PETROLOGY AND STRUCTURE OF THE TUZO CREEK MOLYBDENITE PROSPECT NEAR PENTICTON, BRITISH COLUMBIA

by

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B. Sc. University of British Columbia, 1967

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

in the Department

of

GEOLOGY

We accept this thesis as conforming to the

required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1970

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ABSTRACT

The Tuzo Creek Molybdenite Prospect is in southern British Columbia approximately twenty air-miles east-southeast of Penticton within the Nelson-Valhalla batholithic complex.

A stock of porphyritic quartz monzonite, approximately 1½ miles in diameter, and younger sub-volcanic sills, dykes and masses of quartz-albite-sanidine porphyry were emplaced into a basement of Nelson granodiorite of probable Jurassic Age. Mid (?) Tertiary alkaline basic dykes are the youngest intrusions present. Porphyries were emplaced successively at three different times along structures developed either by subsidence of the stock or by regional deformation. Differentiation, level of crystallization of phenocrysts, level of emplacement and regional correlation of acid intrusions are discussed.

Two phases of hydrothermal activity are recognized, separated in time by intrusions of porphyry. In both cases, alteration was controlled by fractures and local shear and breccia zones. The first phase resulted in widespread wallrock alteration, quartz veining and mineralization throughout most of the stock and bodies of pre-mineral porphyry. Zoning of argillization, potash feldspathization and silicification and of oxide or sulphide fields of mineralization occurs on a large scale throughout the alteration halo. A large zone of low grade molybdenite mineralization occurs in a zone of more intense wallrock alteration containing stockworks of quartz veinsand pyrite.

The chemical and physical aspects of wallrock alteration and mineralization are considered in light of experimental

studies done by others.

The second phase of hydrothermal activity only occurred locally and involved development of secondary sericite and quartz with associated Zn, Pb, Cu, Fe and Mo sulphides and calcite and fluorite.

All structures can be explained either by periods of subsidence of the stock or by genetic relationship to forces developed by periodic movements along a nearby regional fault zone following the West Kettle River valley.

Source rocks of hydrothermal fluids, paragenesis, zoning and exploration potential for molybdenite are discussed.

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CHAPTER I

INTRODUCTION

GENERAL REMARKS

This study deals with the petrology of intrusive rocks, wallrock alteration and mineralization and with the structure of a region containing an altered and mineralized granitic stock near Beaverdell in southern British Columbia.

Material presented is based on detailed geological mapping of a four square-mile area, logging and sampling of 4,865 feet of B.Q. Wireline and 976 feet of Packsack diamond drill core, and on a petrographic and mineralographic study involving 152 thin sections and 23 polished sections.

Location and Access

The prospect is located in south central British Columbia within the southern part of the Interior Plateau approximately five air-miles southwest of Beaverdell (Figure 1 and 2). The eastern edge of the map-area that covers the prospect is one-half mile west of the junction of the West Kettle River and Tuzo Creek.

GENERAL LOCATION MAP

TUZO CREEK MOLYBDENITE PROSPECT

Figure 1

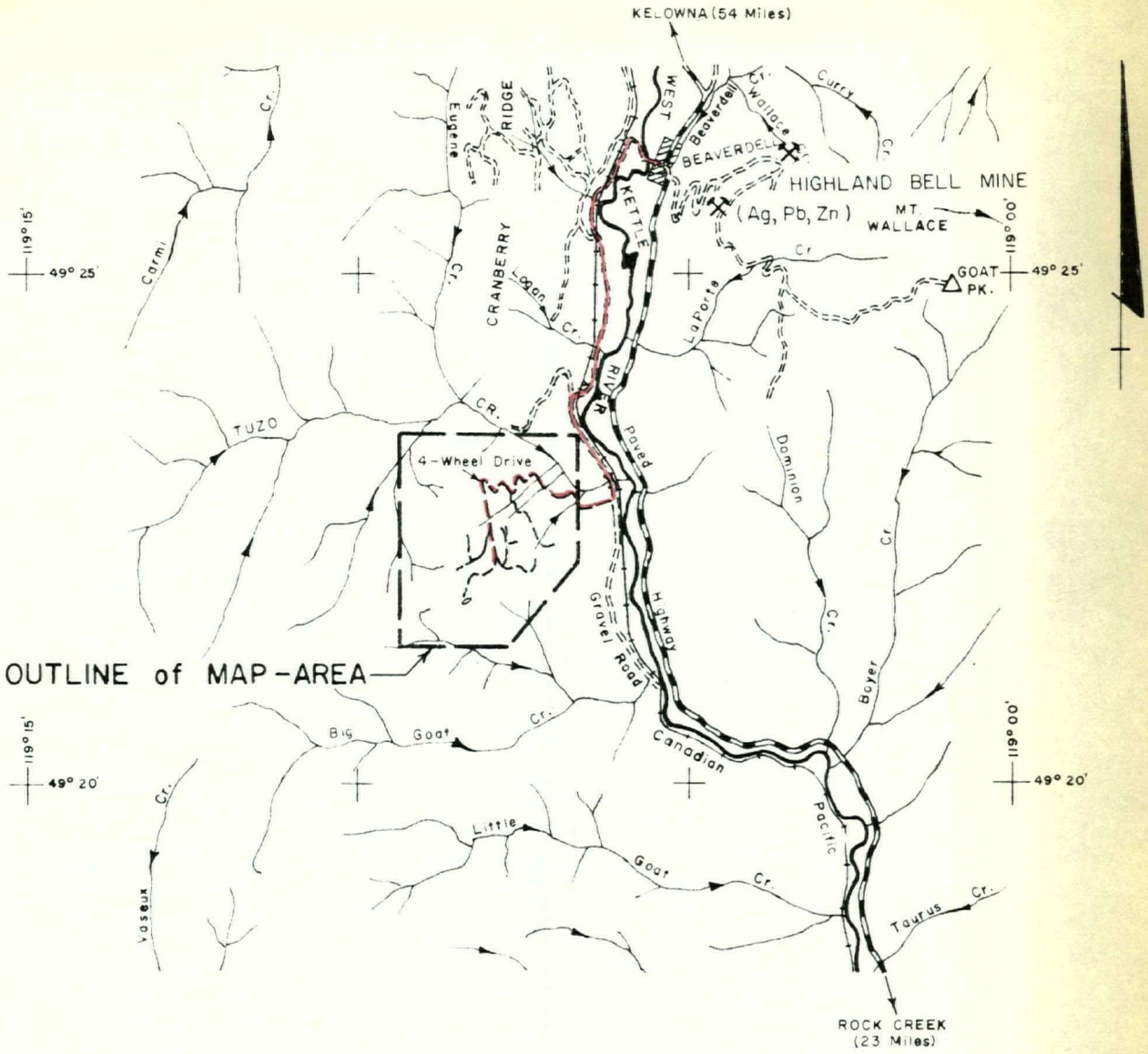


FIGURE 2

LOCATION MAP

TUZO CREEK MOLYBDENITE PROSPECT

BRITISH COLUMBIA

SCALE 1 INCH = 2 MILES

The map-area is accessible from Beaverdell by gravel road. Good access within the map-area is provided by approximately seven and one-half miles of four-wheel drive roads that traverse the east side and top of a ridge.

Physiography

The map-area covers a short, rounded north-south trending ridge and much of its surrounding slopes (Figure 4). Maximum relief is 2500 feet from the Tuzo Creek valley to the top of the ridge at an altitude of 5100 feet. From the top of the ridge to approximately the 4700 foot contour, slopes are gently dipping and rolling, whereas below this level slopes are relatively steep and moderately incised by numerous draws that intermittently have seepages and flowing water. Small local swamps and one permanent lake are present on the upper part of the ridge (see Plates 1 to 4).

The area is covered by a parkland type of evergreen forest growth that is relatively open on the upper part of the ridge but on steeper slopes, and particularly along draws, is mixed with a fairly dense growth of underbrush.

History of Detailed Exploration

The altered and mineralized area was explored for base metal deposits by Kennco Explorations (Western) Ltd. in 1961 and

1962, and by AMAX Exploration, Inc. from 1964 to 1966. AMAX presently holds 18 full-sized claims and one fractional claim (Figure 4).

Main access roads were constructed by Kennco. The results of an induced polarization survey, conducted by McPhar Geophysics for Kennco, are available through the district mining recorder.

The writer, as an employee, was directly involved in all stages of exploration by AMAX. Work included grid construction, geochemistry, geological mapping, diamond drilling, core logging, road building, trenching, sampling, surveying and a ground magnetometer survey.

Acknowledgements

Special acknowledgement is given to J. M. Patterson for his help during preliminary mapping, and especially for his suggestions during detailed exploration of the prospect. Acknowledgement is due to AMAX Exploration, Inc. for bearing the cost of thin and polished sections, map reproductions and photographs, and for permission to publish this thesis. My special thanks are given to Drs. K. C. McTaggart and A. J. Sinclair for their helpful suggestions and criticisms during the preparation of this thesis.

REGIONAL GEOLOGY

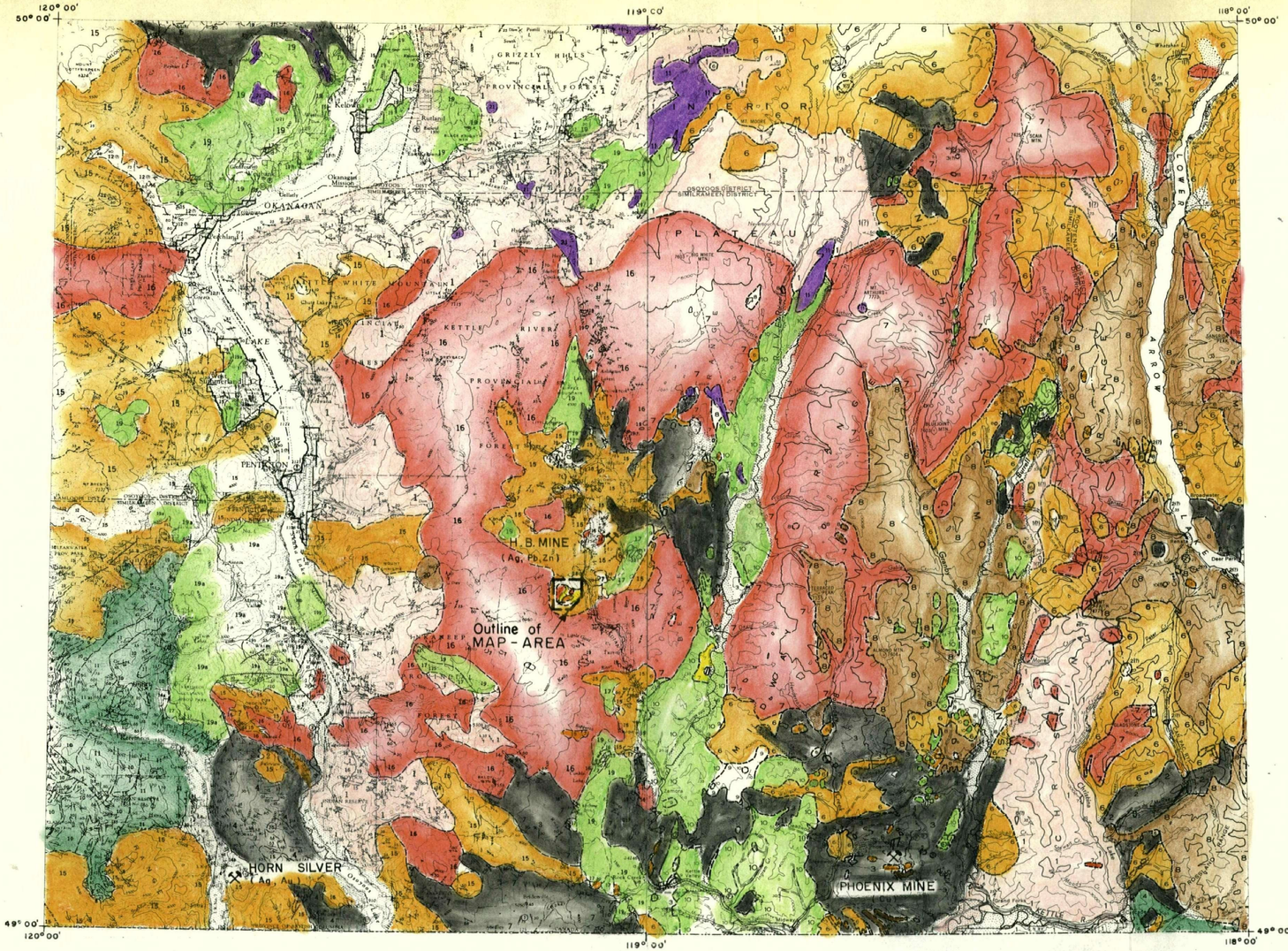
Included is a Preliminary Geological Map of the Kettle River Area (Figure 3) that has been reproduced, though simplified, from maps published by Little (8).

The area is underlain by Precambrian (?) to Jurassic metamorphosed and deformed sedimentary and volcanic rocks that were intruded, during the Mesozoic, by a few ultrabasic plutons and numerous granitic stocks and batholiths. These rocks are partly overlain by Tertiary sedimentary and volcanic rocks, and are intruded by small bodies of acid porphyry and syenitic dykes, stocks and batholiths.

Rock Types

For details of lithology, etc. of rock types refer to Little (8). Rocks older than Mesozoic granitic intrusions are not discussed below.

The center of the area is underlain by a large irregular but roughly circular Mesozoic "granitic" batholith. It comprises a large portion of the quartz monzonitic Valhalla Intrusions that occupy a central position in the Nelson-Valhalla batholithic complex of southern British Columbia. The batholith intrudes largely granodioritic Nelson Intrusions. However, in the far eastern portion of the area, contacts between the two phases are locally gradational, and in the Nelson area to the east, contacts are commonly gradational (8, 11).



PRELIMINARY GEOLOGICAL MAP OF KETTLE RIVER AREA

(EAST AND WEST HALVES)

BRITISH COLUMBIA

SCALE 1 INCH = 8 MILES

Reproduced From Original
Preliminary Geological Maps
By H. W. Little; Maps 6 - 1957
And Map 15 - 1961

L E G E N D

	WEST HALF	EAST HALF		
LATE TERTIARY	21	11	Basalt	PLATEAU BASALT
EARLY TERTIARY	20	8	Coryell Intrusions (Mainly Syenite)	
	17 19	9 10	19, 10 - Midway Volcanic Group 17, 9 - Kettle River Formation	CONTINENTAL SEDIMENTARY and VOLCANIC STRATA
JURASSIC TO CRETACEOUS(?)	18	7	Quartz Feldspar Porphyry Intrusions	
	16	7	Valhalla Intrusions (Mainly Porphyritic Quartz Monzonite, and Granite)	
	15	6	Nelson Intrusions (Mainly Granodiorite and Quartz Diorite)	
	14	5	Ultrabasic Intrusions	
TRIASSIC TO JURASSIC	8 11 12 13	4	4 Rossland Group 13 Limestone 12 Nicola Group 11 Old Tom Formation 10 Shoemaker Formation 9 Independence Formation 8 Barslow Formation	METAMOPHOSED EUGEOSYNCLINAL SEDIMENTARY AND VOLCANIC STRATA
CARBONIFEROUS	4 5 6 7	2 3	2 Mounts Roberts Formation 7, 3 Anarchist Group 6 Blind Creek Formation 5 Cache Creek Group 4 Kobau Group	
PRECAMBRIAN AND LATER	1	2 1	2 Chapperon Group 1 Monashee and Grand Forks Groups	HIGHLY METAMORPHOSED MIOGEOSYNCLINAL SEDIMENTARY STRATA

⚒ Producing Mine

H.B. Highland - Bell

Figure 3

Centered about Beaverdell, within the Valhalla batholith, is an irregular mass of Nelson Intrusions and older metamorphosed rocks. Stocks of Valhalla intrude the mass; one of which is located within the southern portion of the mass and within the map-area of the "Tuzo Creek Molybdenite Prospect".

In the Kettle River area, Nelson Intrusions are predominantly non-porphyritic, hypidiomorphic and contain hornblende whereas Valhalla Intrusions are generally porphyritic with large phenocrysts of microperthite and contain biotite and rarely hornblende. Towards the east, Valhalla Intrusions become, predominantly non-porphyritic and allotriomorphic in texture. The batholithic complex is tentatively assigned to the Jurassic and Cretaceous (?). This is based on stratigraphic evidence and age dating (10).

Stocks, dykes, and sills of quartz feldspar porphyry locally intrude Valhalla and older rocks. Porphyry intrusions include the Shingle Creek Porphyry (4) near Penticton, the Tuzo Creek Porphyry, discussed herein, and the Ouellette Creek Porphyry adjacent to the East Kettle River valley. Porphyries are probably of early Tertiary age because the Shingle Creek and Ouellette Creek intrusions have related contemporaneous pyroclastics that probably are intercalated with strata of the Early Tertiary Kettle River Formation. All porphyries occur adjacent to roughly north-south trending regional fault zones that lie along major valleys.

Early Tertiary sedimentary and volcanic strata unconformably overlie older rocks. In particular, they lie along

parts of the Okanagan Valley and Kettle and Granby River valleys.

Coryell Intrusions consist predominantly of medium grained, reddish syenite that grades locally into basic or acid phases. Dykes and stocks occur widespread whereas batholiths, having north-south elongation, only occur in the eastern part of the region along Granby River and Lower Arrow Lake. They are known to be of Tertiary Age and are likely, in part at least, contemporaneous with the Midway Volcanic Group.

Late Tertiary plateau basalts overlie parts of the north-central portion of the area. These lavas are probably correlative with those of the Columbia River and Interior Plateau regions.

Structure

All formations, except Late Tertiary basalts, have been folded and faulted with most intense deformation in oldest rocks. The structural history of the region has not been worked out in any detail. The most prominent tectonic features are strong fault and shear zones that lie along major north-south trending valleys. Subsequent movements along these zones have affected all rocks except Late Tertiary basalts. Fault and shear zones have controlled localization of Tertiary basins of sedimentation, centers of volcanism, and Coryell batholiths, and probably have controlled localization of porphyry intrusions.

Economic Geology

Copper, gold and silver occurring in replacement and vein deposits have had a long history of interest in the area. Copper is presently being produced from the Phoenix Mine and silver and gold are being produced from the Horn Silver Mine. The Highland-Bell Mine, located near the Tuzo Creek Molybdenite Prospect (Figure 2), produces Ag, Pb and Zn. Only recently has molybdenum been of interest in the area. Numerous molybdenite occurrences are known but none have had any production.

PRELUDE TO PETROLOGY AND STRUCTURE OF THE PROSPECT

Geological Summary Statement

The map-area of the Tuzo Creek Molybdenite Prospect lies over the southern-most portion of a mass of Nelson intrusive rocks that are positioned centrally within a younger batholith of Valhalla intrusive rocks.

Within the map-area is a small stock of Valhalla quartz monzonite that is fringed and partially capped by older Nelson granodiorite. Sills, dykes and masses of quartz feldspar porphyry successivley intruded the above rocks at three different times. Two phases of hydrothermal activity are recognized. Intermediate to basic dykes cut all the above rocks and are themselves offset by late faults. Table I illustrates the geological sequence of events in detail.

TABLE I - GEOLOGICAL SEQUENCE OF EVENTS

(Note: Arrows are pointed towards those features that were controlled by various structures)

	INTRUSIONS	STRUCTURE	HYDROTHERMAL OR DEUTERIC ALTERATION AND ASSOCIATED MINERALIZATION
Probably Mid to Late Tertiary		Erosion to present level	
		PERIOD-III; Faulting	
	Late Dykes		Deuteric Alteration
		Conjugate Tensional Fissures	
Probably Jurassic to Early Tertiary	Post-Mineral Porphyry Dykes and Masses		Deuteric Alteration and Mineralization
		Conjugate Tensional Fissures	
			PHASE-II; Intra-Mineral Porphyry Association. (Argillization and silicification; sphalerite, galena, chalcopyrite, pyrite, molybdenite)
		PERIOD-II; Local shearing, brecciation and fracturing	
	Intra-Mineral Porphyry Sills and Dykes		Deuteric Alteration and Mineralization (included with Phase-II)
		Structures caused by subsidence of the stock	
			PHASE-I; Main Phase of wallrock Alteration and Mineralization. (Widespread argillization, silicification, K-feldspathization; quartz veining; pyrite, hematite, magnetite, molybdenite)
		PERIOD-I; Intense shearing, widespread fracturing and local brecciation	
	Pre-Mineral Porphyry Roof-sill and Dykes		
		Structures caused by subsidence of the stock	
	Porphyritic Biotite Quartz Monzonite Stock		Deuteric Alteration (?)
		Probable regional faulting and shearing	
	Batholithic Hornblende Granodiorite		Deuteric Alteration (?)

Presentation and Data

The main body of this report is divided into three chapters dealing with a) Intrusive Rocks, b) Structure and c) Hydrothermal Alteration and Mineralization. Included are two sets of figures, each comprising of a plan and two sections. One set (Figures 5 and 6) show rock types and faults while the other (Figures 7 and 8) illustrates hydrothermal alteration, mineralization and important structural features along with simplified rock types. Also included is a control map (Figure 4) showing topography, roads, control points and grid lines for mapping diamond drill holes, claims and the outline of the area of molybdenite mineralization. All above figures were drawn at a scale of 1 inch equals 400 feet whereas original surface mapping was done at a scale of 1 inch equals 200 feet. The text is also illustrated with appropriate Tables and Plates.

All known outcrops within the gridded area (Figure 4) were mapped. Elsewhere, outcrops were mapped mainly along roads and particular lines and traverses. Outcrops are abundant, except in more heavily vegetated regions, but are commonly small and, in places, largely are made up of rubble. They commonly rise to only a few feet above the soil cover; making it difficult and often impossible to determine contact attitudes.

Core from four BQ Wireline diamond drill holes*

* Abbreviated to DDH in remainder of text

TABLE II - Classification of Thin and Polished Sections Studied

——Thin sections studied from fresh and altered rock types——

Zone of Hydrothermal Alteration	ROCK TYPES AND NUMBER OF THIN SECTIONS STUDIED											
	Granodiorite		Quartz Monzonite		Pre-Min. Porphyry		Intra-Min. Porphyry		Post-Min. Porphyry		Late Dykes	
	Otc	DDH	Otc	DDH	Otc	DDH	Otc	DDH	Otc	DDH	Otc	DDH
Fresh +	3		5		1		2		10	14	10	
Peripheral Shell x	4		5	5	9		4	1				
Central Zone x	9		3	7	13	16	4	12				
	3*											
Totals	19		25		29		23		24		10	

+Some fresh samples taken from unaltered remnants within peripheral shell
xDefined in section "Hydrothermal Alteration and Mineralization"
*Samples from regionally altered granodiorite
Otc Samples taken from outcrop
DDH Samples taken from B.Q. Wireline diamond drill holes

——Thin and Polished Sections Studied from Mineralized Fractures and Veins——

Type of Mineralization	Number of Thin Sections	Number of Polished Sections
Hematite and Magnetite	1	8
Hematite-Magnetite-Pyrite-Molybdenite	1	3
Pyrite-Molybdenite	1	4
Molybdenite	7	4
Galena-Sphalerite-Chalcopyrite-Pyrite-Molybdenite	2	4
Totals	12	23

totalling 4,865 feet and from 13 Packsack diamond drill holes+ totalling 976 feet was logged and sampled in detail. Wireline drill holes are shown on sections (Figures 6 and 8). Only molybdenite assays equal to or greater than .04% are shown along drill holes (Figure 8). Average molybdenite assays from all holes are given in the text. Core diameter and average percent core recovery, respectively are 1-5/8" at 97% for DDH's and 7/8" at 77% for PSH's.

A total of 152 thin sections were studied from fresh rock types and their altered equivalents and from vein and fracture fillings. Also studied were 23 polished sections containing sulphide and/or oxide minerals. Sample locations for thin and polished sections are shown on accompaning figures and a classification of sections is given in Table II.

Percentages of minerals present in rocks have been estimated visually.

+ Abbreviated to PSH in remainder of text

CHAPTER II

INTRUSIVE ROCKS

This section deals with distribution, field relations, primary petrography and mineralogy, structure and genesis of intrusive rocks (Figures 5 and 6).

HORNBLENDE GRANODIORITE

Fresh and altered equivalents of granodiorite almost completely fringe a younger intrusive complex of quartz monzonite and porphyries. Granodiorite also occurs as a central, east-west trending, irregular mass that caps much of the southern flank of a younger stock of quartz monzonite. This mass is relatively fresh along most of its southern edge.

Granodiorite is a leucocratic, medium grained, hypidiomorphic rock consisting of pale-grey plagioclase, pale-pink interstitial to large poikilitic orthoclase, glassy interstitial quartz and dark-green hornblende prisms (Plate 5). Accessory minerals consist of brown sphene, magnetite, apatite and zircon in order of decreasing abundance. Commonly, the rock is weakly foliated and lineated due to oriented laths of plagioclase and prisms of hornblende. Granodiorite is similar to much of the Nelson Intrusions. Hence, the two are considered equivalent.

Composition of the granodiorite is shown in Table III.

Plagioclase (An_{41} to An_{23})	50-55%
Orthoclase	15%
Quartz	20-25%
Hornblende	7-10%
Accessories (sphene, magnetite, apatite, zircon)	1-2 %

TABLE III: Estimated Mode of Granodiorite

Petrography and Mineralogy

Plagioclase commonly forms euhedral laths 2-5 mm long. It is twinned according to albite, pericline and Carlsbad twin laws and shows nomal oscillatory zoning from An_{41} to An_{23}. Zoning in crystals is more pronounced in the outermost composition zones which commonly form a clear, thin envelope around more calcic plagioclase. Rims of crystals commonly are replaced locally by mermyketic quartz and partly intergrown with fine grained quartz. Orthoclase has an optic angle of approximately 70°. It forms clear, twinned crystals grown interstitially to slightly poikilitically with respect to plagioclase and hornblende and in places with respect to medium grained quartz. Locally, orthoclase occurs as large poikilitic subhedra up to 3 cm long. Orthoclase commonly contains fine-grained, anhedral to euhedral grains of quartz, particularly towards edges of crystals, and also commonly contains minor discontinuous films of quartz along 001 cleavages. Also, orthoclase occasionally contains minor amounts of 010-oriented, exsolved albite. Clear medium-to fine-grained, anhedral quartz occurs interstitial to

hornblende and plagioclase and locally to orthoclase. Commonly, coarser-grained quartz and some orthoclase show undulatory extinction. Hornblende occurs as subhedral to euhedral prisms generally 3 to 6 mm long though occasionally up to 1 cm. long. It is light- to dark-green pleochroic and sometimes twinned on 100. Fine-grained, anhedral to euhedral accessory minerals occur disseminated; often as small composite aggregates. They occur particularly within and adjacent to hornblende prisms. Sphene is occasionally medium grained and brown in hand specimens.

Deuteric (?) Alteration

"Fresh" granodiorite has been affected by slight deuteric and/or hydrothermal alteration. Hornblende is most attacked. It is partially to completely altered to pseudomorphous, green pleochroic chlorite along cleavages with associated disseminated epidote and minor quartz and calcite. Some associated magnetite is likely secondary. Plagioclase has been altered slightly; particularly along cleavages, within cores and certain of the more calcic zones, to hydromica (?), calcite and epidote and locally to chlorite in crystals adjacent to altered hornblende. Orthoclase is replaced locally by euhedral, fine grained epidote with associated quartz adjacent to altered hornblende. Elsewhere it is unaltered or cut by thin calcite veinlets. Sphene shows slight alteration along fractures and crystal edges to leucoxene. "Fresh" granodiorite commonly is cut by sparse epidote veinlets up to 1/8 inch wide.

PORPHYRITIC BIOTITE QUARTZ MONZONITE

Unaltered quartz monzonite is a distinctly porphyritic, light-colored massive rock containing large phenocrysts of dark-pink sanidine in a fine-and medium-grained matrix. The matrix consists of crowded phenocrysts of light-colored plagioclase, quartz and biotite set in a fine grained groundmass of dark-pink sanidine, quartz, biotite and accessory minerals (Plate 6). Quartz monzonite is texturally and mineralogically similar to and, therefore, correlated with Valhalla Intrusions (See "Regional Geology").

Sanidine	
Phenocrysts	10-15%
Groundmass	20%
Plagioclase (An_{30} to An_{16})	40%
Quartz	
Phenocrysts	10%
Groundmass	15%
Biotite	3%
Accessories (Magnetite, apatite, zircon and sphene)	½%

TABLE IV: Estimated Mode of Quartz Monzonite

Structure

Quartz monzonite occurs as a rounded, partially unroofed stock-like body with a triangular plan (sides approximately 1½ miles long). The top of the body is closely coincident with the top of the ridge as described under "Physiography".

Contacts between granodiorite and quartz monzonite were not observed; largely due to the presence of a younger intrusive porphyry sill that in most places separates the two phases on the eastern flanks of the quartz monzonite body, and partly due to shortage of outcrop and/or prevalence of shearing where porphyry was not emplaced. The porphyry sill also separates areas of exposed quartz monzonite at the present level of erosion. The quartz monzonite body is believed an intrusive stock for the following reasons:

1) The quartz monzonite body has a stock-like shape.

2) There is a distinct difference in lithology between granodiorite and quartz monzonite and an absence of lateral textural or mineralogical changes in either rock type towards mutual contacts.

3) Valhalla Intrusions, similar to quartz monzonite, intrude or are otherwise gradational into Nelson Intrusions, similar to granodiorite (see "Regional Geology").

Phenocrysts

Sanidine phenocrysts vary in size from a fraction of an inch to three inches long but are generally 1 to 1½ inches in length. They are commonly euhedral, in places twinned according to Carlsbad twin law and commonly contain minor inclusions of plagioclase, quartz and biotite particularly in the outer portions of crystals. In thin section, interiors of large sanidine crystals are relatively clear whereas outer fringes commonly are "clouded" to a "dirty" dark grey. Outermost portions of sanidine phenocrysts often show a single intergrown seam of

fine-grained, anhedral quartz grains. Edges of phenocrysts commonly are intergrown slightly with fine-grained quartz of the groundmass. Fringes of crystals do not vary optically from their interiors except that faint oscillatory zoning is apparent. Sanidine commonly contains up to 15 percent evenly distributed microcrystalline, exsolved lamellae of albite parallel to 010. In sanidine, the optic axial plane is oriented parallel to 010 and the optic angle varies from 35° to 55°.

Plagioclase phenocrysts occur as evenly distributed, subhedral to euhedral, medium-grained (range 0.5 - 8 mm; average 3 mm long) laths and fairly often as small intergrown clusters of laths. Phenocrysts are normally zoned, with slight oscillations, from An_{30} to An_{16}. Often individual laths do not show the complete range of composition. Twinning according to the albite, pericline and Carlsbad twin laws is common. In thin section, plagioclase phenocrysts are colored irregularly, completely or only in outermost portions to a "dirty" yellowish-brown; probably due to oxidation of contained iron. Edges of crystals are often somewhat irregular since they are intergrown with, and appear bitten-into, by fine-grained quartz.

Medium-to coarse-grained alpha quartz (range 1 mm - 1 cm; average 4 mm) occurs as evenly distributed, rounded to somewhat irregular phenocrysts of short, prismatic hexagonal habit. Occasionally present are aggregates of intergrown cyrstals and aggregate chains of optically continuous euhedral crystals. Quartz phenocrysts commonly are embayed by fingers of fine-grained sanidine with minor quartz, and have rounded to sutured

borders. Quartz with sutured borders is intergrown with fine-grained sanidine of the groundmass. Quartz phenocrysts generally show faint polysynthetic twinning. They commonly show weak to intense undulatory extinction and some phenocrysts are shattered but undistorted.

Fine-to medium-grained (range .05 - 3 mm; average 1 - 1½ mm) plates of greenish black biotite occur evenly distributed in quartz monzonite. Biotite is pale-tan to greenish-brown pleochroic and commonly has ragged ends.

Groundmass

Occurring interstitially to and, in part, intergrown with edges of phenocrystsof sanidine, plagioclase, and quartz is a fine grained (range .03 to 2.5 mm) groundmass consisting of highly "clouded" sanidine, quartz and minor biotite, plagioclase and accessory minerals. The average grain size of the groundmass is variable. In general, it averages 0.77 mm in outcrops and in drill holes to a depth of a few hundred feet. At greater depths, average grain size is approximately 0.12 mm. The finer-grained groundmass is a granophyric intergrowth of quartz and sanidine. The coarser-grained groundmass is more granular with quartz and sanidine showing mutual grain relationships. Sanidine in groundmasses is optically identical to sanidine phenocrysts though is more highly "clouded".

Fine-grained accessory minerals are euhedral to anhedral. They include apatite, magnetite, sphene and zircon in decreasing order of abundance.

Lithologic Variations

Apart from slight variation in average grain size of groundmass with depth, the only other lithologic variation observed occurs near the center of the eastern-most exposure where phenocrysts are widely dispersed and plagioclase occurs more abundantly in the fine-grained groundmass and is highly intergrown around edges with quartz. One exposure, within the western part of the central granodiorite mass, shows a dyke with similar texture cutting granodiorite.

Deuteric (?) Alteration

Plagioclase and biotite in "fresh" quartz monzonite have been very slightly altered deuterically (?). Plagioclase contains minor disseminated fine-grained hydromica and clear to "dirty" epidote. Biotite has been altered to varying degrees, though is generally only peripherally altered to green pleochroic chlorite with associated opaque leucoxene (?) along cleavages and locally with associated magnetite and fluorite. Accessory sphene has been altered to an opaque, white reflective mineral (probably leucoxene).

QUARTZ-ALBITE-SANIDINE PORPHYRIES

Introduction

Dykes, sills and dyke-like masses of light-colored quartz-albite-sanidine porphyry have successively intruded granodiorite and the quartz monzonite stock. Intermittent to intrusion of porphyry were periods of shearing and fracturing, hydrothermal alteration and mineralization.

The primary texture and mineralogy of all porphyries is practically identical although three main intrusive phases can be distinguished in the field and show some differences in thin section. These porphyry phases include pre -, intra - and post-mineral porphyry. Field criteria for separation into phases is listed below:

1) Presence or absence of fracturing, hydrothermal alteration and mineralization within the alteration halo (Figure 7 and 8);

2) Intrusive relationships among the three porphyry phases;

3) Pre-mineral porphyry has inherent structural characteristics;

4) Presence or absence of well defined chilled contacts;

5) Degree of hydrothermal alteration.

Use of above criteria is believed to have resulted in a high degree of certainty regarding the validity of the three

separate phases shown on accompanying maps. Distinction between pre- and intra-mineral porphyry is difficult on the surface towards the center of the alteration halo, where alteration has been most intense, and some porphyry may be mapped incorrectly in this region. Also, near the outer edge and outside the alteration halo, intra- and post-mineral porphyries are difficult to distinguish. However, because post-mineral dykes widen outwards from within the alteration halo into large dyke-like masses, it is believed that most porphyry bodies outside the alteration halo are post-mineral.

Since all porphyry phases have primary petrographic and mineralographic similarities they are described together in the following section. Distribution, mode of emplacement and particular characteristics of each of the porphyry phases is discussed in other following sections.

General Description

Colors of phenocrysts and groundmasses mentioned below, refer to all post-mineral porphyry but only to fresher equivalents of altered pre- and intra-mineral porphyry. Some of the petrographic variations of phenocrysts and groundmasses in different porphyry phases are described in this section.

Porphyries consist of phenocrysts of large pink sanidine, varicolored albite, clear to smoky quartz and chloritized biotite set in an aphanitic to fine-grained, pale

greenish-grey groundmass (Plates 7 to 10). The average mode of porphyries is shown in Table V.

Phenocrysts	
Large Sanidine (>1 cm)	10-15%
Small Sanidine (<1 cm)	5-10%
Albite	20-25%
Quartz	10%
Chloritized biotite	2-3 %
Accessories (apatite, magnetite, pyrite, sphene, zircon)	1 %
Groundmass	40-50%

TABLE V: Average Estimated Mode of Quartz-Albite-Sanidine Porphyries

Phenocrysts

Sanidine phenocrysts are commonly euhedral and range in length from .05 mm to three inches. Large phenocrysts, greater than 1 cm long, average about 1 to 1½ inches in length. They are commonly light-to medium-pink, occasionally with white to cream colored interiors (Plate 10). Small phenocrysts, less than 1 cm in length, are commonly light-pink to cream colored and often blend in with the groundmass or are indistinguishable from albite phenocrysts. Sanidine most commonly occurs as simple crystals elongated along the a-axis with 010 and 001 faces terminated by 110 and $20\bar{1}$ faces. Some crystals show twinning according to the Carlsbad twin law and are elongated along the c-axis. Large sanidines commonly contain minor inclusions of albite, quartz and altered to fresh biotite. Inclusions are more abundant towards edges of crystals where albite laths are oriented parallel to growth zones of sanidine crystals. In thin section, all sanidines are

relatively clear though they contain disseminated specks of opaque material which is more abundant in fine-grained sanidine and in the fringe of large crystals. This opaque material appears the same as that clouding sanidine in quartz monzonite and probably consists of iron oxides. Fine grained sanidine commonly show partial to locally complete overgrowths on albite phenocrysts. Partial overgrowths occur on sides, ends and/or corners of albite laths. The optic plane in sanidine is oriented parallel to 010 and the optic angle varies from 30° to 60 . Large phenocrysts generally show minor exsolved microcrystalline albite lamellae oriented along 010 and have concentric oscillatory zoning. Individual growth zones always show rounded corners and locally show seams of exsolved albite and discontinuous transverse fractures.

Albite phenocrysts are subhedral to euhedral and vary in size from .05 to 8 mm (average 1-4 mm). They are variously colored from pale green, light grey, cream and locally white to light to medium reddish-pink. In thin section, albite is nearly always "clouded" light to dark yellowish-brown, probably due to oxidation of contained iron. It is unzoned and shows complex albite, pericline and carlsbad twins. Composition of albite is always in the range An_0 to An_{10} but is predominantly less than An_5. Composition of albite in various porphyry phases is shown in Table VI.

Pre-mineral Porphyry--------An_2 - An_8 (Average of An_5)
Intra-mineral Porphyry------An_0 - An_4
Post-mineral Porphyry-------An_0 - An_5

TABLE VI: Composition of Albite in Porphyries

All porphyries contain some albite showing stress twinning and bending but in pre-mineral porphyry, deformed albite is much more common.

Quartz phenocrysts are glassy to smoky and are commonly euhedral, though they are generally rounded and embayed. They vary in size from .05 mm to 1½ cm (average 2-5 mm) and have a short, hexagonal dipyramidal habit typical of primary beta-quartz though they are now alpha-quartz. In thin section, quartz is clear, shows finger-like embayments of the groundmass and often shows faint polysynthetic twinning. Inclusions of albite and altered biotite are rarely found in quartz. Quartz is undeformed or shows weak undulatory extinction in intra- and post-mineral porphyry. In pre-mineral porphyry, quartz is commonly more intensely deformed and includes quartz showing moderate to intense undulatory extinction to crystals that are broken and undeformed or strung-out and often recrystallized to fine aggregates. Strung out aggregate crystals of quartz are commonly recognized in hand specimens of pre-mineral porphyry.

Green chloritized biotite occurs as phenocrysts varying in size from .05 to 3 mm (average .5 - 1.5 mm). Remnants of light-to dark-greenish brown pleochroic biotite are rare. Alteration of biotite is discussed in later sections.

Accessory minerals are fine-grained, euhedral to subhedral and consist of apatite, magnetite, pyrite, sphene and zircon in decreasing order of abundance.

Subhedral to euhedral, medium-to coarse-grained, cream colored phenocrysts consisting of an unknown feldspar with intergrown graphic quartz are present locally. The feldspar shows albite - and pericline-like twins in parts of crystals that fade out into untwinned parts having apparent lower birefringence. The intergrowth probably represents a binary eutectic of an unmixed anorthoclase and quartz. Also present locally are small phenocrysts of a feldspar (possibly anorthoclase) with spindle-like parallel twins.

Groundmass

The groundmass in all porphyries is commonly aphanitic and colored a pale greenish-grey. In thin section, it is commonly slightly "dirty" and microcrystalline-granular with an average grain size of .01 to .02 mm.

Dark chilled contacts occur only in intra- and post-mineral porphyry. They range from ½ foot to 15 feet in width. Narrow dykes and sills are often entirely chilled. Widest chilled contacts occur in post-mineral porphyry. Such contacts contain fewer phenocrysts in a dark green, aphanitic groundmass that grades into normal appearing porphyry. Close to contacts phenocrysts are often slightly broken and in thin sections, porphyries show a "dirty" brown, microcrystalline

groundmass with or without flow lines around broken phenocrysts. Towards the center of wider intra- and post-mineral dykes and sills the groundmass commonly becomes slightly coarser-grained and phenocrysts become more abundant. Coarser groundmasses are uneven grained but grains average approximately .03 to .07 mm in size. They show eutectic-like intergrowths between clear graphic to skeletal and spherulitic crystals of quartz up to .5 mm in size and finer-grained, "dirty" alkali feldspar. Partial spherulites of quartz have commonly grown around edges of feldspar phenocrysts. Also, quartz commonly shows wide dark halos of optically continuous quartz and intergrown "dirty" alkali feldspar.

Locally, in pre-mineral porphyry the groundmass is slightly coarser-grained with grains averaging .03 to .05 mm in size. Such groundmasses have a granular texture and consist of clear quartz and "dirty" alkali feldspar.

Regional Correlation

The above porphyries are very similar to the Shingle Creek Porphyry (Bostock) near Penticton. Similarities of detailed textures and optical properties of sanidine phenocrysts are striking. These porphyry intrusions are undoubtedly correlative. It is suggested that porphyry occurring at the Tuzo Creek Molybdenite Prospect be referred to as the Tuzo Creek Porphyry.

Pre-Mineral Roof-Sill and Dykes

From distribution, contact relations and inherent structural features, the pre-mineral porphyry is thought to be a gently easterly dipping, inverted saucer-shaped mass up to 350 feet thick that was conformably and forcefully intruded between granodiorite and the top and eastern flanks of the quartz monzonite stock. Pre-mineral porphyry can be referred to as a roof-sill. Dykes of pre-mineral porphyry, cutting quartz monzonite in DDH 1, are likely feeder-dykes to the roof-sill from a buried porphyry stock.

Distinguishing Features

Pre-mineral porphyry was recognized early during mapping because it is fractured, altered and mineralized in degrees comparable to that in coarser crystalline rocks and predominatly occurred as irregular masses. Pre-mineral porphyry is commonly more intensely altered than intra-mineral porphyry. However, other features, listed below, distinguish it from intra-mineral porphyry within the alteration halo and from other porphyries outside the alteration halo.

1) Commonly deformed and strung-out phenocrysts of quartz (Plate 7);

2) Some large sanidine phenocrysts are broken and somewhat strung out;

3) Locally foliated altered biotite phenocrysts

best shown where porphyry is freshest; locally more intensely altered porphyry shows a crude foliation due to parallel strung-out phenocrysts and/or some indication of foliation in the groundmass;

4) Generally, the groundmass appears fine-grained due to an abundance of fine grained phenocrysts.

Pre-mineral porphyry also shows differences in thin sections from other porphyries. These include the common presence of stress twinning and bending of albite phenocrysts, a slightly more calcic composition of albite (Table VI) and locally parallel orientation of albite laths.

Distribution

Pre-mineral porphyry underlies areas along the top and on the northeastern slope of the ridge (see "Physiography"). Outer parts of the porphyry mass occur as elongate lobes concordant with and separating the quartz monzonite stock and southeastern capping and northeastern fringe of granodiorite. The west-central portion of the porphyry mass separates areas of exposed quartz monzonite. In DDH's 2, 3 and 4 pre-mineral porphyry was found in thicknesses of 75 to 340 feet separating the granodiorite capping from underlying quartz monzonite. Packsack holes collared in quartz monzonite near pre-mineral porphyry (ie: PSH's 9, 10 and 11) did not intersect porphry in holes bottoming at 37 to 156 feet. An inclined drill hole (ie: PSH 12), located at the top of the ridge and collared in granodiorite, intersected pre-mineral porphyry and showed that the adjacent lobe of porphyry dipped beneath granodiorite

at an angle of approximately 40° and has an approximate true thickness of 150 feet.

In DDH 1, feeder-dykes of porphyry from 25 to 110 feet wide were found cutting the quartz monzonite stock. These dykes are probably apophyses from a mass or stock of porphyry at depth. Also, a few small dyke-like bodies of probable pre-mineral porphyry occur within the granodiorite capping and in one place, on the lower road east of Fault-A, a dyke-like apophysis of the large porphyry mass, described above, has intruded quartz monzonite.

Contact Relationships

Contacts with coarser crystalline rocks are not defined clearly because of diffuse textures due to hydrothermal alteration. Also, lack of outcrop and shearing in contact regions has obscured contacts. However, where contacts are fairly well defined, especially in drill holes, they commonly show fairly sharp breaks in lithology between porphyry and granodiorite or quartz monzonite. Near the top of DDH 3, porphyry shows a sharp, narrow chilled contact against granodiorite and, at a depth of 381½ feet in DDH 2, porphyry has a sharp intrusive contact with quartz monzonite and is chilled for 10 feet from the contact. In DDH 3 at a depth of 349½ feet, a sharp contact between porphyry and quartz monzonite, examined in thin section, showed porphyry to consist of an intrusive breccia adjacent to a sharp contact with quartz monzonite. Another thin section of porphyry from the surface, near DDH 4, showed small inclusions of quartz

monzonite. Porphyry commonly contains some inclusions that generally can be identified near contacts with granodiorite and quartz monzonite.

Some contacts between porphyry and quartz monzonite appear gradational. They occur along the top of the ridge, in DDH 4 and locally in DDH 1. They show increasing amounts of plagioclase phenocrysts in porphyry towards contacts with the groundmass remaining light-colored microcrystalline-granular. Sharp contacts with quartz monzonite generally are not found in these cases but porphyry is probably intrusive since locally it also contains inclusions of quartz monzonite.

Intra-Mineral Sills and Dykes

Intra-mineral porphyry occurs as fractured, altered and mineralized sills and dykes intruding all of the above rock types. They particularly intrude the granodiorite capping and underlying pre-mineral porphyry roof-sill and quartz monzonite stock. They commonly intrude more intensely, and often differently, altered rocks and cut off some mineralized fractures.

Where intra-mineral porphyry does not intrude pre-mineral porphyry it can be distinguished by the following features:

1) Lack of inherent structural features (ie: deformed quartz and foliation) characteristic of pre-mineral porphyry;

2) Presence of chilled contacts up to 5 feet wide (only rarely present in pre-mineral porphyry);

3) Presence of lesser degrees of alteration than in pre-mineral porphyry;

4) Crosscutting relationships with some mineralized fractures and veins;

5) Crosscutting relationships with, and presence of inclusions of, differently altered and mineralized rocks.

Locally observed, both on surface and in drill holes, are chilled contacts between similar intra-mineral porphyry intrusions. The earlier intrusion generally shows slightly more intense alteration.

Structure

Intrusions of pre-mineral porphyry to the southwest of collars of DDH's 2, 3 and 4 occur as four irregular masses that contain large included blocks of granodiorite. The northwestern-and southwestern-most bodies are gently dipping as determined, respectively, from diamond drill hole intersections and outcrop, and appear to be composite sill-like sheets intruded near to and along the contact between the pre-mineral porphyry roof-sill and granodiorite. These sills range from 40 to 100 feet thick. Two larger exposed masses, occurring between the above sills, are elongated northeasterly and commonly have off-shooting dykes, particularly at their ends. Attitudes of off-shooting dykes are variable and in a general manner radiate from the central masses. These central masses are probably sill-like in nature.

Also, at the top of the ridge is a small intrusion occurring approximately concordant with the southeasterly-dipping contact between pre-mineral porphyry and granodiorite.

Apart from the thick intra-mineral porphyry sills intersected near the tops of DDH 2 and 3, two other zones, consisting of several narrow dykes, were intersected below depths of 650 feet within the quartz monzonite stock in each of DDH's 3 and 4. A few other narrow dykes intrude quartz monzonite and pre-mineral porphyry in the upper portion of DDH 4. Dykes commonly range from a few feet to 30 feet in width. Core attitudes of all chilled intra-mineral porphyry contacts (ie; 28 measurements) in vertical drill holes most frequently range from 45° to 90° to the core axis. Most porphyries are, therefore, moderately to gently dipping and for this reason the two dyke zones, mentioned above, are probably connected between DDH's 3 and 4.

Deuteric Alteration and Mineralization

Intra-mineral porphyry bodies are strongly altered and sparsely mineralized deuterically. These features are discussed under "Phase-II: Intra-mineral Porphyry Association".

Post-Mineral Dykes and Masses

Post-mineral porphyry occurs as abundant dykes and dyke-like masses throughout the central-southwestern to north-eastern portions of the region. It is intrusive into all

above rock types. Contacts are sharp and show up to ten feet of chilling in the porphyry groundmass. Post-mineral porphyry always appears nearly fresh or slightly altered deuterically. Outcrops are elongated parallel to the strike of dykes, show joint planes, weather to a grey color and show differential erosion with respect to adjacent outcrops of rusted and broken older intrusive rocks.

Structure

A series of post-mineral porphyry dykes and small dyke-like masses lie in a northeasterly trending zone that approximately commences at, and widens to the northeast from, the top of the ridge. In this zone, porphyry commonly occurs as a series of connected en echelon pinching dykes. The most prominent series of dykes trend north-northeasterly to northeasterly and dip moderately to steeply to the northwest. A less prominent series of dykes trend northerly to north-northwesterly and dip moderately to steeply to the west.

In the southern, far eastern and far northern portions of the map-area are large massive bodies of porphyry from which dykes project inwards towards the center of the area. The main massive body of porphyry to the south occurs as an east-west elongated, lense-like body that is slightly concave to the north. Attitudes of dykes emanating from these large masses conform to those for dykes within the central portion of the region.

All dykes and masses are coarsely jointed and weakly fractured. Dykes show transverse and conformable, longitudinal joint sets. In DDH's, dykes are sheared locally in zones up to one foot wide, especially near or at contacts.

Lithologic Variations

The predominant phase of grey to pink post-mineral porphyry is named on the basis of color of albite phenocrysts. Various colors of phenocrysts can be found in the same dyke. Gradations across dykes and masses of porphyry from predominantly pink to grey and pale-green albite are common. From thin sections, pink albites are, as a rule, less altered deuterically than are lighter-colored albites.

Two minor variations of post-mineral porphyry are recognized (Figure 6). They consist of an early fine-grained pink phase and a late (?), dark-pink phase (Plate 9). The early phase occurs as dykes towards the bottom of DDH's 2 and 3 and has been intruded by dykes of grey to pink porphyry. It shows more dispersed phenocrysts of feldspar and quartz in a pinkish-red, fine-grained granular goundmass. The dark-pink phase is very similar to the predominant phase of porphyry, but its albite phenocrysts are a very dark pinkish-red and are very fresh in thin section.

Occurring locally, within the eastern portion of the large body of porphyry to the south, are small areas showing broken crystals of feldspars and quartz in a light green, aphanitic groundmass. Similar rocks near to granodiorite

contain abundant inclusions of granodiorite. Thin sections showed broken phenocrysts to be the same as phenocrysts in porphyry. The groundmass is brown colored and microcrystalline, similar to that in chilled contacts of porphyry dykes. These areas are likely sites of explosive sub-volcanic vents developed during emplacement of porphyry. They are referred to as "Intrusive Crystal Breccia" on Figure 5.

Deuteric Alteration and Mineralization

All post-mineral porphyry intrusions have been more or less uniformly deuterically altered and mineralized. Joint planes and fractures are commonly sparsely coated with chlorite and minor amounts of fluorite. Veinlets, up to ¼ inch wide, consisting of calcite, fluorite, quartz, hydromica and minor epidote are present locally. In places, pyrite, magnetite, sphalerite, galena and molybdenite, in order of decreasing abundance, occur along joints and fractures, and in veinlets; commonly with associated gangue minerals (types as noted above). Assays show that post-mineral porphyry dykes contain between .01 and .02 percent molybdenite.

Shear zones, commonly have minor associated chlorite, fluorite and sparse sulphide minerals.

Alteration of post-mineral porphyry has affected feldspar phenocrysts and the groundmass to a minor degree. Albite generally is altered slightly to plates of hydromica (?) with associated disseminated calcite and less commonly

fluorite or epidote. Alteration is often slightly more intense in the centers of albite crystals. Pink albite often shows less alteration than grey or pale-green albite. Pink envelopes are observed in places around more altered, lighter-colored cores. Sanidine phenocrysts are fresh, or are altered to minor disseminated calcite and very minor amounts of hydromica along cleavages. Fluorite, chlorite and/or epidote are present locally in sanidine. Biotite has been altered completely to pseudomorphs of chlorite plates commonly with rims and some interleaving of hydromica and with calcite and minor fluorite along cleavages. Pseudomorphs contain a disseminated opaque mineral which is probably leucoxene. Accessory sphene is commonly altered to leucoxene some of which has cores of magnetite. Embayments in quartz phenocrysts are commonly intensely altered. All secondary minerals can be found in embayments.

Disseminated in the groundmass are minor very fine-grained alteration products. Commonly in the groundmass are local, irregular patches of secondary minerals consisting of calcite, hydromica, fluorite, chlorite, epidote and/or quartz often with associated minor amounts of pyrite, magnetite, hematite, sphalerite and/or molybdenite. Pyrite often has an associated extremely high reflective, hexagonal, platy, opaque mineral that is possibly a telluride. Chlorite in patches occurs as concentrically zoned, spherulites and is probably prochlorite. Patches of secondary minerals are most abundant

where the groundmass is slightly coarser grained and, in these cases, patches often occur along a mid-line between phenocrysts with eutectic-like overgrowths.

Features indicating that alteration and mineralization of post-mineral porphyry was deuteric in origin are listed below:

1) Fairly uniform alteration of porphyry in conjunction with widespread joints and fractures, indicate that alteration is not related to fluid movement along joints, etc;

2) Complex assemblage of secondary silicate, oxide and sulphide minerals, occuring along fractures and disseminated, indicate lack of chemical or other gradients such as is often the case with hydrothermal environments;

3) Intense alteration and deposition of secondary minerals in embayments of quartz phenocrysts, indicate that embayments acted as traps to generated late fluids;

4) Patches of secondary minerals occurring along the mid-line between phenocrysts with eutectic-like overgrowths, indicate a late crystallization of secondary minerals in remaining open spaces.

LATE DYKES

Porphyritic, basic to intermediate fine-grained dykes of alkaline nature intrude all above rock types. Most common are composite basalt-trachyte dykes showing gradations, along and across strike, from more basic to more alkaline phases. Estimated modes of dykes are given in Table VII.

Structure

Dykes are widespread, but are particularly concentrated in a northeasterly-trending zone across the center of the map-area. The zone is coincident with the post-mineral porphyry dyke zone (described above). Dykes commonly trend north-northeasterly to northeasterly and dip 45° to 70° to the northwest. Not uncommon are dykes trending approximately northerly or transverse dykes trending northwesterly to west-northwesterly. They commonly curve and pinch-out along strike and locally occur as a series of en echelon dykes. Structures controlling intrusion of late dykes are similar to those that controlled intrusion of post-mineral porphyry dykes.

Alkaline Quartz Gabbro

Gabbro dykes occur in the south and far-northern portions of the map-area. They are not present in the dyke-zone described above. They are medium greyish-green and porphyritic and consist of fine to medium grained subhedral to euhedral phenocrysts of labradiorite (An_{60}) and augite in a fine grained (.1 - .5 mm), granophyric-like groundmass of alkali feldspar, biotite, chloritized augite, quartz and magnetite (Plate 11). Locally, augite and labradorite phenocrysts occur intergrown. Augite commonly contains a few

grains of fine-grained, euhedral apatite grains near edges of crystals. Labradorite phenocrysts commonly are aligned crudely. They show oscillatory zoning but no significant change in composition towards edges of crystals. They locally show replacement quartz and alkali feldspar in cores and commonly contain various amounts of evenly disseminated specks of alkali feldspar, except for outermost portions of crystals which are clear. Augite in the groundmass and some augite phenocrysts are deuterically altered in varying degrees to chlorite and minor amounts of biotite. Biotite also shows local alteration to chlorite.

Gabbro dykes have chilled contacts. A thin section from one contact was texturally and mineralogically similar to alkaline basalt dykes (described below).

Composite Alkaline Basalt - Augite Trachyte

Composite dykes are most common and contain fine to medium grained, subhedral to euhedral phenocrysts of slightly aligned feldspar lathes and augite in a fine grained, black or dark-green to buff-orange colored groundmass (Plate 12). Gradations from dark to orange colored groundmasses are common and occur over a few feet, both along and across dykes.

Darker phases are alkaline basalt and contain pale green phenocrysts of labradorite laths and augite in a fine grained (.01 - .08 mm) groundmass, consisting of sub-parallel

microlites of a more sodic plagioclase (greater than An_{20}), biotite plates, augite, interstitial "dirty" alkali feldspar and quartz and disseminated magnetite. Intermediate to buff-orange colored phases are augite trachyte. They contain phenocrysts of white to cream colored laths or elongated rhombs (up to 1 cm long) probably an alkali feldspar, in addition to augite and minor biotite. The groundmass is fine-grained (.05 - .2 mm) and granular and consists of laths and interstitial "dirty" alkali feldspar with biotite plates and disseminated magnetite. One thin section showed a minor interstitial feldspathoid mineral, probably sodalite. Another thin section showed phenocrysts of labradorite in a groundmass typical of augite trachyte. It probably represents a type of gradational phase. Texture of labradorite in basalt, and of augite in both phases is the same as that described for quartz gabbro. However, labradorite locally shows rims in hand specimens of basalt. In thin section, these rims consist of laminated, oscillatory zoned labradorite around cores showing replacement to alkali feldspar. In trachyte, feldspar phenocrysts show zoned rims, with negative relief and a negative optic angle of approximately 50° to 60°; probably high albite. Cores of these phenocrysts are polysynthetically twinned and have weak, positive relief and a very high, negative optic angle. Cores are probably a high temperature mixed Na-K-Ca feldspar.

Both basalt and trachyte phases are deuterically altered. Labradorite shows incipient carbonate and argillic alteration. Some cores of alkali feldspar phenocrysts are

weakly to moderately altered to hydromica (?) and minor calcite and are grey in hand specimen whereas rims remain fresh and pale colored. Augite in both phases, is altered in varying degrees to calcite, chlorite and biotite. Some biotite in groundmasses is altered to chlorite. Some calcite and clay minerals are common in the groundmass of trachyte.

Altered Latite

Dykes of latite mainly occur locally in the central dyke-zone and cut composite dykes. They typically show slaty cleavage parallel to attitudes and are uniformly textured. They consist of fine grained (.5 - 1.5 mm) phenocrysts of white, altered feldspar laths and minor biotite in a greenish-grey, fine grained (.5 - .2 mm) groundmass consisting of biotite plates, altered alkali feldspars, interstitial quartz and disseminated magnetite and minor pyrite (Plate 13). In thin section, feldspar phenocrysts have a form typical of plagioclase but are entirely altered to pseudomorphs of calcite and minor amounts of kaolinite. Alkali feldspars in the groundmass are"dirty" and show no twinning. They commonly are altered partly to kaolinite and calcite.

Minerals	Alkaline Quartz Gabbro(1)	Alkaline Basalt(3)*	Augite Trachyte(4)	Altered Latite(1)
--Phenocrysts--				
Labradorite (approximately An_{60})	50%	10-15%		
Alkali(?) Feldspar			10-20%	
Altered Plagioclase(?)				20%
Augite	15%	5-10%	5-10%	
Biotite			0-2%	1-2%
--Groundmass--				
Sodic Plagioclase >(An_{20})		40-60%		
Alkali Feldspar	25%	5-15%	60-70%	60%
Biotite	5%	5-10%	5-10%	10%
Augite and altered Augite	3%	1-3%	1-2%	
Quartz	5%	1-5%		5%
Feldspathoid (Sodalite ?)			0-3%	
--Accessories--				
Magnetite	2%	2-5 %	2-5 %	1-2%
Pyrite				½ %
Apatite	1%	1-2 %	1-2 %	

(1) - Number of thin sections studied

(*) - Includes chilled border of quartz gabbro dyke.

TABLE VII: Estimated Modes of Late Dykes.

Discussion

The complex mineralogy and replacement textures of composite dykes, as well as the presence of sudden transitions from one phase to another, indicate conditions of magmatic disequilibrium; probably due to assimilation of granitic crustal material by primary basaltic magma. Dykes are correlated with Coryell Intrusions on the basis of petrographic similarities.

DIFFERENTIATION OF ACID INTRUSIVE ROCKS

The quartz monzonite stock and younger quartz - albite - sanidine porphyries all have similar mineralogy, modal composition and textures. The composition of plagioclase is more sodic in porphyries than in the stock. These features clearly show that these intrusions are differentiates of a common parent magma. Also, these features suggest a close relationship in time and environment of emplacement of the stock and porphyries. Granodiorite is likely a related early differentiate as features listed below serve to indicate:

1. Nelson and Valhalla Intrusions commonly grade into one another in some regions (see "Regional Geology");

2. Large poikilitic grains of orthoclase in granodiorite are reminiscent of the presence of large sanidine phenocrysts in the stock and porphyries;

3. The composition of plagioclase in granodiorite is more calcic than in younger intrusions;

4. Lesser amount of potash feldspar in granodiorite than in younger intrusions;

5. The crystallization history of granodiorite includes early growth of andesine-oligoclase succeeded by probable ternary eutectic crystallization of potash feldspar-oligoclase-quartz as indicated by textural relationships between mineral phases. As discussed below under "Crystallization of Phenocrysts", both quartz monzonite and porphyries undoubtedly crystallized phenocrysts under ternary eutectic conditions involving two feldspars and quartz. Therefore, the history of crystallization of oldest to youngest intrusives indicates a genetic relationship, through differentiation, between granodiorite and younger intrusives;

6. Presence of the same accessory minerals in all intrusions.

LEVEL OF EMPLACEMENT OF THE STOCK AND PORPHYRIES

Crustal level of emplacement of the stock and porphyries must have been within a few thousand feet of the old erosion surface and, therefore, sub-volcanic. Porphyritic textures, fine-grained to aphanitic groundmasses and presence of sanidine phenocrysts in both the stock and porphyries and chilled porphyry contacts are features typical of acid

intrusive rocks that cooled rapidly in a sub-volcanic environment. Porphyries correlative to above (i.e. Shingle Creek and Ouellette Creek Porphyries; see "Regional Geology") have related contemporaneous pyroclastic rocks and, therefore, reached or came within a few thousand feet of the old erosion surface. Pyroclastic rocks are not known to be associated with the Tuzo Creek Porphyries but local explosive breccias occur within some bodies of post-mineral porphyry.

CRYSTALLIZATION OF PHENOCRYSTS

Phenocrysts of quartz, albite and sanidine in porphyries are believed to have crystallized contemporaneously under ternary eutectic conditions. Inclusions of albite and quartz in the outer portions of large sanidine phenocrysts and overgrowths of sanidine on albite phenocrysts indicate simultaneous crystallization of the two feldspars and quartz. Also, mode of porphyries is very similar to that of the Shingle Creek Porphyry (4) whose normative composition lies close to the experimentally determined (13) eutectic point in the calcium-free "granite system". Since only very minor amounts of calcium is present in plagioclase (i.e. An_5), crystallization of phenocrysts can be considered to have occured in the $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O system. In order for two feldspars to crystallize together with quartz in this system, water vapour pressures of 3,500 Kg/cm^2 or more, or

crustal depths of approximately 11 km's or more are required as determined experimentally by Tuttle and Bowen (1958). Conditions of crystallization must explain oscillatory zoning in large sanidine phenocrysts and rounded and embayed forms of quartz. Similar textures of phenocrysts, mode, composition of albite and optical properties of sanidine in the Shingle Creek Porphyry lead Bostock to the same conclusion with regards to crystallization of phenocrysts.

Quartz, oligoclase and sanidine phenocrysts in quartz monzonite are similar petrographically to phenocrysts in porphyry. Since plagioclase is more calcic (ie. An_{30} to An_{16}) in quartz monzonite, ternary eutectic crystallization of phenocrysts can occur at any reasonable depth because of the calcic nature of its source magma (13). However, because of the close similarity between phenocrysts in porphyry and quartz monzonite, depth of crystallization of phenocrysts in both rock types must have been essentially the same. Ternary eutectic crystallization in quartz monzonite continued in the high-level crustal environment because sanidine and oligoclase phenocrysts show continued growth (ie. intergrown with fine-grained quartz in outer portions of phenocrysts) and the groundmass shows a eutectic-like intergrowth between fine-grained quartz and sanidine.

CONCLUSION

From the foregoing, the writer concludes that granodiorite, quartz monzonite and porphyries are all related to the same parent magma and belong to a continuous differentiation series. Also, quartz monzonite and porphyries are related late differentiates derived from partially crystallized differentiated magma at depths of 11 Km's or more, and were emplaced in a sub-volcanic environment.

It is suggested that quartz monzonite and porphyry were derived from a deep pocket of partly crystallized magma related to the Nelson-Valhalla batholithic complex. Batholithic rocks are believed to be the earlier differentiates of the parent magma.

CHAPTER III

STRUCTURE

INTRODUCTION

The region has had a complex structural history involving shearing, fracturing, faulting, brecciation and fissuring. Successive structural deformation is recognized. Structures developed are defined according to their type and time of occurrence on Table I. Temporal aspects are based on crosscutting relationships between structural elements and intrusive rocks and between differently mineralized crosscutting structures.

Structures that controlled hydrothermal alteration and mineralization or are post-mineral and post-intrusive in age are grouped into three periods of deformation. These periods of deformation occurred after intrusion of the pre-mineral porphyry roof-sill. They are listed and defined below in Table VIII. Structural elements developed during Periods I to III deformation are discussed in subsequent sections.

Period-I:	Intense shearing, widespread fracturing and local brecciation; prior to intrusion of intra-mineral porphyry. Structural elements developed include foliation, shear and breccia zones and fractures.
Period-II:	Local shearing, brecciation and fracturing; between time of intrusion of intra- and post-mineral porphyry. Structural elements developed include shear and breccia zones and fractures.
Period-III:	Faulting; after intrusion of late dykes. Structural elements developed include shear and breccia zones.

TABLE VIII: Periods of Deformation

Apart from structures developed during Periods I to III deformation, other structures recognized include the following:

1) Regional shearing prior to intrusion of the quartz monzonite stock (discussed under "Regionally Sheared Granodiorite");
2) Successive development of subsidence fissures and conjugate tensional fissures (see "Discussion of Structures Controlling Emplacement of Intrusive Rocks").

REGIONALLY SHEARED GRANODIORITE

Granodiorite shows widespread intergranular shearing and brecciation, fracturing and hydrothermal alteration along the western and southern portions of the map-area (Figures 5 and 6). Inter-granular deformation is developed uniformly but has been relatively weak. The original hypidiomorphic texture of granodiorite is generally discernible. Deformation and alteration of granodiorite preceded emplacement of the quartz monzonite stock. This is based on observations in the mutual vicinity of exposures

of deformed and altered granodiorite and quartz monzonite since intrusive contacts were not found. That is, in the mutual vicinity of the two rock types quartz monzonite does not show intergranular shearing and is either fresh or contains a different alteration mineral assemblage.

Discussion

The contact between Valhalla and Nelson Intrusions, as mapped by Little (Figure 3), occurs outside but near the western and southern edges of the map-area. This was substantiated by cursory examination of exposures and stream float around the periphery of the map-area. Therefore, it is suggested that the presence of the sheared and altered region of granodiorite within the map-area was the result of intrusive effects of batholithic Valhalla Intrusions occurring outside of the map-area.

The sheared and altered region of granodiorite is further discussed in a later section entitled "Regionally Altered Granodiorite".

FAULTS

Numerous northeasterly-trending faults (Period-III) displace all rock types and occur in the central to northeastern portions of the region. They terminate towards th southwest and merge into only a few faults towards the

northeast. Draws traversing the northeastern slope of the ridge follow faults. Prominent faults, labelled Fault-A, -B, -C, and -D, dip approximately 55° to 80° to the northwest. Dip of faults was determined from attitudes of adjacent shears and intersections in drill holes.

Only Faults-B and -C and local small faults show good displacement of dykes. These faults are reverse, with dip-slip movement ranging from approximately 50 feet to 200 - 300 feet. Probably all or at least most faults have had reverse movement. Since all faults terminate towards the southwest, movement must have been rotational and, therefore, some strike-slip movement has occured. Fault-C shows increasing displacement towards the northwest which is in agreement with rotational movement.

Faults are discussed further in a following section, entitled "Shear and Breccia Zones", as a portion of Period-III zones of shearing and brecciation that are present.

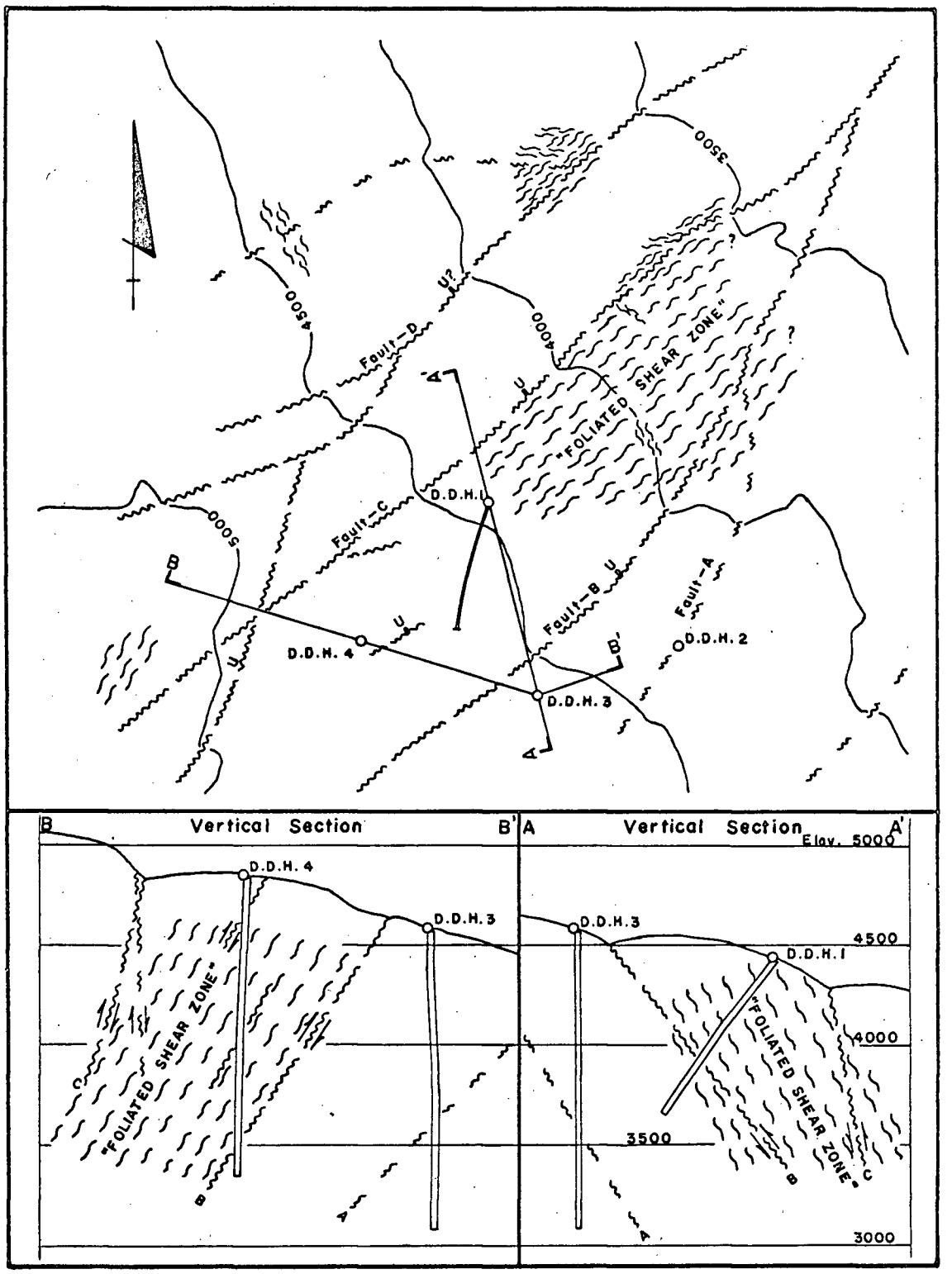
FOLIATION

Weak to intense secondary foliation grouped with Period-I deformation, occurs in zones in pre-mineral porphyry, quartz monzonite and locally in granodiorite. Foliation largely occurs in a zone between and conformable with younger Faults -B and -C (Figure 9). Within this zone (ie;"Foliated Shear Zone "), foliation occurs only locally at the surface towards

the southwest but is well developed at depth in DDH's 1 and 4 and on surface, at lower altitudes, towards the northeast.

Foliation is characterized by varying degrees of breaking and stretching-out of quartz and potash-feldspar phenocrysts and by shearing and granulation of groundmasses. It is commonly only intense in zones approximately 10 to 30 feet wide and is best developed in quartz monzonite. Intensely foliated zones show quartz phenocrysts strung-out into long (up to 1 or 2 inches), thin lenses and sanidine phenocrysts rotated, broken and strung-out to a few inches. Foliated rocks are laminated locally with augen of potash feldspar. Degree of foliation is more intense in DDH 1 than in DDH 4 and, in general, tends to increase towards the northeast.

Foliation commonly strikes northeasterly and dips 65° to 90° northwest, parallel with younger faults. Also present is a less common, cross foliation, trending northwesterly and generally dipping 80° to 90° northeast. Locally, rocks show complex foliation with two or more attitudes in the same outcrop. In DDH 4, foliation has angles to the core-axis ranging most frequently from 60° to 35°. In DDH 1, foliation is parallel in both porphyry and quartz monzonite and has angles to the core-axis ranging most frequently from 45° to 90°. Resolving core angles into dip angles with respect to each DDH, suggests that foliation at depth roughly is parallel to younger faults; though also, cross trends probably are present.



Foliation Trend (Defined and Inferred)

Note: For additional symbols see Figure 7 and 8

Scale: 1 Inch = 800 Feet

FIGURE 9: PERIOD -I FOLIATION AND THE "FOLIATED SHEAR ZONE"

Discussion

Forces causing Period - I foliation must have been compressional and, therefore, movement within the "foliated shear zone" was of reverse character. The indicated increase in degree of foliation towards the northeast is in harmony with rotational movement. Therefore, it is suggested that the "foliated shear zone" is due to confined, reverse shearing movement of a rotational character, similar to that of late faults, and can be expected to pinch-out or disipate towards the southwest. Compressional forces that caused development of foliation probably are related to regional tectonics. The conjugate system of foliation, though northwesterly-trending foliation only occurs locally, indicates either roughly north-south or east-west directed compressional forces. The same tectonics that caused Period - I foliation were likely regenerated to produce Period - III faults.

SHEAR AND BRECCIA ZONES

Shear and breccia zones, commonly up to ten feet wide, occur locally throughout the faulted region. They commonly strike northeasterly and dip 55° to 90° to the northwest. Some strike northerly or rarely west-northwesterly to northwesterly and generally dip steeply to the west or north,

respectively. Shear and breccia zones commonly show intergranular shearing and/or angular to rounded rock fragments up to a few inches accross. These zones are altered and mineralized to varying degrees. Three periods of shearing and brecciation are recognized. These periods are listed and defined above under "Introduction".

Period-I shear and breccia zones occur widespread throughout the faulted region in pre-mineral porphyry and older intrusive rocks. In DDH's, zones are fairly evenly distributed, commonly range from 6 inches to 5 feet wide and have cumulative widths of up to approximately 60 feet in each drill hole. In addition, in DDH's 2 and 3, two zones 118 and 105 feet wide respectively are present (shown on Figure 8). These were also sites of very intense fracturing. Some zones intersected along drill holes within the "foliated shear zone" contain rotated fragments of foliated quartz monzonite or consist of highly granulated or comminuted rock. Also, there are local small breccias in DDH 4, ranging from ½" to 3½" wide and in "intensely fractured zones 1 to 8" (Figure 7; discussed later) ranging from ½" to 1 foot wide. These small breccias consist of angular rock fragments within a fairly sharp walled zone and are largely healed by secondary gangue minerals and hematite and magnetite.

Period-II shear and breccia zones occur mainly in DDH's 3 and 4 where younger faults are intersected, generally below depths of 900 feet. These zones cut intra-mineral

porphyry dykes and previously altered and mineralized rock. They commonly range from a few inches to 5 feet in width. One zone, near the bottom of DDH 4 is 20 feet wide. Cumulative widths of Period-II shear and breccia zones are approximately 50 feet in DDH 4 and 20 feet in DDH 3. In addition, local small breccias up to 1 inch wide commonly cut intramineral porphyry. They contain angular porphyry fragments healed with gouge and gangue and sulphide minerals. Core angles of Period-II zones show that they predominantly dip steeply. Probably, zones are largely parallel to northeasterly-trending and steeply northwest-dipping earlier Period-I foliation and shear and breccia zones and later Period-III faults. See Plate 30.

Period-III shear and breccia zones cut all rock types. They define Period-III faults but also occur widespread as minor zones of deformation. They consist of largely unaltered and unmineralized sheared and brecciated rock, gouge and dark mylonite. These zones commonly are up to 2 feet wide, and rarely are up to 20 feet wide.

FRACTURING

Introduction

Period-I fracturing occurs in pre-mineral porphyry and older intrusive rocks and is present in varying intensity throughout the hydrothermal alteration halo (Figures 7 and 8). These fractures are the most important structural element present for they largely have controlled the main phase of hydrothermal alteration, quartz veining and mineralization (Phase-I: discussed later).

Period-II fracturing probably occurred widespread but generally is not very intense. It is only important in the region along the western ends of Faults-A and -B where Period-II fractures partly controlled Phase-II hydrothermal alteration and mineralization (discussed later) in intramineral porphyry and older intrusive rocks. Quartz veining, related to Phase-I hydrothermal activity, is termed Period-I quartz veins in this section for purposes of simplicity because quartz veins occur along Period-I fractures.

Azimuth and dip frequency diagrams and frequencies of Period-I fractures and quartz veins are shown on Figures 10, 11 and 12 and are given in Table IX, respectively. Attitudes of Period-II fractures, along with those of Period-I fractures, were only obtained from the region along and past the western end of Fault-B. Figures 10 and 11 include both

Period-I and -II fractures from this region.

Period-I Fracturing and Quartz Veining

Weak fracturing, present in unaltered peripheral rocks, rapidly increases in intensity where rocks begin to show hydrothermal alteration and mineralization. Fracturing continues to increase in intensity towards "intensely fractured zones"; shown on accompanying maps (Figures 7 and 8). These zones include, "peripheral zones" occurring in the northern and western portions of the alteration halo and a "central quartz vein stockwork zone". The "stockwork zone" located near the centre of the alteration halo, trends northeasterly and is conformable with the central to western portions of a larger "central zone" of most intense wallrock alteration and with a region of molybdenite mineralization. The "stockwork zone" is spatially centered above, within and adjacent to the upper portion of the northeasterly-trending "foliated shear zone" (discussed previously). The limits of the "stockwork zone" have only been shown at and near surface on maps, whereas at depth, its limits are roughly conformable to the outline shown for the "central zone" of wallrock alteration.

The "central quartz vein stockwork zone" is characterized by widespread intense fracturing, as are "peripheral zones", and by widespread quartz vein stockworks in its upper

part, particularly in the granodiorite capping, and by local, confined zones of quartz vein stockworks with sparse intervening quartz veins at depth (Table IX). Within the "stockwork zone", foliated rocks are as intensely fractured as others; however, opening along fractures, as evidenced from the distribution of quartz veins, has been more prevalent in the upper part of the zone (ie, in the part particularly lying above the "foliated shear zone ").

"Intensely fractured zones" are structurally characterized by opening and/or shearing along some of the fractures. Fracture fillings, consisting of gangue, sulphide and/or oxide minerals, predominantly are less than 1/16" wide throughout the whole of the alteration halo. However, within "peripheral zones", openings up to ¼" occur along many of the fractures and in the "central quartz vein stockwork zone", openings commonly 1/8" to 1/2" wide have controlled quartz veining. Also, some of the fracture openings in fracture zone-8 have controlled quartz veins. Quartz veining only locally occurs outside of "intensely fractured zones". Shearing along fractures, consisting of minor granulation, shearing and/or brecciation, is more prevalent in "intensely fractures zones" but commonly only occurs along a small percentage of the fractures. (See Plates 16 and 24 to 28).

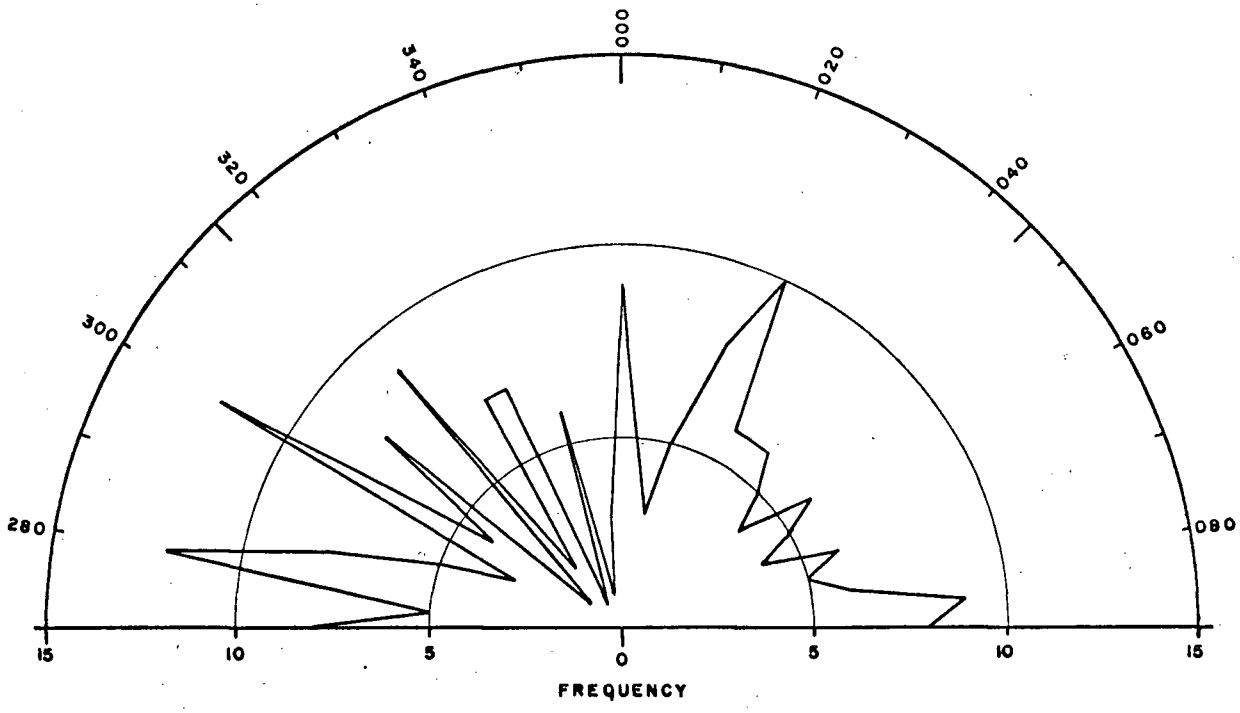
The average range of frequency of fractures plus quartz veins in "intensely fractured zones" is from 4 to 11 per foot. Refer to Table IX for details of frequencies of

	CENTRAL QUARTZ VEIN STOCKWORK ZONE		INTENSELY FRACTURED ZONES 1-8	
	Largely Within the Granodiorite Capping	At Depth (DDH's 1-4)	Zones 1-7	Zone 8
FRACTURE FREQUENCY	Range: 2-9/ft Average: 3-4/ft	No systematic counting of all fractures; however fracturing intensity is comparable to that of Intensely Fractured Zones 1-7. Limits are roughly the same as the "Central Zone" of alteration	Commonly 5-10 prominent fr's/ft. Numerous hair-line fr's (up to 10/inch)	Commonly 6-12/ft
QUARTZ VEIN FREQUENCY	Fairly evenly distributed veins Range: 1-15/ft Average: 3-5/ft	Veins occur in local well defined zones present to depths of 650-870' (DDH 2 bottomed in a veined zone). Zones range from 2-195' wide (commonly 20-50' wide). Veins occur sparsely between zones. Range: 1-13/ft)Within Average: 1-3½/ft) zones	Only local quartz veins	Commonly 1-4/ft; locally up to 20/ft across 1-2 ft
WIDTH OF VEINS	Range: 1/16" - 1" Average: 1/8" - 1/2"		Range: 1/16 - 3/8" Average: 1/8 - 1/4"	
AVERAGE FRACTURE AND QUARTZ VEIN FREQUENCY	7-8/ft	Estimated 4-8/ft throughout zone at depth. Some hairline fractures	5-10 prominent frs/ft; numerous hair-line fractures	8-11/ft
SOURCE OF DATA	Counting and estimation of number of veins in outcrops. PSH's 1-3, 8, 12 and 13	DDH's 1-4	Counting of fractures in some outcrops. PSH 11	Counting of fractures in some outcrops. PSH 9

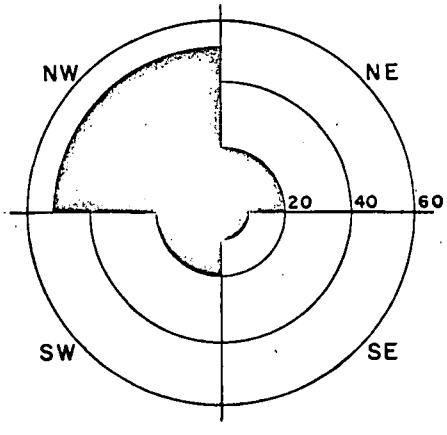
NOTE: Background fracture frequency is approximately 2-5/ft

TABLE IX: Period -I Mineralized * - Fracture and Quartz Vein Frequency in Intensely Fractures Zones 1 to 8 and in the Central Quartz Vein Stockwork Zone

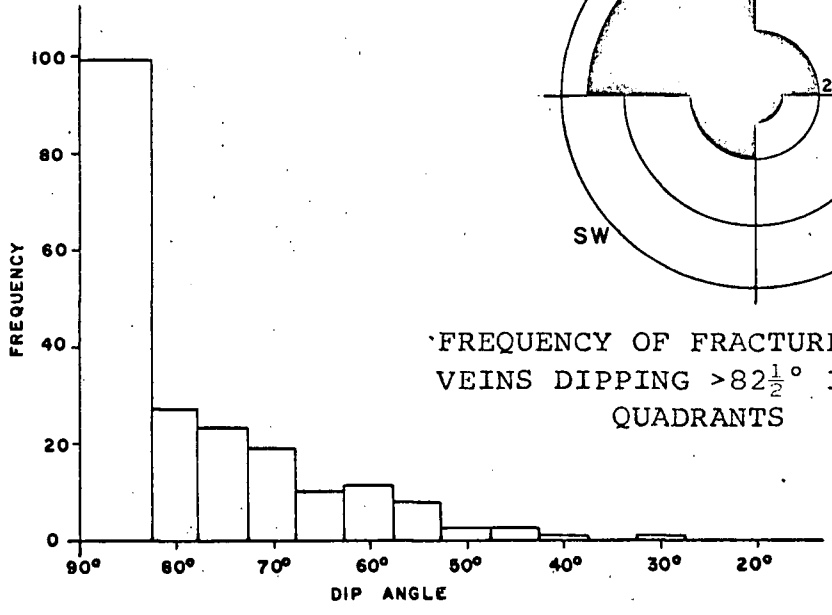
* Includes all fractures containing secondary gangue, sulphide and/or oxide minerals due to Phase -I hydrothermal alteration and mineralization



AZIMUTH FREQUENCY DIAGRAM
(All fractures and quartz veins; 208 observations)



FREQUENCY OF FRACTURES AND QUARTZ VEINS DIPPING >82½° IN VARIOUS QUADRANTS



HISTOGRAM OF DIP FREQUENCY
(All fractures and quartz veins; 208 observations)

FIGURE 10: PERIOD -I FRACTURE AND QUARTZ VEIN AZIMUTH AND DIP FREQUENCY DIAGRAMS

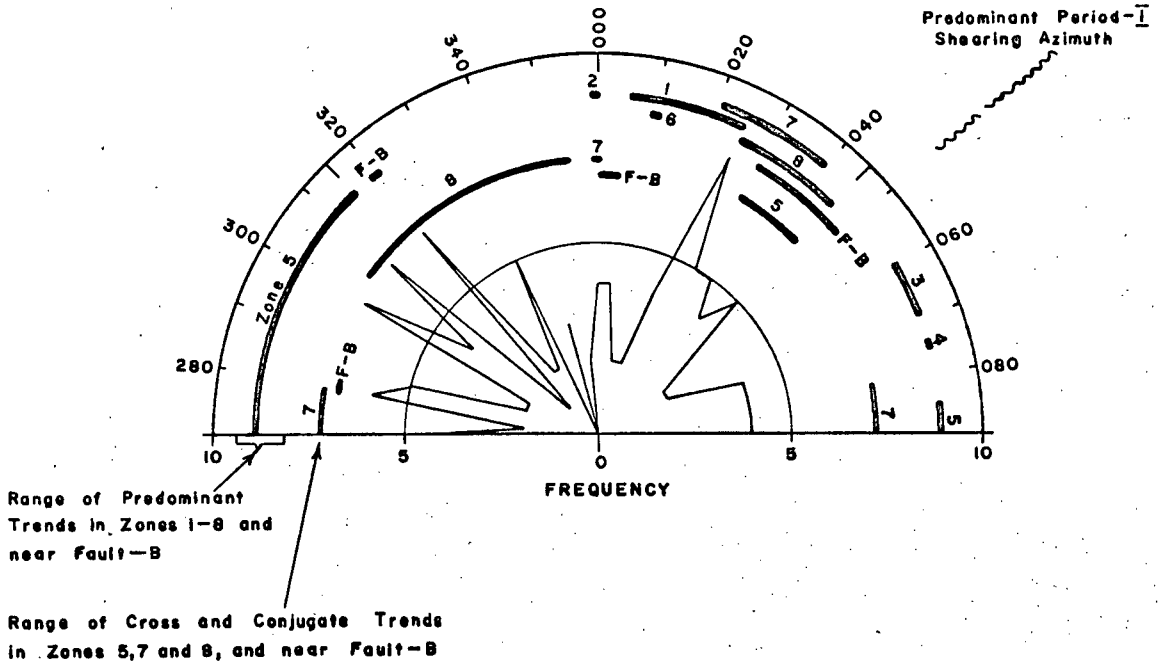
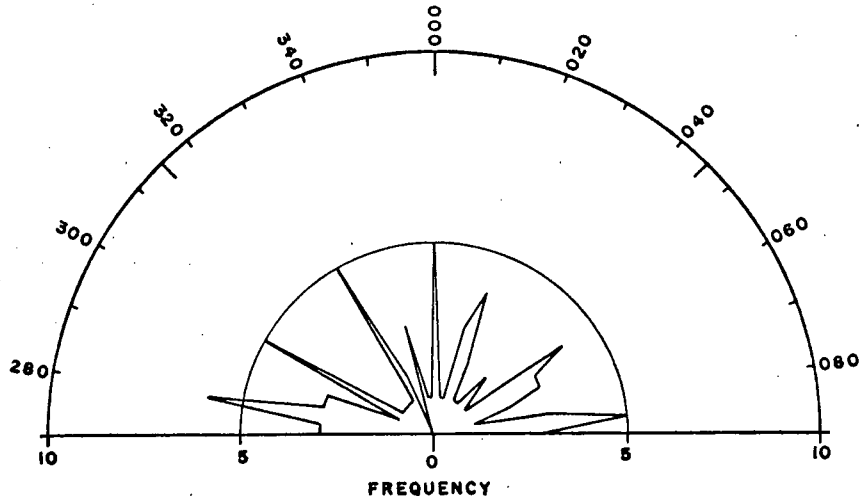
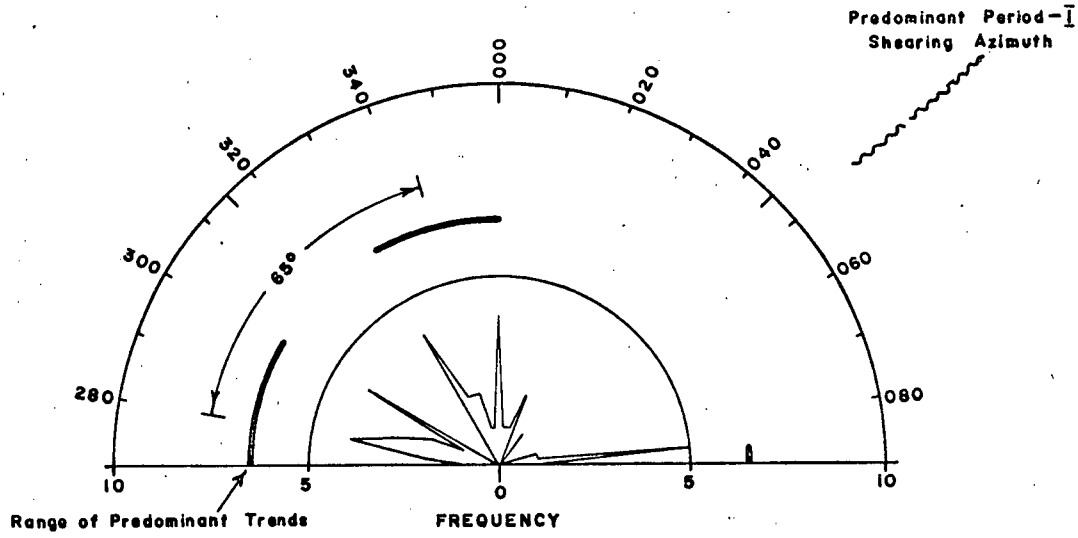


FIGURE 11: PERIOD -I AZIMUTH FREQUENCY DIAGRAM FOR ALL FRACTURES AND QUARTZ VEINS PERIPHERAL TO THE CENTRAL QUARTZ VEIN STOCKWORK ZONE

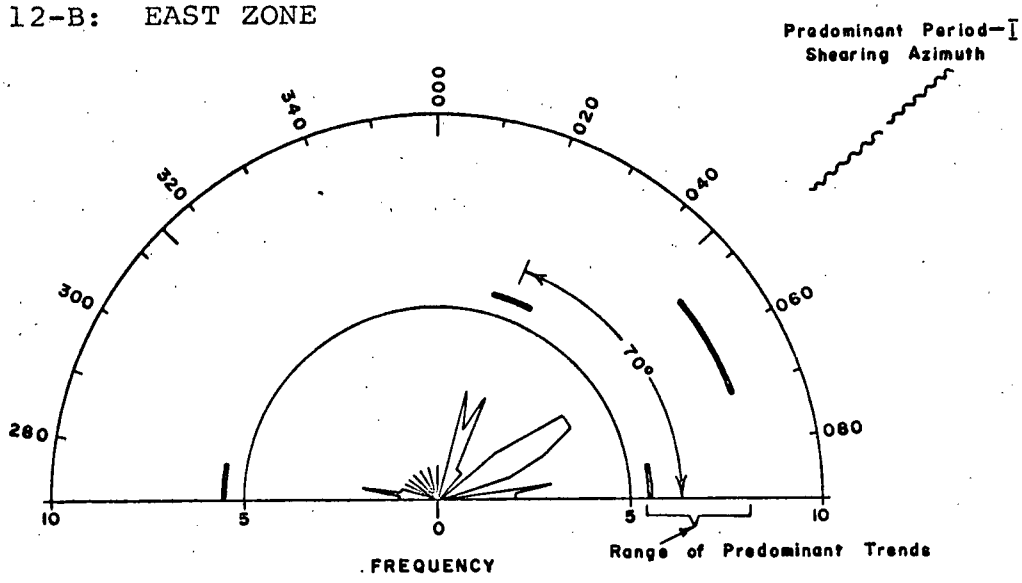
(Showing range of azimuths in Intensely Fractured Zones 1 to 8 and in region of Fault - B.)



12-A: INCLUDES BOTH EAST AND WEST ZONES



12-B: EAST ZONE



12-C: WEST ZONE

FIGURE 12 (A, B AND C): PERIOD -I QUARTZ VEIN AND FRACTURE AZIMUTH FREQUENCY DIAGRAMS FOR THE CENTRAL QUARTZ VEIN STOCKWORK ZONE

fractures and quartz veins, and for width of quartz veins. Background fracture frequency within the alteration halo is estimated to average 2-5 fractures per foot. However, fracture frequency at the bottoms of DDH's below the "stockwork zone" is often similar to that of "intensely fractured zones" but fractures commonly lack opening.

Figures 10, 11 and 12 show azimuth frequencies of fractures and quartz veins. Figure 10 also illustrates that fractures and veins predominantly have dips greater than 70° and, therefore, azimuth frequency diagrams are very useful. From figure 10, which shows azimuth frequencies for all fractures and quartz veins, no regular trend pattern is obvious, except that a great range of predominant trends is present. However, trend regularities become apparent when each of "intensely fractured zones" is considered independently. That is, fracture zones -1 and -3 to -6 (Figure 11) each show a single range of predominant fracture trends that together, roughly radiate about the western end of the "central quartz vein stockwork zone". Also, fracture zone -5 shows a less predominant trend parallel to the predominant shearing azimuth. Fracture zones -7 and -8 and the region along the western end of Fault-B, all show predominant fracture and quartz vein trends from north-northeast to northeast, approximately parallel to the shearing azimuth. They also show either cross trends, as in zone-8, or conjugate trends about the shearing azimuth, as in zone-7 and near the end of Fault-B. Similarly,

in the "central quartz vein stockwork zone" both east and west zones (Figures 7 and 12) show simple conjugate trends of fractures and quartz veins with respect to the shearing azimuth. The west zone also shows a northeasterly-trending fracture and quartz vein set parallel to the shearing azimuth.

Discussion

A genetic relationship between Period-I shearing, that produced the wide "foliated shear zone" and narrow shear and breccia zones, and Period-I fracturing is strongly indicated because of the following features:

1) Close spatial relationship between the region characterized by complex fracturing, including longitudinal (fracture and quartz vien trends that are roughly parallel to the shearing azimuth), conjugate and cross trends, and the "foliated shear zone" ;

2) Relationship between orientations of logitudinal, conjugate and cross fractures and quartz veins and the predominant shearing azimuth;

3) Presence of radial fractures to the southwest, west and northwest of the western end of the "central quartz vein stockwork zone";

4) Shearing nature of some fractures;

5) Most extensive opening occurs along fractures above and to the north of the "foliated shear zone".

Radial fractures are believed to represent a horsetailing feature caused by disipation or pinching-out of the "foliated shear zone". These fractures probably were in part the result of development of strain in the rocks due to reverse rotational movement within the "foliated shear zone". Complex

fracturing, spatially associated with the "foliated shear zone", probably was the result of wrenching effects due to shear movements.

Shearing and fracturing must be related to regional tectonics since these structural features do not indicate any genetic relationship with doming, subsidence or cooling of the stock and/or roof-sill apart from close spatial relationship with the quartz monzonite stock. This spatial relationship probably is inherent. That is, emplacement of the stock probably was controlled in part by a northeasterly-trending shear zone located in the same region affected by Periods -I to -III deformation.

Period-II Fracturing

As stated above under "Introduction", attitudes of Period-II fractures were only obtained from the region along and past the western end of Fault-B. They were obtained from intra-mineral porphyry and adjacent granodiorite. Orientations of both Periods-I and -II fractures are similar and were discussed together in the preceeding section.

Period-II fracturing is developed best along the western ends of Faults-B and -C, and is most intense in regions affected by Period-II shear and breccia zones in DDH's 3 and 4. The frequency of fractures in these regions, attributed to Period-II fracturing, is estimated at 2-4 per foot. Minor

Period-II fracturing also occurs widespread since local fractures and veinlets carrying abundant calcite and fluorite (particularly associated with Phase-II alteration and mineralization) occur in most DDH's, and fractures off-setting Period -I fractures and quartz veins are common along all drill holes. Quartz veins only locally occur along Period-II fractures.

DISCUSSION OF STRUCTURES CONTROLLING EMPLACEMENT OF INTRUSIVE ROCKS

Structures controlling emplacement of various sequential intrusive rocks are believed to have been related, at different times, to either regional or local tectonics.

Structures controlling emplacement of the quartz monzonite stock are not known. It was suggested under "Discussion" of "Period-I Fracturing and Quartz Veining" that emplacement of the stock was controlled in part by a northeasterly-trending shear zone. All Valhalla stocks, intruding Nelson granodiorite and older rocks in the Beaverdell area (Figure 3), occur along or close to the West Kettle River fault zone. It appears then, that the emplacement of stocks was controlled by this fault zone and/or by subsidiary faults. This tends to substantiate the above suggestion.

Control for emplacement of the pre-mineral porphyry roof-sill along the top and eastern flanks of the quartz monzonite stock undoubtedly was due to subsidence of part of the stock. Simultaneous subsidence of the stock and intrusion

of the roof-sill explain primary structural features of pre-mineral porphyry indicating forceful intrusion and absence of evidence for collapse of the granodiorite roof with subsidence of the stock. Gently to moderately dipping dykes and sills of intra-mineral porphyry must have been localized along tensional fissures due to further subsidence of the stock and roof-sill.

Structures controlling emplacement of post-mineral porphyry and late dykes were of a different nature than those controlling pre- and intra-mineral porphyry. Intrusions of post-mineral porphyry and late dykes have similar trends and both consist of single dykes and series of connected en echelon dykes. Predominant dyke trends are northeasterly. Less predominant dyke trends are northerly-to west-northwesterly. The presence of en echelon dykes and conjugate dyke-trends strongly indicate that controlling structures were genetically related to regional tensional forces. Similar structures were developed at two different times because intrusions of post-mineral porphyry preceded that of late dykes. Post-mineral porphyry dykes are most abundant and have conjugate dyke orientations with a least angle of difference of approximately 55°. The bisector of this angle trends roughly N15°E. Therefore regional tensional forces producing conjugate tensional fissures must have been roughly directed W15 N and E15°S.

STRUCTURAL INTERPRETATION

It has already been shown that fracturing was genetically related to shearing. Also it has been concluded that emplacement of pre- and intra-mineral porphyry was controlled by gently to moderately dipping tensional fissures produced by two successive periods of subsidence of the stock.

A simple regional interpretation of other structures, including foliation, shear and breccia zones and faults developed during Periods-I to -III deformation and tensional fissures that controlled emplacement of post-mineral porphyry and late dykes, is possible through application of a combined stress and strain ellipsoid diagram (Figure 13) because of the following structural features:

1) Development of Periods-1 to III deformation and tensional fissures have involved regeneration in type and orientation of structures;

2) Conjugate structures developed for all types of deformation, though both sets of these structures were not equally developed;

3) Compressional forces that caused shearing and faulting were probably directed at right angles to tensional forces that produced fissures.

The third structural feature, listed above, should be clarified. It is known that approximately W15°N and E 15°S directed tensional forces produced conjugate fissures because the bisector of the least conjugate angle should be at right angles to the directions of tensional forces. The orientation

of compressional forces that caused shearing and faulting is not known. However, the estimated average least angle of difference between conjugate shear structures is 70° for which the bisector, and therefore the direction of compressional forces, roughly trends at right angles to the direction of tensional forces.

Figure 13 shows the directions of maximum compressional and tensional forces plus the trends and conjugate angles of structures in relation to a combined stress and strain ellipsoid. Compressional and tensional forces, related in the above described manner and as shown on Figure 13, can be resolved from left or right lateral rotational forces, respectively directed roughly northeast-southwest or north-west -southeast. They are believed to have been resolved from right lateral rotational forces because of the following listed features:

1) N30°W and S30°E directed right lateral rotational forces are approximately parallel to the trend of the West Kettle River fault zone which undoubtedly was active prior to and after emplacement of the quartz monzonite stock;

2) A genetic relationship between structures and the West Kettle River fault zone is strongly indicated because all structures terminate or become less well developed towards the southwest away from the fault zone.

Therefore, it is suggested that both compressional and tensional structures are genetically related to periodic right lateral rotational deformation produced by right lateral strike-slip movements along the West Kettle River fault zone. Periods of

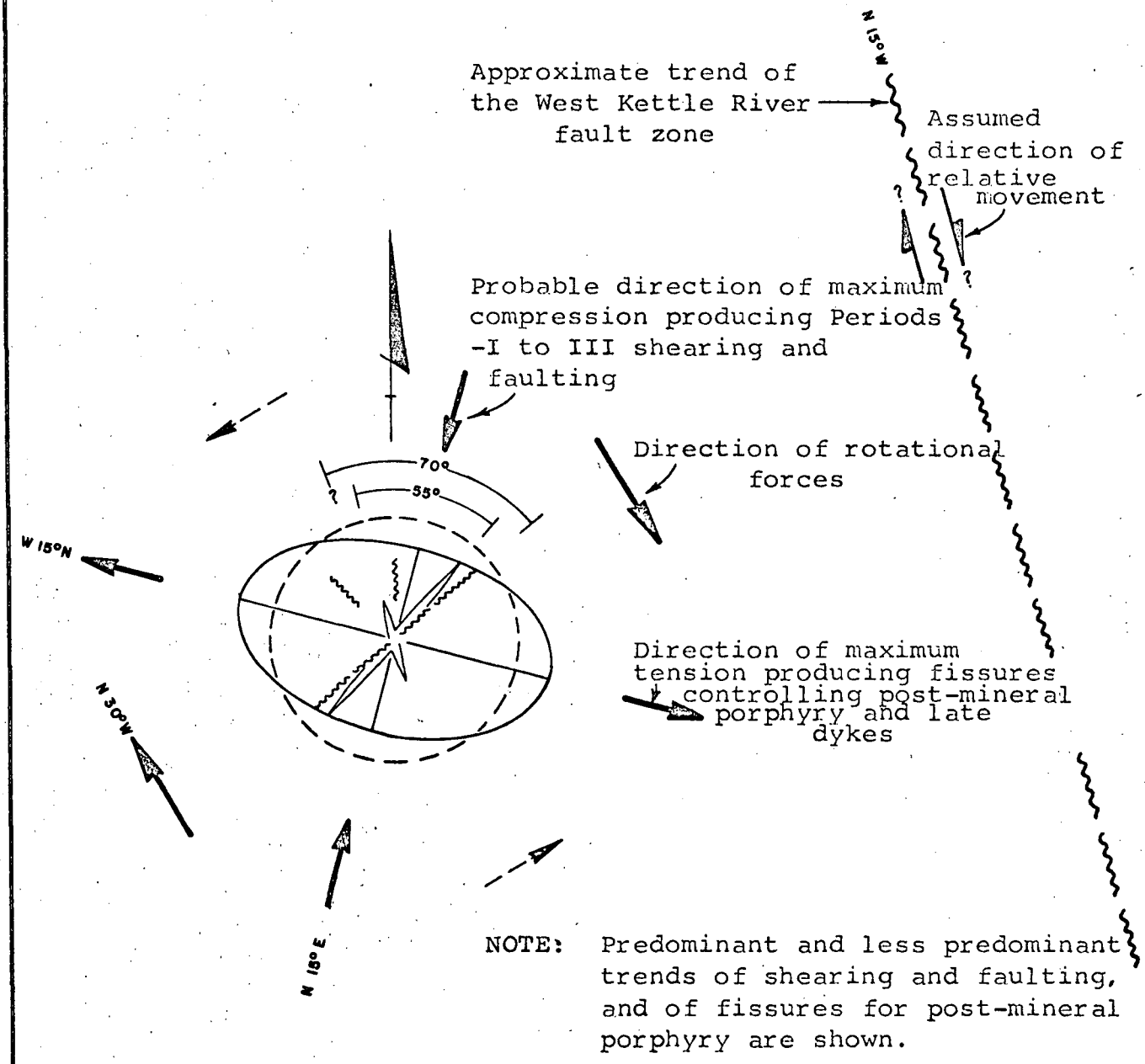


FIGURE 13: COMBINED STRESS AND STRAIN ELLIPSOID DIAGRAM FOR STRUCTURES OF REGIONAL ORIGIN

rotational deformation must have been resolved, at different times, into compressional or tensional forces.

CHAPTER IV

HYDROTHERMAL ALTERATION AND MINERALIZATION

DEFINITIONS AND FIGURES

The terms slight, weak, moderate, intense and very intense are used in subsequent sections in order to quantify degrees of wallrock alteration. These terms are defined in Table X as ranges of percent replacement of one or more host minerals by a particular type of wallrock alteration product or products. Most of the significant types of wallrock alteration including argillization, K-feldspathization, albitization, and propylitization, are quantified by this method. In some cases, above terms are used to quantify degree of replacement of host minerals by two or more types of wallrock alteration. Degrees of silicification are classified differently. That is, weak and intense degrees of silicification are classified, respectively, as approximately up to 10% increase in total quartz content in rocks and from 50% to 90% total quartz content in rocks. Degrees of wallrock alteration were mapped in the field but precise ranges reported were determined from thin sections.

	Degree of Wallrock Alteration				
	Slight	Weak	Moderate	Intense	Very Intense
Approximate Range of percent Replacement of Host Mineral or Minerals	10%	10-25%	26-50%	51-90%	90%

TABLE X: Definition of Degrees of Wallrock Alteration

Periods-I and -II structures each controlled a phase (ie. Phase-I and -II, respectively) of wallrock alteration and mineralization. Rocks affected by Phase-I wallrock alteration and mineralization occur widespread and include granodiorite, the quartz monzonite stock and pre-mineral porphyry roof-sill and related dykes. Phase-II wallrock alteration and mineralization locally affected above rocks and intra-mineral porphyry.

Phase-I altered and mineralized rocks occur much more widespread than Phase-II, and also are much more important because of associated molybdenite. Features of Phase-I, including "periperal shell" and "central zone" of wallrock alteration, fields of hematite-magnetite-pyrite, pyrite and molybdenite mineralization and zones of quartz vein stockworks, are shown on Figures 7 and 8. Also shown on these figures are simplified geology, peripheral intensely fractured zones and young faults. Shown along DDH's on sections (Figure 8) are zones of intense silicification and zones of moderate to intense K-feldspathization.

Also shown along DDH's are zones assaying .04% or more MoS_2 and zones heavily mineralized with hematite and magnetite.

Features of both Phase-I and -II alteration and mineralization are grouped together on Figures 7 and 8 because features of Phase-II do not alter, in any significant way, the features of Phase-I. Regions characterized by Phase-II alteration and mineralization are labelled on figures (ie: near bottoms of DDH's 3 and 4). Intra-mineral porphyry is not shown on Figures 7 and 8, even though it was affected by Phase-II, because it is desirable to show only the geological setting during Phase-I.

Both on surface and along DDH's, features of wall-rock alteration and mineralization appear very discontinuous. However, features are actually quite continuous within host rocks since they are not projected across dykes and/or sills younger than phases of alteration and mineralization.

INTRODUCTORY SUMMARY

A region of sheared, argillized and feldspathized granodiorite fringes the map-area on the west and south (Figures 5 and 6). The age of deformation and alteration of granodiorite within this region is believed to be pre-quartz monzonite. Two younger phases (ie: Phase-I and Phase-II) of hydrothermal alteration and mineralization have occurred intermittent to emplacement of porphyries. These phases are

discussed below.

Partly overlapping the altered and sheared region in granodiorite is a large zoned wallrock alteration and mineralization halo centered within the quartz monzonite stock (Phase-I hydrothermal alteration and mineralization; see Figures 7 and 8). Alteration and mineralization has affected the porphyry roof-sill and older rocks, and was controlled by Period-I structures. The alteration halo has an indicated ellipsoidal shape that is elongated in a northeast -southwest direction. It is up to 9,400 feet long and up to 6,900 feet wide. Wallrock alteration typically is pervasive, though commonly is more intense along fractures and within local shear and breccia zones. Alteration consists mainly of argillization, K-feldspathization, silicification, albitization and propylitization. The alteration halo is sub-divided into a "peripheral shell" of weak to moderate degrees of wallrock alteration, and a "central zone" of intense to very intense degrees of wallrock alteration. The "central zone" is located centrally within the alteration halo. It trends northeasterly and is shaped like an elongate ellipsoid with its shorter axis vertical or tilted slightly to the southeast. At the surface, the zone is 5,400 feet long and up to 1,700 feet wide. It widens at depth to an indicated maximum width of up to 2,300 feet, and has a vertical range of up to 1,050 feet from the present level of erosion. On surface within the "peripheral shell", the degree of argillization increases towards the

"central zone". The "central zone" is divided into an upper and lower part; based on distribution of secondary hydromica, potash feldspar and quartz. These parts are named respectively, "quartz-hydromica sub-zone" and "quartz-potash feldspar sub-zone". Quartz veining occurs widespread in the upper sub-zone but occurs only in local zones in the lower sub-zone. The "quartz-potash feldspar sub-zone" grades downwards into unsilicified rocks of the "peripheral shell".

Sulphide and/or oxide minerals (Phase-I) occur throughout, and largely confined to, the alteration halo. They mainly include specular hematite, magnetite, pyrite, molybdenite and minor Zn, Pb, Cu sulphides in decreasing order of abundance. These minerals occur predominantly along fractures. Lesser amounts occur in quartz veins, along shear and breccia zones and disseminated. Distribution of sulphide (pyrite) and oxide (hematite-magnetite-pyrite) mineral assemblages is zonally arranged and spatially related to wallrock alteration zones. That is, pyrite occurs in a region having the form of a southeasterly-tilted mushroom with its stem occurring throughout much of the "central zone" and cap spreading laterally from below the upper part of the "central zone". At the present level of erosion, the pyrite cap largely is limited to the southern portion of the "peripheral shell" and adjoining "central zone". The pyrite region is referred to as the "sulphide field". Associated hematite, magnetite and pyrite occur laterally about the pyrite stem, below the pyrite

cap. This region is referred to as the "oxide field". Molybdenite occurs mainly within that portion of the "central zone" lying within the "sulphide field". This region is referred to as the "molybdenite zone".

Phase-II alteration and mineralization includes 1) pervasive alteration and relatively sparse mineralization that is confined largely to intra-mineral porphyry sills and dykes and 2) zones of intense argillization and silicification controlled by Period-II structures, particularly at depth near bottoms of DDH's 3 and 4. Wallrock alteration products consist mainly of sericite, quartz and calcite. Open space fillings of Fe, Zn, Pb, Cu and Mo sulphides, in decreasing order of abundance, and calcite, fluorite, sericite and quartz are associated with Phase-II wallrock alteration.

REGIONALLY ALTERED GRANODIORITE

The sheared and altered region of granodiorite, along the western and southern portions of the map-area, has been briefly discussed under "Regionally Sheared Granodiorite" (Figures 5 and 6). Within this region, wallrock alteration is laterally zoned inwards and rocks show corresponding gradual megascopic changes. Altered and intergranular-sheared granitic rock generally retains a poor megascopic medium-grained hypidiomorphic texture. In outermost regions, rocks consist of dark-pink feldspar and lesser amounts of grey-to pale-green feldspar

and quartz. Inwardly, with respect to the edge of the map-area, rocks contain increasing amounts of altered pale-green feldspar. Innermost regions commonly do not contain any dark-pink K-feldspar. A completely altered mafic mineral is present throughout the region and commonly appears to have had a prismatic habit typical of hornblende. Three alteration zones are recognized. They consist of an outer pink zone, a wide mixed zone and a narrow, inner green zone.

One thin section was studied from each characteristic alteration zone. All showed a remnant medium-grained hypidiomorphic texture, similar to granodiorite, with pronounced intergranular shearing and brecciation. Grey feldspar consists of stress twinned and bent laths of secondary albite (approx. An_6) completely replacing primary plagioclase laths in all zones. However, mixed and green zones show some remnants of primary, zoned, more calcic plagioclase. Pink feldspar is secondary K-feldspar with a negative optic angle of approximately 60° and birefringence of .005 or less. It occurs abundantly in the pink zone as pseudomorphs after primary interstitial and poikilitic grains of orthoclase. K-feldspar undoubtedly has replaced some plagioclase because of its abundance in the pink zone. It is not as abundant in the mixed zone; and in the green zone, K-feldspar is entirely primary light colored orthoclase. Hydromica and calcite replace all feldspars in increasing degrees towards the inner edge of the region. The prismatic mafic mineral is altered completely to

chlorite and epidote with increasing amounts of associated hydromica inwardly. Minor disseminated accessory magnetite and apatite occur throughout the region.

Epidote, mauve and green fluorite, calcite, chlorite and locally cassiterite (recognized in one thin section) commonly occur along fractures and shears.

Granodiorite showing similar alteration as described above, though commonly less intense, also occurs locally in the far northeastern portion of the map-area. These altered areas of granodiorite lie outside the younger Phase-I alteration halo.

Discussion

It was suggested previously (see "Regionally Sheared Granodiorite) that the sheared and altered region of granodiorite was due to intrusive effects of batholithic Valhalla Intrusions occurring outside the map-area to the west and south.

The zonal distribution of alteration products within the sheared and altered region suggests that either the movement of hydrothermal fluids was directed laterally inwards from the west and south because more highly feldspathized rocks should lie closer to the source magma; or inwardly decreasing temperature gradients from the west and south were present because feldspathization normally requires higher temperatures than argillization (6,7,9). Either situation is consistent with the above suggestion.

It can only be concluded that both the shearing and hydrothermal alteration of granodiorite along the west and south periphery of the map-area are related genetically to a batholithic mass of Valhalla Intrusions that occurs outside the western and southern limits of the map-area.

PHASE-I: MAIN PHASE OF ALTERATION AND MINERALIZATION

Relationship Between Structure, Wallrock Alteration and Mineralization

Period-I fractures and local shear and breccia zones have controlled Phase-I alteration and mineralization. Fractures have been the main avenues of fluid movement throughout the alteration halo for the following reasons:

1) Absence of fissures and only local shear and breccia zones;
2) Fractures controlled quartz veining;
3) Fractures largely controlled deposition of sulphide and oxide minerals and associated gangue minerals;
4) Selvages of more intense wallrock alteration commonly occur along fractures;
5) The outer edge of the alteration halo closely corresponds to the outward limits of significant fracturing;

Hydrothermal fluids must have ascended in the region of the "central zone" of wallrock alteration for the following reasons:

1) The "central zone" is by far the largest region present of intense wallrock alteration;

2) Intensity of fracturing within a large portion of the "central zone" of wallrock alteration is similar to that in peripheral "intensely fractured zones" though these commonly are regions of only weak to moderate wallrock alterations;

3) The "foliated shear zone" (Figure 9) largely is spatially coincident with the "central zone" of alteration.

It is concluded that the "foliated shear zone" directed hydrothermal fluids upwards. Fluids must have spread upwards and outwards, predominantly along fractures, from the upper part of the "foliated shear zone".

Surface Oxidized Zone

Altered and mineralized rocks exposed within the alteration halo are gossaned. Varying degrees of oxidation and hydration of pyrite, hematite and magnetite to yellow to reddish-brown limonite is present to depths of 15 to 25 feet. Pyrite has been most attacked by surface weathering. Assays for MoS_2 and total Mo from PSH's 1 to 3 indicate partial oxidation and removal of molybdenite also to depths of 15 to 25 feet. Molybdenite occurs sparsely in outcrops. Surface samples nearly always assay .01 or .02% MoS_2. In PSH's, molybdenite becomes more abundant within a few feet of the surface and MoS_2 assays commonly average .03 to .06% (Table XIV). Therefore, significant solution and removal of molybdenite must have occurred to depths of a few feet. Ferri molybdite rarely was recognized. Some thin sections show a yellow mineral that may

be jarosite and locally a yellow, hexagonal, platy mineral that may be wulfenite. Black manganese stain (Probably pyrolusite) commonly occurs in minor amounts coating fractures in all acid rock types and coating quartz phenocrysts in porphyry throughout the "peripheral shell" of wallrock alteration. Locally it occurs abundantly coating outcrops of granodiorite near PSH5. Manganese staining is lacking within the "central zone" except for its presence in post-mineral porphyry.

Wallrock Alteration

Apart from wallrock alteration, fracture fillings (except for quartz veins) also are discussed in subsequent sections.

Peripheral Shell

The "peripheral shell" is a thick shell characterized by weak to moderate degrees of wallrock alteration. It completely surrounds a northeasterly-trending "central zone" of more intense wallrock alteration. The lateral outer limits of the shell show close correspondence to the distribution of pre-mineral porphyry. Within the shell, wallrock alteration in exposed rocks largely is of a different type from that at depth towards the bottoms of DDH's. The "peripheral shell" at depth is discussed under the section "Central Zone".

Altered rocks include granodiorite, quartz monzonite and pre-mineral porphyry. Argillization and propylitization are the predominant types of wallrock alteration. Exposed rocks typically are pervasively bleached white. They commonly show primary textures. The white bleaching is due to weak to moderate argillization of plagioclase in all rock types and of the groundmass in the porphyry roof-sill. Primary pink potash feldspars commonly are fresh or slightly to weakly argillized in all rocks. Mafic minerals commonly are completely argillized and/or chloritized. They generally have a pale green color.

In the outer portions of the "peripheral shell" (up to approximately 500 feet from the edge of the alteration halo), all rocks commonly are pale-greenish colored and grade outwards into fresh rocks and inwards into white, argillized rocks. The pale green coloration is due to the color of the argillic mineral replacing plagioclases along with more predominant chlorite alteration of biotite in porphyry and quartz monzonite, and chlorite and epidote alteration of hornblende in granodiorite.

Degree of argillization of both feldspars and mafics increases towards the "central zone" and towards small local zones within the "peripheral shell" characterized by moderate to locally intense argillization of feldspars and mafics. The largest of these zones roughly is centered about "intensely fractured zone-7".

Many of the fractures within the "peripheral shell" have light colored alteration selvages. Some selvages are not recognized easily in hand specimen. Selvages are more common nearer to the "central zone", particularly in the southern portion of "intensely fractured zone-5", where they commonly are pale-green. Selvages commonly have irregular outer edges and range up to a total width of ½ inch. They show rapidly increasing degrees of argillization of feldspars towards fractures. Local shear and breccia zones, to the north of the "central zone", are intensely argillized and silicified across widths ranging from a few feet to 10 feet. Also, smaller sheared and granulated zones, up to a few inches wide, show similar alteration. They occur more widespread, associated with fracturing, and likely grade into fractures.

In thin section, remnant plagioclase in porphyry and quartz monzonite nearly always is clouded a "dirty" yellowish-brown; probably due to oxidation of contained iron. In all rocks, plagioclase is altered to fairly evenly dispersed very fine hydromica that occurs as plates and mattes. Plates of hydromica commonly occur along cleavages. The more calcic plagioclase in granodiorite occasionally shows more alteration in cores or certain composition zones. Weakly argillized K-feldspars in all rocktypes are altered particularly along cleavages and discontinuous fractures to hydromica. Biotite in porphyry and quartz monzonite shows secondary plates of green pleochroic chlorite that is replaced in increasing degrees

to plates of hydromica towards the "central zone". Hornblende in granodiorite is altered completely to plates of chlorite with disseminated epidote in the outer portion of the shell, and shows increasing degrees of replacement to hydromica, without epidote, towards the "central zone". Pyrite occurs disseminated in granodiorite particularly associated with secondary minerals that replace hornblende within the "sulphide field". Hematite, magnetite and pyrite similarly occur in granodiorite within the "oxide field". The groundmass in porphyry commonly contains minor disseminated, very small, microscopic patches of associated magnetite, pyrite, chlorite, hydromica, quartz and/or calcite. Also, the porphyry groundmass shows evenly disseminated hydromica partially replacing alkali feldspar. Disseminated secondary magnetite in porphyry commonly occurs as complete to partial replacement of some of the accessory and/or secondary pyrite within the "oxide field". All hydromica has similar optical properties, even in more intensely argillized fracture selvages. It shows colorless to very pale-green pleochroism, good cleavage, low positive relief and moderate birefringence, and has a very low optic angle (less than 5°).

Fracture Fillings

Fractures commonly contain variable amounts of hematite, magnetite and/or pyrite with associated quartz and hydromica. Also, epidote and chlorite occur along fractures particularly in outer portions of the "peripheral shell". Minor fluorite and calcite occur locally along fractures. Fracture

fillings commonly are up to 1/16" wide, though many of the fillings are up to ¼ " wide in "intensely fractured zones-1 to -8".

Central Zone

The "central zone" is characterized by intense to very intense degrees of wallrock alteration. Types of alteration mainly include argillization, potash-feldspathization, albitization and silicification. The "central zone" can be classified as a "siliceous" region. Its upper part is weakly silicified pervasively and contains widespread stockwork quartz veining and numerous zones of intense silicification whereas its lower part only contains zones of weak or intense silicification and zones of stockwork quartz veining. Within the "central zone", regions of pervasive argillization or potash-feldspathization of primary feldspars respectively, largely occur conformable with the upper and lower parts of the "siliceous" region. Therefore, the "central zone" is subdivided into an upper "quartz-hydromica sub-zone" and a lower "quartz-potashfeldspar sub-zone". The upper sub-zone largely is limited to the granodiorite capping and underlying porphyry roof-sill. It occurs throughout the exposed portion of the "central zone" to depths of up to 400 feet and overlaps the lower "quartz-potash feldspar sub-zone" by as much as 150 feet. The "quartz-potash feldspar sub-zone" only occurs at depth. It was intersected in all DDH's and occurs to depths of up to

1050 feet. It mainly occurs within the quartz monzonite stock but is also present in pre-mineral porphyry dykes in DDH 1 and sills in DDH 2.

Upper Quartz-Hydromica Sub-Zone

Within the "quartz-hydromica sub-zone" both granodiorite and porphyry commonly show remnant primary textures. However, because alteration is often so intense, remnants of less altered rock must be found in the field in order to identify the rock type with assurance.

Granodiorite commonly has a mottled medium-grained texture and shows white to pale-green intense argillic alteration of feldspars and hornblende (Plate 14). Intensely silicified granodiorite is grey in color and commonly has a slightly mottled texture due to remnants of argillized feldspars and hornblende. Locally, either the clay mineral replacing plagioclase or remnant plagioclase is a bright pinkish color due to "clouding" by iron oxides. This "clouding" is probably due to weathering since it does not occur in drill holes, except locally within the near surface oxidized zone.

Porphyry typically shows white argillized feldspars in a grey siliceous groundmass. Intensely silicified zones contain less amounts of white argillized feldspar.

Remnant primary pink orthoclase is present locally in granodiorite and large pink to white, argillized sanidine phenocrysts commonly are recognizable in porphyry. All feldspars are completely altered in more intensely argillized

and/or silicified rock. Mafic minerals generally are indistinct.

The "quartz-hydromica sub-zone" is characterized by pervasive, intense to very intense replacement of plagioclases and mafics and moderate to intense replacement of potash feldspars by mattes, plates and cleavage controlled seams of hydromica. The optical properties of hydromica and replacement textures are the same as in the "peripheral shell"; though hydromica commonly is slightly more coarse grained in the "central zone". Some secondary quartz (up to 10%) commonly is associated with hydromica that replaces feldspars. Remnant unaltered albite in porphyry is always "clouded" in thin section to a yellowish-brown; identically to that in the "peripheral shell". Altered biotite in porphyry often has minor associated calcite, pyrite and specks of leucoxene (?). Altered hornblende in granodiorite commonly has minor associated pyrite, quartz and leucoxene (?).

Many fractures have alteration selvages up to a total width of 1 inch (plate 14). Selvages consist of more intensely argillized feldspars with variable amounts of associated secondary quartz. Some of the quartz veins, discussed later in detail, laterally grade into intensely altered wallrocks.

Zones of intense silicification are common. They contain 50 to 90% fine grained, granular quartz with associated remnants of argillized feldspars and mafics. They range greatly in widths from narrow fracture controlled zones to 145 feet

wide. Zones are commonly 10 to 60 feet wide (zones 5 feet wide, or more, are shown on Figure 8).

Pyrite and minor fluorite occur disseminated throughout the "quartz-hydromica sub-zone". Also, minor molybdenite, sphalerite and galena occur disseminated but appear largely limited to the "sulphide field" of mineralization.

Overlap of Sub-Zones

Core from DDH's 3 and 4 showed that the "quartz-hydromica sub-zone" overlaps the "quartz-potash feldspar sub-zone" by approximately 150 feet. Rocks in the overlap include porphyry and quartz monzonite. They show secondary pinkish-red potash feldspar occurring as fillings or selvages along some fractures, as pervasive partial replacement of the plagioclases and as irregular, pervasive aplitic patches with associated quartz replacing groundmasses and some feldspar phenocrysts. K-feldspathized rocks show later crosscutting fractures with hydromica and quartz selvages and show some pervasive argillization and silicification of primary feldspars and secondary potash-feldspars (Plate 15). Also, minor calcite alteration of sanidines commonly occurs in the overlap region. Hydromica alteration shows rapid transition into predominantly potash-feldspar alteration at the base of the "quartz-hydromica sub-zone". Overlap of sub-zones also is present on surface near the eastern end of the "central zone". Here, K-feldspathization, argillization and silicification are all present in the quartz monzonite stock. Secondary K-feldspar

only occurs locally elsewhere in the "quartz-hydromica sub-zone" and always shows varying degrees of replacement to quartz and hydromica. Secondary albite, characteristic of the "quartz-potash feldspar sub-zone", was recognized in only one thin section of granodiorite from the "quartz hydromica sub-zone".

Fracture Fillings

Fracture fillings within the "quartz-hydromica sub-zone" are up to 1/16" wide. They commonly consist of associated hydromica-quartz-pyrite in decreasing order of abundance, generally with minor amounts of associated calcite and/or fluorite (mauve and green). Minor molybdenite, sphalerite and galena also occur along fractures with these gangue minerals but are largely confined to the "sulphide field" of mineralization. Hematite and magnetite occur along fractures with the same gangue minerals in the eastern portion and along part of the northwestern fringe of the "quartz-hydromica sub-zone" within the "oxide field" of mineralization.

Lower Quartz-Potash Feldspar Sub-Zone

Within the "quartz-potash feldspar sub-zone", quartz monzonite generally is recognizable since it commonly shows primary textural features including feldspar and quartz phenocrysts, green plates of altered biotite and a fine-grained, commonly pinkish-red granular groundmass; or shows foliation in varying degrees. Occasionally, pre-mineral porphyry is difficult to distinguish from quartz monzonite, especially where both rock types are foliated. However, porphyry can generally

be distinguished since its groundmass is typically aphanitic, light colored and siliceous-appearing.

Wallrock alteration of quartz monzonite is characterized by weak to commonly moderate to intense degrees of replacement of plagioclase phenocrysts by pinkish-red potash feldspar. Degree of K-feldspathization tends to decrease with depth. Remaining plagioclase nearly always consists of microscopically "dirty", clouded yellowish-brown pseudomorphs of secondary albite with variable but commonly minor amounts of associated plates and mattes of hydromica (optical properties same as in "quartz-hydromica sub-zone"). In hand specimen, albitized and argillized plagioclase is white to pale-green colored and often subhedral. It amounts to 10 to 35% of the rock depending upon the degree of K-feldspathization. In thin section, secondary K-feldspar occurs as clear to very "dirty" or black-clouded, fine-to medium-grained, irregular grains and aggregates replacing plagioclase phenocrysts inwards from edges of crystals. Secondary K-feldspar is similar optically to primary sanidine. That is, it has a negative optic angle of approximately 30° to 50° and a birefringence lower than that characteristic of orthoclase. Hairline fractures are commonly filled with segmented quartz and potash feldspar with minor associated pyrite. Potash feldspar is preferentially deposited where fractures cross plagioclase phenocrysts. Also, these fractures commonly have microscopic, discontinuous selvages of secondary K-feldspar that are confined to

phenocrysts of plagioclase. Other fractures, recognizable in hand specimen and locally common in zones of lesser degrees of K-feldspthization, consist of zones up to 1/4" wide of very fine-grained secondary K-feldspar that replace plagioclase phenocrysts and the groundmass. In more intensely K-feldspthized zones, secondary K-feldspar also locally occurs pervasively in the groundmass in varying degrees probably due to recrystallization of primary sanidine and replacement of quartz. Locally, aplitic patches and irregular veinlets consisting of secondary K-feldspar and quartz occur in the groundmass. Primary phenocrysts of sanidine commonly appear fresh and pinkish-red colored. In thin section, these show local recrystallization to fine-grained secondary potash feldspar. Locally, sanidine phenocrysts are partly to completely cream colored due to argillization. In thin section, primary and secondary potash feldspar (including K-feldspar in the groundmass) commonly are slightly altered to hydromica and calcite. Biotite commonly is completely altered to pseudomorphous chlorite with associated hydromica and minor amounts of associated calcite, specks of leucoxene (?) and fluorite. In the "foliated shear zone", deformed quartz phenocrysts are recrystallized, in varying degrees, to fine-grained aggregates.

Alteration of pre-mineral porphyry does not differ from that of quartz monzonite except that remnant albite is either primary or simply recrystallized. In hand specimen, secondary K-feldspar is commonly cream to pale-pink colored

and generally was not recognized as secondary K-feldspar in the field. Moderate to intense zones of K-feldspathization, shown on sections, were defined by the degree of pinkish-red coloration in diamond drill core. However, the degree of K-feldspathization in pre-mineral porphyry is comparable to that in quartz monzonite, and K-feldspathized zones should be considered to extend across porphyry within the "quartz-potash feldspar sub-zone".

Silicification within the "quartz-potash feldspar sub-zone" occurs widespread. It is only locally intense in zones commonly a few inches to ten feet wide (zones 5 feet wide, or more, are shown on sections) that mainly occur along shear and breccia zones. Also, wide shear and breccia zones in DDH's 2 and 3 are intensely silicified and contain abundant disseminated magnetite and lesser amounts of hematite and pyrite. Intense zones of silicification contain 50 to 90% fine grained granular quartz. These zones commonly contain irregular remnants of argillized feldspar with lesser amounts of associated secondary K-feldspar. Silicification and quartz veining appear related since 1) highly broken less-silicified rock remnants within intensely silicified zones are often riddled with quartz veinlets and 2) quartz veined zones often occur adjacent to intensely silicified zones. Some quartz veins have associated seams of K-feldspar within and/or along edges of veins and locally as alteration selvages. Thinner quartz veins locally grade into fractures mainly filled with K-feldspar.

Weak silicification is fairly common but also tends to occur in narrow zones or as irregular patches mixed with K-feldspathized rocks. Secondary quartz in these zones or patches occurs as variable amounts of fine-grained granular grains in the groundmass of porphyry and quartz monzonite in amounts greater than that present in primary groundmasses (probably amounts up to 10% increase in total quartz content of rocks).

Altered rocks contain disseminated pyrite and very minor magnetite or molybdenite within the "sulphide field" of mineralization. Magnetite occurs more abundantly disseminated in the "oxide field" of mineralization.

Below the "quartz-potash feldspar sub-zone", within the"peripheral shell", degree of K-feldspathization is only locally moderate and is commonly slight to weak. Here, secondary K-feldspar occurs mainly along fractures and in narrow zones. Plagioclase in quartz monzonite nearly always is completely albitized with minor associated hydromica and calcite; identical to remnant plagioclase within the "quartz-potash feldspar sub-zone". Alteration of biotite, and clay and carbonate alteration of primary and secondary K-feldspar are of similar degrees and types as within the "quartz-potash feldspar sub-zone", though chlorite appears to be replacing biotite in higher degrees at greater depths.

Fracture Fillings

Apart from quartz veins along some fractures and K-feldspar along microscopic hairline to local megascopic fractures, the remainder of fractures have fillings up to 1/16"

wide. Fillings consist of quartz, hydromica, chlorite, calcite and fluorite (mauve and green) in decreasing order of abundance. Also present are traces of apatite and local kaolinite or K-feldspar. Commonly, fractures do not have recognizable selvages in hand specimen apart from pervasively K-feldspathized and/or silicified wallrocks. Some fractures show secondary K-feldspar selvages in thin section similar to those along hairline fractures. Pyrite, molybdenite and very minor amounts of sphalerite and galena occur mainly along above described fractures. Except for pyrite, the other sulphides largely are limited to the "sulphide field" of mineralization. Hematite and magnetite also occur along these fractures, mainly within the "oxide field" of mineralization. Chlorite generally is relatively more abundant along fractures within the "peripheral shell" below the "quartz-potash feldspar sub-zone".

Above described mineralized fractures rarely show crosscutting relationships with quartz veins or with fractures having fillings or selvages of secondary K-feldspar. Therefore, wallrock alteration, quartz veining and mineralization are indicated to have occurred contemporaneously. Local paragenetic irregularities are present within the "quartz-potash feldspar sub-zone". They are listed below.

1) K-feldspar rarely was observed along fractures cutting intensely silicified zones.

2) Zones of quartz veins cut intensely silicified and hematite and magnetite mineralized rocks along DDH's 2 and 3 within the "oxide field".

2) Continued -
Both the silicified and mineralized rocks and later quartz veins were associated with K-feldspathization of wallrocks (see Type-1A veins in section on "Quartz Veining").

3) Molybdenite bearing fractures only rarely cut quartz veins.

The above paragenetic variations are not significant. They undoubtedly are due to local re-fracturing of rocks during Phase-I hydrothermal activity since younger fracture fillings tend to show a regeneration of the same hydrothermal conditions at any given site. These features are further discussed in the subsequent section.

Quartz Veining

The distribution and frequency of quartz veins was discussed in the section "Period-I Fracturing and Quartz Veining".

Apart from true quartz veins, two types of pseudo quartz veinlets are present that are not included with quartz vein frequencies or quartz veined zones shown on Figures 7 and 8. One type is relatively common and consists of lensoid to discontinuous ptygmatic seams, up to approximately 2 inches long and generally less than 1/4" wide, consisting of fine granular quartz. They only occur in pre-mineral porphyry and quartz monzonite and are due to deformation and recrystallization of original quartz phenocrysts caused by the shear movements that produced Period-I foliation. The other type of

pseudo quartz veinlets consists of irregular and discontinuous fine-grained quartz veinlets riddling less-silicified rock remnants within and adjacent to intensely silicified zones (especially associated with silicified Period-I shear and breccia zones shown alond DDH's 2 and 3).

True quartz veining is relatively unimportant since most molybdenite occurs along fractures. However, some important genetic conclusions can be drawn from their study. Quartz veins commonly range in width from 1/8" to 1/2" and consist predominantly of fine-grained granular quartz. Three different types of veins occur within the "central quartz vein stockwork zone". One type of vein is similar to those occurring in "fracture zone-8". Distribution of types of veins is related spatially to the "oxide" or "sulphide" fields of mineralization, and to sub-zones of wallrock alteration within the "central zone". Types of veins are listed and discussed in Table XI. (See plates 16, 17 and 23 to 25).

1) Banded Straight-Walled Veins Within the "Oxide Fields"

a) Sharp walled; some containing seams of potash feldspar and discontinuous seams of magnetite and/or disseminated pyrite; probably fairly continuous; located in DDH's 2 and 3; see Plate 16 and 24 (right). These veins have local very thin selvages of secondary potash feldspar and cut silicified zones with associated riddling of quartz veinlets, abundant disseminated magnetite and K-feldspathization and argillization of rock remnants. They also commonly cut magnetite and hematite mineralized zones where oxides occur mainly along fractures.

b) Sharp walled veins in "Fracture Zone-8"; West Portion: veins contain abundant magnetite that occurs along borders and disseminated; commonly associated K-feldspar veinlets and selvages along quartz veins; associated fractures filled with abundant magnetite and lesser amounts of quartz and K-feldspar also with local K-feldspar selvages; minor associated pyrite; see Plate 24 and 25. East Portion: veins contain hematite and magnetite and have selvages of hydromica, probably with some secondary quartz; numerous fractures with hematite and magnetite, also with some selvages of hydromica; minor associated pyrite.

2) Continuous to Discontinuous Massive Veins within the "Sulphide Field"

Variable from sharp to gradational walls and from continuous (up to 10 feet on surface) to discontinuous (6 inches to a few feet on surface); most common type of veins within the "sulphide field"; some are pale-pinkish colored; commonly branching; rarely show crosscutting relationships with other quartz veins or mineralized fractures commonly contain minor amounts of disseminated calcite, fluorite (colorless to green), hydromica, pyrite and traces of molybdenite; veins contain hematite and magnetite within those parts of the western fringe of the "central quartz vein stockwork zone" that lie within the "oxide field"; see Plate 17.

3) Banded Discontinuous Veins within the "sulphide field"

a) Vuggy and often somewhat irregular; relatively common and occur only within the "quartz-hydromica sub-zone" (particularly within the granodiorite capping); contain seams of quartz of different grain size with inwardly projecting

euhedral medium-grained quartz crystals along portions of the center of veins; contain seams of hydromica and minor molybdenite; contain minor disseminated pyrite.

b) Irregular; Contain good seams of molybdenite and abundant seams of hydromica with lesser amounts of associated calcite, fluorite (colorless to green) and pyrite; locally occur mixed with Type-2 veins; particularly occur in zones of significant molybdenite mineralization (ie: greater than .03% MoS_2) that are spatially associated with quartz veined zones; veins of this type and Type-2 only occur locally within the "oxide field"; See Plate 23.

TABLE XI - Classification of Quartz Veins.

Conclusions

Three important genetic conclusions with respect to Phase-I wallrock alteration and mineralization can be drawn from the above classification of quartz veins and data given in the section "Wallrock Alteration". These conclusions are listed below:

1) Near surface environment during hydrothermal activity (indicated by the presence of vuggy veins which are limited to the "upper quartz-hydromica sub-zone")

2) Wallrock alteration, quartz veining and mineralization were contemporaneous. This is indicated by the following features:

a) Veins respectively contain oxide and/or sulphide minerals depending on the field of mineralization in which they occur;

b) Some veins grade into altered wall-rocks and others have alteration selvages of the same type as pervasive wallrock alteration;

c) Spatial association of more widespread quartz vein stockworks with the relatively more intensely silicified "quartz-hydromica sub-zone", and of zones of quartz vein stockworks with intensely silicified zones within the "quartz-potash feldspar sub-zone";

d) Mineralized fractures and quartz veins only rarely show crosscutting relationships;

e) Mineralogy of fracture fillings and quartz veins are similar.

3) Local re-fracturing of rocks during hydrothermal activity with regeneration of earlier type of hydrothermal conditions. (Indicated by paragenetic irregularities as given above under Type-1A and -2 quartz veins and as listed under "Fracture Fillings" in the section "Lower Quartz-Potash Feldspar Sub-Zone").

Mineralization

Secondary sulphide and/or oxide minerals occur throughout, and largely confined to, the alteration halo. These minerals include hematite (predominantly specularite), magnetite, pyrite, molybdenite, brown to black sphalerite, galena, chalcopyrite, a platy telluride (?) and cassiterite in decreasing order of abundance. They are predominantly fine-grained and occur mainly along fractures. Lesser amounts occur disseminated or coating rock fragments in shear and breccia zones, as partial healing of narrow breccias, in quartz veins and disseminated in altered wallrocks. Associated gangue minerals along fractures and in quartz veins were discussed, respectively, in sections entitled "Fracture Fillings" (in sections dealing with the "Peripheral Shell" and "Central Zone") and "Quartz Veining". Alteration selvages along fractures were discussed in the section entitled "Wallrock Alteration". See Plates 14, 15 and 18 to 28.

"Oxide" and "Sulphide" fields of mineralization are defined on the basis of distribution of hematite, magnetite and pyrite, and are characterized respectively, by the assemblage hematite-magnetite-pyrite and by pyrite. Boundaries between fields are shown on Figures 7 and 8. The shape of fields and their relationship to wallrock alteration was discussed under "Introductory Summary". Relatively sharp boundaries occur between fields. Only locally does minor amounts of magnetite (less than 1/2% across a few 10's of feet) occur within the "sulphide field". Fields of mineralization are discussed in detail in following sections.

Oxide Field (Hematite-magnetite-pyrite)

"Intensely fractured zones-1 to -8" and zones along DDH's 2 and 3 (including sheared and brecciated zones and highly fractured zones) are heavily mineralized with hematite and magnetite. These zones contain between 3 to 5% oxide minerals (locally contain up to 10% oxide minerals across widths up to 30 feet or more) and up to 1% pyrite. Oxide minerals and minor pyrite are fairly evenly distributed throughout the remainder of the "oxide field" and commonly amount to approximately 1% of rocks. Relative distribution of hematite and magnetite is irregular. Often either hematite or magnetite predominate in highly fractured zones. Overall, both appear to be present in roughly equal proportions.

Minor chalcopyrite, malachite and azurite locally

occur along fractures and disseminated, associated with oxide minerals and minor pyrite, to the northwest of Fault-C in the contact region of quartz monzonite and pre-mineral porphyry with granodiorite. Locally, the estimated highest grade of copper mineralization present is .5% across a few feet.

Also, in that part of the "oxide field" that lies within the "central zone" of wallrock alteration, minor molybdenite occurs with oxide minerals and pyrite along fractures adjacent to the "sulphide field".

Sulphide Field (Pyrite)

As described previously under "Introductory Summary", the "sulphide field" has the form of a tilted mushroom. Its stem trends northeasterly at depth and occurs within and below the central to western portions of the "quartz-potash feldspar sub-zone". Its cap spreads laterally, largely from below the upper "quartz-hydromica sub-zone", to the south, east and probably in all other directions (ie: it is inferred to have been eroded). The limit of the stem is not known at depth and is open at the bottoms of DDH's 1 and 4.

Pyrite (probably minor associated marcasite; included with estimates of % pyrite) occurs throughout the "sulphide field". It is most abundant along the southern portion of the "quartz-hydromica sub-zone" and, up to at least 500 feet to the south from its edge, within the adjoining "peripheral shell". This region commonly contains 2 to 3% pyrite to depths up to

at least 210 feet (ie. high pyrite content was found in rocks to depths of 90 feet and 210 feet, respectively, in DDH's 3 and 2 and to bottoms of PSH's 4 to 8 at depths of up to 106 feet). In this region, pyrite occurs disseminated with lesser amounts along fractures and in massive veinlets. Commonly 1/2 to 1% pyrite is present throughout the remainder of the "sulphide field". Here it occurs along fractures, disseminated and as minor amounts in quartz veins.

Apart from pyrite and gangue minerals, fractures within that part of the "sulphide field" that lies within the "central zone" commonly carry variable amounts of molybdenite, minor sphalerite and galena and traces of chalcopyrite, a microscopic platy, hexagonal telluride (?) and microscopic grains of cassiterite. These minerals also occur sparsely disseminated. Surface chip samples, taken across widths of up to 75 feet, assayed as follows:

Pb	.05 to .10%
Zn	.15 to .20%
Cu	trace to .20%
MoS_2	.01 to .03%

These assays only show the approximate order of magnitude of metal content because of processes of surface leaching, oxidation and hydration, and enrichment (see "Surface Oxidized Zone"). Sphalerite and galena occur widespread but are more abundant within the "quartz-hydromica sub-zone". They occur disseminated and along fractures in roughly equal proportions. All sulphides, except for pyrite, appear subordinate in abundance with respect to molybdenite in drill holes.

Molybdenite Zone

On surface, distribution of molybdenite is confined to the western to east-central portion of the "central zone" that lies within the "sulphide field", except for a slight overlap into the "oxide field" in the eastern portion of the "central zone" (zone of molybdenite mineralization is up to 4300 feet long on surface). At depth, molybdenite occurs to the bottom of all DDH's beyond the limits of the "central zone" and "sulphide field". However, distribution of zones containing significant grades of molybdenite mineralizaion (ie: .04% MoS_2 or more) largely are related spatially to that part of the "central zone" occurring within the "sulphide field". This region defines the "molybdenite zone" and includes most of the western to central portions of the "central zone". Therefore, the "molybdenite zone" has a length of up to 4000 feet, in a northeasterly direction, and a width commonly ranging between 800 to 1000 feet on surface. It widens at depth to an indicated maximum width of up to 1800 feet and has a vertical range of up to 1050 feet.

Modes of occurrence of molybdenite are listed in Table XII, in decreasing order of importance.

1) Coatings along planar (locally serrate) fractures (associated with quartz, hydromica, pyrite, calcite and fluorite in decreasing order of abundance; associated chlorite is also relatively abundant along fractures within the "quartz-potash feldspar sub-zone"); see Plates 14, 15 and 18 to 22;

2) Seams and disseminated in banded discontinuous quartz veins (Type-3; Table XI);see Plate 23;

3) Disseminated in continuous to discontinuous massive quartz veins (Type-2; Table XI);

4) Coating angular to rounded rock fragments in shear and breccia zones; see Plate 18;

5) Disseminated in wallrocks.

TABLE XII: Modes of Occurrence of Molybdenite

Molybdenite is always fine-grained and occurs as single plates and massive scales in all modes of occurrence. All modes of occurrence often occur together or show close spatial associations without crosscutting relationships. Within mineralized zones containing .04% MoS_2 or more, approximately 80% of the molybdenite occurs along fractures (determined from counting of mineralized fractures and seams of molybdenite in quartz veins, and estimation of the effect of disseminated molybdenite in quartz veins and wallrocks).

Significant molybdenite mineralization occurs in fairly evenly distributed zones. These zones commonly range from 10 to 60 feet wide and contain .04 to .14% MoS_2 (10 foot assay intervals). One 10 foot zone assayed .27% MoS_2. Also one high grade zone, intersected for 50 feet in DDH 1, contains an average of .47% MoS_2 and is bordered by zones 100 and 70 feet wide, respectively containing .04 and .05% MoS_2 (Plate 20).

However, the reported grade in the high grade zone is misleading since relatively continuous veins up to 3/8" wide were heavily mineralized with molybdenite and closely paralleled the drill core axis. Also present, however, are similar heavily mineralized transverse veins and numerous associated mineralized fractures. Veins are dark-colored and consist of quartz with abundant seams and disseminations of molybdenite with lesser amounts of associated hydromica, chlorite, fluorite, calcite and apatite. Veins consist of the same minerals that coat fractures.

Mineralized zones mentioned above, are not characterized by more intense fracturing but by more abundant molybdenite along fractures.

Most of the best molybdenite mineralized zones show a close spatial relationship with pre-mineral porphyry intrusive contacts.

Both the width and grade of significant MoS_2 mineralization in zones tend to decrease with depth within the "molybdenite zone."

Mineralized or unmineralized fractures and quartz veins at depth probably are oriented mainly in conjugate pairs as are fractures and quartz veins on surface within the eastern portion of the "central quartz vein stockwork zone". Orientations of heavily mineralized fractures or veins that were transverse and roughly parallel to the core axis in the high grade zone in DDH 1 probably conform to conjugate trends (Figure 12B)

of fractures and quartz veins for the eastern portion of the "central quartz vein stockwork zone".

Average percent MoS_2 in host rocks (ie. granodiorite, quartz monzonite and pre-mineral porphyry) within the "molybdenite zone" in DDH's, from east to west, is given below in Table XIII. Similarly, average percent MoS_2 in all PSH's is given in Table XIV, from both within and outside the "molybdenite zone".

DDH	Avg.%MoS_2 in Host Rocks Only	Length of Host Rocks (feet)	Length of DDH to Base of "Molybdenite Zone" (feet)
2	.02	342	550 (base of "sulphide field")
3	.03	331	530 "
1	.08	482	750 (base of "quartz-potash feldspar sub-zone")
4	.04	713	1028 "

Note: Average core recovery is 97%;
Diameter of core is 1-5/8"

TABLE XIII - Average Percent MoS_2 in Host Rocks in DDH's 1-4 within the "Molybdenite Zone"

PSH	Average % MoS_2 in Host Rocks Only	Length of Host Rock (feet)	Total Length of Hole (feet)
		Within the "Sulphide Field" "Molybdenite Zone"	
1	.06	43	60
2	.04	63	63
3	.06	65	65
6	.01	37	37
7	.07	54	72
8	.03	73	106
12	.02	96	123
13	.05	56	56
		Outside the "Molybdenite Zone"	
4	.02	103	103
5	.01	40	50
		Within the "Oxide Field"	
9	.02	104	156
10	.02	37	37
11	.005	48	48

Note: Average core recovery is 77%; Diameter of core is 7/8"

TABLE XIV: Average Percent MoS_2 in Host Rocks in PSH's 1-13.

Minor molybdenite locally occurs along fractures in association with hematite, magnetite and pyrite in DDH's 2 and 3 and on surface, to the east, within the "oxide field" adjacent to the "molybdenite zone". Also, a few fractures and irregular patches and veinlets of associated hematite, magnetite, pyrite, and molybdenite occur in DDH 2 within the "sulphide field". However, in most instances where minor magnetite occurs within the "sulphide field" (hematite rarely occurs within the "sulphide field"), fractures either contain magnetite, with or without pyrite, or pyrite and/or molybdenite and do not

crosscut one another, even on a microscopic scale (Plate 19). These features strongly indicate that hematite, magnetite, pyrite, and molybdenite were all deposited contemporaneously.

Paragenesis and Zoning

Phase-I wallrock alteration, quartz veining and mineralization were developed simultaneously due to a continuous phase of hydrothermal activity. This is strongly indicated by the following listed features:

1) Selvages along mineralized (presence of sulphide and/or oxide minerals) fractures and quartz veins consisting of the same secondary minerals (hydromica or K-feldspar) that occur as pervasive wallrock alteration products in any given part of the alteration halo.

2) Quartz-hydromica or quartz-potash feldspar association in different parts of the "central zone".

3) Silicification and quartz veining are related spatially and temporaly.

4) Near absence of crosscutting relationships between mineralized structures.

5) Very similar mineralogy of fracture fillings and quartz veins.

6) Zonal arrangement of "sulphide" and "oxide" fields of mineralization and spatial relationship with zones of wallrock alteration. Local intimate association between sulphide and oxide mineral assemblages.

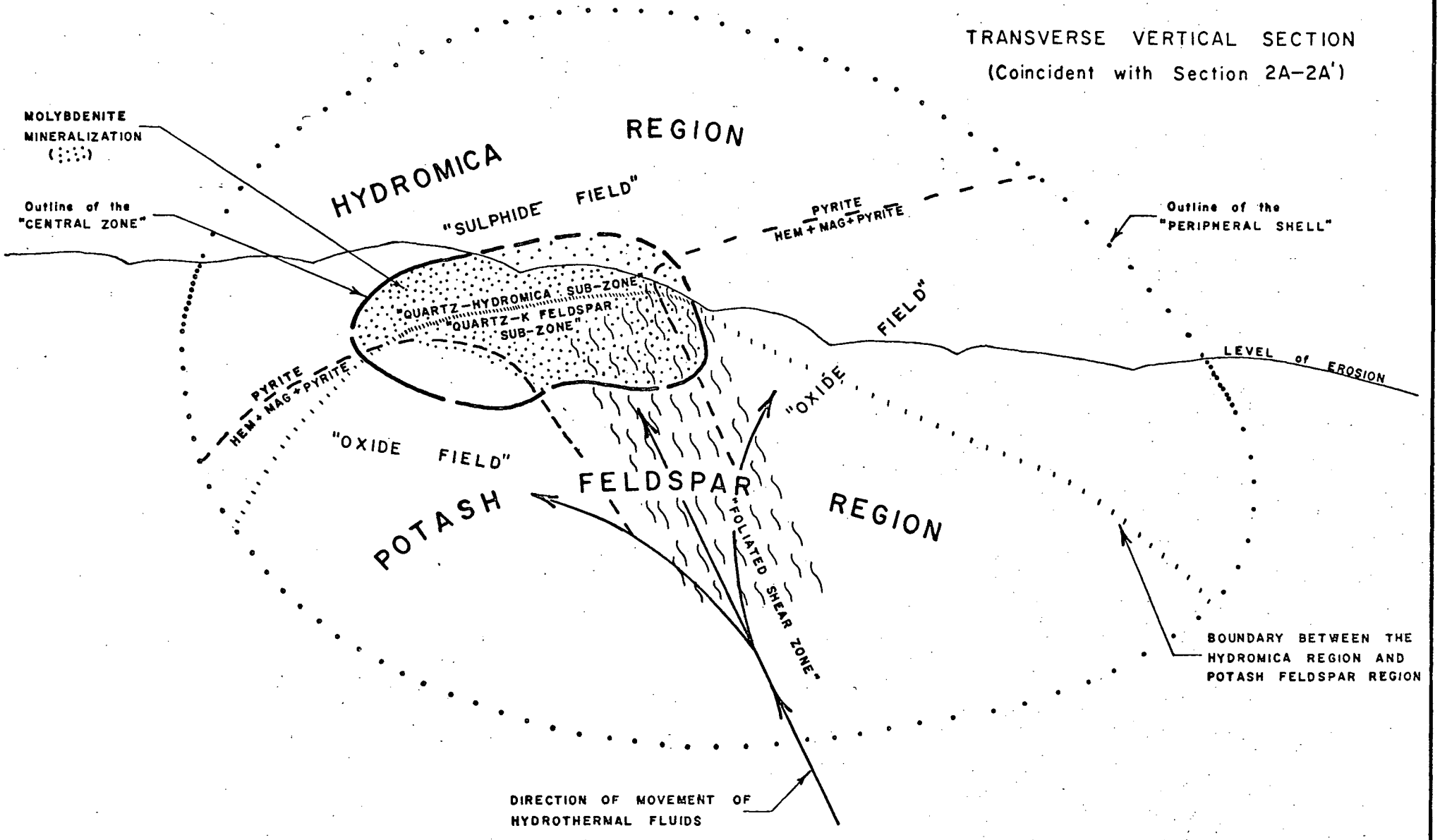
7) Gradual increase in degree of argillization within the "peripheral shell" towards the "quartz-hydromica sub-zone".

8) Gradual decrease in degree of K-feldspathization within the "quartz-potash feldspar sub-zone" into the "peripheral shell" at depth.

9) Sudden transition from the "quartz-hydromica sub-zone" into the "quartz-potash feldspar sub-zone" with only a narrow zone of overlap that is conformable with the boundary between sub-zones.

10) Minor stages of re-fracturing during hydrothermal activity commonly show a regeneration of the earlier type of hydrothermal conditions in any given part of the alteration halo.

Zoning of wallrock alteration products and oxide and sulphide mineral assemblages occurs on a large scale. It is illustrated in an interpretive, transverse cross-section of the alteration halo on Figure 14. Wallrock alteration is strongly indicated to have occurred throughout an ellipsoidal-shaped region. Alteration essentially consists of a hydromica region or cap lying above a K-feldspar region that has the form of a flat-lying double convex lense. Degree of wallrock alteration, to either hydromica or K-feldspar, increases inwards towards an ellipsoidal-shaped core ("central zone") characterized by intense to very intense degrees of wallrock alteration. The "central zone" occurs within both the hydromica and K-feldspar regions. Silicification and quartz veining conformably occur throughout the "central zone" and are zoned vertically since they are best developed in the "quartz-hydromica sub-zone". A sharp boundary exists between the "upper quartz-hydromica" and "lower quartz-potash feldspar" sub-zones. The upper sub-zone overlaps the lower sub-zone up to 150 feet. The"sulphide field" and "oxide field" of mineralization have a symmetrical distribution with respect to parts of the alteration halo. That is, the



Scale: 1 Inch = 800 Feet

FIGURE 14: INTERPRETIVE REPRESENTATION OF ZONAL ARRANGEMENT OF PHASE -I WALLROCK ALTERATION AND MINERALIZATION

"sulphide field" has the form of a tilted mushroom with its cap occurring throughout most of the hydromica region and stem passing downwards into the potash feldspar region through the "quartz-potash feldspar sub-zone". Molybdenite mineralization mainly occurs within that part of the "central zone" that lies within the "sulphide field". It is zoned vertically as evidenced by decreasing width and grade of significantly mineralized zones with depth.

Geochemical Character of Wallrock Alteration

As previously concluded under "Relationship between Structure, Wallrock Alteration and Mineralization", the "foliated shear zone" directed hydrothermal fluids upwards and that fluids must have spread upwards and outwards, predominantly along fractures, from its upper part (Figure 9 and 14). Movement of fluids along fractures and migration into wallrocks resulted in chemical reactions between wallrocks and hydrothermal fluids that produced secondary wallrock minerals. Significant secondary wallrock minerals, that indicate important transfer of elements between wallrocks and hydrothermal fluids, are discussed. Element transfers given are substantiated from studies of hydrothermal systems by others (6, 7, 9).

Within the potash feldspar region (Figures 8 and 14), secondary K-feldspar occurs replacing plagioclase of different compositions in different rock types (ie: quartz monzonite and porphyry). Associated albitization with minor hydromica and

calcite alteration of remnant plagioclases do not indicate any net addition or removal of elements except for a slight addition of H+ ions and CO_2. Essentially, chemical reactions within the K-feldspathized region are characterized by base ion exchanges. That is, K+ ions are introduced and exchanged for Na+ and Ca++ ions that are leached out of rocks.

Within the hydromica region, secondary hydromica occurs replacing all primary minerals in all rock types, though the important reaction has been with plagioclases. Therefore, the hydromica region is characterized by K+ and H+ ion introduction and leaching of Na+ and Ca++ ions with generation of excess SiO_2. Excess silica mainly was deposited along with replacement hydromica since the two minerals occur intimately mixed in the "quartz-hydromica sub-zone".

Silica was introduced within the "central zone". Here, introduced quartz is present as a pervasive wallrock alteration mineral mainly occurring in zones containing up to 90% quartz. Generation of excess silica from wallrocks within the "quartz-hydromica sub-zone" along with introduction of silica throughout the "central zone" accounts for more abundant silicification and quartz veining within the "quartz-hydromica sub-zone" than in the "quartz-potash feldspar sub-zone".

In essence, the geochemical character of wallrock alteration involved increasing degrees of leaching of Na+ and Ca++ ions and introduction of K+ ions towards the center of the "central zone" with similarly associated increasing degrees of

H+ ion introduction within the hydromica region. Also, silica was introduced within the "central zone" and generated excess silica was deposited in situ within the "quartz hydromica sub-zone". Hydrothermal fluids supplied K+ and H+ ions and SiO_2. Leached Ca++ ions probably reappear largely in calcite and fluorite that are associated with quartz veins and fracture fillings. Na+ ions may have been removed upwards or may have migrated downwards in hydrothermal fluids, due to chemical gradients. Downward migration is more likely since secondary albite becomes more abundant in deeper levels of the "peripheral shell". Also, hydrothermal fluids must have supplied S, Fl, Fe, Mo, Pb and Zn.

Intrepretation of the Hydromica-Potash Feldspar Boundary

The lower boundary of the "quartz-hydromica sub-zone" is relatively sharp but overlaps and shows crosscutting relationships with the underlying "quartz-potash feldspar sub-zone" for distances of up to 150 feet. The position and character of the boundary can be explained in either purely chemical or physical terms, based on experimental studies in hydrothermal systems by others (6,7, 9).

In chemical terms, the K+/H+ activity ratio in hydrothermal fluids would decrease upwards due to K+ ion introduction within the "quartz-potash feldspar sub-zone" until the ratio is such that both K+ and H+ ion introduction occur with the

development of the "quartz-hydromica sub-zone". With isothermal conditions, the effect of temperature of wallrocks also would tend to control the level at which the boundary occurred.

In physical terms, argillization occurs preferentially to K-feldspathization at lower temperatures. Therefore the boundary can be explained as a result of a steep temperature gradient with higher temperatures at depth.

Also, the overlap can be explained by changing chemical or physical parameters with time.

Probably both chemical gradients in hydrothermal fluids and steep temperature gradients controlled the position and character of the boundary. However, steep temperature gradients are believed to have been more important because of the following features:

1) The lower boundary of the "quartz-hydromica sub-zone" is relatively sharp and is conformable with the shape of the top of the stock and porphyry roof-sill.

2) If the boundary was due entirely to chemical gradients, secondary K-feldspar likely would have been developed widespread in the "quartz-hydromica sub-zone" as an early wallrock alteration mineral.

3) The overlap of sub-zones can be explained easily in terms of decreasing temperature with time.

4) The environment is one in which a steep temperature gradient, with depth, is to be expected because of the a) subvolcanic level of emplacement of the stock and porphyries, b) vuggy character of quartz veins in the granodiorite capping that indicate a sub-volcanic environment during hydrothermal activity and because c) hydrothermal activity undoubtedly was related genetically to porphyry and did not occur at some late date after subsidence of temperature gradients. (see following section on "Source Rocks of Hydrothermal Fluids").

5) The upward discontinuity of the "foliated shear zone", which is roughly coincident with the lower boundary of "quartz-hydromica sub-zone ", also can be explained as a result of a steep temperature gradient. That is, in the shear zone foliation occurred in deeper higher-temperature regions while contemporaneous extensive fracturing occurred in higher lower-temperature regions.

Geochemical Character of Mineralization

The presence of well defined "sulphide" and "oxide" fields of mineralization were the result, respectively, of sulphidizing and oxidizing conditions in the hydrothermal fluid during mineral deposition (3). These conditions were developed at the same time but in different parts of the alteration halo.

The presence of more abundant total iron in the "oxide field" (ie. contains an estimated average content of 2% hematite + magnetite + pyrite) than in the "sulphide field" (ie. contains an estimated average content of 1% pyrite) indicates that iron, during transport in the hydrothermal fluid, was preferentially associated with oxygen-rich complex ions. Also, the fact that the "molybdenite zone" occurs within the "sulphide field" indicates that molybdenum, during transport in the hydrothermal fluid, was either preferentially associated with sulphur-rich complex ions or was simply preferentially associated with hydrothermal fluids of lower O/S fugacity ratio. Deposition of molybdenite was preferentially associated with the region of most intense degrees of K^+ ion or K^+ and H^+ ion metasomatism (ie. "central zone").

The relatively sharp boundary between the "sulphide field" and "oxide field" is to be expected. That is, experimental studies in the Fe-S-O system have shown that well defined fields of iron oxide and iron sulphide deposition occur in hydrothermal environments. Deposition of oxide or sulphide minerals depends upon the relative fugacities of oxygen and sulphur (ie. O/S fugacity ratio). The relative position and shape of the "oxide field" with respect to that of the "sulphide field" (Figure 14) indicates that development of the "oxide field" must have been the result of an increasing O/S fugacity ratio in the hydrothermal fluid in a lateral direction about the stem of the "sulphide field". Such an increasing O/S fugacity ratio could have been caused by mixing of hydrothermal fluids with oxygenated meteoric waters or by some chemical gradient brought about by reactions between hydrothermal fluids and wallrocks.

Exploration Potential of the Molybdenite Zone

The "molybdenite zone" is a favourable exploration target for economic deposits of molybdenum ore. It occurs in a geological environment similar to that of many major producers of molybdenum ore. Similarities are listed below:

1) The presence of a small composite granitic intrusive complex emplaced in a high level crustal environment;

2) Intrusions are quartz monzonite to granite in composition;

3) Intrusions have a porphyritic texture.

4) Development of favourable structures that controlled mineralization;

5) Presence of quartz veining and K-feldspathization, argillization and silicification of wallrocks.

Exploration programs for molybdenum ore should be directed towards further testing of the "central zone" of intense wallrock alteration, and in particular, where the "central zone" lies within the "sulphide field" of mineralization (ie. the "molybdenite zone" as defined). Also within the molybdenite zone, exploration should be directed towards (a) regions of pre-mineral porphyry intrusive contacts and (b) regions of more intense fracturing.

The eastern part of the "molybdenite zone" has been eliminated by four deep DDH's as a potential bearerof any large tonnage, low grade ore bodies. However, the high grade zone (ie. 50 feet of .47% MoS_2) intersected in DDH 1 has potential as a low tonnage, high grade zone or pod and could be further tested by a transverse, inclined drill hole.

The western part of the "molybdenite zone" has not been tested at depth. It is up to 2000 feet long and between 500 and 1000 feet wide on surface and probably extends to depths of up to 1100 feet or more. This region is an attractive exploration target for the following reasons:

1) Predominant fracture trends in "intensely fractured zone-5" are directed towards, and could intersect, the "molybdenite zone" at depth.

2) From the structural interpretation of fracturing it is expected that (a) intensity of fracturing would remain high at depth and that (b) degree of opening along fractures may increase with depth.

PHASE II - INTRA-MINERAL PORPHYRY ASSOCIATION

General Statement

Phase-II wallrock alteration and mineralization includes 1) slight to moderate degrees of pervasive alteration and associated mineralization of all intra-mineral porphyry sills and dykes and 2) local intense wallrock alteration, with abundant associated sulphide minerals, occurring along Period-II shear and breccia zones and fractures in intra-mineral porphyry and older intrusions. The second type above, particularly occurs in zones near the bottom of DDH's 3 and 4 (outlined and labelled on Figure 8) spatially associated with the lower intra-mineral porphyry dyke-zone (Figure 6). Phase-II wallrock alteration products consist mainly of sericite, quartz and calcite. Sulphide minerals include pyrite, sphalerite, galena, chalcopyrite and molybdenite in decreasing order of abundance. Veinlets of calcite and fluorite (colorless to green), with or without associated sulphides, occur locally along DDH's 3 and 4.

Timing

Phase-II alteration and mineralization occurred intermittent to time of emplacement of intra- and post-mineral porphyry. Intrusion of intra-mineral porphyry followed cessation of Phase-I hydrothermal activity. This is evidenced by the following listed features:

1) Intra-mineral porphyry shows crosscutting relationships with all features of Phase-I including (a) all types of wallrock alteration and (b) sulphide and/or oxide bearing fractures and quartz veins;

2) Intra-mineral porphyry locally contains angular inclusions of rocks showing features of Phase-I as listed in 1 (a) and 1 (b) above;

3) K-feldspathization and hematite and magnetite mineralization indicative of Phase-I hydrothermal activity, do not occur in intra-mineral porphyry.

Phase-II alteration and mineralization followed intrusion of intra-mineral porphyry and preceeded intrusion of post-mineral porphyry. Phase-II shows a close time relationship with the latest period of crystallization of intra-mineral porphyry intrusions. That is, pervasive alteration and mineralization is clearly of deuteric nature. Furthermore, zones of intense wallrock alteration and associated sulphides show a genetic relationship with intra-mineral porphyry since zones commonly occur within and adjacent to intra-mineral porphyry intrusions. These features are discussed in detail in subsequent sections.

All features of Phase-II wallrock alteration and mineralization show crosscutting relationships with all features of Phase-I wallrock alteration and mineralization. Post-mineral porphyry shows crosscutting relationships with all altered and mineralized rocks.

Pervasive Wallrock Alteration and Mineralization

Intra-mineral porphyry typically is altered pervasively and mineralized uniformly. Albite phenocrysts are varicolored, though commonly are bleached to a light-grey or pale-green to pale-pink. Sanidine phenocrysts commonly are pale-pink and occasionally white to pale-green. Groundmasses are pale-green to bleached-white. In thin sections, feldspar phenocrysts show slight to moderate degrees of replacement to sericite (mattes and plates) and calcite. Biotite always is altered completely to plates of sericite, often with minor amounts of associated calcite, chlorite, leucoxene (?) and occasionally fluorite. Groundmasses contain disseminated sericite, calcite, minor pyrite and locally fluorite, galena, sphalerite and molybdenite. Phenocrysts and groundmasses locally contain minor secondary granular quartz. Embayments in quartz phenocrysts commonly consist of sericite, calcite, quartz, fluorite and pyrite. In exposed intra-mineral porphyry and in some of the upper dykes and sills in DDH's, porphyry commonly contains local disseminated rounded spots in the groundmass, up to 1/2" across, consisting of aggregates of pyrite and sericite with rims of sericite.

Fractures in intra-mineral porphyry commonly are coated with sericite, calcite, quartz and/or fluorite (colorless to green) and mineralized sparsely with pyrite, sphalerite, galena, chalcopyrite and/or molybdenite. Fractures occasionally have alteration selvages, up to a total width of 1/4", consisting of more intense sericite alteration of feldspars with minor associated quartz. Many of these coated fractures probably are due to Period-II fracturing. However, the bulk of them probably were developed by shrinkage of porphyry upon crystallization. This is evidenced by the fact that some mineralized fractures were observed to be discontinuous in intra-mineral porphyry at intrusive contacts.

Sericite, in all modes of occurrence, commonly shows a good platy form. It has positive relief and a negative optic angle of approximately 30 . Minor kaolinite (very low birefringence; positive relief) is associated with sericite and occurs as very fine-grained scales, specks and/or mattes.

Near the western end of Fault-B on surface, sericitization (local associated silicification) uniformly is more intense throughout irregular regions in both intra-mineral porphyry and granodiorite. Some of these regions are included within the outline of the "central zone" (ie. Phase-I) and account for some of the irregularities in its outline. They also include separate outlined regions in the same area. Elsewhere, Phase-II pervasive alteration largely is limited to intra-mineral porphyry bodies.

Commonly less than 1% pyrite, occurring along fractures and disseminated, is present in intra-mineral porphyry. Molybdenite content commonly is .01 to .02%.

Intensely Altered Zones and Related Features

Zones of intense argillization and silicification, outlined near the bottoms of DDH's 3 and 4 (Figure 8), are characterized by intense alteration of intra-mineral porphyry and quartz monzonite adjacent to fractures and within several shear and breccia zones (commonly up to five feet wide). Also, locally present are altered breccias up to one inch wide. Altered rocks consist of variable amounts of sericite and quartz, replacing feldspar phenocrysts and groundmasses, with minor amounts of associated calcite, fluorite and pyrite. Pyrite, sphalerite (yellow to black), galena, chalcopyrite, minor molybdenite and traces of a platy telluride (?) occur with variable amounts of sericite, quartz, calcite, and fluorite as (1) fracture fillings up to 1/8" wide, (2) irregular fracture fillings, veinlets and patches in shear and breccia zones and as (3) the matrix in breccias up to one inch wide. Sulphides are fine to medium grained except for molybdenite which always is fine grained. Shear and breccia zones commonly contain 1-2% pyrite and 1-3% combined Zn, Pb and Cu sulphides. Sulphides are more abundant in the outlined zone shown along DDH 4 than along that in DDH 3. The best mineralized zone is a 20 foot wide shear and breccia zone that occurs in DDH 4 at depths

between 1350 and 1370 feet. It is estimated to contain 5% combined sphalerite and galena and 1% chalcopyrite. The lower ten feet of this zone assayed .05% MoS_2. Other zones of molybdenite mineralization, shown on sections within the intensely altered zones outlined, are also Phase-II features and occur in shear and breccia zones. Veinlets of calcite with minor amounts of associated fluorite and pyrite and local veinlets of pyrite, up to ½ inch wide, occur widespread throughout outlined zones near the bottoms of DDH's 3 and 4.

Elsewhere in DDH's 3 and 4, Phase-II mineralized fractures and shear and breccia zones (up to 3 feet wide) only occur locally in intra-mineral porphyry and older intrusions. They become more abundant towards intensely altered zones near the bottoms of DDH's 3 and 4. Also present are local veinlets of massive sulphides, up to ½" wide, segmented with the gangue mineral assemblages calcite-fluorite and/or quartz-sericite (Plate 29). Mixed calcite and fluorite veinlets , up to ½" wide, containing minor amounts of pyrite occur more widespread but are only abundant (up to 1 per foot) across a few feet. They also occur locally in DDH 1. Six banded calcite-fluorite-sulphide veins, up to 2" wide, occur scattered in DDH 4 (Plate 29). Quartz veins, up to ¼ inch wide, only occur rarely in intra-mineral porphyry and generally are barren. Shear and breccia zones and veinlets commonly occur in rocks adjacent to intra-mineral porphyry intrusions.

Discussion

Restriction of the pervasive type of Phase-II alteration to bodies of intra-mineral porphyry indicates deuteric processes. Also, the presence in intra-mineral porphyry of disseminated spots of sericite-pyrite, more intense alteration of embayments in quartz phenocrysts and evenly distributed sulphides indicate deuteric processes.

Intense alteration and associated abundant sulphide minerals that occur along Period-II structures cutting intra-mineral porphyry and older rocks are features of hyrdrothermal origin. The close spatial relationship of zones of intense alteration with the lower dyke-zone, intersected near the bottoms of DDH's 3 and 4, and the close spatial relationship of other local zones of intense alteration and veinlets with intra-mineral porphyry intrusions strongly indicate a genetic relationship between Phase-II hydrothermal activity and intra-mineral porphyry.

It is concluded that alteration and mineralization of intra-mineral porphyry is largely of deuteric origin; except at depth, where crosscutting Period-II structures have controlled movement of hydrothermal fluids generated from intra-mineral porphyry intrusions.

From the width and estimated contents of sulphide minerals in Phase-II mineralized zones, it is probable that

these zones are not of economic significance for any of the base metals. However, drill core was only assayed for molybdenite content.

GROSS PARAGENESIS

Predominant sulphide, oxide and gangue mineral assemblages associated with each phase (ie. Phase-I and -II) of hydrothermal activity show a gross paragenesis that is characteristic of classical sequences of mineral deposition in hydrothermal environments. Mineral assemblages are given below in Table XV.

HYDROTHERMAL PHASE	PREDOMINANT MINERALS DEPOSITED ALONG FRACTURES	
	Metallic Minerals	Gangue Minerals
Phase-I (main phase)	Hematite, magnetite, pyrite and molybdenite	Quartz hydro-mica and K-feldspar
Phase-II	Pyrite, sphalerite, galena, chalcopyrite and molybdenite	Sericite, quartz, calcite and fluorite

TABLE XV: Phase-I and -II Gross Paragenesis

SOURCE ROCKS OF HYDROTHERMAL FLUIDS

Phase-I and -II hydrothermal activity, respectively, are believed related genetically to pre- and intra-mineral porphyry. A genetic relationship between Phase-II hydrothermal activity and intra-mineral porphyry is clearly demonstrated as discussed in earlier sections. Features that suggest a genetic relationship between Phase-I hydrothermal activity and pre-mineral porphyry are listed below:

1) Intra- and post-mineral porphyry intrusions were rich in volatile and acqueous fractions because both were altered and mineralized deuterically. Furthermore, intral-mineral porphyry generated hydrothermal fluids as a result of structural deformation (ie. Period-II structures). Intuitively then, pre-mineral porphyry was probably also rich in volatiles and acqueous fractions;

2) Close spatial relationship between best zones of molybdenite mineralization and pre-mineral porphyry intrusive contacts;

3) Extent of the Phase-I alteration halo shows a close correspondence to the distribution of pre-mineral porphyry;

4) Pre-mineral porphyry dykes, intersected in DDH 1 within the center of the alteration halo, probably lead into a mass or stock or pre-mineral porphyry at depth from which the bulk of hydrothermal fluids could have been generated;

5) From the geochemistry of Phase-I alteration and mineralization along with the controlling structural framework, it is certain that hydrothermal fluids ascended upwards along the "foliated shear zone" near the center of the alteration halo in the region of pre-mineral porphyry dykes, intersected in DDH 1, that are probably apophyses from an underlying stock of pre-mineral porphyry;

6) The gross paragenesis of Phase-I and -II sulphide, oxide and gangue mineral assemblages indicate a genetic affiliation between phases of hydrothermal activity and, therefore, indicate that pre-mineral porphyry was a source rock to phase-I hydrothermal fluids just as intra-mineral porphyry was a source rock to Phase-II hydrothermal fluids.

Above listed features are believed to sufficiently demonstrate that Phase-I hydrothermal activity was related genetically to pre-mineral porphyry intrusions. Hydrothermal fluids were generated from the pre-mineral porphyry roof-sill and feeder-dykes, though the bulk of the fluids must have been generated from a buried mass or stock of pre-mineral porphyry. Period-I deformation produced avenues for release of volatile and acqueous fractions from pre-mineral porphyry. Also, this was clearly the case for Period-II deformation and intra-mineral porphyry. Post-mineral porphyry was altered only deuterically probably since no deformation closely followed its emplacement.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY

The region of the Tuzo Creek Molybdenite Prospect has had a complex history of igneous intrusion, structural deformation and hydrothermal activity.

Intruding a basement of Nelson granodiorite is a triangular-shaped (sides approximately 1½ miles long), rounded, partially capped stock of Valhalla porphyritic quartz monzonite. Subsidence of the stock was accompanied by emplacement, along its top and eastern flanks, of a quartz-albite-sanidine porphyry sill (pre-mineral) up to 350 feet thick. Feeder-dykes lead upwards into the sill, probably from a porphyry stock at depth.

Strong regional deformation (Period-I) produced a northeasterly-trending and steeply north-dipping upwardly and probably southwesterly-discontinuous "foliated shear zone" in the south-central portion of the stock. Contemporaneously, there was local development of northwesterly-trending foliation and shear and breccia zones. Movement in the "foliated shear zone" probably was of a reverse rotational character and hinged to the southwest in the west-central portion of the region. Widespread fracturing was produced by shear movements.

Fracture trends show a radial pattern or horsetailing effect at the southwestern end of the "foliated shear zone". Within and adjacent the "foliated shear zone", throughout the central to northeastern portions of the region, fracture and quartz vein trends show conjugate, longitudinal and/or cross trends with respect to the predominant northeasterly-trending shearing azimuth. Most intense fracturing occurs within and peripheral to the "foliated shear zone". Most extensive opening along fractures, commonly up to ¼" or ½" occurs peripheral to the "foliated shear zone".

Hydrothermal activity (Phase-I) was controlled by Period-I structures, and centered about the "foliated shear zone". Fractures and local shear and breccia zones controlled wallrock alteration, quartz veining and mineralization. Wallrock alteration has affected most of the stock and porphyry sill and occurs throughout a northeasterly-trending ellipsoidal-shaped halo. The alteration halo is zoned and consists of 1) a "peripheral shell" characterized by lesser degrees of alteration mainly consisting of argillization (hydromica) at higher levels and feldspathization (potash feldspar and albite) at lower levels and (2) a large, northeasterly-trending "central zone" (completely surrounded by the peripheral shell) characterized by more intense alteration consisting of argillization (hydromica),feldspathization (K-feldspar and albite) and silicification. The central zone is sub-divided into an upper "quartz-hydromica sub-zone" and a lower "quartz-potash feldspar sub-zone". A sharp boundary occurs between the upper hydromica

and lower potash feldspar regions. The boundary is indicated to extend throughout the alteration halo as a gently outward-dipping surface. Quartz veining and silicification occur throughout the "central zone" but are most abundant in the "quartz-hydromica sub-zone". Chemically, wallrock alteration is essentially characterized by increasing degrees of leaching of Na+ and Ca++ ions and introduction of K+ ions towards the "central zone" with associated increasing degrees of H+ ion introduction within the upper hydromica region. Also, some silica was introduced into wallrocks and deposited along open fractures within the "central zone". Mineralization is present throughout the alteration halo, predominantly occurring along fractures and to a lesser degree in quartz veins. Distribution of sulphide and oxide mineral assemblages define a mushroom-shaped "sulphide field", with its stem roughly centered along the "central zone", and an "oxide field", surrounding the stem and below the cap of the "sulphide field". The "sulphide field" is characterized by widespread pyrite whereas the "oxide field" is characterized by the assemblage hematite-magnetite-pyrite. A "molybdenite zone" occurs in that part of the "central zone" that lies within the "sulphide field". The "molybdenite zone" measures up to 4000 feet in a north-easterly direction. It has an indicated maximum width of up to 1800 feet and has a vertical range of up to 1050 feet. Significant grades of molybdenite occur in separate zones, commonly up to 10's of feet wide, containing .04 to .47% MoS_2.

Economic potential for large ore-bodies of low grade molybdenite mineralization is limited to the western portion of the "molybdenite zone" which has not been tested by diamond drilling. Also, one 50 foot intersection, in DDH 1, containing .47% MoS_2 could be tested further by a cross hole.

Cessation of Phase-I hydrothermal activity was followed by further sibsidence of the stock producing a series of gently dipping tensional fissures that controlled further emplacement of porphyry (intra-mineral). This porphyry was strongly altered deuterically (mainly sericite) with associated minor amounts of pyrite, sphalerite, galena, chalcopyrite and molybdenite occurring disseminated and along fractures. Also, deformation (Period-II) of a character similar to Period-I, but lacking foliation, locally affected intra-mineral porphyry and adjacent rocks at depth. Period-II structures controlled intense argillization (sericite) and silicification of wallrocks (Phase-II) and more abundant sulphide deposition, particularly within and adjacent to bodies of intra-mineral porphyry, of a mineralogy identical to that related to deuteric mineralization. Phase-II mineralization was not extensive enough to be economically important for any of the base metals.

Further emplacement of porphyry (post-mineral) consists of en echelon series of a moderately-to steeply-dipping conjugate dyke system and of local large dyke-like masses that were controlled by tensional fissures. Post-mineral porphyry is weakly altered deuterically and sparsely mineralized.

Late basic to intermediate dykes of alkaline nature largely occur within a northeasterly-trending zone across the center of the region. They were emplaced along northeasterly-trending and local northwesterly-trending tensional fissures.

Northeasterly-trending and northwesterly-dipping reverse rotational faults (Period-III) offset all rock types. They were hinged to the southwest in the central portion of the region. Transverse shears also occur locally.

CONCLUSIONS

Conclusions, largely of genetic nature, concerning the petrology and structure of the Tuzo Creek Molybdenite Prospect are listed below:

1) Granodiorite, quartz monzonite and porphries are all part of a single differentiation series.

2) Phenocrysts in porphyries and probably those in quartz monzonite have crystallized at depths of approximately 11 km's or more.

3) The quartz monzonite stock and porphyries were successively emplaced from great depths (ie. at least 11 km's) into a sub-volcanic environment.

4) Both local and regional structures were regenerated successively in type and orientation. Local structures include

(a) two periods of development of gently-dipping fissures due to subsidence of the stock and

(b) two periods (I and II) of fracturing, genetically related to wrenching shear movements due to termination or pinching-out of regional reverse rotational shearing.

Regional structures include

(a) two periods (I and II) of shearing and a late period (III) of faulting and

(b) two periods of development of tensional fissures.

5) Regional structures can be interpreted through application of a combined stress and strain ellipsoid diagram.

They were caused by successive and intermittent periods of compression and tension whose respective forces must have been resolved from successive periods of development of rotational forces generated by right lateral strike-slip movements along the West Kettle River fault zone.

6) Phase-I and -II hydrothermal activity were controlled, respectively by Periods-I and -II structures and followed emplacement of pre- and intra-mineral porphyry, respectively. Gross paragenesis of deposited gangue, sulphide and oxide minerals is in line with other hydrothermal environments.

7) Phase-I hydrothermal activity was the most important since it developed a large, zoned alteration halo and had associated significant molybdenite mineralization. Wallrock alteration, quartz veining and mineralization are related paragenetically to a single, probably prolonged phase of hydrothermal activity. Hydrothermal fluids must have ascended upwards along the "foliated shear zone" and spread outwards and upwards from its upper part mainly along fractures. Control of wallrock alteration mineral assemblages was undoubtedly both chemical and physical, though physical control is believed to have been the most important since steep temperature gradients best explain the sharp boundary between the potash feldspar and hydromica regions in view of experimental studies in hydrothermal systems by Hemley, and others. "Oxide" and"sulphide" fields of mineralization, due to differences in O/S fugacity ratio in the hydrothermal fluid were brought about by an increasing O/S fugacity ratio laterally about the stem of the "sulphide field". Molybdenum in transport in the hydrothermal

fluid was associated preferentially either with S-rich complex ions or simply with fluids of lower O/S fugacity ratio. Deposition of molybdenite was associated preferentially with regions of most intense K^+ ion or K^+ and H^+ ion metasomatism.

8) Source rocks of Phase-I and -II hydrothermal fluids were undoubtedly pre- and intra-mineral porphyry, respectively. Fluids were released from porphyries as a result of Period-I and -II deformation. Phase-I fluids must have been released largely from a buried stock of pre-mineral porphyry.

9) Geological characteristics of the prospect are reflective of major producers of molybdenum ore. Considerable economic potential for molybdenum ore still remains within the "molybdenite zone".

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Plate 1: View looking west towards map-area from the access road near the junction of Tuzo Creek and West Kettle River. ("X" marks a common spot on Plates 1 to 4).

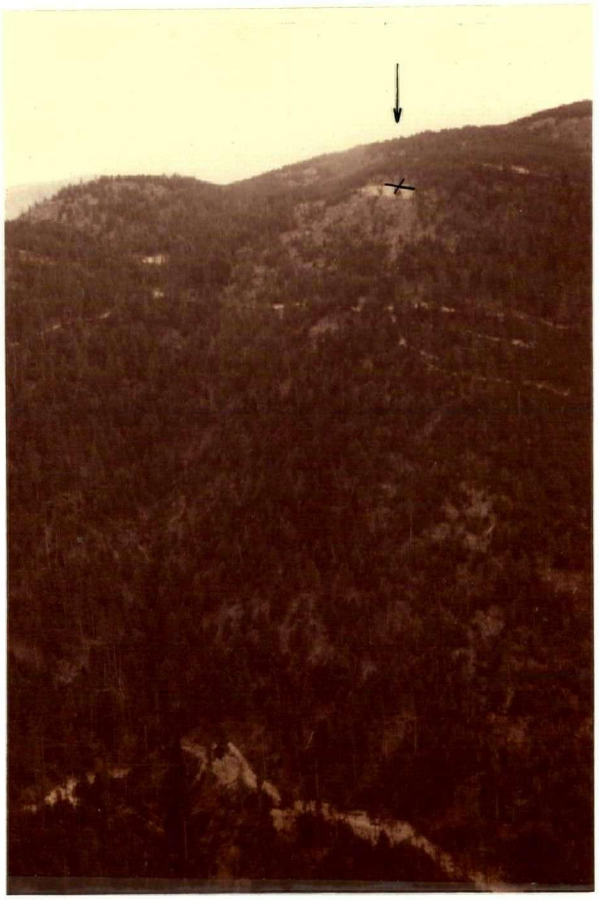


Plate 2: View looking southwest from a helicopter; note the straight, moderately incised draw (follows a young fault).

Plate 3: View looking north over the campsite from a helicopter; note the level of the incised Interior Plateau upland in the background.

Plate 4: View looking north of the West Kettle River Valley; the town of Beaverdell lies at the intersection of major valley in the background; note the Interior Plateau upland surface.

Plate 5: Fresh hornblende granodiorite; note the hypidiomorphic texture, weak foliation and large interstitial grains of quartz (pale grey).

Plate 6: Fresh porphyritic Biotite Quartz Monzonite; note the large euhedral sanidine phenocrysts (light grey) and medium grained phenocrysts of oligoclase (white), rounded quartz (glassy grey) and biotite (black) and the fine grained groundmass.

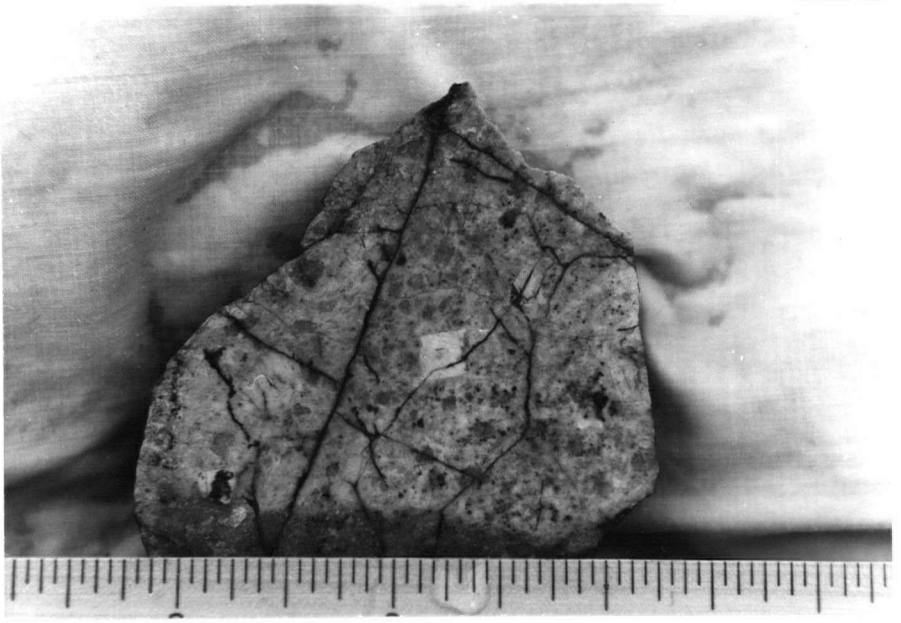


Plate 7: Pre-mineral Porphyry (altered); note the large euhedral sanidine phenocrysts and deformed quartz (light grey) phenocrysts.

Plate 8: Intra-Mineral Porphyry (weakly altered); note phenocrysts consisting of rounded grains of quartz (glassy grey), large euhedral sanidine (white), indistinct albite (grey) and altered biotite (dark), also note the aphanitic groundmass.

Plate 9: Post-Mineral Porphyry (relatively fresh); note the similar texture of pre-, intra- and post-mineral porphyry,

Left: Fine-grained pink phase showing a granular texture.
Center: Grey to pink predominant phase.
Right: Dark pink phase

Plate 10: Sanidine phenocrysts from post-mineral porphyry; left and center crystals are oriented with a-axis vertical and c-axis downwards to the left, crystals show 010, 001, 110 and $20\bar{1}$ faces.

Plate 11: Alkaline Quartz Gabbro (late dyke); note the medium grained phenocrysts consisting of labradorite laths (light grey) and augite (dark) in a fine-grained, granophyric-like groundmass.

Plate 12: Composite Alkaline Basalt - Augite Trachyte (late dykes);

Left: Alkaline basalt showing phenocrysts of labradorite laths (light grey) and augite (dark) in a fine-grained groundmass,

Right: Augite Trachyte showing phenocrysts of alkali feldspar laths to rhombs (white), augite (dark grey) and biotite (black) in a fine-grained granular groundmass.

(note rims around feldspar phenocrysts in both rock types)

Plate 13: Altered Latite (late dyke); note small phenocrysts of altered feldspar (white) in a fine grained groundmass.

Plate 14: Argillized Granodiorite from the "quartz-hydromica-sub-zone"; note the alteration selvage consisting of hydromica and quartz along a pyrite-molybdenite bearing fracture.

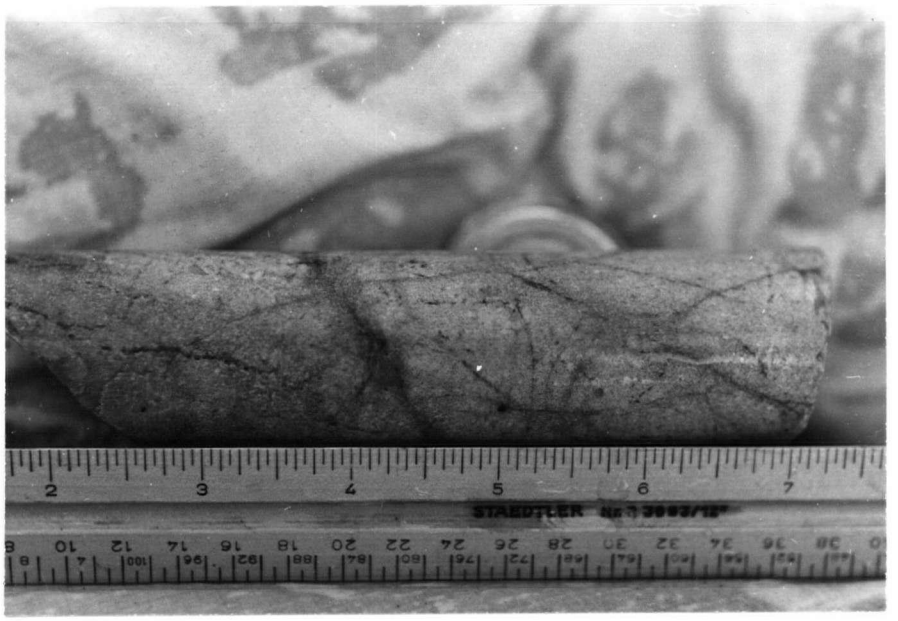


Plate 15: Sample from the overlap zone between the upper "quartz-hydromica sub-zone" and the lower "quartz-potash feldspar sub-zone"; sample illustrates pervasively K-feldspathized pre-mineral porphyry showing later pyrite-molybdenite bearing fractures with selvages of quartz and hydromica.

Plate 16: Samples illustrating quartz veins in K-feldspathized rocks from the "central quartz vein stockwork zone" (see Table XI).

Plate 17: Discontinuous, irregular quartz veins and silicified zones in argillized granodiorite from the "quartz-hydromica sub-zone"; Type 2 veins (Table XI).

Plate 18: Abundant molybdenite (black) occurring along fractures and coating breccia fragments in brecciated and K-feldspathized quartz monzonite from the "quartz-potash feldspar" sub-zone".

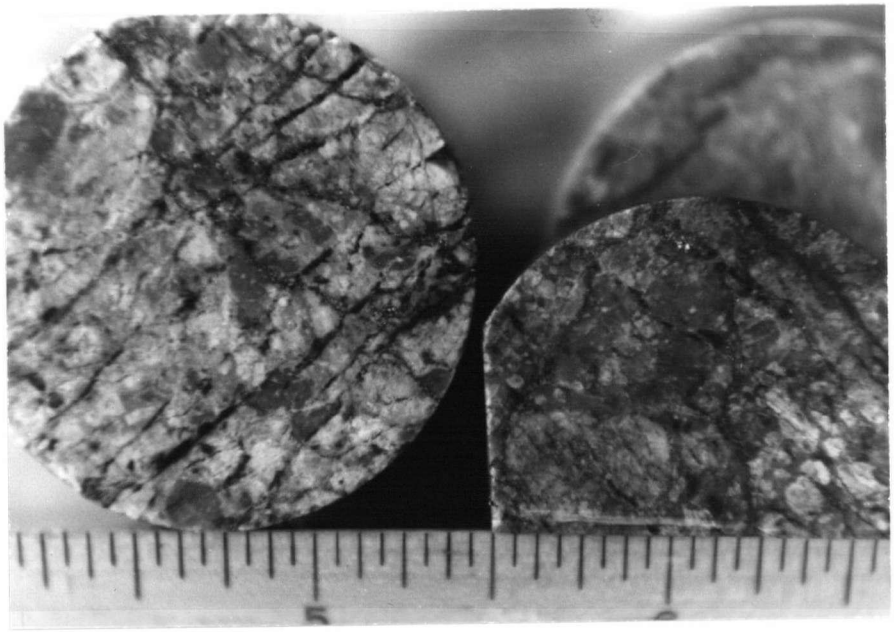


Plate 19: Molybdenite (dark metallic) and magnetite (black) occurring exclusive of one another along fractures without showing crosscutting relationships in K-feldspathized quartz monzonite.

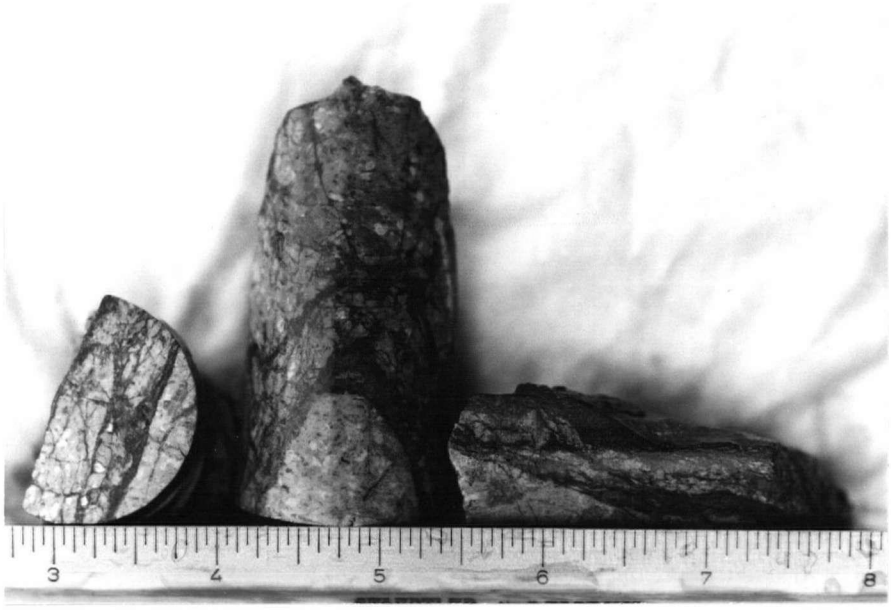


Plate 20: Heavy molybdenite (black) mineralization occurring in veinlets and along fractures in K-feldspathized quartz monzonite from the high grade zone intersected along DDH 1.

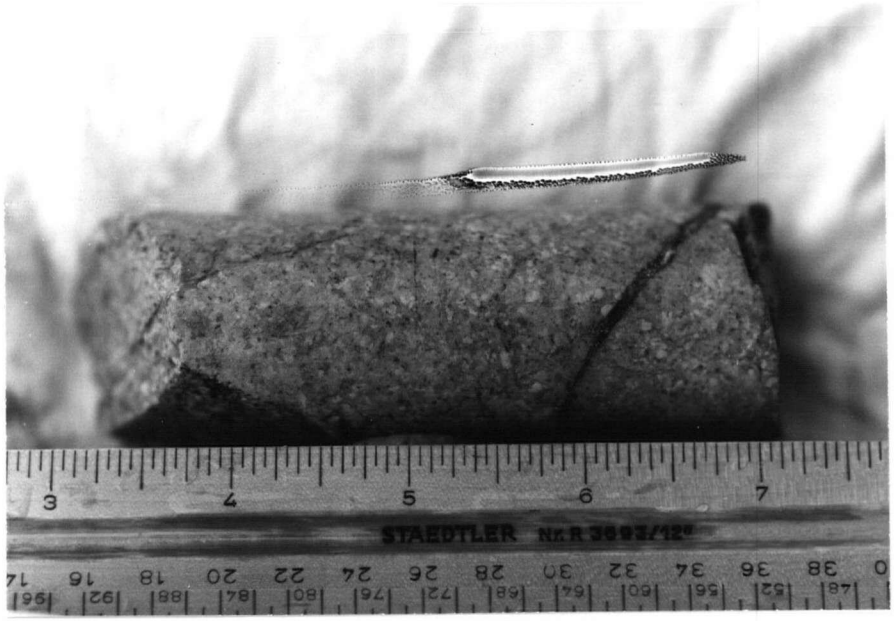


Plate 21: Molybdenite (black) bearing fracture with a selvage of hydromica and quartz in argillized pre-mineral porphyry from the "quartz-hydromica sub-zone".

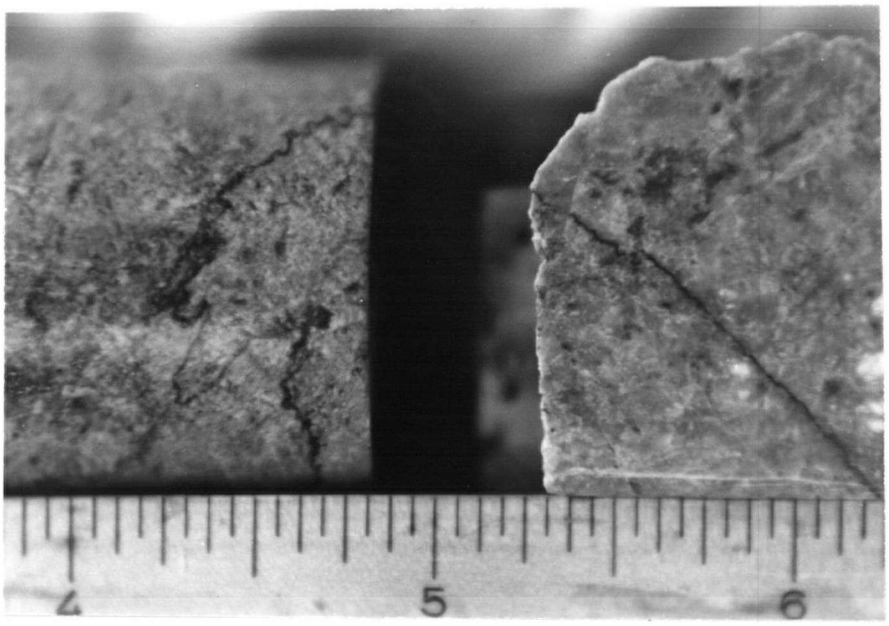


Plate 22: Serrate fracture coated with molybdenite (black).

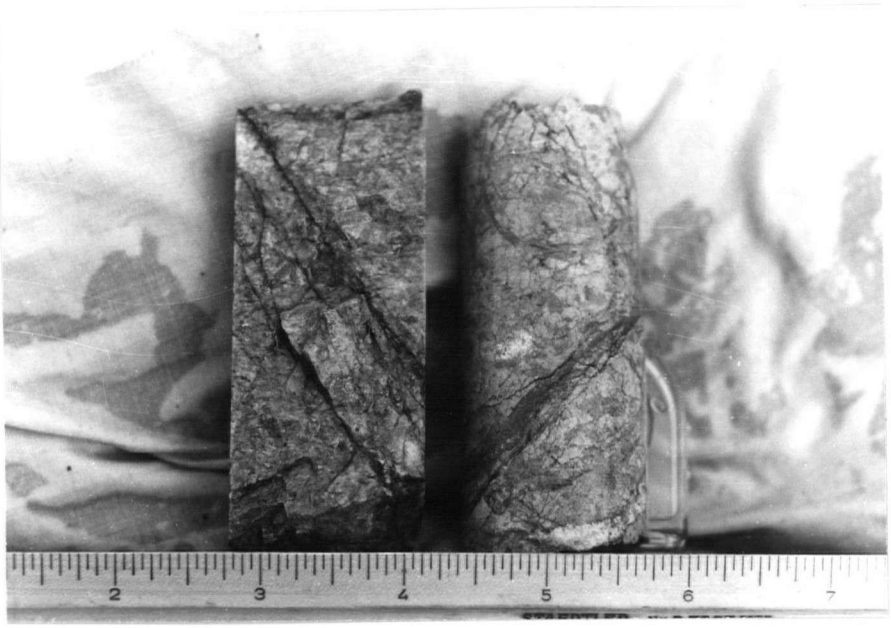


Plate 23: Banded quartz-hydromica-molybdenite veinlets (Type 3b veins; see Table XI)

Plate 24: Banded quartz-magnetite veins and magnetite bearing fractures in K-feldspathized rocks (Type 1 veins; see Table XI); Left: from the "oxide field" at depth

Center and right: from "fracture zone-8" within the "oxide field".

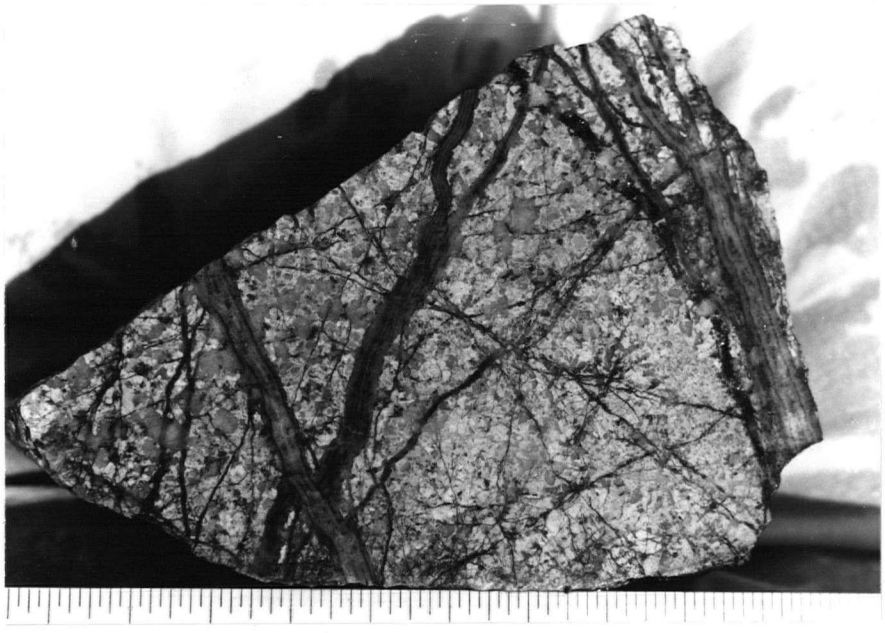


Plate 25: Banded quartz-magnetite veins in argillized and K-feldspathized granodiorite; sample taken from float below "fracture zone-8".

Plate 26: Heavy hematite (specularite) and magnetite mineralization in intensely fractured and granulated, argillized and silicified pre-mineral porphyry from "fracture zone-5".

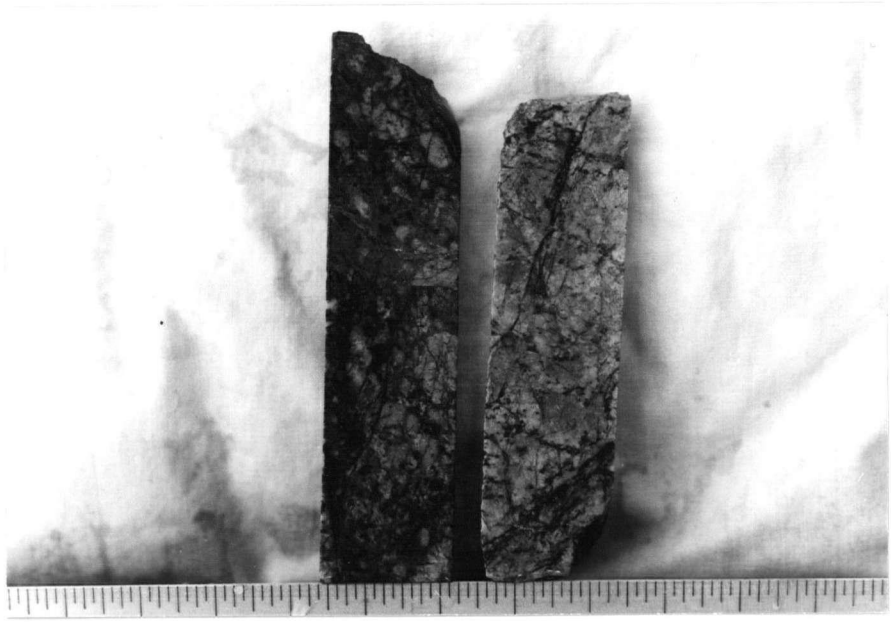


Plate 27: Hematite and magnetite along fractures in argillized and silicified pre-mineral porphyry from "fracture zone-5".

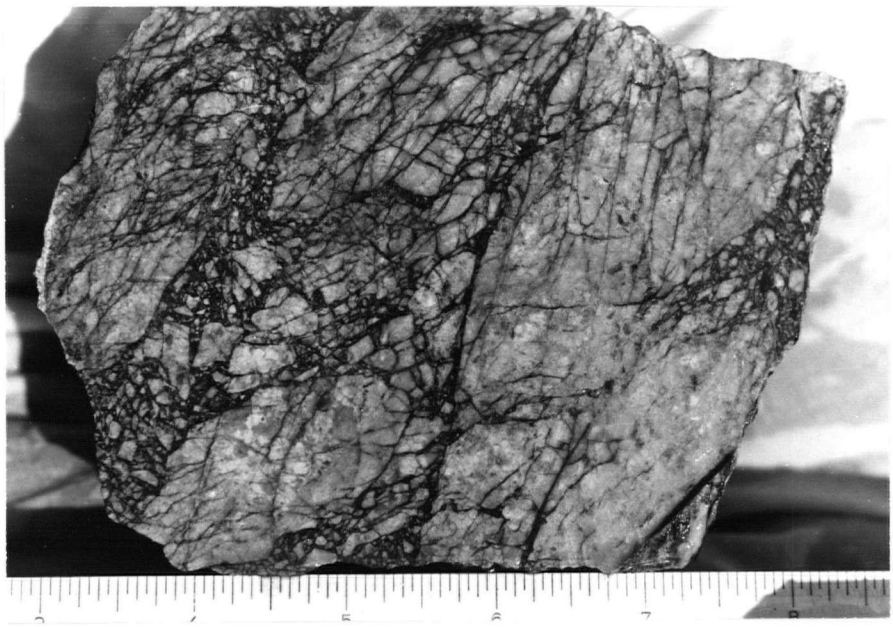


Plate 28: Brecciated and intensely silicified and argillized quartz monzonite from "fracture zone-5"; abundant hematite and magnetite healing breccia fragments.

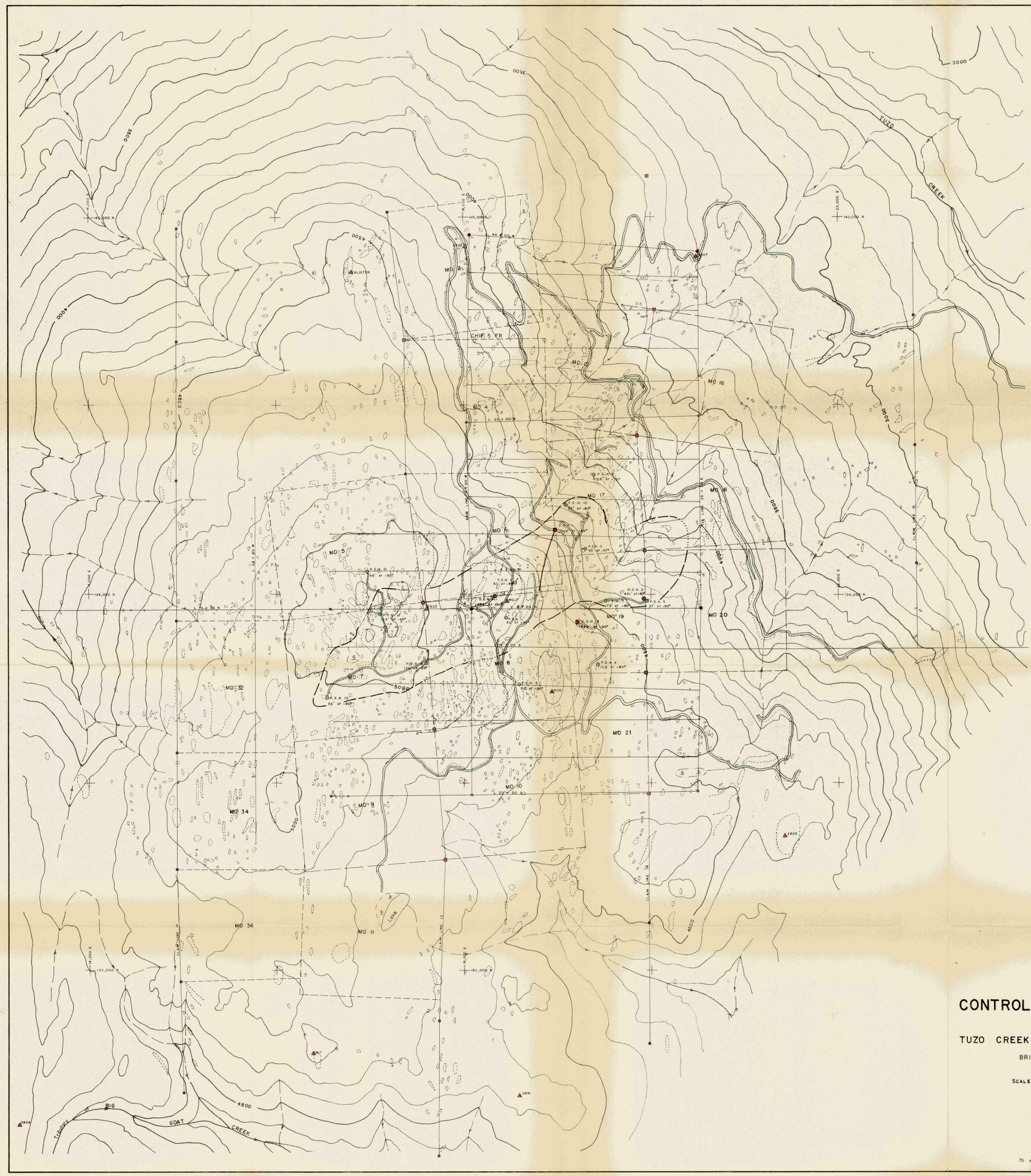
Plate 29: Massive sulphide veinlets (Phase-II mineralization);

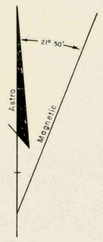
Left: Banded pyrite-molybdenite-calcite vein

Center: Sphalerite-galena-pyrite-chalcopyrite vein cutting pre-mineral porphyry

Right: Galena-chalcopyrite vein.

Plate 30: Breccia zone (Period-II) in quartz monzonite containing a large fragment of molybdenite mineralized rock (on left); note calcite filling (white).





S Y M B O L S

OUTLINE OF AREA OF MOLYBDENITE MINERALIZATION

B.Q. WIRELINE DIAMOND DRILL HOLE
Vertical, Inclined; Showing Number, Inclination and Length
Located by Transit Survey

PACKSACK DIAMOND DRILL HOLE
Vertical, Inclined; Showing Number, Inclination and Length
Located with respect to Grid

CUT GRID PICKET-LINE
(Line 2000 feet South) - Marked at 100' Intervals

CUT CLAIM LINE
(Claim Post) - Marked at 100' Intervals

MAIN CONTROL STATION
Name, Number; Located by Tellurometer Survey

GEODETIC GRID POINTS
As Defined by MCLAREN AND ASSOCIATES

TOPOGRAPHIC CONTOUR
100' Intervals; Plotted by LOCKWOOD SURVEY CORP. LTD.
From Airborne Photographic and Ground Survey Data

DENOTES POINT TIED IN BY TRANSIT SURVEY
B.Q. Wireline Diamond Drill Hole
Claim Post
Grid Point

DENOTES POINT TIED IN BY AIRBORNE SURVEY
Claim Post
Grid Point

CLAIM POST
Approximately Located by Chain and Compass

CLAIM BOUNDARY
Plotted From Surveyed Positions of Claim Posts

CLAIM BOUNDARY
Approximately Located

NOTE:
Claims Shown are Presently Held by AMAX EXPLORATION INC.
(ie: Mo2, 4-10, 15-21, 32, 34 and 36; Chip 5 Fraction)

ROCK OUTCROP

SWAMP

STREAM; INTERMITTENT STREAM

ROAD (Four Wheel Drive Road)

NOTE:
B.Q. Wireline Diamond Drilling by CANADIAN LONGYEAR LTD. (1966)
Packsack Diamond Drilling by Local Contract (1965, 1966)
Topography by LOCKWOOD SURVEY CORPORATION LTD. (1967)
Control Stations and Field Survey by: MCLAREN AND ASSOCIATES (1967)
Picket-Line Grid by Local Contract (1964, 1965)

Drawn by G.M. Leary (1969); Completed by N. Grant Brown

FIGURE 4

CONTROL SURVEY MAP

TUZO CREEK MOLYBDENITE PROSPECT

BRITISH COLUMBIA

SCALE 1 INCH = 400 FEET

To Accompany Thesis: "PETROLOGY AND STRUCTURE OF THE TUZO CREEK MOLYBDENITE PROSPECT" by G.M. Leary (1969)

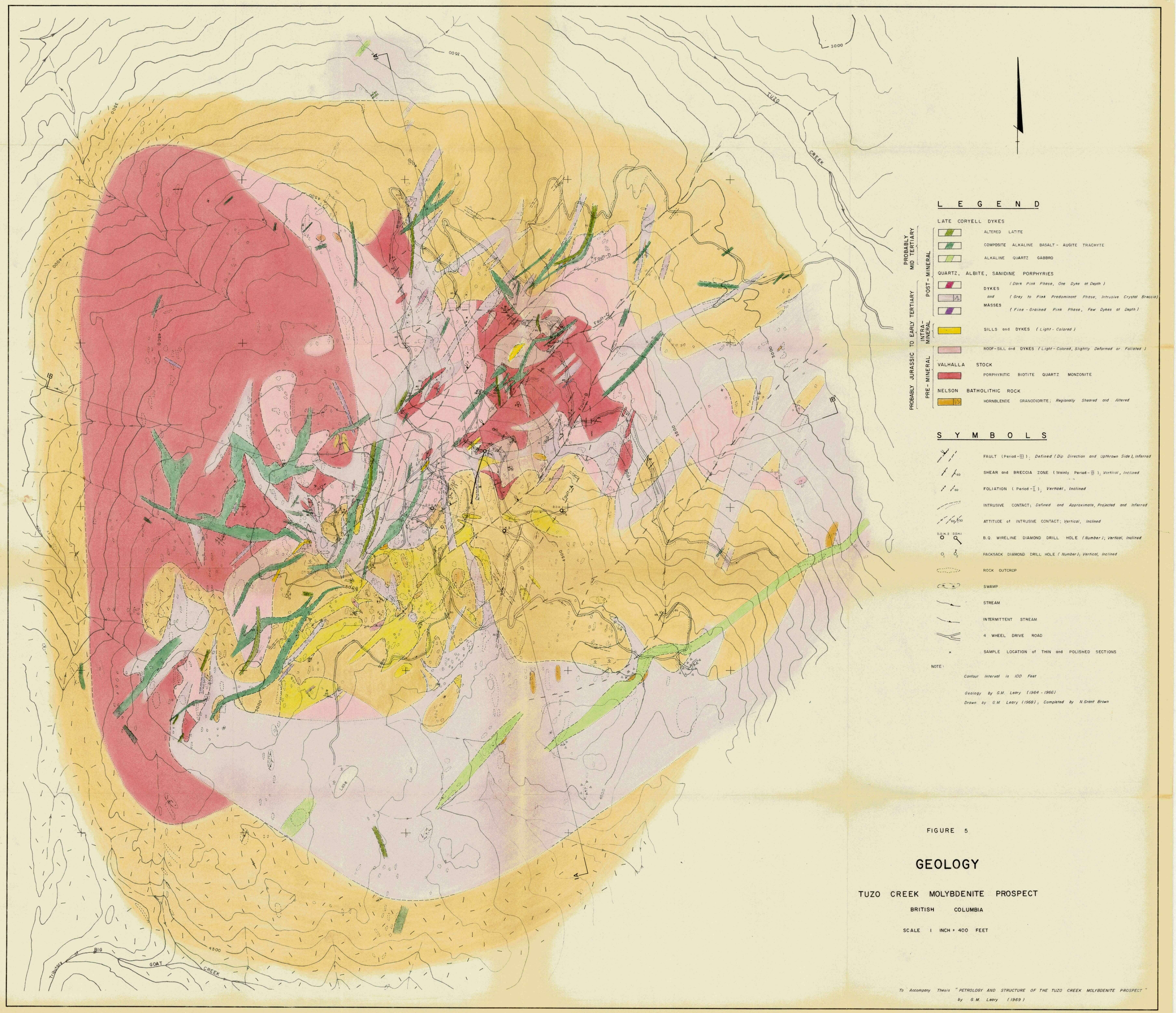


FIGURE 5

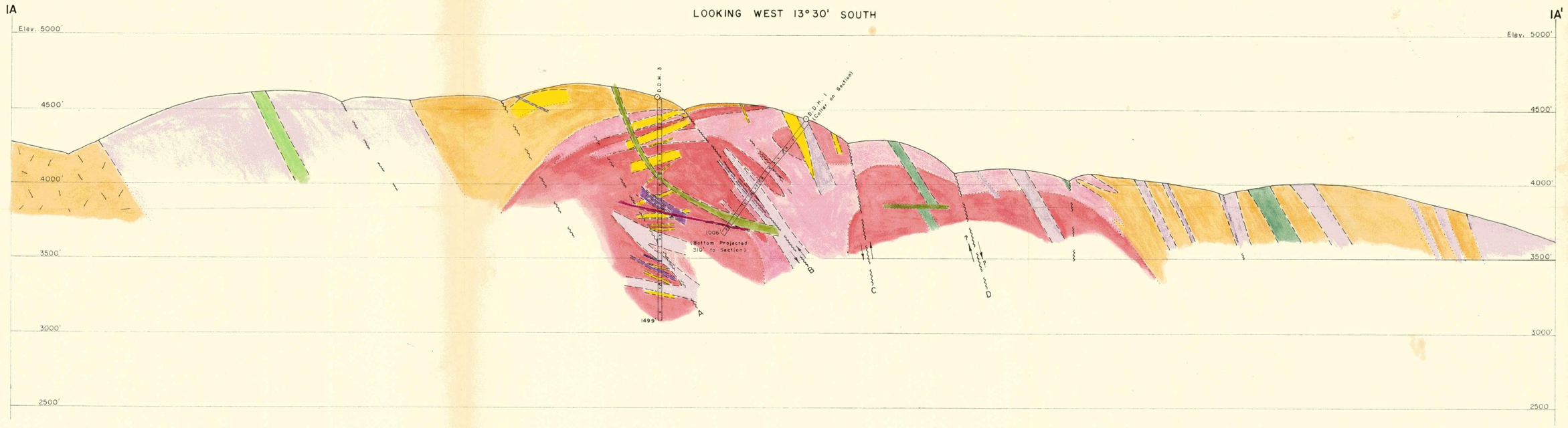
GEOLOGY

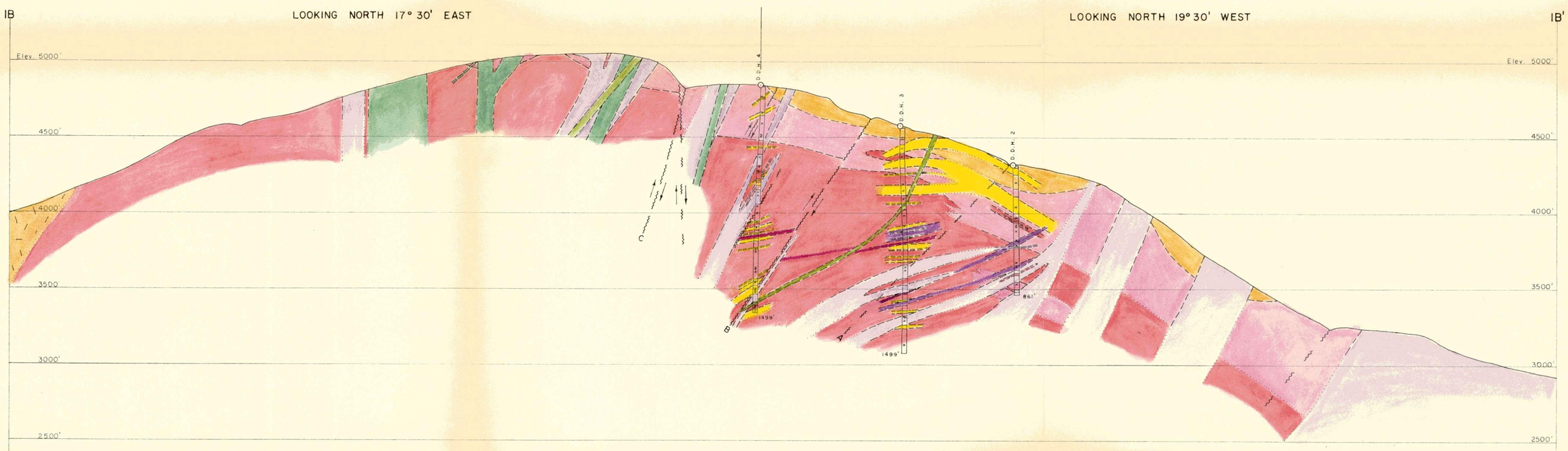
TUZO CREEK MOLYBDENITE PROSPECT

BRITISH COLUMBIA

SCALE 1 INCH = 400 FEET

To Accompany Thesis "PETROLOGY AND STRUCTURE OF THE TUZO CREEK MOLYBDENITE PROSPECT" by G.M. Leary (1969)





SECTIONS To ACCOMPANY FIGURE 5

S Y M B O L S

FAULT (Period III); *Defined (Relative Direction of Movement), Inferred*

D.D.H. 2
861'

B. Q. WIRELINE DIAMOND DRILL HOLE *(Number, Length of Hole)*

NOTE:

Geology by G.M. Leary (1964 - 1966)

Drawn by G.M. Leary (1968); Completed by N. Grant Brown

FIGURE 6

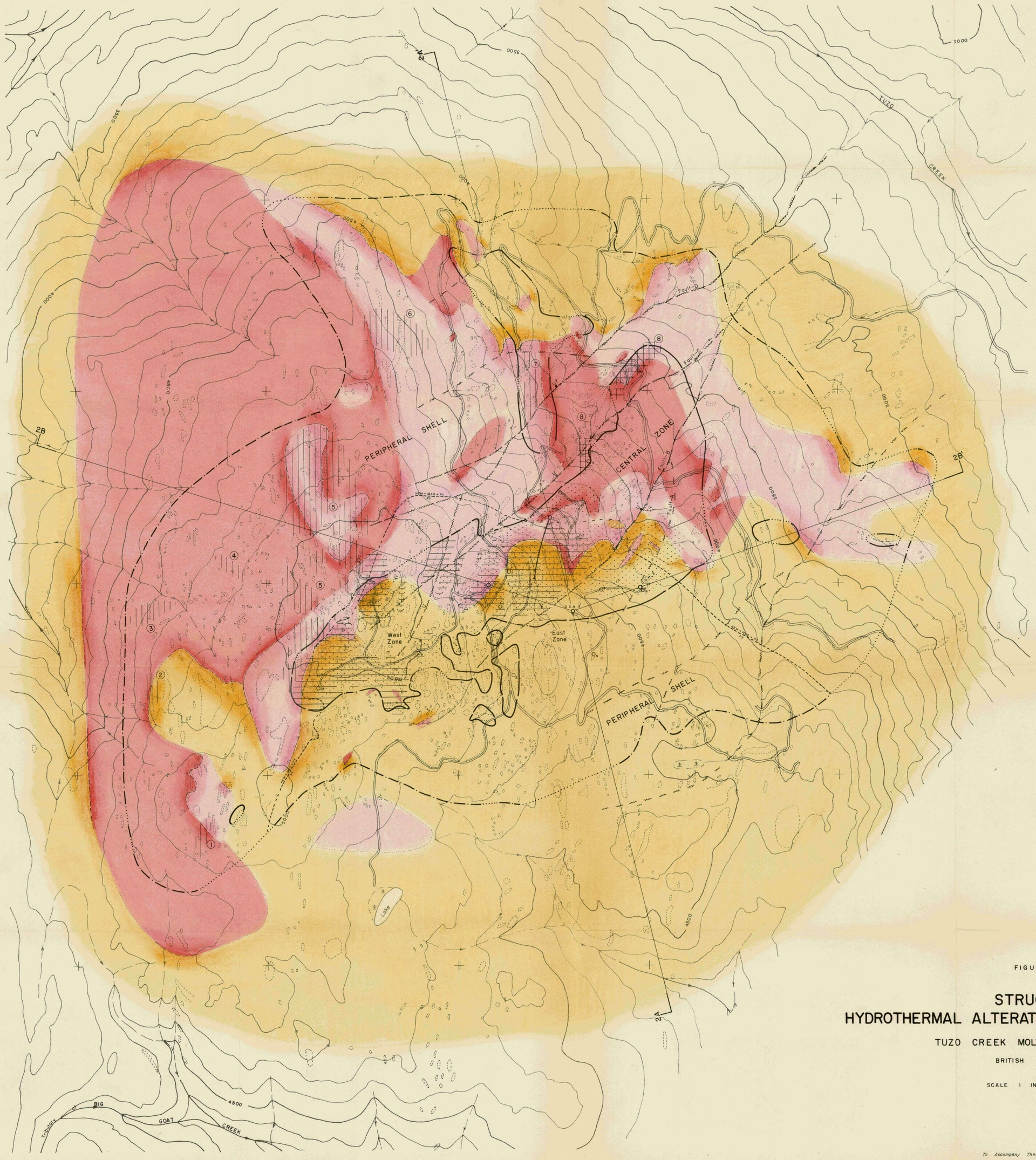
VERTICAL SECTIONS IA-IA' AND IB-IB'
GEOLOGY

TUZO CREEK MOLYBDENITE PROSPECT

BRITISH COLUMBIA

HORIZONTAL AND VERTICAL SCALE 1 INCH = 400 FEET

To Accompany Thesis "PETROLOGY AND STRUCTURE OF THE TUZO CREEK MOLYBDENITE PROSPECT" by G.M. Leary (1969)



LEGEND (Simplified)

PRE- MINERAL

- PORPHYRY ROOF - SILL AND DYKES
- QUARTZ MONZONITE STOCK
- HORNBLENDE GRANODIORITE

NOTE: *Intrusive Contacts Are Projected Across Intra - And Post - Mineral Intrusives*

SYMBOLS

PERIOD - III FAULTS; *Defined (Dip Direction And Upthrown Side), Inferred*

PERIOD - I INTENSELY FRACTURED ZONES

- *Peripheral Zones - 1 To - 7* — *Heavily Mineralized With Hemitite And Magnetite (Phase - I)*
- *Peripheral Zone - 8, With Quartz Veining (Phase - I)*
- *Central Quartz Vein Stockwork Zone (Quartz Veins Are Phase - I)* — *Associated Pyrite And Molybdenite (Phase - I)*

PHASE - I WALLROCK ALTERATION

- *Outline Of The Alteration Halo*
- *Outline Of Moderately Argillized Regions Within The Peripheral Shell*
- *Outline Of Region Of Intense To Very Intense Alteration;* Mainly { *Argillization And Silicification In Upper Part (Exposed)* / *Potash Feldspathization And Silicification In Lower Part (At Depth)*
- *Region Of Weak To Moderate Alteration;* Mainly { *Argillization In Upper Part (Exposed)* / *Potash Feldspathization In Lower Part (At Depth)*

PHASE - I MINERALIZATION

- *Boundary Between Hematite - Magnetite - Pyrite And Pyrite Fields Of Mineralization. (Defined, Projected)*
- *Area Of Molybdenite Mineralization*

NOTE: *Geology by G.M. Leary (1964 - 1966)*
Drawn by G.M. Leary (1968), Completed by N. Grant Brown

FIGURE 7

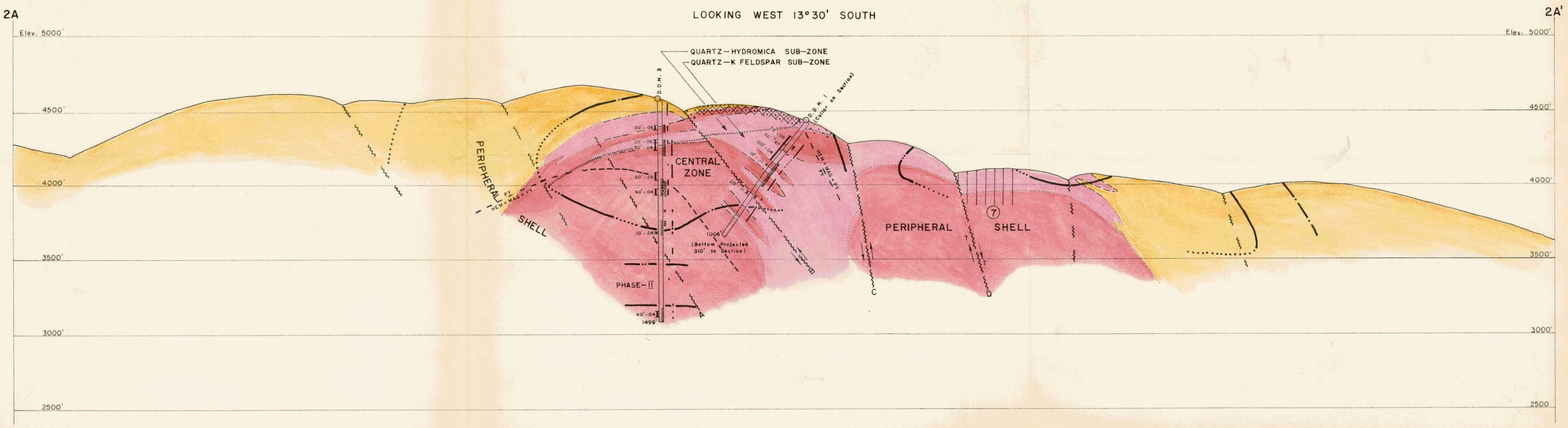
STRUCTURE, HYDROTHERMAL ALTERATION AND MINERALIZATION

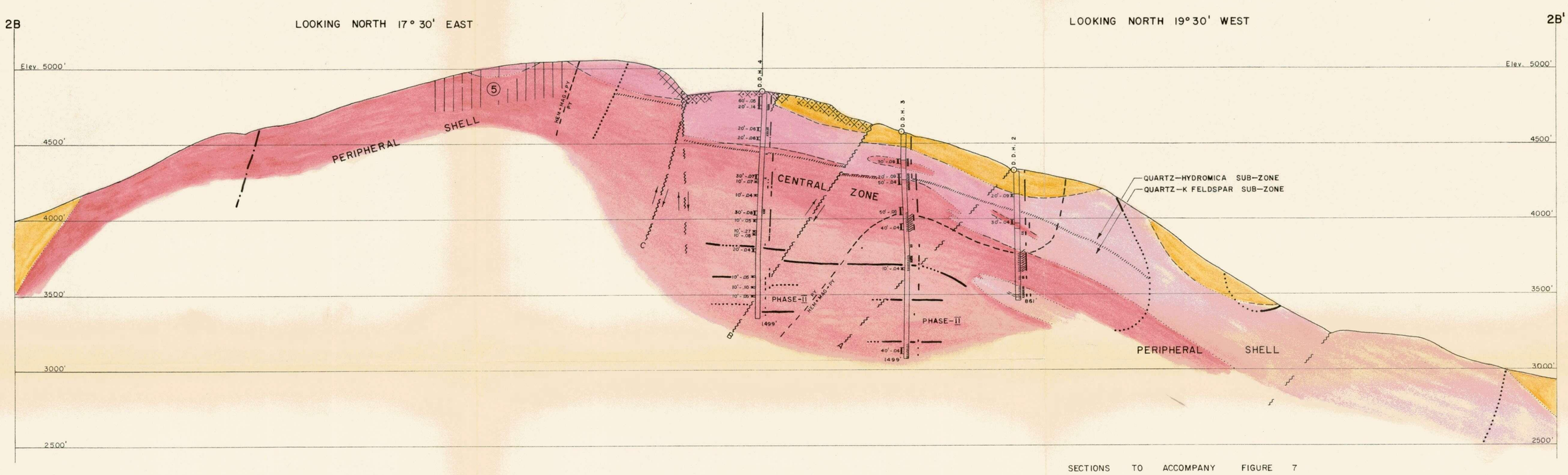
TUZO CREEK MOLYBDENITE PROSPECT

BRITISH COLUMBIA

SCALE 1 INCH = 400 FEET

To Accompany Thesis "PETROLOGY AND STRUCTURE OF THE TUZO CREEK MOLYBDENITE PROSPECT" by G.M. Leary (1969)





SECTIONS TO ACCOMPANY FIGURE 7

S Y M B O L S

Period - III Faults; Defined (Relative Direction Of Movement), Inferred

Wide Shear And Breccia Zone (Period - I)

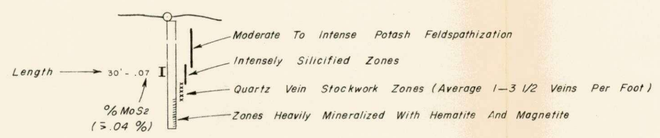
5 *Peripheral Fracture Zones - 5 And - 7 (Period - I)*

Projected Surface Area Of The Central Quartz Vein Stockwork Zone

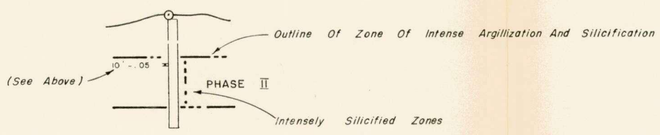
Projected Surface Area Of Molybdenite Mineralization

DIAMOND DRILL HOLE ILLISTRATIONS

PHASE - I FEATURES



PHASE - II FEATURES



NOTE:

Geology by G.M. Leary (1964 - 1966)

Drawn by G.M. Leary (1968) Completed by N. Grant Brown

FIGURE 8

VERTICAL SECTIONS 2A - 2A' AND 2B - 2B'

STRUCTURE, HYDROTHERMAL ALTERATION AND MINERALIZATION

TUZO CREEK MOLYBDENITE PROSPECT

BRITISH COLUMBIA

HORIZONTAL AND VERTICAL SCALE 1 INCH = 400 FEET

To Accompany Thesis " PETROLOGY AND STRUCTURE OF THE TUZO CREEK MOLYBDENITE PROSPECT "
by G.M. Leary (1969)