AN ABSTRACT OF THE THESIS OF

James Peter Olson for the degree of Master of Science

in Geology presented on June 1, 1978

Title: GEOLOGY AND MINERALIZATION OF THE NORTH SANTIAM MINING DISTRICT, MARION COUNTY, OREGON

Abstract approved: Redacted for Privacy

Cyrus W. Field

The North Santiam Mining District is located approximately 50 km east of Salem in the Western Cascade Subprovince of Oregon. Although the district has produced only $10,000 in metals and all mines are now presently dormant, the presence of widespread hydrothermal alteration and mineralization of a type associated with many porphyry copper-molybdenum deposits now renders this area above average in exploration significance.

Bedrock in the district consists of flow and pyroclastic volcanics of the Miocene Sardine Formation that have been intruded by dikes and plugs of diorite, quartz diorite, quartz monzodiorite, and granodiorite. The volcanic rocks in the center of the district were domed upward during the emplacement of these intrusions. An alkali-lime index of 60.5 for these plutonic rocks indicates they are representative of a highly calcic calc-alkalic sequence of magmatism. In addition, their distribution on AFM and NKC diagrams is atypical compared with normal calc-alkalic trends. These plutonic rocks are

deficient in K_2O and potassium feldspar relative to average rocks of similar modal composition, and they are chemically and mineralogically similar to plutons associated with porphyry-type metallization in island arc environments.

Hydrothermal alteration and mineralization were closely associated in time and space with the emplacement of the youngest intrusions of granodiorite. Metallization consists of a central area of disseminated chalcopyrite and minor bornite that is surrounded by a zoned system of sulfide-bearing veins. The location and orientation of these veins was controlled by pre-existing northwest trending fault and fracture zones. Chalcopyrite, the dominant sulfide near the center, grades laterally outward into assemblages dominated by pyrite and then by sphalerite and galena. A central zone of potassium silicate alteration is coincident with the area of disseminated mineralization. This zone, in turn, grades laterally outward into alteration zones characterized by phyllic and then propylitic assemblages. At least six tourmaline-bearing breccia pipes, interpreted to have formed by collapse into solution voids, were developed concurrently with mineralization and alteration.

Geology and Mineralization of the North Santiam Mining District, Marion County, Oregon

by

James Peter Olson

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed June 1978

Commencement June 1979

APPROVED:

Redacted for Privacy

Professor of Geology
in charge of major

Redacted for Privacy

Chairman of Department of Geology

Redacted for Privacy

Dean of Graduate School

Date thesis is presented June 1, 1978

Typed by Opal Grossnicklaus for James Peter Olson

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

GEOLOGY AND MINERALIZATION OF THE NORTH SANTIAM MINING DISTRICT, MARION COUNTY, OREGON

INTRODUCTION

The North Santiam Mining District is the northernmost of five mining districts located in the Western Cascade subprovince of Oregon. The district was first discovered in 1860. Vein deposits of base and precious metals were mined sporadically until 1941 when the Santiam Copper Mine closed. Compared with the other mineral districts, the North Santiam area has lower abundances of gold and silver, and higher abundances of copper, lead, and zinc. It is the abundance of base metals that has recently caused renewed interest in the economic potential of the area.

The North Santiam District is located in T. 8 S., Rs. 4 and 5 E., in the northeast corner of Marion County, Oregon, as shown in figure 1. This study was focused on an area of 14 square miles composed of secs. 13, 23, 24, 25, and 26, of T. 8 S., R. 4 E., and secs. 18, 19, 20, 27, 28, 29, 30, 31, and 32, of T. 8 S., R. 5 E. The central part of the area was known formerly as the Lester Mining District and the eastern part as the Mineral Harbor District. The northern part of the area mapped, including the mines of the Rainbow and Eureka claims, was formerly known as the Gold Creek Mining District.

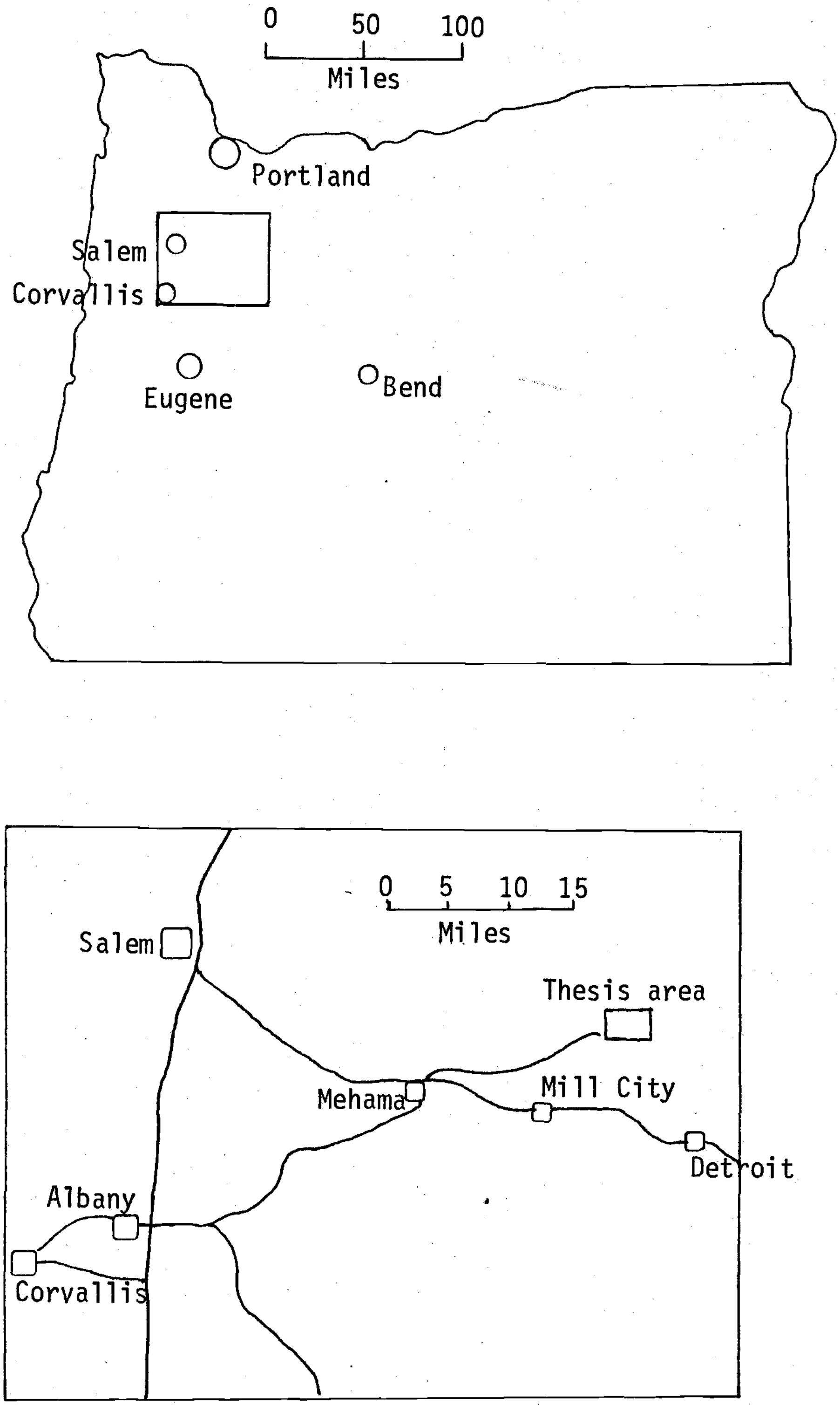


Figure 1. Index map of the North Santiam District

The district is located about 80 km east of Salem by road. Access is by State Highway 22 to Mehama, a distance of 55 km, and from there for 25 km by a paved light duty road to Elkhorn, which is situated on the western edge of the district. Access to the area east of Elkhorn is by a single track dirt road that follows the course of the Little North Santiam River. A dirt logging road provides access to the Cedar Creek valley along the southwest and south sides of the area. The district lies wholly within the confines of the Willamette National Forest and some parts of the area can be reached by Forest Service trails.

The district, located in a mature, deeply dissected portion of the Western Cascade subprovince is characterized by narrow steep-walled stream valleys separated by long sharp ridges. Drainage within this area is characterized by a dendritic stream pattern that flows to the west via Gold Creek on the north, Battle Ax and Opal Creeks on the east, and Stoney Creek on the south. All are tributary to the Little North Santiam River which drains the central portion of the area.

Local relief is as much as 1100 meters. Altitudes along the bed of the Little North Santiam River range from 400 meters in the west to 750 meters in the east part of the district. The surrounding mountains and ridges within 1 1/2 km of the river attain altitudes of over 1500 meters. The area is claimed to be one of the most rugged of the mineral districts in the Cascade Range (Callaghan and Buddington, 1938). This severe relief is largely attributable to the high ratio of flow rocks to pyroclastics that preferentially leads to the formation of many steep slopes and high cliffs.

The climate is moderate and humid. According to the inhabitants of Jawbone Flat, the summer temperatures range from 55° to 65°F. Winter temperatures are variable and range from 20° to 40°F. According to a local Forest Service employee the average annual precipitation is between 65 and 70 inches. The wettest season is the period from October to March with much of the precipitation at higher altitudes falling as snow.

Except for a small logged section in the southern part of the district, the area is covered with dense forest and brush. Fir, hemlock, and cedar are the most common trees. Rhododendron and vine maple comprise the greatest portion of the underbrush, which in some places is sufficiently thick to be all but impassable. Huckleberry, manzanita, and salal are also present in abundance.

Previous Geologic Work

Reconnaissance of the North Santiam Mining District was first made by Stafford (1904) who briefly described the mines and ore deposits. Callaghan and Buddington (1936; 1938) described the intrusive and volcanic rocks of the Western Cascade subprovince along with their study of the mining districts. Their U.S. Geologic Survey Bulletin No. 893 (1938) is the most thorough study of the mines and mineralization of this district to date. Leever (1941) described some of the larger mines and did a petrologic study of the ore.

Three papers by Thayer in the 1930's discuss the stratigraphy and general geology of the Cascade Range in Oregon. He defined the Sardine Series as the sequence of flows and tuffs exposed on Sardine Mountain (Thayer, 1936). Peck (1960) and Peck and others (1964) have described the structure, stratigraphy, and volcanic lithologies of the central and northern parts of the Western Cascades. Recent K-Ar age determinations on a large number of samples by McBirney and Sutter (1974) have provided new detailed information on the stratigraphic and temporal relationships of the Cascade volcanics.

Purpose and Methods of Investigation

The purposes of this study were to determine (1) the geologic history of the area; (2) structural and geologic controls of the emplacement of the dioritic intrusions; (3) physical controls of mineralization; (4) the relationships between alteration, mineralization, and intrusive rocks; and (5) to evaluate these in terms of modern concepts of metallogenesis.

Field work was conducted during the Spring and Fall of 1976 and the Spring of 1977. Geology, mineralization, and alteration were mapped on enlarged portions (1:12000) of the U.S. Geological Survey, Battle Ax and Mill City, Oregon, 15 minute quadrangle maps. Representative samples from each of the major rock units were examined petrographically and modal analyses were determined by counting 600 points per slide using a mechanical stage. To determine the percentages of potassium feldspar and plagioclase feldspar, polished slabs were stained using the methods outlined by Bailey and Stevens (1960). Compositions of plagioclase feldspar were determined using combined carlsbad-albite twin, Michel-Levy, and microlite extinction methods (Heinrich, 1965). Plutonic rocks were named using the quartz-orthoclase-plagioclase ternary classification of the I. U. G. S. (1973).

Samples of 19 plutonic and volcanic rocks were analyzed by X-ray fluorescence, atomic absorption, and visible light spectrophotometric methods for SiO_2, TiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O, and K_2O. This analytical work was performed by Dr. E. M. Taylor and R. Lightfoot of Oregon State University. Two samples were also analyzed by K. Aoki, Tohoku University, Japan, for Fe_2O_3, FeO, H_2O, and P_2O_5 in addition to the oxides previously mentioned. Trace element analyses for Cu, Mo, Pb, Zn, and Ag were made on 55 rock chip and eight stream silt samples by Chemical and Mineralogical Services, Salt Lake City, Utah.

REGIONAL GEOLOGY

The Cascade Range extends from southern British Columbia to northern California and forms a geographic province over 1000 km in length. From north to south the range is divided into three sections. The North Cascades and the Southern Cascades are located in northern Washington and northern California, respectively. The area from central Washington to southern Oregon is known as the Central Cascades.

In Oregon, the Central Cascade Range is 400 km long, 50-120 km wide, and has a general north-south trend. On the basis of age, structure and geomorphology, the Cascade Range is divided into two roughly parallel geologic subprovinces. They are known as the Western Cascade subprovince and the High Cascades subprovince. The western belt, or Western Cascade subprovince, is composed predominantly of volcanic and volcaniclastic rocks of Eocene to late Miocene age that erupted from centers within the subprovince. These are partially covered by Pliocene to Recent volcanics that erupted primarily from centers within the High Cascades subprovince to the east (McBirney and Sutter, 1974).

The Western Cascade subprovince is the region of greatest interest to the economic geologist. All of the base metal districts in the Cascade Range of Oregon occur in this subprovince. The stratigraphy of this region, as described below, is modified from Peck and others (1964).

The volcanic rocks erupted within the Western Cascades have been divided into three major units (Peck, 1960). In order of diminishing age they are the Colestin Formation, the Little Butte Volcanic Series, and the Sardine Formation. This sequence rests concordantly upon a basement of predominantly marine clastics, basalt flows, and pyroclastic rocks of the Eocene Umpqua, Tyee, and Spencer Formations (Peck and others, 1964). A sequence of basalt flows present near the base of the Sardine Formation has been referred to as Columbia River Basalt by Peck and others (1964). Recent K-Ar age dating by McBirney and Sutter (1974) indicates that as a time stratigraphic unit the Sardine Formation is much thicker than previously thought and should include the basalt flows and part of the underlying Little Butte Volcanic Series.

The late Eocene Colestin Formation consists of clastic volcanics and flows. Tuff, lapilli tuff, and tuff breccia of andesitic composition compose the clastics which form the major portion of this unit. Basaltic andesite accompanied by some pyroxene andesite comprises the remainder. The maximum thickness is about 900 meters, but averages less than 450 meters over most of its extent (Peck and others, 1964). The Colestin Formation is much eroded and unconformably overlain by the Little Butte Volcanic Series of Oligocene age.

The Little Butte Volcanic Series, according to Peck and others (1964) includes the Mehama Volcanics and the lower part of the Breitenbush Series of Thayer (1936). K-Ar age determinations by White (1977, personal communication) for the section of the series exposed in the North Santiam River drainage indicate an age of 24.2 to 25.0 m.y. The series ranges from 1,500 to 3,000 m in thickness and covers most of the area south of the McKenzie River.

Tuff and lapilli tuff that range from andesite to dacite in composition comprise approximately three-fourths of the series. The remainder consists of flows of andesite, basaltic andesite, and olivene basalt that individually average about 20 m in thickness and are commonly separated by zones of reddish volcanic breccia.

Many vents of the Little Butte Volcanic Series have been located and Peck and others (1964) have postulated that the eruptive centers formed north-south trending mountain chains. Eruptive centers for dacitic and rhyodacitic volcanics form a belt centered along the eastern edge of the Western Cascade subprovince. In contrast, vents of andesitic and basaltic rocks occupy a belt near the western edge.

A thick sequence of columnar-jointed basalt flows is present near the contact between the Little Butte Volcanic Series and the overlying Sardine Formation in some parts of the northern section of the Western Cascades. This unit has been designated as the Stayton Lavas (Thayer, 1936) and as Columbia River Basalt (Peck and others, 1964). Recent K-Ar dating by White (1977, personal communication) indicates these basalts are much older than the Columbia River Basalt and that basalt flows found within the Sardine Formation are chemically similar to and of the same age as Yakima type Columbia River Basalt.

The Sardine Series as defined by Thayer (1936) included the earlier named Mehama, Stayton, and Fern Ridge Formations. The Sardine Formation as used by Peck and others (1964) excluded the dissimilar Mehama and Stayton Formations, but included instead the upper part of the Breitenbush Series. According to their redefinition the Sardine Formation is dominantly hypersthene andesite of middle Miocene age.

Total thickness of the Sardine Formation is less than 1000 m over most of the Western Cascade subprovince. However, it attains a maximum thickness of over 3,000 m near Detroit. Approximately a dozen vents for the rocks of the Sardine Formation have been located. The eruptive centers probably formed a north trending mountain chain along the eastern edge of the subprovince (Peck and others, 1964).

Approximately three-quarters of the Sardine Formation is made up of flows of hypersthene andesite. The remainder consists of pyroclastics and flow rocks that range in composition from rhyodacite to olivine basalt. Most of the flows are porphyritic and may contain up to 40 percent phenocrysts. Pyroclastic rocks include tuff, lapilli tuff,

tuff-breccia, mudflow, and ash flow deposits.

The Sardine Formation is unconformably overlain by nonmarine sedimentary rocks of the early Pliocene Troutdale Formation (Peck, 1960) and by basaltic lavas of the Elk Lake Formation (McBirney and Sutter, 1974). K-Ar dates for the basaltic rocks of the Elk Lake Formation range from 9 to 11 m.y. in age (McBirney and Sutter, 1974). They are believed to be part of a volcanic sequence that was erupted from source areas in the High Cascade subprovince.

Many small intrusions of Tertiary age cut the volcanic stratigraphy of the Western Cascades. In general, two types are recognized; fine-grained intrustions that are texturally and compositionally equivalent to the volcanic rocks, and medium-grained intrusions. However, there is a complete gradation between these end members. The fine-grained intrusions are often impossible to distinguish from their extrusive host rocks. They are porphyritic to aphyric in texture, and range from rhyodacite to basalt in composition.

Mineralization in the Western Cascade subprovince is associated with the medium-grained intrusions which range in composition from augite diorite to biotite-quartz monzonite. They are present as pipes, dikes, and small stocks. These bodies are usually circular to elliptical in plan and have nearly vertical margins. Most of the medium-grained intrusions are porphyritic, but equigranular types are also present. Plagioclase feldspar, zoned and of intermediate composition, is the most common phenocryst.

The Cascade Range occupies a broad downwarp that is elongate in a northerly direction (Peck and others, 1964). The High Cascade subprovince is located within a large north trending graben (Taylor, 1968 and 1975, personal communication). The cause of this downward movement may be tectonic forces, or subsidence as a result of material being transferred from the underlying crust to the surface. The major structural element in the northern part of the Western Cascades is a series of broad gentle folds that trend northeasterly. These folds include the Mehama, Clackamas, and Breitenbush Anticlines and the Sardine Syncline, as well as many other similar but smaller folds that have not been named.

Northwest-trending faults are common throughout the Western Cascade subprovince, but few are large enough to have been traced for any significant distance. Most of the faults are steeply dipping to vertical, and apparent displacements have rarely exceeded 20 meters (Peck and others, 1964). The northwest orientation of most faults in the Cascades may be related to northwest trending strike-slip faults of southeastern Oregon which are believed to be related to Basin and Range extension (Lawrence, 1976). Lack of recognizable marker units and large amounts of cover make the delineation of small scale structures difficult in the Western Cascades.

SARDINE FORMATION

Peck and others (1964) tentatively assigned the lower part of the stratigraphic sequence exposed in the North Santiam Mining District to the Little Butte Volcanic Series and the upper part to the Sardine Formation. However, on the basis of field work undertaken in this study it was found that the lowermost part of the section within the thesis area closely resembles the Sardine Formation as described by Peck and others (1964). This relationship, together with the lack of any rocks that could be positively correlated with the Little Butte Volcanic Series, has led to the conclusion that all of the volcanic rocks in the North Santiam Mining District should be assigned to the Sardine Formation. Rocks resembling those of the Little Butte Volcanic Series as described by Peck and others (1964) crop out in the valley west of Elkhorn and probably underlie the district at depth.

The extrusive volcanic rocks in the area have been divided into two units and assigned the informal names Lower Member and Upper Member. The break between the two units roughly corresponds to the break between the Little Butte Volcanic Series and the Sardine Formation as mapped by Peck and others (1964). The Lower Member consists predominantly of andesite flows with a few interbedded lenses of polymictic breccia. The Upper Member is composed of pyroclastic rocks interbedded with flows of andesite and basalt.

Lower Member

Andesite flows comprise about 98 percent of the Lower Member with the remainder consisting of a distinctive polymictic breccia of probable mudflow origin. The base of this unit is not exposed within the district. A minimum thickness of 365 meters is inferred from the outcrop pattern and the dip of the unit. Exposures are good along the Little North Santiam River and its tributaries below an elevation of 900 m (2900 feet).

Polymictic Breccia

Sedimentary breccias comprise a very minor part of the sequence and are poorly exposed in most of the area. The largest outcrop is found in the N.W. 1/4 sec. 27, T. 8S., R. 5 E., where it is exposed in the bed of Battle Ax Creek for several hundred feet. This unit of breccia is also exposed in both the Blue Jay and Ruth mines where it is partially mineralized. In the area mapped, the polymictic breccia is confined to secs. 27, 28, and 29, T. 8 S., R. 5 E. Other outcrops are present to the southeast along Opal Creek in sec. 33, T. 8 S., R. 5 E. Although the breccia occurs at several horizons within the stratigraphic sequence, it is restricted to the middle and lower sections of the Lower Member.

An easterly or southeasterly source is inferred for the breccia on the basis of the following evidence. The size of clasts decreases from east to west from a maximum of 15-20 cm in diameter near the Blue Jay Mine to 1-2 cm near Stoney Creek; a distance of about 3 km. Breccia with clasts up to 20 cm in diameter was also found along Opal Creek, about 1.5 km southeast of the map area. Outcrops of breccia become smaller and more rare to the west, and apparently disappear completely west of sec. 29, T. 8 S., R. 5 E.

Weathered surfaces generally have a light gray (N 7) to brownish gray (5 YR 2/1) color. Fresh surfaces have a distinctive light brownish gray (5 YR 6/1) color to the matrix and a grayish green (10 GY 5/2) to dusky yellowish green (10 GY 3/2) color to the lithic fragments.

Lithology and Petrology. The polymictic breccia is a massive well indurated rock of low porosity. Neither sorting nor bedding were visible in any of the outcrops examined. Angular to moderately rounded clasts varying in size from fine sand to cobbles comprise up to 70 percent of the rock and are set in a matrix of altered volcanic ash. Clasts consist of both rock fragments and crystals.

Rock fragments comprise 65 percent of the breccia and consist predominantly of fine-grained andesite accompanied by subordinate amounts of tuff and rare clasts of basalt. Andesite fragments are pilotaxitic to felty in texture and consist of microlites of plagioclase feldspar (andesine, An 40) in a matrix of green clay and finely crystalline magnetite. These clasts closely resemble the andesite flows at the base of the Lower Member. Tuff fragments are composed mostly of devitrified glass and are often porous or filled with secondary calcite. All rock fragments are highly altered to chlorite, epidote, albite, and quartz.

Crystals and crystal fragments comprise approximately three percent of the polymictic breccia. Most of the crystals are andesine (An 35), which are partially or completely replaced by clay and quartz. Pyroxene crystals were probably originally present but are now represented by sparse subhedral to euhedral masses of chlorite. Cubes of pyrite 0.2-0.3 mm in diameter were found in all samples.

Flows

Andesite flows of the Lower Member cover approximately 60 percent of the district. The best exposures of the flows are along the road to Jawbone Flats in secs. 23, 24, and 26, T. 8 S., R. 4 E., and along Cedar Creek in the southwestern part of the area. Outcrops are common and form steep moss covered cliffs along stream valleys and ridges in the lower elevations. Flows average 15 to 20 m in thickness and appear to be continuous over the area.

The weathered surfaces are light greenish gray (5 G 8/1) to brownish gray (5 YR 4/1) in color. Fresh surfaces of the andesite flows vary in color from greenish gray (5 G 6/10) to greenish black (5 GY 2/7).

Lithology and Petrology. Flows of the Lower Member are holocrystalline and include aphanitic equigranular and inequigranular textural types and more phaneritic porphyritic textural types. The basal 80 m of the exposed portion of the Lower Member is composed of aphanitic equigranular flows. Upward the flows become progressively more porphyritic. Modal analysis of four samples are given in Table 1.

Amygdules are common throughout the sequence of flows. They are most abundant in the lowermost flows exposed in sec. 28, T. 8 S., R. 5 E. Most amygdules are less than 2 mm in diameter and are filled with chlorite, epidote, and calcite. Small amounts of quartz and a zeolite are sometimes present.

Porphyritic andesite is the dominant rock type in the Lower Member. Phenocrysts of plagioclase feldspar, augite, magnetite, and hypersthene comprise as much as 40 percent of some flows. Plagioclase feldspars (An_{28-40}) are the most common phenocrysts. They are present as subhedral to euhedral laths 0.3 to 5 mm in length. These phenocrysts of plagioclase feldspar commonly show slight progressive zoning, and oscillatory zoning was found in one sample from the middle of the Lower Member. Alteration of the plagioclase crystals is variable in intensity and type. Weak to moderate alteration to clay and zeolite is most common, whereas there is moderate to intense alteration to epidote, calcite, quartz, and albite near areas of mineralization.

Ferromagnesium minerals present are augite and hypersthene. Augite is far more abundant and is present as equidimensional subhedral to euhedral crystals averaging 1-2 mm in diameter. Rare crystals of hypersthene were identified in two of the thin sections studied. In most samples, all of the mafic silicates have been completely altered to chlorite, epidote, and magnetite. These alteration products form pseudomorphs that usually comprise between 1 and 5 percent of most flows. It is possible that mafic silicate minerals other than augite and hypersthene were originally present but have now been replaced by the alteration assemblage listed above.

The pilotaxitic groundmass consists predominantly of microlites of plagioclase feldspar in a matrix of chlorite, magnetite, and clay. Composition of the plagioclase is difficult to determine but is estimated to be calcic oligioclase in most samples. The feldspar microlites are surrounded by as much as five percent magnetite that is accompanied by variable amounts of dark green chlorite and light brown clays. Small amounts of hematite and pyrite were present in all samples examined, and euhedral crystals of zircon and apatite were found in most thin sections.

The results of major oxide and trace element analysis of four samples of flow rock from the Lower Member are listed in Table 1. They all plot within the andesite field using the K_2O Vs. SiO_2 classification scheme of Mackenzie and Chappell (1972) (Figure 2).

Table C-1	Andesites, Lower Member				Andesite, Upper Member	Basaltic Andesite, Upper Member	
	SS-3-A	SS-7	S-1-12	TB-1	P-18	G-5	Average Andesite[1]
SiO_2	58.7	60.9	58.3	60.0			58.65
TiO_2	0.95	0.75	0.78	1.61			0.79
Al_2O_3	16.6	18.9	21.9	17.56			17.43
FeO	8.5	6.3	6.2	7.5			6.37
MgO	3.8	2.3	2.6	4.2			3.28
CaO	6.1	5.4	5.3	1.67			6.26
Na_2O	3.4	4.0	5.2	0.7			3.82
K_2O	1.48	1.05	0.24	1.87			1.99
Total	99.53	~~95.11~~ 99.60	100.52	~~99.60~~ 95-11			
Trace elements in ppm							
Cu	60	35	90	60			
Zn	80	60	90	100			
Pb	35	10	30	15			
Mo	1	-1	-1	-1			
Ag	.6	.3	.3	.3			
Modal Composition							
Phenocrysts	41	35	47		37	52	
P-feld.	32	30	39		33	43	
Pyx.	7	4	6		2	6	
Magnetite	1	1	2		1	3	
Quartz	-1	--	--		1	--	
Groundmass	59	65	53		63	48	
P-feld.	40	44	36		45	30	
Chlorite*	12	17	13		15	15	
Magnetite	5	3	3		1	2	
pyrite	-1	-1	1		-1	-1	

*Fine grained mixture of chlorite and clays that probably formed by alteration of pyroxene and volcanic glass.

[1] Nockolds and Allen, 1953.

Table 1. Modal and chemical analyses of volcanic rocks from the North Santiam District.

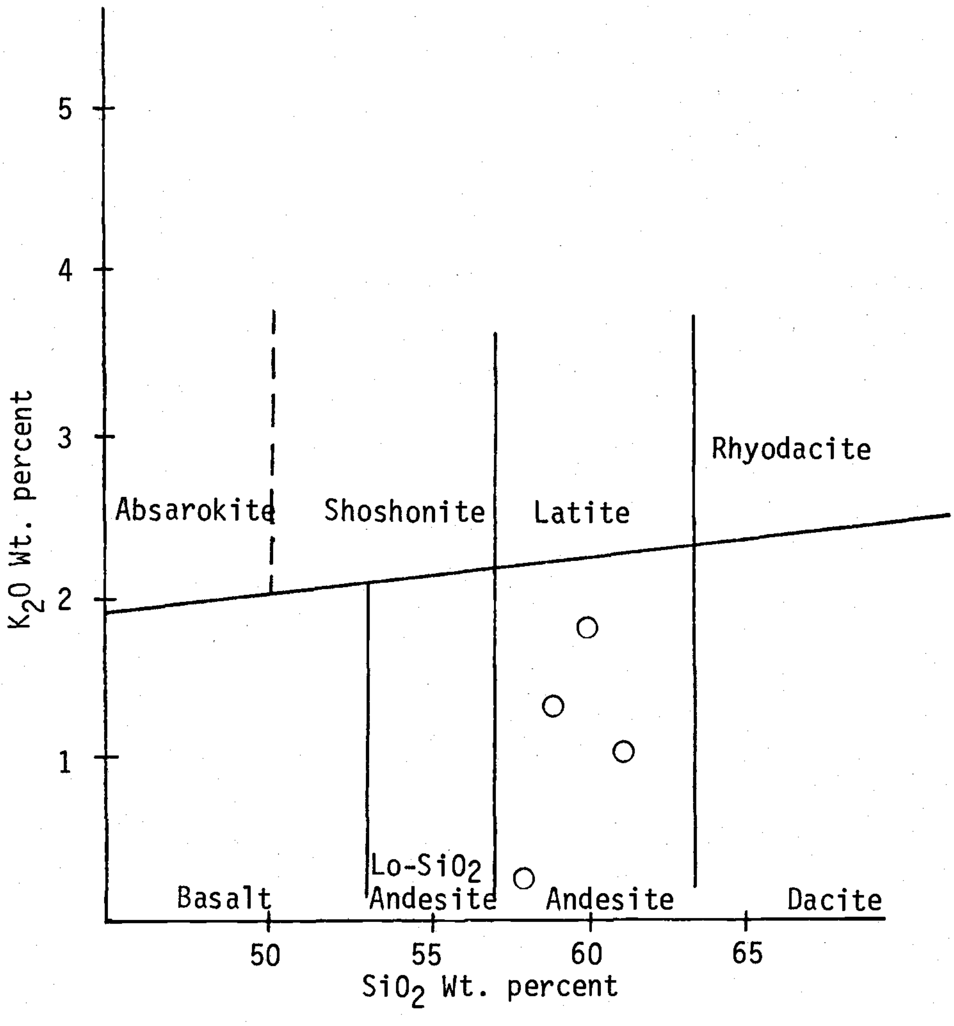


Figure 2. Chemical classification of volcanic rocks from the North Santiam District. (after Mackenzie and Chappell, 1976).

The systematic variation in all of the major oxides is believed to be largely a result of hydrothermal alteration and is discussed in detail in the alteration section of this report. When compared with average calc-alkaline andesites from continental margins (McBirney, 1969) the least altered North Santiam andesite (sample SS-3-A) differs significantly only in having a lower K_2O value and higher total iron content. In this respect, the North Santiam rocks more closely resemble calcic andesites from island arcs (McBirney, 1969). However, these variations are more likely the result of introduction of iron in the form of secondary magnetite and pyrite and leaching of potassium during propylitic alteration. Chemical variations of the North Santiam samples do not appear to reflect any differences in primary mineralogy.

The flows of the Lower Member are mineralogically and texturally similar to those of the Sardine Formation as described by Peck and others (1964). However, the dominant pyroxene is augite in the flows of the North Santiam Mining District whereas it is hypersthene in the type section of the Sardine Formation. It is believed that this difference may be a local effect. In contrast, the top of the type section for the Little Butte Volcanic Series is dissimilar because it consists of dacite and rhyodacite tuffs. In addition, the major oxide chemistry of the andesites in the North Santiam District match more closely the hypersthene andesites of the Sardine Formation than the andesites of the Little Butte Volcanic Series (Peck and others, 1964).

Therefore, on the basis of these stratigraphic, mineral, lithic, and chemical relationships the Lower Member is tentatively assigned to the Sardine Formation.

Upper Member

The Upper Member is characterized by flows of andesite that are interbedded with pyroclastic volcanics. The lowermost occurrence of pyroclastic material, other than the mudflow breccia that was previously described, was chosen as the base of the Upper Member. The actual contact between the flows of the Lower Member and the tuffs of the Upper Member is not exposed within the thesis area. Debris from these poorly indurated tuffaceous units covers most of the slopes near the contact.

Flows and pyroclastic rocks of the Upper Member cover approximately 40 percent of the North Santiam Mining District. The best exposures of the Upper Member are along road cuts in sec. 31, T. 8 S., R. 5 E., on the cliffs near the top of Whetstone Mountain in sec. 21, T. 8 S., R. 5 E., and in Horn Creek above an elevation of 850 m (2800 feet). The maximum thickness of the Upper Member within the North Santiam district is about 500 m. It is not known how thick this unit may have been before development of the present erosional surface.

Flows

Flows comprise approximately 40 percent of the Upper Member. Andesite is the predominant rock type except near the base of the unit where a single flow of basaltic andesite is present in the southern half of the thesis area. The andesitic flows of the Upper Member are indistinguishable from the upper flows of the Lower Member. Most of the flows are thinner than those of the Lower Member, averaging 10 to 15 m in thickness. Good exposures of the andesite flows are found on Whetstone Mountain and along the upper part of Horn Creek.

The flow of basaltic andesite crops out along ridges south of the Little North Santiam River, and is well exposed in roadcuts in the N. 1/2 sec. 31, T. 8 S., R. 5 E. It is usually found near an altitude of 900 m (3000 feet). Because of its reddish color and large amounts of magnetite the basaltic andesite is easily recognized and serves as a useful stratigraphic marker in this area.

Weathered surfaces of the basaltic andesite are very dusky purple (5 RP 2/2) to grayish black (N 2) in color. Fresh surfaces are a distinctive grayish purple (5 P 4/2).

Lithology and Petrology. The andesite flows in the Upper Member are texturally and mineralogically similar to those in the Lower Member. A petrographic study was made of one sample from the middle of the unit. In addition, several polished and stained slabs were examined using a binocular microscope. All of the flows in the Upper Member are porphyritic and contain between 10 and 40 percent, phenocrysts of plagioclase feldspar, augite, and hypersthene. The only difference between the andesite flows of the Lower and Upper Members is the presence of a few small phenocrysts of quartz in one flow from the Upper Member. A modal analysis of that flow is given in Table 1.

The single flow of basaltic andesite is porphyritic and hypidiomorphic in texture. Phenocrysts of plagioclase feldspar, augite, hypersthene and magnetite comprise 51 percent of the flow. The microcrystalline groundmass has an intersertal texture and is composed of plagioclase microlites, magnetite, and an unidentifiable material that is "dirty" brown in color and probably an alteration product of volcanic glass. A modal analysis is given in Table 1.

Zoned crystals of plagioclase feldspar are the most common phenocrysts. The composition ranges from (An 57) at the core of the largest crystals to (An 50) at the margins. The subhedral to euhedral laths are 0.5 to 4 mm in length and most are slightly to moderately corroded. Most phenocrysts of the labradorite are weakly altered to clay and zeolite.

Augite and hypersthene are both present in small amounts. The equidimensional subhedral to euhedral crystals average approximately 1 mm in diameter. Crystals of augite are slightly more corroded and clearer than those of hypersthene. Some augite crystals are completely enclosed within large plagioclase feldspar phenocrysts. The hypersthene is slightly pleochroic from green to pink. Alteration of the pyroxenes is weak with only minor replacement by epidote and chlorite.

Magnetite crystals up to 0.5 mm in diameter are dispersed throughout the rock. Tiny crystals of magnetite, interstitial to the plagioclase microlites comprise a significant percentage of the rock. Much of the magnetite has altered to hematite giving the basaltic andesite its characteristic reddish color. The plagioclase feldspar microlites are andesine (An 48) in composition.

Pyroclastic Rocks

Pyroclastic rocks present in the Upper Member include tuff, lapilli tuff, tuff-breccia, and welded tuff. Distributions of the various tuffs may indicate a general location for the source area of some of these units. Medium to coarse grained tuffs are present north and west of secs. 32, and 33, T. 8 S., R. 5 E. These tuffs become progressively finer-grained to the northwest. Lapilli tuff and tuff-breccia are restricted to secs. 31, 32, and 33, T. 8 S., R. 5 E. Welded tuff units are present in the Upper Member throughout the area of study. The degree of welding, although somewhat variable, and thicknesses of these tuffs appear to decrease towards the northwest.

The amount of pyroclastic rock in the section also varies laterally. In the northern and western sections of the district, flows predominate over tuffs in the Upper Member. However, flows are relatively rare in the southeast corner of the area. Thus, it may be inferred that the source for the pyroclastic material was to the southeast and probably nearby. The lapilli tuff and tuff-breccia may have formed a wedge adjacent to the source vents against which the flows pinched out.

Lapilli tuff and tuff-breccia are well exposed in the southeastern part of the thesis area where these rocks form numerous steep slopes and cliffs. The best outcrops of the welded tuff units are in roadcuts in the sec. 31, T. 8 S., R. 5 E., and on Whetstone Mountain in secs. 20 and 21, T. 8 S., R. 5 E. The fine- to coarse-grained nonwelded tuffs are poorly exposed in the district. Outcrops are infrequently present in the upper segments of Tincup and Horn Creeks in the northwestern part of the area.

Colors on the weathered surfaces of the fine- to coarse-grained tuff and the welded tuff vary from light brown (5 YR 6/4) to pale yellowish brown (10 YR 6/2). Weathered surfaces of the lapilli tuff and tuff-breccia tend to be dusky olive brown (5 Y 6/4) to moderate olive brown (5 Y 4/4) in color. Fresh surfaces of the fine- to coarse-grained tuffs and the welded tuffs are generally shades of gray. Fresh surfaces of the Lapilli tuff and tuff-breccia have a medium light gray (N 6) to greenish gray (5G 6/1) color to the matrix, and a grayish green (10 GY 5/2) color to most of the clasts.

Lithology and Petrology. Pyroclastic rocks of the Upper Member are characteristically crystal lithic tuffs that are andesitic to dacitic in composition. The angular to subangular rock fragments are predominately of andesite prophyry. Occasional fragments of pumice and clasts of basalt are also present. Crystals and crystal fragments consist mostly of plagioclase feldspar that may be accompanied by smaller amounts of augite and hypersthene. Crystals of quartz are locally common in some of the welded tuff units. Petrographically, there is no apparent difference between the lapilli tuff and the fine- to coarse-grained tuff, except for the grain size.

The tuffaceous units are variable in texture. Lapilli tuff and tuff-breccia tend to be massive and well-indurated and show no graded bedding or stratification. Weathering of the fine- to coarse-grained tuff in the northwest part of the district yields tabular shaped fragments 1 to 3 cm thick. This indicates that weak bedding may be present. The welded tuffs usually have poorly to moderately well-developed eutaxitic textures.

Rock fragments comprise from 25 to 30 percent of the lapilli tuff and tuff-breccia, and from 1 to 10 percent of the other tuff units. The sizes of the fragments vary from 0.2 to 40 mm. Lithic fragments of andesite are porphyritic and contain phenocrysts of plagioclase feldspar (An_{35-40}), augite, and rarely quartz in a pilotaxitic groundmass that consists mostly of microlites of andesine (An 32) and of chlorite and clay as alteration products.

Crystals of plagioclase feldspar (An_{32-45}) are present as subhedral laths 0.5 to 2 mm in length. They commonly show progressive zoning and some crystals may have as many as three zones of oscillatory zoning. The crystals of andesine are usually extensively altered to epidote, sericite, and clay. Euhedral to subhedral crystals of augite are present in most, but not all, of the tuffaceous units. Crystals of augite average about 0.5 mm in diameter and may be partially to completely altered to chlorite and magnetite. Quartz, which may occur as irregularly shaped corroded crystals, is common only to the welded tuffs in the eastern half of the district.

The groundmass of the tuffs generally varies with the type of hydrothermal alteration in the area. In general, it is microcrystalline and consists of quartz, chlorite, feldspar, and clay. Variations in the amounts and proportions of these minerals in the welded tuffs imparts a banded texture to these rocks. Hydrothermal alteration is more extensive to the pyroclastic rocks than in the flows. Two factors are probably responsible for this relationship. First, the high porosity and permeability of the moderately indurated tuffs may have allowed for more effective circulation of hydrothermal fluids, and second, the tuffs are generally more felsic than the flow which results in greater proportions of clay and sericite in the alteration assemblage and imparts to the outcrops a bleached and more altered appearance.

PLUTONIC ROCKS

A wide variety of intrusive rock types are present in the North Santiam Mining District. The seven different types mapped in this study can be separated into general classes: fine-grained rocks ranging from basalt to rhyodacite in composition, and medium-grained dioritic rocks. Intrusions of the first class are characteristically porphyritic with an aphanitic groundmass. The dioritic intrusives range in composition from diorite to quartz monzonite with quartz diorite being the most abundant. However, gradations exist between the two classes, and some intrusions are difficult to classify.

The four intrusive types included in the fine-grained class are andesite dikes, dacite sills or plugs, basaltic andesite plugs, and quartz latite dikes. These intrusions are closely similar in mineralogy and texture to the extrusive rocks found in the area. The andesite dikes, at least in part, were the feeders for the andesite flows of the Lower Member. The dacite and quartz latite intrusions may be closely related to the tuffs of the Upper Member, but extensive hydrothermal alteration makes a positive correlation difficult at best.

Prior to this study all medium- to coarse-grained intrusive rocks in the district were mapped as a single unit and given the name diorites (Callaghan and Buddington, 1938; Leever, 1941). Three dioritic intrusive types were defined on the basis of field work during this study. They are the Ruth Diorite, Microdiorite, and Hewlit Granodiorite. Intrusions of Ruth Diorite and Microdiorite are predominantly quartz diorite in composition. However, each is discussed separately in this report because of their distinctly different macroscopic and petrographic character. The name Hewlit Granodiorite has been applied to intrusions of similar character that include granodiorites, quartz monzodiorites, and tonalites.

Andesite Intrusions

Dikes and eliptical plugs of porphyritic andesite are common throughout the Lower Member. Only rarely could any of these dikes be traced into the lower part of the Upper Member and intrusions of andesite were never found more than 100 meters above the base of the Upper Member. The best exposures of andesite intrusions are along the ridge crests north of the Little North Santiam River. The largest numbers of dikes are between Cold and Gold Creeks in sec. 24, T. 8 S., R. 4 E., and sec. 19, T. 8 S., R. 5 E. Several small plugs are exposed along the valley of Cedar Creek in sec. 36, T. 8 S., R. 4 E., and sec. 31, T. 8 S., R. 5 E.

Characteristically, the andesite intrusions are 2 to 30 m wide, near vertical in dip, and trend N. 20° to 40°W. As a result of differential erosion, some of the dikes form steep wall-like ridges up to 15 m in height. They range from 20 to over 500 m in length with the average being less than 100 m. In the field, the dikes could often be distinguished from the andesite flows only by the presence of horizontal columnar joints or by sharp changes in the percentage of phenocrysts. Horizontal jointing is common in dikes less than 4 m in width. Chilled margins are generally absent.

The andesite dikes were not studied in thin section. However, a binocular microscope examination of polished and stained slabs was made. No differences between the andesite dikes and the andesite flows were revealed using this method. All of the dikes and plugs are porphyritic, containing between 22 and 45 percent phenocrysts, of which most are plagioclase feldspar accompanied by a dark green pyroxene that is probably augite, and occasionally by sparse crystals of hornblende. Alteration of most dikes is extensive with epidote, chlorite, and calcite being the most common secondary minerals.

The andesite intrusions are believed to be the oldest intrusive rocks exposed in the thesis area. The absence of these bodies in most of the Upper Member indicates that their emplacement was closely related in time to the eruption of the andesite flows. This temporal relationship and the mineralogic and textural similarities, suggest that some of the andesite dikes may have been feeders for the andesite flows in the Lower Member and basal parts of the Upper Member.

Basaltic Andesite Intrusions

Two plugs of porphyritic basaltic andesite crop out in the S. 1/2 sec. 32, T. 8 S., R. 5 E. The smaller of the intrusions is a circular plug less than 100 m in diameter. This plug may be an apophysis of the larger intrusion which is located less than 400 m to the west. The larger intrusion is eliptical in plan with the major axis trending approximately N. 30°W. The contacts of both plugs are nearly vertical in dip and in places appear to be fault controlled. Exposures are good in roadcuts and along the center of the ridge in the S.W. 1/4 sec. 32, T. 8 S., R. 5 E. Little structural deformation is visible in the country rock surrounding this intrusion. However, xenoliths of pyroclastic rock several meters in length are present. Outcrops of this intrusion are most easily recognized from the andesite flows by their strongly magnetic character. Weathered surfaces are variable in color, usually ranging from moderate yellowish brown (10 YR 5/4) to moderate brown (5 YR 3/4). The color of fresh surfaces is medium dark gray (N 4) to dark greenish gray (5 G 4/1).

Lithology and Petrology

The basaltic andesite plugs are hemicrystalline and porphyritic in texture. They contain approximately 40 percent phenocrysts, consisting of plagioclase feldspar, augite, hypersthene, and magnetite in a felty to pilotaxitic groundmass. Modal analyses of two samples are listed in Table 2.

Plagioclase feldspar is present as short stubby laths 0.5 to 3 mm in length. The labradorite phenocrysts are euhedral to subhedral in outline and usually show only slight corrosion along the borders. Many crystals exhibit progressive zoning that ranges from (An 60) at the core to (An 53) at the rims. Twinning is common in the plagioclase phenocrysts with both albite and carlsbad types present. The more calcic cores of some phenocrysts have been selectively altered to epidote. Kaolinite and minor calcite are also present as replacements of the plagioclase feldspar.

The ferromagnesium minerals present in the basaltic andesite plugs are augite and hypersthene. Augite occurs as euhedral to subhedral equant crystals ranging from 0.2 to 1 mm in diameter. Hypersthene is present as wide subhedral laths 0.2 to 2 mm in length. The augite crystals are commonly twinned and occasionally contain exsolution lamellae of hypersthene. Most of the augite and hypersthene is extensively altered to uralite and chlorite.

Irregular blebs of devitrified glass up to 3 mm in diameter comprise five percent of the basaltic plugs. They are composed of a core of radially-crystalline chlorite surrounded by a rim of quartz and albite. Some blebs are flattened and others are nearly spherical in shape.

	Basaltic Andesite		Quartz Latite		Dacite
	32-1	P-15	RD-1	RD-2	FA-Dp
SiO_2			77.0		
TiO_2			0.15		
Al_2O_3			13.1		
FeO			1.85		
MgO			0.3		
CaO			2.3		
Na_2O			0.4		
K_2O			3 0		
Total			98.1		
Trace elements in ppm					
Cu			45	10	40
Zn			525	60	55
Pb			205	40	15
Mo			2	-1	-1
Ag			1.0	0.6	0.4
Modal Composition					
Phenocrysts	37	34	13	24	57
P-feld.	31	27	2	8	39
Pyx.	6	5	--	--	-1
Magnetite	-1	2	--	--	-1
Quartz	--	--	10	12	1
Muscovite	--	--	-1	-1	--
K-feld.	--	--	1	3	--
Hornblende	--	--	--	-1	15
Groundmass	63	66	87	76	43

Table 2. Modal and chemical analyses of sub-volcanic intrusions from the North Santiam District.

The microcrystalline groundmass consists primarily of microlites of plagioclase feldspar (An 50), magnetite, chlorite, and brown iron-stained volcanic glass. These minerals are accompanied by small amounts of pyrite, calcite, and epidote.

Quartz Latite

Intrusions of porphyritic quartz latite were found in two localities in the North Santiam Mining District. Several dikes are present in the N.W. 1/4 sec. 27, T. 8 S., R. 5 E., on the eastern edge of the area. Farther west, one outcrop and several blocks of float of similar material were found in the N.W. 1/4 sec. 29, T. 8 S., R. 5 E. Three dikes of this group are exposed in sec. 27 along the first 100 meters of the fifth level of the Ruth Mine. These intrusions are intensely altered and some are mineralized. Outcrops and float of the quartz latite in sec. 29 are also highly altered but are not significantly mineralized. Because of the great intensity of alteration the dikes tend to weather recessively and thus form subdued outcrops. Characteristically, the dikes are 5 to 8 m in width, stike N. 53° to N. 72° W., and dip 60° to 75° to the southwest. Colors of the weathered surfaces range from pinkish gray (5 YR 8/1) to light brownish gray (5 YR 6/1), whereas fresh surfaces are light gray (N 7) to white (N 9) in color.

Lithology and Petrology

All dikes of quartz latite are porphyritic and range from hypidiomorphic to allotriomorphic in texture. Phenocrysts comprise between 11 and 23 percent of the rock and consist of quartz, orthoclase, plagioclase feldspar, muscovite, and hornblende. All samples of the quartz latite are highly altered and the holocrystalline groundmass consists mostly of quartz, sericite, and feldspar. Modal analyses of two samples are listed in Table 2.

Phenocrysts of quartz are anhedral to rarely subhedral in form and range from 1 to 2.5 mm in diameter. Some are broken with the optically continuous fragments being stretched into a subparallel alignment up to 6 mm in length. Microcrystalline quartz in the groundmass is probably of secondary origin in part, having been introduced during a period of extensive quartz-sericite alteration. Phenocrysts of subhedral orthoclase are present in most of the dikes. These equidimensional crystals range from 1 to 3 mm in diameter. Plagioclase feldspar (An 15) occurs as subhedral to anhedral laths 0.5 to 3 mm in length. Carlsbad and albite twinning is common, and only rarely was slight progressive zoning of these plagioclase feldspars observed. Most of the orthoclase and oligoclase is weakly to moderately altered to clay and sericite. Phenocrysts of green hornblende were found in only one of the three dikes studied petrographically and these are nearly completely altered to uralite and chlorite. Plates of muscovite up to 1.5 mm in diameter are present in most of the quartz latite dikes. Many of these muscovite crystals are bent. Sphene and apatite are present as accessory minerals in minor amounts.

The results of major oxide analyses of one quartz latite dike are listed in Table D-1. When plotted on a SiO_2 vs. K_2O diagram (Mackenzie and Chappell, 1972), this sample falls within the rhyodacite field. However, a quartz latite designation is indicated from petrographic evidence by the plagioclase feldspar to potassium feldspar ratio. In addition, hydrothermal alteration may have greatly modified the composition of this rock. The presence of quartz microveinlets and a quartz-sericite groundmass indicate that the SiO_2 content has been increased through alteration. For these reasons the name quartz latite has been used in this report.

<u>Age and Correlation</u>

The relative age of the quartz latite dikes could not be accurately determined. One dike is truncated by a diorite intrusion in the N.W. 1/4 sec. 27, T. 8 S., R. 5 E. The diorite is believed to be the oldest of the medium grained intrusive rocks. Host rocks for the quartz latite dikes are the andesite flows and polymictic breccia of the Lower Member, and less commonly the andesite dikes. Intrusions of quartz latite were not identified in the Upper Member. However, the poor exposures of most of the Upper Member make it entirely possible to miss such small features. In terms of mineralogy and texture, the quartz latite dikes closely resemble the welded tuffs of the Upper Member. Many of the welded tuffs are also classified as quartz latites and rhyodacites. Clasts of rock, similar to that of the quartz latite dikes, were found in one of the welded tuff units in the southern part of the thesis area. These relationships suggest that emplacement of the quartz latite dikes was probably closely associated in time and space with the formation of the welded tuffs. It is doubtful that the small dikes exposed in the area were actual feeders for the tuffs. More probably, the dikes were a peripheral and possible comagmatic intrusion associated with the welded tuff and located around the eruptive center. However, extensive quart-sericite alteration of all the quartz latite dikes complicates this interpretation. Indeed, if the dikes were related to the tuffs, then they would be premineralization in age and their altered condition would be fortuitous. Alternatively, these felsic dikes may have been more reactive to hydrothermal fluids and thus underwent more intense alteration than the surrounding andesites. Emplacement of the dikes was probably to some extent structurally controlled and these same structures may have localized the hydrothermal fluids. Trace element geochemistry (Table 2) for two dikes located less than 100 meters apart indicate that they were premineralization in age. The large differences in copper, lead, and zinc content would be difficult to explain if mineralization was directly associated with the emplacement of the dikes. From the field and laboratory evidence, I conclude that the quartz latite dikes were more closely related to the welded tuffs rather than to the mineralization event.

Dacite Intrusions

Several small intrusions of porphyritic dacite are scattered throughout the thesis area. Five such bodies were found during field investigations and it is probable that others are also present. The best exposures of these bodies are in secs. 29, and 30, T. 8 S., R. 5 E., just north of the Little North Santiam River and along the upper part of Horn Creek in the N.W. 1/4, sec. 24, T. 8 S., R. 4 E.

In the field, the dacites were distinguished from the andesites by the presence of visible quartz and phenocrysts of hornblende. Color of the weathered surfaces of these intrusions varies from light gray (N 7) to light brown (5 YR 6/4). Fresh surfaces range from medium gray (N 5) to greenish gray (5 G 6/4) in color. The greenish cast to some intrusions results from propylitic alteration.

Contacts between the dacite intrusions and the andesite flows were not observed, nor was any visible evidence of structural deformation associated with the emplacement of the dacites. Intrusions consisting of more than a single outcrop appear to be roughly circular in plan. However, the broad extent and flat top of the intrusion in sec. 29, led Decker (1977, personal communication) to speculate that this intrusion may be a sill.

Lithology and Petrology

Two of the five dacite intrusions were studied in detail. Stained slabs from the intrusion in Horn Creek were examined using a binocular microscope, and one thin section and several slabs from the altered dacite in sec. 29 were also studied. Most of the other dacite intrusions are similar in mineralogy and form to these.

The intrusion in Horn Creek consists of porphyritic dacite that contains 32 percent phenocrysts of plagioclase feldspar, hornblende, and quartz. Plagioclase feldspar appears to be oligoclase or andesine in composition. These crystals are 0.5 to 5 mm in length, and most are moderately altered to epidote. Subhedral elongate crystals of hornblende range from 0.2 to 1.5 mm in length and are highly altered to chlorite. The phenocrysts of quartz are rare, small in size, and irregular in shape. Staining of the slabs revealed approximately five percent potassium feldspar in the microcrystalline groundmass.

The dacite porphyry plug in sec. 29, T. 8 S., R. 5 E., resembles the Horn Creek intrusion except that it has a greater percentage of phenocrysts and is highly altered. Petrographic studies indicate that it is composed of 55 percent phenocrysts that include plagioclase fledspar, hornblende, quartz and minor pyroxene. The microcrystalline groundmass consists predominantly of plagioclase feldspar, hornblende, quartz, potassium feldspar and magnetite. A modal analysis of one dacite porphyry sample is listed in Table 2.

Plagioclase feldspar (Average An 30) is present as subhedral to euhedral laths, usually 1 to 4 mm in length. Progressive and oscillatory zoning are common with up to three zone repetitions in some crystals. Carlsbad, albite, and pericline twinning are all present in the crystals of plagioclase feldspar. Alteration of these phenocrysts is moderate with clay and quartz accompanied by minor amounts of potassium feldspar and sericite.

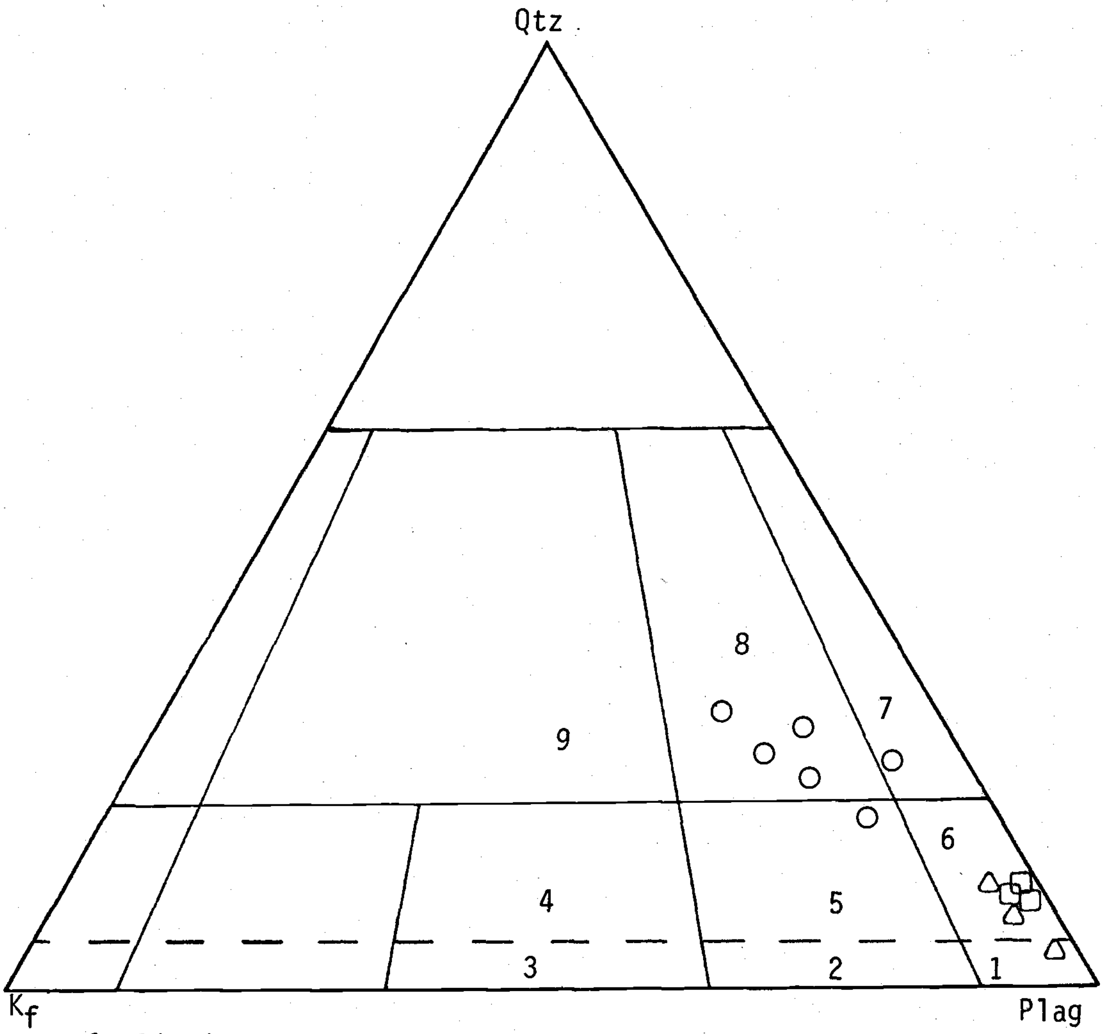
Hornblende is the dominant ferromagnesian mineral in the dacites. It is present as elongate anhedral phenocrysts up to 2.5 mm in length, and as small irregular crystals in the groundmass. The hornblende is moderately pleochroic from green to light brown. Many of the crystals are twinned and all are partially to completely altered to chlorite, magnetite, and uralite. The magnetite is commonly present as rims around a central core of chlorite. A few small badly altered crystals of an unidentified pyroxene are also present.

Sparse phenocrysts of quartz were found in most of the samples studied. However, most of the quartz in the dacites is present as small irregular blebs in the groundmass. The rest of the groundmass consists mostly of plagioclase feldspar (An 28), chlorite that probably formed as an alteration product of hornblende, and potassium feldspar. Accessory minerals include magnetite, zircon, sphene, and apatite. Much of the feldspar in the groundmass has been altered to clay and some magnetite has altered to hematite. Much of the magnetite in sample FA-DP may be a result of minerali zation as this sample was taken in the area of a magnetic anomaly located by the Freeport Exploration Company.

Microdiorite

The term microdiorite is used herein for a series of porphyritic finely-crystalline intrusive rocks of diorite to quartz dirotie composition (see Figure 3) that were first recognized by the author in drill core from the Freeport Exploration holes in sec. 29, T. 8 S., R. 5 E. Several outcrops were subsequently found in the south central portion of the thesis area. Because the Microdiorite is difficult to recognize, perhaps in part because of its proximity to hydrothermal alteration, it is the least perfectly understood intrusive phase in the North Santiam District.

Intrusions of Microdiorite are restricted to the central part of the thesis area in secs. 19, 29, 30, and 32, T. 8 S., R. 5 E. They were never found to penetrate the Upper Member. The best exposures of Microdiorite are along the Little North Santiam River in the W. 1/2, sec. 29, T. 8 S., R. 5 E., where altered intrusions are exposed in the canyon walls of some tributary streams. The size and shape of most of the intrusions could not be accurately determined because of poor exposures and the difficulty of distinguishing them from the



1 Diorite
2 Monzodiorite
3 Monzonite
4 Quatz monzonite
5 Quartz monzodiorite
6 Quartz diorite
7 Tonalite
8 Granodiorite
9 Granite

○ Hewlit Granodiorite
□ Ruth Diorite
△ Microdiorite

Figure 3. Quartz-alkali feldspar-plagioclase feldspar ternary diagram for classification of plutonic rocks of the North Santiam District. (I.U.G.S. classification, 1973)

volcanics in areas of hydrothermal alteration. However, some of the bodies along the Little North Santiam River appear to be dikes trending roughly north to northwest.

In the field, the Microdiorite closely resembles the andesite flow rocks in color and texture. Plagioclase feldspar is the only primary mineral identifiable in hand specimen. These phenocrysts, which tend to occur in clusters, are smaller and more equidimensional than the plagioclase feldspar laths in the andesites. These differences were often the only distinguishing characteristics of the microdiorite that were visible in the field.

The color of the Microdiorite is variable because of differing types and intensities of alteration. In general, weathered surfaces are greenish gray (5 G 6/1) to light brownish gray (5 YR 6/1) in color. However, some outcrops are bleached nearly white while others are heavily iron-stained giving them an orange color. Fresh surfaces are usually yellowish gray (5 Y 7/2) to greenish gray (5 GY 6/1 in color.

Lithology, Petrology, and Chemistry

The most noticeable feature of the Microdiorite intrusions is the high intensity of alteration to which it has been subjected. For example, many samples are so greatly altered as to render the identification of the primary mineral phases impossible. A few of the least altered samples have been used for this study and I believe them to be the best representative of this intrusive phase.

The Microdiorite is characteristically holocrystalline and porphyritic in texture. Small phenocrysts of plagioclase feldspar, quartz, and hornblende are present in a finely-crystalline to aphanitic groundmass which consists predominantly of feldspar, chlorite, and quartz. The equigranular allotriomorphic to hypidiomorphic texture of the groundmass is the major petrographic feature distinguishing the Microdiorite from the dacitic to andesitic intrusive and extrusive rocks discussed previously. In one sample, (NS-2-2003), the groundmass consists completely of plagioclase feldspar laths with interstitial chlorite and carbonate. This groundmass closely resembles the finely-crystalline Ruth Diorite in mineralogy and texture, and it is possible that this sample represents a transitional phase between the two intrusive types. Modal, major oxide, and trace element analyses of some representative Microdiorite samples are listed in Table 3.

Two distinct generations of plagioclase feldspar phenocrysts are present in the Microdiorite. The earlier formed generation consists of stubby laths of labradorite (An 56) which range from 2.0 to 2.5 mm in length. These crystals are present in only two of the six samples studied petrographically and comprise a small percentage of the rock. Many of the labradorite crystals are anhedral in form as a result of extensive resorbtion and some are surrounded by overgrowths of less calcic plagioclase feldspar. The predominant phenocrysts in all Microdiorite samples are elongate lathes of andesine that range from 0.7 to 1.5 mm in length. The andesine crystals are commonly zoned from (An 45) at the core tc (An 40) at the rim. All plagioclase feldspar phenocrysts are moderately altered to clay, calcite, and epidote.

Phenocrysts of hornblende were found in most thin sections. They are present as highly corroded anhedral crystals 0.5 to 2 mm in length. Pleochroism is weak with the color varying from light to medium green. Alteration of the hornblende to biotite and chlorite is intense and complete replacement has occurred in some samples. Much of the secondary biotite and chlorite present in the groundmass probably formed as an alteration of hornblende.

Quartz is present in all samples as irregular crystals up to 0.5 mm in diameter. Because of the altered condition of the Microdiorite it was difficult to determine whether the quartz was a primary constituent or a secondary replacement. Microveinlets of quartz are common throughout the Microdiorite indicating that some of the silica has been hydrothermally introduced. However, the presence of single quartz crystals scattered evenly throughout the rock suggests that some of the quartz may be of primary origin.

The finely-crystalline groundmass is intensely altered in all samples. It consists of a mosaic of andesine, chlorite, biotite,

	Microdiorite			Ruth Diorite			Average
	2-2003[2]	1-2013[2]	1-1944[2][1]	0-1[2]	0-2[2]	P-4[2]	hb B_{10}[1] diorite
SiO_2	52.0	56.3	60.5	55.0	55.4	54.7	53.0
TiO_2	1.5	1.3	1.1	1.2	1.3	1.2	1.6
Al_2O_3	21.3	18.1	16.0	19.3	19.6	19.1	18.2
FeO	9.8	8.5	7.4	10.1	9.2	8.2	8.3
MgO	3.6	2.4	3.0	4.0	3 8	4.8	4.75
CaO	5.8	6.1	4.0	6.6	6.4	7.9	7.6
Na_2O	3.7	4.9	2.8	3.8	4.1	3.5	3.5
K_2O	1.65	1.55	2.25	0.15	0.72	0.37	1.65
Total	99.35	99.15	97.05	100.15	100.52	99.77	
Trace Elements in ppm[3]							
Cu	340	1010	5100	590	170	100	
Zn	30	35	45	130	100	255	
Pb	8	6	8	40	30	40	
Mo	5	7	13	-1	1	-1	
Ag	1.0	1.0	1.0	0.6	0.8	0.6	
Modal Composition							
Qtz	3	5	8	7	6	7	
P-feld.	56	60	55	68	71	66	
K-feld.	1	2	2	--	1.5	tr	
Hblde	10	1	2	--	--	--	
Biotite	21	16	3	--	--	--	
Chlorite	4	5	20	16	13	17	
Sulfide	4	7	9	4	3	3	
Epidote	tr	2	tr	1	2	2	
Magnetite	--	tr	--	tr	tr	tr	
Calcite	-1	tr	tr	3	3	4	
Apatite	tr	1.5	tr	tr	tr	tr	

[1] After Nockolds (1954)

[2] Analyses by E. M. Taylor and R. Lightfoot, Oregon State University

[3] Analyses by Chemical and Mineralogical Services, Salt Lake City, Utah

Table 3. Modal analyses of Microdiorite and Ruth Diorite.

quartz, epidote, calcite, potassium feldspar, magnetite, and chalcopyrite crystals. The small irregular patches of chalcopyrite are usually associated with clumps of biotite that are replacing hornblende phenocrysts.

Variations in the major oxide and trace element geochemistry of the Microdiorite samples is believed to reflect differences in type and degree of alteration, and not differences in primary mineralogy. For example, the higher SiO content of samples 1-2013 and 1-1944 is a direct result of the introduction of secondary quartz in the form of replacements and microveinlets. The geochemical effects of alteration are discussed in detail in the section concerning hydrothermal alteration. Sample 2-2003 is the least altered and mineralized of the Microdiorites. This sample, compared to the average hornblende-biotite diorite of Nockolds (1954), differs significantly by having higher Al_2O_3 and total FeO contents and lower CaO and MgO contents. However, the evidence is not conclusive as to whether or not these differences resulted from hydrothermal alteration are a primary feature of the Microdiorite.

Age and Correlation

Contacts between the Microdiorite and other rock types in the area are for the most part sharp. Angular xenoliths of andesite are common in some of the larger intrusions. Microdiorite intrusions are cut by bodies of Hewlit Granodiorite in several places and diamond drilling by the Freeport Exploration Company has revealed that a granodiorite intrusion underlies the Microdiorite in the central part of the district. Evidence indicating the age relationship between the Microdiorite and the Ruth Diorite is inconclusive at best. Some intrusions of Ruth Diorite in sec. 32, T. 8 S., R. 5 E., contain small xenoliths of altered porphyritic rock that might be equivalent to the Microdiorite. The Microdiorite is mineralogically similar to the dacite porphyry described previously. However, the two rock types have not been found in contact and thus definite age relationships between the two cannot be established. On the basis of the contact relationships and the general appearance of the Microdiorite, I believe it to be the youngest of the dioritic intrusive phases. It was probably emplaced at a high level in a subvolcanic environment where it cooled slightly more slowly than the andesite and dacite porphyry intrusions. Emplacement probably took place in several stages of upward movement, which resulted in the formation of multiple generations of plagioclase feldspar phenocrysts.

Ruth Diorite

Intrusions of a distinctive quartz diorite, named herein the Ruth Diorite, are common in the eastern half of the thesis area. The best exposures are along Battle Ax Creek in secs. 27, and 28, T. 8 S., R. 5 E., and near Stony Creek in the N.W. 1/4, sec. 32, T. 8 S., R. 5 E. Two of the bodies mapped in sec. 29, T. 8 S., R. 5 E., were located only by the presence of float. Ruth Diorite was not found above an elevation of 800 m and it appears that it does not penetrate into the Upper Member.

Ruth Diorite is recognized in the field by its nonporphyritic finely-crysalline texture and by the medium gray (N 5) to dark gray (N 3) color of the fresh surfaces. The presence of chlorite and epidote gives the fresh surfaces a slight greenish cast when wet. Colors on the weathered surfaces of the Ruth Diorite vary from grayish orange (10 YR 7/4) to greenish gray (5 GY 6/1). In general the Ruth Diorite is considerably less intensely altered than the other dioritic intrusive rocks.

These intrusions are usually in the form of dikes 5 to 60 m in width and up to 300 m in length. They trend N. 20°40° W., and are near vertical in dip. Some of the dikes have narrow chilled margins. In sec. 27, some of the Ruth Diorite dikes contain subrounded clasts of quartz diorite that texturally and mineralogically are near identical to these intrusions, and which indicate multiple stages of diorite emplacement. The predominant northwest trend of these dikes, which is subparallel to the regional trend of fractures, suggests a structural control to their emplacement. In addition, the presence of abundant angular xenoliths of andesite indicates the possibility that they were emplaced along pre-existing fracture zones.

<u>Lithology and Petrology</u>

The Ruth Diorite is holocrystalline and hypidiomorphic granular to seriate in texture. Crystals range from 0.2 to 1.5 mm in size.

Plagioclase feldspar is the only primary mineral that can be identified in hand specimen. Petrographically, the major minerals are plagioclase feldspar, chlorite, quartz, and calcite. Modal analyses of two representative samples are listed in Table 3. All samples are classified as quartz diorites when plotted on quartz-plagioclase feldspar-potassium feldspar ternary diagrams (Figure 3).

Plagioclase feldspar constitutes almost 70 percent of the Ruth Diorite. Many crystals exhibit strong progressive zoning with the composition varying from (An 63) at the core to (An 46) at the rim. Carlsbad and albite twinning are both common and combined twins were used for determining the composition. The plagioclase feldspar crystals are in the form of anhedral to subhedral narrow laths 0.5 to 1.5 mm in length. Many of these crystals are bent and/or broken. Alteration is weak with small amounts of clay, calcite, epidote, and sericite partially replacing most crystals. Quartz is present as irregular patches up to 1 mm in diameter filling the interstices between the laths of plagioclase feldspar. Veinlets or replacements of quartz were not found, and it appears that all of the quartz is of primary origin. A small amount of orthoclase was identified in one sample of Ruth Diorite. This feldspar is believed to be of primary origin on the basis of its occurrence and texture.

The primary ferromagnesian minerals of the Ruth Diorite have been completely replaced by an assemblage of deuteric or hydrothermal chlorite and magnetite. Shapes of the numerous pseudomorphs indicate that the original minerals were at least in part subhedral to euhedral crystals of hornblende up to 1.5 mm in length. Evidence suggesting the possible presence of other ferro-magnesian minerals was not found in any of the thin sections studied.

The accessory minerals are magnetite, apatite, zircon, and sphene. All occur as well-formed crystals filling the interstices between plagioclase feldspar laths. The pyrite content increases sharply near the Ruth Mine and other prospects and indicates that most or all of the pyrite is secondary.

Major oxide and trace element analyses of three Ruth Diorite samples are listed in Table 3. The most diagnostic feature of these rocks is the consistently low K_2O content as compared to the other intrusive rocks in the North Santiam District, and to the average diorite of Nockolds (1954). The presence of almost two percent potassium feldspar in sample O-2 is reflected by its significantly higher K_2O content. High Al_2O_3 values for the Ruth Diorite are probably a result of the large percentage of intermediate plagioclase feldspar. Anomalous concentrations of copper and zinc in these samples are believed to be the result of post intrusion metalization rather than to high primary metal concentration in the magma. Other samples of Ruth Diorite (see Appendix A), collected away from areas of mineralization, contain normal background levels of metals.

Age and Correlation

In sec. 27, T. 8 S., R. 5 E., a large dike of Ruth Diorite is intruded by a small dike of granodiorite that is believed to be related to the Hewlit Granodiorite. The contact between the two intrusions is gradational over a distance of 10 cm. Thus, it is possible that emplacement of the granodiorite was accomplished at least partially by assimilation. Contacts between the Ruth Diorite and older rocks are usually sharp and the emplacement of the diorites appears to have had little effect on the host rocks. The deformed state of the plagioclase feldspar crystals indicates that the emplacement of these dikes may have been part a forceful injection of a crystal liquid mush. As mentioned previously, small xenoliths of porphyritic diorite that are believed equivalent to the Microdiorite are present in some intrusions of Ruth Diorite. From these contact relations, the Ruth Diorite is inferred to be older than the Hewlit Granodiorite and at least in part younger than the Microdiorite.

Hewlit Granodiorite

The Hewlit Granodiorite is the most abundant and widespread intrusive rock type present in the North Santiam Mining District. It is found in every part of the area except secs. 22, and 27, T. 8 S., R. 5 E., on the eastern edge of the district. Well-exposed outcrops of the granodiorite can be found along East Gold Creek in sec. 18, T. 8 S., R. 5 E., along the Little North Santiam River in sec. 29, T. 8 S., R. 5 E., and in the roadcuts along the ridge crest in sec. 31, T. 8 S., R. 5 E.

The Hewlit Granodiorite intrusion mapped in the northern one-half of sec. 31, appears to be a single elliptically shaped plug containing many roof pendants of welded tuff and andesite flow. Because the tuffs are intensely altered in and around this plug, it is often difficult to locate an exact contact between the tuff and the granodiorite. This large intrusion actually consists of at least two, and possibly three, separate phases that were not mapped individually. Elsewhere throughout the thesis area, the Hewlit Granodiorite is present as small dikes and elongate plugs of irregular shape. The dikes are usually 1 to 40 m in width and up to 400 m in length.

The primary minerals that can be identified in hand specimen are plagioclase feldspar, hornblende and quartz. In the field the Hewlit Granodiorite is recognized by the large size and abundance of these crystals. The color of these rocks is variable depending on the type and intensity of alteration. Fresh surfaces of relatively unaltered samples range from light gray (N 7) to greenish gray (5 GY 6/1) in color. Weathered surfaces are variable in color. Some are stained brown from the oxidation of pyrite and others associated with quartz-sericite alteration are bleached white.

Lithology and Petrology

Rocks mapped under the heading of Hewlit Granodiorite include hornblende granodiorites, quartz monzodiorites, and tonalites (Figure 3). Several of the intrusions consist of more than one phase, whereby an earlier quartz monzodiorite or tonalite is intruded by granodiorite. In restricted localities there appears to be a distinct temporal separation between the different intrusive phases. However, on a district wide basis there appears to be a complete gradation between the various intrusive phases.

The tonalite, quartz monzodiorite, and most of the granodiorite bodies are porphyritic in texture. However, fine- to coarse-grained equigranular to seriate granodiorite intrusions are present in a few restricted localities. All of these intrusions are holocrystalline. Modal analyses of six samples of Hewlit Granodiorite are listed in Table 4. The porphyritic quartz monzodiorite and granodiorite are characterized by phenocrysts of plagioclase feldspar, hornblende, quartz, and occasionally potassium feldspar surrounded by a finely-crystalline groundmass that is mineralogically similar to the phenocrysts. The tonalites are similar, but lack phenocrysts of quartz and are depleted in potassium feldspar.

Plagioclase feldspar is the most abundant mineral in all phases. As phenocrysts the subhedra range in size from 1 to 7 mm and in composition from oligioclase to calcic andesine (An_{20-48}). Plagioclase feldspar in the tonalite and quartz monzodiorite is typically more calcic and progressive zoning is common, whereas in the granodiorite it is oligioclase and phenocrysts are rarely zoned. The plagioclase feldspar in the groundmass is subhedral to anhedral in outline and generally is more sodic than the accompanying phenocrysts. Two of the granodiorite intrusions contain abundant myrmekitic intergrowths of quartz and plagioclase feldspar. Quartz is also present as anhedra up to 5.0 mm in diameter in the granodiorite and smaller phenocrysts are usually present in the quartz monzodiorites. Approximately 80 percent of the quartz in the intrusions of Hewlit Granodiorite is part of the groundmass where it is present as small anhedra intimately intergrown with plagioclase feldspar. Potassium feldspar phenocrysts up to 2 mm in diameter were found in one quartz monzodiorite intrusion which crops out along East Gold Creek. However, it is usually present as anhedral crystals in the groundmass and could only be positively identified by staining for potassium.

Hornblende is the only primary ferromagnesian mineral that was identified in the Hewlit Granodiorite. However, some petrographic evidence suggests that another ferromagnesian mineral may have been present prior to hydrothermal alteration. The weakly altered portion of the large granodiorite intrusion in sec. 31, T. 8 S., R. 5 E., contains equidimensional pseudomorphs of chlorite and epidote in addition to abundant phenocrysts of unaltered hornblende. These pseudomorphs probably formed as replacements of a calcium-bearing pyroxene. The quartz monzodiorite and tonalite also contain significant quantities of secondary chlorite but it is not known how much, if any, has formed from pyroxene. Hornblende in most of the Hewlit Granodiorite is moderately to intensely altered to uralite, chlorite, and magnetite. Accessory minerals include apatite, sphene, zircon, and magnetite. These are usually present in the groundmass as small euhedra. In addition, pyrite and some magnetite have been introduced during mineralization.

Major oxide and trace element analyses of six samples of Hewlit Granodiorite are listed in Table 4. Chemical variations observed within this group reflect to some extent the primary compositional variations between the three separate phases. The tonalite, relative to the quartz monzodiorite and granodiorite, contains less K_2O (1.1 versus 2.2 percent) and slightly less SiO_2 (62.0 versus 64.7 percent). Chemical variations between the quartz monzodirotie and the granodiorite are generally no greater than the variations within the granodiorite suite. Compared with the average tonalite and granodiorite of Nockolds (1954) the Hewlit Granodiorite has consistently lower concentration of K_2O and SiO_2. This is consistent with the relatively high abundance of plagioclase feldspar in the Hewlit Granodiorite.

Age and Correlation

The Hewlit Granodiorite is believed to be the youngest intrusive rock type exposed in the district. Where two phases

	Y-4[2]	M-9[2]	M-1[2]	K-1-A[3]	0-9[2]	P-10[3]	Average hb+B_i[1] Granodiorite
SiO_2	62.0	64.0	65.5	63.73	65.0	64.90	65.50
TiO_2	0.67	0.65	0.65	0.67	0.65	0.54	0.61
Al_2O_3	16.0	17.4	15.6	16.5	16.3	15.44	15.65
Fe_2O_3				2.01		1.63	1.63
FeO	5.3	5.75	5.0	2.58	5.1	2.74	2.79
MgO	2.7	2.7	2.3	2.00	1.9	1.83	1.86
CaO	5.2	4.6	3.8	4.17	5.8	3.63	4.10
Na_2O	3.3	3.3	4.1	3.94	3.6	3.21	3.84
K_2O	1.1	2.1	2.2	2.01	1.6	2.99	3.01
H_2O				1.78		2.66	0.69
P_2O_5				0.12		0.10	0.23
Total	96.27	100.5	99.15	99.5	99.95	99.67	99.91
Trace elements in ppm[4]							
Cu	45	55	35	50	30	30	
Zn	585	65	55	55	75	50	
Pb	45	30	30	40	25	25	
Mo	-1	-1	-1	-1	-1	1	
Ag	0.3	0.4	0.6	1.0	0.8	0.7	
Modal Composition							
Quartz	20	16	21	19	28	26	
K-felds	5	9	13	11	11	17	
P-felds	57	57	52	55	53	46	
Hblde	10	7	10	8	7	10	
Chlorite	5	7	2	4	3	--	
Biotite	--	--	--	1	tr	--	
Sulfide	2	1	1	tr	1	-1	
Magnetite	tr	1	tr	tr	tr	tr	

[1] After Nockolds (1954)

[2] Analyses by E. M. Taylor and R. Lightfoot, Oregon State University

[3] Analyses by K. Aoki, Tohoku University, Japan

[4] Analyses by Chemical and Mineralogical Services, Salt Lake City, Utah

Table 4. Modal and chemical analyses of Hewlit Granodiorite samples.

are found in contact, the more silicic phase is generally the youngest. Some intrusions in the central part of the area are breccias containing xenoliths of andesite up to 50 percent by volume. Many of the quartz monzodiorites and granodiorites contain partially rounded finely-crystalline clasts that are mineralogically identical to the main intrusion. Thexe xenoliths probably represent an earlier shell that was brecciated after solidification and carried upward by subsequent pulses of granodiorite magma.

Contacts between these intrusions and the volcanic country rocks are usually sharp. However, the contact between the granodiorite and the tuffs of the Upper Member is broad and gradational in some localities of intense hydrothermal alteration. Chilled margins, 2 to 10 cm wide, are common in the smaller dikes, but are rarely present in the larger intrusive masses. Sharp contacts and abundant xenoliths of all intruded rock types indicate that the emplacement of the Hewlit Granodiorite was not passive. This conclusion is corroborated by structural evidence such as the doming and rotation of some tuff units.

PETROCHEMISTRY

Major Oxide analyses of plutonic rock samples from the North Santiam Mining District exhibit a series of systematic variations with age and silica content. These variations are characteristic of a rock suite exhibiting late potassium enrichment. The limited data available at this time indicates a trend atypical when compared to the average calc-alkalic trend of Nockolds and Allen (1953). Moreover, it should be noted that on the basis of the alkali-lime (Peacock) index these plutonic rocks barely plot within the calc-alkalic trend. The suite has an alkali-lime index of about 60.5 percent SiO_2 as determined from the ratio of weight percentages $CaO:Na_2O + K_2O$ at unity versus percentage SiO_2. As rocks of the calc-alkalic trend plot between 55 and 61 percent, the plutons of the North Santiam District are therefore representative of a highly calcic calc-alkalic sequence of plutonic magmatism. Analysis of volcanic rocks from the area are too few in number to indicate any trends of significance. However, the andesitic volcanic host rocks are chemically similar to the average composition of the plutonic rocks exposed in the district.

Chemical analyses of 19 samples of fresh and altered rock (Tables 1, 2, 3, and 4) from the North Santiam District are plotted on Harker variation diagrams in Figure 4. The plutonic rocks show a continuous increase in SiO_2 and K_2O with decreasing age of emplacement. This is accompanied by a decrease in FeO, Al_2O_3, TiO_2, CaO, and MgO. However, Na_2O remains nearly constant. These variations are typical of a rock suite differentiated from a single

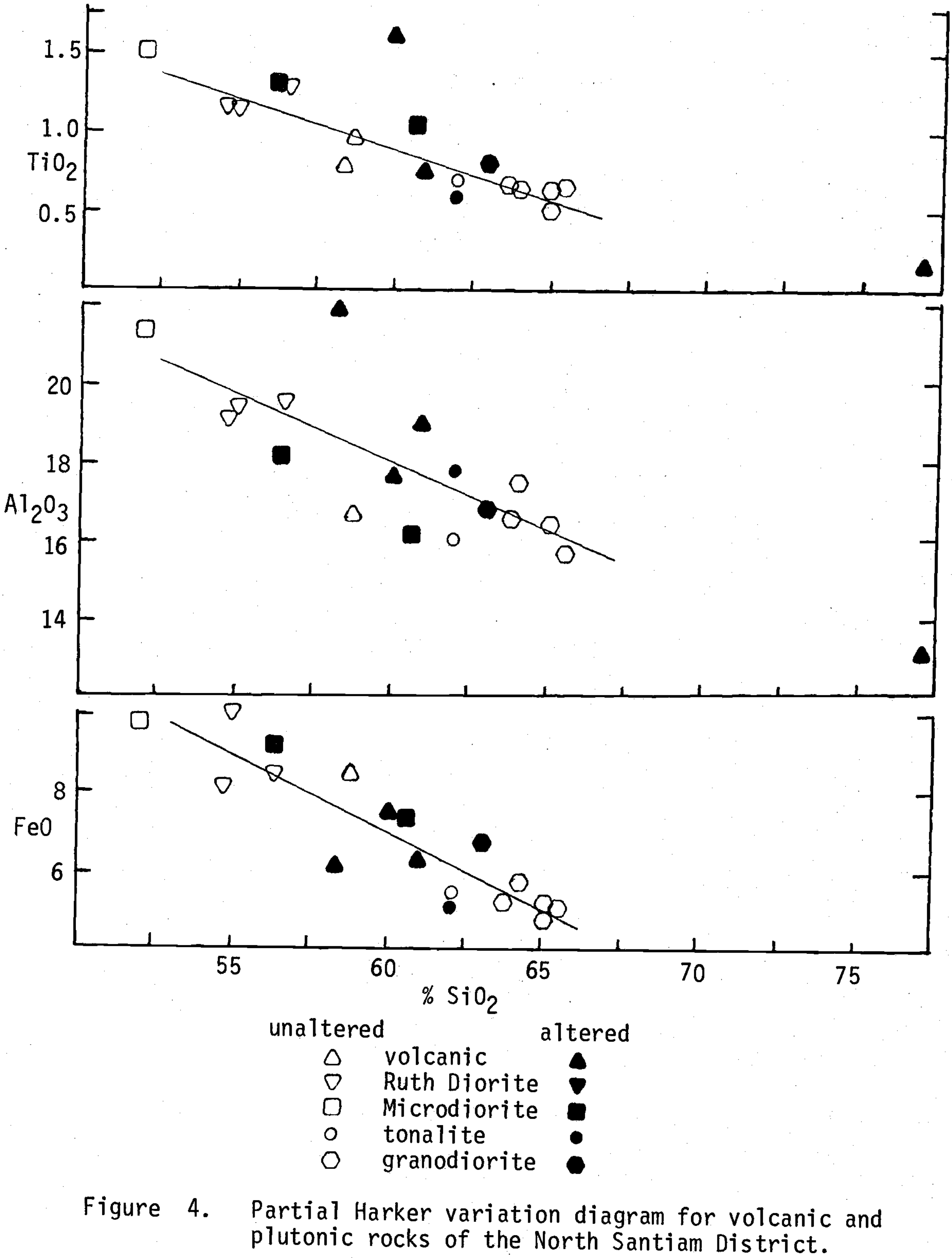


Figure 4. Partial Harker variation diagram for volcanic and plutonic rocks of the North Santiam District.

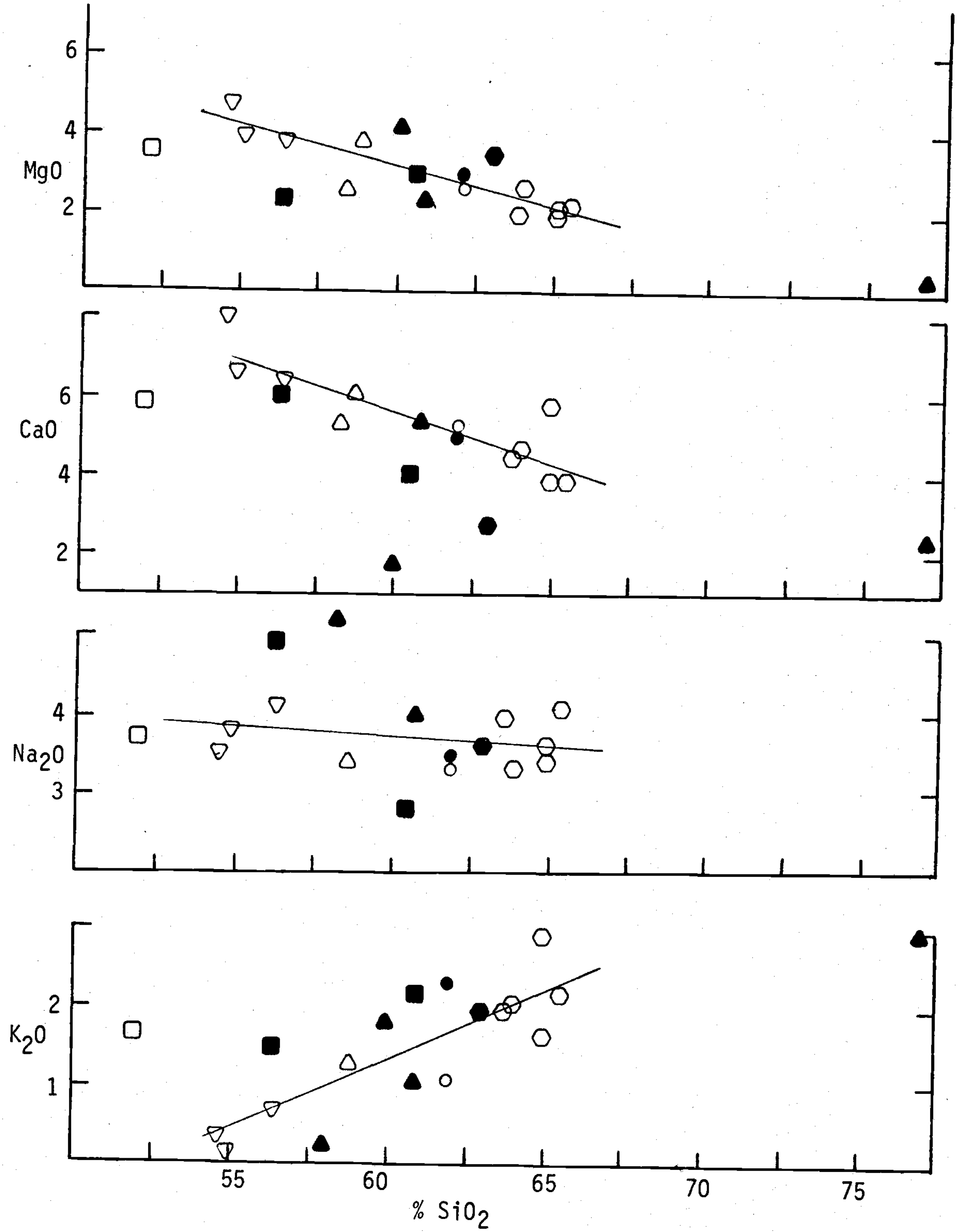
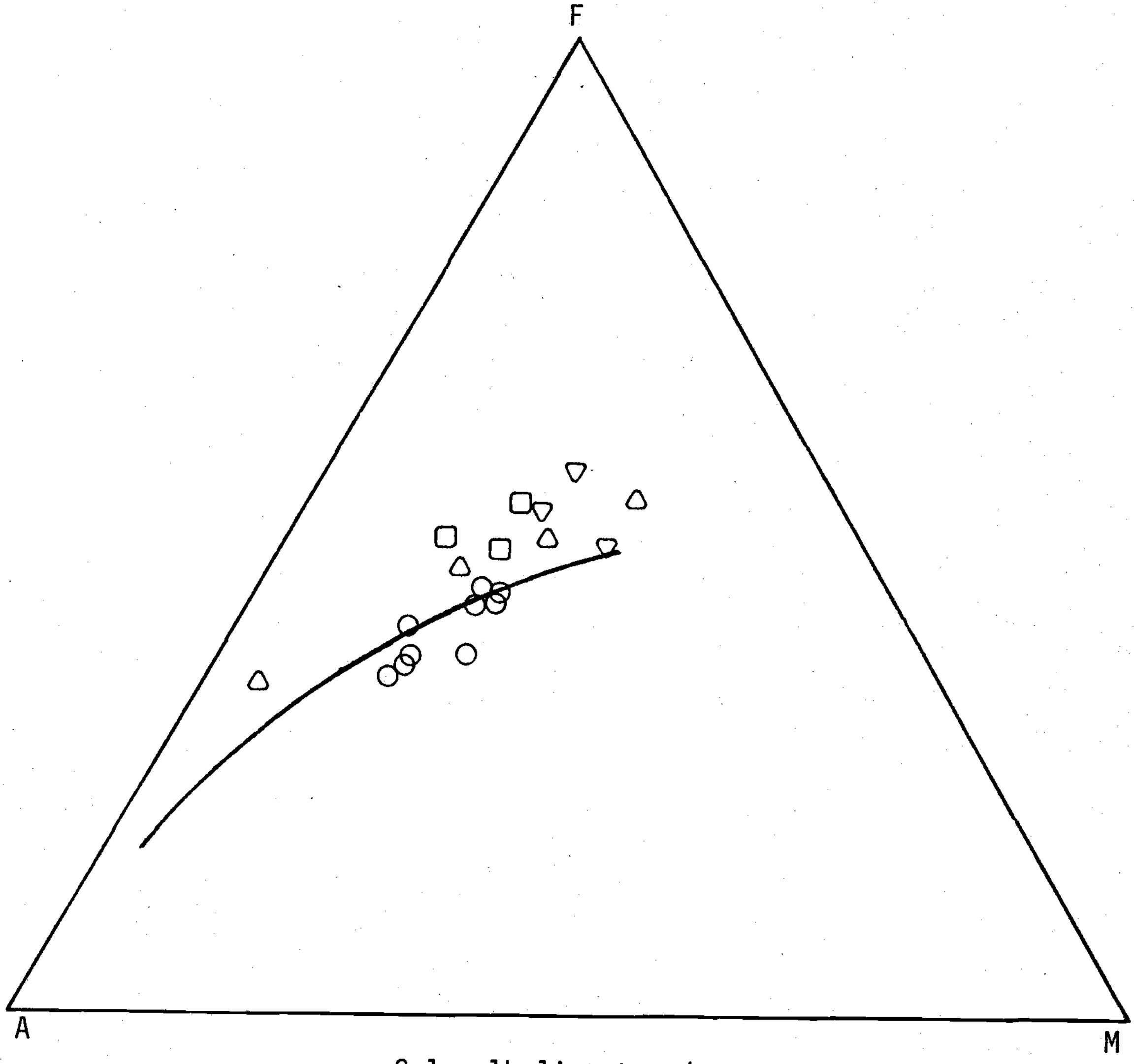


Figure 4. (continued)

magma. When the chemical components $K_2O + Na_2O$, FeO, and MgO and CaO, Na_2O, and K_2O for the plutonic samples are plotted on ternary AFM and CNK diagrams, respectively (Figures 5 and 6), they exhibit trends that are divergent from those for calc-alkalic rock suites from the southern California batholith and the Lassen Peak area (Nockolds and Allen, 1953). The rock suite from the North Santiam District is more depleted in K_2O relative to Na_2O and CaO in the earlier less silicic intrusions and it exhibits a more rapid increase in K_2O with increasing silica content. In addition, all of the North Santiam rocks are depleted in K_2O relative to average rocks of similar modal composition described by Nockolds and Allen (1953). The earlier silica-deficient plutonic rocks in the district are also enriched in FeO relative to $K_2O + Na_2O$ and MgO, as compared to average calc-alkalic trends. This variation may be in part a result of the widespread introduction of secondary magnetite during hydrothermal alteration. However, petrographic examination of the least altered samples revealed only slight differences in type and intensity of alteration. From this evidence, I conclude that most of the variations in composition among these samples represent different original compositions of the magmas, rather than chemical changes resulting from hydrothermal alteration. In addition, these anomalous variations may be partly attributable to the fact that the plutonic suite is slightly more calcic than the typical calc-alkalic sequence as defined by Nockolds and Allen (1953).

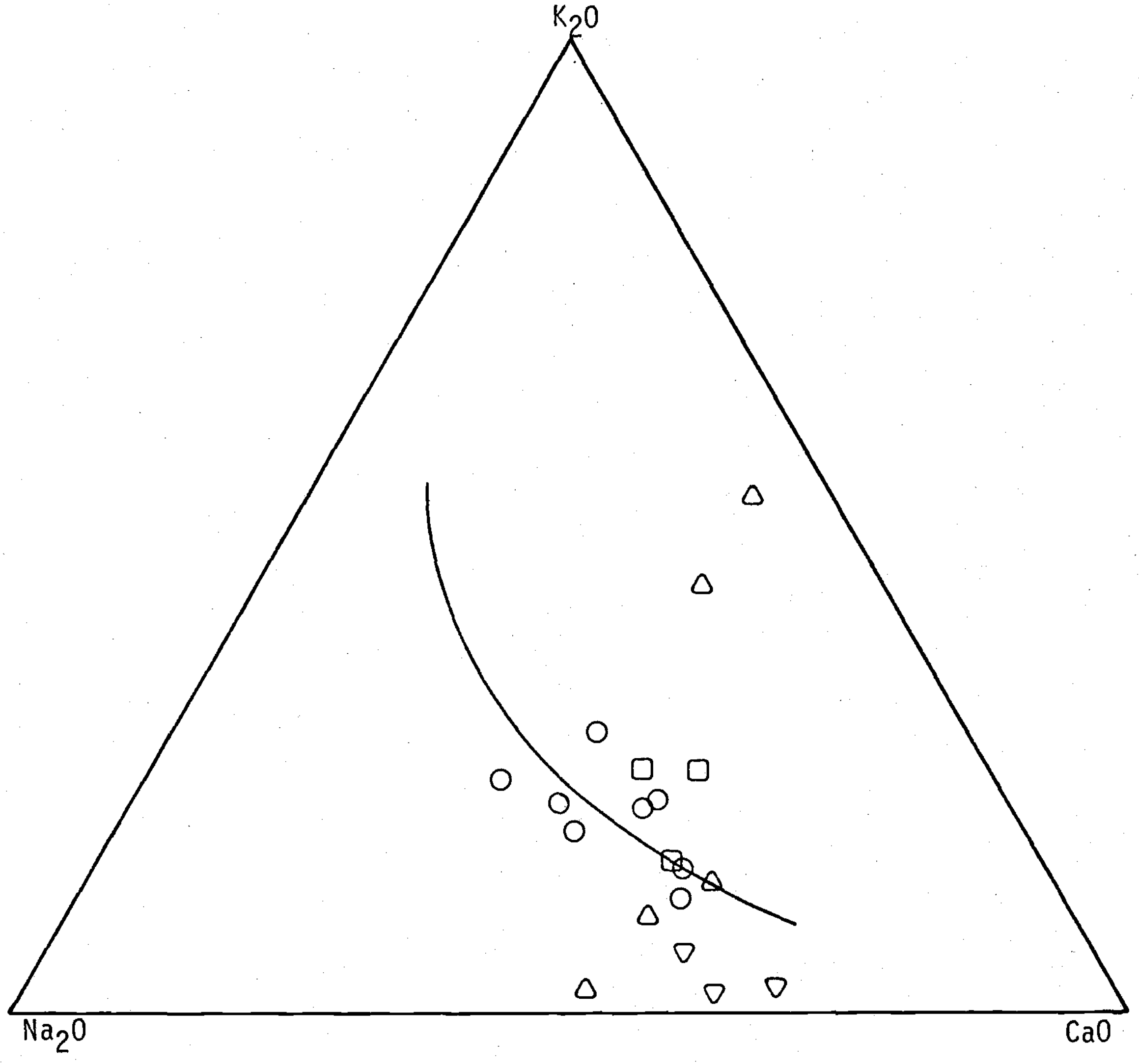
In general, the intrusive rocks of the North Santiam District



Calc-alkaline trend
(Nockolds and Allen, 1953)

△ volcanic
▽ Ruth Diorite
□ Microdiorite
○ Hewlit Granodiorite

Figure 5. AFM diagram for plutonic and volcanic rocks of the North Santiam District. $A=Na_2O+K_2O$; $F=FeO+Fe_2O_3$; $M=MgO$.



Calc-alkaline trend
(Nockolds and Allen, 1953)

△ volcanic
▽ Ruth Diorite
□ Microdiorite
○ Hewlit Granodiorite

Figure 6. NKC diagram for plutonic and volcanic rocks of the North Santiam District.

are mineralogically and chemically similar to intrusions associated with porphyry copper-type mineralization in island arc environments. Characteristically the island arc intrusions are depleted in potassium (Field and others, 1975) and have lower $^{87}Sr/^{86}Sr$ ratios relative to intrusions associated with continental-type deposits such as those in the southwestern United States (Kesler and others, 1975). The chemical trends exhibited by the North Santiam plutonic suite are similar to variations found within the Guichon Creek Batholith by Field and others (1975). They attributed the trends to a trondhjemitic variation of the calc-alkaline trend. Intrusive rocks associated with the Bohemia Mining District (Schaubs, 1978) and the Blue River Mining District (Storch, 1978) also exhibit consistently low potassium concentrations. McBirney and White (1977) report that the volcanic rocks of the Western Cascade subprovince have low $^{87}Sr/^{86}Sr$ ratios.

The distributions of modal compositions for several porphyry copper districts are shown along with the North Santiam data on a quartz-plagioclase-orthoclase ternary diagram in Figure 3. This distribution indicates that the plutonic rocks of the North Santiam district most closely coincide with the granodiorite branch of the Guichon Creek Batholith trend (Field and others, 1975) and the granodiorite trend of Kesler and others (1975) for plutonic rocks associated with porphyry copper mineralization in the Caribbean. In contrast, Schaubs (1978) found the intrusive rocks of the Bohemia District to fall predominantly along the quartz diorite trend of Field and others (1975) and Kesler and others (1975).

On the basis of chemical and mineralogical data Kesler and others (1975) concluded that island arc intrusions are compositionally more primitive than their cratonic counterparts. According to them, the melts are mantle derivatives that have undergone little or no contamination from cratonic material or subducted sea floor and sediments.

STRUCTURE

With respect to the regional structure, the North Santiam District is located between the Sardine Syncline to the east and the Mehama Anticline to the west. The regional dip associated with these broad northeast trending folds is 5° to 10° to the southeast. According to Peck and others (1964), the valley of the Little North Santiam River is located along the axis of a smaller anticline trending N. 60 °E. However, evidence of this anticline was not observed within the thesis area. The regional structure may be partially obscured by local deformation within the district. This consists of northwest and northeast trending faults and fractures, and a poorly-developed dome centered near the northeast corner of sec. 31, T. 8 S., R. 5 E.

The dome appears to have resulted from the emplacement of magma forming the large intrusions in the center of the area. The welded tuff units above the Hewlit Granodiorite in sec. 31, T. 8 S., R. 5 E., have been tilted as much as 20°. Dips associated with this dome outward and beyond the immediate vicinity of the intrusions are generally less than 10 degrees.

Fracture zones and small faults are common throughout the district. Fracture orientations were measured and the poles to planes were plotted on lower hemisphere Schmidt equal-area nets. The various trends within the district are shown in Figure 7. The

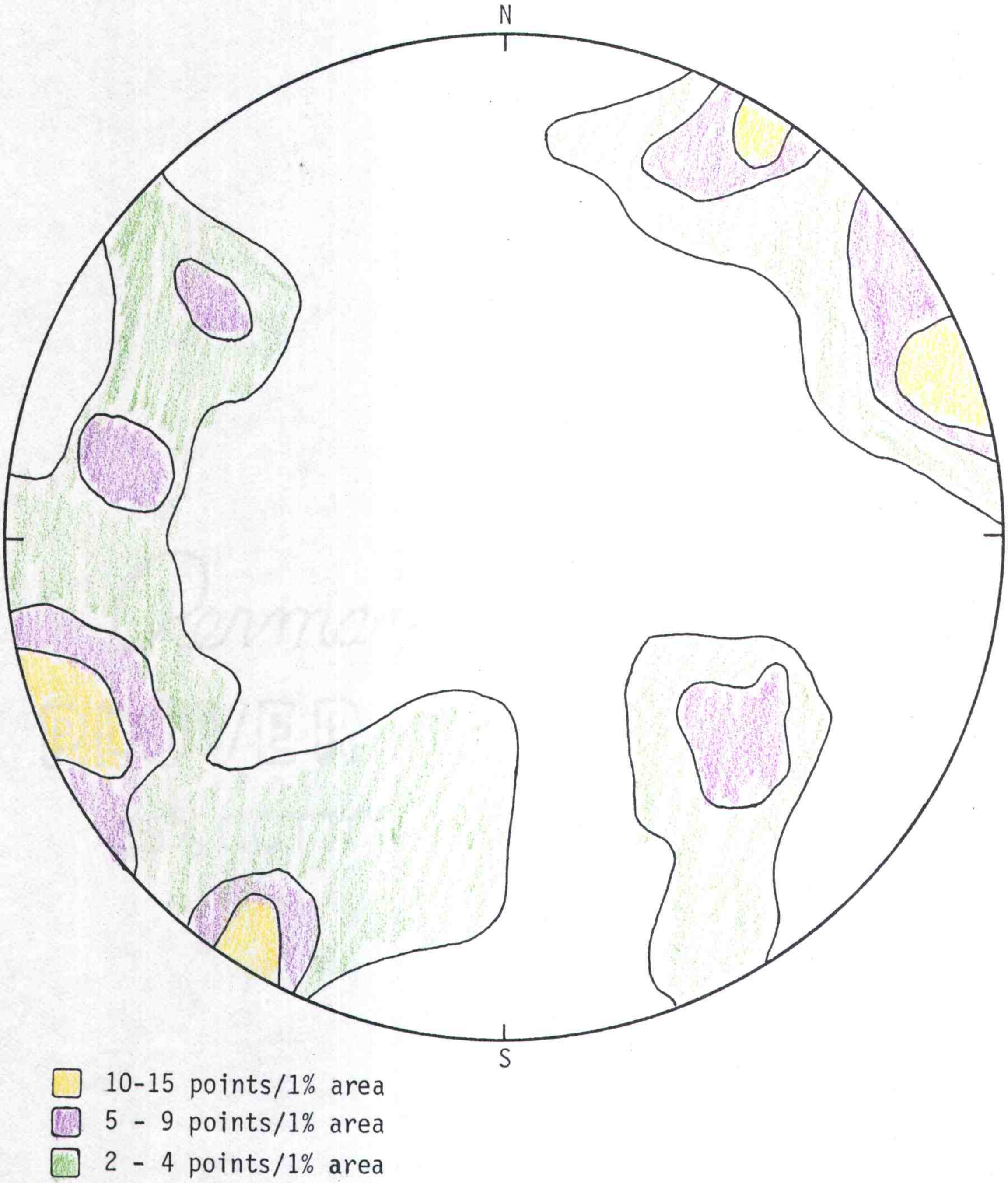


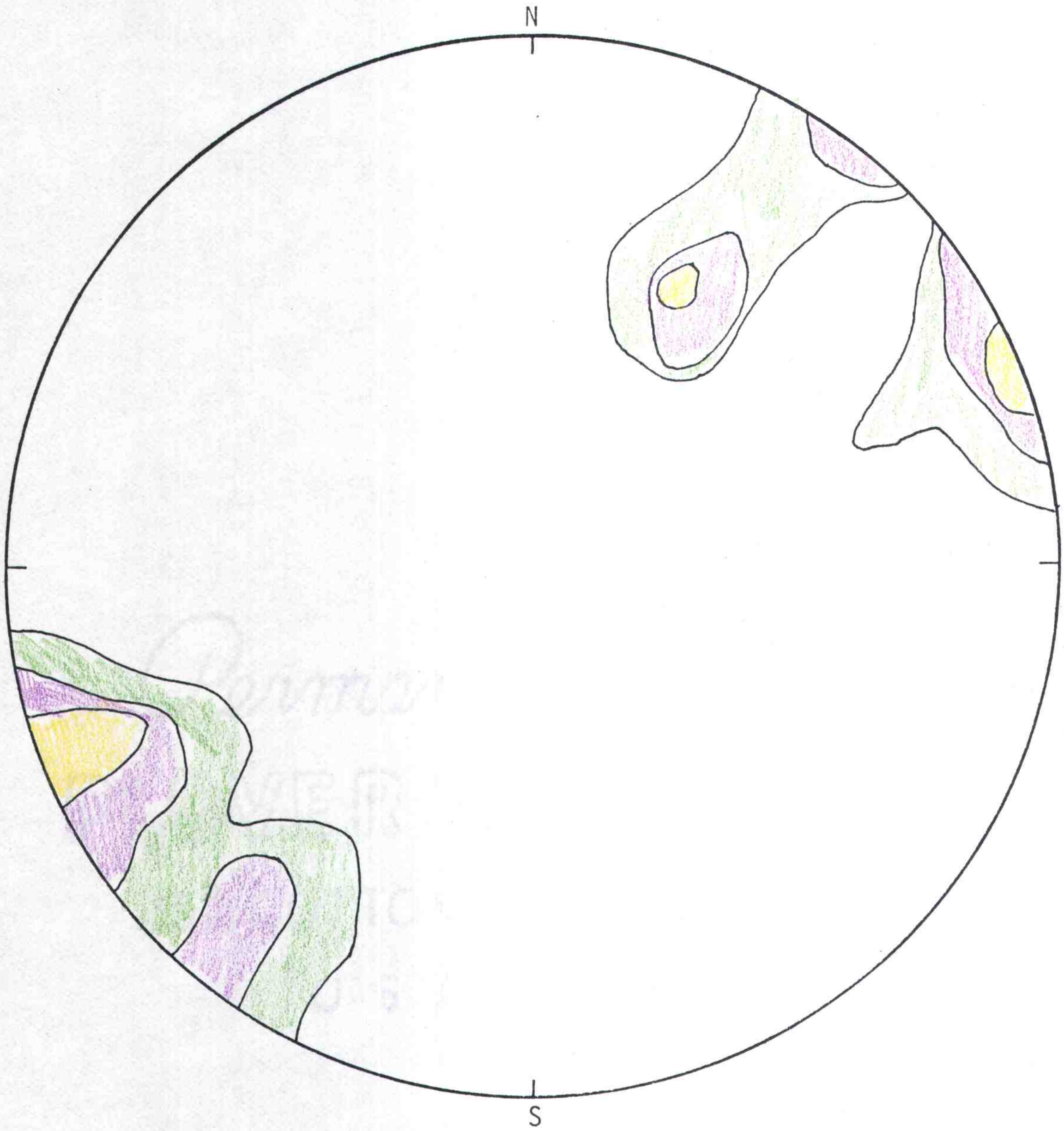
Figure 7. Lower hemisphere projection of poles to planes for fractures of the North Santiam District. (120 measurments)

well-developed trends striking N. 20° W., and N. 60°W. are prevalent throughout the entire district and are believed to be a conjugate pair resulting from regional stresses. They indicate a maximum compressive stress oriented northwest-southeast across the district. In addition, a trend striking N. 10°E. and dipping 65° to 70°E. is present in the area of the Ruth Diorite intrusions on the eastern edge of the district. This orientation may be related to the emplacement of these intrusions. However, a more detailed study would be necessary to verify this interpretation. In secs. 29-32, T. 8 S., R. 5 E., a set of fractures that strike N. 43°E. is present in addition to the two northwest striking sets previously mentioned. Several small northeast-striking faults are also present in this part of the district. This northeast fault and fracture system appears to be in close spatial association with the main mass of the Hewlit Granodiorite, and thus possibly directly related to the emplacement of this intrusion. Dips for all fractures normally range from 55° to 90°.

Numerous faults of short length are present throughout the district. However, because of the small offsets involved and a lack of good marker beds, the direction and amount of movement could rarely be determined. In general, most of the faults are parallel to the two northwest-trending fracture sets. The fault pattern becomes more complicated in the south central part of the district. Here, the set that strikes northeast as previously mentioned becomes predominant. All of the faults are steeply dipping and most are believed to be normal faults. Displacements for the majority are probably less than 10 m. Rarely could they be traced in outcrop for more than a few tens of meters. These faults, together with the fractures, are important because many are the loci of vein deposition and thus provided structurally controlled channelways for the later hydrothermal mineralization.

The orientation of mineralized veins is shown in Figure 8. Two distinct trends can be recognized. These have average strikes of N. 20° W. and N. 52°W., and both sets dip steeply. The set trending N. 52°W. is more variable in strike and has a stronger component of southerly dips. It is present only in secs. 29-32, where these veins constitute the dominant set and exhibit subparallel trends with associated intrusive dikes. The N. 20°W. set predominates throughout the remainder of the district.

The stress pattern responsible for the northwest-trending faults and fractures was developed early in the history of the district as is indicated by the northwest-trend of the andesite feeder dikes. Faulting is presumed to have continued episodically into and through the hydrothermal event as is indicated by the presence of post-mineralization gouge and slickensides in and along many of the veins.



10-15 points/1% area

5 - 9 points/1% area

2 - 4 points/1% area

Figure 8. Lower hemisphere projection of poles to planes for mineralized veins of the North Santiam District. (82 measurments)

ECONOMIC GEOLOGY

Most of the early history of the discovery of the mineral deposits in the North Santiam Mining District has been lost. Claims were initially staked during the 1860's, although Callaghan and Buddington (1938), report that ore was first found in 1896 at what is now the Ruth Mine. By 1903 most of the properties had been located. Total recorded production for the district amounts to only $25,000, but this figure is probably much too low because production was not recorded for many of the mines. Metal production consisted of 454 ounces of gold, 1,412 ounces of silver, 41,172 pounds of copper, 40,700 pounds of lead, and 110,000 pounds of zinc (Brooks and Ramp, 1960). Individual dollar values for this production are not available.

Of the 26 properties known in the district, only a few had significant values and development recorded. The three most important producers were the Ogle Mountain, the Santiam Copper, and the Ruth Mines. Recorded production from the Ogle Mountain Mine was $10,000 which was derived mostly from free and wire gold. Operation of this mine, which is located just east of Ogle Creek in the S. 1/2, sec. 9, T. 8 S., R. 4 E., was undertaken from 1903 to 1914 and again from 1918 to 1919. Workings in several adits and levels totaled approximately 3,000 feet. Production from the Santiam Copper Mine was sporadic from 1908 to 1941, with both ore and concentrates shipped at various times. Chalcopyrite was the major ore mineral and it was accompanied by small amounts of gold and silver. Most of the work was on the Northwestern vein, which crosses the Little North Santiam River in the N. W. 1/4, sec. 30, T. 8 S., R. 5 E. Workings included at least 1300 feet of drifts and several stopes and raises (Brooks and Ramp, 1968). At the present time, workings south of the river are inaccessible due to filling of the drift by stream gravel. The Ruth Mine, formerly known as the Amalgamated Mine, has been the most thoroughly developed and explored property in the district. Production took place at various times between 1902 and 1939, but total production and ore values were not recorded. Zinc was the major metal recovered from this property together with small amounts of lead and a little gold and silver. Workings include over 4000 feet of drifts on five levels with several small tunnels and prospects nearby. Reserves are reported at from 200,000 to 800,000 tons containing from 4 to 11 percent zinc (Brooks and Ramp, 1968). Development work is again being conducted on the Ruth Vein by Shiney Rock Mining Company, and it appears to be the only vein deposit in the district with future potential.

There has been renewed interst in the economic potential of the district during the past few years. Several major mining companies have conducted exploration projects in the area, and Freeport Exploration and Amoco Minerals are presently active in the district.

Geophysical work accomplished to date includes I.P., V.L.F. and magnetic surveys. At least seven diamond drill holes have been drilled. Although the final results of these efforts are not yet available, the drilling programs have demonstrated the presence of pyrite, chalcopyrite, bornite, and molybdenite at depth and in spatial association with a finely-crystalline dioritic intrusive.

Breccia Pipes

One of the most significant features of the North Santiam Mining District is the presence of tourmaline-bearing breccias. Intensely altered pipe-like bodies that are circular to ellipitcal in plan and range from 10 to over 100 meters in length are scattered throughout the central portion of the area. Two classes of breccias have been distinguished in the district. The first, termed shatter breccias, consist of highly fractured rock that has been partially to completely altered to an assemblage consisting predominantly of tourmaline, quartz, and sericite. Little or no movement of the fragments has occurred in the shatter breccias. The second class of breccias is characterized by highly-altered angular to sub-rounded clasts cemented by quartz, sericite, tourmaline, oxides, sulfides, and rarely carbonate. Displacement of clasts is evident in these breccias. However, the direction and amount of movement cannot be determined. Characteristic features of several individual pipes are described below.

General Character and Distribution

The Spokane breccia is an elliptical-shaped body approximately 90 meters in length and trending N. 60°W. It is one of a small group of similar breccias located in the S.W. 1/4, sec. 29, T. 8 S., R. 5 E. This pipe appears to be a shatter breccia, although complete hydrothermal replacement of the central portion may have destroyed any fragmental texture that was originally present. The host rocks for this pipe are porphyritic andesite flows of the Lower Member. Finely-crystalline dioritic plutonic rock is present near the southeast end of the pipe, but a contact between the pluton and the pipe was not found.

The borders of the pipe are gradational over a distance of several meters as the number of fractures and intensity of alteration decrease rapidly outward. Relict textures of the andesite are visible along the margins of some pipes and a few phenocrysts of plagioclase feldspar can be identified. Inward from the margin, the primary textures and mineralogy of this volcanic host are completely obliterated. The center of the Spokane pipe consists entirely of a secondary assemblage of tourmaline, sphene, quartz, sericite, an unidentified clay mineral, potassium feldspar, and sparse pyrite and chalcopyrite.

The Freeport breccia is an elliptical pipe 150 m in length and 50 m in width. It is located in the S.W. 1/4, sec. 29, T. 8 S., R. 5 E., about 200 m to the southwest of and subparallel to the Spokane breccia. The Freeport pipe is the best exposed breccia in the district as it is bisected transversely to its major axis by a small stream. Host rocks for this pipe consist of andesite flows and intrusions of quartz monzodiorite and Microdiorite. These rock types are also present as clasts within the pipe. This and the Prince breccia are the only two pipes in the district for which extensive movement of the fragments is well-documented.

The margins of the pipe are characterized by a shatter zone grading outward into weakly fractured host rock. Inward, the pipe consists in part of altered clasts cemented by a mixture that may include tourmaline, quartz, sericite, specular hematite, and magnetite. Elsewhere, some parts of the breccia are composed of angular to subrounded clasts in a matrix that is composed almost completely of finely-crystalline magnetite (Figure 9). Large sections of the pipe consist of massive altered rock in which the original minerals and textures have been destroyed. Mineralogically, these zones of hydrothermal replacement contain similar assemblages to those in the Spokane pipe.

An interesting feature of the Freeport pipe is the presence of breccia zones in which clasts of tourmaline are cemented by a matrix of quartz, sericite, potassium feldspar, and clay. The formation of this breccia occurred in several stages. Large sections of host rock

Figure 9. Spokane breccia showing magnetite cement.

were apparently completely replaced by a complex intergrowth of tourmaline starbursts. This secondary mineral was then broken into tabular clasts up to 10 cm in length, and these subsequently underwent translation and rotation prior to being cemented by the finely-crystalline matrix. Displacement of the clasts is usually less than 5 cm and commonly but a few millimeters. The presence of these tourmaline fragments is evidence that part of the brecciation of these pipes post-dated hydrothermal alteration. The clasts are subparallel and the zones containing them resemble the sheeted zones of some breccia pipes in Chile described by Sillitoe and Sawkins (1971).

The Prince breccia crops out less than 300 meters to the northwest of the Freeport pipe. Although similar in size and shape it differs from the Freeport pipe by having larger amounts of chalcopyrite that accompany the tourmaline and by the lack of a distinct shatter zone at the margins. The Prince pipe grades outward from an intensely-altered core to a margin of weakly altered andesite flows and Microdiorite. In a few areas within the pipe there are angular clasts cemented by tourmaline and quartz. Andesite flows are the predominant host rocks, although intrusions of granodiorite and quartz diorite are found nearby.

Three other small shatter breccias are located within a few hundred meters of the Spokane, Freeport, and Prince pipes. Also present in the immediate area are several small zones of phyllic and (or) argillic alteration that are accompanied by tourmaline. All of these breccias appear to form a structurally-related group. Individually, the pipes are elliptical in plan, the long axis of each trends northwest, and the entire group of breccias is collectively aligned along a northwest trend. In two instances, pairs of pipes are located along the same N. 55 W. trend. It is probable that only a few major channelways served as conduits for the hydrothermal fluids associated with these pipes. This structural trend of about N. 50° to 65°W., is well-developed only in the central portion of the thesis area. It may have resulted from forces associated with the emplacement of the large amounts of intrusive rock found at depth beneath the group of breccia pipes.

Two similar, but apparently unrelated, shatter breccias were also found to the west of the central group. A circular shatter breccia is well exposed in a road cut in the north central part of sec. 30, T. 8 S., R. 5 E. The accompanying alteration is confined to the area of fracturing, and sparse tourmaline is present only as fracture fillings that accompany quartz. A single outcrop of highly-altered tourmaline-bearing rock was discovered in the S. E. 1/4, sec. 23, T. 8 S., R. 4 E. The size and shape of this body are unknown although the distribution of float nearby indicates a small areal extent. A dike of quartz monzodiorite is located nearby, but was not found in contact with the breccia. Tourmaline is also present in the alteration halo associated with the Crown Mine, which is located in the S. E. 1/4, sec. 33, T. 8 S., R. 4 E., just to the southwest of the thesis area.

Zones of hydrothermal alteration accompany all of the breccia pipes in the district. The alteration halos usually extend 50 to 100 m beyond the margins of the pipes. The association of hydrothermal alteration with all of the pipes indicates that it probably is genetically related to the formation of the breccias.

The last event in the formation of the breccia pipes was the deposition of quartz to form numerous veins. As the veins are composed of large quartz crystals oriented perpendicular to the vein walls, they have formed by the common process of open space filling. Because the veins are symmetrically zoned from their centers outward, they presumably represent a sequential period of formation.

Mineralogy

Tourmaline is most abundant alteration mineral in the breccia pipes. It constitutes up to 60 percent of large portions of several pipes. The tourmaline is present as starbursts up to 5 cm in diameter, as irregularly shaped finely-crystalline masses, and as microcrystalline coatings on fractures. In hand specimen, the tourmaline is dark gray green to black. Petrographic study reveals two separate types. One is a green to blue-green pleochroic variety that composes most of the starbursts. It was identified as the iron rich member, schorlite. The other is a yellow to amber variety that generally is found surrounding the starbursts. It has been tentatively identified as dravite, a magnesium rich tourmaline. Gradations between the two types are commonly observed. Void space usually composes 5 to 15 percent of the intensely tourmalinized portions of the pipes.

Magnetite is locally abundant in the breccia pipes, and in the altered host rocks surrounding them as well. It is commonly found in veins within the pipes where it forms the outermost and, thus, earliest zone or selvage. Elsewhere, as in some sections of the Freeport and Prince pipes, magnetite is the dominant cementing material for the clasts. In the volcanics, the magnetite is present as microcrystalline euhedra and subhedra that are randomly dispersed throughout the rock. This finely-crystalline magnetite composes up to ten percent of some altered rocks.

Specular hematite is associated with all of the breccias in the group located in the S.W. 1/4, sec. 29, T. 8 S., R. 5 E., but it has not been identified in the pipes to the west of this group. The specularite is largely restricted to late stage quartz veins. Only rarely is it found as tiny thin flakes scattered throughout the tourmalinized rock. In the quartz veins it occurs as scaley to bladed aggregates which commonly occupy one or more distinct zones paralleling the vein walls.

Quartz and sericite are abundant minerals in all of the breccia pipes. They are present as a granular microcrystalline matrix surrounding larger masses of tourmaline. The matrix of most pipes also contains significant quantities of potassium feldspar. In addition, an unidentified clay mineral is abundant in a few pipes. The proportions of quartz, sericite, potassium feldspar, and clay vary widely within a single pipe, but quartz is invariably the most abundant. Intensely altered portions of the Spokane and Freeport pipes contain up to several percent sphene as irregular masses and aggregates.

The breccia pipes contain only small quantities of sulfide minerals. Chalcopyrite is by far the most abundant, and it may be accompanied by small amounts of pyrite in a few localities. Small disseminated blebs of chalcopyrite are found with tourmaline in the Prince pipe. Chalcopyrite is also associated with quartz in veins of the Prince, Freeport, Spokane, and other nearby pipes. Pyrite is common in the alteration haloes in country rock that surround the pipes, but it is rarely found within the breccias themselves.

Comparison with Other Breccia Pipes

Tourmaline-bearing breccia pipes have been noted in numerous localities throughout the circum-Pacific area. Their occurrence is generally coincident with the distribution of porphyry copper-type mineralization. A major belt of breccia pipes extends from southern Peru to central Chile (Sillitoe and Sawkins, 1971). Comparable breccia pipes are found in the Cananea district, Mexico (Perry, 1961), the Copper Basin district, Arizona (Johnston and Lowell, 1961), the Cascade Range of Washington (Grant, 1969), and in the Republic of Korea (Fletcher, 1977). Tourmaline-bearing pipes are also present in the Bohemia Mining District, Oregon (Schaubs, 1978) and Schriener (1978) reports tourmaline and amphibole-bearing breccia pipes from the Silver Star area in southern Washington. Brief descriptions of a few breccia pipes that closely resemble those in the North Santiam Mining district are given below.

The Chilean pipes are characteristically steeply dipping circular to oval shaped bodies emplaced within Tertiary epizonal plutons or adjacent volcanics. Sillitoe and Sawkins (1971) divided the hydrothermal alteration of the pipes into two stages. An early replacement stage produced pervasive quartz-sericite alteration accompanied by tourmaline. A later stage of open space filling around breccia fragments consisted predominantly of quartz, tourmaline, specularite, and sulfide deposition. The breccias consist of angular to subrounded fragments of host rock. The margins of the pipes grade outward into zones of vertical sheeting. Some pipes terminate upward and are overlain by zones of hydrothermal alteration.

The ore body at the Ilkwang Mine, in the Republic of Korea, is a breccia pipe consisting of angular to tabular fragments of quartz monzonite cemented by tourmaline, quartz, sulfides, and tungstates.

The predominant alteration assemblage of fragments within the pipe is quartz, sericite, and pyrrhotite. The pipe is incorporated within a quartz monzonite stock that intrudes a sequence of Upper Cretaceous sedimentary and pyroclastic rocks. Hydrothermal alteration associated with the breccia has a zonal distribution. An outer zone of propylitic alteration grades into a central zone of quartz-sericite alteration (Fletcher, 1977).

Origin

Many theories have been proposed for the formation of mineralized breccia pipes similar to those in the North Santiam Mining District. Characteristics of the North Santiam breccias that must be accounted for in proposing a possible origin are: (1) the angularity of most of the breccia fragments; (2) the absence of a rock flour matrix; (3) upward termination of the pipes; (4) shatter breccia peripheral to fragmental breccia; (5) compositional similarity of host rocks and breccia fragments; (6) presence of tourmaline fragments; (7) abundant void space within breccia fragments, and (8) the occurrence of quartz-sericite alteration accompanying all of the breccias. All of the features listed above are present in the Chilean breccia pipes (Sillitoe and Sawkins, 1971; Howell and Molloy, 1960).

Many mechanisms have been proposed for the formation of breccia pipes. Among the most tenable hypotheses are fluidization, magma pulsations, solution-stopping collapse, and collapse into a vapor bubble void. The last three mechanisms have many features in common and breccias formed by them may be difficult to differentiate. Each of the theories proposed is discussed below with respect to its possible application to the origin of breccias in the North Santiam Mining District.

The process of fluidization involves the suspension and transportation of particles in a fluid that has a lower density than that of the particles. The fluid, either a gas or a liquid, is derived from a magmatic source snd rises along fracture systems. In order to produce a sufficient pressure gradient to cause rapidly rising solutions, the system would probably have to be open to the surface. Deposition of the suspended material takes place when the fluid pressure differential is insufficient to transport the fragments, or when the channels become blocked. Bryant (1968) attributed the formation of breccias in the Warren Mining District, Arizona, to the process of fluidization. He suggested that brecciation there was essentially a pre-alteration event and that because of this the breccias in the Warren District could not have been formed by solution-stopping. Characteristically, breccias formed by fluidization consist of well-rounded fragments in a matrix of finely comminuted rock flour. In breccias of the North Santiam District, the lack of rock flour in the matrix, upward termination of some pipes, and post-alteration brecciation as shown by the tourmaline clasts, indicate that some process other than fluidization was responsible for the formation of these breccias.

Breccia formation by magma pulsations, solution-stoping, and collapse into a vapor bubble void involves the collapse of a rock mass into an open space. The method by which the void forms is the only significant difference between these processes. Once a sufficiciently large open space is formed, overloading in the roof of the void will result in fracturing followed by collapse into the void. This process is analogous to the block caving method of mining. An origin by collapse is suggested for the North Santiam pipes because of the upward termination of some breccias.

Successive advances and retreats of a magma body (magma pulsations) were proposed as a mechanism for the formation of breccias by Perry (1961). He described breccia pipes from the Cananea District, Mexico, and suggested that they formed by the episodic advance of a column of quartz porphyry magma into an andesite host. In the case of the La Colorada Pipe, Perry (1961) suggested that repeated advances of the magma resulted in the formation of a breccia completely enclosed within a plug of quartz porphyry. Hydrothermal alteration and mineralization were caused by reactions with upward migrating aqueous magmatic fluids.

Norton and Cathles (1973) developed a model for the formation of breccias in which the pre-breccia void results from entrapment of vapor in the cupula of an intrusion. According to them the early cooled rind of the intrusion seals the system and allows water vapor exsolved from the magma to collect under high pressure. Eventual piercement of the rind results in a drop in pressure that initiates the collapse. Calculations by them for the porphyry system at Santa Rita, New Mexico, indicate a sufficient volume of water would have exsolved from the stock to have easily formed the pre-breccia void.

Formation of breccias by the mechanism of solution stoping was proposed for the Chilean tourmaline breccia pipes by Sillitoe and Sawkins (1971). In their model, dissolution and removal of rock material by corrosive hydrothermal fluids formed open spaces into which collapse occurred. Alteration and fragmentation would take place gradually, proceeding outward and upward from a central area until a relative chemical equilibrium was established between the host rocks and the hydrothermal fluids.

Several features characteristic of the breccias in the North Santiam Mining District support the theory of solution stoping for the formation of these pipes. Intensely tourmalinized areas within some pipes contain up to 15 percent solution vugs and thereby verify the former presence of corrosive fluids. Breccia pipes are invariably associated with zones of hydrothermally altered rock, and thus indicate that hydrothermal alteration is an integral part of the formation of breccias. Alteration and replacement preceded part of the brecciation event. If the location of the breccia pipes is structurally controlled by the northwest fracture system, as suggested earlier, these fractures then may have acted as channelways for the ascending corrosive fluids. This hypothesis is in agreement with the drill hole data from the Freeport exploration project which indicates that only a narrow zone of tourmaline replacement is present at depth beneath one of the breccia pipes. It must be pointed out that processes of magma pulsation and collapse into a vapor bubble void cannot be dismissed entirely on the basis of the evidence listed above. One or both of these mechanisms may have participated in the brecciation. However, I believe that neither magma pulsations, nor collapse into a vapor bubble void, can uniquely account for the consistent relationships found in the North Santiam breccia pipes. Additionally, it is possible that brecciation in some cases reached the surface and that processes such as fluidization also altered these pipes.

Several questions about the formation of solution collapse breccias remain unanswered. Do the corrosive fluids exsolve from the magma or are they recirculated ground water, or both? What happens to the dissolved material carried away in solution? Under what conditions can a fluid form in such disequilibrium with the associated magma that it can dissolve large volumes of rock chemically similar to the magma? The source of the hydrothermal fluids is discussed in the section concerning alteration. The only apparent site of deposition for the dissolved material is the abundant quartz veins. However, a much wider range of chemical constituents was dissolved from the rock than was deposited in the veins. Much of the material may have remained in solution and been carried out of the system.

Alteration

Each of the base metal mining districts in the Western Cascades Subprovince of Oregon is surrounded by large zones of alteration similar to zones of hydrothermal alteration associated with known occurrences of porphyry copper mineralization. The predominant alteration assemblage of these zones in the Cascade Range consists of chlorite, epidote, calcite, and quartz. This assemblage is diagnostic of both late magmatic deuteric alteration, and the outermost propylitic fringe zone of weak hydrothermal alteration. However, a hydrothermal origin for this mineral assemblage is suggested on the basis of the following evidence: (1) the alteration is of limited areal extent surrounding zones of mineralization and plutonic rocks; (2) there are usually small zones of higher grade hydrothermal alteration present; and (3) oxygen stable isotope studies by Taylor (1971) indicate that the aqueous media involved in the alteration process was of meteoric rather than magmatic origin.

Hydrothermal alteration in the North Santiam Mining Distric has been divided into zones following the usage of Creasey (1966), Rose (1970), and Lowel and Guilbert (1970), for the classification of secondary mineral assemblages associated with prophyry copper-type mineralization. Propylitic, phyllic, and potassic alteration assemblages have been recognized in the district, and their distribution is shown in Figure 10. In general, a central potassium silicate zone is partially surrounded by an irregular zone of phyllic alteration. Elsewhere, the rocks have all undergone varying degrees of propylitic alteration.

The outermost zone of propylitic alteration extends well beyond the boundaries of the mining district and grades imperceptibly outward into unaltered rock. Within the thesis area it has affected all rock types. However, the extrusive rocks are usually more intensely altered than the plutonic rocks. In addition to the assemblage listed above albite, sericite, kaolinite, magnetite, and pyrite are also common in restricted localities. Plagioclase feldspar is uually altered to epidote and calcite, and the ferromagnesian minerals are all partly to completely replaced by chlorite that is commonly accompanied by pyrite and magnetite. The groundmass of propylitically altered rocks contains variable amounts of secondary quartz and albite. The intensity of alteration increases sharply with close proximity to mineralized veins and commonly grades into a narrow zone of phyllic alteration that is immediately adjacent to the vein walls.

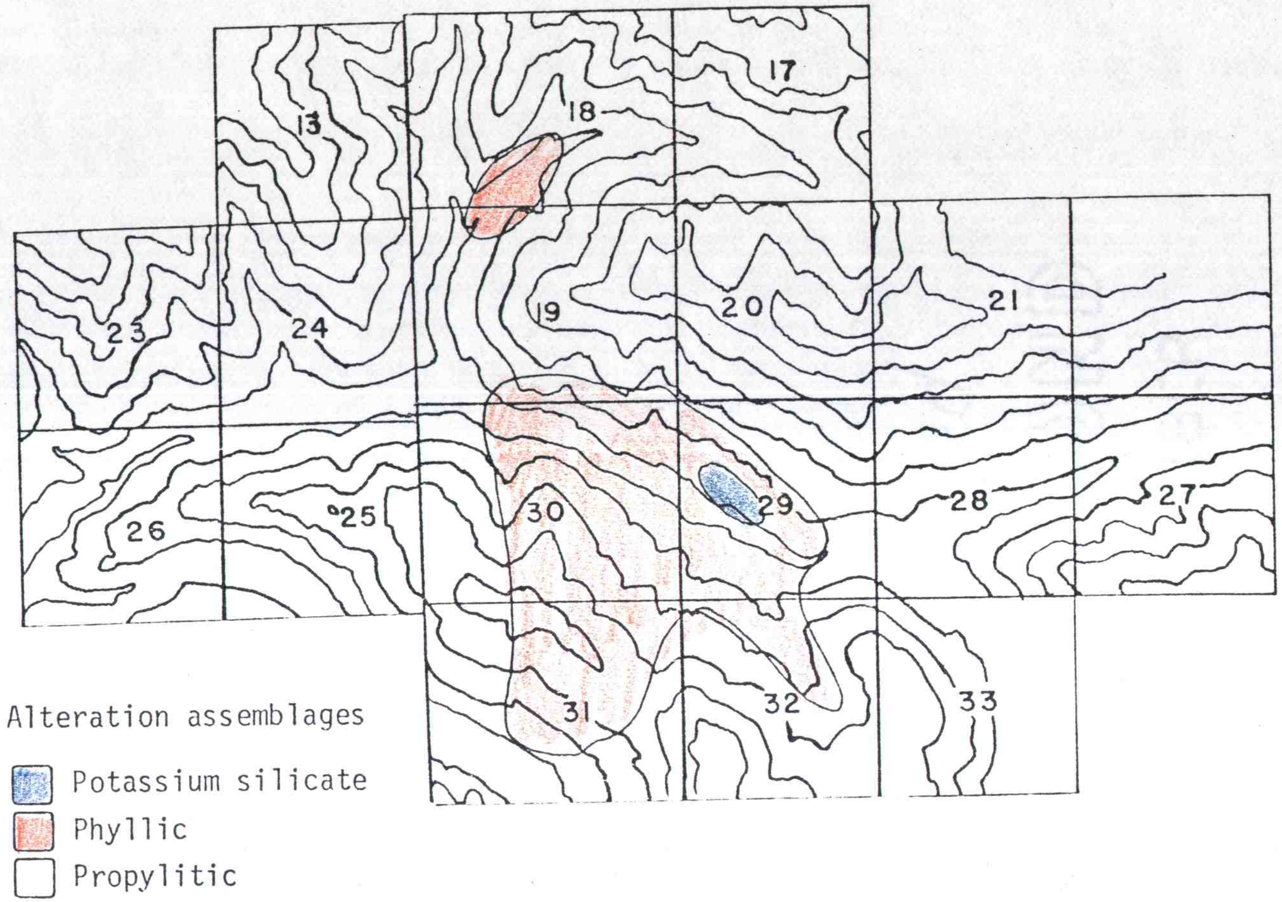


Figure 10. Distribution of hydrothermal alteration assemblages.

The location of phyllic alteration is strongly controlled by structure. It is most extensive along and adjacent to the northwest-trending shear and fracture zones in secs. 29, 30, and 31, T. 8 S., R. 5 E. The diagnostic assemblage of the phyllic zone consists of quartz, sericite, and kaolin. In addition, large quantities of tourmaline are present in restricted localities near breccia pipes. Replacement by the quartz-sericite-tourmaline assemblage is complete in areas of intense alteration and the original texture and mineralogy of the host rock has been obliterated. Where alteration is less intense, the primary ferromagnesian minerals have been completely replaced by irregular masses of light green chlorite and ghosts of plagioclase feldspar phenocrysts can be recognized.

The alteration assemblage of the potassium silicate zone consists predominantly of biotite, quartz, sericite, kaolin, and occasionally small quantities of potassium feldspar. Potassic alteration at the surface is restricted to a small elliptical area in the W. 1/2, sec. 29, T. 8 S., R. 5 E. However, diamond drilling has revealed that this alteration is more widespread and of greater intensity at depth beneath secs. 29, 30, and 31, T. 8 S., R. 5 E. The biotite, which occurs as shreddy masses replacing hornblende and augite, is commonly partially altered to chlorite. This retrograde alteration apparently took place during the waning stages of the hydrothermal event as the system cooled and the alteration zones migrated inward.

Microdiorite is the predominant rock type within the potassic zone, although weak potassic alteration is also present in the enclosing volcanic units.

Chemical Effects of Alteration

The effects of hydrothermal alteration can be analyzed in terms of the changes in whole rock major oxide composition that have taken place. Major oxide analyses of four samples of porphyritic andesite from the middle of the Lower Member are listed in Table 1. Sample SS-3-A, petrographically the least altered, is taken to best represent the original chemical composition of this volcanic host. Samples SS-7 and S-1-12 respectively, have been subjected to increasing intensities of propylitic alteration. Alteration has resulted in a consistent increase in the Al_2O_3 and Na_2O contents, a sharp decrease in the amount of K_2O, and smaller but still significant decreases in the FeO, MgO, and CaO concentrations. The increase in Al_2O_3 may be a result of removal of other constituents, thus causing the proportion of Al_2O_3 relative to the remaining rock mass to increase. Potassium has been strongly leached from the propylitic zone and may have been transported into the phyllic and potassic zones by circulating heated groundwater. The higher FeO, MgO, and CaO concentrations in sample SS-3-A are believed to be a result of outward migration of these components toward the periphery of the district. Calcite, epidote, and magnetite are the predominant alteration minerals in this sample, whereas the more intensely altered samples contain significant amounts of albite and kaolin. The presence of secondary albite in the more intensely altered samples accounts for their higher Na_2O values.

Phyllic alteration of the volcanics is represented by sample TB-1. This sample contains a large quantity of tourmaline and, therefore, may not be representative of all stages of phyllic alteration. It appears that titanium and potassium have been added during phyllic alteration and that CaO and Na_2O have been removed. Concentrations of iron and magnesia were little affected. However, in the phyllic zone, these oxides have been reconstituted to form tourmaline, whereas in the unaltered rocks they are contained in pyroxenes and amphiboles. The addition of TiO_2 and K_2O is reflected by the abundance of secondary sphene and sericite. Sodium and calcium have probably migrated outward and have been added to the propylitic zone. The small amount of CaO remaining is ~~sample~~ TB-1 is probably incorporated into the tourmaline structure. Two samples of tonalite were analyzed and the results for the least altered sample are shown in Table 4. The only chemical change that accompanied intense alteration to a quartz-sericite assemblage was a more than 100 percent increase in the K_2O content.

Chemical changes resulting from potassic alteration are best observed within the Microdiorite, as this is the only rock type in which such alteration is intense. Major oxide analyses of the three samples listed in Table 3 are arranged in increasing order of alteration intensity from weak potassic (2-2003) to intense potassic (1-1944). The effect of the alteration has been to increase the concentrations of SiO_2 and K_2O, and to decrease those of TiO_2, Al_2O_3, FeO, and CaO. The influx of potassium has resulted in hornblende being completely replaced by secondary biotite, and the replacement of part of the groundmass by potassium feldspar. The increase in silica can be correlated with an increase in the number of micro-veinlets of quartz present.

Mineralization

Metallic mineral deposits within the North Santiam Mining District consist predominantly of northwest trending sulfide veins. In addition, disseminated porphyry copper type mineralization is known to exist at depth in the center of the district from diamond drill hole data. Although gold was the primary mineral sought early in the history of the district, the most abundant metallic ore minerals in the veins are sulfides of copper, lead, and zinc. Gangue minerals include quartz, specularite, pyrite, carbonates, chlorite, barite, white mica, epidote, magnetite, tourmaline, and clays.

In general, the veins have a northwest stirke and are steeply dipping to vertical. They range from a few centimeters to over 15 m in width. However, veins over 50 cm in width are uncommon. Larger veins commonly consist in part of breccia fragments of host rock that have been cemented predominantly by quartz. These fragments have been corroded, and they may be angular or subrounded in shape. The veins, which represent open space fillings of fissures, are localized in the andesite flows and to a lesser extent in dioritic intrusions.

Individual veins usually consist of several different minerals or assemblages that form distinct layers parallel to the vein walls. These veins are symmetrically zoned in cross section, with the earliest-formed minerals located along the margins and successively younger minerals located toward the center. In addition, the mineral deposits as a whole are zoned on a district wide scale. These zonations resulted from changes in the physical and chemical state of the hydrothermal fluids that took place during the mineralization event. The dominant physical change is presumed to be a cooling of the fluids away from the center of mineralization. Changes in the chemistry of the fluids probably resulted from interactions between the hydrothermal fluids, host rocks, and groundwater.

The existence of a zonation to the vein deposits was first recognized by Callaghan and Buddington (1938). Three zones designated I, II, and III, have been delineated during this study and are shown on Figure 11. The incompleteness of the zonation pattern is partially

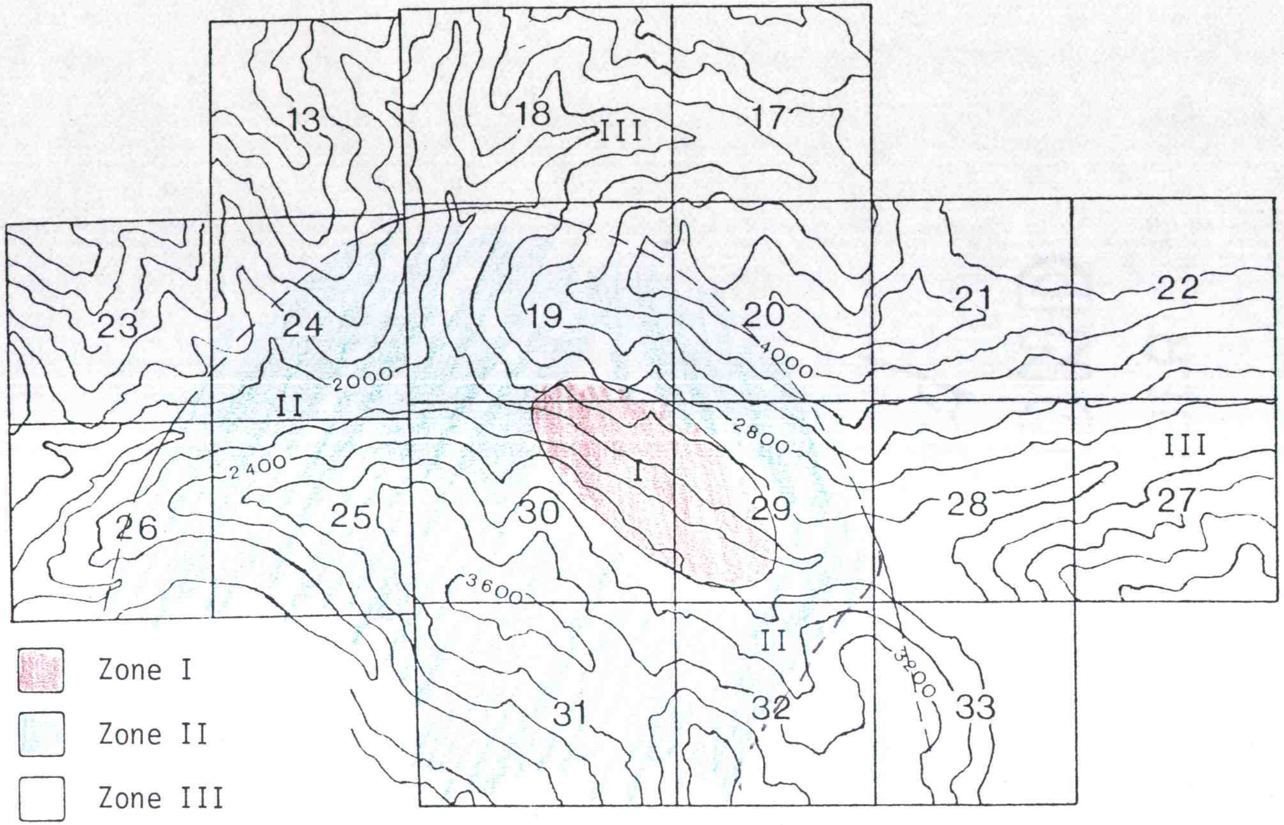


Figure 11. Distribution of vein zones discussed in thesis.

a result of the local topography and drainage pattern. Mineralized veins are well exposed only in the lower elevations along the major drainage systems. The areal zonation may also be partially a result of vertical zonations, as erosion has exposed deeper levels in the central part of the district than in the northern and eastern parts.

Zone I is defined as the area where chalcopyrite and specularite are the predominant metallic minerals, whereas, in zone II, the diagnostic assemblage is chalcopyrite and pyrite. Veins in zone III, are characterized by containing sphalerite and galena as the dominant sulfides. Zone I, which is centered in the area of the tourmaline breccia pipes, is characterized by a vein assemblage of quartz, specular hematite, magnetite, chalcopyrite, and occasionally tourmaline. Calcite is commonly present in small amounts and barite was found at one locality. Veins in zone II consist predominantly of quartz, chalcopyrite, and pyrite. The high temperature minerals hematite, and tourmaline were not found in this zone. Sphalerite is common but never abundant in the veins of zone II. Calcite is more abundant than in the veins of zone I, and locally may be the dominant gangue mineral. Veins within zone III are more complex than those in the central zones. Sphalerite is the predominant sulfide accompanied by galena, chalcopyrite, and pyrite. Quartz and calcite are the primary gangue minerals. In general, there is a systematic spatial distribution to the vein sulfides that consists of a central high temperature zone of chalcopyrite that gives way outward to pyrite and then to low temperature lead-zinc mineralization. This zonation is typical of hydrothermal systems and especially of porphyry copper deposits. In addition, the zonation is better defined in the North Santiam District than in the other epithermal vein type mineral deposits located in the Western Cascades of Oregon.

Metalization located at depth in the center of the district consists of micro-veinlets and disseminated blebs of chalcopyrite that rarely may be accompanied by bornite and molybdenite. The gangue minerals in the micro-veinlets consist predominantly of quartz and calcite. These are occasionally accompanied by small amounts of barite, anhydrite, or flourite. The disseminated sulfide blebs are present as replacements usually of a ferromagnesian mineral and are accompanied by chlorite and biotite. Where chalcopyrite and bornite are found together, the chalcopyrite usually has replaced the apparently earlier-formed bornite.

Mineralogy

Magnetite and hematite are the only primary oxide minerals found in veins of the North Santiam District. The magnetite is present as finely-crystalline selvages along the margins of veins and as a replacement of ferromagnesian minerals in the adjacent host rocks. Bladed crystals of specular hematite are common in the veins of zone I, and in a few localities near tourmaline-bearing breccia pipes it is the most abundant metallic mineral. Quartz is usually intergrown with the hematite, and occasionally chalcopyrite is also present. Where specularite and magnetite occur together the specularite forms the more central zone of the vein.

Quartz is present in all three zones and is the most abundant vein mineral in the district. It is found as terminated coarsely-crystalline vug fillings, massive finely- to coarsely-crystalline crustifications, and as microcrystalline replacements of host rock adjacent to the veins. Quartz is intergrown with all other vein minerals and appears to have crystallized nearly continuously throughout the period of mineralization. Calcite is the only other abundant gangue mineral in the district. It is most common in zone III, but is found in small quantities in the other zones. Calcite is commonly found in late stage veinlets of zone I cutting across altered host rock and earlier formed veins. The calcite in zones II and III occurs as terminated crystals lining vugs, masses intergrown with sulfides and quartz, and as the last mineral formed in some crustified veins. Fluorite and anhydrite were found in some veinlets in the drill core.

Primary sulfide minerals of the district include sphalerite, galena, chalcopyrite, bornite, and pyrite. Sphalerite is the most abundant sulfide in the veins. It is common only in zones II and III, where it is usually present as irregular masses and stringers without crystal form. At the Eureka No. 13 mine on East Gold Creek, well-formed and sometimes twinned dodecahedrons up to 2 cm across are present in vugs and intergrown with quartz and pyrite. The color is dominantly resinous yellow to light green but black varieties were also found. In some localities several colors of sphalerite were deposited in a single vein. Sphalerite in the Eureka, Ruth, and Blue Jay veins occasionally surrounds and partially replaces earlier crystallized chalcopyrite. Galena is the only primary lead mineral identified in the district. It is common in the veins of zones II and III where it is almost always associated with sphalerite. Galena was not found in the veins of zone I. It commonly occurs as intergrowths with other sulfides and as cubic crystals in vugs. Leever (1941) described galena cubes from the area that are hollow in the center, and speculated that they may have formed by chemical solution or by incomplete crystal growth.

Chalcopyrite is the only primary copper mineral found in the veins. It is the most ubiquitous of the sulfide ore minerals as it is common to the veins of all three zones. In zone I it is commonly the only primary sulfide present. It is usually in the form of irregular lens-shaped masses and bands. Callaghan and Buddington (1938) reported vugs containing sphenoidal crystals of chalcopyrite in the Blende Oro (Eureka No. 12) and Crown Mines. It is also found as scattered replacement blebs in altered host rock fragments within the veins.

Pyrite is present throughout the entire district, both as a vein mineral and as disseminated crystals in all host rocks. It is uncommon to the veins in zone I, but is usually abundant in the silicified wall rocks adjacent to them. In zones II and III, cubes and octahedrons of pyrite are common in vugs and scattered throughout the vein matrix. Marcasite has not been reported from the North Santiam District.

Oxidation and supergene processes have affected the surficial portions of many veins. Minerals resulting from oxidation of the primary sulfides include azurite, malachite, chrysocolla, dioptase, anglesite, cerussite, goethite, and hematite. Chrysocolla is the predominant copper mineral in the Black Eagle Mine where it is accompanied by small amounts of dioptase and forms masses up to 1.5 cm thick surrounding and replacing chalcopyrite. Thin coatings of malachite and azurite are common on chalcopyrite bearing veins that are exposed in the subsurface. Oxidation of galena in the Ruth and Blue Jay Mines has resulted in the formation of small quantities of cerussite and anglesite.

Products of supergene enrichment are sparse in the North Santiam Mining District. Covellite and secondary chalcocite are the only supergene minerals recognized. They are restricted to the sections of chalcopyrite veins of zone I that are near stream base. In the Santiam No. 1 vein, covellite and chalcocite are intermixed with pyrite and chalcopyrite in fault gouge. Covellite is also present in the Spokane and Black Prince Mines. The lack of supergene enrichment is probably a result of rapid erosion and open circulation in the veins which results in unstable chemical conditions.

Paragenesis

The paragentic sequence of mineral deposition for the mineral deposits of the North Santiam District is shown in Figure 12. It was established on the basis of the textural relationships between the various minerals and their relative positions in the zoned veins. However, individual veins rarely contain more than a few of these minerals, and therefore it is necessary to combine the data from a large number of veins to arrive at the sequence. Because of this necessary qualification, the abscissa in Figure 12 represents both time and distance from the center of mineralization. In general, minerals on the left side of the diagram crystallized earlier, and at higher temperatures, and/or in more central portions of the district than did those on the right side. This sequence is typical for the paragenetic and spatial distribution of minerals in and adjacent to porphyry copper systems.

Origin of Metals and Hydrothermal Fluids

Two hypotheses are commonly suggested for the origin of the

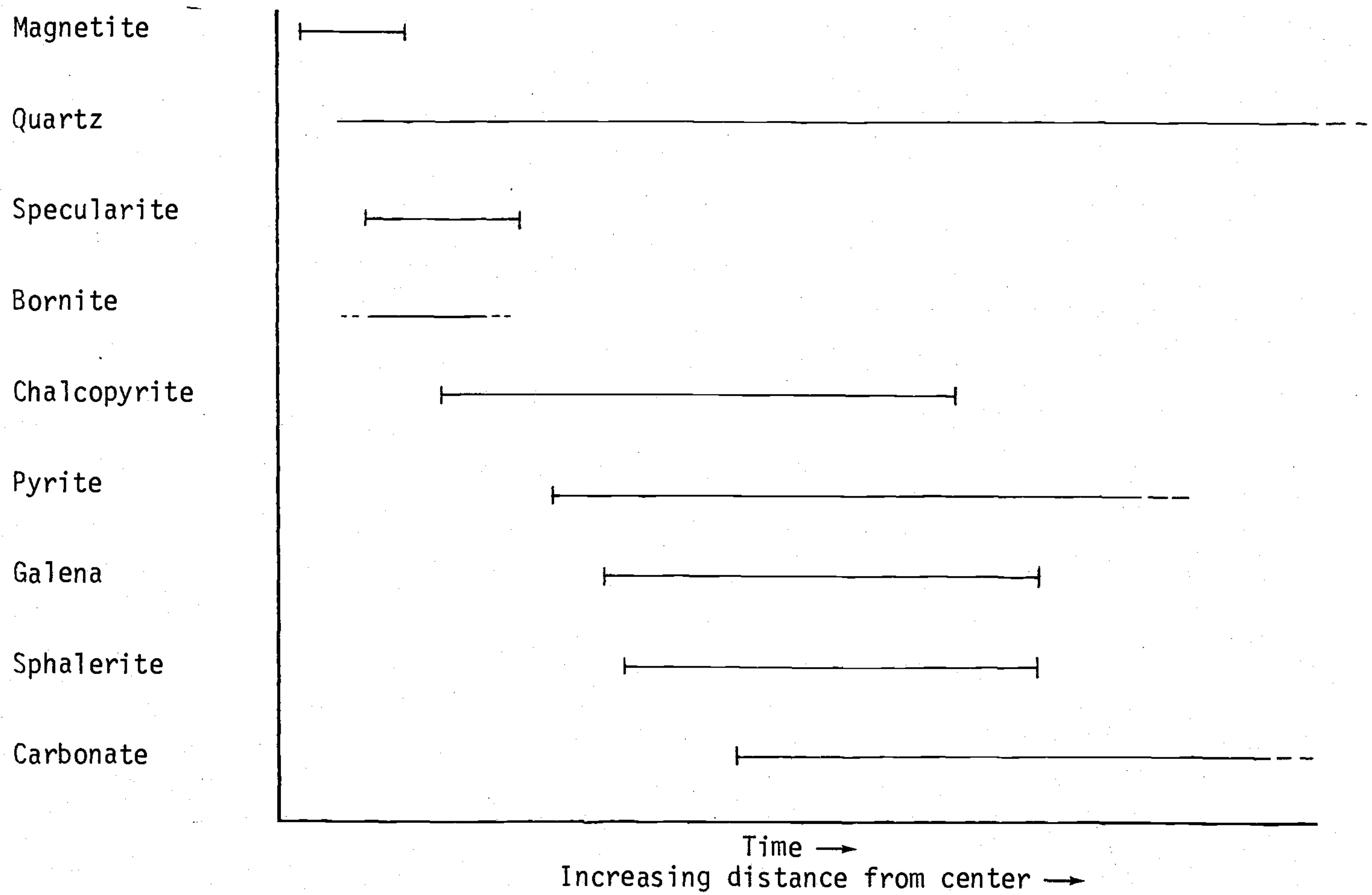


Figure 12. Generalized paragenetic sequence for vein mineralization of the North Santiam District

fluids and metals in porphyry copper deposits and hydrothermal vein systems. The most commonly accepted theory is that they were derived directly from the plutonic complexes with which these deposits are universally associated. However, White (1968) proposed that the intrusions merely serve as heat sources that generate convective systems of circulating groundwater in surrounding host rocks. This heated meteoric water leaches metals and other ions from the country rock and redistributes them in a zonal pattern surrounding and within the intrusions. The currently available evidence indicates that a combination of both processes is probably responsible for the formation of porphyry systems.

Oxygen isotope studies of alteration minerals in porphyry copper systems by Sheppard, Nielson, and Taylor (1969, 1971) and Sheppard and Taylor (1974) suggested to them that the water involved in the zones of phyllic, argillic, and propylitic alteration is predominantly meteoric, being generally depleted in both D and O^{18}. Furthermore, their studies show that alteration minerals in the potassium silicate zone have isotopic compositions similar to primary magmatic water. The hydrothermal fluids in the North Santiam District are probably of mixed origin, although detailed work on this problem has not been undertaken to date.

The source of the metals in the district is believed to be from the granodiorite intrusions on the basis of the following evidence:

(1) disseminated mineralization occurs as a halo around the large granodiorite intrusion in the S. 1/2, sec. 30, and the N. 1/2, sec. 31, T. 8 S., R. 5 E., and is generally restricted to the earlier Microdiorite intrusions; (2) the metals are zonally arranged in the veins peripheral to this intrusion; (3) the metals with greater mobilities are usually located farther from the center of mineralization, indicating that the fluids were transporting metals outward away from the granodiorite; and (4) the district does not appear to contain a sufficient volume of leached rock to supply all of the metals present in the vein and disseminated deposits.

Trace Element Geochemistry

Trace element analyses for Cu, Pb, Zn, Ag, and Mo, were made on 36 samples of intrusive and 17 samples of extrusive rocks from the North Santiam Mining District. The complete results are listed in Appendix A, and sample locations are shown in Figure 13. When average values for unaltered samples are compared with averages for granodiorite (Turekian and Wedepohl, 1961), the Guichon Creek Batholith (Field and others, 1974), and Caribbean intrusions associated with porphyry copper deposits (Kesler and others, 1975), the igneous rocks of the North Santiam District are found to be slightly enriched in all metals (Table 5). This enrichment is probably a result of the ubiquitous weak propylitic alteration present throughout

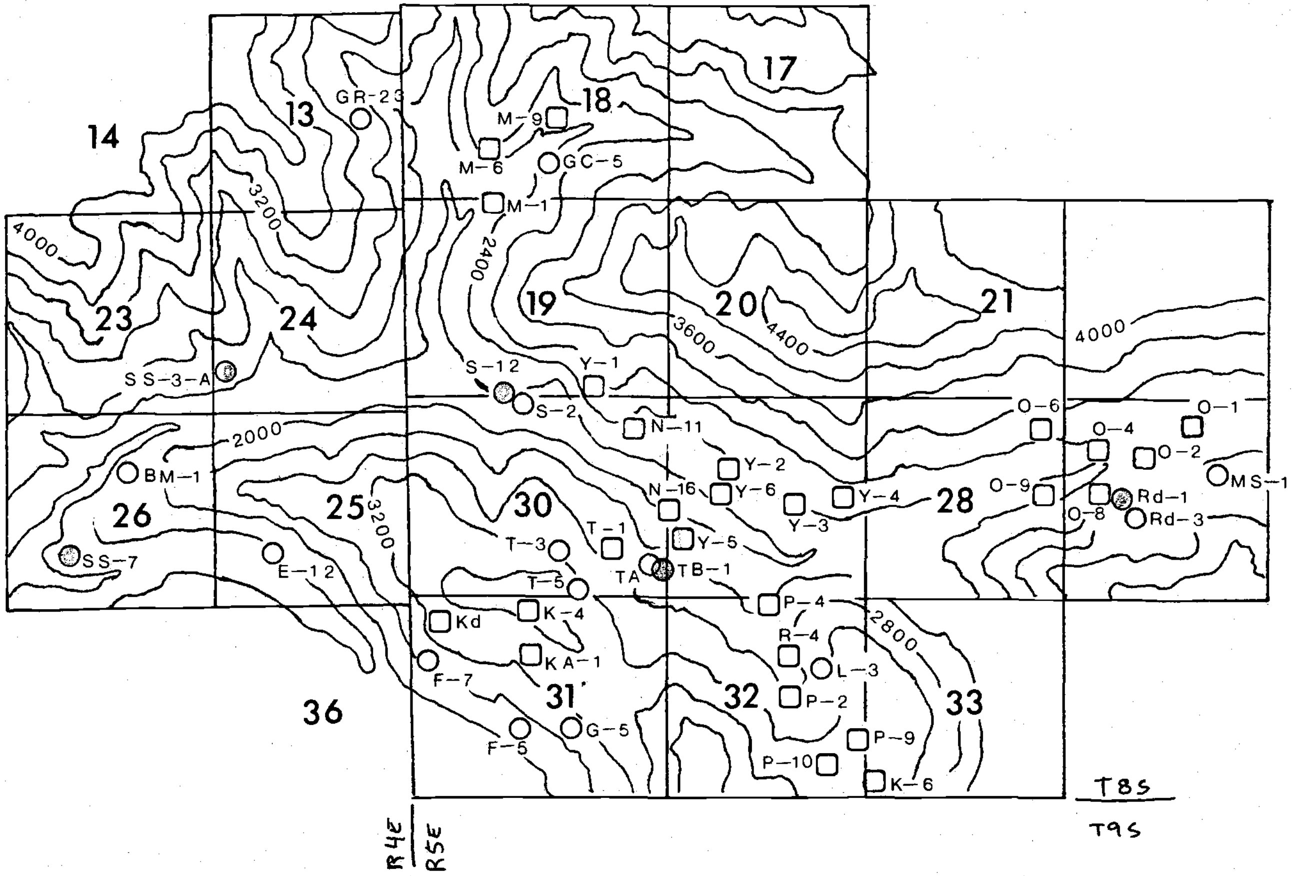


Figure 13. Sample locations discussed in thesis

Trace Metal Concentration

	North Santiam[a]				Average Granodiorite[1]	Caribbean Intrusions[2]
	Plutonic		Volcanic			
	Average	Range	Average	Range	Average	Average
Cu	57	19-255	42	17-90	30	61
Zn	69	25-265	73	20-115	60	50
Pb	38	15-180	27	10-40	15	7.5
Ag	.55	.3-1.0	.52	.3-1.1	.07	--
Mo	1.0	-1-8.0	.8	-1-2	1	--

Threshold values determined from cumulative frequency diagrams.

	Plutonics	Plutonic and volcanic combined
Cu	65	90
Zn	65	92
Pb	--	35

Metal values in ppm

*Only relatively fresh samples in which no significant mineralization was visible

[1] Turekian and Wedepohl, 1961

[2] Kesler and others, 1975

Table 5. Trace metal concentrations and threshold values for the North Santiam District.

the district.

Normal background concentrations of metals for the rocks in the district were determined by plotting metal values versus cumulative frequency on probability graph paper as shown in Figures 14 and 15. When plotted in this manner the presence of more than one distinct linear distribution indicates a multi-modal (more than one population) genesis of the metal (Lepeltier, 1969). The lower population is believed to represent the normal background distribution for the rocks and presumably reflects the primary magmatic concentrations of the metals. The upper population, where skewed toward higher metal values, results from the introduction of large quantities of metals into a relatively small proportion of the sample area during a period of hydrothermal mineralization. The trends for copper and zinc in volcanic rocks (Figures 14 and 15) are skewed toward lower concentrations. This is probably an effect of leaching of these metals from the volcanics during propylitic alteration or surficial oxidation. The threshold values, indicated by the break between normal background and anomalous metal concentrations as interpreted from the frequency diagrams, are listed in Table 5. Rock samples from the district containing metals in excess of these threshold values may be considered as potential exploration guides to mineral deposits.

The spatial distributions of Cu, Pb, Zn, and Mo are shown in Figures 16, 17, 18, and 19 respectively. Metal concentrations in

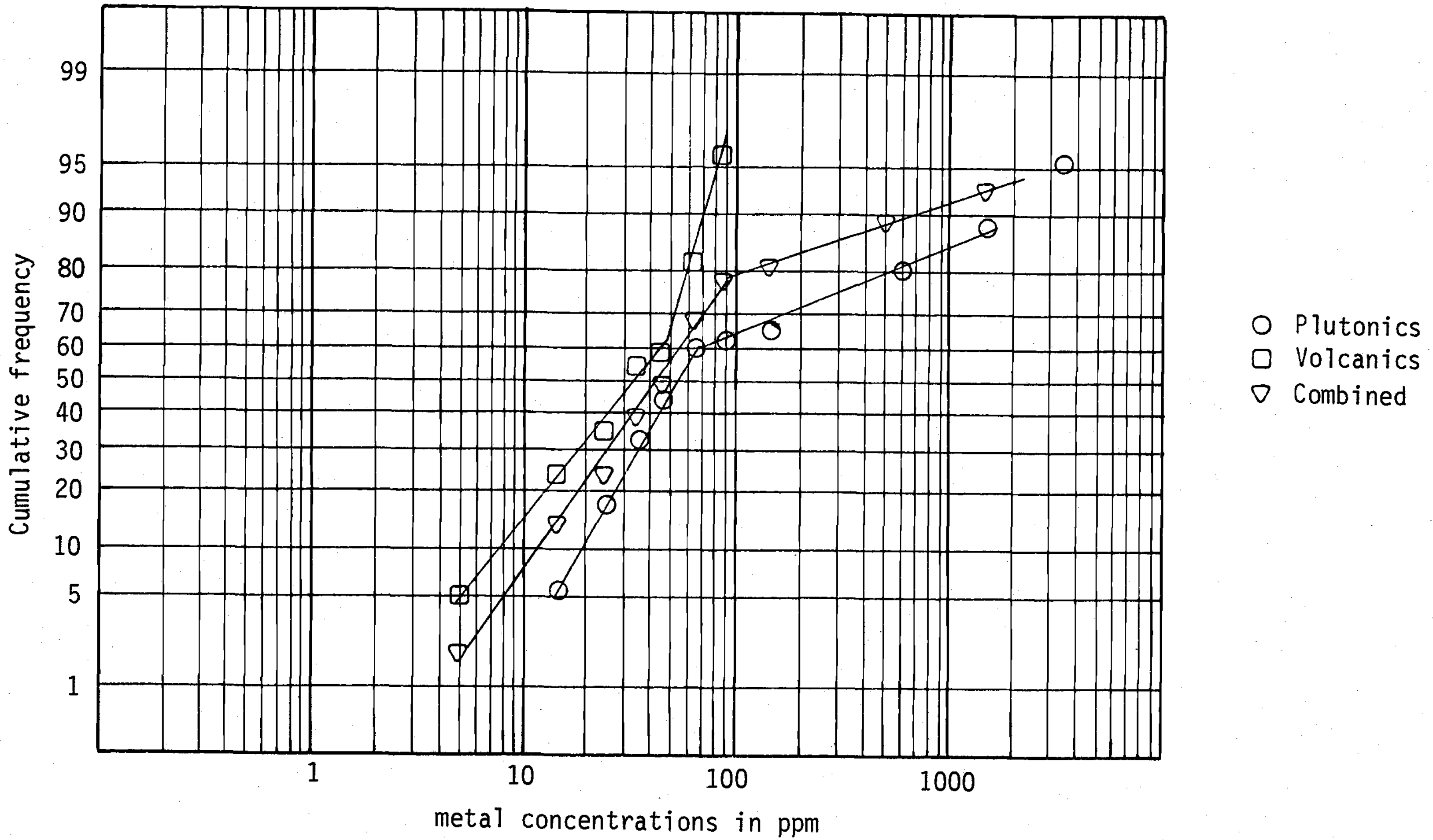


Figure 14. Cumulative frequency distribution of copper.

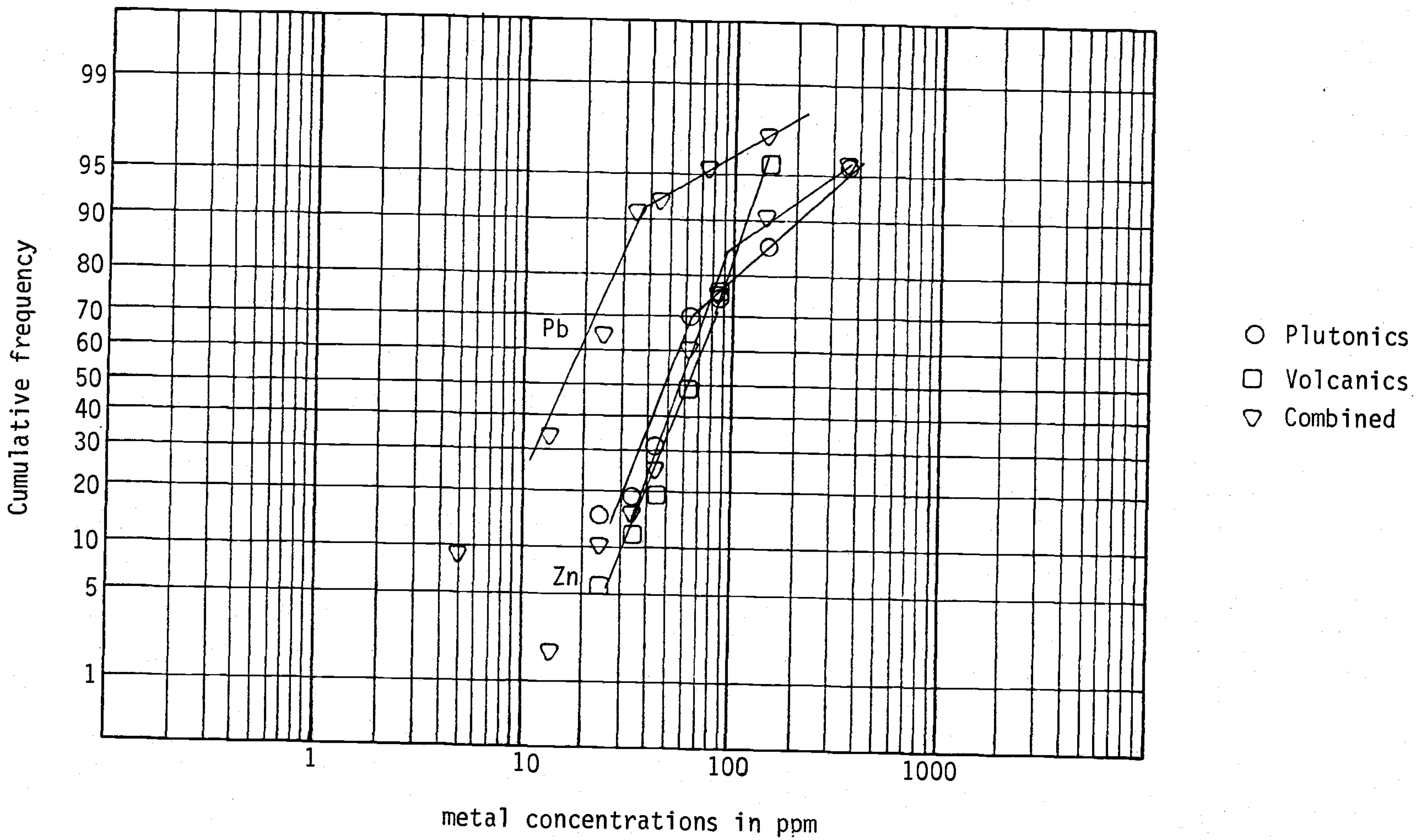


Figure 15. Cumulative frequency distribution of lead and zinc.

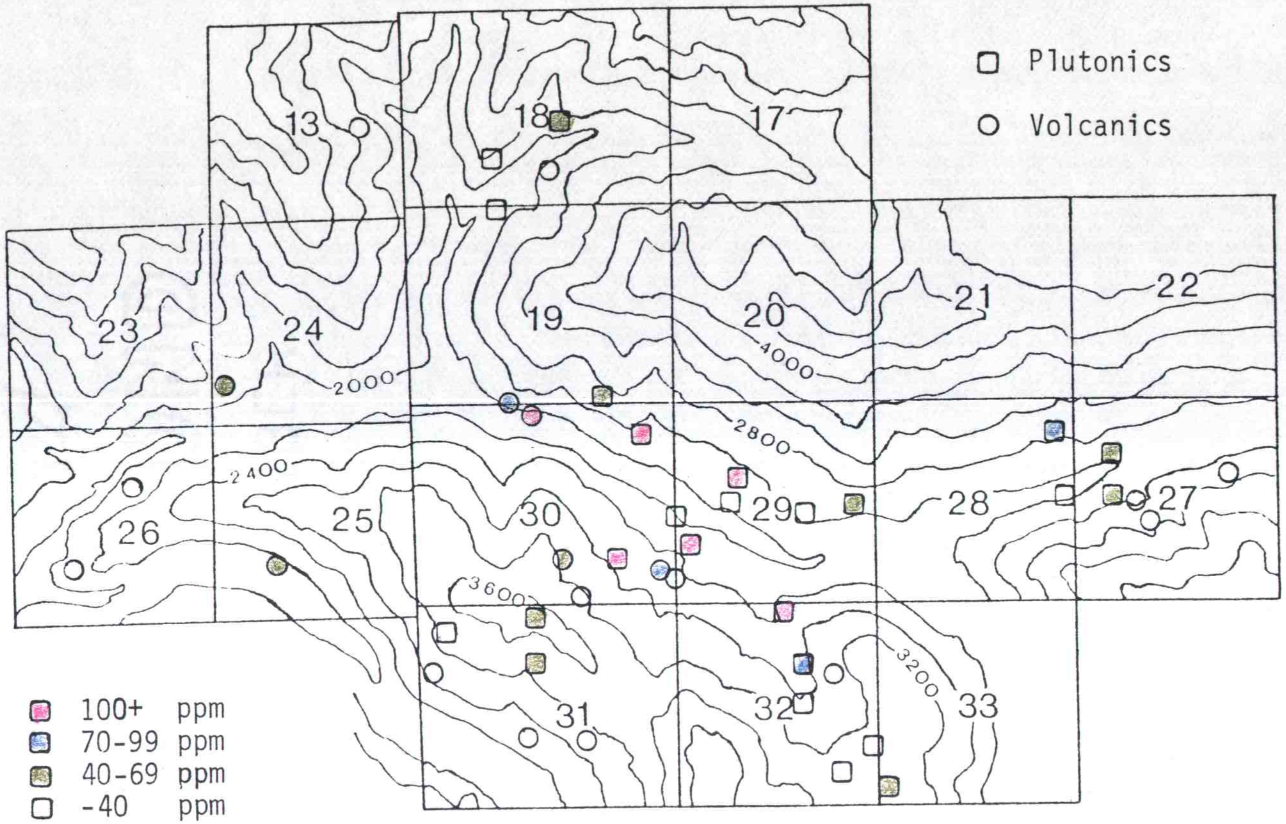


Figure 16. Distribution of copper values in rock chip samples.

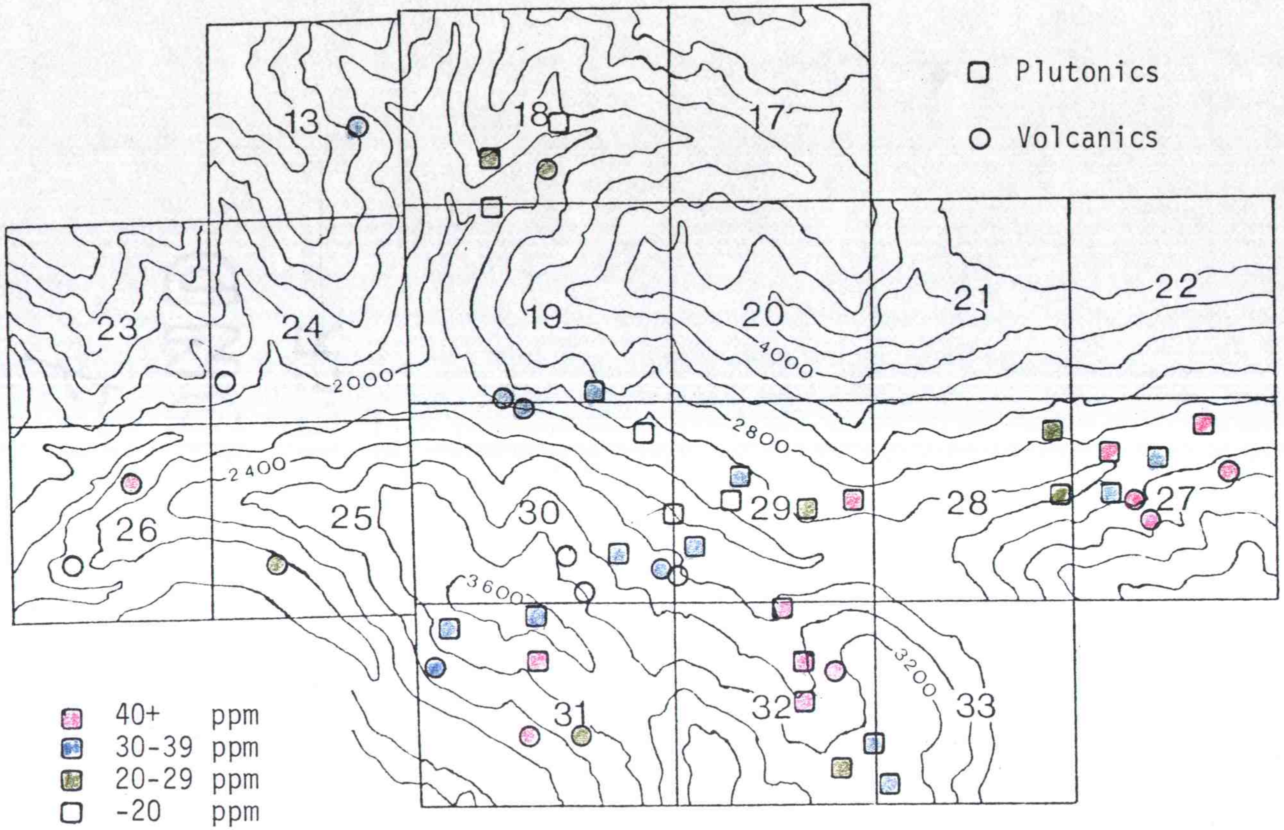


Figure 17. Distribution of lead values in rock chip samples.

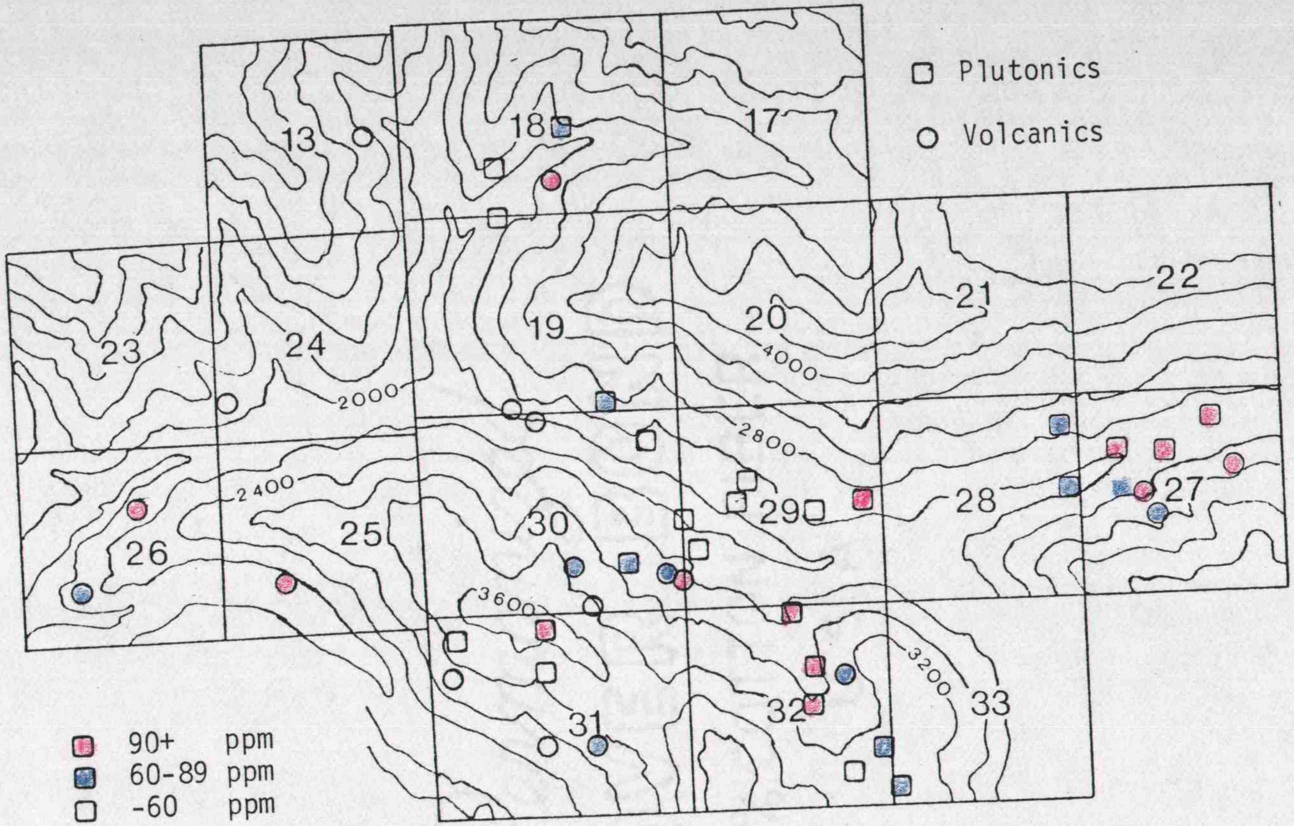


Figure 18. Distribution of zinc values in rock chip samples

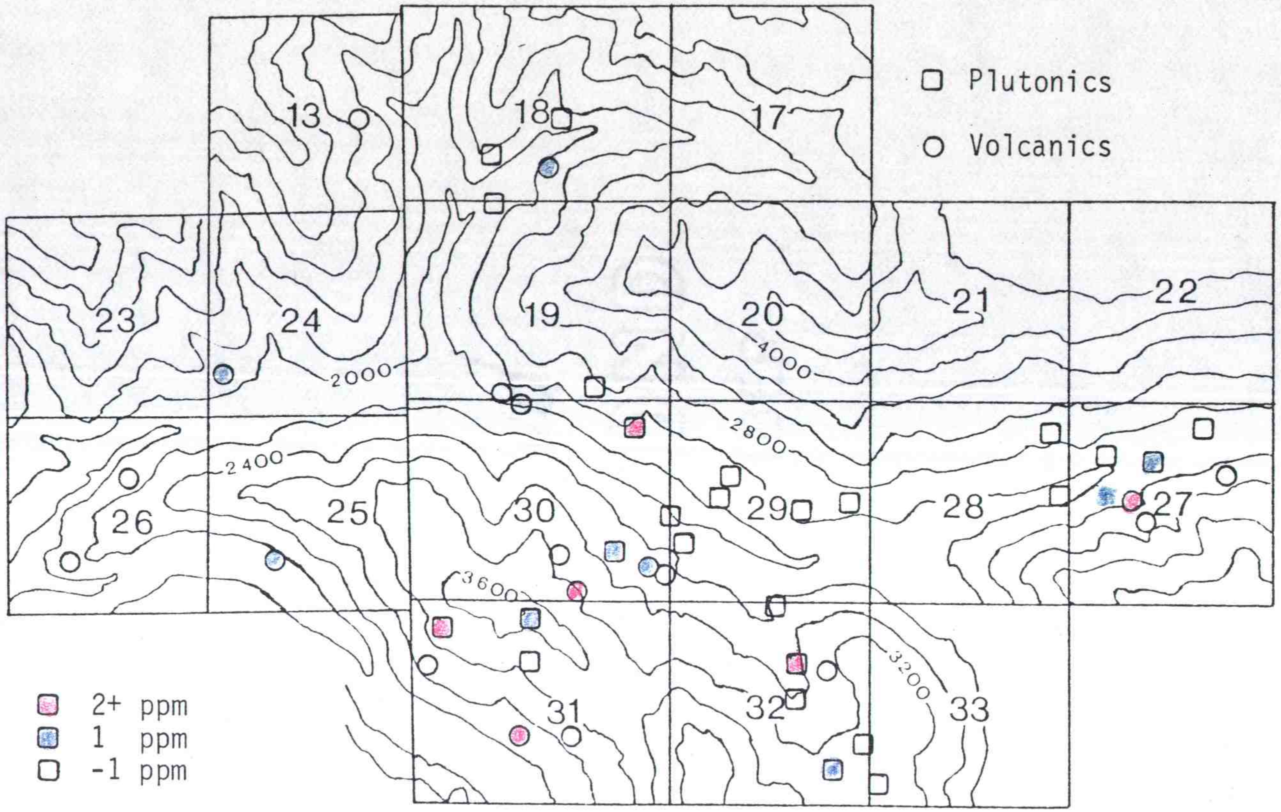


Figure 19. Distribution of molybdenum in rock chip samples.

both the plutonic and volcanic rocks exhibit zonal distributions similar to those previously described for sulfides in the vein deposits. Anomalous copper values are confined to a small area centered around the zone of potassic alteration and tourmaline bearing breccia pipes in secs. 29, and 30, T. 8.S., R. 5 E. This zone is partially coincident with areas of high molybdenum values and low values for lead and zinc. The peripheral parts and higher elevations in the center of the district are characterized by being enriched in lead and zinc and depleted in copper and molybdenum. Silver concentrations were not shown because of the erratic distribution of anomalous samples.

The results of trace metal analyses for eight stream silt samples are listed in Appendix A. Sample locations and relative composite values are shown on Figure 20. When compared with background values for the Pacific Northwest (Field and others, 1975), most samples of the district are found to be anomalous in one or more metals. However, sample 1-1 from Cedar Creek above the area of visible mineralization, compares closely with the averages for the Pacific Northwest. The slightly larger lead and zinc values in this sample are attributed to the high mobility and widespread distribution of these elements in the district. Extremely high metal concentrations, such as in samples 1-4 and 1-8, can be directly correlated with the presence of nearby sulfide-bearing veins.

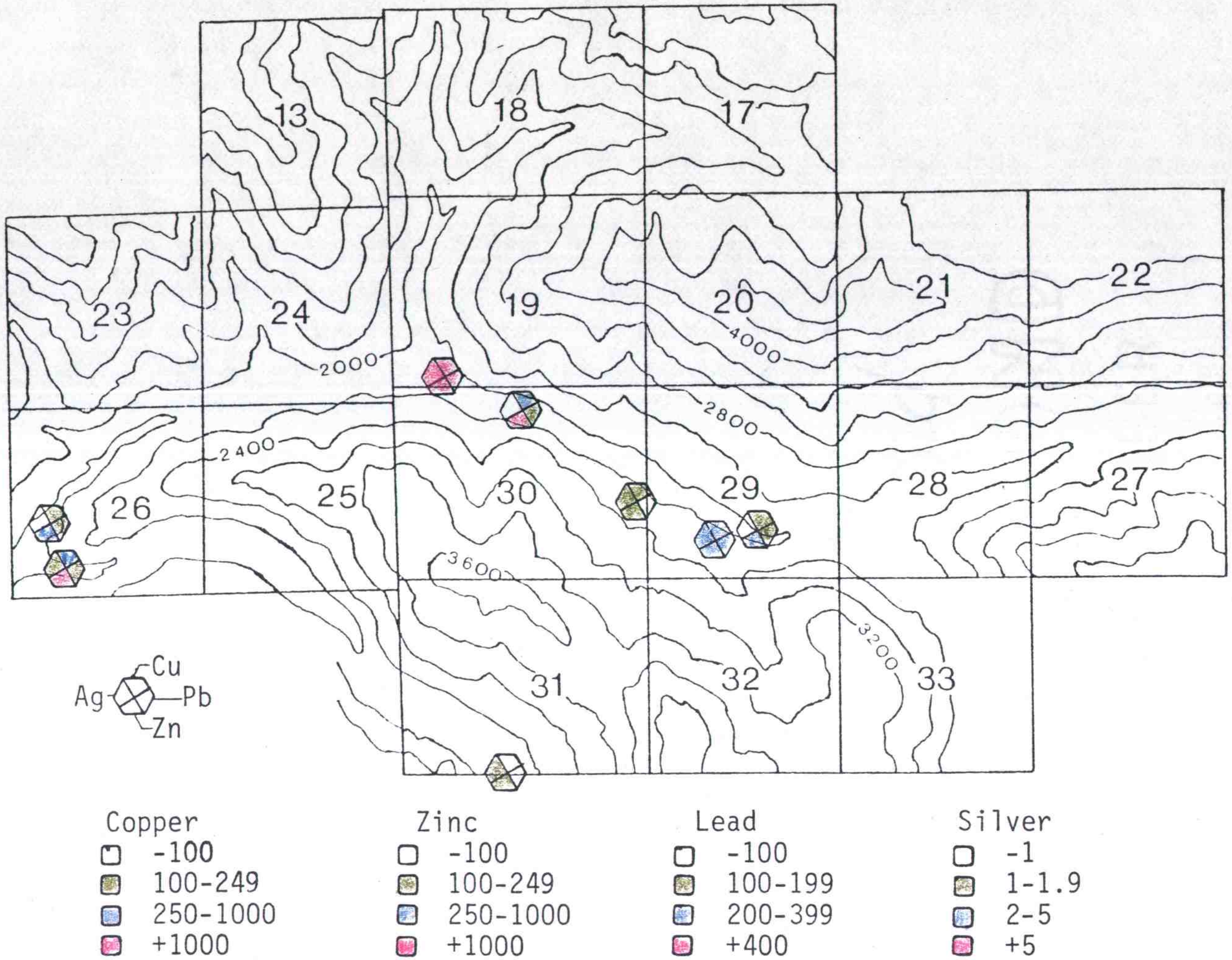


Figure 20. Stream silt sample locations and composite values. (all metal values in ppm).

Economic Potential

The potential for future discoveries of base metal ore deposits is probably greater in the North Santiam district than for any other district in the Cascade Range of Oregon. However, the numerous vein deposits that were important in the early history of the district can no longer be considered the primary exploration target, even though currently available geophysical and geochemical techniques could probably be used successfully in searching for additional metal-bearing veins. The small size, discontinuous character, and low total metal values of the presently exposed veins indicate that the discovery of new and economically minable vein deposits is unlikely. Instead, the current exploration emphasis is on the discovery of disseminated porphyry-type deposits.

The alteration and mineralization of the North Santiam district is inferred to be part of a porphyry-type system by comparison to others described by Burnaham (1962), Creasey (1966), Rose (1970), Lowell and Guilbert (1970), Sillitoe (1973), Field and others (1974), and Guilbert and Lowell (1974). Typically, porphyry copper-molybdenum deposits are associated in time and space with the emplacement of high level, porphyritic, calc-alkaline intrusions. In such hydrothermal systems, the mineralization and alteration are usually concentrically zoned around and within the intrusions. It is proposed that the North Santiam Mining District represents a porphyry system that has recently been exposed by erosion to levels just above the zone of disseminated mineralization.

Two companies are currently exploring the district for porphyry-type targets. Extensive geophysical and geochemical surveys have been carried out and diamond drilling commenced in the fall of 1976. Although this drilling revealed extensive disseminated chalcopyrite mineralization at depth, it is not presently known if the grades and tonnages are sufficient to be economicably recoverable. Continued exploration and drilling will be necessary to delineate the size and shape of the disseminated zone, and to determine whether or not minable concentrations of either copper or molybdenum are present. Nonetheless, the preliminary results of these programs constitute an encouraging development and milestone in the exploration history of the Western Cascades of Oregon.

GEOLOGIC SUMMARY

The North Santiam Mining District is located in the Western Cascade Subprovince of Oregon. This region is composed predominantly of a thick sequence of volcanic and volcaniclastic rocks that were derived from north-south trending belts of eruptive centers during Eocene to Late Miocene time. Bedrock within the thesis area consists of flows and pyroclastics of the Miocene Sardine Formation that have been intruded by dioritic dikes, plugs, and stocks.

The oldest rocks exposed in the district consist of augite bearing andesite flows that contain interbedded lenses of laharic breccia at some localities. Numerous small andesite dikes present in this part of the sequence were at least, in part, the feeders for these andesite flows. The source of the laharic breccia is inferred to be nearby and to the southeast of the area. Stratigraphically younger units consist of dacitic and quartz latitic pyroclastic rocks interbedded with flows of andesite and basaltic andesite. The pyroclastics include tuff, lapilli tuff, tuff-breccia, and welded tuff. A southeasterly source for the tuffs is indicated by a consistent decrease in the size of fragments and the thickness of individual units toward the northwest.

Subsequent to the deposition of these volcanics, a series of dioritic intrusions were emplaced within the district. Three major intrusive phases are present. The earliest phase consists of dikes and plugs of finely-crystalline, porphyritic diorite and quartz diorite that are located in the central part of the district. Their emplacement was followed in time by intrusion of fine-to-medium-grained equigranular diorite dikes in the eastern part of the district. The youngest intrusive event is represented by porphyritic to equigranular dikes, plugs, and stocks of granodiorite and quartz monzodiorite. The dominant primary mineral in all of these intrusions is plagioclase feldspar. This is accompanied by variable amounts of quartz, hornblende, augite and potassium feldspar.

Major oxide chemistry of the plutonic rocks varies with age and silica content. These variations are characteristic of a rock suite differentiated from a single magma that underwent late potassic enrichment. However, these intrusions are all depleted in K_2O relative to averages for rocks of similar modal composition. This is typical for intrusions emplaced in an island arc. The North Santiam suite exhibits trends that are atypical compared to average calc-alkaline trends when plotted on AFM and CNK ternary diagrams. In addition, a Peacock index for these rocks of approximately 61 indicates that they lie on the boundary between calc-alkalic and calcic magma trends.

Structural deformation in the district consists predominantly of northwest trending faults and fracture zones. In addition, emplacement of the main granodiorite mass resulted in the development of a small dome in the center of the area. The stress pattern responsible for the northwest structural trend was developed early in the history of the district, as is indicated by the northwest orientation of andesite feeder dikes and veins. A continuation of faulting throughout the mineralization event is indicated by the presence of gouge and slickensides in and along many of the veins.

Mineral exploration and mining have taken place sporadically in the North Santiam Mining District from the 1860's to the present. Vein deposits of gold and base metals were the primary targets in the past. However, recent recognition of the area as a porphyry copper system has caused exploration emphasis to switch toward locating large bodies of disseminated Cu-Mo mineralization.

Hydrothermal alteration and mineralization were closely associated in space and time with emplacement of the granodiorite intrusion located in the central part of the district. Phases of this intrusion discovered at depth during diamond drilling were probably the source of the metals and at least some of the hydrothermal fluids. Part of the fluid was probably meteoric in origin, and derived from the adjacent volcanic country rocks as groundwaters that were incorporated into the convecting hydrothermal system. These fluids were presumably responsible for the pervasive alteration and disseminated copper metallization in the core of the mineralized zone. As the fluids migrated outward and upward in response to local pressure and thermal gradients, they were channeled along pre-existing fault and fracture zones. Precipitation of the vein minerals took place in open spaces along these channelways in response to changing physical and chemical conditions. A zonal distribution of sulfide mineral deposition, similar to that found in many other districts, took place as a result of differing mobilities among the various metallic ions in this environment. Disseminated mineralization at the center of the system consists predominantly of chalcopyrite and minor bornite. The vein deposits are concentrically zoned; with chalcopyrite the dominant sulfide near the center, and giving way to pyrite and then to sphalerite and galena toward the peripheral margins.

Hydrothermal alteration in the district consists of a central potassic core that is surrounded by a discontinuous zone of phyllic alteration. Weak propylitic alteration is pervasive throughout the remainder of the area. The center of this alteration system appears to be coincident with the area of known disseminated mineralization.

A series of tourmaline-bearing breccia pipes were formed contemporaneously with the mineralization. These pipes are believed to have originated by collapse into voids formed by the corrosive action of hydrothermal fluids. They appear to have formed along pre-existing structures, and all are intensely altered. Disseminated chalcopyrite is present in some of these pipes although for the most part the breccias are largely unmineralized.

From similarities to other porphyry copper systems in the circum-Pacific region, it is concluded that the potential for future ore discoveries is higher here in the North Santiam Mining District than in other districts of the Oregon Cascades. However, should an ore body be found, environmental considerations here and elsewhere in the Cascades might slow or preclude the immediate development of the deposit in the near future.

SELECTED REFERENCES

Bailey, E. H., and Stevens, R. E., 1960, Selective staining of K-feldspar and plagioclase on rock slabs and thin sections: Am. Mineralogist, v. 45, p. 1020-1025.

Bailey, M. H., M. S, thesis in progress: Oregon State University.

Barnes, H. L. and Czamanske, G. K., 1971, Solubilities and transport of ore minerals, in Barnes, H. L., ed., Geochemistry of hydrothermal ore deposits: Holt, Rinehart and Winston, Inc., p. 334-381.

Barton, P. B., 1957, Some limitations on the possible composition of the ore-forming fluid: Econ. Geol., v. 52, p. 333-353.

Benioff, H., 1954, Orogenesis and deep crustal structures: additional evidence from seismology: Geol. Soc. America Bull., v. 65, p. 385-400.

Berzina, A. P., and Sotnikov, V. I., 1977, Physiochemical Conditions of Endogene Processes in Copper-Molybdenum Deposits in Central Asia: Econ. Geol., v. 72, p. 25-36.

Brabec, D. and White, W. H., 1971, Distribution of copper and zinc in rocks of the Guichon Creek Batholith, British Columbia: Canadian Inst. Mining Metallurgy, Spec. Vol. 11, p. 291-297.

Brooks, H. C., and Ramp, L., 1968, Gold and Silver in Oregon: State of Oregon Dept. of Geol. Mineral Ind. Bull. 61, p. 309-321.

Bryant, D. G., 1968, Intrusive breccias associated with ore, Warren (Bisbee) mining district, Arizona: Econ. Geol., v. 63, p. 1-12.

Buddington, A. F. and Callaghan, E., 1936, Dioritic intrusive rocks and contact metamorphism in the Cascade Range in Oregon: Am. Jour. Sci. 5th ser., v. 31, p. 421-449.

Burnham, C. W., 1962, Facies and types of hydrothermal alteration: Econ. Geol., v. 57, p. 768-784.

Callaghan, E., and Buddington, A. F., 1938, Metalliferous mineral deposits of the Cascade Range in Oregon: U.S. Geol. Survey Bull. 893, 141 p.

Chayes, F., 1969, The chemical composition of Cenozoic andesite, p. 11, in McBirney, ed., Proceedings of the Andesite Conference: Ore. Dept. Geol. Mineral Industries Bull. 65, 193 p.

Creasy, S. C., 1959, Some phase relations in hydrothermally altered rocks of porphyry copper deposits: Econ. Geol., v. 54, p. 351-373.

Creasy, S. C., 1966, Hydrothermal alteration, In Titley, S. R. and Hicks, C. L. eds. Geology of the Porphyry Copper Deposits, Southwestern North America, University of Arizona Press, Tucson, p. 51-74.

Dickenson, W. R., 1969, Evolution of calc-alkaline rocks in the geosynclinal system of California and Oregon, in McBirney, A. R., ed., Oregon Dept. Geol. Mineral Ind. Bull. 65, p. 151-156.

Dodge, F. C., 1972, Trace element content of some plutonic rocks of the Sierra Nevada Batholith: U.S. Geol. Survey Bull. 1314-F, 13 p.

Dyhrman, R. F., 1976, Geology of the Bugby Hot Springs Area, Clackamas and Marion Counties, Oregon: Oregon State University unpub. M.S. thesis, 76 p.

Emmons, W. H., 1938, Diatremes and certain ore bearing pipes: Am. Inst. Min. Metall. Engrs. Tech. Publ. 891, p. 1-15.

Field, C. W., Jones, M. B., and Bruce, W. R., 1971, Sulfur isotopic composition of Cordilleran hydrothermal sulfides and the role of Eh-pH: Geol. Soc. America Annual Meeting Abstracts with Programs, v. 3, no. 2, p. 18.

Field, C. W., Jones, M. B., and Bruce, W. R., 1974, Porphyry copper-molybdenum deposits of the Pacific Northwest: A.I.M.E. Trans., V. 255, p. 9-22.

Field, C. W., Briskey, J. A., Henricksen, T. A., Jones, M. B. Schmuck, R. A., and Bruce, W. R., 1975, Chemical trends in Mesozoic plutons associated with porphyry type metallization of the Pacific Northwest: Am. Inst. Min. Engrs. preprint 75-L-359.

Fletcher, C. J. N., 1977, The Geology, Mineralization, and Alteration of the Ilkwang Mine, Republic of Korea. A Cu-W-Bearing Tourmaline Breccia Pipe: Econ. Geol., v. 72, p. 753-768.

Gates, O., 1959, Breccia Pipes in the Shoshone Range, Nevada: Econ. Geol., v. 54, p. 790-815.

Gilmour, P., 1977, Mineralized Intrusive Breccias as Guides to Concealed Porphyry Copper Systems: Econ. Geol., v. 72, p. 290-303.

Grant, A. R., 1969, Chemical and physical controls for base metal deposition in the Cascade Range of Washington: Wash. Div. Mines and Geology Bull. 58, 107 p.

Green, H. T. and Ringwood, A. E., 1969, High pressure experimental studies on the origin of andesites: State of Oregon Dept. Geol. Mineral Ind. Bull. 65, p. 21-32.

Hatherton, T. and Dickenson, W. R., 1969, The relationship between andesitic volcanism and seismicity in Indonesia, the Lesser Antilles, and other island arcs: Jour. Geophys. Res., v. 74, p. 5301-5310.

Hopson, C. A., Crowder, D. F., Tabor, R. W., Cater, F. W., and Wise, W. S., 1965, Association of andesitic volcanoes in the Cascade Mountains with Late Tertiary epizonal plutons: Geol. Soc. America Spec. Paper 87, 80 p.

Howell, F. H., and Molloy, J. S., 1960, Geology of the Braden Ore Body, Chile; South America: Econ. Geol., v. 55, p. 863-905.

International Union of Geological Sciences, 1973, Plutonic rocks-classification and nomenclature recommended by the I. U. G. S. Subcommission on the Systematics of Igneous Rocks: Geotimes, V. 18, no. 10, p. 26-30.

James, A. H., 1971, Hypothetical Diagrams of Several Porphyry Copper Deposit: Econ. Geol., v. 66, p. 43-47.

Kents, P., 1964, Special breccias associated with hydrothermal developments in the Andes: Econ. Geol., v. 59, p. 1551-1563.

Kesler, S. E., Jones, L. M., and Walker, R. L., 1975, Intrusive rocks associated with porphyry copper mineralization in island arc areas: Econ. Geol., v. 70, p. 515-526.

Kesler, S. E., Sutter, J. F., Issigonis, M. J., Jones, L. M., and Walker, R.L., 1977, Evolution of Porphyry Copper Mineralization in an Oceanic Island Arc; Panama; Econ. Geol., v. 72, p. 1142-1153.

Lawrence, R. D., 1976, Strike-slip faulting terminates the basin and range province in Oregon: Geol. Soc. America Bull., v. 87, p. 846-850.

Leever, W. H., 1941, Origin of the Mineral Deposits of the North Santiam District, Oregon. Unpublished M.S. Thesis, Oregon State Coll., 1941.

Levinson, A. A., 1974, Introduction to exploration geochemistry: Applied Publishing Ltd., Calgary, 612 p.

Lepeltier, C., 1969, A simplified treatment of geochemical data by graphical representation Econ. Geol., v. 64, p. 538-550.

Locke, A., 1926, The formation of certain ore bodies by mineralization stoping: Econ. Geol., v. 21, p. 431-453.

Lowell, J. D. and Guilbert, J. M., 1970, Lateral and vertical alteration-mineralization zoning in porphyry ore deposits: Econ. Geol., v. 65, p. 373-408.

MacKenzie, D. E. and Chappell, B. W., 1972, Shoshonitic and calc-alkaline lavas from the highlands of Papua, New Guinea: Contr. Mineralogy and Petrology, v. 35, p. 50-62.

McBirney, A. R., Sutter, J. F., Naslund, H. R., Sutton, K. G., and White, C. M., 1974, Episodic volcanism in the central Oregon Cascade Range: Geology, v. 2, p. 585-589.

Meyer, C. and Hemley, J. J., 1967, Wall rock alteration: in Barnes, H. L., ed., Geochemistry of hydrothermal ore deposits, Holt, Rinehart and Winston, Inc., p. 167-235.

Nockolds, S. R., 1954, Average chemical composition of some igneous rocks Geol. Soc. America Bull., v. 65, p. 1007-1032.

Nockholds, S. R. and Allen, R., 1953, The geochemistry of some igneous rock series: Geochim. et Cosmochim. Acta, v. 4, p. 105-142.

Norton, D. L., and Cathles, L. M., 1973, Breccia pipes - Products of exsolved vapor from magmas: Econ. Geol., v. 68, p. 540-546.

Park, C. F., 1955, The zonal theory of ore deposits: Econ. Geol. 50th Anniversary Vol., p. 226-248.

Peacock, M. A., 1931, Classification of igneous rock series: Jour. Geol., v. 39, p. 54-67.

Peck, D. L., 1960, Geologic reconnaissance of the Western Cascades in Oregon north of latitutde 43 degrees, U.S. Geol. Survey open file report.

Peck, D. L., Griggs, A. B., Schlicker, H. G., Wells, F. G., and Dole, H. M., 1964, Geology of the central and northern parts of the Western Cascade Range in Oregon: U.S. Geol. Survey Prof. Paper 449, 56 p.

Perry, V. C., 1961, The significance of mineralized breccia pipes Min. Eng., v. 13, p. 367-376.

Pungrassami, T., 1970, Geology of the western Detroit Reservoir area, Quartzville and Detroit quadrangles, Oregon: Oregon State University M.S. thesis, 76 p.

Reynolds, D. L., 1954, Fluidization as a geologic process and its bearing on the problem of intrusive granites: Am. Jour. Sci., v. 252, p. 577-614.

Richard, K., and Courtright, J. H., 1958, Geology of Toquepala, Peru: Mining Eng. Trans. of A.I.M.E., Feb. p. 262-266.

Rose, A. W., 1970, Zonal relations of wall rock alteration and sulfides distribution at porphyry copper deposits: Econ. Geol., v. 65, p. 920-936.

Sawkins, F. J., 1969, Chemical brecciation, an unrecognized mechanism for breccia formation ?: Econ. Geol., v. 64, p. 613-617.

Schaubs, M. P., 1978, Geology and Mineral Deposits of the Bohemia Mining District, Lane County, Oregon: Oregon State University unpub. M.S. thesis, 135 p.

Schriener, A., M. S. thesis in progress: Oregon State University.

Sheppard, S. M. F., Nielsen, R. L., and Taylor, H. P., 1969, Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits: Econ. Geol., v. 64, p. 755-777.

_______________ 1971, Hydrogen and oxygen isotope ratios in minerals from porphyry copper deposits: Econ. Geol., v. 66, p. 515-542.

Sillitoe, R. H., 1973, The tops and bottoms of porphyry copper deposits: Econ. Geol., v. 68, no. 6, p. 799-815.

Sillitoe, R. H., 1977, Permo-Carboniferous, Upper Cretaceous, and Miocene Porphyry Copper-Type Mineralization in the Argentinian Andes: Econ. Geol., v. 72, p. 99-109.

Sillitoe, R. H., and Sawkins, F. J., 1971, Geologic, mineralogic and fluid inclusion studies related to the origin of copper bearing tourmaline breccia pipes, Chile: Econ. Geol., v. 66, p. 290-303.

Stanton, R. L., 1972, Ore petrology: McGraw-Hill Book Co. Inc., New York, p. 578-611.

Storch, S. G. P., 1978, Geology of the Blue River Mining District, Linn and Lane Counties, Oregon: Oregon State University unpub. M.S. thesis, 70 p.

Sutter, J. F., and McBirney, A. R., 1974, Periods of Cenozoic volcanism in theCascade province of Oregon: Geol. Soc. America Abs. with Programs, v. 6, p. 264-265.

Taylor, E. M., 1968, Roadside geology, Santiam and McKenzie Pass Highways, Oregon in Dole, H. M., ed., Andesite Conference Guidebook: Oregon Dept. of Geology and Mineral Industries, Bull. 62, p. 3-33.

Taylor, H. P., Jr., 1971, Oxygen isotope evidence for large scale interaction between meteoric ground waters and Tertiary granodiorite intrusions, Western Cascade Range, Oregon Jour. Geophys. Research, v. 76, p. 7855-7874.

Taylor, S. R., 1969, Trace element chemistry of andesites and associated calc-alkaline rocks: State of Oregon Dept. Geol. Mineral Ind. Bull. 65, p. 46-63.

Taylor, S. R., and White, A. J R., 1965, Geochemistry of andesites and growth of continents: Nature, v. 20, p. 271-276.

Tennant, C. B., and White, M. L., 1959, Study of the distribution of some geochemical data: Econ. Geol., v. 54, p. 1281-1290.

Thayer, T. P., 1939, Geology of the Salem Hills and North Santiam River basin, Oregon: State of Oregon Dept. Geol. Mineral Ind. Bull. 15, 40 p.

Titley, S. R., 1975, Geologic Characteristics and Environment of some Porphyry Copper Occurrences in the Southwestern Pacific: Econ. Geol., v. 70, p. 499-514.

Turekian, K. K. and Wedepohl, K. H., 1961, Distribution of the elements in some major units of the earth's crust: Geol. Soc. America Bull., v. 72, p. 175-192.

APPENDIX

APPENDIX A

Rock Chip Geochemistry

Sample #	Ag ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm
F-5	.5	17	2	40	20
F-7	.8	20	1	30	45
MS-1	.6	20	<1	100	550
SS-7	.3	35	<1	10	60
E-12-A	1.1	60	1	25	115
SS-3-A	.6	60	1	35	80
S-1-2	.4	170	<1	35	95
S-1-12	.3	90	<1	30	90
BM-1	.3	35	<1	40	115
W-9	14.6	84000*	3	40	70
G-51	.4	30	<1	20	80
RD-1	1.0	45	2	205	525
3	.6	10	<1	40	60
L-3	.4	35	<1	40	65
RC-44	.8	90	3	40	140
GR-23	.5	35	<1	30	75
GC-5	.4	20	1	20	110
TA-1	.4	75	1	30	60
TB-1	.3	60	<1	15	100
T-1	.3	100	1	35	65
3	.4	55	<1	15	60
5	.3	25	2	15	40

Sample #	Ag ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm
Y-3	.3	30	<1	25	50
4	.7	45	<1	45	585
5	.7	250	<1	35	25
FA-DP	.4	40	<1	15	55
M-1	.6	35	<1	30	55
6	6	19	<1	25	25
9	.4	55	<1	30	65
K-4	.4	50	1	30	135
6	.4	60	<1	30	70
KA-1	1.0	50	<1	40	55
KD-1	.5	18	8	35	25
N-11	.8	30	<1	15	50
16	.6	380	2	15	30
O-1	.6	590	<1	40	130
2	.8	170	1	30	100
4	.6	65	<1	55	95
6	.7	70	<1	20	60
8	.4	50	1	30	70
9	.8	30	<1	25	75
P-2	.5	35	<1	180	265
4	.6	100	<1	40	255
9	.4	35	<1	30	65
10	.7	30	1	25	50
Y-1	.3	55	<1	30	60
2	.8	340	<1	30	45

Sample #	Ag ppm	Cu ppm	Mo ppm	Pb ppm	Zn ppm
1-1944	1.0	5100	13	8	45
1-1979	.3	3700	5	9	65
1-2013	1.0	1010	7	6	35
1-2052	.7	4000	8	12	120
1-2090	1.0	400	4	15	170
2-1018	.3	1120	30	12	70
2-2003	1.0	340	5	8	30

Stream Silt Geochemistry

1-1	1.0	50	< 1	50	110
2	1.0	300	< 1	130	1150*
3	.6	170	< 1	105	600
4	3.4	370	< 1	245	800
5	.8	150	< 1	150	1000*
6	1.0	110	< 1	50	190
7	.9	310	< 1	155	2250*
8	11.6	11200*	1	440	2500*