composition cut the volcanic rocks of the Western Cascades. Peck (1960) has divided these intrusions into three groups consisting of medium grained rocks of dioritic to granitic composition, fine-grained mafic and intermediate rocks (basalts and andesites), and fine-grained felsic rocks (rhyodacites and dacites). The medium-grained granitic intrusions occur as plugs, dikes, and small stocks along north-trending belts. All of the stocks occur below altitudes of 4,000 ft., and most crop out at less than 3,000 ft. This preferred vertical distribution suggests that most stocks of the Western Cascades are roofed between 3,000 to 4,000 ft. (Peck, 1960).

The intrusive rocks range from late Eocene to late Miocene in age (Peck, 1960). They cut strata of the Colestin Formation, Little Butte Volcanic Series, and the Sardine Formation. Lead-alpha ages obtained from zircons have been used to date the Nimrod quartz monzonite, which intrudes the Little Butte Volcanic Series, at 35 $\pm$ 10 m.y. and the granodioritic Detroit Dam Stock, which intrudes the Sardine Formation, at 25 $\pm$ 10 m.y. (Peck, 1960).

VOLCANIC ROCKS

Little Butte Volcanic Series

Bedrock of the Bohemia district consists essentially of a volcanic pile belonging to a portion of the Little Butte Volcanic Series (Peck and others, 1964), which has been intruded by plugs and stocks of quartz diorite. The volcanics have been mapped as four different units; tuffs, multi-lithic breccia, massive flows of intermediate to mafic composition, and flows of dacite porphyry. Two distinct periods of volcanism have occurred within the district. Explosive pyroclastic volcanism was characteristic of the earlier period, with deposition primarily of lapilli tuffs, crystal-lithic tuffs, volcanic breccias, and minor flows. The later volcanic episode consisted of the extrusion of homogeneous andesite and basalt flows that were accompanied by minor pyroclastic material.

A significant period of volcanic quiescence occurred between the two episodes of volcanism, leading to the development of a highly dissected topography in the tuff units. Over one hundred feet of relief can be observed within a tuff unit on the north side of North Fairview Mountain. This erosion surface was subsequently filled and buried with the extrusion of later flows. The two units are disconformable to unconformable with a small angular discordance.

Pyroclastics

The lowermost stratigraphic units of the Bohemia District consist of tuffs. Because of the northeast regional dip, this rock-type crops out predominantly in the southern and western portions of the area mapped. Although normally found at lower elevations, exposures of the pyroclastics may extend up to altitudes of 5,200 ft. on the Champion Saddle. This is attributed to the development of a mature topography in the pyroclastics prior to the extrusion of the flows. The pyroclastics are most commonly light green in color, but other shades of green, grey, magenta and tan are not uncommon. Color is dependent on the intensity and type of alteration. Chlorite is the characteristic alteration product, but kaolinitic clays and oxides of iron are also common. Alteration of the pyroclastics tends to be significantly more intense than in adjacent flows as a consequence of the greater permeability afforded to aqueous solutions.

Lapilli tuffs are the most common form of pyroclastic rock. Individual lapilli usually range from 5 to 45 mm in diameter. However, complete gradations exist from crystal-lithic tuffs to volcanic breccias composed of blocks nearly a meter in diameter. The fragments tend to be very angular and irregular in form, and they are usually poorly sorted. In places, however, a crude gradational sorting is present.

Bedding is apparent on a small scale in some of the crystal-lithic and fine lapilli tuffs. It becomes less distinct and finally disappears with an increase in average size of the fragments. Crude layering on a scale of meters is prominent in some of the coarser tuffs and breccias. This is attributed to periods of quiescence between eruptions of the pyroclastics.

Fragments of carbonized wood are widespread throughout the pyroclastic rocks. In one instance, a charcoal log two feet in diameter was found in the SW 1/4 of the NW 1/4 of sec. 17, southeast of Grouse Mountain. This log is well-preserved with the original texture of the bark and the annual growth rings of the core readily identifiable. Substantial periods of volcanic quiescence amounting to at least several hundred years are implied by the presence of these large trees.

The pyroclastics have been deposited subaerially for the most part, although some of the tuffs may have been deposited in small lakes and streams. Leaf imprints have been reported in the tuffs from Elephant Mountain (Leabo, 1976, personal communication) and their presence supports an aqueous environment of deposition for these fine-grained rocks.

Petrography. The tuffs have all been highly altered. Both groundmass and lithic fragments have been recrystallized to a microcrystalline intergrowth of chlorite, clays and epidote.

Phenocrysts of both plagioclase feldspar and ferromagnesian minerals may be present. The feldspars may be fresh, but commonly they show variable alteration to sericite, epidote and carbonate. Almost without exception, the ferromagnesian minerals are completely altered to chlorite. Epidote frequently occurs as clots in the groundmass. Magnetite and secondary pyrite are commonly finely disseminated throughout the groundmass and within the lithic fragments.

Mafic Flows

The upper part of the volcanic sequence is composed predominantly of flows of basalt, andesite, and dacite porphyry, that are intercalated with minor lenses of tuff. The flows are usually porphyritic, and generally contain phenocrysts ranging between 5 and 20 percent by volume of the rock. Plagioclase feldspar is the most common phenocryst, although lessor amounts of augite, hornblende, and biotite may also be present. Although aphanitic the groundmass may exhibit a grainy texture.

For purposes of field mapping it was impractical to distinguish between the andesites and basalts because they are stratigraphically interbedded and they are chemically and mineralogically gradational into one another. Callaghan and Buddington (1938) have distinguished what they defined as a labradorite andesite, or basaltic andesite based on the classification of G. W. Tyrell (1926). These rocks have a felsic to mafic mineral ratio that is typical of andesites, but they contain very calcic plagioclase feldspars.

The flows are found predominantly at higher altitudes capping mountains and ridges, although they also occur at relatively low elevations in the northern part of the area. The distribution of the flows is partly attributable to the northeast-trending regional dip of all stratified lithologies in the area. The resistant flows form cliffs, whereas the less resistant tuffs are defined by relatively smooth slopes.

Where exposures are good, individual flows can be readily identified and they may be traced for distances of up to one-half mile. Flow boundaries are frequently accentuated by a thin layer of tuff or tuffaceous sediment that may range from several centimeters to 30 cm in thickness. These clastic interbeds are composed of fragments of devitrified glass with microlites, pumice, phenocrysts of plagioclase feldspar and pyroxene, and fragments of flow rock. Regardless of composition, all fragments are usually less than 1 cm in diameter. Well-brecciated flow tops were not observed. However, the upper parts of several flows appear to be composed of small angular fragments set in a matrix of compositionally identical material.

The thickness of individual flows varies from 3 to 15 m. Most are very local in extent and satisfactory marker beds could not be found anywhere in the area. Individual flows on Grouse and Bohemia Mountains, where exposures are excellent, could not be traced from one side of these mountains to the other.

There is an unusual flow rock that appears to be phaneritic at the base of the flow sequence on Grouse Mountain. This flow is actually porphyritic, and it contains up to 60 or 70 percent phenocrysts of plagioclase feldspar and augite. Many of the plagioclase feldspar phenocrysts appear to be red, the result of the infilling of micro-fractures with hematite.

Petrography. The flows of andesite and basalt are dominantly porphyritic. Non-porphyritic flows are rarely present. They contain euhedral phenocrysts of plagioclase feldspar and augite, and minor olivine, which invariably has been altered to serpentine, in certain basalt flows. The phenocrysts average 2 to 4 mm in length, and constitute between 5 and 30 percent of the host. Phenocrysts of plagioclase feldspar vary from andesine to labradorite (An_{35-65}) in composition, with labradorite being the most common variety. They typically are normally zoned. In general, the phenocrysts of plagioclase feldspar are unaltered, although small but variable amounts of sericite, carbonate and epidote may be localized in their cores. Phenocrysts of augite may be fresh, but more commonly they are partly to totally altered to chlorite and magnetite. Also present as phenocrysts is green biotite that has been weakly altered to chlorite. Hypersthene was not observed, although it may have been formerly present prior to alteration.

The groundmass of these porphyritic flows is aphanitic diabasic to pilotaxitic in texture. They are nearly holocrystalline, with devitrified glass representing only 3 to 7 percent of the groundmass. The remainder consists of plagioclase feldspar, augite, and magnetite, and related alteration products. Plagioclase feldspar is subhedral to nearly euhedral, and is generally 2 to 4 times larger than other minerals of the groundmass. This feldspar is probably less calcic than that occurring as phenocrysts. Pyroxene, as augite, occurs as anhedral crystals that are interstial to the feldspar. Microcrystalline euhedra of magnetite are commonly disseminated throughout the groundmass. Trace amounts of tourmaline, in the form of needles, are widespread as inclusions contained in plagioclase feldspar of the groundmass.

Dacite Porphyry Flows

The dacite porphyry flows are readily distinguished from the andesites by color, which ranges from tan to dark grey; groundmass material which has a cherty appearance; and the presence of well defined flow banding in the matrix that is accompanied by a lineation of the phenocrysts. Phenocrysts consist entirely of plagioclase feldspar, although some clots of chlorite may represent former phenocrysts of ferromagnesian minerals.

The most unusual of the dacite porphyry flows is the mass located at the southern boundary of the map area on Jackass Butte. This body is about 450 m in diameter and nearly a hundred meters in thickness. It was interpreted as being a dome by Lutton (1962), and the writer concurs.

A long narrow protuberance of dacite porphyry, over 550 m long and with a vertical range of nearly 250 m, projects to the northeast off of the main body at Jackass Butte. Flow banding generally dips gently eastward, indicating horizontal movement. However, the great thickness and restricted width of this mass suggests that it is probably a dike.

Petrography. The flows of dacite porphyry consist of plagioclase feldspar phenocrysts contained in a groundmass of devitrified glass, chlorite and magnetite. The euhedral feldspar phenocrysts average 2 to 4 mm in length and are compositionally sodic andesine (An_{35-40}). They are strongly altered to sericite and carbonate, along with trace quantities of epidote and uncertain amounts of kaolinite. Up to one-third of individual feldspar phenocrysts may have been recrystallized in this way. They constitute 10 to 20 percent of the rock with the remainder being a groundmass that consists predominantly of equidimensional cryptocrystalline patches of uniform optical extinction. The individual patches are about 0.25 mm in diameter. Flow banding is continuous through these patches, which indicates that the patches are a post-solidification feature. Magnetite constitutes about 2 percent of the rock and occurs disseminated throughout the groundmass. Magnetite crystals are euhedral to subhedral and are generally microcrystalline in size. They may be as large as 0.5 mm in diameter. Chlorite is also disseminated throughout the groundmass, but in places is present as clots which may represent altered phenocrysts of ferromagnesian minerals.

Rhyolites

Several small masses of sperulitic material, usually less than 50 m in diameter, occur in the area. These rocks consist of sperules ranging from 0.1 to 1.5 cm in diameter that are composed of a white, highly altered aphanitic material. The sperules may or may not be hollow. Interstices are filled with a chlorite-rich material. According to Lutton (1962) these rocks are rhyolites.

Multi-lithic Breccia

A multi-lithic breccia of uncertain origin is located on the western side of Fairview Peak and extends north as far as North

Fairview Mountain. It is composed of angular to rounded fragments from 2 to 30 cm in diameter. The fragments constitute greater than 60 percent of the breccia. They consist of andesitic flow rock which is massive to highly vesicular in texture. Vesicules, where present, are usually filled with epidote or chlorite. The groundmass is similar, both compositionally and texturally, to the fragments. Thus, the fragments are easily recognized only on weathered surfaces except where they contain vesicles.

Callaghan and Buddington (1938) have suggested that this rock may be a flow breccia. I disagree with their interpretation because of the apparent large thickness of the unit, which is well over 50 m. The breccia has also been interpreted as representing a volcanic vent facies (Lutton, 1962). However, the presence of angular to rounded and randomly mixed multi-lithic fragments suggests that this breccia could be a lahar.

Related Feeder Dikes and Subvolcanic Intrusions

Dikes and other small irregularly shaped bodies composed of andesite, basalt, or dacite porphyry occur throughout the area. These intrusives are believed to have been feeders for the volcanic flows and tuffs in the area. As such, these intrusives were contemporaneous or slightly later than the volcanics into which they are intruded.

These subvolcanic intrusions constitute but a small percentage of the rocks in the area. However, there are probably many more than noted because of difficulties in the recognition of these bodies. The feeders are probably sufficient in number and size to account for the volume of volcanic material exposed in the district.

Basalt-Andesite Intrusions. Intrusions of basalt and andesite usually take the form of dikes. These bodies served as feeders for the flows of the upper volcanic unit, and they are compositionally and texturally similar to the flows. For this reason the dikes were generally not recognized as cutting the flows unless they were well exposed. Dikes were most often observed cutting the tuffs, because they form an obvious color and textural contrast with the host. The dikes range from 2 to 8 m in thickness. They are usually vertical and commonly oriented N. 60 W. or N. 60 E., although other orientations were observed.

Irregularly shaped mafic intrusive bodies are also present. One such body northeast of the Musick mine (in sed. 14) could be distinguished from the flow rocks into which it was intruded only on the basis of its irregular crosscutting contacts. A similar mass was observed northeast of Fairview Peak intruding flows. Again, discordant contacts were the primary reason for its recognition, although it also contained angular to subrounded xenoliths of flow rock. The exact size and shape of these intrusions are uncertain because of the paucity of outcrop, but all are probably under 60 m in diameter.

Dacite Porphyry Plugs. A single intrusion of dacite porphyry was recognized north of the Champion Saddle in sec. 12. Except for the absence of flow banding, this intrusion is texturally and compositionally identical to the dacite porphyry flow on Jackass Butte. Although contacts were not observed, this mass is inferred to be an intrusive on the basis of its large vertical range relative to its limited horizontal dimensions. In addition to this body, Lutton (1962) identified several other dacite porphyry intrusions in the district which were not observed by the writer.

Chemistry of the Volcanics

Thirteen samples of flows and their related feeders were analyzed for major oxide constituents. The results are summarized in Table 1. A modified chemical classification scheme from MacKenzie and Chappell (1972) has been adopted to portray these volcanics which range from basalt to dacite in composition (Figure 3). More than one-third of the samples plot in the low-silica andesite field, and nearly one-quarter in the basalt field. The presence of these low-silica andesites further justifies the labradorite andesite designation of Callaghan and Buddington (1938).

The chemistry of these volcanic rocks do not exhibit any patterns of spatial or temporal distribution. However, certain

Table 1. Chemistry of the Bohemia Volcanics.

	1 8-2	2 1-13	3 1-14	4 1-14b	5 1-14c	6 1-14d	7 1-15	8 5-16	9 3-17	10 3-18	11 2-21	12 2-25	13 2-29
SiO_2	54.3	49.2	56.3	55.5	53.7	55.5	71.5	49.6	55.8	59.7	49.5	71.6	53.4
TiO_2	1.20	1.60	1.65	1.15	1.15	1.70	.45	1.25	1.30	1.30	1.30	.55	1.0
Al_2O_3	16.9	19.2	15.8	16.4	16.2	15.4	14.6	17.9	16.4	15.1	17.2	15.1	15.4
FeO	9.5	11.3	10.0	9.3	9.6	3.8	3.5	10.0	8.3	10.5	9.8	3.5	9.8
MgO	5.6	3.8	4.6	6.0	6.8	4.6	.9	7.5	4.6	3.6	7.3	.7	8.1
CaO	8.8	10.4	7.6	8.2	8.2	7.2	2.1	10.2	8.9	4.8	9.3	2.0	7.7
Na_2O	2.8	2.8	3.4	3.0	3.4	3.5	4.5	2.3	2.7	3.7	2.8	4.2	2.6
K_2O	.65	.45	1.35	1.05	.90	1.55	2.55	.55	1.30	.75	.40	2.40	2.35
Total	99.75	98.75	100.70	100.60	99.95	~~98.25~~ 93.25	100.10	99.30	99.30	99.45	97.60	~~100.10~~ 100.05	100.35

Table 1. Continued

Sample Number	Rock Type	Location
8-2	Andesite porphyry flow	NE1/4, SE1/4, sec. 12
1-13	Basalt porphyry flow	NE1/4, SW1/4, sec. 18
1-14	Andesite flow	NE1/4, SW1/4, sec. 14
1-14B	Andesite flow	NE1/4, SW1/4, sec. 14
1-14C	Andesite flow	NE1/4, SW1/4, sec. 14
1-14D	Andesite flow	NE1/4, SW1/4, sec. 14
1-15	Dacite porphyry flow	SE1/4, SE1/4, sec. 14
5-16	Basalt porphyry flow	SW1/4, SW1/4, sec. 2
3-17	Andesite porphyry flow	NE1/4, SE1/4, sec. 13
3-18	Andesite flow	NE1/4, SW1/4, sec. 1
2-21	Basalt porphyry flow	SW1/4, SE1/4, sec. 11
2-25	Dacite porphyry intrusion	SE1/4, SW1/4, sec. 12
2-29	Shoshonite porphyry dike	SW1/4, NE1/4, sec. 14

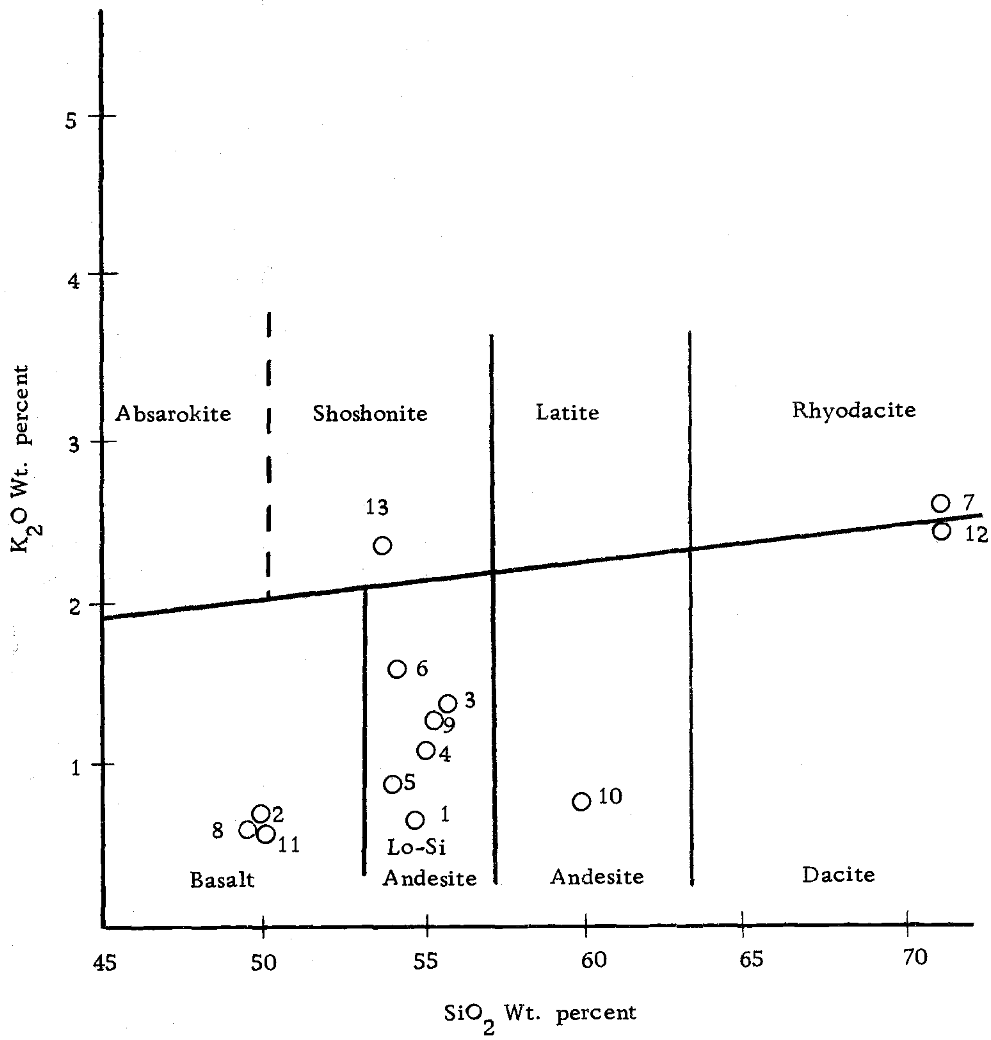

Figure 3. Chemical classification of volcanic rocks from the Bohemia district (diagram modified after Mackenzie and Chappell, 1976).

correlations based on stratigraphic position can be made. Two of the basalt samples are from flows at the tops of Fairview Peak and Elephant Mountain. These flows are similar texturally, chemically and mineralogically, and are at roughly the same stratigraphic position. It is possible that the flows sampled are dissected portions of a single flow, or were erupted separately from different feeders having a common magma source.

Four successive flows from approximately the same stratigraphic position on the south side of Bohemia Mountain were sampled and analyzed (the 1-14 series). On the basis of the chemical analyses, these flows are classified as low silica andesites. Although these four chemical analyses are quite uniform, they lack systematic variations of the components, or show only vague imperfect trends at best. These chemical data suggest that the four flows were possibly derived from a common magma chamber which was not chemically homogeneous throughout.

Any of several possible interpretations might explain the presence of andesites and basalts at approximately the same stratigraphic level. These might include: (1) contemporaneous subvolcanic magma sources that varied in composition and gave rise to interstratified flows of different compositions; (2) a single flow sequence dissected by erosion with the topographic lows subsequently filled with lavas of another composition; and (3) two magma types erupted at different levels and times that were juxtaposed by later faulting.

Analyses of two dacite porphyries, one from the flow on Jackass Butte and the other from a subvolcanic intrusive north of the Champion Saddle (samples 1-15, 2-25), are chemically identical. Relative to the mafic volcanics, the dacites are characterized by high contents of SiO_2, K_2O, and Na_2O and low contents of FeO, TiO_2, CaO, and MgO. Plotted on the chemical classification chart (Figure 3), these samples straddle the rhyodacite-dacite boundary. These chemical, textural and mineralogical similarities suggest that the dacite porphyries were derived from a common source at the same time, or were a common end-product of magmatic differentiation of separate magma sources.

FELSIC INTRUSIVE ROCKS

The emplacement of felsic intrusions is the last recognizable magmatic event to occur in the area. Compositionally, these intrusions range from quartz diorite to quartz monzonite. If volcanic activity was associated with this intrusive event, it occurred at a much higher level and the lithic evidence for it has since been eroded away. Lutton (1962) estimated that the intrusions were emplaced at a depth of about 1.5 to 2 km.

There are over forty separate felsic intrusions in the map area. They usually form small circular plugs and elongate bodies, generally under 200 m in diameter. These small intrusions are volumetrically minor compared to the much larger Champion Stock[1] in the northern part of the area.

Although the small intrusions are widespread throughout the district, their distribution displays a definite spatial pattern. A broad belt of small intrusions extends to the south from the Champion Stock to the Champion Saddle. There it splits into a narrow linear belt trending S. 45 W. and possibly another vague belt trending slightly south of east (Plate 1).

The small intrusive bodies are dominantly porphyritic quartz diorites, although a cluster of three intrusions southeast of

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[1] Also known as the Bohemia Stock.

Bohemia Mountain are finely crystalline equigranular granodiorites. The bulk of the Champion Stock is granodiorite, but varies inward to a quartz monzonite in the central part of the stock.

Small Intrusions and Plugs

Quartz Diorite Porphyry Intrusions

The quartz diorite porphyries contain 40 to 70 percent phenocrysts consisting predominantly of plagioclase feldspar, with lesser amounts of ferromagnesian minerals, and minor quartz. The phenocrysts are contained in an aphanitic groundmass. Magnetite is a common constituent, and all of the intrusions are strongly magnetic. Color varies from light to dark gray, depending on the ratio of plagioclase feldspar to ferromagnesian minerals, and on the degree of propylitic alteration.

These intrusions are small, generally under 200 m, although several of the larger ones have a long dimension which exceeds 300 m. Where contacts can be observed, they are generally steep and dipping away from the center of the intrusion. Some of the larger intrusions exhibit a vertical range of over 120 m, and one on the ridge northeast of North Fairview Mountain is exposed over a vertical range of more than 200 m. In three dimensions, these intrusions appear to crudely approximate steep-sided cones which have their apices pointing upwards.

Contact effects are typically lacking. Evidence of either chilled margins of the intrusions or of significant thermal contact metamorphism of the adjacent country rock is conspiciously absent.

Xenoliths of andesite are common throughout the intrusions, and in places they are so abundant that the rock could be called an intrusion breccia. The xenoliths are generally rounded or sub-rounded, and range from a few centimeters to two meters in diameter. Some xenoliths are nearly totally recrystallized, and are identifiable only as a concentration or clot of ferromagnesian minerals having diffuse borders. However, digestion to this degree is rare. Most xenoliths show only a slightly coarser grain size, along with the possible growth of plagioclase phenocrysts relative to the host volcanic rocks.

Several small dikes of quartz diorite porphyry project out from an intrusive body located on the ridge northeast of Fairview Peak. They are approximately 25 cm wide and appear to have been emplaced by forceful injection into pre-existing joints.

Petrography. The quartz diorites are hypidiomorphic-porphyritic. Phenocrysts are chiefly plagioclase feldspar, along with subordinate amounts of augite, hypersthene and hornblende and rarely quartz. The phenocrysts of plagioclase feldspar tend to be somewhat larger than those of other minerals. They range from

2 to 7 mm in length and constitute 40 to 70 percent of the rock.

The major mineral phases of the quartz diorite porphyries are plagioclase feldspar (46 to 67 percent, including alteration products); ferromagnesian minerals (9 to 22 percent); magnetite (2 to 5 percent); and orthoclase (less than 2 percent). The ferromagnesian minerals include augite, hypersthene, hornblende, biotite, and chlorite. Tourmaline is invariably present as a trace constituent of the groundmass, and the accessory minerals include apatite, sphene, and zircon.

Propylitic alteration of these intrusions ranges from weak to moderately intense. Plagioclase feldspar is replaced by an assemblage of epidote, sericite, albite and carbonate. The ferromagnesian minerals have been altered predominantly to chlorite, magnetite, and rarely epidote. Modal quartz is highest in rocks that have undergone the most intense alteration.

The plagioclase feldspar varies from a calcic oligoclase to calcic andesine (An_{28-48}). It is present as euhedral to subhedral laths. The phenocrysts are normally zoned, but the groundmass plagioclase feldspar is not. Alteration to sericite, where present, is usually pervasive, although it may also occur selectively along certain compositional zones. Alteration to epidote and carbonate shows a slight preference for the more calcic cores of the feldspars.

With the exception of rare phenocrysts, quartz is generally present as interstial anhedra. The phenocrysts are pitted and embayed, and thus indicate partial resorption. Intrusions that contain potassium feldspar also have graphic intergrowths of quartz and orthoclase.

Orthoclase is almost totally lacking in most of these intrusions. Where present, the orthoclase is volumetrically minor, and it occurs either as intergrowths with quartz, or as inter anhedra.

Augite is the most abundant of the ferromagnesian minerals, and it may be accompanied by lesser quantities of biotite, hornblende and rarely hypersthene. Hornblende is the dominant ferromagnesian mineral in a few intrusions. In most intrusions, hornblende is either rare or lacking and hypersthene is present only as altered relicts. As phenocrysts, these minerals are subhedral to euhedral, although they are anhedral to subhedral in the groundmass, and they range from fresh to totally altered, often within the same thin-section. The complete alteration of ferromagnesian minerals in some samples forms a chlorite pseudomorph having a core of epidote.

Magnetite occurs as microcrystalline euhedra and subhedra disseminated in the groundmass. It is also commonly present in intergrowths of chlorite which represent the site of former ferromagnesian minerals.

Granodiorite Intrusions

Three small intrusions of granodiorite were identified southeast of Bohemia Mountain. They range from 40 to 75 m in diameter. Size, shape and other general features are similar to those of the quartz diorite porphyry intrusions previously discussed. These intrusions are unusual in that they are finely crystalline and equigranular.

Petrography. The granodiorites are finely crystalline hypdiomorphic-granular in texture. The major constituents are plagioclase feldspar (40 percent); quartz (18 percent); orthoclase (13 percent); ferromagnesian minerals (24 percent); and magnetite (4 percent). The ferromagnesian minerals consist of augite, its alteration products, and minor biotite.

The plagioclase feldspar is oligoclase, An_{27-29}. Both the plagioclase and the augite occur as stubby euhedral to subhedral crystals. The plagioclase feldspar is normally unaltered, and only minor amounts of epidote, sericite, and carbonate are present as replacements. Both augite and biotite are altered to chlorite. The interstices between the euhedral crystals are filled with anhedra of orthoclase, quartz, augite and chlorite, and microcrystalline euhedral magnetite. In some places optically continuous micrographic intergrowths of quartz and orthoclase are found completely surrounding the euhedra of plagioclase feldspar.

Lutton (1962) identified these intrusions as diorites, for which they could easily be mistaken in the field. Thin-sections stained for potassium feldspar and major oxide chemistry both collectively indicate that these rocks are compositionally more similar to granodiorites than to diorites.

Champion Stock

The Champion Stock is composed predominantly of granodiorite. The stock itself actually consists of two relatively large intrusive masses. One is located in sec. 1 of the map area and extends north into sec. 36. The other lies three quarters of a mile farther north and extends as far as Brice Creek. The following discussion is concerned primarily with the body in sec. 1.

Within the map area the Champion Stock is generally confined to the lower elevations of valley floors. The stock has a nearly horizontal roof at slightly above the 3200 ft. elevation contour. This apparently flat-topped contact gives the stock an irregular outline to its surficial distribution. The western margin of the stock is interpreted to be steeply dipping (Buddington and Callaghan, 1936) because the contact is independent of topography and because of the paucity of intrusive plugs west of this contact.

An apophysis extends upward more than 800 ft. across a spur of the Noonday Ridge, along the boundary between secs. 1 and 6. Most of the small intrusions in this area probably coalesce at depth to form a larger body. The apophysis and surrounding country rock have been intensely altered to clays and sericite. The apophysis presumably acted as a channel for upward migrating fluids which were exsolved at depth from the larger crystallizing magma chamber (Lutton, 1962).

Contact Alteration

Hydrothermal alteration is intense along the southern margin of the stock where it may extend outward from the contact a hundred or more meters; especially where the intrusive contact is inferred to be gently dipping outward. The marginal rocks of the intrusion have been as intensely altered as the host volcanic rocks, thus making it difficult to delineate the exact position of the intrusive contact. The alteration is pervasive, but with increasing distance from the contact, the alteration becomes increasingly concentrated along and controlled by fractures and veins. The mineralogy of this alteration, which consists primarily of sericite, potassium feldspar, tourmaline and chlorite, will be more fully discussed in Chapter VII.

Plutonic Phases

The Champion Stock contains several compositional phases that vary from granodiorite through quartz monzonite to felsic aplite. The granodiorite is porphyritic and makes up the bulk of the intrusion. It is located marginally relative to the quartz monzonite. In contrast, the aplite occurs as small dikes.

Contact relations between the granodiorite and quartz monzonite were not observed. The quartz monzonite may either be a separate, later intrusive phase, or a product of inward zoning. The granodiorite, because of its marginal position is most closely associated with the contact metasomatic alteration. Xenoliths of volcanic lithology are common throughout the stock, but they are more abundant in the marginal phase. Xenolithic blocks of a slightly coarser grained, equigranular granodiorite, up to 1.5 m in diameter, have been reported by Lutton (1962), indicating that discrete granodiorite phases are present.

The quartz monzonite occupies the interior portion of the stock. This rock is generally medium-grained equigranular, but it may contain sparse phenocrysts of plagioclase feldspar. The quartz monzonite is chemically and texturally similar to the granodiorites southeast of Bohemia Mountain, which thus may represent rapidly chilled apophysis of the same phase.

Felsic aplite dikes are the latest phase of intrusive activity. They range from 15 to 30 cm in width, and cut both granodiorite and quartz monzonite phases of the Champion Stock. According to Lutton (1962), the aplites contain up to 50 percent quartz as phenocrysts, anhedral groundmass grains and granophyric intergrowths. The remainder of the rock is composed of oligoclase and orthoclase, with mafic minerals such as chlorite accounting for less than 5 percent of the rock.

Petrography of the Granodiorite Phase. The granodiorite phase is hypidiomorphic-porphyritic. The phenocrysts are composed of plagioclase feldspar and augite 2 to 3 mm in length that are set in a fine-grained holocrystalline groundmass. The phenocrysts of plagioclase feldspar are slightly larger than those of the ferromagnesian minerals.

The major constituents of the granodiorite are plagioclase feldspar (47 percent, including alteration products); quartz (22 percent); orthoclase (8 percent); and magnetite (3 percent). The ferromagnesian minerals are augite, biotite, and chlorite. Apatite, sphene and zircon are common accessory minerals.

The plagioclase feldspar composition is andesine (An_{38-45}). Phenocrysts are weakly zoned. Up to five percent of the rock is composed of epidote that replaces plagioclase feldspar. Dustings of sericite are also present as a minor alteration product in the plagioclase feldspar.

Quartz and orthoclase form interstial anhedra. Augite and biotite have been extensively altered to chlorite. Relict hypersthene may occur in the core of chlorite intergrowths.

Petrography of the Quartz Monzonite Phase. The quartz monzonite phase is medium-grained hypidiomorphic-granular. However, rare phenocrysts of plagioclase feldspar up to four times larger than the groundmass crystals may be present. This rock-type is the least altered of the intrusive phases in the district.

Mineralogically, the quartz monzonite is composed of plagioclase feldspar (38 percent); quartz (24 percent); orthoclase (21 percent); ferromagnesian minerals (12 percent); and magnetite (3 percent). The ferromagnesian minerals consist of biotite and augite, and their alteration products. Trace amounts of epidote are found in the groundmass in addition to the usual accessory minerals such as magnetite, apatite and sphene.

The plagioclase feldspar varies mainly from calcic oligoclase to sodic andesine (An_{25-32}). Crystals are subhedral and are weakly zoned. Only a minor amount of alteration to epidote has occurred.

Quartz and orthoclase were probably the last minerals to crystallize as they occur interstially as anhedra. Approximately one-quarter of the quartz forms micrographic intergrowths with orthoclase. There are two distinct types of these intergrowths.

One variety is an angular microcrystalline intergrowth and the other a slightly sinuous intergrowth which is an order of magnitude finer in scale. Crystals of plagioclase feldspar are commonly entirely rimmed by these optically continuous micrographic intergrowths.

Biotite and augite are subhedral to anhedral. They tend to be smaller than crystals of plagioclase feldspar. Both the biotite and pyroxene have been moderately altered to chlorite.

Chemistry of the Felsic Intrusions

The major oxide chemistry was determined for 21 of the felsic intrusions. Samples analyzed came from the champion quartz monzonite and granodiorite, the granodiorites southeast of Bohemia Mountain, and from various quartz diorite intrusions located throughout the district.

Although these rocks have been distinguished modally as quartz diorite, granodiorite and quartz monzonite, they are essentially chemically identical (Table 2).

Comparisons between the mean oxide compositions of the quartz diorites versus those of the granodiorites and quartz monzonites indicate that the only significant chemical variation is that the quartz diorites relative to the granodiorites and quartz monzonites have a higher MgO content (4.3 versus 3.3 percent) and

Table 2. Major and trace element chemistry and modal composition of some Bohemia intrusions.

	6-1	8-1	6-8	3-15	5-15	4-29	8-32	Ave. Bohemia	Ave.* qtz-d.	Ave.* grd.
SiO_2	62.5	64.3	63.5	60.8	66.3	60.5	65.3	62.0	66.2	66.9
TiO_2	.90	.85	.90	1.00	.80	1.30	.75	.95	.62	.57
Al_2O_3	16.1	16.0	15.9	16.4	15.4	17.9	14.6	16.3	15.6	15.7
FeO	6.6	6.0	6.4	6.6	5.8	4.6	5.6	6.6	4.9	4.1
MgO	3.1	3.1	2.8	3.6	2.2	1.0	1.9	3.3	1.9	1.6
CaO	5.7	5.2	5.1	5.4	3.9	5.4	4.4	5.1	4.7	3.6
Na_2O	3.5	3.4	3.9	3.7	3.6	4.3	4.0	3.5	3.9	3.8
K_2O	1.85	1.70	1.85	2.05	2.55	2.15	2.05	1.95	1.42	3.07
Total	100.25	100.55	100.35	99.55	100.55	97.15	98.60			
Trace Elements in ppm										
Cu	25	20	25	25	25	16		39		30**
Zn	35	60	65	55	50	40		96		60
Pb	8	7	18	5	12	5		20		15
Mo	1	1	-1	-1	1	-1		.76		.07
Ag	.3	.3	1.4	.7	.3	.7		1.4		1.0
Modal Composition										
Qtz	23	12	23	21	22	18	24			
K-feld.	60	64	48	55	68	40	39			
P-feld.	--	--	--	--	--	13	21			
Biotite	--	tr.	13	tr.	--	6	7			
Hblde.	--	9	1	12	--	--	--			
Pyx.	10	3	1	--	--	9	4			
Chl.	6	9	9	8	9	9	2			
Mag.	2	4	5	3	2	4	3			

* Nockolds, 1954.

** Turekian and Wedepohl, 1961.

Table 2. Continued

Sample #	Rock Type	Location
6-1	Quartz diorite porphyry	NE1/4, SW1/4, sec. 12
8-1	Quartz diorite porphyry	NE1/4, SW1/4, sec. 12
6-8	Quartz diorite porphyry	SW1/4, NE1/4, sec. 13
3-15	Quartz diorite porphyry	SE1/4, NE1/4, sec. 14
5-15	Quartz diorite porphyry	NE1/4, SE1/4, sec. 14
4-29	Granodiorite	SW1/4, SW1/4, sec. 14
8-32	Quartz monzonite porphyry phase, Champion Stock	NE1/4, NW1/4, sec. 1

a lower Na_2O content (3.5 versus 4.3 percent).

With the exception of the MgO and Na_2O contents, the so-called quartz monzonite is chemically indistinguishable from the quartz diorites. Moreover, it is chemically equivalent to Nockolds' (1954) average quartz diorite. The content of modal orthoclase is anomalously high with respect to K_2O (2.05 percent), in that a minimum of 3.50 percent K_2O is necessary to account for the potassium-feldspar observed. This discrepancy probably in part results from over estimation of the potassium-feldspar content in point counting the quartz-feldspar micrographic intergrowths. Furthermore, soda can proxy for up to 30 percent of the potash in potassium-feldspar (Deer and others, 1963), and such substitution would further tend to reduce the discrepency.

The average composition of the Bohemia intrusions compares moderately well with the average quartz diorite defined by Nockolds (1954, Table 2). Intrusions of the Bohemia District are slightly deficient in SiO_2 and contain greater percentages of Al_2O_3, FeO, and CaO than the average quartz diorite. Mineralogically, this difference is probably attributable to larger percentages of augite, chlorite and calcic plagioclase feldspar in these samples. Surprisingly, K_2O is slightly higher in these plutons of the Bohemia district than in the average quartz diorite.

Comparison to Island Arc Plutons

The plutons of the Bohemia district are generally quartz dioritic and have been intruded into the calc-alkaline volcanic pile of the Western Cascade Range. These magmas are all believed to have been generated along a subduction zone (Morgan, 1968) and as such the intrusions of the Bohemia district are closely comparable to island arc plutons in terms of chemistry, petrography and tectonic environment. An excellent summary of data for island arc plutons associated with mineralization in the Caribbean has been published by Kesler and others (1975).

The island arc plutons are predominantly quartz diorites, although granodiorites, quartz monzonites and syenites are present (Kesler and others, 1975; Titley, 1975; Field and others, 1975). The content of potassium is relatively low in most metallized island arc intrusives. However, Kesler and others (1975) have found two distinct populations of intrusions in the Caribbean based on potassium-feldspar content. These are defined as a relatively high potassium feldspar granodioritic trend that contrasts with a low potassium feldspar quartz dioritic trend. Modal data for these trends are summarized on a ternary diagram for quartz-orthoclase-plagioclase, and on which equivalent data for intrusions of the Bohemia District have been plotted for comparison (Figure 4).

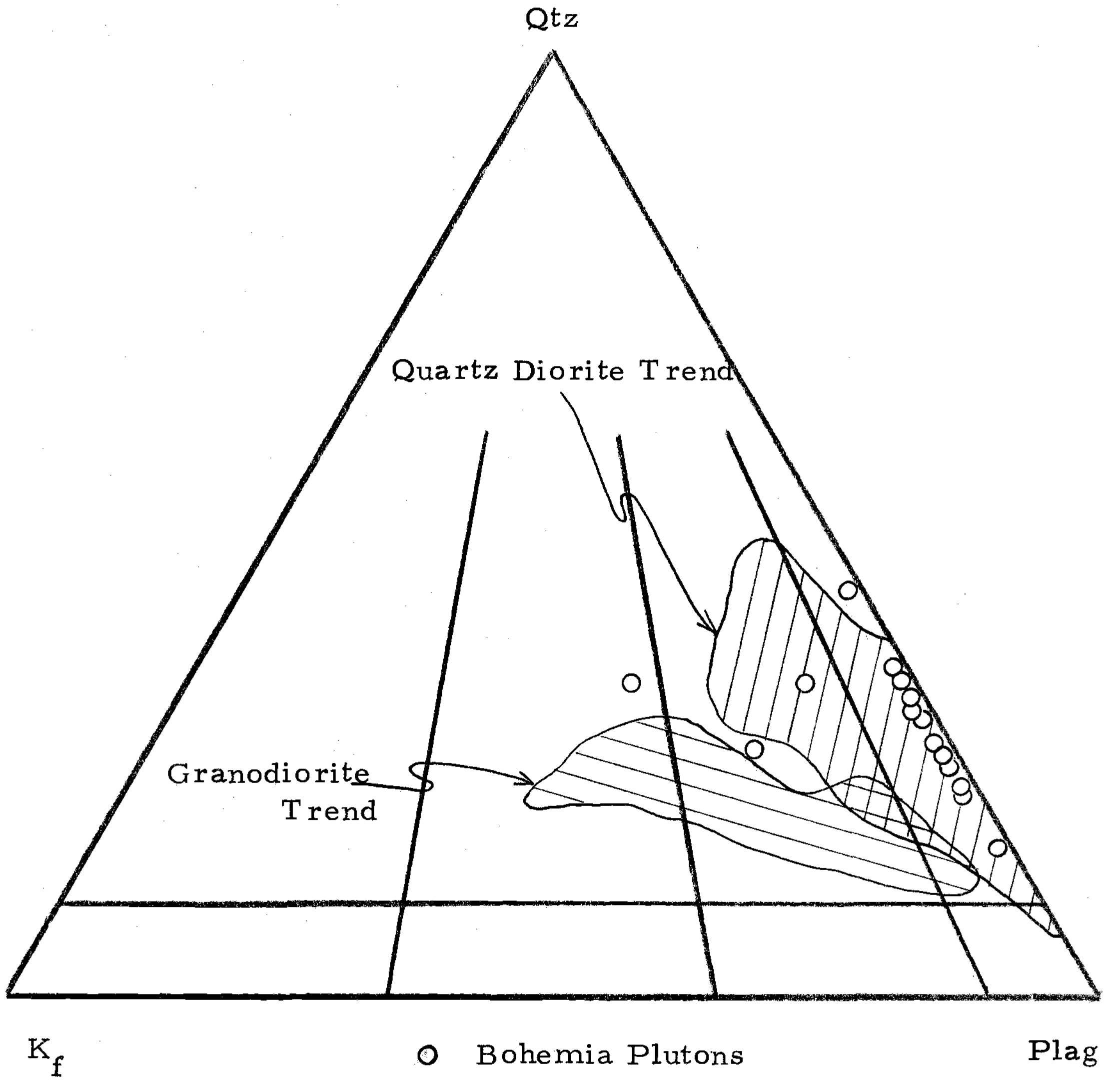


Figure 4. Model composition trends for intrusive rocks of the northern Caribbean compared to intrusive rocks of the Bohemia District (after Kesler and others, 1975).

The distribution indicates that plutonic rocks of the Bohemia District exhibit an affinity towards the quartz diorite trend.

Biotite and hornblende are the predominant ferromagnesian minerals present in the Caribbean intrusives, as contrasted to augite and biotite with minor hornblende which is characteristic of the Bohemia intrusions. Potassium-feldspar is generally late and occurs interstitially with quartz. According to Kesler and others (1975) phenocrysts of potassium-feldspar are rare in the island arc intrusions of the Caribbean, even in the K_2O-rich intrusions.

The major oxide chemistry of the Caribbean intrusions is consistant with their quartz dioritic affinities. Aside from normal lithic variations, the bulk oxide chemistry of the Bohemia intrusions is very similar to those of the Caribbean.

The chemical, mineralogical and tectonic similarities of the Caribbean island arc intrusions with those of the Cascade Range is evidence of a possible broad genetic relationship. It contrasts markedly to intrusions associated with mineralization in the southwestern United States. These were emplaced into a thick sequence of cratonic rock. The most significant difference between the island arc intrusions and those of the Southwest is the higher K_2O content of the latter (Figure 5), even at the same SiO_2 content (Kesler and others, 1975). This difference presumably indicates

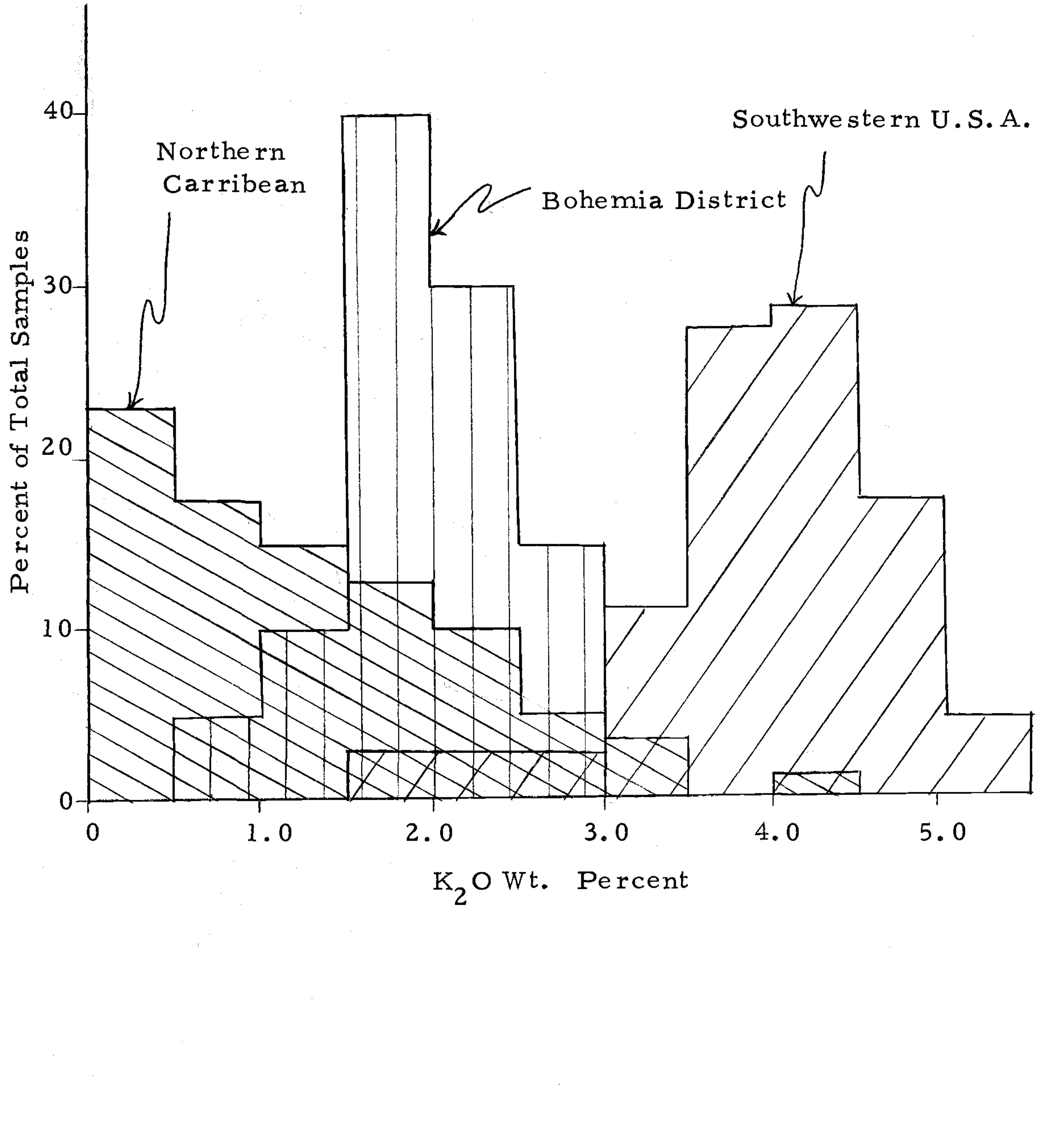


Figure 5. Comparison of the abundance of K_2O in intrusive rocks of the Northern Caribbean and Southwestern United States (after Kesler and others, 1976) versus that in plutonic rocks of the Bohemia District.

that island arc intrusions associated with mineralization are compositionally more primitive than their counterparts on the craton (Kesler and others, 1975; Field and others, 1975).

PETROGENESIS

The Cascade Range, as is common to other volcanic mountain chains, is located at a convergent plate boundary. These chains are characteristically composed of large volumes of calc-alkaline rocks, dominantly of andesitic or basaltic composition. The mechanism for generating these large volumes of relatively homogeneous calc-alkaline magmas is still an unresolved problem, mainly from lack of adequate constraints. However, low Sr_{87}/Sr_{86} ratios, along with other trace element data indicate that these rocks are derived from the mantle (Taylor, 1969; Gilluly, 1971).

Experimental petrology has shown that there is a wide variety of possible mechanisms by which andesite magmas can be generated. Most of these fall into one of three general catagories: (1) deviation from a parent basaltic magma by fractional crystallization, assimilation and hybridism, or some combination of these; (2) mantle anatexis producing a primary andesite magma; (3) anatexis of oceanic crustal material under conditions that might prevail in the mantle, such as along subduction zones (Wyllie, 1971).

The close association of magmatic arcs with convergent plate boundaries indicates that the generation of these magmas is genetically related to the subduction process. A widely accepted model for the generation of these magmas from mantle material that is consistent with plate tectonics, involves two stages of differentiation. The first is represented by fractionation of the mantle eclogite or pyrolite under mid-ocean spreading centers, which gives rise to tholeiitic basaltic magmas. The tholeiites are intruded and extruded to form new oceanic crust at the rises. The second stage involves subduction of the tholeiitic crust at convergent plate boundaries, with partial fusion of the subducted tholeiites forming magmas having the composition of andesite (Taylor and White, 1965; Dickinson, 1969; Green and Ringwood, 1969; and Taylor, 1969).

It must be emphasized again that the ideas and hypotheses concerning the origin of calc-alkaline magmas are still highly speculative, and could be modified radically as additional knowledge from experimental studies is integrated with data obtained from basic field and laboratory investigations.

Petrogenesis of the Western Cascade Range

The Western Cascade Range is composed predominantly of andesites and basalts, the basalts being secondary to the andesites. (Peck and others, 1964; McBirney and others, 1974). Although the range is similar to other such volcanic chains located along convergent plate boundaries and is probably broadly similar in origin, subduction has slowed or possibly stopped, and the magmatism associated with Cascade volcanism is believed to be in its last stages of activity (Morgan, 1968).

The unaltered igneous rocks of the Western Cascade subprovince are calc-alkaline and have an alkali-lime index of 60 (Peck and others, 1964). In contrast, the Bohemia rocks vary only slightly, with an alkali-lime index of slightly over 61. According to Peacock (1931) the boundary between the calc-alkalic and calcic rock series is 61, so by definition the Bohemia rocks are weakly calcic. However, Harker variation diagrams of rocks of the Western Cascade subprovince (Peck and others, 1964) compared with those of the Bohemia District are much the same and show only minor variations in trends of the different oxide components (Figure 6). A possible explanation for the slightly higher alkali-lime index of the Bohemia rocks is that widespread propylitic alteration has occurred in the Bohemia District with the consequent formation of epidote, a calcium rich mineral, as well as calcite. The propylitically altered rocks of the North Santiam District also have an alkali-lime index of slightly over 61, which would tend to support this contention (Olson, M.S. thesis in progress). In contrast to the igneous rocks of the Western Cascades, unaltered volcanics of the High Cascade subprovince are definitely calcic, having an index value greater than 62 (Williams, 1942).

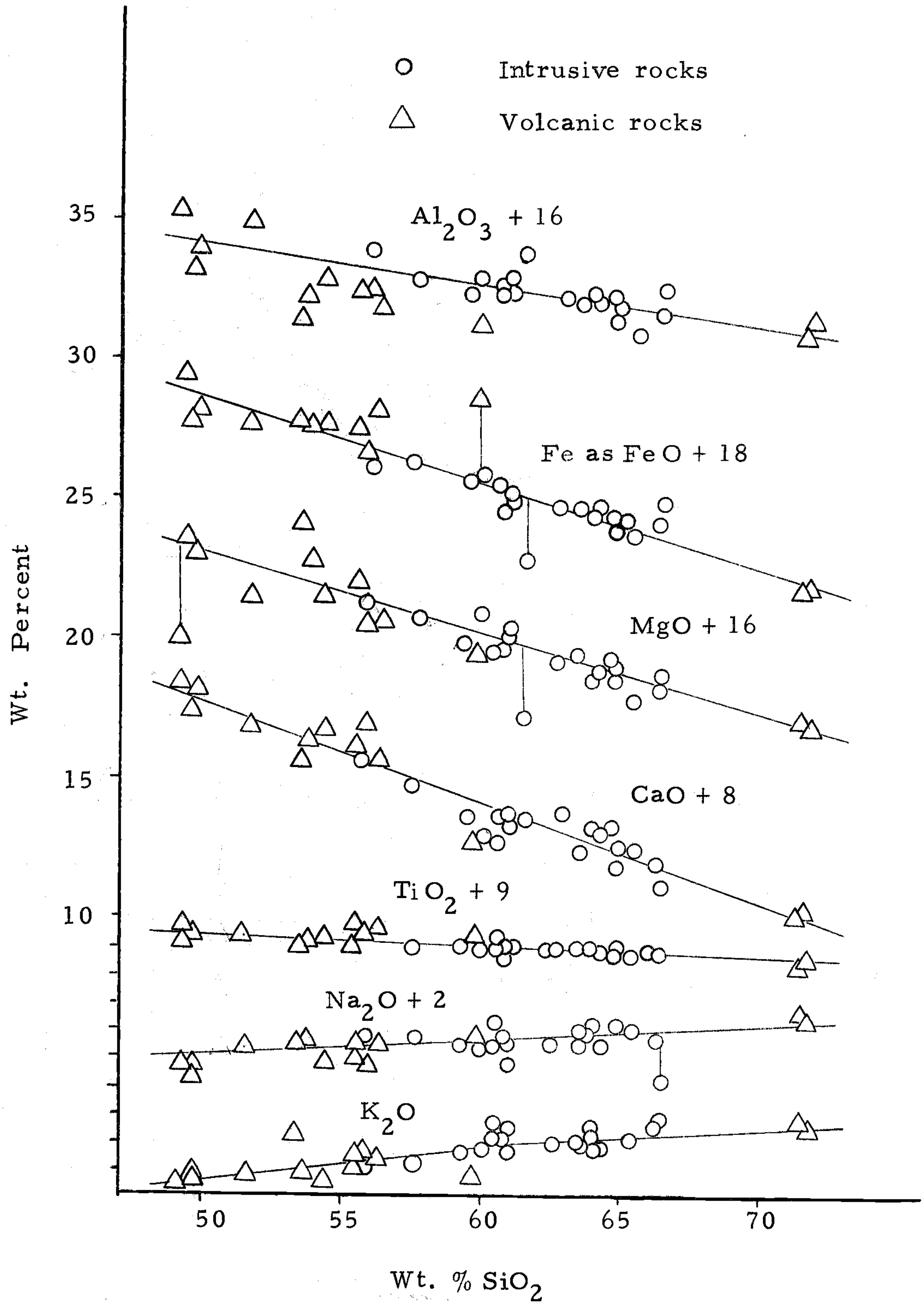


Figure 6. Harker variation diagram of igneous rocks from the Bohemia district.

The major oxide chemical data have been plotted in Figures 7 and 8 on AFM and NKC ternary diagrams to show their differentiation trends. The values plotted on the diagrams, recalculated to 100 percent, were determined as follows:

A = $Na_2O + K_2O$

F = total iron as FeO

M = MgO

and

N = Na_2O

K = K_2O

C = CaO

The calc-alkaline line in these figures is based on the calc-alkaline magma trend (basalt-andesite-dacite-rhyolite) described by Nockolds and Allen (1953).

On the AFM diagram the intrusions plot as a compact mass that coincides with a segment of the calc-alkaline line, in contrast to the volcanics which are dispersed about the undifferentiated MgO-FeO end of the line. The systematic distribution of the intrusive sequence implies that it was related to a single magmatic event, which was emplaced as three or four separate phases. Because the intrusions had the same history of differentiation until

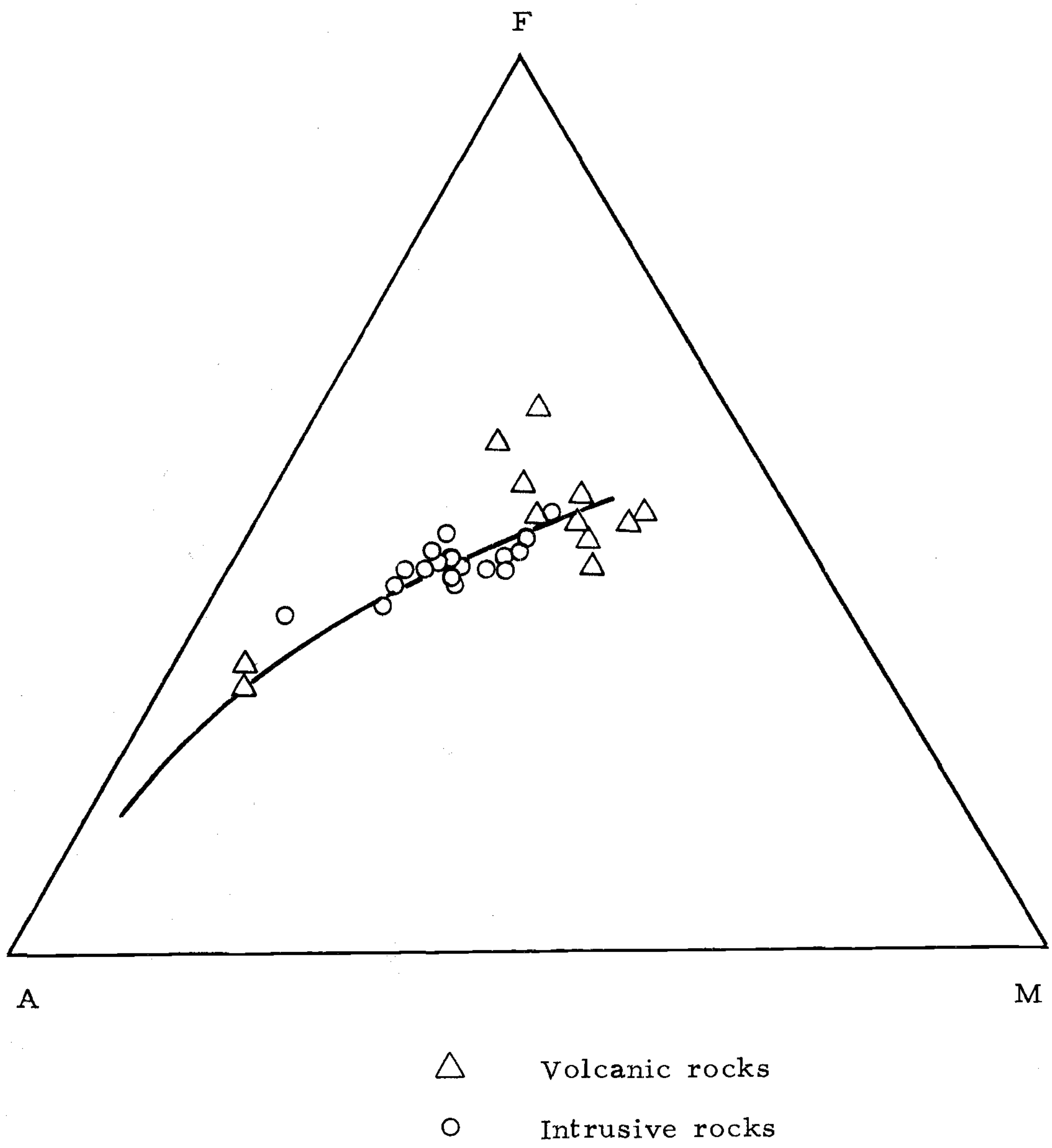


Figure 7. AFM diagram of rocks from the Bohemia district.

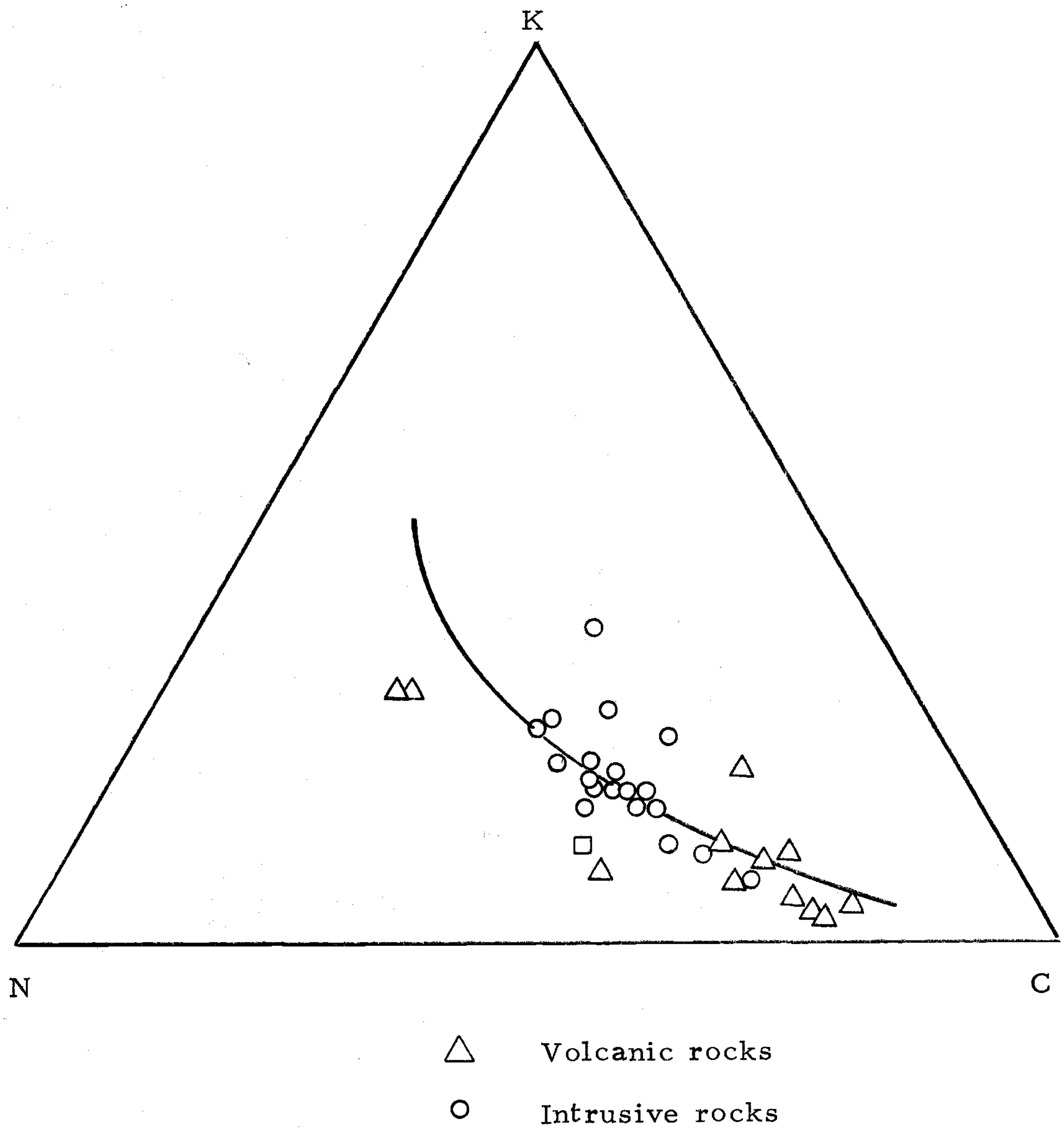


Figure 8. NKC diagram of rocks from the Bohemia district.

slightly before or during emplacement, the chemical divergence of the individual plutons is small. Chemical variations that approximately parallel the calc-alkaline trend presumably were generated as a result of limited differentiation which took place prior to, or during emplacement of the intrusions.

In contrast, the magmas associated with the volcanism are believed to have been supplied by discrete or semi-discrete sources of magma. Each had its own history of fractionation, contamination, hybridism, and movement. The scatter of points for the chemical data of the volcanic rocks supports this hypothesis of discrete magma sources, each having a unique crystallization history.

The association of calc-alkaline magmas with consuming plate margins is well demonstrated. Moreover, it is generally accepted that partial melting of mantle or oceanic crustal rocks at depth along subduction zones generates the calc-alkaline magmas (Taylor and White; 1965; Dickinson, 1969; Green and Ringwood, 1969). The compositions of the igneous rocks produced along subduction zones has been shown to vary systematically with respect to both depth to the Benioff Zone, and distance to the trench (Dickinson and Hatherton, 1967; Hatherton and Dickinson, 1969). However, because such chemical variations are not constant in magnitude from island arc to island arc, conclusions concerning the position of the Benioff Zone should not be drawn from such data alone.

STRUCTURE

The structural style of Tertiary volcanic rocks comprising the Western Cascades of Oregon may be characterized as gently deformed. Within the map area, the volcanic strata generally dip northeast. However, the dips are predominantly north-northeast west of Champion Creek, whereas they are mainly to the east in the vicinity of Grouse Mountain. Locally, the strikes and dips are variable and in places the dips may be entirely reversed.

Folds and Unconformities

Small folds and minor local unconformities are widespread throughout the district. They are easiest to recognize in the bedded tuffs. Small folds having wavelengths of less than 60 m and amplitudes of less than 5 m are present in the tuffs southwest of Grouse Mountain. Many of these folds terminate upwards within a few meters. This suggests that they were formed contemporaneously with the deposition of the tuffs, and were subsequently buried by later eruptions.

Further support for the contemporaneity of warping and volcanism comes from slight angular unconformities in the flows of Bohemia Mountain. These are best exposed on cliff faces along the east side of the mountain. The uppermost flows of the mountain dip 2 to 3° NE, whereas the lower flows dip 7 to 8° NE.

These minor folds and warps appear to have formed continuously and concurrently with the accumulation of the tuffs and flows. This small scale deformation is provisionally interpreted to have originated with subvolcanic activity related to the volcanism. It can best be explained in terms of subsidence and doming caused by periodic venting and filling of near surface magma chambers.

The major structure in the Bohemia District is an anticline trending north-northeast through the central part (Callaghan and Buddington, 1938; Lutton, 1962). This anticline was recognized by systematic changes in strike and dip of the bedded lithologies, and for this reason is limited to the southern part of the map area where tuffs are common. However, it may extend farther north. A linear belt of small intrusive bodies is also coincident with the axis of the anticline. Thus, emplacement of these intrusions from a larger magma chamber at depth may have served as the deformational force that formed the anticline, although it is more likely that the anticline influenced the shape of the intrusion.

Faults

Faults having a significant displacement were not recognized anywhere within the district. The fault on Grouse Mountain is the only one found to have a notable displacement, and this is less than 30 m. In general, the faults are difficult to recognize due to the homogeneity of the volcanic rocks and the scarcity of continuous bedrock exposure.

All of the faults observed show the affects of hydrothermal alteration. It is also suspected that many, if not all, of the vein deposits of the district are localized along minor faults (Lutton, 1962). This is supported by specimens from mine dumps which exhibit healed slickensides and ore breccias caused by movement during mineralization. Post mineralization faulting or displacement was not recognized.

Veins in the Bohemia District strike predominantly N. 55 to 80° W. and are steeply dipping. This is roughly comparable to the preferred orientations of veins in other mining districts in the Western Cascades. This regionally widespread preferred orientation suggests that a major tectonic stress was applied to the entire Cascade Range. It is possible that this stress may have been related to the termination of basin and range extension in southeastern Oregon (Lawrence, 1976). A subordinate set of steeply dipping cross-veins, striking N. 20 to 40° E. cuts across the district transversely (Plate 2 overlay F). The cross-veins are roughly parallel to the axis of the anticline, and their distribution is spatially related to this structure throughout the district.

Structural Development in Relation to Intrusive Events

The spatial coincidence of the anticline, intrusive bodies and the cross-veins strongly implies a genetic relationship. The sequence of events is interpreted to be as follows: (1) intrusion of an elongate pluton whose shape and orientation was controlled by pre-existing basement structure (Lutton, 1962). This pluton is believed to be still largely unexposed, with the numerous small intrusions merely being upward protruding apophyses. Emplacement of the magma was partly forceful, with displacement of the volcanic host rocks by doming and shouldering aside, thus accentuating the anticline. Tensional stress across the axis of the anticline was released by the development of a series of subparallel fractures and minor faults. Metal-bearing hydrothermal fluids were subsequently evolved by the crystalizing magma. These fluids employed the tensional fractures and faults as channels for movement, and when the chemical environment was suitable, as a site of mineral deposition.

ECONOMIC GEOLOGY

The Bohemia Mining District was discovered by Dr. W. W. Oglesby and Frank Brass in 1858. However, it wasn't until 1863 that gold was discovered by James Johnson and George Ramsey near the head of City Creek. The district derived its name from the nickname of Johnson, who was popularly known as "Bohemia" Johnson.

Interest in the district increased dramatically with the discovery of gold, and by 1902 over 2000 claims had been registered (Callaghan and Buddington, 1938). Mining activity, although erratic in intensity, was more or less constant from 1872, when the first 5-stamp mill in the district was constructed, until 1950 when production at the Champion mine was concluded (Brooks and Ramp, 1968). In the early 1960's exploratory work in the form of diamond drilling and extension of old adits was performed. The results of this work was disappointing because little new ore was discovered.

Mineral production from the Bohemia District has come primarily from the Champion, Helena and Musick mines, with significant contributions from the Noonday, Vesuvius and Star mines. Total production from the district has been estimated at about one million dollars, mainly from gold and silver, with minor additions from copper and lead. Although zinc is the most abundant metal found in the ores, it was considered to be a liability throughout most of the production period, because its presence caused complications during smelting.

It is interesting to note that the price of gold in the United States was fixed at $20.67 per troy ounce from 1837 to 1933, at which time it was raised to $35.00 per troy ounce. From 1880 to 1930 the Bohemia District produced 28,285 ounces of gold and 9,567 ounces of silver with a total value of nearly 600,000 dollars (Callaghan and Buddington, 1938). At current market prices (approximately $160/oz gold and $4/oz. silver) this quantity of gold and silver would be worth more than 4.5 million dollars.

Activity within the district has been dormant from the early 1960's until the summer of 1976, when a major exploration company spent several months mapping, performing geophysics and diamond drilling. In contrast to the earlier exploration work, their target was not gold bearing vein deposits, but large tonnage and low grade deposits of base metals.

Mineral Deposits

Since its discovery in 1858 nearly one million dollars worth of metals have been produced in the Bohemia District. This value has been derived primarily from gold and silver, with less important additions from copper and lead. The ore deposits of the district are present predominantly as fissure fillings, or veins, of which there are over 70 (Callaghan and Buddington, 1938). In addition, ore was mined from a stockwork of small veinlets in the Knott shaft at the top of Grouse Mountain (Lutton, 1962). Both volcanic and felsic plutons constitute the host rocks for the deposits. The latter are believed to be genetically related to the deposits as originally stated by Callaghan and Buddington (1938).

Although gold and silver were the commercially important metals produced here, the veins of the district fall into the classification of base metal sulfide veins because of the much greater quantities of these metals. The base metals are chiefly zinc, along with subordinate amounts of lead, copper and iron. These are the principal metallic components of the host sulfide mineral phases that are sphalerite, galena, chalcopyrite and pyrite respectively. Gangue minerals include quartz, carbonates, barite, stibnite, hematite, sericite, chlorite, and clays. Other minerals reported in the district, but not observed by the writer, include adularia and johansenite (Callaghan and Buddington, 1938). As a class, deposits of base metal sulfide veins are often found to be spatially associated with and peripheral to disseminated porphyry copper-molybdenum deposits.

Typically the veins are composed of alternating crusts of variable mineralogy which are duplicated on both walls of the veins.

Thus, the sulfide-gangue assemblages are crustified and symetrically distributed within the veins. Angular fragments of country rock are frequently included in the vein material, in addition to earlier stages of vein material which have been brecciated and rehealed by syn-metallization movements and hydrothermal fluids.

A very crude zonation of vein mineralogy occurs relative to the center of the district (Callaghan and Buddington, 1938). Such zoning, according to Stanton (1972), is never prominent or well developed in vein deposits, possibly because the veins are such efficient "plumbing" systems that the fluids are rapidly flushed through them before they can fully equilibrate to the rapidly changing chemical and physical conditions within the veins. Furthermore, the zonation present is probably obscured as a consequence of the three-dimensional configuration of the hydrothermal system.

Coarse specular hematite, a high temperature hydrothermal mineral, is present as a paragenetically early phase in the core of the district. In contrast, stibnite, a low temperature mineral, is found in several mines at the extreme peripheral southwest margin of the district. Systematic variations of sphalerite, galena and chalcopyrite are not prominent. However, the proportion of base metal sulfides to gangue minerals in the veins appears to decrease from the central core to the peripheral margin of the district. Additionally, the ratios of galena to sphalerite, and galena to chalcopyrite seem to be highest in the center of the district. This area of high galena ratios is also partially coincident with a zone of anomalously high trace metal concentrations for lead in the host rocks of the district. Although the presence of these large galena ratios and high lead concentrations in the central part of the district are unusual in terms of typical hydrothermal zonations (where galena and lead are least abundant in the center), these anomalies are also coincident with the topographically highest part of the district, and may thus be partly attributable to a vertical zonation.

Mineralogy

Coarse specular hematite appears to have been one of the earliest minerals formed, on the basis of its marginal position in the veins adjoining the country rock. It is characteristic of, although not limited to, the cross-veins. Associated quartz and the sulfides, to a lesser extent, are contemporaneous with this early hematite. Finely crystalline hematite is later, and is present intimately mixed with quartz as jasper, or as scarlet bands transecting quartz crystals.

Quantitatively, quartz is the most abundant mineral of the vein deposits and it is volumetrically greater than all other minerals combined. The quartz is present as moderately large terminated crystals (up to 4 cm in length) lining vugs, as crusts or bands exhibiting a comb texture, and as cherty masses commonly having a colloform structure. This cryptocrystalline vein filling of silica is late, and has been interpreted as having formed by the precipitation of colloidal silica (Lutton, 1962). Thus quartz was an important mineral throughout the duration of hydrothermal mineralization.

Sphalerite is the most abundant sulfide mineral in most veins of the district. Its color varies from light yellow-green to almost black. These color variations are largely a function of iron substituting for zinc. Systematic variations of the color of sphalerite with its location in the district were not observed. In fact, both light and dark varieties may be found in the same vein. Euhedral crystals of sphalerite are moderately common in vugs and may be up to 8 mm in diameter. However, most of the sphalerite, as well as galena and chalcopyrite, occur as mono- or poly-mineralic crusts, or as disseminations contained in silicate vein material. Cubes of galena and sphenoids of chalcopyrite are also present in vugs, but they are not as common as the crystals of sphalerite. Chalcopyrite is usually subordinate to both sphalerite and galena in veins throughout the district. An exception to this is the Oregon-Colorado mine in the southeast part of the district, where only chalcopyrite with minor pyrite comprise the sulfide assemblage exclusively. Tetrahedrite has been reported from several mines, but none was observed by the writer.

Sphalerite, galena, and chalcopyrite were deposited contemporaneously during hydrothermal mineralization. Where one is found, the others are usually present as well. Although precipitation of these sulfides began during the early deposition of coarse specular hematite, the bulk of these sulfides were deposited later.

Although its presence is nearly ubiquitous, pyrite is the least abundant sulfide phase of the veins. It is present as disseminated cubes, pyritohedrons, anhedral grains and occasionally as crusts. It is not preferentially associated with any particular mineral. Pyrite is far more abundant as disseminations in the altered host rocks adjacent to the veins, than it is within the veins. Deposition of small amounts of pyrite appears to have been continuous throughout the entire period of hydrothermal mineralization.

Stibnite, as found at the President mine, is present as radiating needles up to 10 cm in length and 1.5 mm in diameter. The stibnite is almost entirely enclosed by cherty quartz and calcite. This mineral is interpreted to have been late in the paragenetic sequence because it is intimately associated with late-stage carbonates. Furthermore, stibnite is known from other districts to be a low temperature mineral (Park, 1955) and its peripheral location in the Bohemia District supports this contention.

There are three carbonate minerals common to the district. They are dolomite, calcite and ankerite according to Lutton (1962).

Where present, they characteristically occupy the center of the veins and thus are among the latest hydrothermal minerals to be deposited. Where vugs or other open spaces were available, the carbonates are present as rosettes that crown terminated crystals of quartz or sphalerite. An earlier period of carbonate deposition, possibly contemporaneous with the deposition of base metal sulfides, is indicated by textural evidence from the Musick Mine. Here, pseudomorphs and molds of quartz in the shape of rhombohedral crystals up to 2.5 cm in diameter are found and which are believed to be after an earlier pre-existing carbonate mineral. However, this early carbonate became unstable during the later stages of hydrothermal activity and consequently underwent dissolution.

Barite was one of the latest minerals to have been precipitated. At the Helena Mine it is found as coarse laths, up to 2 mm in width and nearly 1 cm in length, that form crusts in vugs. Unusual crusts of intimately intergrown cubic pyrite crystals are closely associated with this barite, although slightly later.

Oxidation and Supergene Mineralization

Oxidation of the mineral deposits commenced when erosion had dissected the district to sufficient depths to lower the water table to and below the level of the veins. This oxidation has continued to the present as is indicated by the acid and oxidizing mine waters which precipitate thick limonitic oozes on contact with the atmosphere.

Secondary minerals formed as a result of this oxidation of the primary sulfide minerals are relatively uncommon. This is because mechanical weathering (erosion) has proceeded more rapidly than chemical weathering (oxidation and leaching), as is further suggested by the mature topography. Of the secondary minerals found in the zone of oxidation, those of lead are most common. Large quantities of cerrusite were reported to have been present in the upper workings of the Musick mine where it was extracted as an ore of lead (Callaghan and Buddington, 1938). Elsewhere, coatings of anglesite on galena were commonly observed from samples on mine dumps which had been exposed to the atmosphere. Crystals of pyromorphite, a lead chloro-phosphate, $Pb_5(PO_4)_3Cl$, up to 2 mm in length, were found at the Crystal mine. For this mineral to have formed, presumably another phosphate mineral such as apatite must have been oxidized to provide the phosphate ion.

Other secondary minerals formed by oxidation of the primary sulfide assemblages include minor amounts of malachite and azurite. In addition, stibiconite, a hydrous antimony oxide, is reported to have been found in the oxidized portions of veins containing stibnite (Callaghan and Buddington, 1938).

The presence of supergene mineralization is exceedingly erratic and is poorly developed at best. This is a result of the adjacent mature topography with deeply incised streams which enhances rapid surface erosion and subsurface drainage. Because of the open nature of the veins, the circulation of water is extremely variable leading to an erratic distribution of oxidizing and reducing waters beneath the water table (Lutton, 1962). These factors have combined to inhibit the development of supergene enrichment at and below the water table. Chalcocite was the only supergene mineral observed. It is not abundant and where present it forms sooty coatings on chalcopyrite. Callaghan and Buddington (1938) reported that minute amounts of covellite also may be associated with the chalcocite.

Genesis of the Deposits

The vein-type deposits of the Bohemia District are typical of hydrothermal occurrences and the nature of this process is well known. They are formed as precipitations from hydrothermal fluids in response to the changing physical and chemical environments to which the fluid is exposed as it moves through the veins (Lindgren, 1933; Barton, 1957; White, 1959). Because the veins are widely distributed over an area of 60 or more square miles, the associated heat source was necessarily large and was probably an unexposed phase of the Champion Stock. Presumably this stock was also the source of the hydrothermal fluids and metals (Callaghan and Buddington, 1938). However, the sequence of events and order of mineralization that lead to the development of these veins was a complicated process and thus is difficult to interpret.

Lutton (1962) has devised a complex sequence of depositional stages based on the mineral assemblages observed in these deposits. These stages are both complex and somewhat confusing, and thus are of limited applicability to individual veins of the district. A more realistic approach should involve an examination of the hydrothermal processes as a continuously evolving system of chemical and physical regimes with respect to both distance from the center of mineralization and to time. Temperatures will decrease with increasing distance from the center of mineralization and with time at a given location. Similarly, the chemistry of the fluids will change with distance from the center as minerals are precipitated or dissolved, and as reactions with the host rocks, or mixing with meteoric groundwater occurs. In addition, heat from the plutonic source at depth diminished with time, and the thermal aureole thus decreases in size and intensity, which results in an inward collapse of the thermal zones. It is also possible that the composition of fluids being exsolved by the crystallizing magma will evolve through time, systematically changing in composition and temperature, or fluctuating in a pulsatory manner.

In addition to the complications accruing from this two-way evolution of the hydrothermal system in space and time, further complications may result from tectonic activity affecting the fissures in which the veins were being formed. It is inconceivable that the fissure openings were ever as wide as the veins they presently contain. They probably opened gradually, or by a series of small steps, with the fissures being filled by vein material as the open space was created. Evidence that such movement did accompany mineralization is present in the form of breccias of crustified or massive vein fragments that were subsequently cemented by later deposition of minerals from the hydrothermal fluids. The breccias may have been produced both by rapid dilational opening of the fissures, which resulted in the sloughing off of the unsupported vein material to form the fragments, or by intra-mineralization faulting within the plane of the fissures, which crushed the brittle vein material. Further evidence for movement comes from within the mines, where slickensides and gouge zones within the veins have been reported (Lutton, 1962). Should a fissure become temporarily or permanently filled, further mineralization would not take place in that vein and subsequent episodes of mineral deposition would not be represented at that site. Thus, additional complications to any paragenetic interpretations derived from a single vein may be attributed to differing histories of mineralization as dictated by location (zoning) in the district and the timing and duration of the events which created the open space.

Theoretically, it should be possible to arrive at the complete history of mineralization by the detailed examination of all veins in the district. An "interpretive" paragenetic sequence, given in Figure 9, has been established for hydrothermal mineralization in the Bohemia District. This sequence is based on textural relationships observed in numerous vein samples and mine workings. In general, minerals appearing near the left margin of the illustration (such as hematite and quartz) were deposited earlier in the paragenetic sequence, and presumably at higher temperatures and/or at locations in the deeper central parts of the district, relative to those (such as stibnite, barite and carbonate) near the right margin. Ideally, this entire sequence might be represented by a symetrically crustified assemblage of all these minerals at a single location in a vein. However, such an ideal assemblage was never found. Mineral assemblages varied from vein to vein, and, or in different parts of the same vein. Thus, it may be concluded that although there is an apparent systematic distribution to the occurrence and paragenesis of hydrothermal minerals when broadly viewed on a district-wide basis, the mineral constituents of these veins locally exhibit overlap and discontinuities and thus are individually unique.

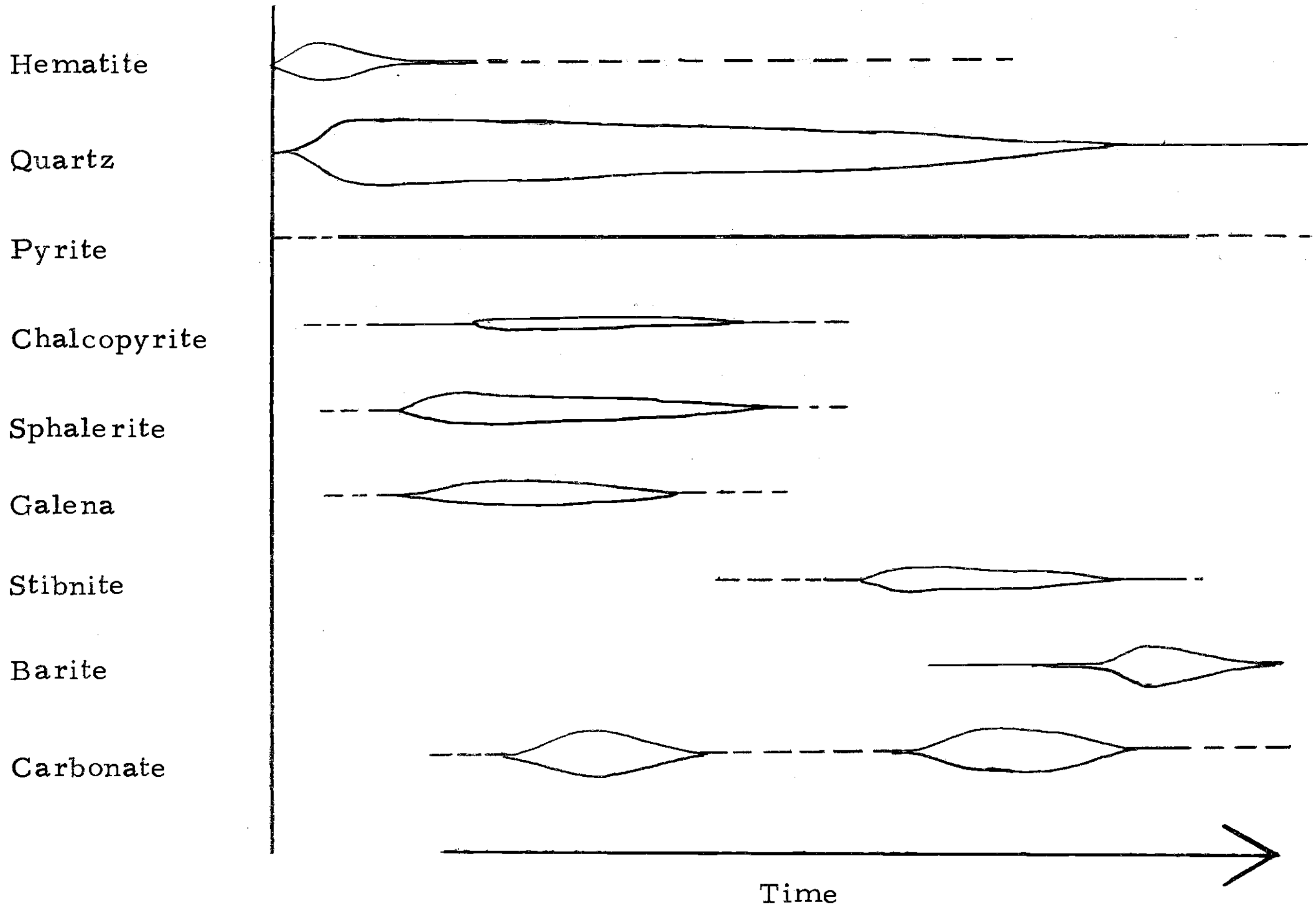


Figure 9. Generalized paragenetic diagram for vein mineralization of the Bohemia District.

Breccia Pipes

The Bohemia District contains at least eight distinct breccia pipes that were mapped in detail (see Plate 2) in addition to others which were inferred on the basis of float. These breccia pipes are described in some detail in view of their importance in localizing mineralization in mining districts elsewhere.

General Character of the Breccia Pipes

The breccia pipes of the Bohemia District consist of country rock which has been fractured and fragmented without appreciable vertical movement. The fragments show both rotational movement and differential separation relative to each other. Frequently tourmaline is present in these breccias as disseminations within the fragments and in the matrix between fragments as cement. There is considerable variation in the size of these breccias, which range from 3 m to over 100 m in diameter. These are generally sub-circular to elliptical in plan view. Where the breccias are present on steep slopes, they can be traced over large vertical distances, which indicates they are vertical or steeply dipping cylindrical bodies.

The pipes are probably genetically related to the hydrothermal activity associated with the intrusions of the area, and several are contained within, or adjoining intrusive bodies. However, most are located entirely within volcanic rocks. The pipes are commonly restricted to zones within the country rocks that have been extensively altered and bleached. These altered zones are white to light orange in color and now consist primarily of limonite-stained quartz, sericite and kaolinite. The breccia pipes may be situated either centrally or marginally to these zones of alteration.

It is difficult to determine with any certainty the original composition of the breccia fragments because of their intense alteration to microcrystalline quartz and sericite. However, in most instances they are inferred to be the highly altered equivalents of the enclosing country rocks. The individual fragments do not exhibit major displacement with respect to either each other, or to the host rock. However, some exotic fragments are present. These are distinguished on the basis of apparent differences in texture, which may have resulted in part from variable intensities of alteration.

The breccia fragments have been entirely altered to masses of microcrystalline quartz and sericite, commonly in association with disseminated needles and starbursts of tourmaline. This tourmaline is dominantly of the schorlite variety, although minor elbaite, as determined by optical petrographic methods, may also be present. Clusters of tourmaline crystals are frequently rimmed by relatively coarse mats of sericite. Many of the starbursts have extensive void spaces developed around the constituent tourmaline needles. The genesis of these vugs is probably related to the replacement of the original rock material by tourmaline. This relationship will be more fully discussed in a later section. Solution vugs are particularly well developed in both the Grouse Mountain and Champion breccias.

The breccia fragments are irregular in shape and tend to be angular. Size varies from 1 mm to 0.5 m. The most common shape among the fragments is a tabular lath. These laths are generally 5 to 10 times as long as they are wide and usually they do not exceed 7 cm in length. The laths are probably the result of brecciation of a rock which was initially cut by closely spaced, parallel fractures. The breccia pipes may contain zones which are composed predominantly of these uniformly tabular-shaped fragments. The Champion Sheeted breccia is composed almost entirely of these laths, which are locally sub-parallel, but are randomly oriented over the entire exposure (Figure 10). In contrast to the other breccias, the Noonday breccia differs significantly in that it contains fragments which are frequently subrounded to rounded.

The breccia fragments show evidence for both differential separation and rotational movement. Such evidence takes the form of fragments which fit in a "jigsaw puzzle" fashion, or show no obvious relation to their neighbors. Evidence for both types of

Figure 10. Champion Sheeted breccia showing tabular, lathlike fragments with sub-parallel orientation.

Figure 11. Grizzly breccia showing both rotation and differential separation of fragments.

movement are often found intimately intermixed (Figure 11). The close association of both types of movement in the breccias can be explained in terms of a process by which brecciation was caused by a gradual collapse or settling. New fragments would be formed continuously by the disintegration of larger previously formed fragments. With continued settling, these fragments would be rotated and separated from their nearby neighbors.

The breccias are generally cemented by quartz, tourmaline and rarely hematite. This cement was precipitated from the hydrothermal fluids which were channeled through the breccia. The ratio of quartz to tourmaline is highly variable, although quartz is usually predominant. The Grouse Mountain breccia is cemented by a black, finely crystalline matrix of tourmaline with minor quartz, whereas both the Grizzly and Champion Sheeted breccias have a gray microcrystalline matrix composed of quartz with subordinate amounts of finely disseminated tourmaline needles. Portions of the Grizzly breccia are cemented exclusively by quartz. The Noonday breccia differs from the others in having a matrix of quartz and coarse sericite, the sericite consisting of platy flakes up to 2 mm in diameter. The matrix cement of this breccia, in contrast to the other breccias, is possibly altered comminuted material. Many of the breccias exhibit evidence of late stage mineralization in the form of clear quartz, which fills the remaining voids of the matrix.

However, the void spaces commonly are not entirely filled. The Champion breccia is the most notable in this respect as it contains an abundance of such interfragmental voids. Angular three-dimensional voids up to 15 cm in diameter may be present between fragments in this breccia. Many of the voids contain fragments which are physically free of, or uncemented to the surrounding fragments.

The nature of the contacts between breccia pipes and country rocks are not easily determined because of poor exposures. In some cases, the contacts appear to be diffuse and grade from a collapse breccia of rotated and separated fragments in the core, to a "crackle" breccia (Locke, 1926) of intensely fractured rock with little or no movement at the margins. However, both the Champion Sheeted and Fairview breccias are inferred to have sharp contacts on the basis of an abrupt change from breccia to country rock.

The former presence of sulfides in the breccias can be inferred from limonite stains, which vary from light orange to dark brown in color. However, it is impossible to determine what types of sulfides were present because of the intensity and depth of oxidation and leaching to which the breccia pipes have been subjected. The Un-named breccia in the creek bed separating Noonday and Grizzly ridges has not been leached because of rapid downcutting by the stream. This breccia contains 2 to 3 percent pyrite disseminated in both fragments and matrix. Also, malachite stains are sparingly present at the western margin of the Champion breccia. This suggests minor copper mineralization, probably as chalcopyrite. However, this may be associated with a vein located near the malachite stains.

Specific Features

Grouse Mountain Breccia. The Grouse Mountain breccia is unusual in that it is associated with the most intense tourmaline alteration in the area mapped. Breccia fragments contain abundant disseminated tourmaline needles and starbursts, and the matrix cement is nearly all finely crystalline tourmaline with minor quartz. The fragments are generally tabular in shape and usually less than 4 cm in diameter and averaging 8 mm in diameter. The fragment to matrix ratio is approximately 8 to 1.

In addition, there is a large altered zone surrounding this pipe which is characterized by intense alteration to tourmaline, quartz and sericite. The host rock not uncommonly contains up to 60 percent tourmaline starbursts in this breccia. These average between 0.5 to 1 cm in diameter, but may reach 5 cm in diameter as composite tourmaline starbursts.

Champion Breccia. There are two noteworthy features of this breccia; a dearth of introduced matrix cement, as already discussed, and the style of brecciation. This breccia has only limited zones of angular, rotated fragments, separated by more extensive zones of highly fractured rock. Accordingly, it matches the description of shatter breccias defined by Sillitoe and Sawkins (1971), which have been observed in the upper portions of many of the breccia pipes of Chile. Shatter breccias are believed to form by the removal of support from below, which causes limited shifting and settling of the rock comprising the shatter breccia.

Tourmaline is present in the Champion breccia mainly as starbursts, with or without associated solution vugs, within the fragments. Only minor amounts of quartz, tourmaline and rarely coarse specularite are present cementing fractures and lining some of the interfragmental void spaces. Many of the void spaces contain loose fragments. This suggests that a late stage hydrothermal event, characterized by dilute and low temperature fluids, was active at the time this breccia was formed.

Grizzly Breccia. This is the "type" breccia of the district, as it displays most of the features previously described under general characteristics. This breccia contains angular fragments which range from 20 cm to 4 mm in diameter. These have been highly altered to quartz and sericite, with minor disseminated tourmaline. The fragments show the effects of both rotation and separation. The breccia has a fragment to matrix ratio of approximately 9 to 1. The matrix cement is an admixture of quartz and tourmaline and also contains minor amounts of disseminated magnetite. Some interfragmental voids are present and these are lined with vuggy quartz. This vuggy quartz is probably of the same generation as that which cements late stage fractures in the brittle matrix material.

Unusual polycrystalline clots of a platey clay mineral are found within the quartz-tourmaline cement. The diameter of individual flakes may be up to 3 mm. The clots are irregular in shape, and the size varies from 2 mm to 2 cm in length. The results of x-ray powder diffraction were inconclusive and thus it is not known what clay mineral this is. Furthermore, it remains uncertain from textural evidence whether or not this mineral was hydrothermally introduced, or was the result of intense alteration of a pre-existing mineral. The latter supposition is favored because this clay mineral is present only as clots, and not as disseminations throughout the matrix.

Grizzly E Breccia. This breccia is another high level shatter breccia similar to the Champion breccia. It is located on a steep slope and can be traced through a vertical distance of more than 60 m. Angular interfragmental voids are common in zones characterized by rotational displacement of the fragments. With increasing depth in the breccia, these zones of rotated fragments become more common. Such a distribution is consistent with a mechanism involving collapse for the origin of these pipes.

Although this breccia is texturally similar to the Champion breccia, it contrasts somewhat with respect to alteration. The fragments are altered to quartz and sericite, but kaolinitic clays are much more prominent, and tourmaline is relatively minor. The tourmaline is disseminated in both fragments and matrix cement, and is present as very fine microcrystalline needles. The matrix to this breccia is sparse, and is composed primarily of quartz.

Un-named Breccia. This is another of the high level shatter breccias, which has only minor zones of rotated fragments. Closely spaced oblique fractures cut the rock into discrete fragments 2 to 6 cm in diameter. The fragments have been altered to quartz and sericite with minor disseminated tourmaline. The matrix cement is composed of a mixture of quartz and tourmaline.

Because this breccia crops out at a low elevation in a stream bed, erosion rates have been sufficiently rapid to prevent extensive surficial oxidation and leaching from having taken place. Thus, sulfides are present and consist of disseminated pyrite in fragments and matrix that constitutes 2 to 3 percent of the rock.

Noonday Breccia. This breccia is unique among the breccias of the Bohemia District in terms of fragments, matrix and probably mode of origin. It is composed of angular to subrounded fragments set in a matrix of smaller fragments and highly altered comminuted material. The fragments are altered to a quartz-sericite-kaolinite assemblage, and tourmaline is completely absent. Fragment size is variable, but is generally less than 5 cm and averages approximately 2.5 cm. The comminuted material has been altered to a flakey clay-like mineral, or sericite. The comminuted material constitutes 25 percent of the breccia.

In comparison to the other breccias in the district, this breccia is distinctly abnormal with respect to the shape of its fragments and type of matrix, which suggests a different mode of origin. The sub-rounded to rounded fragments and matrix of small particles and comminuted material indicate significant particle attrition. As it is presumed that breccias containing rounded fragments vented at the surface (Gilmour, 1977), one may infer that the process of fluidization by gas streaming played an important role in the genesis of this pipe (Reynolds, 1954).

Genesis of the Bohemia Breccia Pipes

Gross similarities between the breccia pipes of the Bohemia District, with the exception of the Noonday breccia, suggests a common mode of origin and development. The four major stages in the developmental history of the pipes are as follows:

1) pervasive alteration of the country rock to a quartz-sericite aggregate, with or without tourmaline and the development of solution vugs;

2) brecciation with both rotational movement and differential separation;

3) fracture and open space filling by an early quartz-tourmaline assemblage followed by later deposition of colorless to yellow quartz; and

4) erosion and deep surficial oxidation and leaching of the pipes.

Although this is the general sequence, these stages are not equally developed in all of the pipes, and some stages may be absent from individual pipes. There may be considerable overlap between the first three stages because they may be both temporally and spatially related. Each succeeding stage took place at deeper levels within the pipe, and with time each transgressed farther upwards as the pipe developed.

Pervasive Alteration. Alteration is interpreted as having spatially preceded brecciation on the basis of its pervasive distribution in and around the shatter breccias. If the host rocks marginal to the shatter breccias were altered, it is likely that the rocks above the shatter breccias were also altered.

The clots of tourmaline, with or without solution vugs, which are disseminated within breccia fragments may have preceded brecciation, but this is not certain. Starbursts of tourmaline and associated solution vugs are found in fragments of the shatter breccias, and in the surrounding country rock, as at the Grouse Mountain breccia, indicating that this mineralization was early. However, in one instance breccia float was found that contained fragments which were altered to tourmaline around their margins indicating tourmaline alteration post-dated brecciation.

Solution vugs are always associated with starbursts of tourmaline. Because of the close association between vugs and starbursts, it is inferred that the vugs are related to the growth of tourmaline rather than tourmaline growing into preexisting vugs. This contention is supported by the morphology of the tourmaline starbursts within the vugs; particularly the large vugs which contain composite forms of the starbursts (Figure 12). The solution vugs could be a result of either inequalities in the mass balance of the reaction-replacement processes between the host rock and the hydrothermal fluids, or replacement which was not volume for volume.

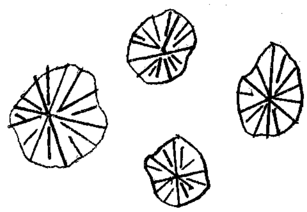
The location of the pervasively altered zones were initially controlled by two features; irregularities or cupolas in the roof of the crystallizing magma chamber which acted to concentrate hydrothermal fluids being exsolved by the magma; and zones of weakness in the roof rocks which channelled the flow of fluids upward.

Thus, pervasive alteration is believed to have taken place in the highest levels of the breccia pipes, preceeding brecciation. As successively higher levels collapsed to form breccias, the level at which alteration was then occurring would move up, implying that other highly altered zones in the Bohemia District may have "roots" associated with breccia pipes at depth. In the Cananea District of northern Mexico, Perry (1961) has reported that none of the breccia pipes are "blind" and that each could be shown to have some form of surface expression.

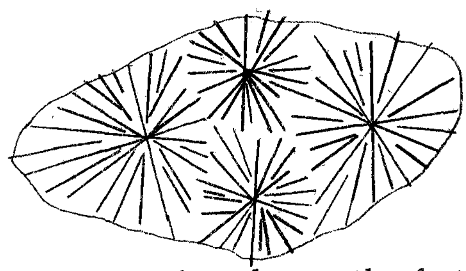
The Brecciation Event. The event which caused brecciation was such as to produce irregular, angular fragments without appreciable comminution. Furthermore, this event produced two styles of fragment motion, rotational and differential separation.

Sawkins (1969) has proposed a mechanism of chemical brecciation which he believes could have produced certain breccias in Tri-State lead-zinc deposits, as well as breccias associated with certain porphyry deposits. The brecciation process is thought to be related to expansive cracking during emplacement of a silica cement into fractures. However, this process is believed to be unlikely for the Bohemia District pipes because in certain breccia samples the matrix cement has been fractured and broken up simultaneously with the formation of new fragments. Chemical brecciation should only be effective within the fragments being brecciated. In addition, the presence of void spaces between fragments makes this process unlikely, because the process is dependent on an expansive force created by the cement between fragments.

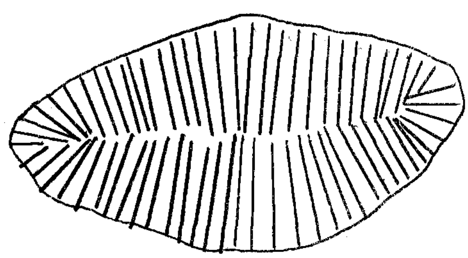
Brecciation, which resulted from a gradual collapse or settling, is a more plausible explanation for the breccia pipes of the Bohemia District. Upward movement of the fragments in the pipes would suggest that fluidization had occurred and that the pipes had reached the surface. These relationships imply that the shatter breccias are unrelated to the breccia pipes. However, the shatter breccias display an increasing degree of disturbance with increasing depth, indicating that they probably represent the uppermost portions of breccia pipes. Furthermore, the block caving method of mining, whereby the ore is induced to collapse into a void, produces results which are consistent with this hypothesis. Also, the similarities of these breccias to those of Chile, which have been well exposed in three-dimensions by mining activity, would indicate a similar origin. Previous work indicates that the Chilean pipes (Sillitoe and Sawkins, 1971) as well as the breccia pipes at Cananea, northern Mexico (Perry, 1961) have a collapse origin. Although an explosive origin has been proposed for these pipes by Emmons (1938) and Kents



A. Development of several small starbursts.



B. Continued growth of starbursts to form composite starbursts in a solution vug.



C. Expected configuration of tourmaline growing into pre-existing vugs.

Figure 12. Morphology of tourmaline starbursts with genetically related solution vugs as opposed to tourmaline crystals growing into pre-existing vugs.

(1964), this interpretation has been found to be untenable because many of the pipes are terminated without ever having reached the surface.

The mechanism of collapse is as yet uncertain, but it must involve the formation of a void or open-space to allow the downward movement and rotation of fragments. There are three major hypotheses which attempt to explain this: solution of the host rocks by corrosive fluids (Sillitoe and Sawkins, 1971); development of a large vapor "bubble" at the roof of the magma chamber exsolving the fluid and into which collapse eventually takes place (Norton and Cathles, 1973); and collapse initiated by an up and down pulsation of magma during the associated intrusive event (Perry, 1961).

The breccia pipes of the Bohemia District exhibit evidence in the form of hydrothermal solution vugs which tend to corroborate the solution hypothesis of Sillitoe and Sawkins (1971). Some breccia fragments contain up to 10 volume percent void space in solution cavities. If a sufficient volume of vugs were created at the base of the breccia pipe, the highly porous rock would be incapable of supporting the overlying rock column. This hydrothermally imposed weakness would result in periodic collapse or settling of the column over short vertical distances (Figure 13).

The common admixture of rotated and differentially separated fragments is most easily explained as a result of periodic settling.

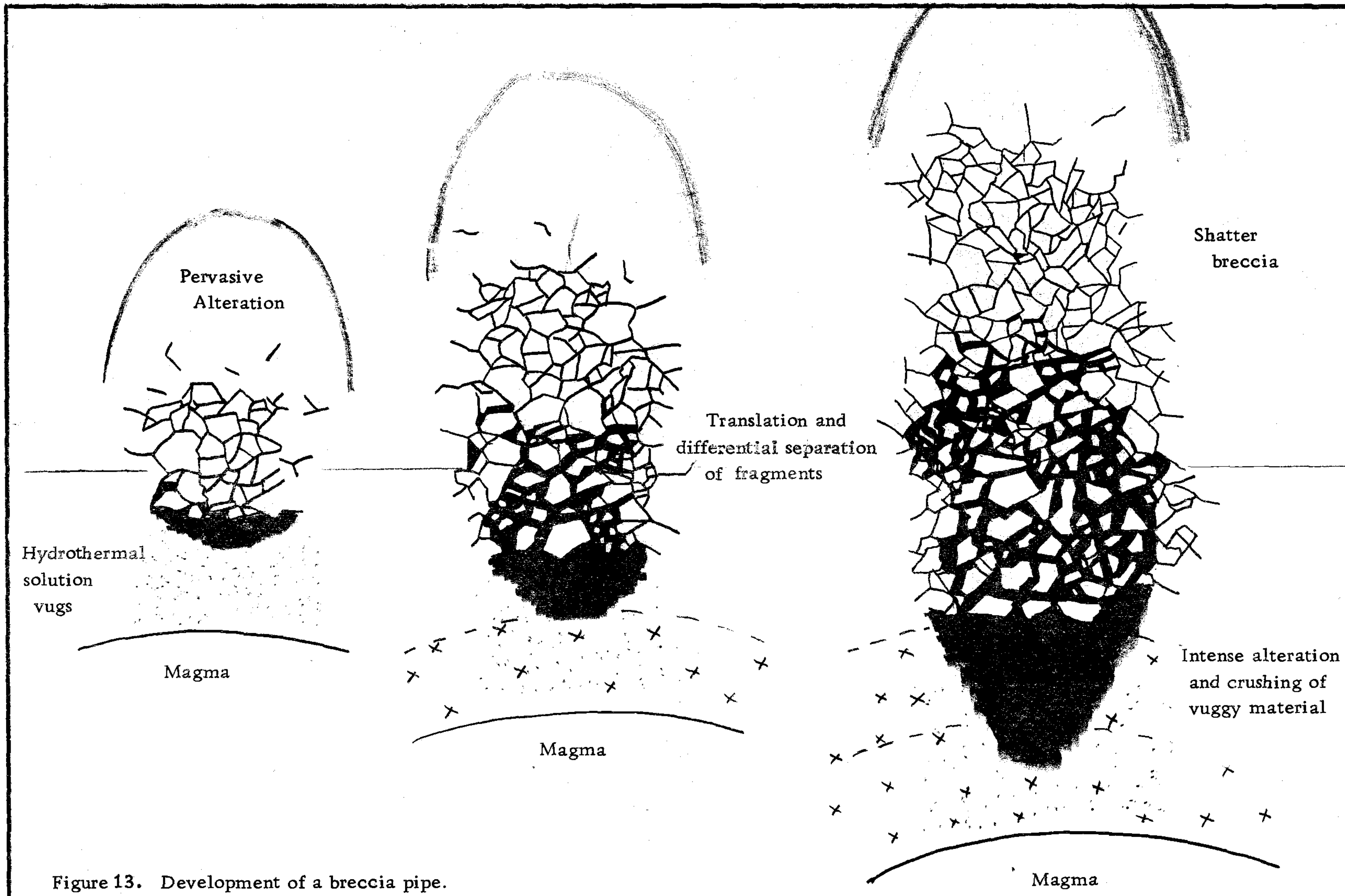


Figure 13. Development of a breccia pipe.

With each settling event, pre-existing fragments in the pipe would be further broken and most of the newly formed fragments would be translated only short distances from the "parent" fragment. During subsequent settling events, the degree of rotation and differential separation would increase as the distance from their point of origin increased. Thus, fragments which have undergone but small differential separation from their neighbors are interpreted to have formed during one of the late settling events prior to the cessation of movement within the pipe.

Fracture and Open-Space Filling. The open-space filling of the breccia matrix was generally initiated by deposition of black, schorlitic tourmaline, or a tourmaline-quartz admixture. Matrix deposition overlapped as well as post-dated brecciation in the Bohemia District. Evidence for this, although sparse, is present in the form of matrix cement which has been brecciated and rehealed, along with fragments of the country rock.

The early period of tourmaline-quartz deposition was followed by a later abrupt transition marked by the deposition of a colorless to yellow, transparent quartz. This quartz fills late fractures in both matrix and fragments, and forms well terminated crystals which project into voids. Some of these crystals may attain lengths of up to 2 cm, but are normally in the 2 to 8 mm range.

Specular hematite is found lining some cavities in the Champion breccia. Because of the scarcity of matrix cement in this breccia, the position of specularite in the depositional sequence is unknown. However, on the basis of its position in the vein deposits, the specularite is inferred to be contemporaneous or slightly earlier than the early tourmaline-quartz stage.

Erosion and Leaching. After volcanism in the Western Cascade Range had terminated, the region was deeply dissected by erosion. Because the district is located on the divide between the Willamette and Umpqua drainages, these rocks have been long exposed to processes of weathering. Consequently, oxidation and leaching of surface exposures has been complete with very little of the original sulfide mineralization remaining at the present level of exposure.

Comparison with the Breccia Pipes of Chile

The breccia pipes of the Bohemia District closely resemble those pipes located in the Andes of northern and central Chile, and therefore a comparison should be instructive. Unless otherwise noted, all information concerning the Chilean breccia pipes is from Sillitoe and Sawkins (1971).

The Chilean pipes are present in groups or clusters containing from two to more than one hundred breccia pipes. They are located in a north-south trending belt that is over 2,000 km. long. Most of the pipes cut small, granitic epizonal plutons of early Tertiary age, although some were emplaced in adjacent andesitic volcanics. The individual pipes range from 3 to 1,200 m in diameter and are circular or elliptical in plan view. Normally these pipes are oriented vertically to steeply dipping. The breccias are composed of fragments which are angular to sub-rounded and in some cases tubular. The fragments are compositionally similar to the host rock, although exotic fragments from below or above may be present. These pipes are bounded on their margins by zones of well developed vertical sheeting. At higher levels the pipes may be terminated by grading transitionally into a body of hydrothermally altered rock surrounded by sheeted zones. Small bodies of fine-grained, porphyritic felsic rock are closely related spatially and temporally to the brecciation.

The Chilean pipes exhibit two major types of hydrothermal mineralization, which include: an early replacement or alteration stage, followed by an open-space filling stage. Pervasive alteration of the fragments has produced quartz-sericite assemblages that may be associated with the introduction of silica and tourmaline. Open space filling commenced with the deposition of tourmaline and specularite. Later minerals to be deposited include quartz, scheelite, pyrite, molybdenite, galena and chalcopyrite, followed by late-stage anhydrite, barite and carbonates.

The major differences between breccia pipes of the Bohemia District and those of Chile involve the breccia-country rock contacts. The Chilean pipes have sharp contacts bounded by sheeted zones. Alteration rarely extends more than 3 m into the surrounding host. Although zones of sheeting have been observed in the Bohemia District, their relation to the breccia-country rock margin is obscure because of limited outcrop. In many cases the Bohemia pipes appear to have gradational contacts with the country rock, and they are usually located in zones of alteration which are large in comparison to the size of the pipe. Quartz-sericite alteration is the predominant type of replacement in both the Chilean pipes and those of the Bohemia District, and although the alteration is invariably intense in the Bohemia pipes, it varies from weak to intense in the Chilean pipes. These variations may depend on the level of observation for the different pipes. Sulfide mineralization cannot be compared because of the intense surficial oxidation and leaching of the Bohemia pipes.

Overall, the breccia pipes of the Bohemia District are closely comparable to those of Chile. The contrasts between these pipes are possibly a result of observing the pipes at different levels of erosion. Furthermore, these contrasts may have been magnified by comparing generalizations applied to hundreds of breccia pipes distributed throughout a major geologic province to the detailed observations of a few breccia pipes in a single mining district.

Alteration

Country rocks bordering ore deposits of hydrothermal origin are generally altered by the fluids which have passed through them. The alteration assemblages produced are dependent on: 1) lithology of the original rock; 2) the composition of the invading fluids; 3) the temperature and pressure at which the reactions took place. In addition, the physical and thermal environments generally vary as a function of distance from the center of mineralization, producing a zonal distribution of the alteration products. Three broad types of alteration mineral assemblages are recognized from high to relatively low temperatures, these being potassic, phyllic-argillic, and propylitic alteration respectively (Creasy, 1959; 1966; Burnham, 1962; Meyer and Hemley, 1969).

There are large areas of propylitically altered rocks in the Western Cascade Range, and they form a discontinuous north-south belt of regional extent. Assemblages of propylitic alteration in the Western Cascades commonly include albite, epidote, chlorite, quartz, carbonates, magnetite and pyrite (Peck and others, 1964). Additionally, many of these areas are associated with precious and base metal mining districts.

Pervasive Alteration

Within the area mapped, propylitic alteration is nearly ubiquitous, although this broad zone does contain smaller areas of higher grade alteration. The propylitic alteration has affected all of the minerals present in the volcanic and intrusive rocks except quartz. Alteration products include albite, epidote, quartz, pyrite, magnetite and sericite, along with minor zeolites. The zeolites are present in only a few small zones within the area mapped, and they are generally found as fillings of vesicles and miarolitic cavities. Excluding the zeolites, these alteration minerals are usually associated with each other although the absolute and relative amounts of each are highly variable. The primary ferromagnesian minerals, particularly the pyroxenes and amphiboles, were very susceptible to this low temperature alteration. Biotite was also unstable, but may remain as relicts in rocks in which the pyroxenes and amphiboles have been entirely replaced. Chlorite is the characteristic alteration product of these minerals. Many of the chlorite masses, which represent former ferromagnesian minerals, contain up to 5 euhedral crystals of pyrite or magnetite in their cores. Less commonly, the chlorite masses have cores of epidote.

Epidote, albite, carbonate and sericite are the characteristic alteration products of plagioclase feldspar. Although these minerals constitute trace amounts in all of the thin-sections studied, they do not become abundant until alteration of the ferromagnesian minerals was well advanced. Generally, the more calcic cores of the plagioclase feldspars were more susceptible to alteration than the marginal, more sodic plagioclase.

The intensity of propylitic alteration varies from weak to moderate in the flows and intrusions. However, the intrusions are generally more intensely altered than surrounding volcanic flows. This difference in alteration may be a result of either late deuteric alteration of the plutons, or that ascending hydrothermal fluids were preferentially channelled within the intrusive bodies.

Small zones of higher grade alteration are found locally throughout the area mapped and are shown on overlay E, Plate 2. These zones are characterized by intensely bleached rocks that are weakly stained by limonite, thus imparting an overall orangish appearance to the outcrops. The light coloration of these rocks is a result of intense alteration to quartz-sericite-kaolinite assemblages. These minerals are characteristic of argillic-phyllic alteration. However, it should be noted that the kaolinite may be a result of processes of surficial weathering rather than hydrothermal alteration. An unusual occurrance of quartz-sericite alteration is located in an altered zone on the ridge northeast of Fairview Peak (SW 1/4 of the NW 1/4 of sec. 12). Here the individual flakes of sericite are up to 1 mm in diameter, the largest observed in the area. Quartz-sericite alteration is most common in association with the breccia pipes and these highly altered zones are believed to represent a high level stage of hydrothermal activity associated with the origin of the breccia pipes.

Potassium silicate alteration was recognized only in alteration zones along the contact at the south and southeast margins of the Champion Stock. Hydrothermal potassium feldspar is the diagnostic mineral of this type of alteration. It is present in these rocks both as patchy replacements of plagioclase feldspar, and as veinlets. The plagioclase feldspar, in addition to having been altered to potassium feldspar, has also been replaced by sericite and carbonate. Trace amounts of epidote are also present in plagioclase feldspars. In addition chlorite has decreased in abundance to less than one-half to one-third of its average abundance in propylitically altered rocks. This chlorite is usually closely associated with biotite, and it may represent late alteration of the biotite. The biotite, which constitutes 2 to 6 percent of the rock, is believed to be of hydrothermal origin because of its presence as finely crystalline aggregates. Magnetite and pyrite are more abundant in these potassically altered rocks relative to their propylitically altered equivalents. Tourmaline is also a relatively common hydrothermal phase of this alteration zone, constituting from trace amounts to 7 percent of the rock. The tourmaline is present both as individual crystals and starbursts disseminated in the host rock, and as veinlets.

Fluid Inclusions. There are two major types of fluid inclusions. Both types appear to be primary and they are found in quartz associated with the potassium silicate alteration. The most common type of inclusion consists of only vapor and liquid phases. Although these are predominantly of a vapor-rich variety, the ratio of vapor to liquid in these inclusions is highly variable. Approximately 70 percent of these inclusions have vapor to liquid ratios greater than 8. Roedder (1971) has proposed that such vapor rich fluid inclusions represent a "steam" phase derived from the boiling of aqueous liquids within the hydrothermal system. The other type of inclusion is highly saline, consisting of liquid, vapor and solid phases. The solid phase is probably halite. This assumption is based on crystal morphology and from the relative abundances of the common minerals contained in fluid inclusions as determined in other studies (Roedder, 1972). Halite is the most common mineral phase in fluid inclusions, and it is usually volumetrically dominant in those containing more than one mineral. Other minerals noted in inclusions of the Bohemia District, in order of abundance, include sylvite and an opaque phase that is possibly hematite. In some cases, CO_2 vapor is also thought to be a component of these inclusions. The second type of inclusions have much lower vapor to liquid ratios, varying from approximately 0.2 to 0.05, than the vapor-liquid inclusions.

The paragenetic relationship between the vapor-rich and highly saline fluid inclusions could not be established from these studies. Nonetheless, it is of interest that Chivas and Wilkins (1977) have noted that highly saline inclusion fluids, which contain halite, sylvite, hematite and sometimes anhydrite, appear to be characteristic of porphyry copper-molybdenum environments; especially when accompanied by abundant vapor-rich inclusions.

Vein Alteration

The alteration zones associated with veins are very narrow, and are usually restricted to selvages within a couple of meters of the veins. Typically, the alteration consists of an inner zone of bleached, punky or disintegrated and highly argillaceous rock. It is composed predominantly of kaolinite, microcrystalline quartz, and rarely sericite. With increasing distance from the vein, the host rock becomes more competent, but remains bleached. Sericite and pyrite are much more prominent in this zone. Alteration in the andesites may "leak" out along fractures transecting the vein for distances up to several meters beyond the average limits of alteration. In contrast, the primary porosity of tuffs was sufficiently great that minor fractures did not significantly control alteration.

MacDonald (1909) has noted that at greater depths the inner punky zone contains an abundance of sericite and calcite with very little associated kaolinite. Lutton (1962) suggested that the kaolinite is supergene and a product of the acid environment associated with the oxidation of pyrite. Evidence for such an acid environment in the inner zone is supported by the presence of cubic, limonite-stained molds, without pyrite, which indicates that pyrite was formerly present but has since been oxidized to limonite with the sulfur released to form acid waters.

Tourmaline may be associated with vein alteration. Where present, it is generally located in the inner zone, but only rarely with the punky, oxidized host rock. The tourmaline is present as starbursts, which are both disseminated and along fractures in an argillized host rock. Tourmaline alteration of this type is found around the adit of the Diamond crosscut of the Champion mine, extending outward for approximately 5 meters from either side of the adit. This occurrence is noteworthy because the tourmaline has been partially replaced by pyrite that forms perfect pseudomorphs after the host mineral. Thus, the deposition of tourmaline appears to have preceded that of pyrite at this locality.

Trace Element Geochemistry

Differentiation has been defined as a process whereby more than one rock type is formed from a common homogeneous source. This may be accomplished either by fractional crystallization or by fractional melting. Differentiation leads not only to changes in the abundances of major and minor elements, but also to those of the trace elements as well (Levinson, 1974). To avoid complications caused by different background concentrations, the samples used for trace element geochemistry were restricted to the felsic intrusions. Because there has been a small degree of differentiation between these intrusions, the trace element values for Cu, Zn, and Pb were plotted against SiO_2 content to determine if there were any significant systematic variations among the different intrusive phases. As the results of this test were negative, it may be concluded that either the extent of differentiation between the intrusive phases was insufficient to produce significant changes in the background concentrations of the trace elements, or that any differences originally present were obliterated by later hydrothermal overprinting.

Trace element concentrations for copper, lead, zinc, molybdenum and silver were determined for 44 samples in the Bohemia District. The average background trace element values and ranges are given in Table 3, along with values for the Sierra Nevada Batholith (Dodge, 1972), the "average" granodiorite (Turekian and Wedepohl, 1961), Caribbean intrusions (Kesler and others, 1975),

Table 3. Trace element data for the Bohemia District, Sierra Nevada Batholith, the Guichon Batholith, Caribbean intrusions and the "average" granodiorite.

	Bohemia		Sierra Nevada*		Average Granodiorite**	Caribbean Intrusions***		Guichon Batholith		
	Average	Range	Average	Range	Average	Average	Range	Average#	Average##	Range##
Cu	26	11-95	20	---	30	61	3-375	50	46.2	5-150
Zn	89	25-430	--	12.5-37.5	60	50	11-175	55	30.0	30-50
Pb	18	3-110	10	---	15	7.5	2-29	--	9.6	10-35
Ag	0.8	.3-2.5	--	1-30	.07	--	---	--	.3	-.1-.4
Mo	1.4	-1-20	--	---	1	--	---	--	1.5	1-3

metal values in ppm

* Dodge, 1972
** Turekian and Wedepohl, 1961
*** Kesler, Jones and Walker, 1975
# Brabec and White, 1971
Field, personal communication, 1977.

and the Guichon Batholith (Brabec and White, 1971; Field, personal communication, 1977) for comparison. Note that the Caribbean intrusions are those which are associated with porphyry copper mineralization, although the rocks sampled were unaltered.

The average values for zinc, and to a lesser extent, lead in the Bohemia intrusions are high in comparison to all other localities. In contrast, the average copper value is comparable to the Sierra Nevada Batholith and the "average" granodiorite, although it is much lower than those plutons with associated porphyry copper mineralization. Values for molybdenum and silver average 1.4 and 0.76 ppm respectively, which are essentially the same as the values given for the "average" granodiorite.

The degree of trace element enrichment or depletion relative to the "average" granodiorite compares favorably with the relative quantities of these base metals in sulfides contained in the vein deposits. In order of abundance the sulfides are sphalerite, galena, and chalcopyrite.

The frequency distributions of copper, lead, zinc and silver were determined by plotting on probability graph paper the metal concentrations versus the cumulative frequencies of cluster samples (Figure 14). The diagramatic expression for a simple lognormal sample population plotted on probability graph paper is a straight line. However, it has been shown from theoretical considerations

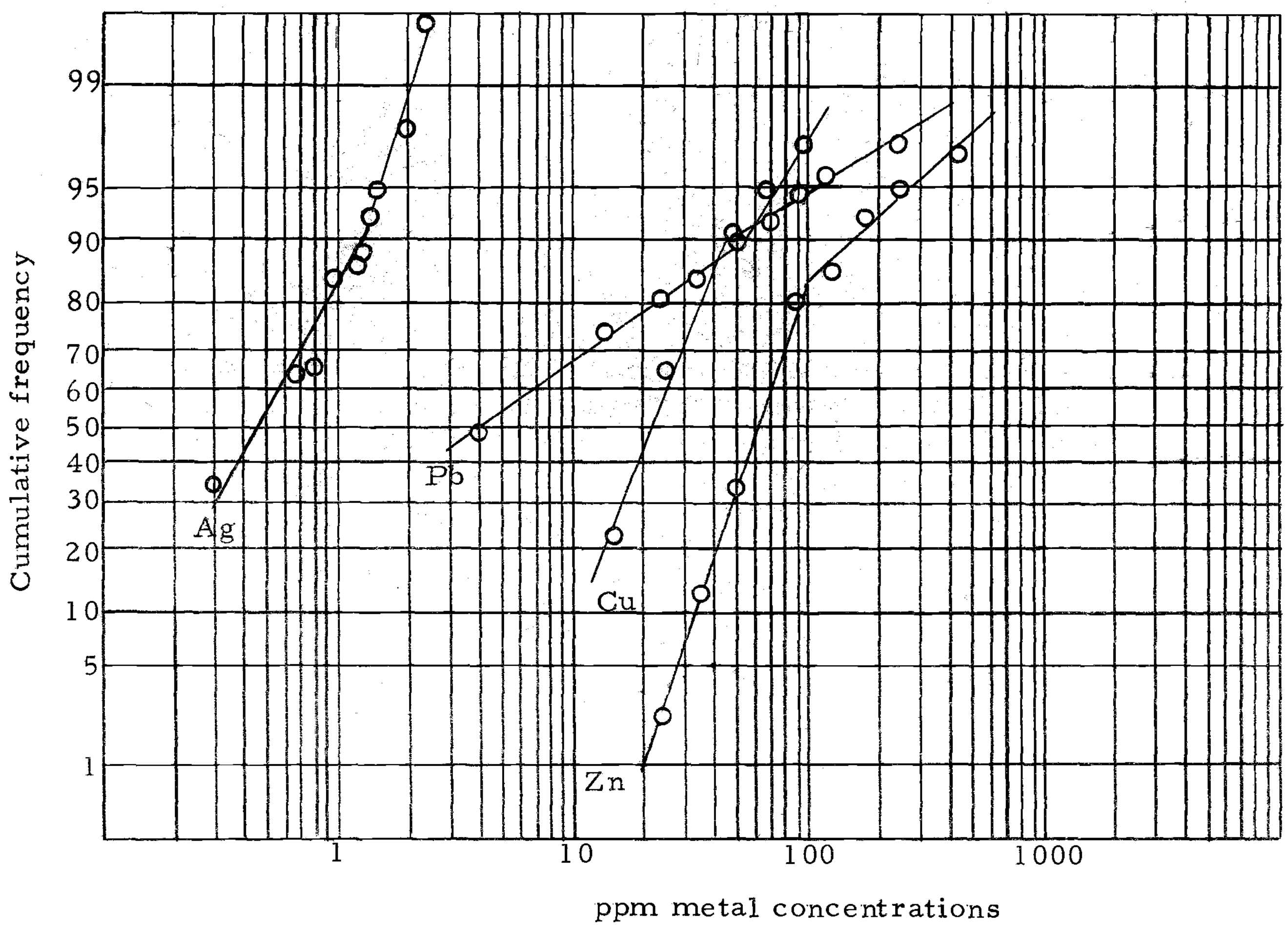


Figure 14. Cumulative frequency distribution of copper, lead, zinc and silver.

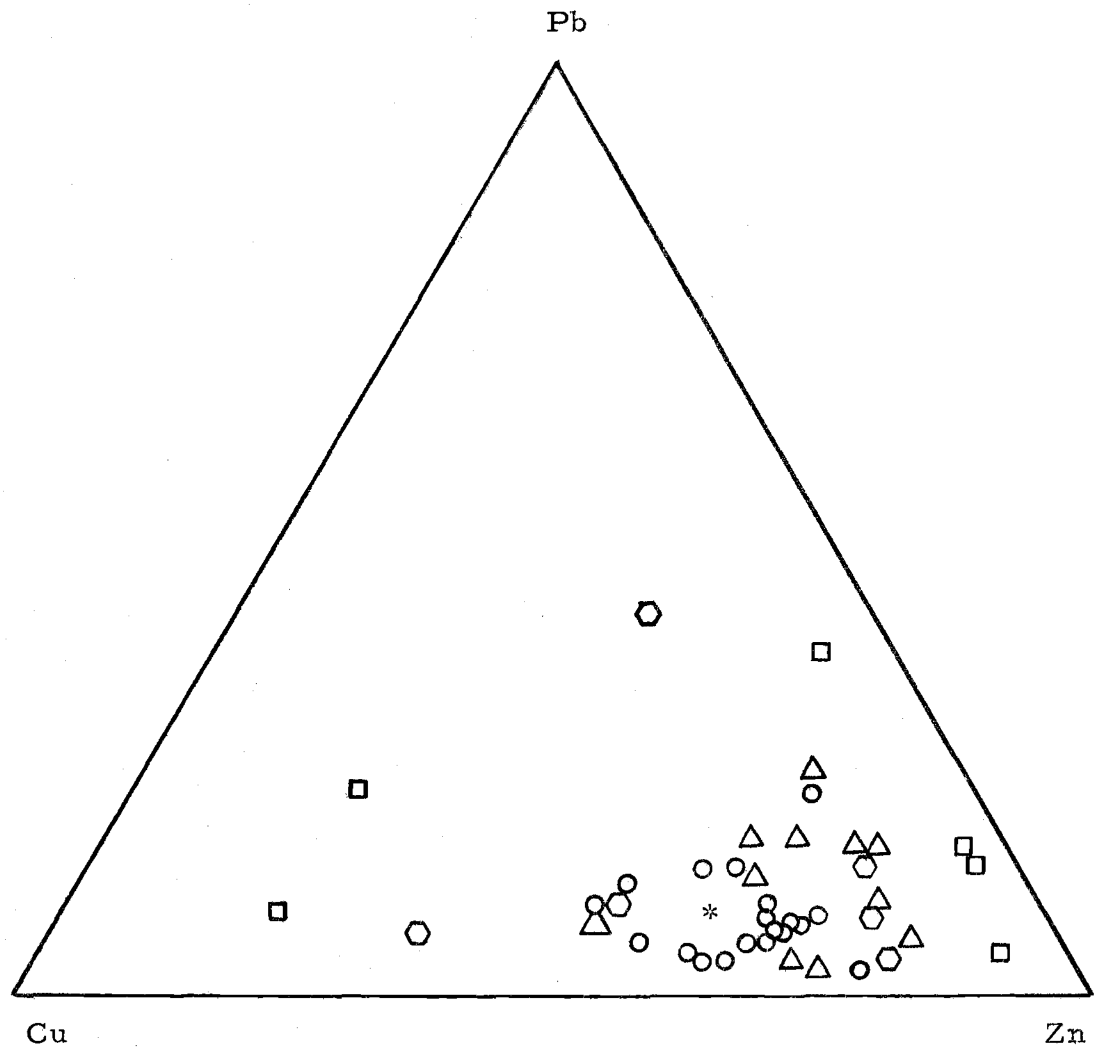
and practical application that plots derived from cumulative frequencies of multi-modal or complex populations are characteristically expressed as two or more distinct line segments. The breaks in slope, or inflections, between line segments define the separate sample populations (Tennant and White, 1959; Lepeltier, 1969).

Well-defined inflections for copper, lead and zinc values are portrayed in Figure 14, although the inflection for silver is poorly defined. The presence of such well-defined inflections suggests at least two populations of metals in these samples. The lower population probably represents the syngenetic or primary magmatic content of these metals (background) in the felsic intrusive rocks, whereas the upper populations are suggestive of an epigenetic hydrothermal contribution of these metals. Samples which were oxidized and leached were not analyzed for trace element geochemistry. However, they would probably constitute a third population related to low temperature surficial processes whereby the original and introduced metal content was leached to values of less than normal background concentration.

In Figure 14 the plots of copper and zinc show negative inflections in contrast to the lead and silver plots which have positive inflections. Thus the logarithmic distributions of copper and zinc are skewed in favor of high values, whereas those of lead and silver are skewed in favor of low values. Because the copper, zinc, lead, and silver data was obtained from the same set of rock samples, it is probable that the same process that was responsible for causing the copper and zinc plots to be positively skewed, caused the lead and silver plots to be negatively skewed. This effect can be tentatively explained by mineral zoning and metal mobility in the hydrothermal system. Lead and silver are more mobile than copper and zinc in hydrothermal solutions and therefore are deposited marginally with respect to the latter metals. In the environment of copper and zinc deposition lead and silver minerals would be relatively unstable. Thus, it is possible that the syngenetic lead and silver in the core of the district was remobilized and redeposited in a peripheral location, resulting in a depletion of lead and silver in the core area.

The copper, lead and zinc data were plotted on a ternary diagram by recalculating these metal values to 100 percent. In addition, the sample points are also distinguished on the basis of total metal content (in ppm).

The distribution of samples in this diagram shows a strong preference for the copper-zinc boundary or join of the diagram, indicating that of the base metals present, lead is quantitatively minor. Of interest is the distribution of the total metal concentrations. The background metal concentrations tend to be clustered around an average value, designated as an asterisk on Figure 15.



Total metal concentrations in ppm.

□ > 250
⬡ 151-250
△ 100-150
○ < 100
* Average background

Figure 15. Cu-Pb-Zn ternary diagram.

This point represents 30 percent copper, 60 percent zinc and 10 percent lead. With increasing total metal content of the samples, the points are arranged concentrically outward from the central low values. The dense cluster of low total metal concentrations represents the final ratios and concentrations of copper, lead and zinc in the magma when it crystallized because these same samples constitute the syngenetic population shown by the cumulative frequency distribution diagram (Figure 14). However, hydrothermal addition of metals did not occur as a constant ratio, which caused the higher value points to lie radially outward from the central low values. This effect was probably produced and controlled by thermal zoning and by local physical and chemical environments which favored the deposition of one metal in preference to the others.

The spatial distribution of copper, lead, zinc and molybdenum are shown on Plate 2 by overlays A, B, C, and D. The geochemical data is confined to a north-south zone through the center of the area as a result of limiting samples to felsic intrusive rocks. The silver data are not illustrated because the values were too erratic to be generalized by contours. Contour intervals for the metal concentrations were determined on the basis of representing the data in the simplest form.

The overlays show that the metals are zoned both laterally and possibly vertically across the center of the area. Lead values increase to the west, copper values increase to the east, and zinc values reach a maximum between the copper and lead highs, although with slight overlap with the lead anomaly. The lead and zinc anomalies are located at the higher central parts of the district.

The reliability of the copper anomalies is suspect because they are one-sample anomalies. However, they are consistant with the trend of increasing copper values to the east. It is significant that the copper anomaly located along the stream in sec. 1 overlaps the molybdenum anomaly, and that both of these geochemical highs are coincident with an area of potassium alteration. These coincident features are internally consistent with each other and indicate that this anomaly is probably real. They are all characteristic of the inner, high temperature part of a hydrothermal system (Lowell and Guilbert, 1970).

The mobility of ore metals in a transporting hydrothermal fluid generally follows the sequence Hg-Pb-Zn-Cu-Sn-Ni-Fe-Co in order of decreasing mobility (Barnes and Czamanske, 1967). Mobility is not related to the solubilities of the ore minerals, but rather is a function the stabilities of the metals as complex ions or molecules. The west-east zoning of lead-zinc-copper in the district duplicates a portion of the above sequence. This zoning implies that the source of metallization was located at depth in east or northeast parts of the area. However, vertical zoning may also be important, because the copper-molybdenum anomaly is located at a significantly lower elevation than the lead and zinc anomalies. Therefore, the position of the copper-molybdenum anomaly may be partially a function of an altitude control.

Economic Potential of the District

Although the district has not been actively mined since the 1950's it is highly unlikely that all of the ore has been discovered. The fact that the ore is located in shoots or lenses, separated by barren zones, would tend to discourage development of a vein if a barren zone were encountered initially. Furthermore, the presence of large areas of dense, nearly impenetrable underbrush, as well as the rugged terrain, have possibly prevented the discovery of many other veins.

Electromagnetic geophysical methods should be of great use in exploring for these hidden veins. Another exploration method with some potential is vapor surveys, particularly soil vapors. Hg, H_2S, and SO_2 are enriched above sulfide deposits (Levinson, 1974).

In spite of the great potential to locate new vein deposits in the district, it is unlikely that the effort will be taken, or that active mining of the veins will take place again because of present economic conditions. Although the price of gold has increased to more than 7 times its value during most of the production period, the cost of exploration, development and operations have increased even more rapidly. During its heyday, the district survived more on hopes and dreams than on profits. It is probable that in the future, as today, mining of these deposits will be limited to weekend "recreational" miners.

Aside from the vein deposits, the district unquestionably has potential in terms of low-grade disseminated base metal deposits. The similarity of the breccia pipes of the district to the mineralized pipes of Chile, as well as the presence of copper bearing breccia pipes in the Skamania District of southern Washington, would indicate that they may be mineralized at depth. Furthermore, Gilmour (1977) has proposed that breccia pipes which contain copper, or other metallic minerals, or limonite derived from the oxidation of sulfide minerals, probably overlie buried or concealed porphyry copper systems. This assumption is based on the close association of breccia pipes with porphyry copper mineralization. The potential for low-grade mineralization in the Bohemia District has been recognized by several major mineral companies, one of which spent two months during the summer of 1976 staking claims, performing geophysics and detailed mapping, and diamond drilling targets later that fall.

GEOMORPHOLOGY

Extensive erosion by alpine glaciers took place in the Bohemia District and evidence for it is widespread throughout the area mapped. The glaciers occupied a valley system that was already well developed prior to the beginning of glaciation. It is probable that this glacial episode was part of the Late Wisconsin Glaciation which climaxed about 18,000 years ago (Flint, 1971).

Cirques are common above 4500 ft. elevation, and are located in the source areas of most streams in the district. U-shaped valleys can be found in the upper portions of some stream valleys where post-glacial erosion has not yet modified this characteristic shape. Glacial alluvium of a lateral moraine can be found up to an elevation of 4300 ft. in the Champion Creek valley at North Fairview Mountain. The valley glacier, at this point, would have been nearly 450 ft. thick and 0.4 miles wide.

Glacial features are particularly well preserved along the course of Crystal Creek. A series of four basins and steps have been developed in this valley from the cirque on the northeast side of North Fairview Mountain at an elevation of over 5200 ft. down to an elevation of 4200 ft., where this glacier presumably merged with the glacier in Champion Creek. Glacially polished and striated surfaces on andesite are preserved in areas which have been protected from weathering until the very recent past. A moderately well-developed stoss-and-lee topography of whaleback forms is obvious in the second basin at an elevation of 4600 ft.

In post-glacial times rapid downcutting by streams has been and remains to this day the major agent of erosion in the district. The area contains features characteristic of both youthful and mature stages of erosion according to the idealized fluvial cycle of Thornbury (1954). Youthful characteristics include: (1) V-shaped valleys, except where modified by glaciation; (2) lack of flood plains except along trunk streams; (3) valley sides which rise from the stream edges; (4) widespread presence of waterfalls and rapids; and (5) lack of meanders. Mature characteristics include: (1) maximum possible relief; (2) stream divides which are sharp ridges; and (3) the region has a well integrated drainage system. Although the area contains more characteristics common to a youthful stage than to a mature stage, the mature characteristics (1) and (2) are very significant in classifying the general morphology as mature.

GEOLOGIC SUMMARY

Continental arc type magmatism has been localized along the western margin of Oregon and Washington from Eocene time until the present. This magmatic activity formed the volcanic mountain chain known as the Cascade Range. The volcanic rocks of the Bohemia District represent a portion of the Little Butte Volcanic Series, which was deposited as a series of volcanic pulses from the beginning of Oligocene time to the middle of Miocene time.

In the Bohemia District, the earliest volcanism took the form of pyroclastic eruptions. The lower section of volcanic rocks is comprised primarily of crystal tuffs, lithic tuffs, lapilli tuffs and volcanic breccias. Although the pyroclastic material was erupted subaerially, reworking and redeposition under fluvial conditions was common. Widespread remains of fossil vegetation in these units suggest periods of volcanic quiescence, which lasted a minimum of several hundred years.

Subsequent volcanism in the area consisted of massive flows of interstratified andesites and basalts, with minor flows and domes of dacite porphyry. Dikes and irregular intrusive bodies which are chemically and lithologically similar to the flows of andesite and basalt, cut the pyroclastic rocks. These intrusive bodies probably represent feeders for the upper volcanic flows.

The later stage of volcanism was separated from the earlier pyroclastic stage by a hiatus, in which up to several hundred meters of relief was developed on the underlying pyroclastics. Into this dissected terrain the later flows were extruded. Initially these flows filled the canyons, and finally they buried the terrain entirely.

Small scale warping took place continuously throughout the deposition of both the pyroclastics and the flows, which lead to the development of folds having small amplitudes and local, low-angle unconformities. This deformation is inferred to have been caused by local subsidence and uplift as shallow subvolcanic chambers were vented or filled.

Subsequent to the deposition of the Little Butte Volcanic Series in the district, a quartz diorite-grandiorite pluton intruded the volcanic pile. The time of this event is uncertain, but is probably Miocene, as based on ages inferred for other similar plutons in the Cascades. Lutton (1962) estimated that approximately 3000 ft. of volcanic cover overlay this intrusion at its maximum level of emplacement. Within the district there is no evidence of contemporaneous or cogenetic volcanism associated with this plutonic event preserved at current levels of exposure. The pluton, of which the Champion Stock is but a part, is believed to be largely unexposed, and the small plugs and dikes of similar chemistry and lithology are interpreted to be upward and laterally protruding apophyses.

The general north-south trend of the intrusions in the Bohemia District parallels the axis of an anticline which is exposed in the southern part of the area. The trend of these intrusions was possibly inherited from deep-seated basement structures (Lutton, 1962). However, it may also have been partly controlled or accentuated by the anticline.

The stock is composite and is composed of three or more plutonic phases. These include a granodiorite, a quartz monzonite, and an aplite. The granodiorite phase was early and is located on the margins of the Champion Stock. This phase also constitutes the majority of other small felsic plugs in the area. The quartz monzonite phase is inferred to have been later than the granodiorite phase because it occupies the central portions of the Champion Stock, and it is chemically more felsic. Lutton (1962) observed discordant plutonic contacts between texturally distinguishable phases of the stock, which supports the concept of discrete plutonic phases. The latest recognizable plutonic phase was a felsic aplite, composed predominantly of quartz, oligoclase and potassium-feldspar, and emplaced as small dikes.

As crystallization of the pluton progressed, a hydrous phase exsolved from the magma. This phase consisted predominantly of water, but included significant concentrations of other components. The aqueous fluids initially became concentrated in cupolas near the top of the magma chamber. Gradually the fluids moved outward and upward from the cupolas in response to thermal and pressure gradients.

Pervasive hydrothermal alteration of the pluton and host volcanic rocks took place as these aqueous fluids moved away from the cupolas. The entire district shows the effects of propylitic alteration, which locally contains smaller zones of higher grade quartz-sericite alteration. The zones of higher grade alteration are generally coincident with zones of structural weakness, such as breccia pipes. Only one zone of potassic alteration was recognized in the area, located at a low elevation in a valley. This alteration is significant because it coincides with anomalously high trace element concentrations of copper and molybdenum. These features are characteristic of the inner, higher temperature core of hydrothermal systems.

The hydrothermal fluids became increasingly concentrated along fissures and fractures with distance from the source area, because these structures facilitated movement. With changing physical and chemical environments during transport of the fluids, different mineral species became unstable in solution and precipitated to form the vein deposits of the district.

Mineral zonation is not prominent in the veins because the fluids were mobile in them. The most notable zonation is the localization of coarse specular hematite in the core of the district, whereas stibnite is at the margins of the principal mineralized area. Although gold was the dominant economic component, the deposits are best classified as base metal veins. The most important metallic constituents are zinc, lead and copper, which are present primarily as sphalerite, galena and chalcopyrite respectively, although these metals are also present in other minerals. The principal gangue mineral is quartz, which may be present in a variety of forms ranging from large euhedral crystals, through finely crystalline crusts, to microcrystalline colloform masses. Other gangue minerals include calcite, dolomite, pyrite, barite, chlorite and other clays.

The veins have two principal orientations. The dominant vein set trends approximately N. 65° W. and the secondary cross-veins trend approximately N. 20° E. The primary orientation is the same or similar to that of the major veins in other mineral districts in the Cascades. Because of this similarity, the N. 65° W. vein set is thought to be a result of a major regional stress. The secondary cross-veins are parallel to the axis of the anticline, which indicates that these veins are tensional features related to the development of the anticline.

The fissures, in which the veins were localized, were tectonically active during the period of hydrothermal activity. This is evident from breccias composed of both vein material and country rock, which have been healed by subsequent hydrothermal activity. This tectonic activity may have resulted from regional stresses which were contemporaneous with the mineralization, or more likely from adjustments caused by movement of magma at deeper levels in the stock.

Concurrent with vein mineralization was the development of the breccia pipes, of which there are a minimum of eight in the area mapped. These bodies are roughly cylindrical in shape, and vary from 3 m to over 100 m in diameter. Many of the breccia pipes grade upward into shatter breccias marked by zones of highly fractured rock with little displacement. The constituent fragments of the breccias are composed of indigenous country rock. The fragments are angular and range from 1 mm to 0.5 m in diameter. The breccias are cemented by an admixture of quartz and tourmaline, and some additionally contain late-stage quartz that is pale yellow in color. Limonite stains are widespread throughout the breccia pipes and clearly indicate that sulfides were present prior to surficial oxidation.

Both the breccia fragments and surrounding country rock have been intensely altered to an assemblage of quartz-sericite±tourmaline. Because of the pervasive imprint of this alteration, it is difficult to determine the direction of movement of the fragments relative to the host rock. However, because the breccia pipes are roofed by shatter breccias, two inferences can be made: 1) the breccia fragments underwent little movement relative to the country rock; and 2) that the breccia pipes originated by collapse.

The geologic process responsible for collapse is not clear, and all explanations to date are inadequate. There are three major hypotheses which attempt to explain collapse: (1) intense solution of host rocks by corrosive fluids (Sillitoe and Sawkins, 1971); (2) development of a large vapor "bubble" at the roof of a magma chamber (Norton and Cathles, 1973); and (3) collapse initiated by up and down pulsation of magma during an associated intrusive event (Perry, 1961). The solution hypothesis of Sillitoe and Sawkins (1971) best fits the breccia pipes of the Bohemia District in that these pipes contain hydrothermal solution vugs indicating a corrosive fluid.

Oxidation of the mineral deposits commenced when erosion had dissected the district to sufficient depths to lower the water table below the level of the veins. However, secondary minerals resulting from the oxidation of primary sulfide minerals are relatively uncommon. This is because mechanical weathering (erosion) has proceeded more rapidly than chemical weathering (oxidation and leaching), as is suggested by the mature topography in the area.

Erosion of the Bohemia District to date has exposed only the high level portions of this altered and mineralized hydrothermal system. Several lines of evidence suggest that the system continues with depth below the currently exposed level of erosion. These included: (1) the irregular occurrences of small areas of higher grade alteration which are coincident with zones of structural weakness (breccia pipes), and (or) are located at low elevations; (2) trace element zonations of copper, lead, zinc and molybdenum, that indicate that most of the district lies in the upper and outermost lead-zinc halo; (3) the abundance of shatter breccias throughout the central part of the district. In addition, geological and geochemical evidence, that includes alteration patterns, fluid inclusions, breccia pipes, and mineral and trace element zonations, collectively suggest that porphyry-type mineralization is present at depth.

Fluvial erosion and mass wasting from late Tertiary time to the present has resulted in the formation of a highly dissected terrain with over 500 m of relief. Alpine glaciation took place at topographically higher parts of the district during Pleistocene time. The conspicuous morphological effects of these glaciers are U-shaped valleys, lateral moraines, and scoured outcrops, but these superficial features are presently being destroyed by fluvial processes.

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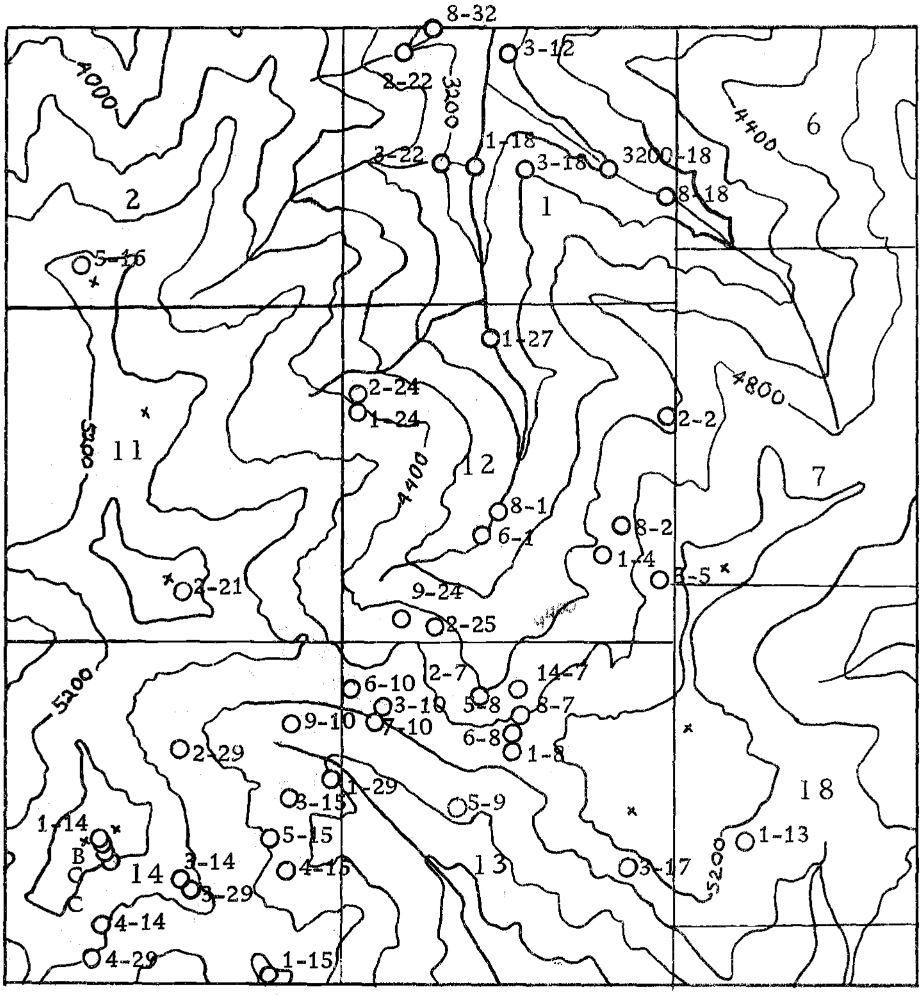
APPENDICES

APPENDIX 1



Locations of samples discussed in the thesis.

APPENDIX 2

Geochemical Data

Sample #	Ag ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm
5-1	2.0	250	6	100	95
6-1	.3	25	1	8	35
8-1	.3	20	1	7	60
2-2	1.0	30	1	5	80
1-4	1.0	25	< 1	7	65
3-5	1.0	50	< 1	9	60
2-7	.7	35	1	20	170
8-7	.3	25	< 1	4	35
9-7	1.0	310	< 1	40	85
10-7	.3	13	1	19	55
11-7	.3	11	< 1	6	25
14-7	1.0	25	< 1	6	120
1-8	.7	25	< 1	10	65
5B-8	.7	30	1	4	55
5C-8	1.4	30	< 1	4	90
6-8	1.4	25	< 1	18	65
5-9	1.0	20	1	13	100
2-10	1.0	20	< 1	3	75

APPENDIX 2 (Continued)

Sample #	Ag ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm
3-10	1.5	20	1	5	50
6-10	1.3	15	< 1	55	280
7-10	.8	20	< 1	6	55
9-10	.7	16	1	7	95
3-12	.7	30	< 1	15	75
3-14	.3	65	< 1	17	85
4-14	1.2	18	1	8	60
3-15	.7	25	< 1	5	55
4-15	.3	25	< 1	6	30
5-15	.3	25	1	12	50
1-18	.7	20	1	35	90
2-18	.7	35	1	25	480
8-18	.3	95	20	11	55
3200-18	.3	30	3	4	60
2-22	.3	20	1	3	35
3-22	.4	35	< 1	70	65
1-24	.7	20	1	18	65
2-24	2.5	17	1	20	85
6-24	.3	20	< 1	110	165
9-24	.3	30	< 1	30	150

APPENDIX 2 (continued)

Sample #	Ag ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm
1-27	.3	13	< 1	18	80
1-29	.3	19	1	75	430
3-29	.7	19	1	6	55
4-29	.7	16	< 1	5	40
Average	.76	38.62	1.37	20.21	95.83

APPENDIX 3

Complete major oxide chemistry of plutons

Sample No. Constituant	6-1	8-1	1-4	3-5	8-7	14-7	6-8	7-10	9-10	3-12
SiO_2	62.5	64.3	64.0	57.6	64.8	63.4	63.5	59.3	64.8	55.8
TiO_2	.90	.85	.90	1.0	.90	.95	.90	1.10	.80	.95
Al_2O_3	16.1	16.0	16.2	16.9	15.7	16.0	15.9	16.2	15.6	17.7
FeO	6.6	6.0	6.2	8.0	5.6	6.5	6.4	7.4	5.6	8.3
MgO	3.1	3.1	2.3	4.8	2.5	3.3	2.8	3.9	2.8	5.0
CaO	5.7	5.2	5.1	6.6	4.5	4.3	5.1	5.5	3.9	7.6
Na_2O	3.5	3.4	4.1	3.7	4.1	3.4	3.9	3.5	3.8	3.7
K_2O	1.85	1.70	1.65	1.20	2.10	1.90	1.85	1.60	2.45	1.25
Total	100.25	100.55	100.45	99.80	100.20	99.75	100.35	98.50	99.75	100.30

Sample No. Constituant	3-15	4-15	5-15	8-18	2-22	1-24	9-24	1-29	3-29	4-29	8-32
SiO_2	60.8	60.0	66.3	70.5	66.5	61.0	60.5	61.0	51.6	60.5	65.3
TiO_2	1.00	1.05	.80	.80	.80	.85	1.00	.90	1.30	1.30	.75
Al_2O_3	16.4	16.9	15.4	14.4	16.2	16.0	16.2	16.5	18.9	17.9	14.6
FeO	6.6	7.6	5.8	3.9	6.8	7.0	7.3	7.0	9.5	4.6	5.6
MgO	3.6	4.8	2.2	1.0	2.7	4.2	3.6	4.0	5.4	1.0	1.9
CaO	5.4	4.9	3.9	4.2	3.0	5.5	4.6	5.4	8.9	5.4	4.4
Na_2O	3.7	3.4	3.6	3.5	2.1	3.2	3.2	2.8	3.4	4.3	4.0
K_2O	2.05	1.70	2.55	.95	2.70	1.55	2.70	2.50	.95	2.15	2.05
Total	99.55	100.35	100.55	99.25	100.80	~~99.80~~ 99.30	99.10	100.10	99.95	97.15	98.60