

THE ALTERATION AND MINERALIZATION OF THE POPLAR
COPPER-MOLYBDENUM PORPHYRY DEPOSIT
WEST-CENTRAL BRITISH COLUMBIA

by

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View of the study area taken from the west. Tagetochlain Lake is seen on the right, and the access road to the property is on the left. The center of the deposit is situated under the stand of fir trees in the foreground.

ABSTRACT

The Poplar copper-molybdenum porphyry deposit, located 270 km west of Prince George, is centered in a late Upper Cretaceous differentiated calc-alkaline stock, which intruded Lower and Upper Cretaceous sedimentary rocks. The stock is capped by late Upper Cretaceous volcanic flow rocks.

The lower Cretaceous Skeena Group consists of intermediate tuff, siltstone, and interbedded sandstone, which steeply dip to the south. This unit is unconformably overlain by a moderately sorted poly lithic pebble conglomerate belonging to the Upper Cretaceous Kasalka Group.

The Poplar Stock, which hosts mineralization, includes a border phase of hornblende quartz monzodiorite porphyry which grades in to a central biotite quartz monzonite porphyry. The stock is intruded by several post-ore dyke units, which include porphyritic dacite, porphyritic rhyolite, felsite, and andesite. Ootsa Lake porphyritic volcanic flow rocks overly the deposit, and are dacite in composition.

Pre-ore, and post-ore rock units have been K-Ar dated, and are within analytical error of each other, having a mean age of 74.8 ± 2.6 Ma. The deposit is covered extensively with glacial till and alluvial sediments. Therefore the majority of geologic information was obtained from logging the drill core from 34 diamond drill holes, twelve of which were logged in detail using a computer compatible logging format. Information logged in this manner was used in statistical studies, and for producing computer generated graphic logs and plots of various geologic parameters, along two cross-sections through the deposit.

Alteration zoning at the Poplar porphyry consists of a 600 m by 500 m potassic alteration annulus which surrounds a 300 m by 150 m argillic alteration core. These are enclosed by 750 m wide phyllic alteration zone, which is itself bordered by a low intensity propylitic alteration zone. Phyllic alteration is defined by the occurrence of sericite, and is the most abundant type of alteration present. Potassic alteration, recognized by the occurrence of secondary K-feldspar and/or secondary biotite, is most closely associated with chalcopyrite and molybdenite.

At least two episodes of alteration are recognized at the Poplar porphyry. The first was contemporaneous with mineralization, following intrusion and crystallization of the Poplar Stock. This episode consisted of potassic alteration in the center of the deposit, which surrounded a 'low grade' core, and graded out to phyllic and propylitic alteration facies at

the periphery. The second alteration event took place after the intrusion of the post-ore dykes and consisted mainly of hydrolytic alteration of pre-existing alteration zones which were adjacent to more permeable centers, such as faults, contacts, and highly jointed areas. This alteration event is responsible for the anomalous central argillic zone, and the alteration of dykes, in addition to probably intensifying and widening the phyllic alteration halo surrounding the deposit. Chalcopyrite and molybdenite were deposited in the potassic zone at approximately 375° C and less than 250 bars, with relatively low oxygen, and relatively high sulfur, activities and moderate pH. As the potassic alteration zone was invaded by more acidic solutions feldspars were altered sericite and clay, and chalcopyrite was destroyed to form pyrite and hematite. Copper was removed from the system.

Statistical studies include univariant one-way and two-way correlation matrices, and multivariant regression analysis. Statistical correlations generally support empirical correlations made in the field. These include positive correlations between various potassic alteration facies minerals, and these minerals and chalcopyrite and molybdenite. Multivariant regression analysis was used to determine which alteration minerals were best suited for indicating chalcopyrite and molybdenite. These minerals are quartz, biotite, magnetite, sericite, K-feldspar, and pyrite. Large error limits and poor correlation statistics in the results from these studies are attributed to deviations from normal distributions for all minerals. A possible cause of this may have been the multistage alteration events that the deposit has undergone

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MAPS

MAP ABack Pocket

MAP BBack Pocket

CHAPTER I

INTRODUCTION

1.1 Location

The Poplar copper-molybdenum porphyry deposit, centered near 54°01'N, 126°58' W (N.T.S. 93L/3E; 93E/15W), is located in west-central British Columbia approximately 270 km west of Prince George and 50 km south-southwest of Houston, in the Omineca Mining Division (Fig. 1.1). The deposit is situated near the centre of the northeast shore of Tagetochlain (local name Poplar) Lake.

1.2 Access

Access to the Poplar porphyry by motor vehicle is made from Highway 16, one km west of Houston, via the Morice River, Owen Lake, and Tahtsa Reach forest access roads to the southeast end of Tagetochlain Lake. A poorly developed dirt road parallels the north-east shore of the lake and terminates at a core shack and abandoned drill camp on the property. The total distance from Houston is 80 km.

Access to the deposit can also be made by helicopter from a helicopter base in Smithers or by float plane which can land on Tagetochlain Lake, adjacent to the property.

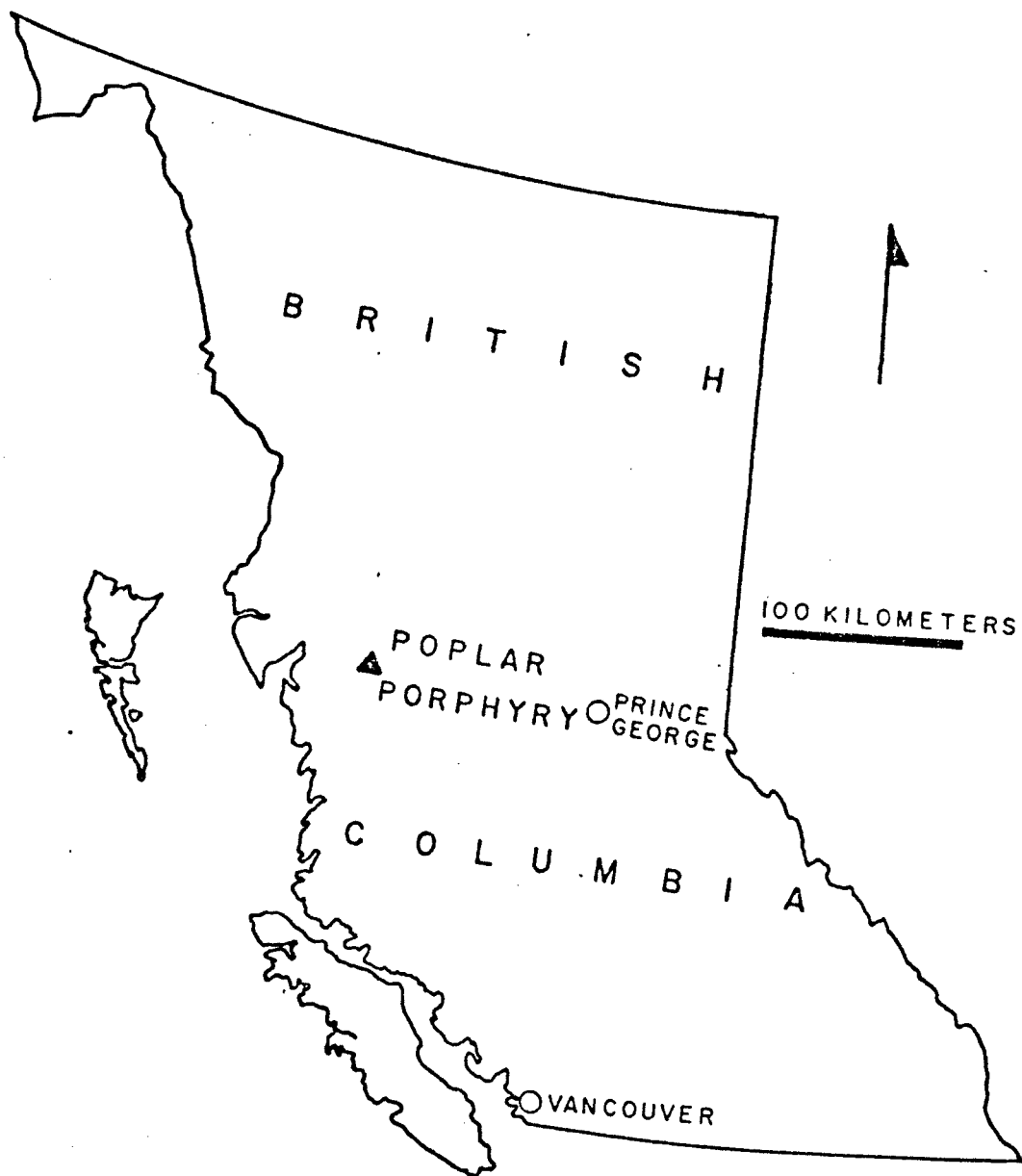


Figure 1.1: Location of the Poplar porphyry deposit; west-central British Columbia.

1.3 Physiographic Setting

The study area lies within the Interior Plateau, approximately 20 km east of its boundary with the Coast Mountains. Major physiographic subdivisions of west-central B.C. are shown in Figure 1.2 (after Carter, 1974; and Holland, 1978). The deposit is located in the west-central portion of the Nechako Plateau, an area of low relief that is largely undissected by erosion (Holland, 1964); elevation generally ranges from 1225 m to 1530 m. This portion of the plateau forms a reentrant into the Hazelton Mountains and is bounded to the north and west by the Bulkley Ranges, and to the south by the Tahtsa Ranges.

Intense glaciation in the area has resulted in the development of many subparallel, northeast trending linear lakes (e.g. Morice, Nanika, and Whitesail Lakes). This orientation indicates a northeast to eastward movement of advancing ice that originated from higher elevations in the Coast Range to the west (Duffell, 1959). Tagetochlain Lake, however, trends almost normal to this direction and evidence presented in Section 3.7 suggests a structurally controlled origin for the lake and adjacent valley. Duffell (1959) estimates that the glacial ice had a minimum thickness of 1345 m because all peaks in the area were covered by ice.

A 10 to 25 km wide physiographic "transition zone" lies

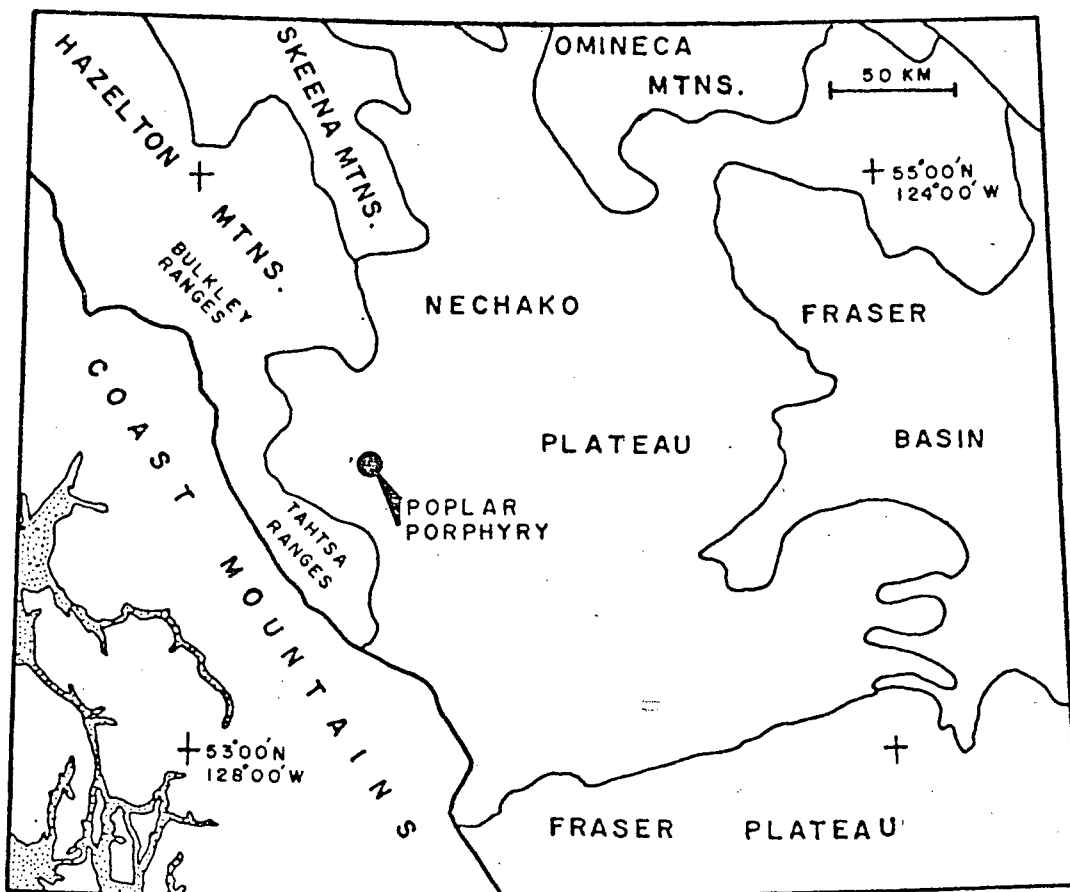


Figure 1.2: Major physiographic subdivisions of west-central British Columbia (after Carter, 1974; and Holland, 1978).

between the Nechako Plateau and the Coast Ranges (Duffell, 1959), and is characterized by small mountain ranges (e. g. Sibola, Tahtsa, and Whitesail Ranges) trending northeast to east, normal to the regional northwest trend of the Canadian Cordillera. Locally, the deposit is situated in a northwest trending valley which parallels Tagetochlain Lake. The area is characterized by moderately rolling topography which ranges in elevation from 840 m at lake level to 1110 m at the western portion of the study area, and rises to 1626 m on Poplar Mountain, 6.5 km to the northeast. Two small streams, Canyon Creek and East Creek, cross the area and flow into Tagetochlain Lake. Local erosional relief varies from less than 1 m to over 10 m, locally forming steep cliffs.

Vegetation includes grasses, wildflowers, and stands of aspen, spruce, and pine trees. Open meadows comprise roughly 60 percent of the land area, and are utilized by local ranchers for cattle grazing. Average annual precipitation averages 75 to 100 cm, but this study was carried out during 1978, an unusually dry and warm field season marked by only eight days of inclement weather.

1.4 History and Development

Evidence of staking and limited assessment work prior to 1970 was discovered in Canyon Creek during the course of field mapping. However, nothing was found to identify the former developers.

The most recent history and development of the property began in the fall of 1970 with the initial staking of six claims by F. Onuchi and C. Critchlow (prospectors under contract to El Paso Mining and Milling Co. Ltd.), following the discovery of geochemical anomalies in silt and soil samples. During the summer of 1971 additional soil geochemical surveys led to the staking of 36 additional claims, which were recorded by F. Onuchi and M. Callaghan (Critchlow, pers. comm., 1978). That fall H. Jones of El Paso Mining and Milling Co. Ltd. commenced limited geologic mapping and extensive soil geochemical surveys (Jones, 1972). Copper and silver anomalies discovered by these surveys were investigated in the spring for 1972 by the excavation of four trenches. Based on the discouraging results from these investigations El Paso Mining and Milling Co. Ltd. transferred all claims on the property to the original prospectors in March of 1973 (Jones, 1972; and Critchlow, pers. comm., 1978). Critchlow brought A. Schmidt of Hudson Bay Oil and Gas Co. Ltd. in to examine the area during the summer of 1973 and additional claims were staked that fall (Critchlow, pers. comm., 1978).

Most of the claims were restaked by Critchlow during June of 1974, after many had lapsed. In August he drilled a hole near the south end of Canyon Creek and discovered "encouraging mineralization" (Critchlow, pers. comm., 1978). T. Schroeter, Resident Geologist at Smithers for the British Columbia Ministry of Mines, investigated the find and following his suggestion the

property was offered to several mining companies. The property was optioned by Utah Mines Ltd. on October 2, 1974.

Exploration and development of the property commenced in the fall of 1974; work included induced polarization and ground-magnetic geophysical surveys and the drilling of four BQ sized diamond drill holes, totalling 937 m (Schmidt, 1975; Witherly, 1975).

Between 1975 and 1977 additional exploration and development included geologic mapping, soil and silt geochemical surveys, geophysical surveys, and the drilling of 36 NQ sized diamond drill holes, totalling 7344 m in depth.

1.5 Scope of Study

Nine weeks were spent on the property, during the course of this study, examining and mapping the surficial geology and logging the subsurface geology from drill core from 34 diamond drill holes.

Particular attention was paid to logging the core along two cross-sections through the deposit (Map A :Sections A-A' and B-B'). Detailed logging involved the use of a computer compatible data format, which was adopted to aid in statistical studies

involving a large number of geologic variables and to facilitate computer plotting of drill hole information. More detailed descriptions of this logging format are given in Chapter III and Appendix E.

CHAPTER II

REGIONAL GEOLOGIC SETTING

2.1 Regional Tectonic Setting

Regional tectonic elements of west-central British Columbia are shown in Figure 2.1; included are the Coast Geanticline, the Hazelton Trough, the Nechako Trough and Bowser Basin, the Skeena Arch and the Pinchi Geanticline. The Poplar porphyry deposit is situated on the southern flank of the Skeena Arch, which was a northeast to easterly trending positive feature from lower Middle Jurassic to Upper Jurassic (Tipper and Richards, 1976).

White (1959) first recognized the Skeena Arch as a salient in the northwest trending folds of the Cordillera. The crest of the arch is marked by a concentration of small stocks and batholiths (Carter, 1974). Various origins for the Skeena Arch have been proposed, including: (1) a reactivated Precambrian basement feature (Carter, 1974); (2) a Jurassic volcanic arc, possibly controlled by basement features (Eisbacher, 1977) and; (3) an interarc high formed synchronously with andesitic volcanism (Monger, et al., 1972).

The Skeena Arch separates the Bowser Basin to the north, from the Nechako Trough to the south. These basins are interpreted as intra-continental successor basins filled with

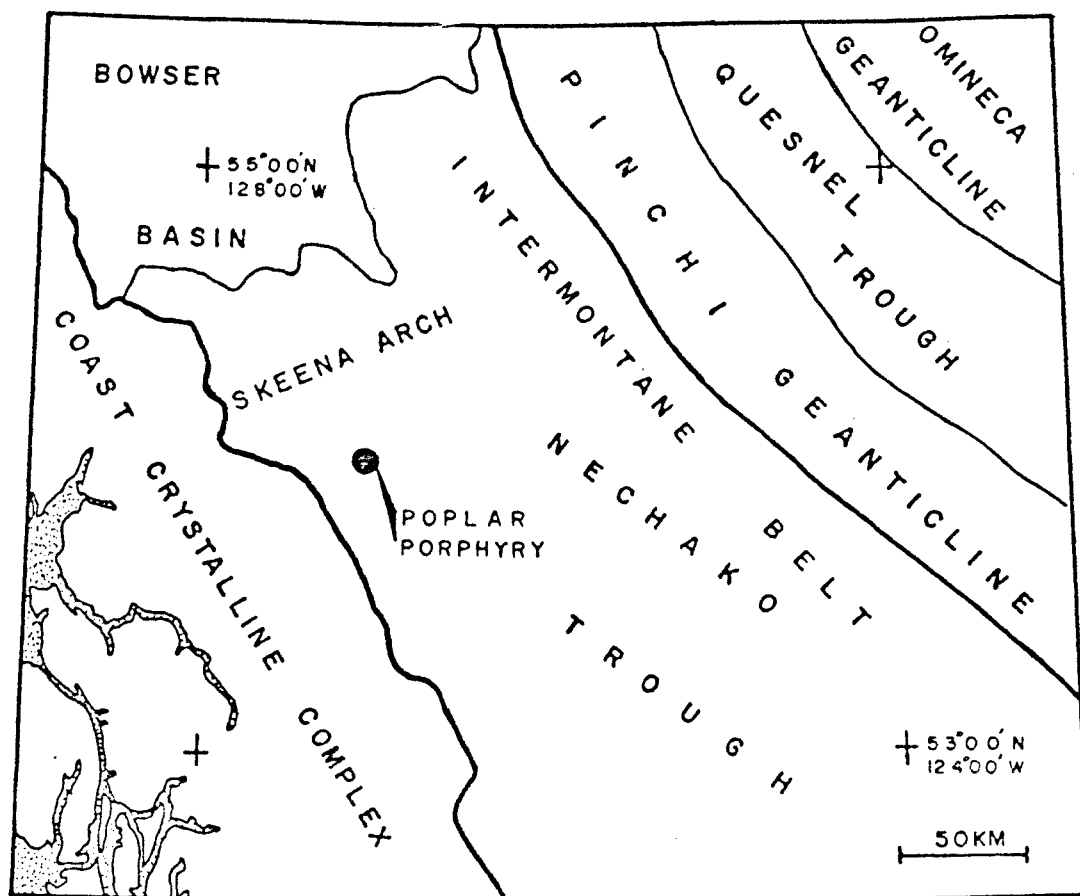


Figure 2.1: Regional tectonic setting of the Poplar porphyry in west-central British Columbia.

Middle to Upper Jurassic flysch and deltaic deposits derived from two paleo-topographic highs; the Pinchi Geanticline and the Skeena Arch (Fistacher, 1977; Carter, 1974; and Tipper and Richards, 1976).

2.2 Regional Geology

The Poplar porphyry deposit is situated within the Intermontane Belt in west-central British Columbia, approximately 30 km east of the boundary with the Coast Crystalline Complex. Stratified volcanic and sedimentary rocks, ranging in age from Lower Mesozoic to Paleocene (Tipper and Richards, 1976b) underlie the Intermontane Belt of west-central British Columbia. Major geologic formations of this region are compiled and summarized in Tables 2.1 and 2.2 (after Duffell, 1959; Carter 1974; MacIntyre, 1976; Tipper and Richards, 1976b; and Woodsworth, 1979).

The Coast Crystalline Complex of west-central British Columbia is underlain by a central gneiss complex composed of banded amphibolite gneisses, plutonic rocks and minor schists, and skarn and marble (Woodsworth, 1979). This complex is in part derived from migmatization of the Paleozoic Gamsby Group, which consists of felsic and mafic tuff, epiclastic volcanic rocks, and limestone and associated skarn. The rocks of this group have all been metamorphosed to at least the greenschist facies (Woodsworth, 1979). Many satellites of the Coast

TABLE 2.1

VOLCANIC AND SEDIMENTARY STRATIGRAPHY OF WEST-CENTRAL BRITISH COLUMBIA

<u>Epoch</u>	<u>Group</u>	<u>Formation</u>	<u>Ref</u> [†]	<u>Description</u>
Oligocene or later	Endako		3	Flat lying basaltic flows and related tuffs and breccia
	unconformity			
Latest Upper Cretaceous to Oligocene	Ootsa Lake		3	Mainly acidic flows with minor basalt, andesite, tuff, breccia, and rare (basal) conglomerate
Upper Cretaceous to Paleogene	Sustut	Brothers Peak	5	Acidic ash-fall tuffs and thick conglomerate bodies
		Local unconformity		
		Tango Creek	5	Feldspathic to chert-pebble-bearing arenites, mudstone and polymictic conglomerate
	unconformity			
Early Upper Cretaceous	Kasalka	Swing Peak	2	Thick succession of flows and coarse clastic rocks (lahars)
		Mt. Baptiste	2	Rhyolite, subordinate andesitic pyroclastic and flow rocks, and basal pebble conglomerate
	unconformity			
Lower Cretaceous	Skeena		1	Greywacke, sandstone, shale, conglom- erate, minor to major coal seams, and basaltic to rhyolitic breccia, tuffs, and flows
	unconformity			
Lower to Middle Jurassic	Hazelton	Smithers	1	Greywacke, lithic sandstone, silt- stone, shale, tuff, volcanic breccia, pebble conglomerate, and silty limestone
		Nilkitwa	1	Interbedded shale, greywacke, andesite to rhyolite tuff and breccia, minor limestone
		Telkwa	1	Clastic, pyroclastic, and flow rocks
Upper Triassic	Takla		1	Basaltic to andesitic volcanic rocks pelitic sedimentary rocks, minor carbonate rocks

[†]References: 1) Tipper and Richards(1976); 2) MacIntyre(1976); 3) Duffell(1959); 4) Carter(1976); 5) Eisbacher(1974)

TABLE 2.2
INTRUSIVE ROCKS OF WEST-CENTRAL BRITISH COLUMBIA

<u>Age(Ma)</u>	<u>Epoch</u>	<u>Intrusive Suite</u>	<u>Ref[†]</u>	<u>Description</u>
47-54	Eocene	Alice Arm	4	Small stocks of quartz monzonite porphyry which host major molybdenum deposits, including B.C. moly
49-53	Eocene	Goosly Lake	4	Porphyritic gabbro and synenomonzonite, representing centers of volcanism(?)
49-55	Eocene	Babine	4	Small plugs, dykes, and dyke swarms of fine grained biotite feldspar porphyry ranging from granodiorite to quartz diorite
47-56	Eocene	Nanika	4	Small plutons of quartz monzonite to granite; hosts major copper-molybdenum deposits
43-51	Middle Eocene	Coast Crystalline Complex Intrusions	4	Quartz diorite, granodiorite, quartz monzonite; forms satellitic stocks east of, and marginal to, a central migmatitic gneiss
-	Upper Cretaceous to Tertiary	Mt. Bolom	5	Porphyritic biotite-hornblende granophyre
70-84	Upper Cretaceous	Bulkley	4	Stocks and small batholiths of porphyritic granodiorite and quartz monzonite; hosts copper-molybdenum and molybdenum-tungsten deposits
104*	Upper Cretaceous	Kasalka	5	Porphyritic latite-andesite, porphyritic dacite, diorite
	Upper Jurassic to Lower Cretaceous	Kitsault	4,5	Quartz diorite, augite porphyry porphyritic andesite, dacite
133-155	Middle to Upper Jurassic	Francois Lake	4,5	Porphyritic quartz monzonite, diorite, quartz diorite, and granodiorite intrusions of batholithic size; Hosts Endako molybdenum deposit
173-206	Upper Triassic to Lower Jurassic	Topley	4	Quartz diorite to quartz monzonite; occupies core of Skeena Arch

[†]References: 1) Tipper and Richards(1976); 2) MacIntyre(1976); 3) Duffell(1959); 4) Carter(1976); 5) Eisbacher(1974)

* MacIntyre determined this K-Ar date is incompatible with other geologic constraints and suggests an Upper Cretaceous age for this suite.

Crystalline Complex forcibly intrude stratified Mesozoic rocks of the Intermontane Belt and are thought to have been generated by ultrametamorphism of the central gneiss complex (Hutchinson, 1970; and Carter, 1974).

Carter (1974; and 1976) has defined four intrusive rock suites, in west-central British Columbia, which host copper only, copper-molybdenum, and molybdenum only mineralization. The individual suites are characterized and distinguished from one another by differences in age, type of mineralization, host rock composition, and location (Carter, 1974, and 1976). The setting of the Poplar porphyry with respect to Carter's classification scheme is discussed in Section 3.6.

CHAPTER III

GEOLOGY OF THE POPLAR PORPHYRY DEPOSIT

3.1 GENERAL STATEMENT

Prior to the initiation of fieldwork it was known that the majority of geological information would have to be obtained from drill core. It further was decided that detailed logging of core from two cross-sections through the previously defined center of the deposit would form the major portion of the study. Drill core from other holes would be logged in less detail to facilitate extrapolation of geologic features in three dimensions. During the course of field study core from 12 holes totalling 2643 m was logged in detail, and core from 22 others totalling 6857 m was logged in less detail.

Emphasis on information from drill core made it desirable to log the core in such a manner that the data obtained would be quantitative and therefore valid for statistical analyses. This required that the measurements and methods used to log the core and record the data be as consistent and accurate as possible. At the same time the methods had to be flexible enough to accomodate any observed geologic feature that was considered pertinent. In addition it was desired that the information be amenable to computer processing.

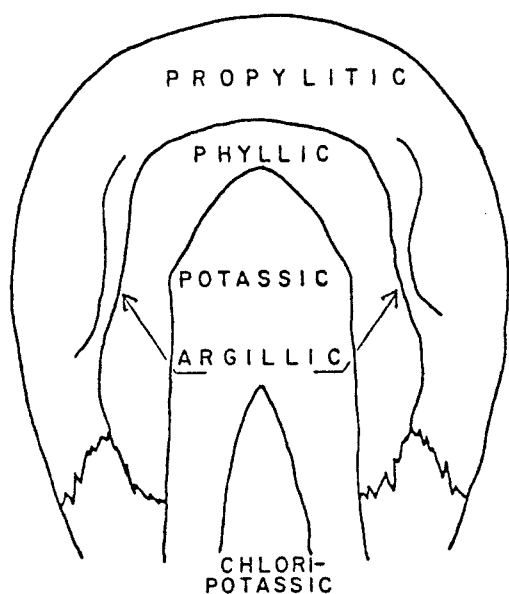
A logging format therefore was designed by modifying previous computer compatible logging formats (c.f. Blanchet and Godwin, 1972; Godwin, et al., 1977; and Wilton, 1978), and is referred to as "Poplarlog".

3.2 Poplarlog

Poplarlog is the name given to a 80 column drill core logging format, designed to be compatible with the 80 columns of a standard computer card. Appendix B contains a blank Poplarlog coding format and a detailed description of its use. Also in Appendix B are tables with the meaning of symbols and codes that were used in filling out the form. The majority of these symbols and codes as well as the diagrams on which they are based, are taken from Godwin (1976), Blanchet and Godwin (1972) and Godwin, et al. (1977).

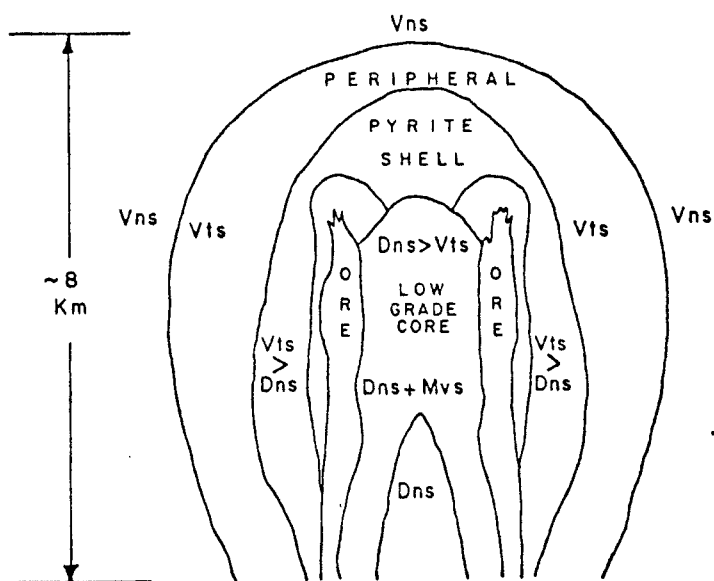
Poplarlog was designed using the Lowell and Guilbert (1970) model of a 'typical' porphyry deposit as a basis, a simplified version of which is shown in Figure 3.1. The major characteristic of this model include:

- (1) concentric shells of alteration and mineralization centered around a porphyritic calc-alkaline stock,
- (2) occurrence of characteristic minerals and/or mineral assemblages of alteration and mineralization in each



MODEL OF ALTERATION ZONATION

PROPYLITIC	chlorite, epidote, albite, carbonate
ARGILLIC	clays, quartz
PHYLIC	sericite, quartz, pyrite
POTASSIC	K-feldspar, biotite
CHLORI-POTASSIC	chlorite, K-feldspar, sericite



MODEL OF MINERALIZATION

Vns	veins
Vts	veinlets
Mvs	microveinlets
Dns	disseminations

(after Lowell and Guilbert, 1970)

Figure 3.1: (a) Typical zonation of alteration facies in a porphyry deposit; (b) model for "modes" of occurrence of alteration and economic minerals in a porphyry deposit. These models formed the basis for the development of Poplarlog.

particular shell, and

- (3) concentric variation in the style of occurrence of mineralization and alteration, from disseminated and pervasive at the center grading to veins at the periphery of the deposit.

Every porphyry deposit, however, is unique, therefore the coding format has been designed to accommodate deviations from the typical deposit. Variables thought to be the most valuable in describing the typical porphyry deposit include:

- (1) position of a described interval of core in x,y,z space,
- (2) zone of enrichment (i. e. hypogene, supergene, oxide, supergene sulfide),
- (3) original (pre-alteration) rock type; with descriptive and qualifying labels to record differences in texture and or mineralogy which could later be used as criteria to form subdivisions of rock units.
- (4) unusual or specific textural features present in the core, and
- (5) sulfide, oxide and silicate alteration and economic

minerals present; their style or "mode" of occurrence, intensity, and position within the Lowell and Guilbert (1970) model.

Three meter depth intervals (roughly equal to two five foot core box lengths) were used to describe the core. However, in a few holes the nature of the core was extremely homogenous and a 6 m (20 ft) interval was used to expedite logging. Shorter intervals were used when abrupt changes in the nature of the core were observed.

3.3 Geological Map and Cross-sections

Map A (1:2500 or 1 cm = 25 m) shows the geology of the Elclar porphyry deposit. The map area, approximately 1800 m north-south and 2100 m east-west, encompasses an area of 3.8 km². Drill holes logged in detail (i. e., 3 m intervals) are shown as closed circles, those logged in less detail are shown as open circles. Figure 3.2 is a map of the central portion of the deposit.

Cross-sections A-A' and B-B' are through those holes logged in detail. Cross-section A-A' trends east-west through eight holes, and is 1500 m long; section B-B' trends 035° azimuth and includes four holes, over a distance of 625 m. The geology of these sections, based on computer plots of drill hole information are shown in Figures 3.3 and 3.4. These sections

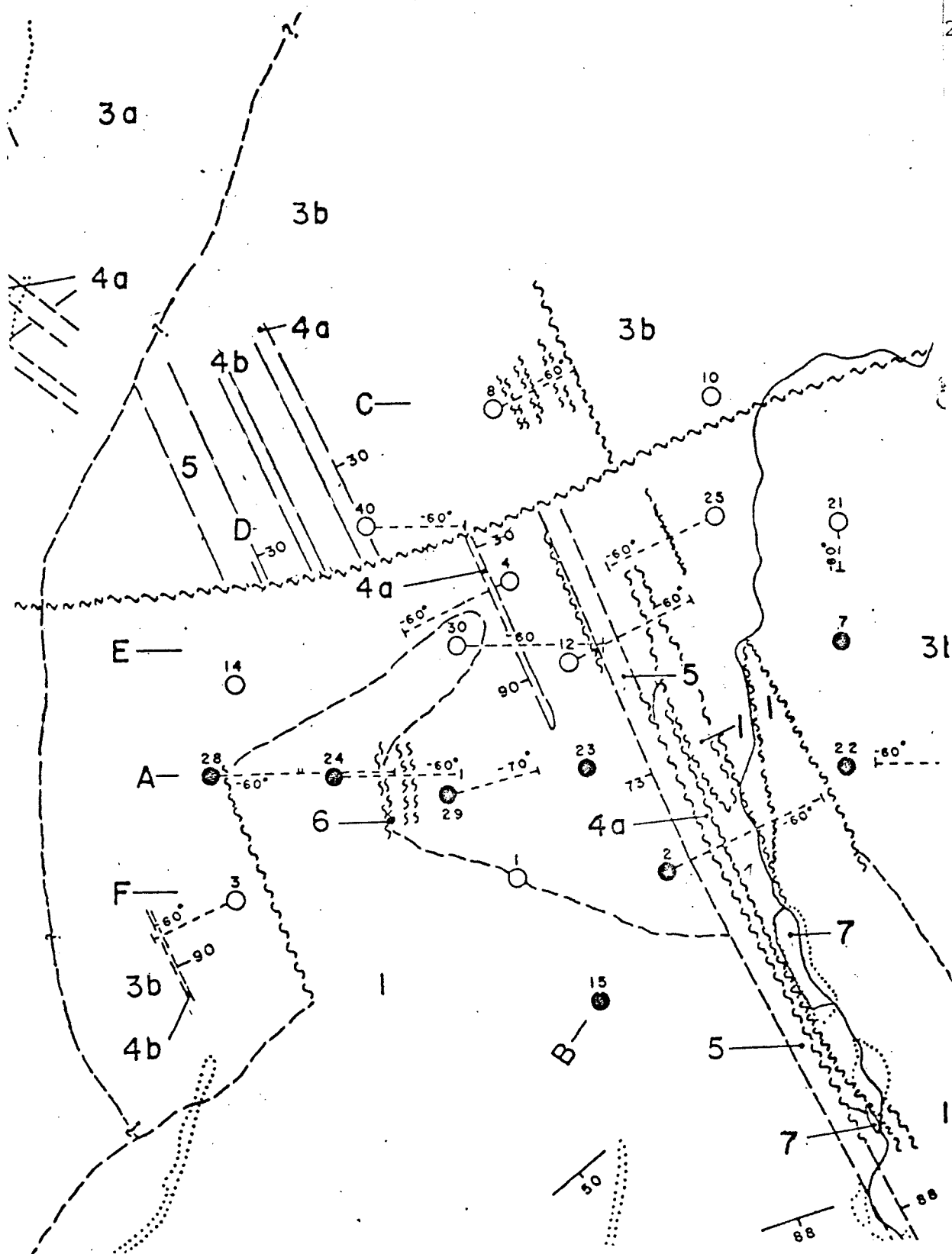










Figure 3.2: Geology of the central portion of the study area (legend identical with Map A), scale= 1:5000. Rock units are: (1) Skeena Group; (2) Kasalka Group; (3a) hornblende quartz monzodiorite, (3b) biotite quartz monzonite; (4a) porphyritic dacite, (4b) felsite; (5) porphyritic rhyolite; (6) andesite; (7) Ootsa Lake Group.



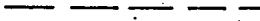
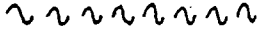
Figures 3.3 and 3.4: Computer generated cross-sections of geology along lines A-A' and B-B' on Map A, respectively.

LEGEND FOR COMPUTER GENERATED CROSS-SECTIONS
OF THE POPLAR PORPHYRY

Geology

<u>Rockunit</u>	<u>Symbol</u>
Andesite	
Rhyolite dyke	
Felsite dyke	
Dacite dyke	
Biotite quartz monzonite porphyry - intrusive breccia	 
Skeena Group	
Interval of core which could not be identified in the field; usu- ally due to intense alteration.	

CROSS-SECTION SYMBOLS

	ground surface
	overburden-bedrock contact
	geologic contact
	fault, or faulted contact
Tl 28	top of drill hole 28, on cross- section 1

T1 28

T1 24

T1 29

T1 23

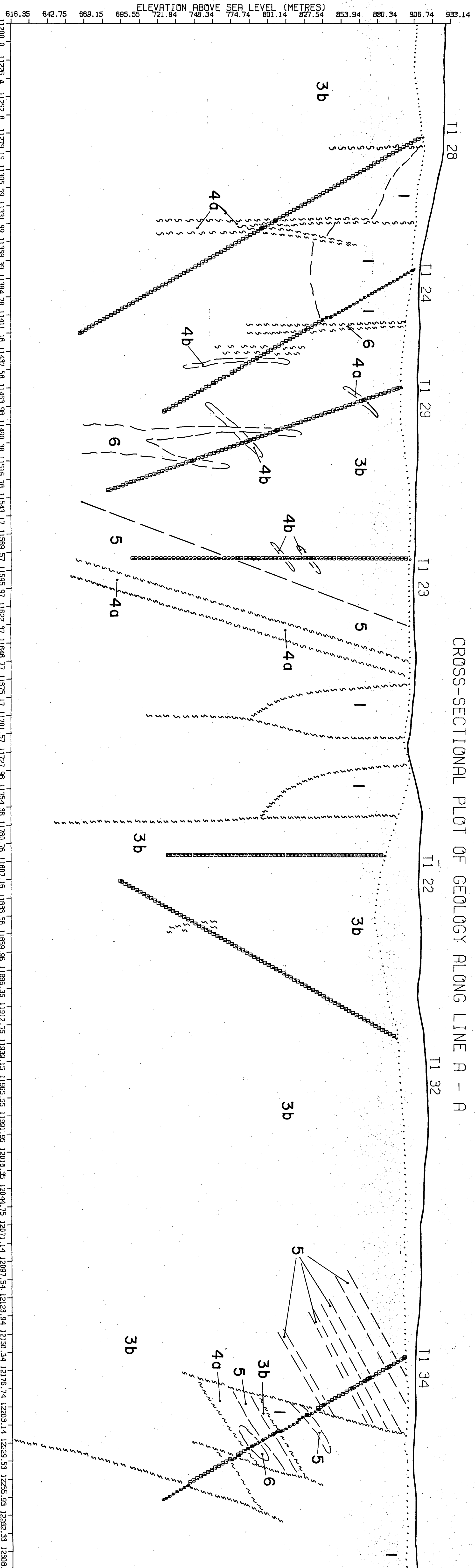
T1 22

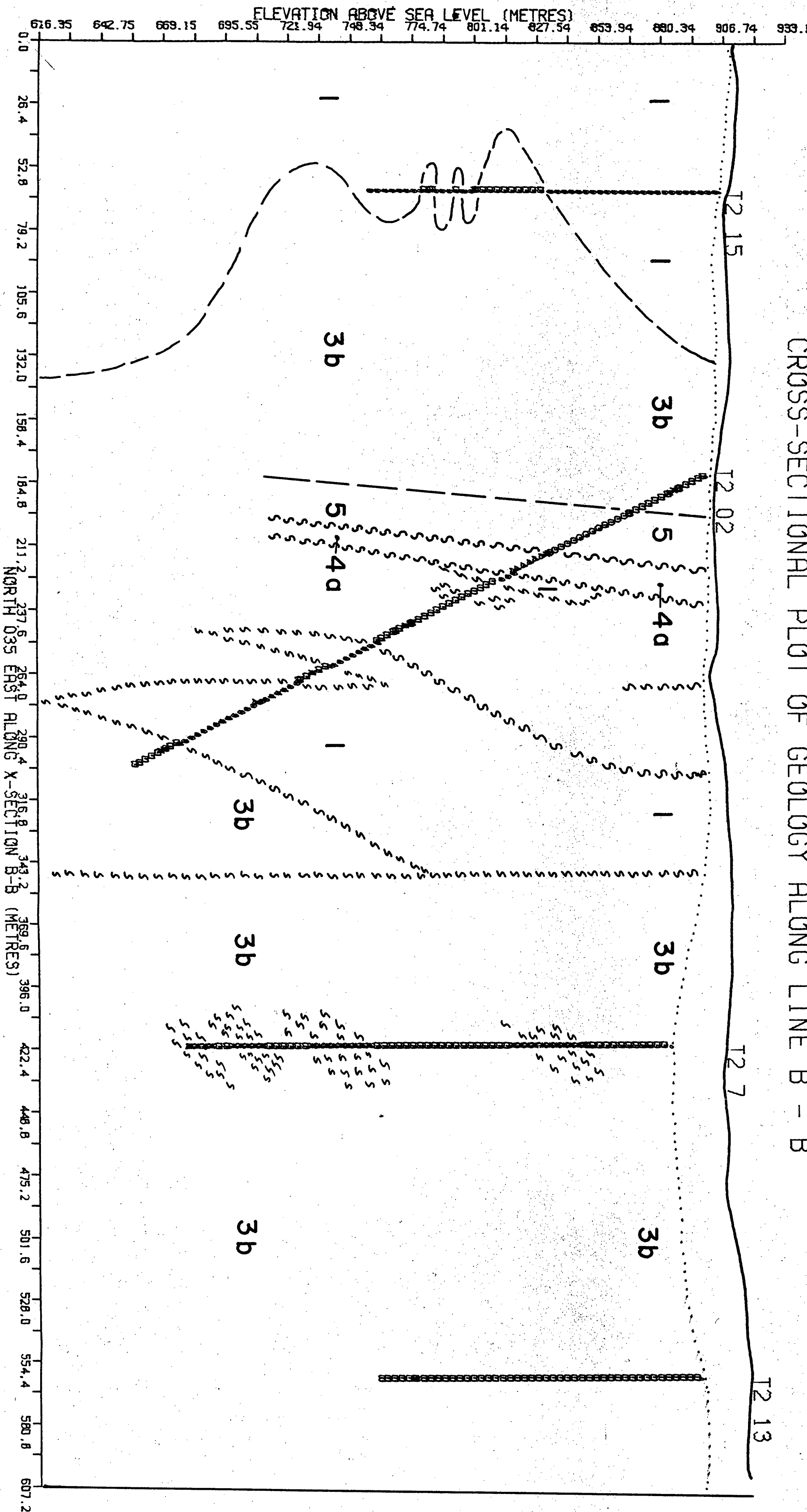
T1 32

T1 34

CROSS-SECTIONAL PLOT OF GEOLOGY ALONG LINE A - A

ELEVATION ABOVE SEA LEVEL (METRES)





are plotted at a scale of 1:1320 (1 cm=13.2 m), which is the smallest size that plotting could be done while retaining adequate resolution between intervals.

Supplementary cross-sections C-C', D-D', E-E' and F-F' (Figs. 3.5, 3.6, 3.7, and 3.8) are based on drill holes logged in less detail. These sections trend east-west with lengths of 800 m, 700 m, 400 m, and 800 m respectively, and are drawn at a scale of 1:2500, compatible with Map A.

3.4 Rock Units

3.4.1 Overview

The Epilar copper-molybdenum porphyry deposit is centered in a late Upper Cretaceous compositionally zoned porphyritic calc-alkaline stock which has intruded upper Mesozoic volcanoclastic and epiclastic sedimentary rocks. Mineralization and alteration were synchronous with emplacement and therefore the deposit is considered to be epithermal (after White, et al., 1968). The deposit is cut by several post-mineralization dykes and is capped by felsic volcanic flow rocks.

3.4.2 Pre-Intrusive Rocks

3.4.2.1 Skeena Group

Skeena Group rocks (Unit 1) consist of thinly bedded dark grey to light tan green crystal and lapilli (aquagene?) tuff and siltstone, and their contact metamorphosed equivalents, with locally interbedded medium grained sandstone lenses up to one meter thick (Plate 3.1).

The unit forms an east-west trending belt through the study area (Map A), ranging from 60 to 725 m wide. Bedding is defined by sharp changes in colour and texture, with planar but locally undulating bedding surfaces that dip between 55° and 80° to the southeast. Upper and lower contacts of this unit are covered so that its total thickness is unknown, but assuming an average dip of 70° and a non-repeated section, there is a maximum 845 m of stratigraphic section present.

Tuffaceous rocks are highly siliceous. Crystal tuff consists of broken quartz crystals ranging in size from 0.1 to 0.35 mm in a chloritic matrix. Clots of chlorite, clay, and spherulitic quartz are probably pseudomorphic after hornblende and biotite. Lithic lapilli range from 4 mm to 3 cm in size.

Most rocks of this unit have undergone varying degrees of



Plate 3.1: Skeena Group rocks (Unit 1, left to right): (a) siliceous ash tuff, iron staining from weathered pyrite veinlets; (b) thinly bedded siltstone, lighter patches are lenses of coarser material; (c) crystal tuff. Scale is in centimeters.

contact metamorphism and/or hydrothermal alteration.

Differences in permeability between sandstone lenses and the tuff probably account for an apparent stratigraphic control to hydrothermal alteration. Sandstone is intensely altered, but adjacent tuff beds are not.

3.4.2.2 Kasalka Group

Kasalka Group rocks (Unit 2) are found in a 300 m by 500 m salient of pre-intrusive rocks in the southeast portion of the study area (Map A). This unit, composed of reddish brown weathering polyolithic conglomerate, lies unconformably over Skeena Group rocks. The contact is nowhere exposed and bedding in the conglomerate is undeterminable; however, outcrops of the Kasalka and Skeena Groups are found less than 10 m apart and neither unit grades towards the contact, therefore the contact appears to be sharp.

The conglomerate (Plate 3.2) consists of 85 percent rounded to subangular clasts of felsic to intermediate tuff, and andesite, quartz, and banded chert. Lithic clasts are the most abundant and largest, ranging from one to five cm in diameter. Quartz clasts are more rounded and are 0.25 to one cm in diameter. Darker tuff fragments appear identical to some of the Skeena Group rocks. The matrix consists of less than two mm grains of chert and quartz. The rock is cemented by silica, pyrite, specular and earthy hematite, and limonite.



Plate 3.2: Kasalka Group conglomerate (Unit 2). Clasts shown consist of rhyolitic (?) and intermediate tuffs, and quartz. Scale is marked in centimeters.

3.4.2.3 Correlation of Pre-Intrusive Rock Units

Tipper and Richards (1967a) have described the upper portion of the Hazelton Group as including an assemblage of greywacke, lithic sandstone, siltstone, tuffaceous shale, tuff, volcanic breccia and a poorly sorted pebble conglomerate. This unit was thought by Bowen (1974, 1975, and 1976), and Mesard et al. (1979) to underlie the study area (Map A). However, with information obtained from recent regional mapping to the immediate south and southeast of Tagetochlain Lake by Woodsworth (1979, and pers. comm. 1978) the lower volcanoclastic and epiclastic unit (Unit 1) is assigned here to the Lower Cretaceous Skeena Group. The Skeena Group has been described by Tipper and Richards (1976a) to consist of greywacke, sandstone, shale, conglomerate and volcanic strata (Table 2.1).

The upper conglomerate unit (Unit 2) is now assigned to the basal portion of the Upper Cretaceous Kasalka Group, which has been defined by MacIntyre (1976) in the Tahtsa Lake area, approximately 30 km south of Tagetochlain Lake. MacIntyre (1976) described this unit as a poorly sorted pebble conglomerate containing rounded to subangular clasts of oxidized Hazelton and Skeena Group rocks in a sandy matrix cemented with iron oxide and silica. The occurrence of the Kasalka Group conglomerate in the study area is the furthest location north of Tahtsa Lake that this unit has been observed.

3.4.3 Mineralized Intrusive Rocks

3.4.3.1 General Statement

Prior to the present study a number of porphyritic intrusive rocks, related to mineralization and alteration, were identified by Utah Mines Ltd. geologists (Bowen, 1975, 1976 and pers. comm. 1978). However, through the detailed logging of core during the course of this study, it is concluded that the textural and mineralogical differences previously attributed to different intrusive rocks are mainly due to the varying effects of hydrothermal alteration.

The majority of mineralization and alteration at the Poplar porphyry deposit occurs within a late Upper Cretaceous quartz monzodiorite to quartz monzonite stock (Units 3a and 3b). Older rocks also host sulfide mineralization; younger rocks are barren except for rare occurrences of pyrite. Therefore the major mineralization - alteration event is genetically related to this intrusive stock. Hornblende quartz monzodiorite (Unit 3a), although mapped as a separate unit, is probably a hybrid border phase of the biotite quartz monzonite porphyry stock (Unit 3b).

Widespread and variable alteration of all rock units (except Ootsa Lake Group volcanic rocks, unit 7) makes hand specimen and thin section examination difficult. Commonly, only pseudomorphs after plagioclase and mafic minerals are available

for the interpretation of original texture and to estimate original mineral abundances. Groundmass minerals were often totally obliterated. Ambiguous relationships between alteration minerals compounded these difficulties.

Rock descriptions which follow ignore alteration effects and are based on samples which have undergone the least amount of alteration. Rock names are taken from the classification of Streckeisen (1967) and the International Union of Geological Sciences, I.U.G.S. (1973).

3.4.3.2 Hornblende Quartz Monzodiorite

Hornblende quartz monzodiorite (Unit 3a) is found at the surface in both the southern and western portions of the study area (Map A). The southern occurrence is bounded on the south by Tagetochlain Lake, and is found in intrusive contact with Kasalka Group rocks (Unit 2) to the north. The western occurrence forms a north-south trending outcrop pattern which is in gradational contact with the biotite quartz monzonite porphyry (Unit 3b) to the east, and in presumed intrusive contact(?) with Skeena Group rocks (Unit 1) to the west. However, this western contact is covered by Ootsa Lake Group volcanic rocks, (Unit 7) and therefore the exact nature of the contact is unknown.

Fresh hornblende quartz monzodiorite, in hand sample, is

pale to dark grey and weathers pale tan to brown. The rock is porphyritic, with plagioclase and hornblende phenocrysts ranging in long dimension from one to eight mm and from one to 20 mm, respectively. Phenocryst packing varies from 10 to 80 percent, and phenocryst size varies inversely with abundance (Plate 3.3). The groundmass is aphanitic to microcrystalline and ranges from light to dark grey in colour.

Thin sections of this unit show it to be composed of five to 20 percent euhedral to subhedral hornblende with an average length of 1.5 mm and a range of 0.1 mm to 20 mm. Seriate euhedral to subhedral plagioclase crystals ranging in size from 0.01 to eight mm, comprise from 10 to 70 percent of the rock. Plagioclase (about An₃₃) is commonly glomeroporphyritic and zoned, and locally contains inclusions of quartz and zircon.

Quartz, ranging from one to 10 percent, occurs as resorbed 0.1 to one mm subhedral crystals and anhedral infillings between plagioclase crystals in the groundmass. Orthoclase comprises about 15 percent of the rock, occurring as clouded equigranular anhedral crystals in the groundmass. Magnetite comprises approximately five percent of the rock, occurring as discrete grains in the groundmass or as inclusions in hornblende crystals. Euhedral books of primary biotite, one to two mm across, range from less than one to five percent of the rock and are less abundant than hornblende.



Plate 3.3: Textural variations within the hornblende quartz monzodiorite (Unit 3a). The sample on the left contains minor chalcopyrite, the others are barren.

Whole rock major element analyses and C.I.P.W. norms of this unit is listed in Table A.2 (Appendix A). These data will be discussed in more detail in Section 3.6.

A K-Ar model age of 76.2 ± 2.7 Ma was determined from a hornblende separate from this unit (Table A.1 in Appendix A). This age is not statistically distinguishable from that of the biotite quartz monzonite porphyry, discussed below. This is a major criterion for interpreting the genetic relationship between these two units (Section 3.5).

3.4.3.3 Biotite Quartz Monzonite Porphyry

Biotite quartz monzonite porphyry (Unit 3b) underlies the northeast quarter of the study area (Map A), and comprises the most abundant rock type in the cross-sections (Figs. 3.3, 3.4, 3.5, 3.6, 3.7, and 3.8). This unit is bordered to the south and east by Skeena Group rocks; to the west it is in gradational contact with the hornblende diorite. Boundaries to the north and northeast have not been mapped.

Contacts between the biotite quartz monzonite and Skeena Group rocks generally are intrusive but locally are faulted forming steeply sheared inliers of Skeena Group rocks within the intrusion (Figs. 3.3 and 3.4). Rocks on both sides of this contact have generally been altered to such an extent that the original texture is totally obliterated which makes

identification of the rock type difficult. This intense alteration is due to abundant fractures and veins near the contact and the effect these fractures had on the localization of hydrothermal fluids. Contacts with the hornblende quartz monzodiorite are gradational and are nowhere observed in outcrop. The contact is arbitrarily defined by a 1:1 hornblende to biotite ratio.

Biotite quartz monzonite porphyry is light grey to black when fresh, and weathers reddish brown (Plate 3.4). One to seven mm euhedral biotite phenocrysts are diagnostic, comprising three to 15 percent of the rock. Euhedral to subhedral plagioclase phenocrysts range from two to eight mm across and comprise five to 80 percent of the rock. Size and packing of plagioclase phenocrysts is variable, even over short distances, and has a profound effect on the intensity and type of alteration present (discussed further in section 4.4.2). Hornblende phenocrysts form up to eight percent of the rock. The aphanitic groundmass is dark to pale grey to pink. Exotic fragments of Skeena Group(?) rocks ranging from one to 10 cm across were locally observed.

Microscopically, the porphyritic texture varies from hiatal to seriate. Rare fresh plagioclase (about An35) has normal and oscillatory zoning and is locally glomeroporphyritic. The groundmass is composed of 0.05 to 0.5 mm equidimensional



Plate 3.4: Biotite quartz monzonite porphyry (Unit 3b). This shows the compositional and textural variation within the unit. Plagioclase abundance and its susceptibility to alteration had the most effect on the variation in appearance. Plagioclase abundance and intensity of alteration increases from left to right.

anhedral orthoclase and quartz, comprising 10 to 15 percent and 10 to 20 percent of the rock, respectively. Orthoclase forms local myrmekitic textures with quartz or plagioclase. Magnetite is commonly present as minute disseminations. Minor euhedral to subhedral apatite is also observed.

Biotite quartz monzonite porphyry very locally consists of an intrusive breccia (Plate 3.5). The breccia consists of fragments of biotite porphyry and Kasalka Group(?) rocks which comprise 40 to 80 percent of the rock. Fragments are angular to subrounded, vary in size from 0.5 to 5 cm across and are rotated and generally matrix supported. The matrix is black to grey and varies from aphanitic to porphyritic with one to eight mm zoned and glomeroporphyritic plagioclase phenocrysts and one to two mm biotite phenocrysts. The groundmass of the matrix is composed of 25 percent 0.05 to 1.5 mm euhedral to subhedral biotite, and 50 percent subhedral to anhedral plagioclase 0.05 to one mm in length. The remainder consists of fine grained quartz, orthoclase, magnetite and apatite.

Normative mineral abundances for the biotite quartz monzonite porphyry are listed in Table A.2 (in Appendix A). Two concordant late Upper Cretaceous K-Ar model ages for this unit, have been determined from biotite separates to be 76.9 ± 2.3 Ma and 73.7 ± 2.5 Ma (Table A.1 in Appendix A).

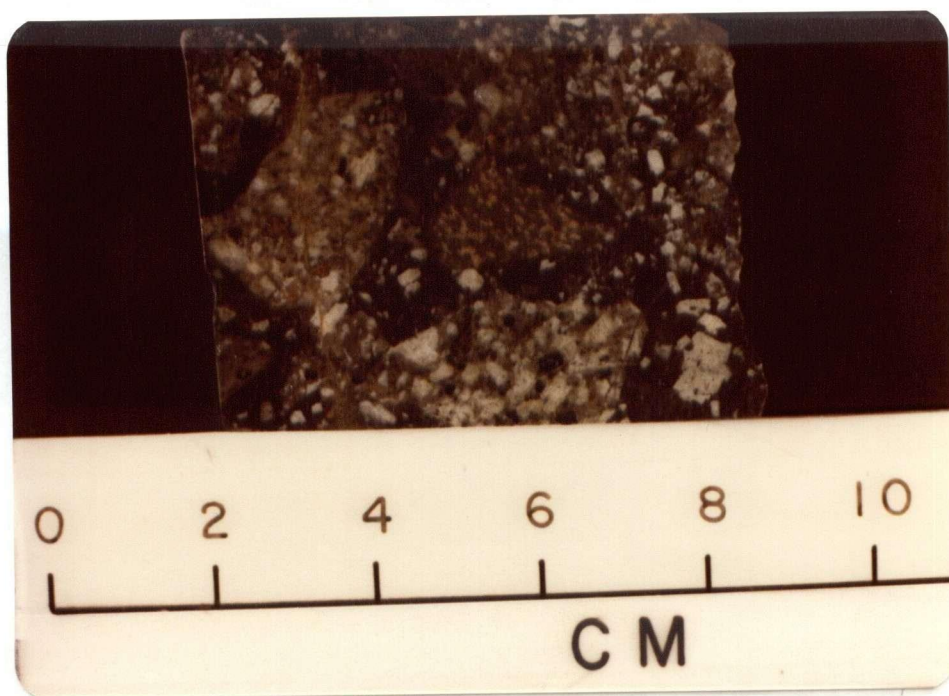


Plate 3.5: Intrusive breccia phase of the biotite quartz monzonite (Unit 3b). The clasts consist of both fragments of the porphyritic phase of Unit 3b, and of Kasalka Group rocks (Unit 2). The matrix consists of 25% biotite. Chalcopyrite veinlet runs vertically through the sample one centimeter from the left edge.

3.4.4 Post-Ore Dykes

3.4.4.1 General Statement

Several north to northwest trending dykes intrude all previously described rock units (Map A and Fig. 3.2). The dykes do not contain any sulfides but are generally altered, especially at their contacts. This strongly indicates a second post-mineralization alteration event, and will be discussed in more detail in Section 4.4.5. There are four lithologically distinct dyke units; from oldest to youngest these are: porphyritic rhyodacite, felsite, porphyritic rhyolite, and andesite. Relative ages are defined by cross-cutting relationships.

3.4.4.2 Porphyritic Dacite Dykes

Porphyritic dacite (Unit 4a) occurs in faulted and intrusive contact with all other rock units except Kasalka Group rocks. The unit is found in three separate areas (Map A): (1) just east of the contact between Ootsa Lake Group volcanic rocks and the hornblende diorite, in the western portion of the study area, (2) in contact with a porphyritic rhyolite dyke (Unit 5), where both dyke units intrude mineralized biotite porphyry in the center of the study area, and (3) as one of many dyke units which occur between the biotite quartz monzonite porphyry and Skeena Group rocks in the eastern portion of Map A .

Porphyritic dacite (Plate 3.6) is characteristically red to



Plate 3.6: Porphyritic dacite (Unit 4a). The drill core sample on the left shows pilotaxitic texture and contains xenoliths. The middle sample is a quartz latite-andesite from outcrop and is correlated with the dacite. The sample on the right shows the unit as it was most commonly observed, with biotite phenocrysts.

purple in colour, with a fine grained pilotaxitic texture. Amygdules, one to 20 mm across contain quartz and calcite. Rounded quartz "eyes" are locally observed. Fine to medium grained euhedral plagioclase, biotite, and hornblende phenocrysts comprise up to 25, 10 and five percent of the rock respectively. Zoned and glomeroporphyritic plagioclase (about An28) ranges from one to 10 mm across and have been partially resorbed. Biotite is one to five mm in diameter. Hornblende is one to five mm in length and has generally been altered to chlorite. The groundmass of the porphyritic dacite consists of mostly 0.1 mm laths of plagioclase with lesser anhedral grains of quartz and orthoclase. Fine grained apatite is an accessory mineral.

Whole rock analyses of two samples of this unit are presented in Table A.2; one sample is from outcrop, the other from drill core. The former is classified as a quartz latite-andesite and the latter as a dacite (after Strechenisen, 1967). The term porphyritic dacite is preferred as a field name, and is used here to describe both rock types.

One K-Ar model age of 72.2 ± 3.0 Ma has been determined for this unit from a biotite separate taken from drill core (Table A.2 in Appendix A). This date is important because it places an upper limit on the age of the mineralizing event at the Poplar porphyry. Field evidence, including chilled contacts and

paucity of sulfide mineralization, also indicates that this unit is younger than the mineralizing event which accompanied the intrusion of the biotite quartz monzodiorite porphyry.

3.4.4.3 Felsite Dykes

Light pink to tan aphanitic dykes (Unit 4b) less than two meters thick were noted in drill core . This unit resembles chilled portions of the porphyritic dacite dyke and is probably equivalent to it. However, locally this unit may be the chilled equivalent to the porphyritic rhyolite.

3.4.4.4 Porphyritic Rhyolite Dykes

Steeply dipping porphyritic "quartz eye" rhyolite dykes (Unit 5) are the most abundant type of dyke rock in the study area (Map A), and are found in faulted or intrusive contact with all other rock units except the Kasalka Group. Contacts with the porphyritic rhyodacite are generally chilled, but are locally gradational. Dykes of this unit generally trend northwesterly and are concentrated in areas marked by aerial-photograph lineaments which probably reflect fault zones.

Porphyritic rhyolite (Plate 3.7) is characteristically white to tan with distinctive one to five mm embayed quartz phenocrysts ("eyes") comprising 10 percent of the rock. Chloritized biotite patches, one to five mm across are locally observed; one to two mm argillized plagioclase phenocrysts are rare. The aphanitic groundmass consists of 0.05 to 0.2 mm equidimensional

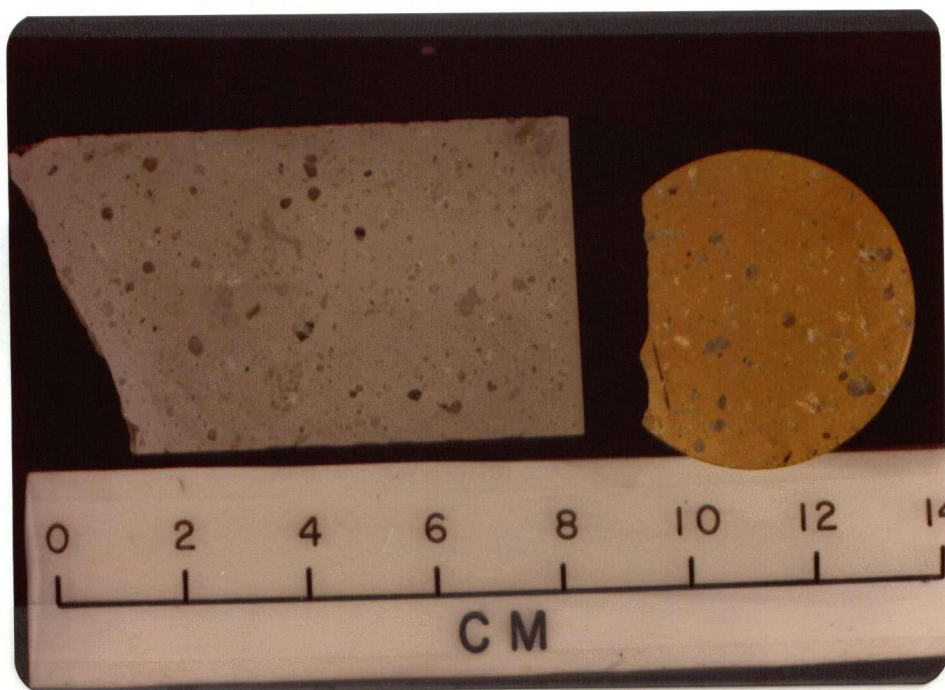


Plate 3.7: Porphyritic rhyolite (Unit 5). Embayed quartz "eyes" are the most distinctive feature of this unit. Greenish spots are chlorite patches after biotite. The sample on the right has been stained to show K-feldspar in the groundmass.

equigranular quartz and orthoclase.

3.4.4.5 Andesite Dykes

Dark grey andesite dykes (Unit 6) were intersected in a few drill holes. This unit is highly magnetic and consists of two percent altered, subhedral plagioclase and quartz phenocrysts 0.5 to 1.0 mm in diameter. The equigranular groundmass consists of 95 percent subhedral plagioclase and three percent anhedral quartz, 0.1 to 0.2 mm in diameter. Locally the texture is amygdaloidal and pilotaxitic. A few 0.5 mm pseudomorphs of chlorite after hornblende(?) are also observed.

3.4.5 Extrusive Rocks

3.4.5.1 Ootsa Lake Group

Ootsa Lake Group volcanic flow rocks (Unit 7) cap the hill immediately west of the deposit (Map A). From aerial photographs the lower contact of this unit, both near the deposit and on hills 1.5 km north and northwest of the map area, lie at approximately the same elevation; therefore, the lower contact of this unit is horizontal. Although the contact is obscured in the study area the flat attitude requires an unconformable contact with underlying units. Ootsa Lake Group volcanics also crop out topographically much lower, in Canyon Creek (Map A), and probably were emplaced by block faulting (see Section 3.7).

These rocks have not been dated isotopically, but are post-intrusive since they overlie and are not displaced by the major east-west trending fault which cross-cuts the deposit in Map A, yet protrudes from both sides of volcanic cover on aerial photographs.

Outcrop of Ootsa Group rocks is characterized by subparallel cleavage that produces platy rubble which is pink, grey, or brown in colour (Plate 3.8). The rock is porphyritic, with lateral variations in phenocryst size; phenocrysts of coarse grained plagioclase and hornblende occur in the southwest, but become finer grained and impart a pilotaxitic texture to the rock in the northwest portion of Map A.

Mineral content consists of 15 to 25 percent seriate plagioclase phenocrysts ranging from 0.5 to five mm in long dimension, and up to 10 percent hornblende phenocrysts ranging from one to five mm in length. Plagioclase phenocrysts locally are pink due to inclusions of hematite, and can resemble orthoclase. The groundmass consists of 0.1 to 0.3 mm plagioclase laths and slightly larger and less abundant subhedral to anhedral quartz and anhedral orthoclase. Minor apatite is also observed.

A whole rock analysis from a coarse grained porphyritic



Plate 3.8: Ootsa Lake Group volcanic flow rocks (Unit 7). The coarse grained porphyritic sample on the left comes from the southwestern portion of Map A. The middle sample shows pilotaxitic texture, and comes from Canyon Creek. The sample on the right comes from the northwest, and shows pilotaxitic texture, as indicated by fine grained chloritized hornblende phenocrysts.

flow rock from this unit is presented in Table A.2 (Appendix A). The rock is classified as a dacite (after Streckeison, 1967). To the writer's knowledge there are at present no published data on the chemical composition of Ootsa Lake Group rocks. Therefore, no comparison can be made between "typical" Ootsa Lake Group rocks and the volcanic flow rocks found in the study area.

3.4.5.2 Correlation of Extrusive Rocks

Duffell (1959) described Ootsa Lake Group volcanic rocks as consisting of "... mainly acid flows with minor amounts of basalt, andesite, tuff, breccia, and rare conglomerate...." (Table 2.1). Tipper and Richards (1967a, and 1976b) have mapped Upper Cretaceous volcanic rocks in the Tagetochlain Lake area as belonging to both the Endako and Ootsa Lake Groups (Table 2.1). After examining the volcanic flow rocks in the study area (Map A), Richards (pers. comm., 1978) believed them to belong to the Ootsa Lake Group.

3.5 K-Ar Age Determinations

Four K-Ar model ages were obtained at the Poplar porphyry (Table A.1, Appendix A): two from biotite separates of the biotite quartz monzonite porphyry (Unit 3b), one from a biotite separate of the dacite (Unit 4a), and a hornblende separate from the hornblende quartz monzodiorite (Unit 3a). All ages are indistinguishable from each other within analytical error limits. The mean age of these dates is 74.8 ± 2.6 Ma.

Because the age obtained from the post-mineralization dacite dyke is essentially the same as for mineralized rock units, the age of the mineralizing event can be considered geologically synchronous with the intrusion of the biotite quartz monzonite porphyry stock. White, et al (1968) have used the term "paramagmatic" to describe deposits which are epigenetic and can be shown by geological and/or radiometric evidence to be an integral feature of a magmatic event.

3.6 Comparison of the Poplar Porphyry to Other Porphyry Deposits of West-Central British Columbia.

There are a number of porphyry deposits located in west-central British Columbia (Christopher and Carter, 1976). Carter (1974, and 1976) has separated the intrusive rocks which host these deposits into four intrusive rock suites. Each suite is unique in one or more of the following: geographic distribution, type of contained mineralization, host rock composition, and K-Ar model age for intrusion.

These four intrusive rock suites form crude north-south trending belts. These belts consist of the following: the molybdenum bearing Alice Arm intrusions of Eocene age, on the west; copper and molybdenum bearing intrusions of the Upper Cretaceous Bulkley intrusions and Eocene Nanika intrusions, in the center; and copper bearing Babine intrusions of Eocene age, to the east.

Based on geographic location and type of contained mineralization, the Poplar Porphyry deposit cannot belong to either the Alice Arm or the Babine intrusive suites. However, intrusions of both the Bulkley and Nanika suites host copper-molybdenum porphyry deposits, and both types are known to occur within 50 km of the Poplar porphyry. The huckleberry, Ox Lake, Nadina, and Duck Lake intrusions are members of the former, and the Lucky Ship, Berg, Nadina Mountain, Goosley, and Morice Lake intrusions belong to the latter. The Nanika intrusive suite, however, is Eocene in age, and the Bulkley intrusions are Upper Cretaceous. A comparison between these ages and those obtained from the Poplar porphyry (Table A.1, Appendix A; and Section 3.5) indicates that all dated rock units at the Poplar porphyry were intruded during the Bulkley intrusive event.

Further support of this classification is presented in Figure 3.9, which shows the normative compositional fields of the Bulkley and Nanika intrusions plotted on a ternary quartz-orthoclase-plagioclase diagram taken from Carter (1974, and 1976). Also shown on Figure 3.9 are the normative compositions of the hornblende quartz monzodiorite porphyry (Unit 3a) and the biotite quartz monzonite porphyry (Unit 3b). Hornblende quartz monzodiorite lies within the Bulkley compositional field and the biotite quartz monzonite porphyry lies on the boundary of this field. The latter is more potassium rich than most Bulkley rocks but is less siliceous than the Nanika compositional field.

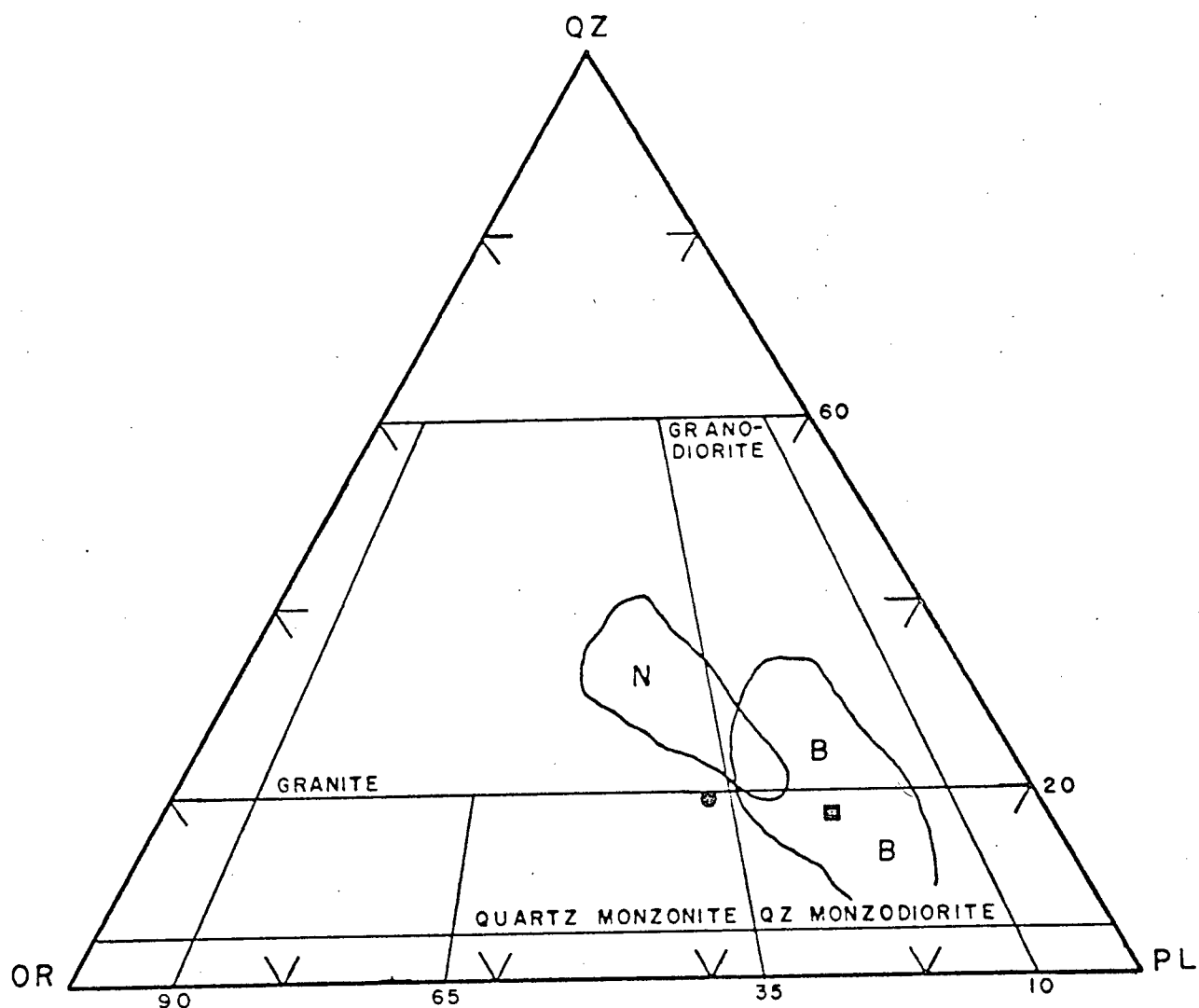


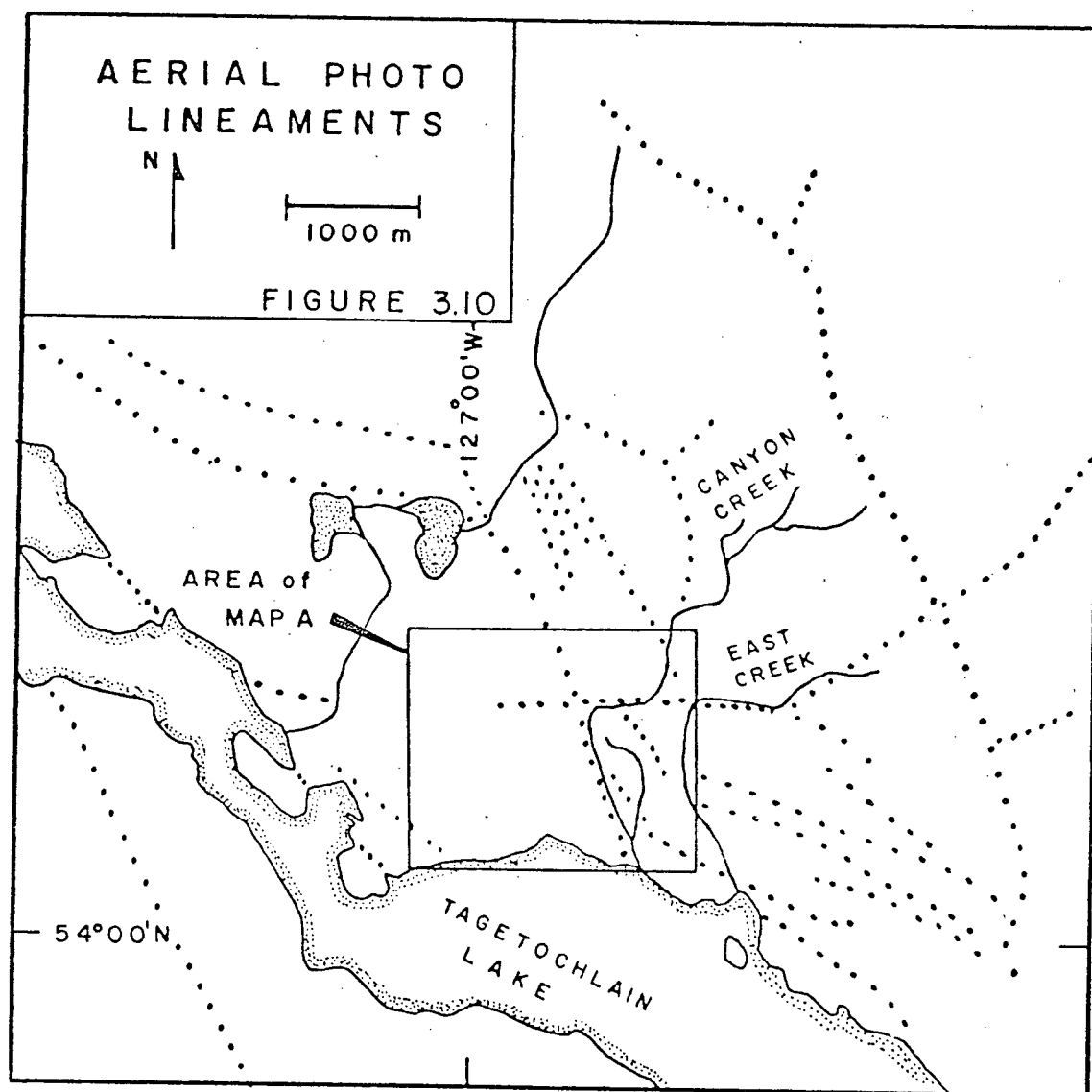
Figure 3.9: Orthoclase-Plagioclase-Quartz ternary diagram showing the compositional fields of the Nanika (N) intrusions, and the Bulkley (B) intrusions (after Carter, 1974, and 1976). Square is whole rock analysis of hornblende quartz monzodiorite, and circle is whole rock analysis of quartz monzonite from the Poplar porphyry.

From these criteria (geographical location, contained mineralization, K-Ar model age, and host rock composition) the Poplar porphyry is classified here as a Bulkley intrusion.

3.7 Structure

Regionally, the study area (Map A) lies just east of an area referred to as a "Transition Zone" between the Intermontane and Coast Crystalline tectonic belts (Woodsworth, 1979; and Duffell, 1959). The area surrounding Tahtsa (and probably Tagetochlain Lake) has been described by MacIntyre (1976) as containing major structural elements including "... high angle normal and reverse faults, which bound uplifted, down faulted, and tilted blocks". Woodsworth (1979, and pers. comm., 1979) identified major low angle thrust faults, southwest of the study area, with probable northeast movement -a direction normal to the trend of the Coast Crystalline Complex. The dominant structural trend in the study area is north-northwest, which parallels the trend of the eastern margin of the Coast Crystalline Complex; the uplift of which most likely dominated the structural regime in the area (MacIntyre, 1976).

Due to a paucity of outcrop in the study area faults could be identified only in canyons and traces were extrapolated from drill core information. Aerial photograph interpretation was used to define larger structures (Fig. 3.10). Outcrop distribution, the dilational nature of dykes, the orthogonal nature of drainage patterns, and the alignment of these patterns



with major aerial photograph lineaments also were used to tentatively identify faults in the study area. The regionally discordant trend of Tagetochlain Lake also is likely due to structural control, as can be seen in Figure 3.10 (Woodsworth, pers. comm. 1979; and Tipper and Richards 1976a).

Jointing, although common in drill core, is observed in outcrop only in Canyon Creek and East Creek canyons. Joint sets are spaced from centimeters to meters apart, forming a blocky to parallel pattern in Canyon Creek. Locally abundant, one to five cm, quartz-pyrite veins in Canyon Creek parallel the dominant north to northwesterly trend of jointing. This indicates the importance of jointing for localization of hydrothermal solutions during mineralization of the Poplar porphyry, and is evidence for directional permeability of these solutions (discussed in Section 4.5).

CHAPTER IV

MINERALIZATION AND ALTERATION OF THE POPLAR PORPHYRY DEPOSIT4.1 General Statement

The major problem in deciphering and interpreting the geology of the Poplar porphyry deposit was distinguishing the textural and mineralogical changes in the rock due to variations within the original rock from those changes due to the effects of hydrothermal and supergene alteration. Early in the course of field study it was determined that the majority of variations in the appearance of the core was due to widespread alteration which varied in type, intensity, and mode of occurrence rather than differences in the original rock type. The effect of this variation is most discernible in the biotite porphyry (Plate 3.4).

To define alteration and mineralization zoning at the Poplar porphyry the mode of occurrence (degree of dispersion, e. g. veins, patches, envelopes, or pervasive) and intensity (on ranked scale of abundance from nil = 0 to most intense = 9; see Appendix B) of twelve silicate, carbonate, sulfate, oxide, and sulfide alteration minerals, and four sulfide ore minerals were recorded for each 3 m depth interval (Table 4.1). The "intensity" of a particular mineral is used here to mean the volumetric abundance of the mineral, and implies no connotation to the physical conditions (i. e. pressure-temperature) of the mineral's formation. Separate scales were used to rank the

intensity of different mineral groups. Silicate, carbonate, and sulfate minerals were ranked on one scale, and sulfide and oxide minerals ranked using another scale (Table B.6, Appendix B). Separate scales were used because the former group of minerals generally occurred in greater abundance than the latter, and to maintain resolution between differences in intensity in the sulfide-oxide group smaller intervals were used to rank their intensity. For example, a 3 m interval of core which contained 12% chalcopyrite and 12% K-feldspar would be described as being "Very High" in chalcopyrite and given a rank of 8 while the K-feldspar would be described as "Fair" and given a rank of 3.

The occurrence and relative abundances of these minerals, in every interval of core, was compared to a "checklist" of those abundances expected in any one of nine particular hypogene mineralization and alteration facies in the Lowell and Guilbert (1970) model, as modified by Blanchet and Godwin (1976) (See Tables B.7, and B.9 in Appendix B). A major problem encountered by using this approach was that two or more minerals, characteristic of separate and mutually exclusive alteration zones, according to the "checklist", were commonly observed in a single interval of core.

TABLE 4.1

Alteration And Ore Minerals Recorded At The Poplar Porphyry
Using Poplarlog

<u>Alteration Minerals</u>	<u>Ore Minerals</u>
Quartz	Chalcopyrite
K-feldspar	Bornite
Biotite	Chalcopyrite
Sericite (muscovite)	Molybdenite
Chlorite	
Clay	
Epidote	
Carbonate	
Anhydrite-gypsum	
Pyrite	
Hematite	
Magnetite	

This problem reduced the effectiveness of the "checklist" method of defining alteration zones. Examples of conflicting mineral assemblages which may be found in a particular interval include: (1) vein minerals may be incompatible with pervasive alteration, (2) supergene mineral assemblages may be superimposed on hypogene assemblages, (3) incomplete alteration reactions are represented, (4) metastable mineral assemblages may occur, and (5) assemblages represent multiple alteration events.

There were, however, definite but more general mineral associations, observed at various intervals of occurrence in drill core, that parallel the Lowell and Guilbert (1970), Blanchet and Godwin (1972), and Godwin (1976) alteration and mineralization zones. These zones are defined here as the potassic, phyllic, argillic, and propylitic facies of alteration, and the chalcopryite-molybdenite zone of mineralization. This classification has no genetic connotation and refers only to the occurrence of the diagnostic mineral(s) defined for each facies. Each zone is characterized by a diagnostic mineral, or minerals, which define a particular facies; associated minerals are also commonly present, but are not considered diagnostic since they occur in more than one facies (Table 4.2).

TABLE 4.2

ALTERATION FACIES AT THE POPLAR PORPHYRY DEPOSIT, AND THEIR
DIAGNOSTIC AND ASSOCIATED MINERALOGY. IN ORDER OF DECREASING
ALTERATION GRADE.

<u>Facies</u>	Mineralogy (<u>underlined minerals are diagnostic</u>)
Potassic	<u>K-feldspar</u> , <u>biotite</u> , magnetite, quartz carbonate
Phyllic	<u>sericite</u> , quartz, pyrite, carbonate, hematite, gypsum
Argillic	<u>clay</u> , carbonate, quartz, gypsum
Propylitic	<u>epidote</u> , chlorite, carbonate

4.2 Distribution Of Alteration And Mineralization Zones At The Poplar Porphyry

The distribution of alteration and mineralization zones at the Poplar porphyry is shown in plan on Map B and Figure 4.3, and in cross-section along lines A-A' and B-B' on Figures 4.1 and 4.2, respectively. Alteration and mineralization zones are defined by plotting the abundances of individual diagnostic minerals, from drill hole data, on computer generated cross-sections. Intervals that are above background levels of ranked abundance were used to determine the distribution of a particular facies. Because some phyllic alteration was recorded

Figures 4.1 and 4.2: Computer generated cross-sections of alteration and mineralization along lines A-A' and B-B', respectively.

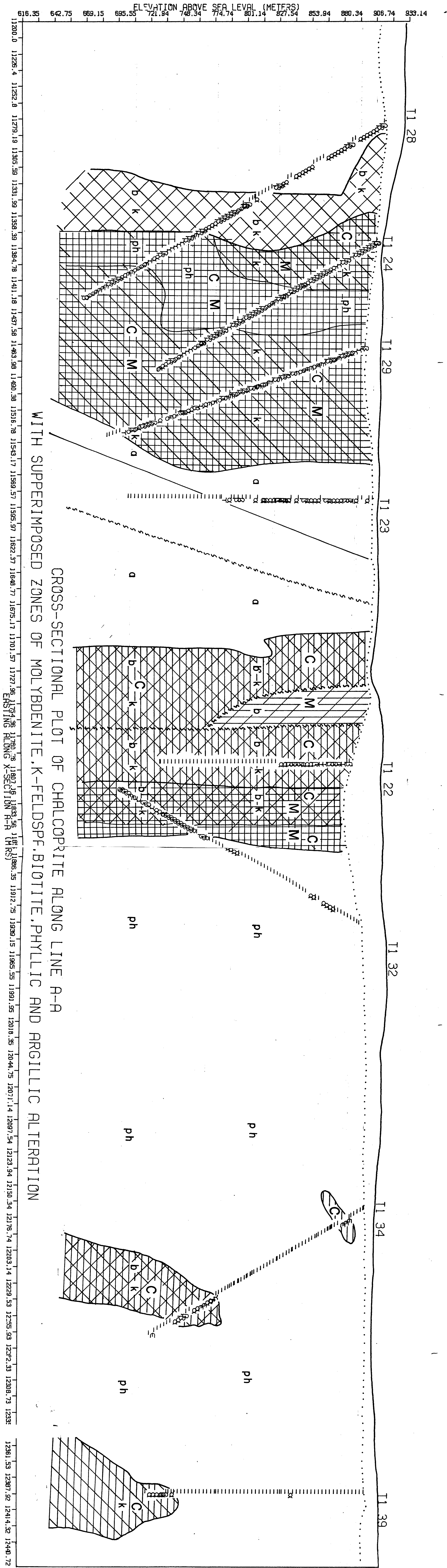
LEGEND FOR COMPUTER GENERATED CROSS-SECTIONS
OF THE POPLAR PORPHYRY

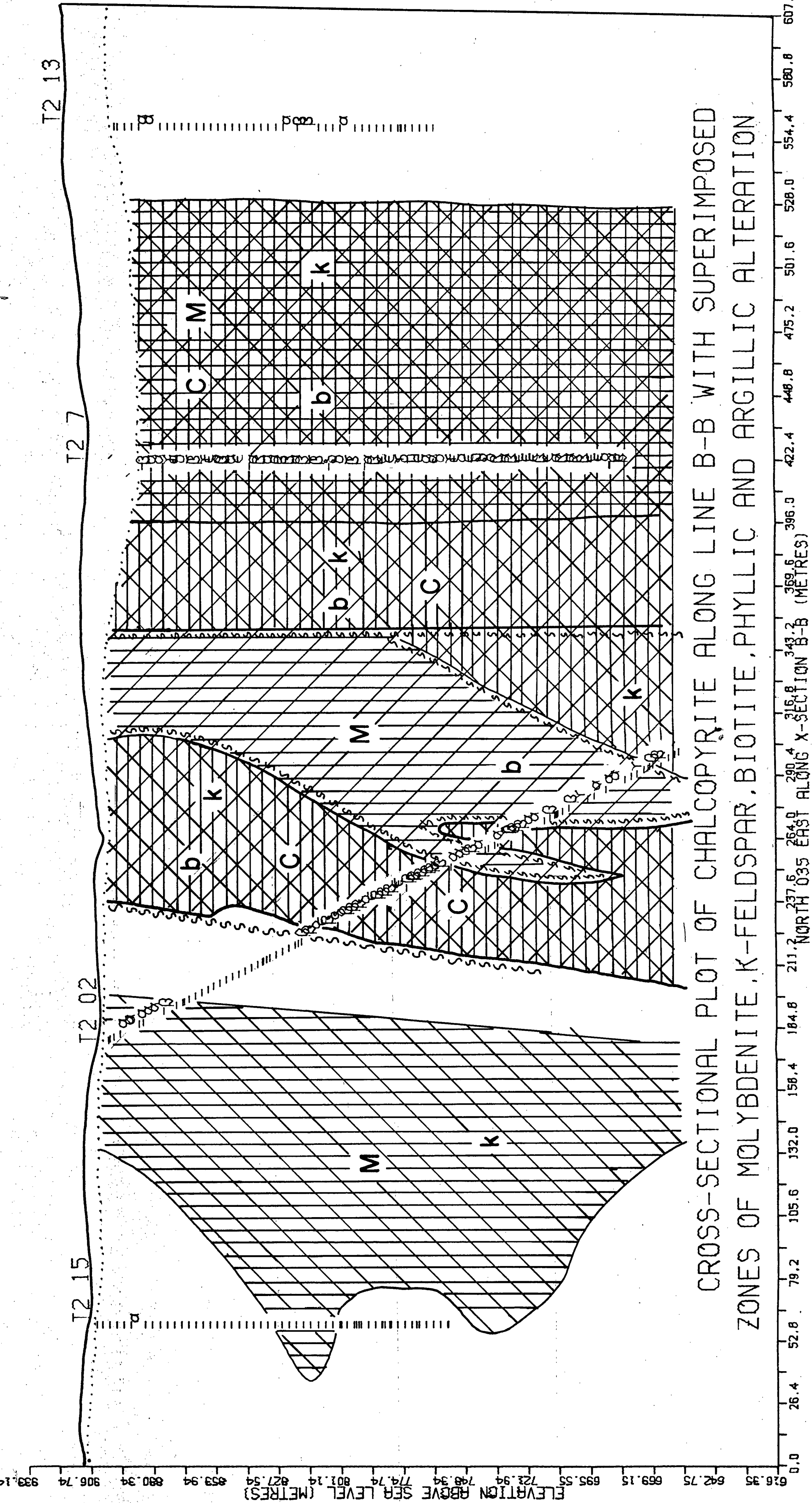
Chalcopyrite Abundance

<u>Volume Percent</u>	<u>Ranked Intensity</u>	<u>Symbol</u>
0	0	-
≤ 0.25% (trace)	1	a
< 0.25%	2	B
0.25-0.5%	3	Y
0.5-1.0%	4	δ
1.0-2.0%	5	ε
2.0-4.0%	6	η
4.0-8.0%	7	θ
8.0-16.0%	8	λ
16.0%	9	μ

CROSS-SECTION SYMBOLS

_____	ground surface
.....	overburden-bedrock contact
— — — — —	geologic contact
~~~~~	fault, or faulted contact
TI 28	top of drill hole 28, on cross-section 1





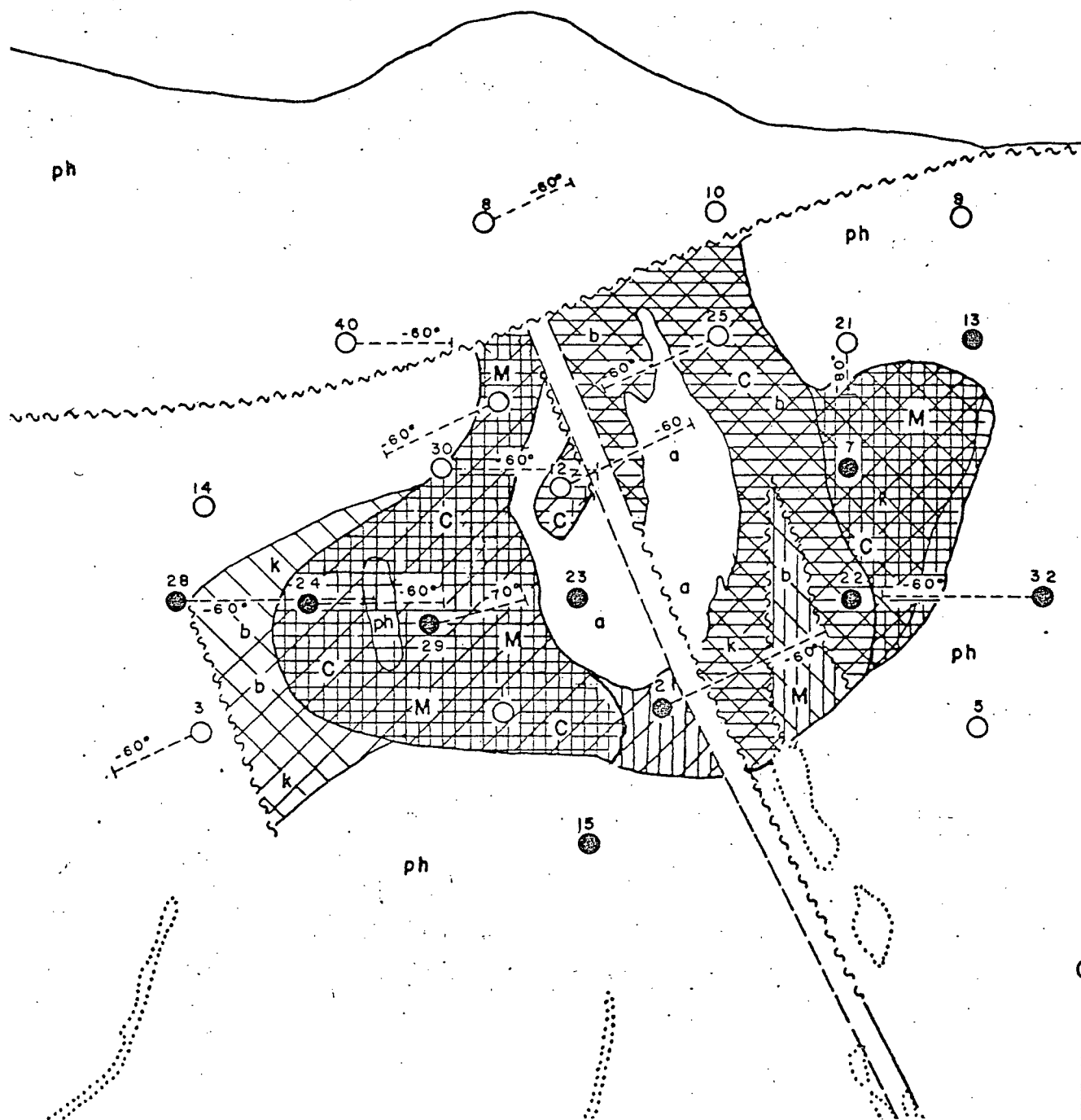


Figure 4.3: Mineralization and Alteration of the central portion of the Poplar porphyry deposit (see Map B for more detail; legend identical with Map B). Scale= 1:5000. Horizontal lines= chalcopryrite zone (C); vertical lines= molybdenite zone (M); right sloping lines= biotite zone (B); left sloping lines= K-feldspar zone (K); ph= phyllic zone; a= argillic zone; pr= propylitic zone.

in almost every interval of core, potassic alteration was given priority when both facies were present in an interval of core. Zoning so defined avoids the complexity, noted in Section 4.1, caused when diagnostic minerals of more than one facies occur together in the same interval of core.

Zoning is shown on Map A to consist of a 600 m by 500 m ring of potassic alteration associated with chalcopyrite and molybdenite mineralization. The potassic annulus surrounds a 300 m by 150 m central core consisting mostly of phyllic and argillic alteration. A 750 m wide east-west trending peripheral zone, consisting largely of phyllic alteration at depth and phyllic and argillic alteration near the surface, encompasses the potassic alteration zone. Fresh rocks are locally observed within this peripheral zone; however, most have undergone argillic to phyllic alteration. Outside the peripheral zone, rocks are generally fresh but locally propylitized. A portion of the potassic alteration annulus is truncated by an east-west trending fault (Map A). The offset portion was not intersected north of the fault by any drill hole. Therefore, its location is unknown, and offset along the fault is undetermined.

This zonation is atypical for porphyry deposits in general (Fig. 3.1). Since the Poplar porphyry consists of an argillic core which is lower in 'alteration grade' than the potassic annulus which surrounds it, a second alteration event likely

took place. This is discussed in more detail in Section 4.4.5.

### 4.3 Sulfide Mineralogy

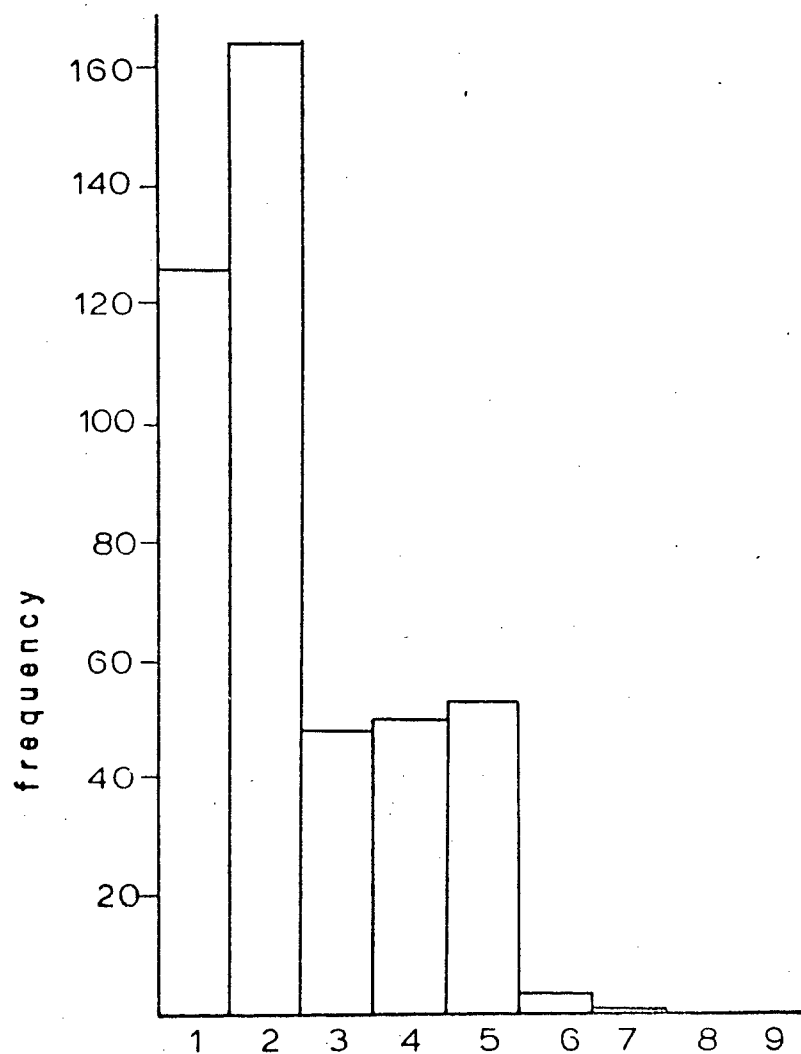
Chalcopyrite and lesser molybdenite are the most abundant economic minerals present at the Poplar porphyry. Bornite, covellite, and tetrahedrite are minor and seldom observed in hand samples. Traces of chalcocite, sphalerite and galena were also observed.

#### 4.3.1 Chalcopyrite

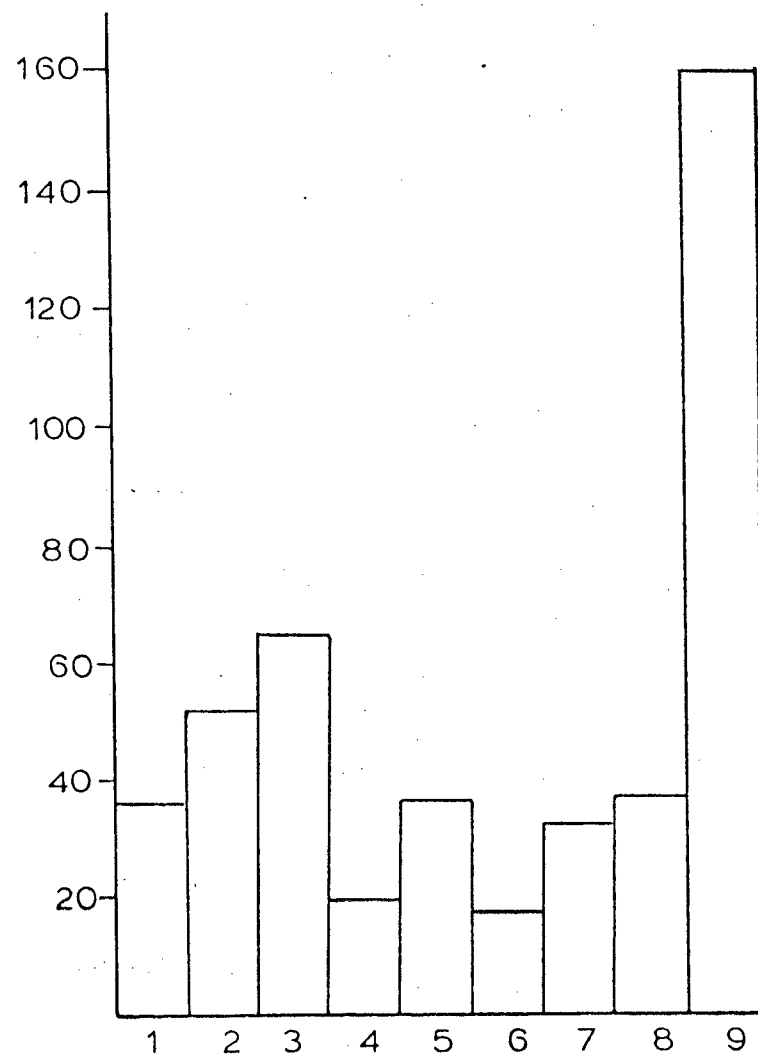
Chalcopyrite at the Poplar porphyry is associated with the potassic zone, encompassing the central low grade core (Figs. 4.1, 4.2, and 4.3,; and Map B). High grade chalcopyrite zones also occur in holes 34 and 39, and are thought by Bowen (pers. comm. 1978) to be part of a deeper or separate ore body.

Chalcopyrite commonly occurs as 0.5 to 3 mm rounded to stellated disseminations, and is less abundant as veins and veinlets, which may also contain quartz (Fig. 4.4). Numerous intervals hosted chalcopyrite in several separate modes of occurrence (i. e., as veins and disseminations, or as patches and veins, etc.).

As observed in polished section, disseminations of chalcopyrite are generally the result of dilation or



CHALCOPYRITE intensity



CHALCOPYRITE mode

Figure 4.4: Bar graphs of the ranked intensity of chalcopyrite, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).

intersections of microveinlets, and less commonly as isolated grains, commonly in altered mafic minerals (Plate 4.1). Chalcopyrite occurs with disseminated pyrite grains, and occurs as 0.01 to 0.05 mm inclusions in magnetite.

During the course of field work a strong positive empirical relationship between the abundance of chalcopyrite mineralization and of biotite and K-feldspar alteration was observed. This relationship was especially discernible where alteration facies changed over short intervals. Statistical studies (Chapter V) emphasize these relationships, all of which have been described in the literature (Norton, 1972; Creasey, 1966; and Carson and Jambor, 1977).

#### 4.3.2 Molybdenite

It is difficult to estimate molybdenite intensity in hand sample because of its generally low abundance. However, a definite spatial zonation of molybdenite is shown in Sections A-A' and B-B' (Figs. 4.1, 4.2, and 4.3; and Map B). Molybdenite, like chalcopyrite, is spatially associated with potassic alteration minerals, but also has a strong empirical correlation with quartz veins.

Molybdenite is largely restricted to quartz veins (Fig. 4.5), and is commonly either "ribboned" (see Wallace, et al., 1978), which consists of alternating layers of quartz and

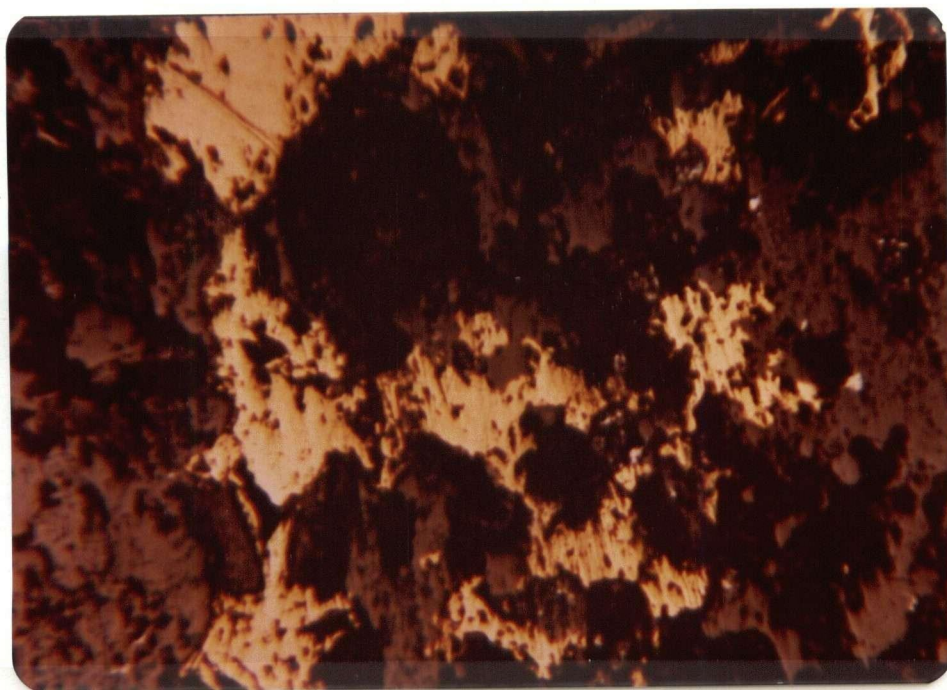


Plate 4.1: Photomicrograph (30 X) showing anhedral grains of disseminated chalcopyrite (yellow) with very small spots of magnetite (white) located on the site of a chloritized (?) biotite phenocryst.

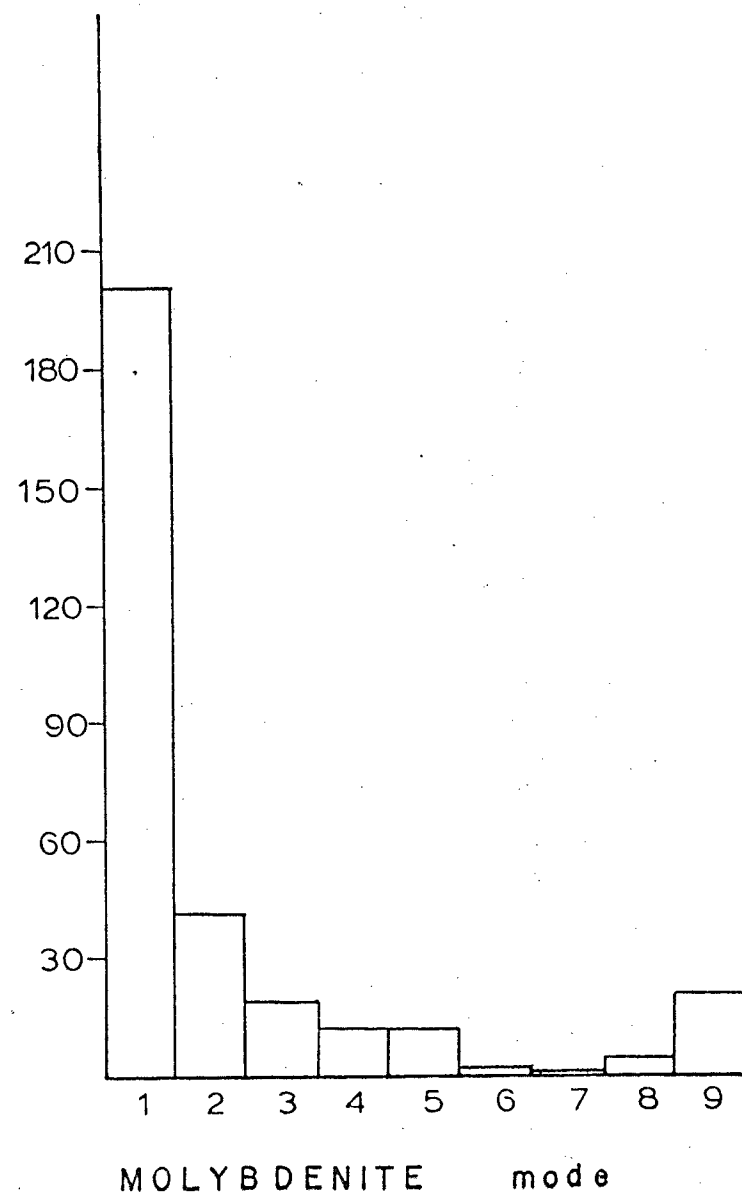
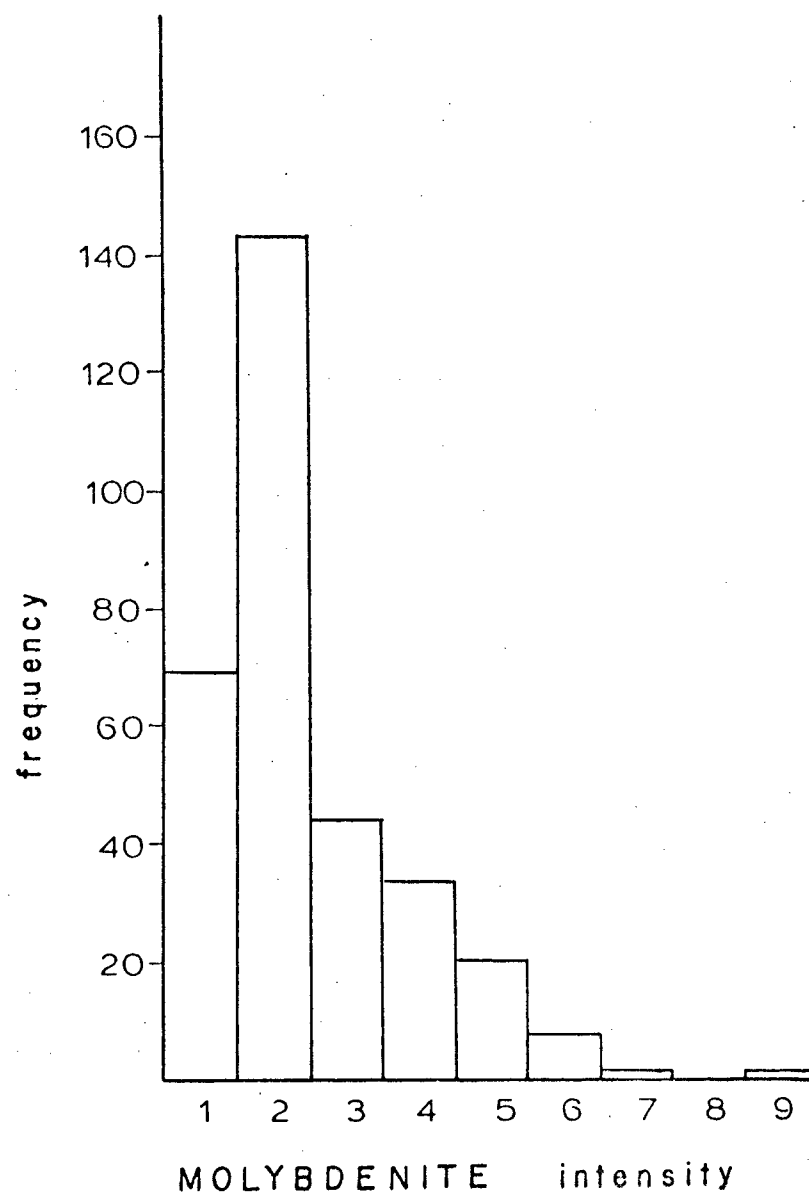


Figure 4.5: Bar graphs of the ranked intensity of molybdenite, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).

coarse grained molybdenite, or occurs in a dark coloured mixture of quartz and very fine grained molybdenite (Plate 4.2).

#### 4.3.3 Bornite

Bornite, only rarely observed in drill core, occurs as fine grained disseminations, associated with chalcopyrite and locally with specular hematite. It occurs in polished section as rims around tetrahedrite inclusions in chalcopyrite and between chalcopyrite and hematite grains (Plate 4.3).

#### 4.3.4 Covellite

Chalcopyrite and bornite are observed in drill core to be very locally tarnished with a blue to purple iridescent coating of covellite. In polished section covellite is in contact with chalcopyrite along grain boundaries and fractures.

#### 4.3.5 Tetrahedrite

Tetrahedrite was identified only once in a hand sample of drill core. However, in polished section tetrahedrite appears to be more widespread. It is found as borders on, and inclusions in, chalcopyrite (Plate 4.3). The presence of tetrahedrite indicates that silver might be a recoverable by-product at the Pöplär porphyry.

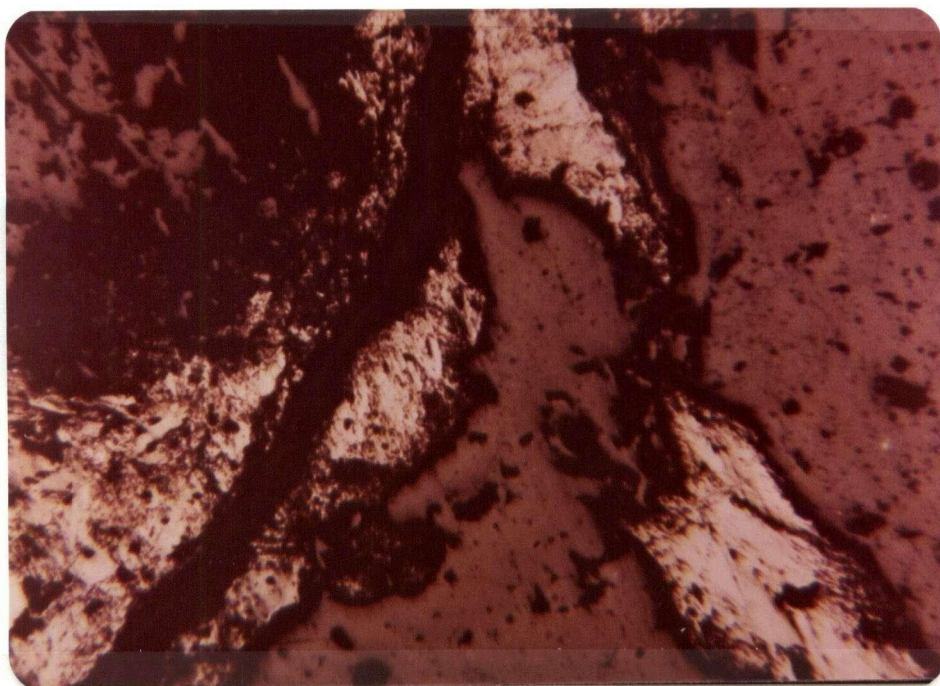


Plate 4.2: Photomicrograph (30 X) of a molybdenite selvage in a quartz vein; the edge of a molybdenite vein in the lower left corner.

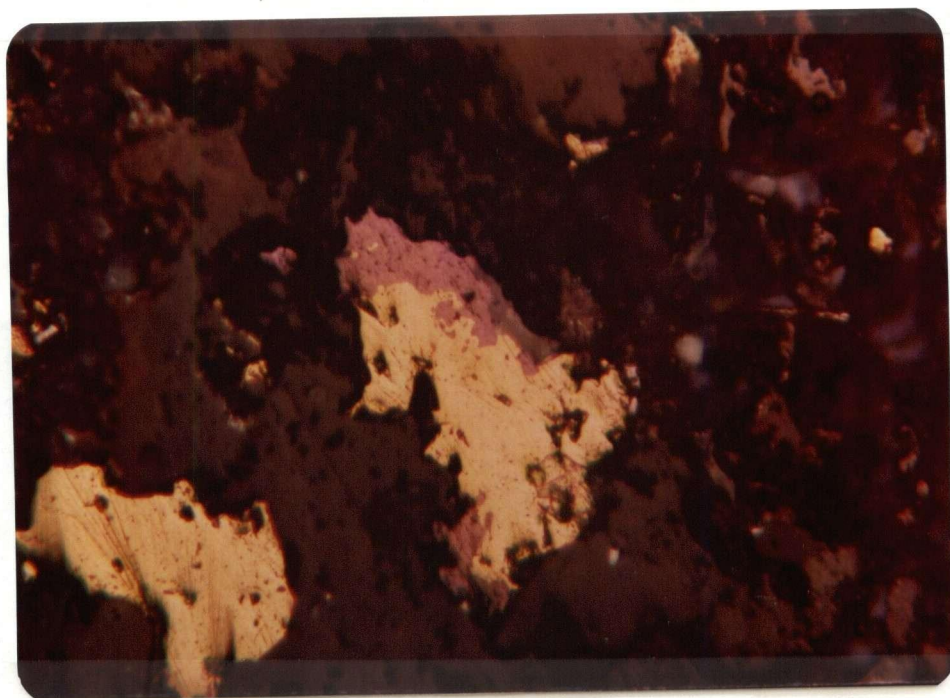


Plate 4.3: Photomicrograph (125 X) showing intergrown bornite (violet) and chalcopyrite (yellow) dissemination with small rim of tetrahedrite on the upper right edge.

#### 4.4 Alteration Mineralogy

##### 4.4.1 Potassic Alteration

Numerous names and mineralogical definitions have been given for the potassic alteration assemblages found in porphyry deposits throughout the world (q. v. Creasey, 1959 and 1966; Burnham, 1962; Lowell and Guilbert 1970; Rose, 1972; and Gustafson and Hunt, 1975). Based on chemical equilibria studies by Hemley (1959) and Hemley and Jones (1964), Jambor and Beaulne (1978) have defined potassic alteration at the Highland Valley, British Columbia, as consisting of secondary K-feldspar and/or secondary biotite, exclusive of all minerals considered essential constituents of other alteration facies (i. e., sericite, and kaolinite).

The assemblages K-feldspar ± biotite, and biotite ± K-feldspar are observed in the field to be associated closely with chalcopyrite and lesser molybdenite. Other minerals commonly observed in this facies are magnetite, carbonate (mainly calcite) and quartz (Plate 4.4). A typical interval of potassic alteration in drill core is shown graphically in Figure 4.6, which is a bar graph of mineral abundances recorded for each 3 m interval of drill core.

Salmon pink orthoclase is the only potassium feldspar observed in the deposit (Plates 4.5, and 4.6). The majority of secondary K-feldspar occurs as envelopes around veins of quartz,



Plate 4.4: Example of potassic alteration. Magnetite vein is surrounded by a K-feldspar envelope which grades out to pervasive secondary biotite. A later chalcopyrite vein can be seen offsetting the magnetite vein.

R 1 32 COMMON ROCK TYPE		DIAPYZ	K-SPAR	BIOTITE	MUSCOVITE	CLAY	CARBONATE	ANHYDRITE	PYRITE	CHALCOPY	MOLYBDENITE
T	1 24 27	6									
	27 HHHHNN	**	*****	***	**				****	**	
	30 HHHHNN	**	*****	***	**				****	**	
	40 HHHHNN	**	*****	***	**				****	**	
	50 HHHHNN	**	*****	***	**				****	**	
	60 HHHHNN	***	*****	***	****		*****		****	**	*
	70 HHHHNN	***	*****	***	****		*****		****	**	*
	80 HHHHNN	****	*****	**	***		**		**	**	*
	90 HHHHNN	****	*****	**	***		**		**	**	*
	100 HHHHNN	*****	*****	**	**		***		**	**	**
	110 HHHHNN	*****	*****	*	**		***		**	**	**
	120 HHHHNN	*****	*****	*****	**		**		**	**	**
	130 HHHHNN	*****	*****	*****	**		**		**	**	*
	140 HHHHNN	**	*****	*****	**		**		****	**	
	140 HHHHNN	**	*****	*****	**		**		****	**	
	160 HHHHNN	***	*****	***	*****		****		**	*	
	170 HHHHNN	****	*****	***	*****		****		**	*	
	180 HHHHNN	*****	***	***	*****	****	****		**	**	***
	190 HHHHNN	*****	**	***	*****	****	****		**	**	***
	200 HHHHNN	***	**		*****		****		**	**	*
	210 HHHHNN	***	**		*****		****		**	**	*
	220 HHHHNN	***	*****		*****	**	**		**	**	**
	230 HHHHNN	***	*****		*****	**	**		**	**	**
	240 HHHHNN	**	*****		*****	**	**		*	*	***
	250 HHHHNN	**	*****		*****	***	**		*	*	***
K	253 HHHHNN	***	*****	**	*****		**		**	**	*
	260 HHHHNN	****	*****		*****		**		**	**	***
	270 HHHHNN	****	*****		*****		**		**	**	***
	280 HHHHNN	*****	***		*****		**		**	**	***
	290 HHHHNN	*****	***		*****		**		**	**	***
	300 HHHHNN	*****	***		*****		*****		**	***	**
K	309 HHHHNN	****	**		*****	*	**		**	****	**
	310 HHHHNN	****	**		*****	*	**		**	****	**
D	316 HHHHNN	**	**		*****	**	**		**	*	
	320 HHHHNN	*****			*****	*****			**	*	*
	330 HHHHNN	*****			*****	*****			**	*	*
	340 HHHHNN	*****			*****	*****			****	****	****
	350 HHHHNN	*****			*****	*****			****	****	****
	360 HHHHNN	*****			*****	*****			****	****	****
	370 HHHHNN	*****			*****	*****			****	****	****
	380 HHHHNN	*****			*****	*****			*	**	*
	390 HHHHNN	*****			*****	*****	**		*	**	*
	400 HHHHNN	*****	**		*****	*****	**		*	**	*****
	410 HHHHNN	*****	**		*****	*****	**		*	**	*****
	420 HHHHNN	*****			*****	*****	**		*	**	*****
	430 HHHHNN	*****			*****	*****	**		*	**	*****
	440 HHHHNN	*****			*****	*****	*		*	**	*****
K	450 HHHHNN	*****			*****	*			*	**	*****
D	452 HHHHNN	*****			*****				*	**	*****
	460 HHHHNN	*****			*****	**	****		*	**	*****
	470 HHHHNN	*****			*****	**	****		*	**	*****
	480 HHHHNN	*****			*****	*	**		*	**	*****
	490 HHHHNN	*****			*****	*	**		*	**	*****
	500 HHHHNN	*****			*****	*	*****		**	**	*****
	510 HHHHNN	*****			*****	*	*****		**	**	*****

Figure 4.6: Graphic log of mineral intensity (from zero to nine stars) for all minerals recorded on Poplar log. This interval is from drill hole 24 and represents a typical interval of potassic alteration (i. e. K-feldspar, and biotite).



Plate 4.5: Examples of potassium feldspar envelopes (left to right). K-feldspar surrounds a quartz vein and grades out into a green sericite envelope; K-feldspar envelope surrounding a quartz-chalcopyrite vein is developed in previous pervasive secondary biotite alteration; and a similar sample to the middle one, which has been stained to show the nature of the K-feldspar (yellow) alteration. Plagioclase is white.



Plate 4.6: K-feldspar alteration of plagioclase phenocrysts in an envelope surrounding a quartz-chalcopyrite vein. Scale is in centimeter.

chalcopryrite and carbonate, and as combinations of veins and pervasive occurrences (Fig. 4.7). There is no empirical correlation between vein material or width, and width of the associated envelope. One mm to five cm envelopes are well defined in intervals which also contain pervasive secondary biotite.

Pervasive secondary biotite imparts a dusty brown to jet black colour to the rock, depending on the intensity of biotite alteration (Plate 4.7); envelopes and patches are observed less often (Fig. 4.8). In general, biotite is most abundant in intervals of low vein and fracture densities. Biotite patches, locally associated with chalcopryrite disseminations, consist of one to three cm wide spots, pseudomorphic after mafic xenoliths. Pervasive biotite occurs as 0.05 mm to 0.2 mm subhedral to anhedral pseudomorphs after primary biotite and hornblende (Plate 4.8). Opaque minerals (pyrite, chalcopryrite, magnetite, etc.) are commonly associated with the latter type of occurrence.

Magnetite is most commonly observed as 0.1 to 2 mm euhedral to subhedral disseminated grains and in rare quartz-magnetite ± pyrite ± chalcopryrite ± hematite veins. Magnetite is intimately associated with chalcopryrite, in both disseminations and veins (Plate 4.9). Magnetite and hematite are both found as intergrowths or pseudomorphs after primary mafic minerals and

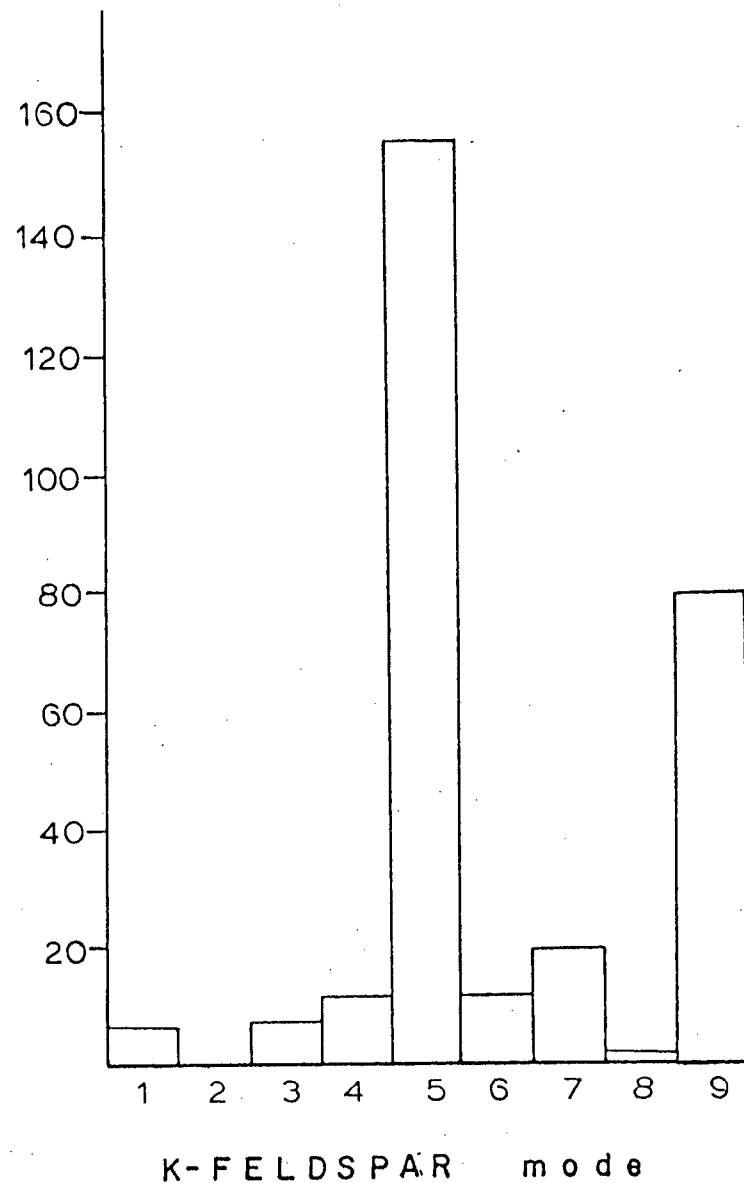
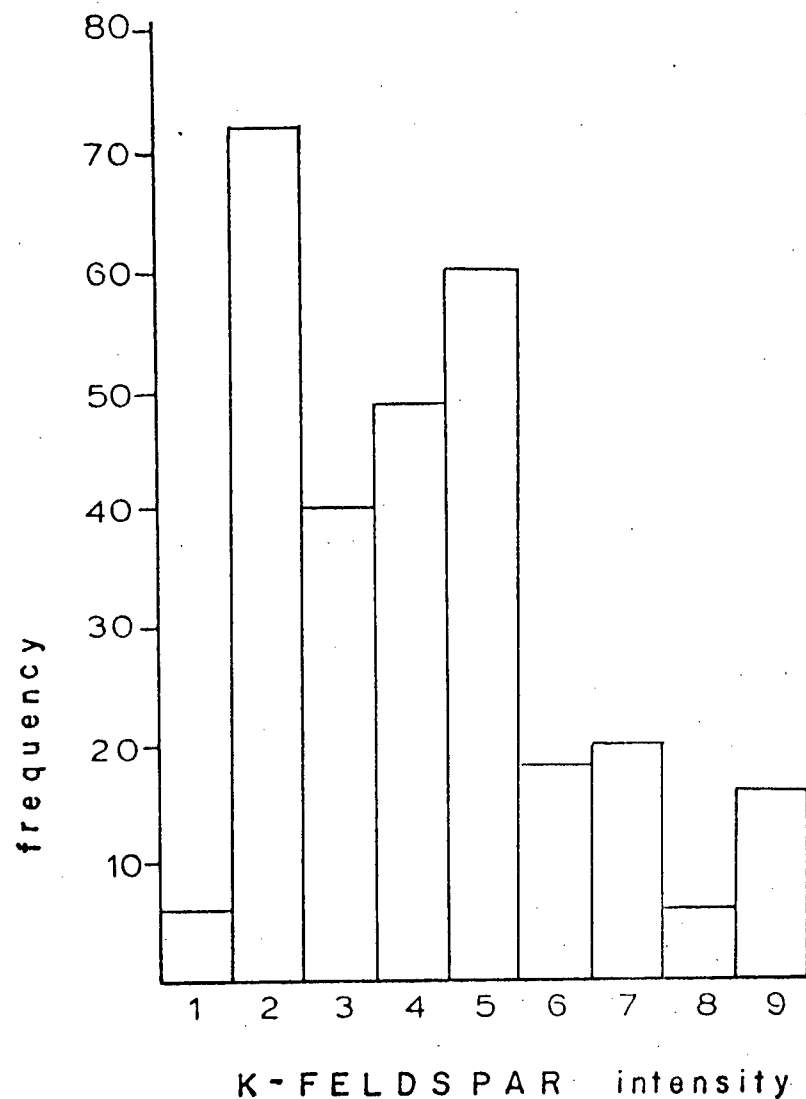


Figure 4.7: Bar graphs of the ranked intensity of K-feldspar, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).



Plate 4.7: Dusty dark brown secondary biotite near the bottom of the sample is overprinted by a K-feldspar envelope (middle of sample) adjacent to a split molybdenite vein (metallic grey in upper portion of sample).

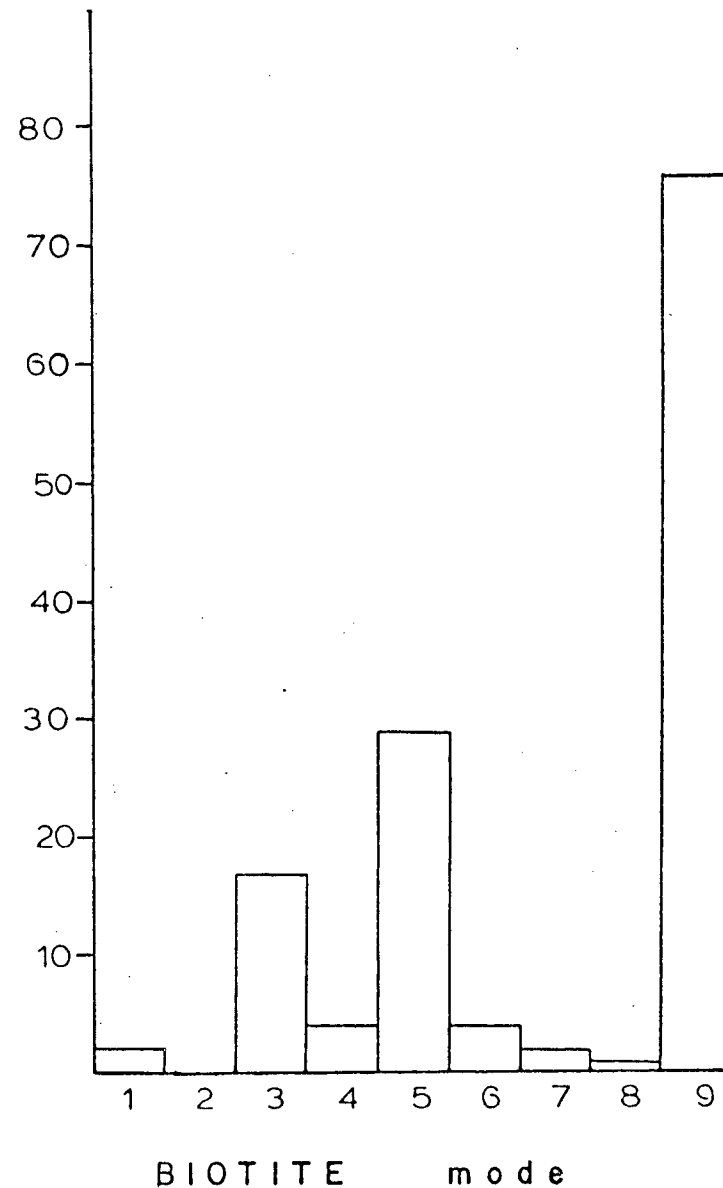
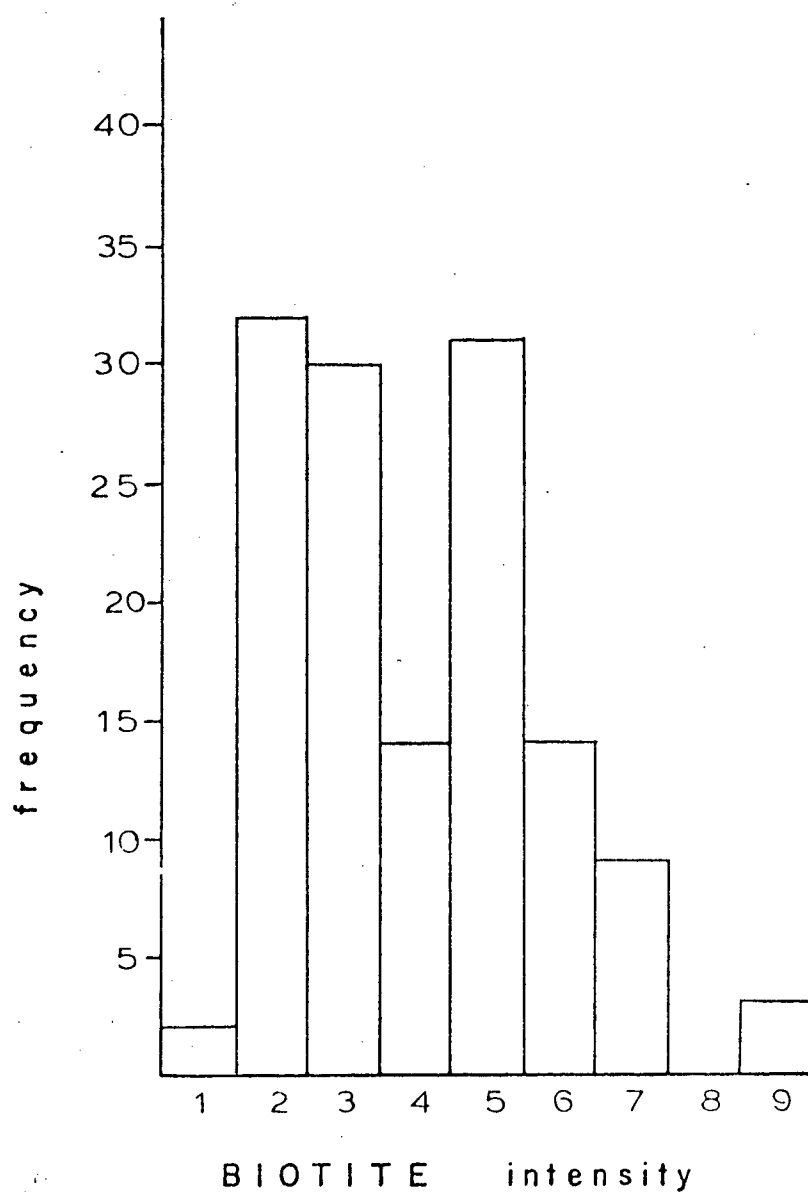


Figure 4.8: Bar graphs of the ranked intensity of biotite, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).

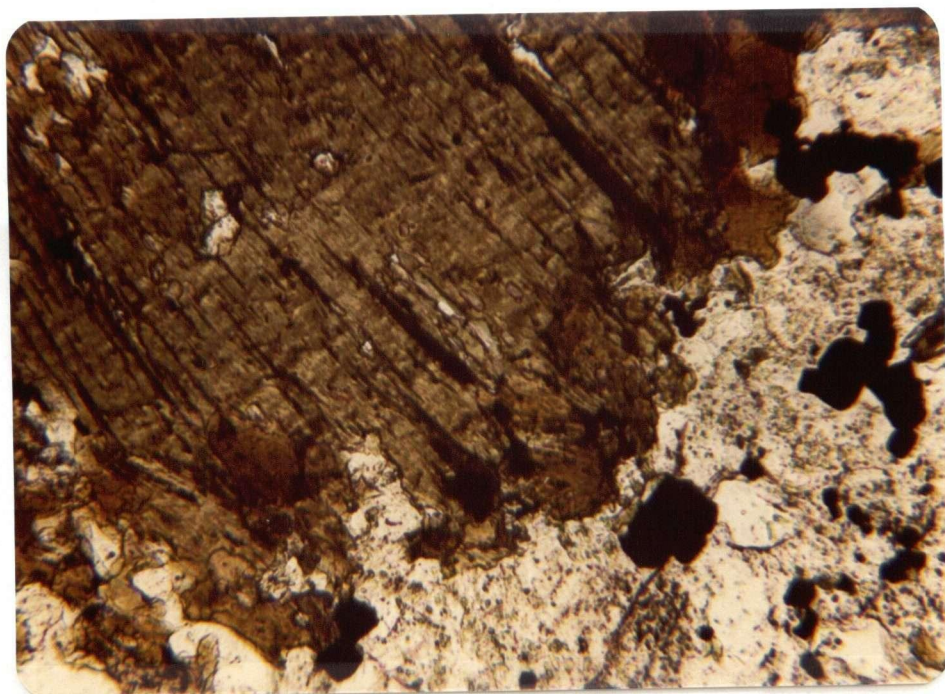


Plate 4.8: Photomicrograph (125 X) showing dark irregular grains of secondary biotite replacing primary biotite phenocryst. Opaque grains are magnetite (?).

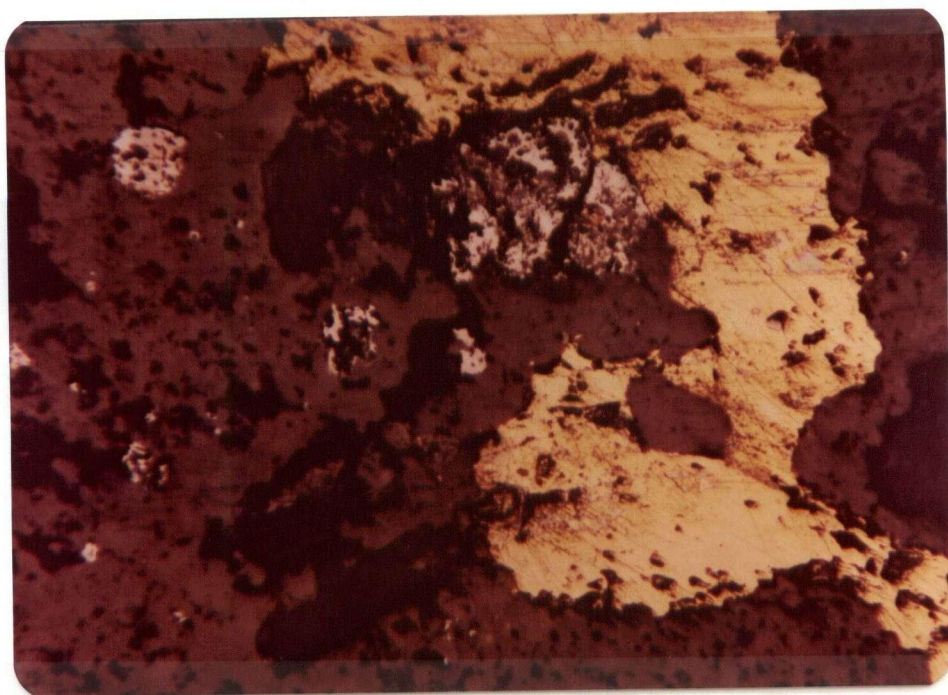


Plate 4.9: Photomicrograph (30 X) showing irregular disseminations of chalcopyrite (yellow) and magnetite (white).

associated with secondary biotite.

Potassic alteration, was in general the earliest alteration event at the Poplar porphyry. This is discernible where the diagnostic mineral(s) of more than one alteration facies are observed together. Cross-cutting relationships of veins and envelopes and replacement textures (Section 4.4.2) indicate that phyllic and argillic facies are superimposed on rocks that have undergone previous potassic alteration (Plate 4.10). Locally, however, potassic and phyllic alteration are synchronous (i. e., a quartz vein with a K-feldspar envelope grading into a sericite envelope; Plate 4.5).

#### 4.4.2 Phyllic alteration

Phyllic alteration is the most abundant alteration facies observed at the Poplar porphyry deposit (Map B; and Figs. 4.1, 4.2, and 4.3); affecting to some extent, almost every interval of core. Sericite, pyrite and quartz are the most commonly observed mineral of this facies (Fig. 4.9); pervasive carbonate alteration also is commonly observed in thin section.

Sericite is in equilibrium with K-feldspar or kaolinite along univariant lines in temperature-pH space (Hemley and Jones, 1964). Under other than univariant conditions these minerals are mutually exclusive, consequently sericite alone is diagnostic of this alteration facies. The term sericite is used



Plate 4.10: Green and brown sericite envelopes from numerous veinlets and fractures impart a pervasive alteration to the rock. Note that a small portion which had undergone previous potassic alteration remains.

DEPTH	QUARTZ	K-SPAR	BIOTITE	MUSCOVITE	CLAY	CARBONATE	ANHYDRITE	PYRITE	CHALCOPY	MOLYBDENITE
T 1 32 4										
660 030000F	*****		***			*****		*	**	*
660 000000D	****		*****			**		****	*****	
670 000000D	*****		*****			**		****	*****	
680 01 0000F	**		**					**	**	**
690 01 0000F	**		**			*		**	**	**
700 010000F	*****		****			**		****	***	***
710 040000F	*****		****			**		****	***	***
720 01 0000F	****		****			**		***	***	****
730 01 0000F	****		****			**		***	***	****
740 01 0000F	****		****			*		*	***	**
750 01 0000F	****		****			*		*	***	**
760 000000F	**		**			**		****	**	**
770 000000F	**		**			**		****	**	*
780 01 0000F	***		*****					**	*	****
790 01 0000F	**		*****					**	*	****
800 000000F	**		*****					**	***	*****
810 000000F	**		*****					**	***	*****
820 000000F	**		*****			*		***	****	*****
830 000000F	**		*****			*		***	****	*****
840 000000F	**		*****			**		**	****	*****
850 000000F	**		*****			*		**	****	*****
860 000000F	**		*****			*		****	*****	*****
870 000000F	**		*****			*		****	*****	*****
880 000000F	****		**			*	****	*	*	*
890 000000F	****		**			*	****	*	*	*
900 000000F	**		**			*	****	****	**	*
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920 000000F	*****		****			*	****	**	**	**
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990 000000F	*****		****				**	*	****	**
1000 040000F	*****		*****					*	****	
1005 000000F	**		*****					*	**	
1 28										

Figure 4.9: Graphic log of mineral intensity (from zero to nine stars) for all minerals recorded on Poplar log. This interval is from drill hole 32 and represents a typical interval of phyllic alteration.

here to describe fine grained secondary muscovite, after Hurlbut (1971), Jambor and Delabio (1978), and Lowell and Guilbert (1970). The mineral is identified in hand specimen by lightly scratching the surface of a sample with a needle; a resultant "sheen" is indicative of sericite. Clay minerals on the other hand, produce a dull earthly scratch. If both minerals are present distinction is difficult. A binocular microscope facilitated field identification.

Sericite occurs as a pervasive alteration with less commonly observed envelopes and patches (Fig. 4.10). Pervasive sericite alteration occurs; as (1) pseudomorphic replacement after biotite and hornblende phenocrysts and is commonly associated with pyrite, carbonate, and chlorite; (2) as an alteration of fine grained biotite, plagioclase, and orthoclase in the groundmass, which imparts a pervasive bleaching to the rock, and (3) as a light green to white selective alteration of plagioclase phenocrysts. The latter type of occurrence has the greatest affect on the alteration intensity recorded, since the volumetric intensity of alteration is dependent on the original plagioclase abundance in the rock. Plagioclase and biotite phenocrysts and are the most susceptible to phyllic alteration (commonly altered in an otherwise fresh rock) followed by plagioclase, biotite and K-feldspar in the groundmass (Plate 4.11). In zoned plagioclase sericite selectively alters particular zones, either singularly or with associated carbonate and clay (Plate 4.12). Envelopes of sericite, quartz, and

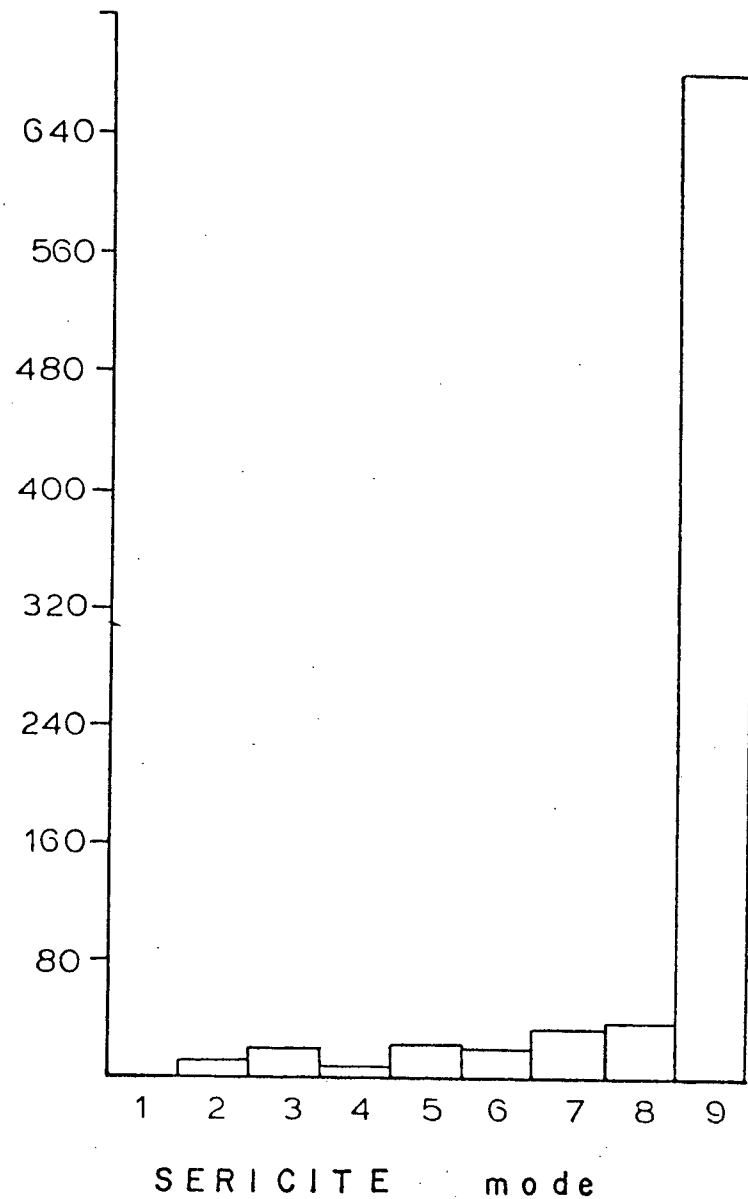
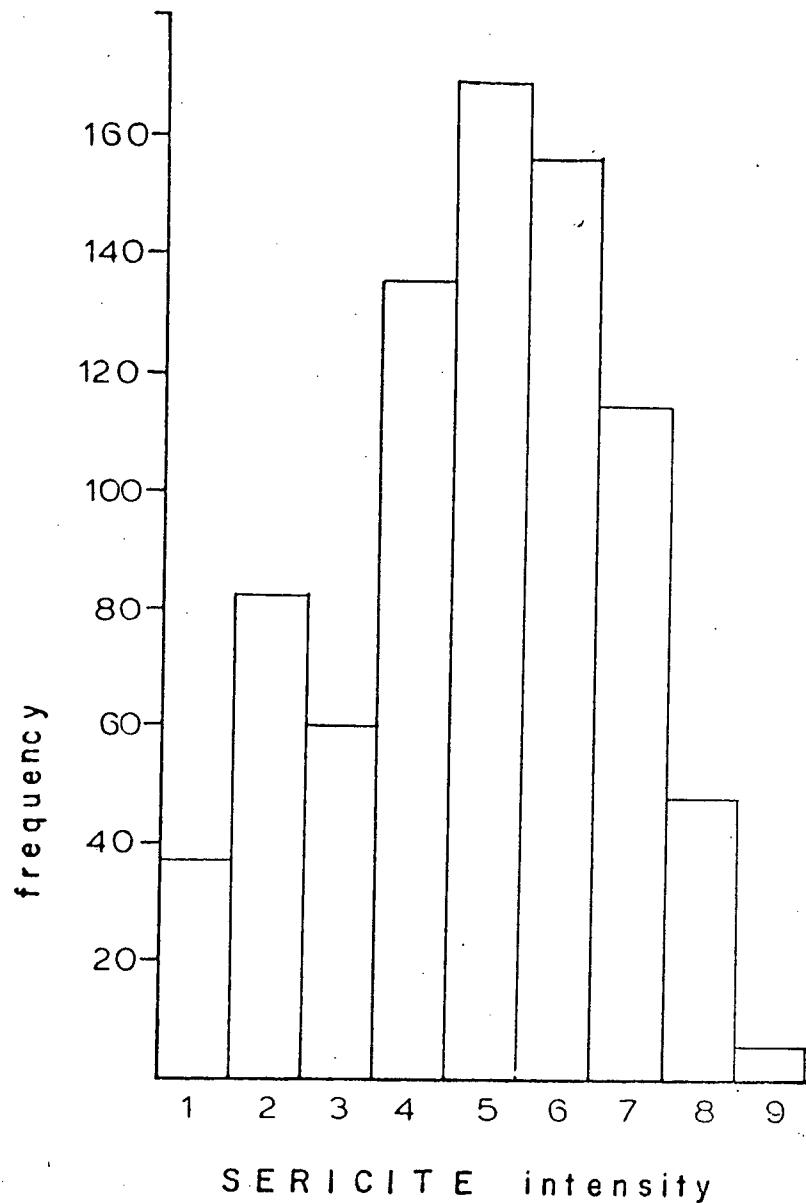


Figure 4.10: Bar graphs of the ranked intensity of sericite, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).

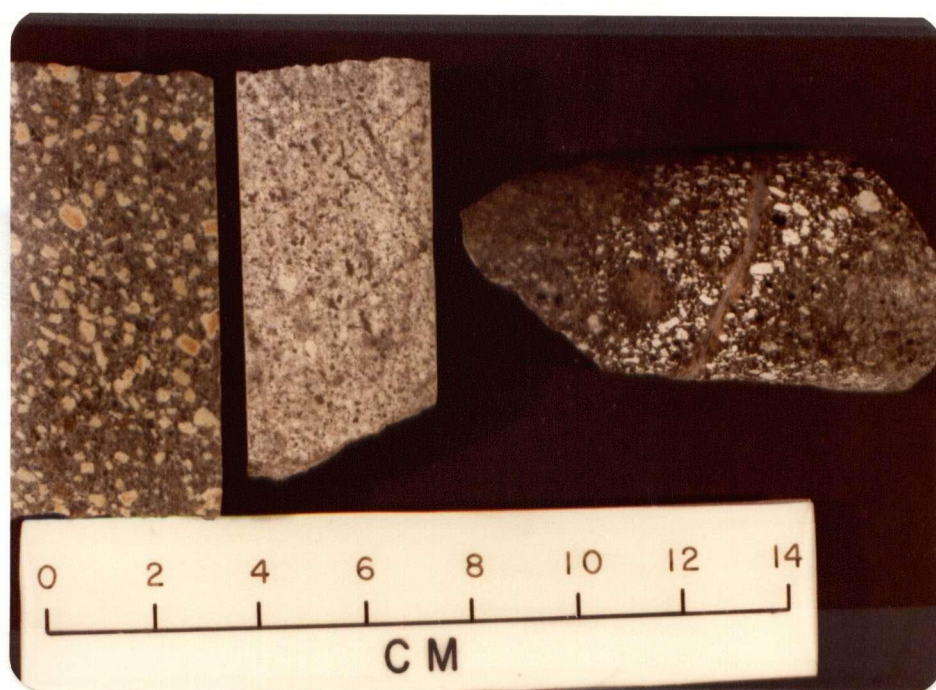


Plate 4.11: Three examples of phyllic alteration. Left: sericitization of biotite phenocrysts (brown, limonite patches) and plagioclase phenocrysts (bleached); middle: extreme pervasive pyrite-sericite-quartz bleaching. Pyrite and quartz veinlets cross the sample, sericite bleaches plagioclase phenocrysts and groundmass; right: sericite envelope affects only plagioclase phenocrysts, around a K-feldspar envelope and quartz vein.

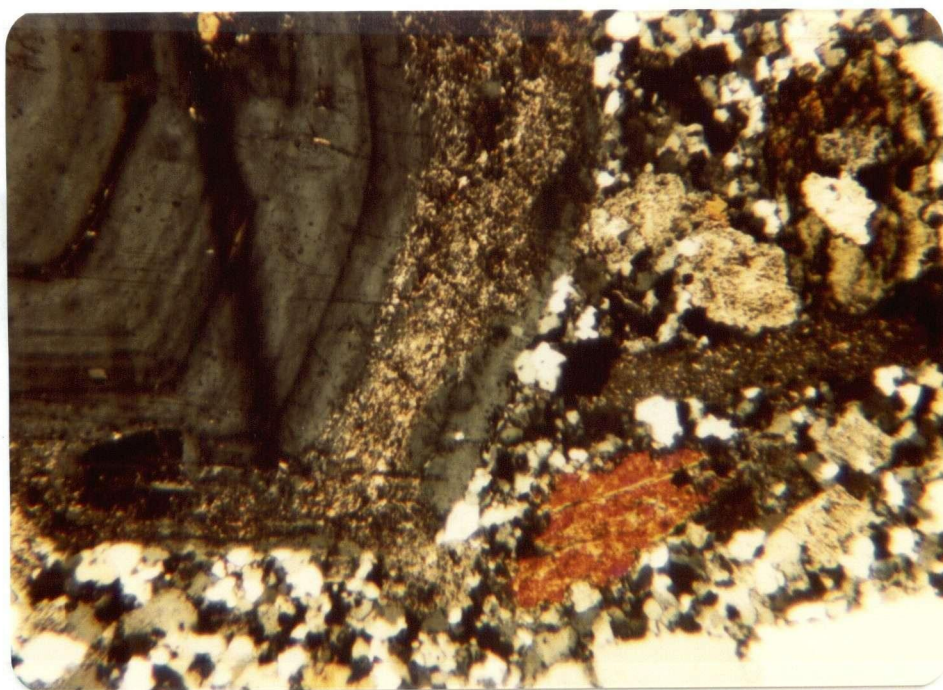


Plate 4.12: Photomicrograph (30 X) showing selective alteration of zoned plagioclase along specific compositional zones. Fine grained material consists of sericite and carbonate. Highly bi-refrangent mineral at lower left is hornblende.

pyrite range in width from less than one mm up to tens of centimeters. Quartz and quartz-pyrite veins are most commonly associated with sericite envelopes. Greenish one to 15 mm patches of sericite, generally with quartz surrounding a pyrite nucleus are formed from the alteration of mafic phenocrysts or xenoliths. In thin section sericite generally is less abundant than had been recorded in the field, and is more commonly associated with clay and carbonate than had been thought during core logging.

Quartz is the most widespread and abundant alteration mineral in the deposit, and occurs at least locally, with all other alteration minerals; however, it is most commonly observed with sericite and pyrite. Quartz is largely confined to veins, combinations of veins and patches, and patches and envelopes (Fig. 4.11). Quartz veining is the most important criterion affecting the distribution and mode of occurrence of other alteration minerals; veins of quartz are commonly surrounded by K-feldspar and/or sericite envelopes. Locally quartz extends outwards from veins to form pervasively silicified rock. Quartz also occurs in veins containing pyrite, molybdenite, chalcopyrite and locally specularite and magnetite.

Pyrite is the most abundant and widespread sulfide at the Poplar porphyry and is observed in almost all intervals of core. Pyrite has a bimodal mode of occurrence. Figure 4.12

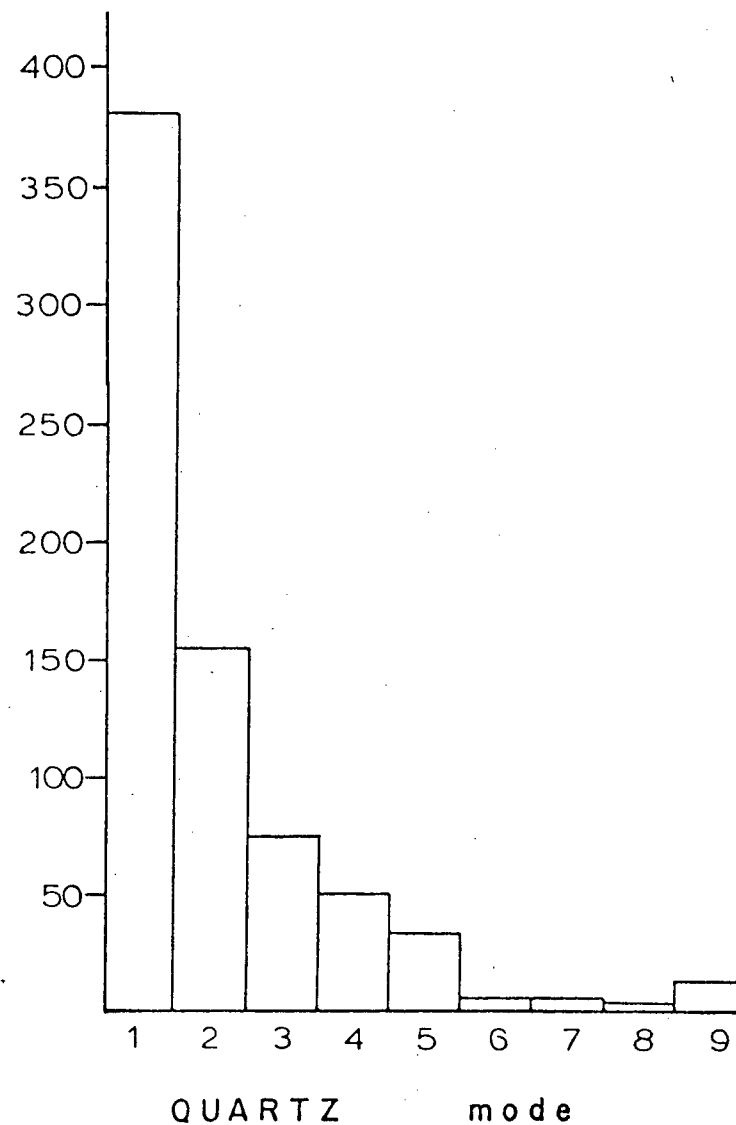
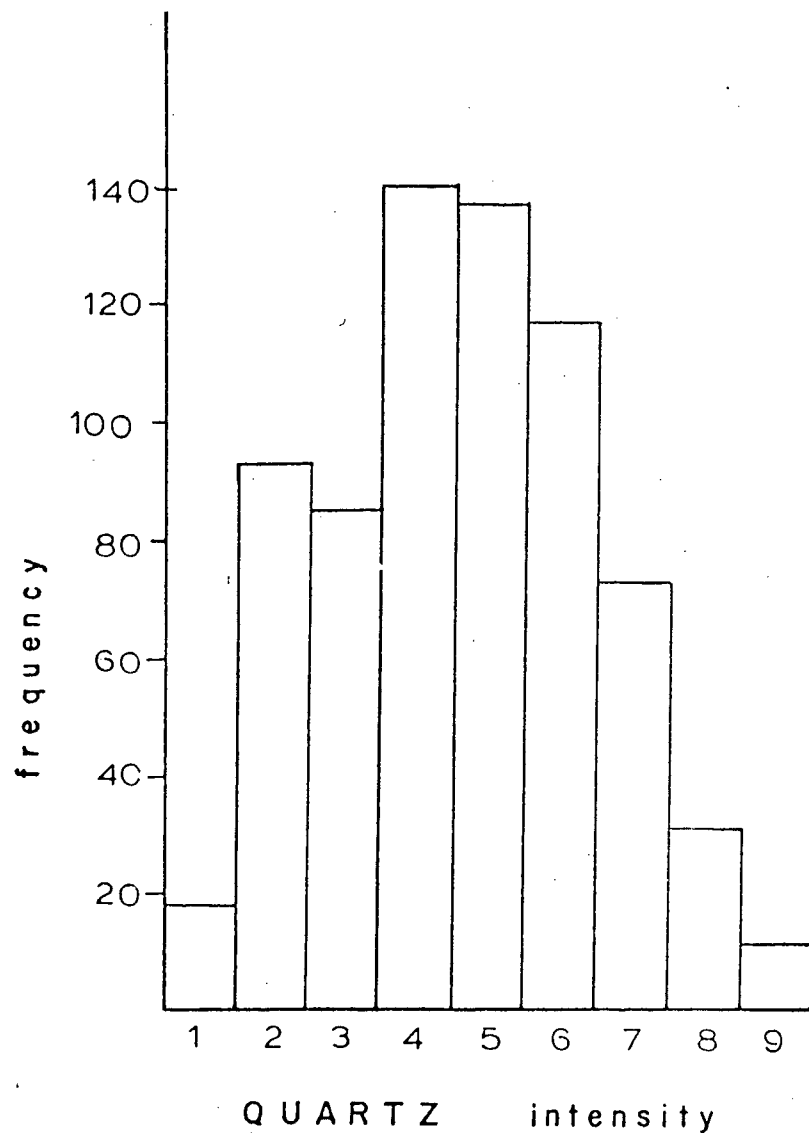


Figure 4.11: Bar graphs of the ranked intensity of quartz, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).

illustrates that pyrite occurs either as patches, and combinations of patches and veins, or as disseminations. Pyrite is commonly observed on the sites of altered mafic minerals and less commonly as patches replacing mafic xenoliths. Pyrite may contain intergrowths of both chalcopyrite and bornite.

Specular hematite is associated with both phyllic and potassic alteration. However, because magnetite is much more abundant in potassic alteration, hematite is probably an oxidized product of magnetite in the phyllic alteration facies which is observed to have been superimposed on previous potassic alteration. Hematite occurs as one mm disseminations, and with quartz and calcite in veins.

Calcite and lesser siderite and dolomite were observed in drill core, mainly as veins and veinlets and less commonly as pervasive alteration of plagioclase phenocrysts, with clay and sericite. Carbonate veins are associated with pyrite and minor chalcopyrite. Pervasive calcite alteration observed in thin section is associated with sericite, clay and chlorite occurring as subhedral to anhedral crystals and patches on altered plagioclase and hornblende phenocrysts. Carbonate observed in thin section shows it to be more abundant than had originally been thought during the field study. In particular carbonate is strongly associated in thin section with sericite and clay.

Gypsum and lesser anhydrite, is widespread and locally

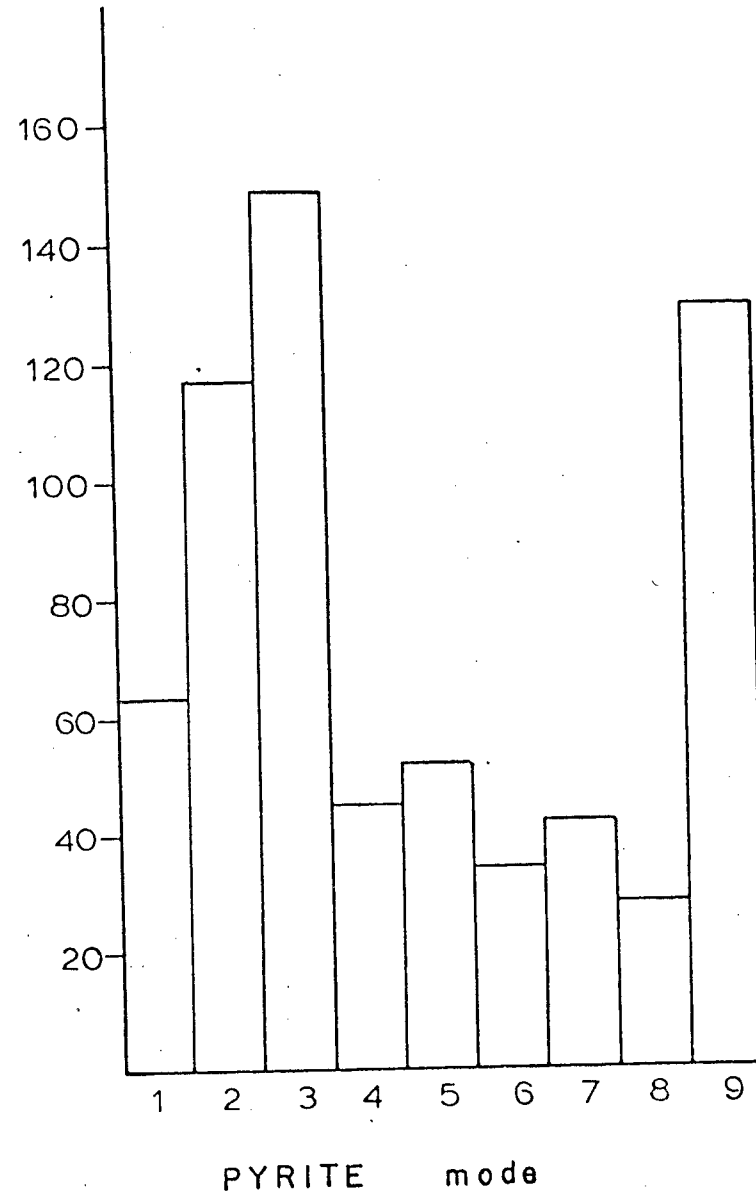
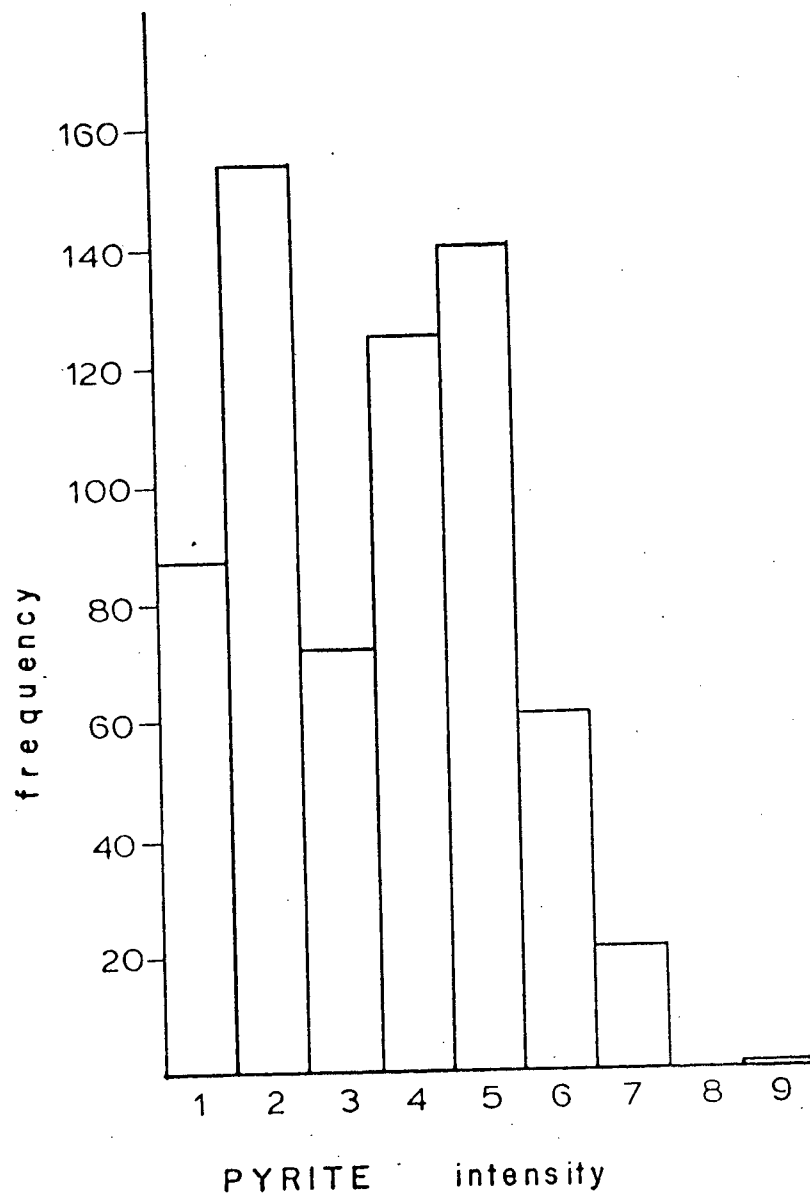


Figure 4.12: Bar graphs of the ranked intensity of pyrite, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).

abundant in the deposit, occurring in veins, averaging one cm wide. Although gypsum is widespread, and found within the potassic zone, it is most strongly associated with phyllic alteration. Gypsum is characteristically white to pink and varies from a dull massive translucent variety to a rare clear euhedral variety, with crystals up to five cm across. Veins of gypsum are commonly vuggy and locally associated with quartz and calcite. Pyrite is a commonly associated mineral.

Phyllic alteration is closely associated with veins and fractures, and although sericite generally occurs as a pervasive alteration it is almost always associated with quartz, gypsum or pyrite veining, or barren fractures. Much of pervasive sericitic alteration is the result of overlapping envelopes. Some of the most intense phyllic alteration occurs on both sides of the contact between biotite porphyry and Skeena Group rocks.

#### 4.4.3 Argillic Alteration

Argillic alteration is restricted in distribution and only locally is intensely developed. Clay is the diagnostic mineral of this facies; however no distinction could be made in the field between different clay minerals. Carbonate and quartz are associated minerals in the argillic facies. The most abundant and continuous occurrence of clay is found in the upper portion of drill hole 23 and in intervals of extremely sheared rock in drill hole 3 (Map B).

Clay is indentified in hand sample by a tackiness to the tongue, an argillaceous odor, the lack of a sheen when scratched with a needle, and by a pock-marked appearance in drill core due to its removal by drilling fluids (Fig. 4.13). Plagioclase phenocrysts were the most susceptible to argillic alteration (Plates 4.13). Clay forms extremely fine grained patches of low birefringence and low relief. Limonite may locally occur as a dark brown to opaque high relief stain with clay minerals to form a dusty or clouded appearance in thin section.

Samples of drill core, selected from intervals where clay was recorded on Poplarlog in the field were analyzed by X-ray diffraction techniques to ascertain the type of clay minerals present (c. f. Godwin, 1976). Kaolinite was identified in every sample analyzed; illite was detected in only one sample. Sericite, biotite, and chlorite were locally recorded in addition to kaolinite. No pyrophyllite was detected.

#### 4.4.4 Propylitic Alteration

Propylitic alteration was never observed in drill core, nor was it obvious in surface samples, because of its low intensity and limited occurrence. Epidote is the diagnostic mineral of this facies, but chlorite, carbonate and albitized plagioclase are also observed.

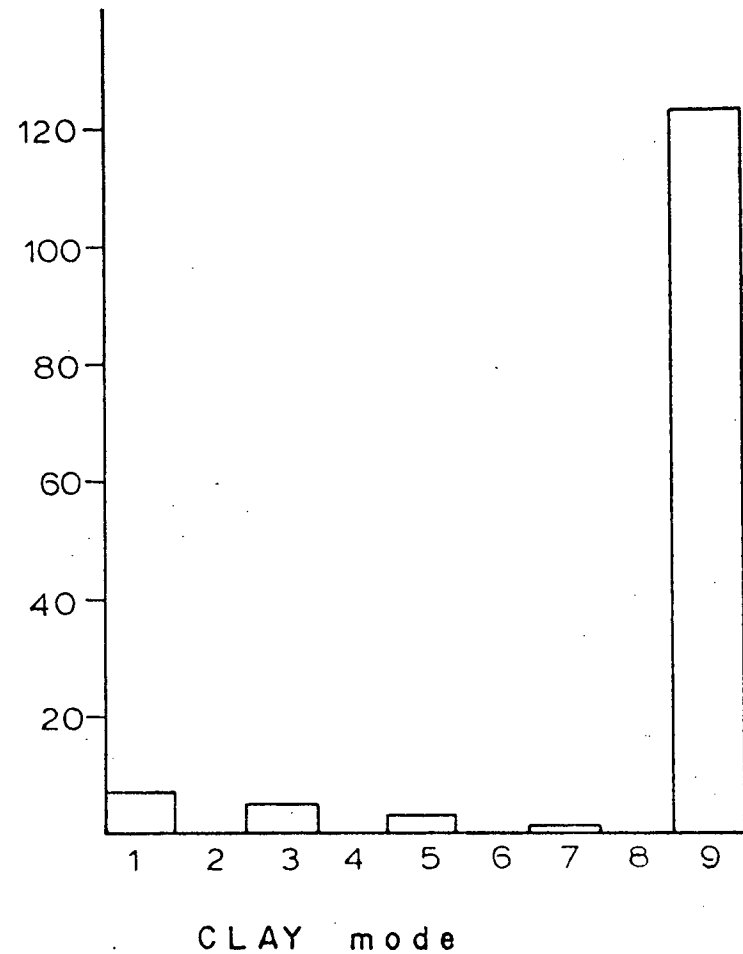
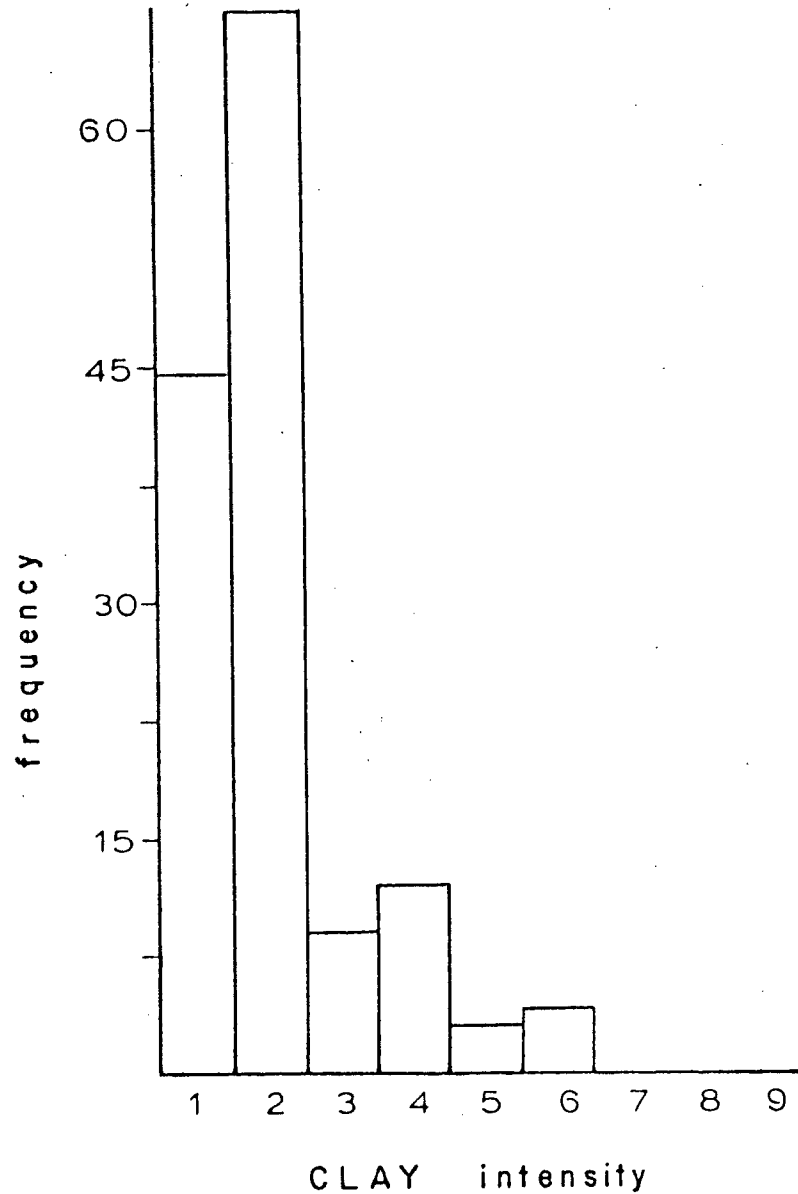


Figure 4.13: Bar graphs of the ranked intensity of clay, and its mode of occurrence, recorded for each 3m interval of core. Intensity increases from 1= trace to 9= extreme; mode increases from 1= veins to 9= disseminated (see Appendix B for more detail).



Plate 4.13: Argillic alteration in the biotite quartz monzonite from the central argillic zone. Phenocrysts of plagioclase are bleached to kaolinite. Greenish patches are sericite. Note that biotite remains fresh.

Epidote occurs in hornblende phenocrysts and as 0.1 to 0.5 mm subhedral intergrowths with albitized plagioclase phenocrysts (Plate 4.14).

Chlorite is the most abundant propylitic alteration mineral, but it is also observed in other facies (i. e. argillic) and is therefore not diagnostic. It occurs as intergrowths in biotite and hornblende developed parallel to original cleavage or along rims.

#### 4.4.5 Secondary Alteration

The general paucity of clay minerals in drill core compared to locally moderate to high abundances in surficial rocks, and the localization of clay in zones of relatively high permeability near fault zones suggests that much argillic alteration is secondary, and possibly supergene, in origin. The close spatial relationship between this central argillic alteration zone and the major north-northwest trending Canyon Creek fault is further evidence for a secondary origin to this alteration due to a locally higher permeability. However the differentiation of clays derived by supergene processes from clays derived from hypogene processes is difficult (Rose, 1970; Creasy, 1966; and Godwin, 1976).

The general lack of intense argillic alteration at the periphery of the deposit, and its occurrence at the center,

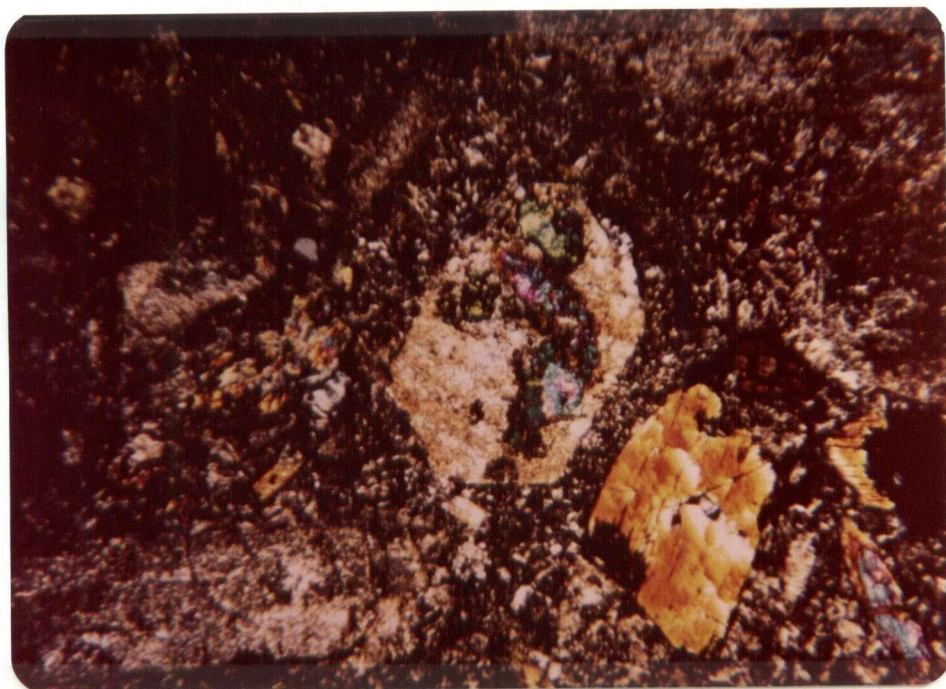


Plate 4.14: Photomicrograph (30 X) of propylitic alteration in the hornblende quartz monzodiorite. Highly birefringent mineral is epidote in altered plagioclase grain. Groundmass is largely chlorite and clay.

surrounded by a potassic alteration zone, is contrary to alteration zonation observed at the other deposit and described in the literature (i. e. Lowell and Guilbert, 1970; Drummond and Godwin, 1976; Rose, 1970; and Helgeson 1972). This is especially so, since no supergene sulfide or oxide minerals are present with the intense argillic alteration. Therefore this central argillic alteration zone was formed either by a late stage hydrothermal event which affected only those locations adjacent to areas of higher permeability such as the Canyon Creek fault; or from supergene processes which would have used the same permeable channels.

Based only on the distribution of alteration facies which are present in rocks which host mineralization at the Poplar porphyry this second alteration event could be either supergene or hypogene in origin. However, since many post-ore dykes are also altered (i. e. sericitization of plagioclase phenocrysts in the porphyritic dacite, and chloritization of biotite in the porphyritic rhyolite) the solutions which altered these rocks must have been relatively warm and had a relatively low pH. Since traces of unoxidized and unaltered pyrite and chalcopyrite are observed in the central argillic core of the deposit the second alteration event was most likely not supergene in origin, or secondary copper minerals would be expected (i. e. covellite, chalcocite, cuprite, etc.). Therefore this alteration episode is considered to be hypogene in nature and may in fact be related to the intrusion of the dykes themselves which would have locally raised the temperature of the Poplar Stock, or to the overlying Ootsa Lake Group volcanics, which cap the deposit.

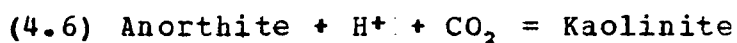
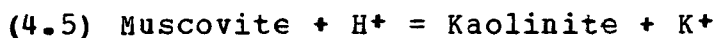
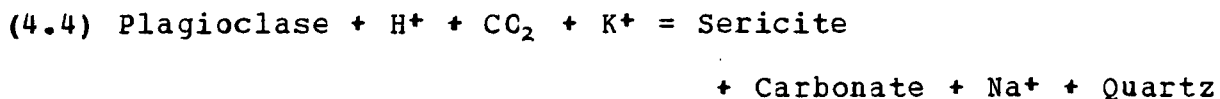
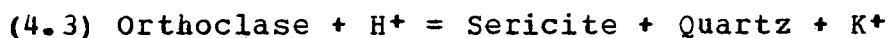
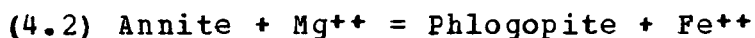
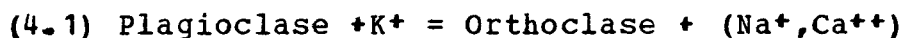
## 4.5 Chemical Aspects of Mineralization and Alteration Zoning

### 4.5.1 General Statement

The three criteria for determining the stability of a mineral or mineral assemblage in an aqueous system are: pressure, temperature and chemical potential (or activity ratio) of all components (Gibbs, 1873). In this section the zonation observed at the Poplar porphyry will be discussed in terms of these variables.

### 4.5.2 Discussion

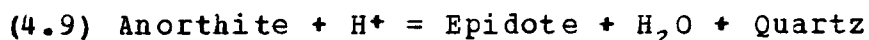
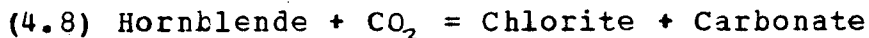
The generalized chemical reactions which best characterize the mineralogy of specific alteration zones, based on minerals observed in hand and thin section and the distribution of these zones, include:



+ Carbonate + Quartz



+ Carbonate



These chemical reactions are generalized and are used only to help account for many of the mineral relationships observed in hand sample and thin section. Products of the reactions are observable alteration minerals (i. e. carbonate and sericite after plagioclase), and reactants can be identified locally from pseudomorphs (i. e. chlorite after hornblende), or as a remaining part of a primary mineral which did not react (see detailed thin section descriptions in Appendix D). Microprobe analyses of biotites was beyond the scope of this study, however reactions (4.2) is probable for the deposit based on studies of biotites from North America porphyry deposits by Beane (1974).

Reactions (4.1) and (4.2) occur within the potassic alteration facies; (4.3) and (4.4) occur within the phyllic facies; (4.5) and (4.6) characterized the argillic facies and (4.7), (4.8) and (4.9) define the propylitic facies.

The reactions (4.3) to (4.6) and (4.9) are hydrolytic reactions (Hemley, 1964), that is, they involve the consumption of  $H^+$  and the consequent release of a cation (i. e.  $K^+, Ca^{++}, Na^+$ ). Numerous authors (e. g. Helgeson, 1970; Lowell and Guilbert, 1970; Hemley, 1959; Hemley and Jones, 1964; and Rose, 1970), have suggested that the typical potassic to phyllic to argillic to propylitic alteration observed at many porphyry deposits are due to various degrees of hydrolytic alteration.

Helgeson (1970) has suggested that alteration patterns at porphyry deposits are compatible with acidic solutions entering the margin of a pluton and reacting with host and country rocks, becoming less acidic with distance travelled inwards towards the core. As the fluid rises, due to thermally induced gravitational instability (Norton and Knight, 1977), it cools and may precipitate sulfides (Helgeson, 1964), thereby reducing solution pH, which promotes further acidic attack at shallow depths producing phyllic and argillic alteration zones above the deposit as well as along its margins (Helgeson, 1970). Implicit in this and similar models (i. e. Norton, 1972; Norton and Knight, 1977; Norton and Knapp, 1977; Villas and Norton, 1977; Cathles, 1977; Cunningham, 1978) is that fluid flow is free and permeability is symmetrical and isotropic.

Figure 4.14 is a mineral stability diagram after Hemley and Jones (1964), Hemley (1959), and Hemley, Meyers, and Richter

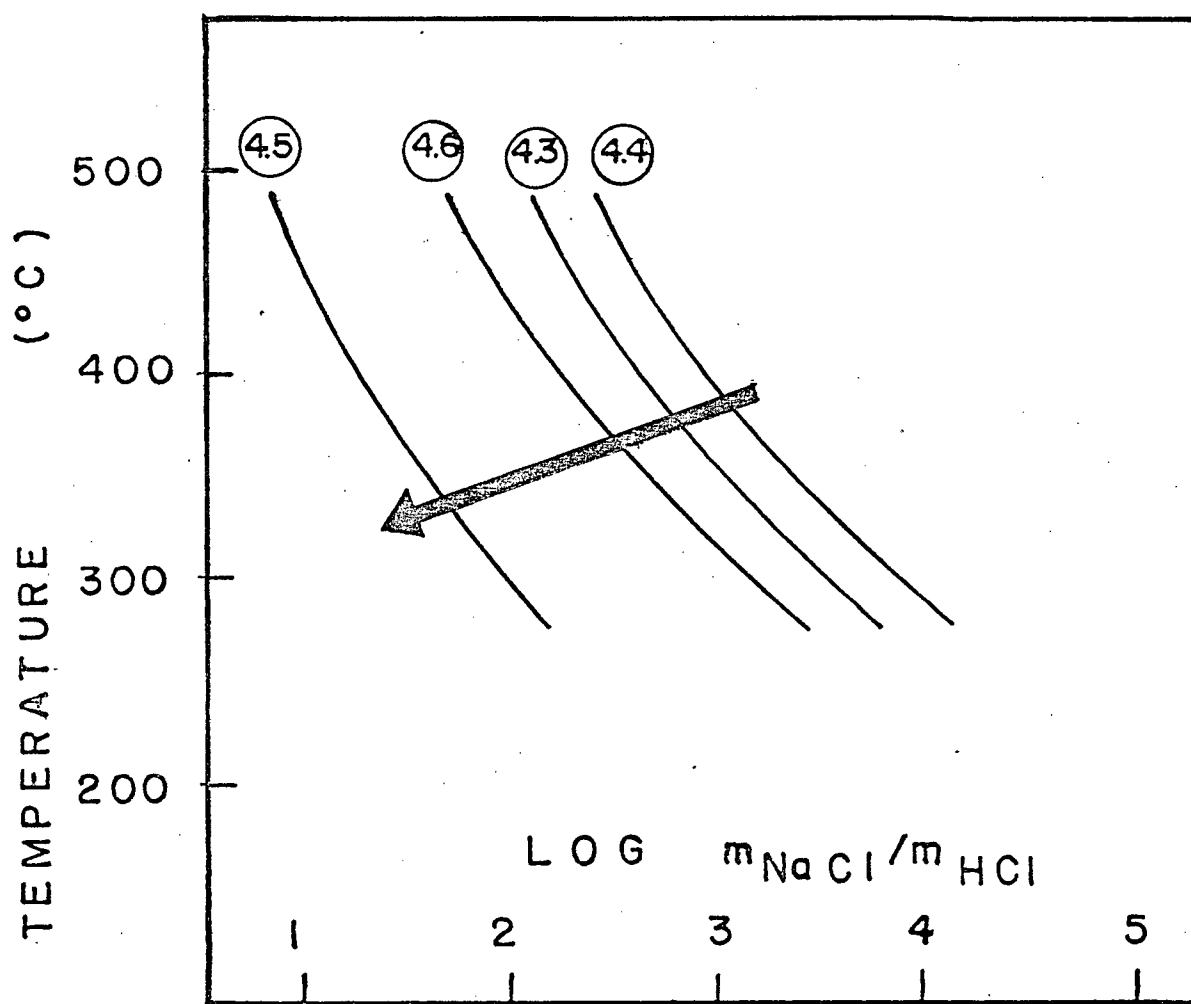


Figure 4.14: Univariant stability relations in the system  $\text{Al}_2\text{O}_3$ - $(\text{K}_2\text{O}, \text{Na}_2\text{O})$ - $\text{SiO}_2$ - $\text{H}_2\text{O}$  (after Hemley, et al., 1960). Circled numbers represent chemical equations; possible mechanisms are discussed in the text, to inhibit a fluid from entering the Kaolinite stability field. Total pressure= 1 kb.

(1961); with the 'direction' that a fluid packet, belonging to on the fluid pathline in Figure 4.15, takes from potassic to argillic alteration facies indicated by an arrow. Superimposed on the diagram are numbered reactions (4.3) to (4.6).

A schematic diagram of a porphyry type hydrothermal system with convective path lines, after Norton and Knight (1977), is shown in Figure 4.15. Numbered reactions (4.3) to (4.6) are placed at appropriate positions along the path lines to produce the alteration zoning observed at 'typical' porphyry deposits.

The lack of hydrothermal argillic alteration at the Poplar porphyry may be due to one or more of the following reasons (Fig. 4.14): (1) the original groundwater may not have had a sufficiently low pH to bring plagioclase or K-feldspar into the kaolinite stability field; (2) isotropic permeability along faults and joints may have restricted groundwater to certain areas of the deposit; and (3) the temperature of the intrusion and surrounding rocks may have been high enough to keep feldspar in the muscovite stability field (Fig. 4.14) for most of the hydrothermal event, and then a rapid cooling and quick cessation of thermally induced hydrologic flow, with the majority of the deposit spending little or any of its time in the kaolinite stability field, until the second alteration event.

Reactions (4.1), (4.4) and (4.7) involve potassium and/or

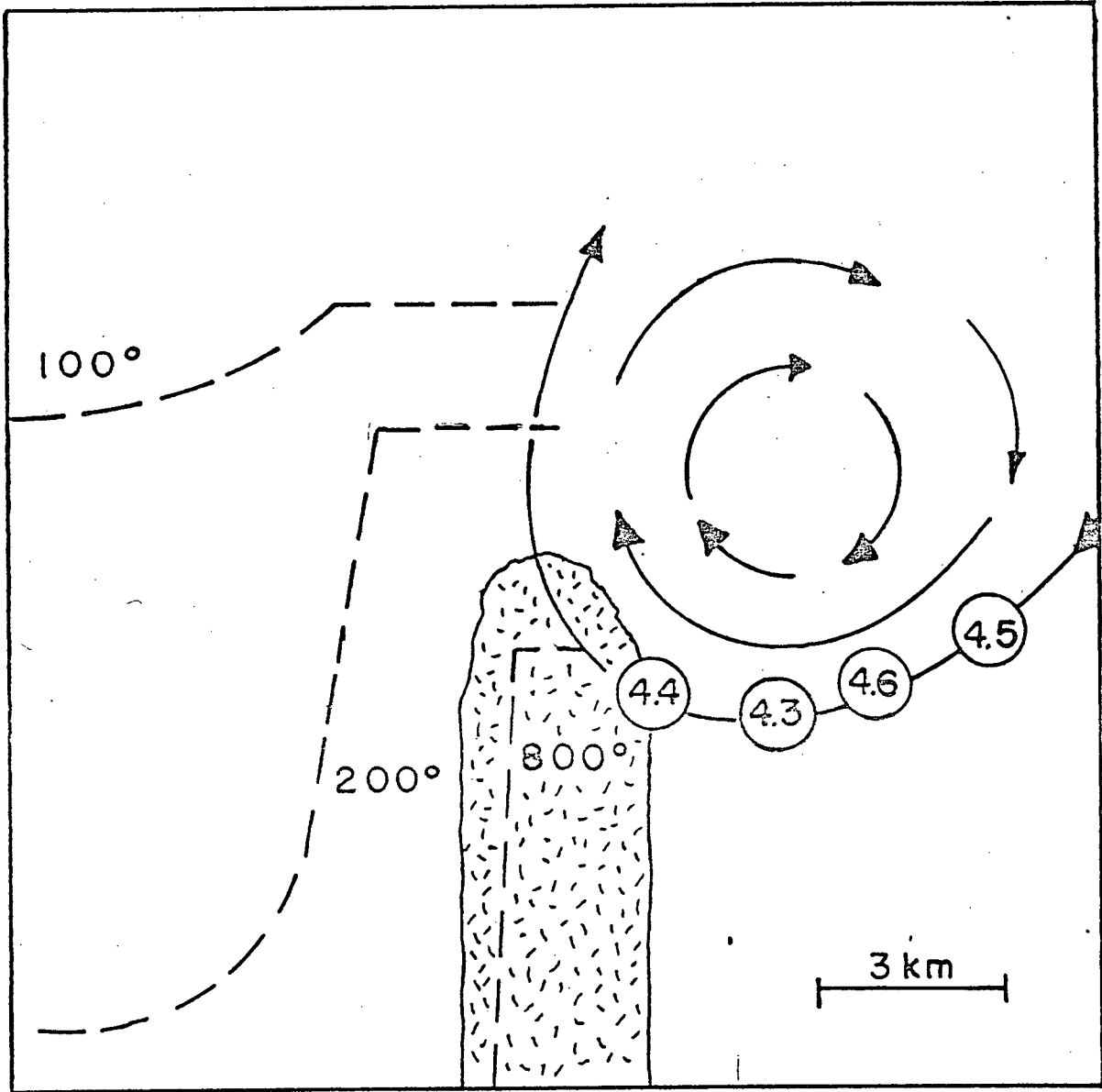


Figure 4.15: Schematic diagram of fluid pathlines adjacent to a hot porphyry type intrusion (after Norton, and Knight, 1977). Circled numbers refer to chemical equations referenced in the text and Figure 4.14; dotted lines are isotherms.

sodium metasomatism. Alternatively (4.4), (4.6), (4.7) and (4.8) may involve an increase in  $f(\text{CO}_2)$ . The high relative alkali activity of the solution, implicit in (4.1), (4.4) and (4.7), may in part be due to the release of these cations into solution during hydrolytic alteration. Norton (1977, Fig. 4) shows that depending on rock permeability and initial position of a "fluid packet" with respect to the intrusion, some fluid would indeed invade the already formed potassic zone after travelling through rocks that had undergone hydrolytic alteration. However, mass balance calculations by Helgeson (1970), indicate that the actual molality of cations in solution remains essentially constant, and that the high alkali activities are instead due to a decrease of up to two orders of magnitude of hydrogen ion. This finding has been substantiated by Hemley and Jones (1964) who show that the stability of a particular mineral is a function of the "activity ratio" (i. e.  $a(\text{Na}^+)/a(\text{H}^+)$ ) rather than the activity of a species alone. Therefore alkali metasomatism may occur either by a rise in the alkali activity due to cation release during hydrolytic alteration, or more likely, a decrease in  $a(\text{H}^+)$  in solution during this alteration.

Another source of alkalis for potassic or propylitic alteration (4.1), (4.2) and (4.7), could be the intrusive itself. Alkalis, water and silica are partitioned to the latest volatile rich phase of a crystallizing granitic magma (Jahns and Burnham, 1969; Hyndman, 1972; Burnham, 1967; and Carmichael, et

al., 1974). This fluid has been shown to make a substantial contribution to a hydrothermal system (Taylor, 1974; and Forester and Taylor, 1974). Fracturing of a chilled and impermeable brittle shell which encloses a crystallizing water saturated magma, either by  $P(H_2O)$  exceeding lithostatic pressure plus tensile strength, or by outside tectonic influence, could initiate boiling, and the consequent release of alkali rich fluids along fractures and microveinlets producing alkali deuteric alteration. Boiling also promotes sulfide deposition, since it raises solution pH, and concentrates aqueous species (Cathles, 1977; Cunningham, 1978).

Particular characteristics of alteration and mineralization zoning at the Poplar porphyry deposit are compatible with some of these features. Ignoring the central phyllic and argillic zone (Section 4.2) because it is likely a secondary alteration feature (Section 4.4.5), the Poplar porphyry consists of an annular potassic alteration zone around a 'barren' core surrounded by a zone of phyllic and lesser argillic alteration (c. f. Fig. 4.3).

The high biotite abundance in the mineralized intrusive breccia, of the biotite porphyry (Section 3.4.3), suggests that the last phase of the crystallizing biotite porphyry was alkali and volatile rich (Section 4.4.1). Therefore the majority of potassic alteration is probably pneumatolytic in origin.

However, local reversals in the sequence of alteration (Section 4.4.1) suggests that some potassic alteration may be derived from later hydrogen ion depleted hydrothermal solutions (c. f. Helgeson, 1970; and Norton, 1977; above). Villas and Norton (1977), and Norton (1977) suggest that phyllic alteration takes place simultaneously with potassic alteration, at a lower temperature, outside the potassic zone. This probably took place in highly fractured and permeable Skeena Group rocks (Section 3.4.2 and 3.7) during the hydrothermal event. As the intrusion cooled large scale fracturing occurred due to thermal contraction. Permeability was enhanced along these fractures (Section 4.1 and 4.4.2) and meteoric waters flowed inward towards the centre of the deposit, hydrolytically altering both fresh rocks and those which underwent previous potassic alteration (Section 4.4.2) and produced the alteration patterns observed at the Poplar porphyry (Section 4.2). As the intrusion cooled, isotherms, and consequently phyllic alteration collapsed around the centre of the deposit as the lower stability limit of K-feldspar and plagioclase was reached (Fig. 4.14; and Hemley and Jones, 1964). Those areas of the deposit which were not fractured, would be unaffected by hydrolytic alteration, and therefore the original potassic alteration minerals would remain (Section 4.1 and 4.4.1).

The occurrence of a breccia pipe in many porphyry deposits is generally thought to be an expression of an explosive release of a vapor dominated phase above a shallow crystallizing stock.

This brecciation has an enormous influence on the localization of copper and molybdenum mineralization (Cunningham, 1978; Cathles, 1977), and symmetrical hypogene zoning influenced by the greater permeability (Norton, 1977). If however, the excess pressure ( $P(H_2O) > P(Lith) + \text{Tensile Strength}$ ) is "tapped" by local fracturing events during emplacement and cooling of the stock, the pressure necessary for the development of a breccia pipe might not materialize. Consequently the alteration patterns observed would be controlled by much more directional permeability (faults, fractures, shear zones) about the intrusion. The locally faulted contact between the Poplar Stock and Skeena Group rocks (Section 3.4.3) may have aided such pressure release. Variables such as the healing and opening of fractures, multiple intrusive events and regional tectonics could further affect the circulation patterns of the hydrothermal system, and consequently the alteration patterns observed. Variation in the texture (i. e. plagioclase phenocryst abundance and packing, Section 4.4.2) and bulk composition of the altered host and country rock also has a profound affect on the intensity of a particular alteration facies.

Reactions (4.2) and (4.8) are dependent on the activity of ferrous iron and the activity ratio of  $a(Fe^{++})/a(Mg^{++})$ . The oxidation potential of the system would have a major influence on this ratio since  $Fe^{++}$  can be oxidized to  $Fe^{+++}$ , while Mg has no equivalent trivalent state. Also the oxidation of  $Fe^{++}$

coupled with a sulfate-sulfide reduction could supply additional sulfide ion to the system. Precipitation of magnetite from solution would further tend to favour the right hand side of equation (4.2). The occurrence of magnetite within the ore zone of the Poplar porphyry and its association (along with chalcopyrite) with secondary biotite (Section 4.4.1) is compatible with these chemical relationships.

Carbonate is an abundant alteration product in most samples of phyllic and argillic alteration at the Poplar porphyry (Section 4.4.2 and 4.5.2, reactions (4.4), and (4.6), (4.8)). Because of the close association of altered plagioclase with calcite, the  $\text{Ca}^{++}$  released from plagioclase during hydrolytic alteration is probably the cation reactant for the carbonate (Section 4.4.2).

Locally high fracture density in the host and country rocks makes the deposit locally susceptible to a second alteration event. The zonation at the Poplar porphyry includes a central zone of argillic and phyllic alteration which borders Canyon Creek fault. This zone is either secondary hypothermal or supergene in origin (Section 4.4.5). In addition, this zone occurs in an area bounded by a potassic alteration annulus and is suggestive of a "low-grade core" similar to that found in the Lowell and Guilbert (1970) model, because of a negligible amount of either supergene or hypogene mineralization.

#### 4.6 Environment of Ore Deposition

Mineral assemblages found in alteration and mineralization zones at the Poplar porphyry would, by themselves, place little constraint on the actual pressures and temperatures of formation and the chemical characteristics of the ore forming solutions. However, work at other porphyry deposits, with similar potassic zone alteration and mineralization, can be used to place some limits on the environment of ore formation based on fluid inclusion (Roedder, 1971), stable isotope (Shepard et al., 1971), and biotite geothermometry (Beane, 1974) studies. A temperature of 375°C, and a pressure of 250 bars (approximately equivalent to 2.5 Km of hydrostatic head) for potassic alteration and chalcopyrite mineralization at the Poplar porphyry is compatible with these studies.

Chalcopyrite is the only copper bearing mineral observed in the deposit, except for traces of bornite, covellite and tetrahedrite, and is found almost exclusively in the potassic alteration zone (Map B), associated with magnetite. Figure 4.16 is a  $\text{Log } a(\text{O}_2)$ -vs- $\text{Log } a(\text{S}_2)$  diagram for the Cu-Fe-S₂-O₂ system, at 250 bars and 375°C. The chalcopyrite-magnetite field is shown cross-hatched. This diagram indicates that potassic facies alteration and chalcopyrite mineralization occurred in an area ranging from -34 to -26  $\text{Log } a(\text{O}_2)$  and from -13 to -4  $\text{Log } a(\text{S}_2)$ .

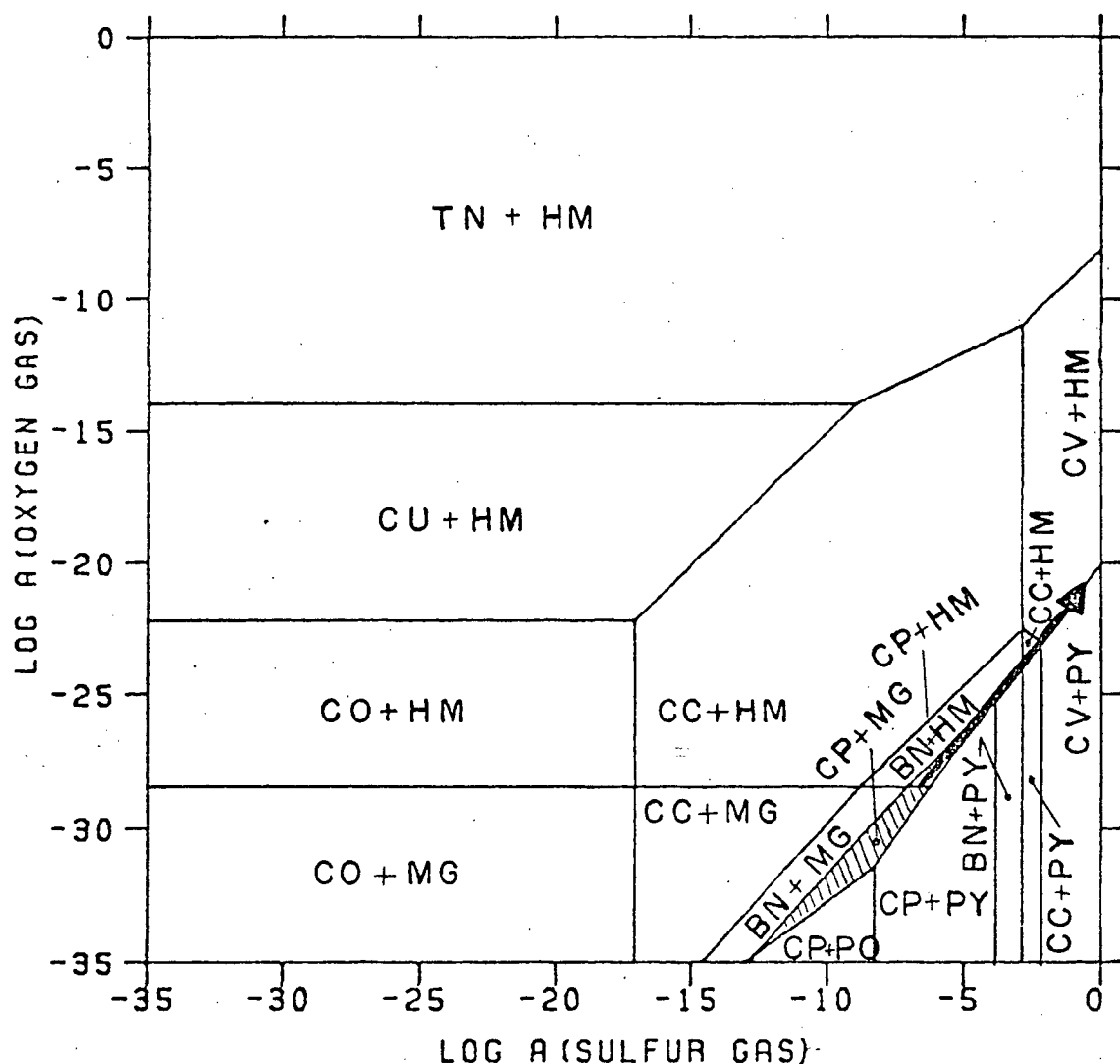
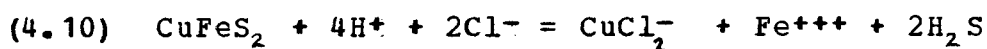


Figure 4.16: A  $\text{Log } a(\text{S}_2)$ -vs-  $\text{Log } a(\text{O}_2)$  diagram for the system  $\text{Cu-Fe-O}_2\text{-S}_2$ , at 375 C and 250 bars. TN=tenorite, CU=cuprite, CO= native copper, CC= chalcocite, CP= chalcopyrite, CV= covellite, BN= bornite, MG= magnetite, HM= hematite, PO= pyrrhotite, and PY= pyrite. The cross-hatched area is the stability field of magnetite-chalcopyrite, found in the potassic zone of the Poplar porphyry. Arrow indicates direction of solution movement from potassic to phyllic alteration facies.

The phyllic alteration assemblage contains no copper bearing minerals , but does contain a pyrite ± hematite assemblage (Section 4.4.2). If copper was removed from the system (Fig. 4.16) then pyrite and hematite would coexist along the join dividing their respective fields. The arrow in Figure 4.16 indicates the direction a solution would move from being in equilibrium with chalcopyrite-magnetite in the potassic facies to reaching equilibrium with pyrite ± hematite in the phyllic facies; both  $a(S_2)$  and  $a(O_2)$  increase.

If copper was present as the solution changed as described above then chalcocite+hematite, covellite+pyrite, or covellite+hematite should be precipitated as stable phases and observed in the phyllic alteration zone , which they are not. This suggests that chalcopyrite was removed by the same solutions which produced phyllic alteration minerals, rather than reacting to form another copper sulfide. Equation 4.10 may indicate a possible mechanism which may explain what happened.



As the solutions became more acidic rocks which had undergone previous potassic alteration and contained K-feldspar, plagioclase, and chalcopyrite were hydrolytically attacked. K-feldspar and plagioclase were altered to sericite or clay ± carbonate, and chalcopyrite was removed. The H₂S and Fe⁺⁺ released in reaction 4.10 may have been redeposited as pyrite ±

hematite ± chalcopyrite(?) in the phyllic alteration facies.

#### 4.7 Evolution of Mineralization and Alteration Zoning at the Poplar Porphyry

In summary a model for the evolution of the Poplar porphyry deposit includes:

- A) Intrusion of a quartz monzonite stock, of the Late Cretaceous Bulkley intrusive suite, into Lower Cretaceous marine and volcanogenic sedimentary rocks of the Skeena Group, with concomitant fracturing and faulting of country rocks.
- B) Chilling of an impermeable monzodiorite shell around a cupola of the stock in contact with country rocks. Within this shell a water saturated alkali rich melt develops.
- C) Local fracturing of the shell, due to either excess vapor pressure, or an external tectonic event, initiates open but directional flow between intrusive and country rock, developing a convective hydrothermal system. Potassic alteration is formed early in the alteration sequence from late stage magmatic fluids, high in alkali metals (and/or low in  $H^+$ ) concomitant with deposition of copper and molybdenum sulfide. Fluids which are involved in hydrolytic alteration at the periphery of

the ore deposit convect inwards along localized fractures towards the central potassic alteration zone, reacting with wall rock, raising its pH and temperature along its path; eventually coming into equilibrium with the potassic alteration facies.

- D) As the stock cools, peripheral meteoric waters travel further through previously hydrolytically altered rocks, without raising its pH or temperature; subsequently the phyllic and lesser argillic alteration zones collapse around the central potassic alteration zone. Continuous fracturing and healing of conduits, alternately enhances and inhibits the wall rock from reacting with hydrothermal solutions, leaving some higher "alteration grade" potassic - chalcopryite - molybdenite zones unaffected by hydrolytic alteration.
- E) Reduction of stock temperature and the gradual diminution of the hydrothermal system. While the hydrothermal system was in its last stages numerous dykes were intruded followed by a second "lower grade" alteration event which overprinted most previous alteration zones that were within, or adjacent to, permeable areas (i. e. the central argillic alteration zone).
- F) Holocene glaciation and removal of any cap or supergene mineralized horizons.

## CHAPTER V

GEOSTATISTICS OF THE POPLAR PORPHYRY5.1 General Statement

One of the most valuable characteristics of the Poplarlog format (Section 3.1, and Appendix B) for logging drill core is that geologic information is amenable to statistical analyses. Major advantages of statistical treatment of the large amount of data obtained at the Poplar porphyry include: the determination of geological variables which are most valuable for describing systematic spatial variations within the deposit; numerical results which may either verify or alter previously developed relationships based on field observations; and to indicate relationships not readily apparent from normal field observation. In particular, the determination of the type and strength of relationships among chalcopyrite, molybdenite, and alteration mineral abundances can be assessed statistically.

In this chapter the results and interpretation of statistical analyses, consisting of linear correlations, and multivariant analysis, are presented. In addition to analytical statistical studies numerous computer programs have been designed to produce graphic illustrations of the spatial distribution and correlation between geologic variables (i. e. HISTLOG and CPY; Appendix C).

Over 1000 quantitative observations of 21 separate variables were made during the course of detailed logging of drill core along cross-sections A-A' and B-B' (Fig. 3.3, and 3.4; and Map A). These data were reduced to 739 observations by excluding data from unmineralized rock units such as post-ore dykes. Twenty-one variables that were examined in detail are listed and described in Appendix B; but for the purpose of this chapter the variables of most interest are the ranked intensities of 14 hydrothermal minerals (Table 5.1).

Two computer packages, available at the Computer Science Centre at the University of British Columbia, were used in this study; TRP and MIDAS. TRP is an acronym for 'Triangular Regression Package', the major purpose of which is regression analysis (Le and Tenisci, 1978). The major subroutines of TRP that were used, and their purpose are: INMSDC, for producing means, standard deviations, and simple correlation coefficients; SIMREG, for producing univariant linear regressions; and STPREG, for multivariant regression analysis. MIDAS, or 'Michigan Interactive Data Analysis System' was used to calculate one-way correlations. Each of these subroutines are shown in Appendix D as they were used in a Fortran computer programs which were written by the author.

## 5.2 Correlations Between Variables

### 5.2.1 Two-way Correlation Matrix

"Two-way" correlations is a term applied when all observations have equal weight in the correlation equation (Equation 5.1) (Le and Tenisci, 1978).

$$(5.1) \quad r = \frac{\sum_i W_i (X_i - \bar{X}) (Y_i - \bar{Y})}{\left| \sum_i W_i (X_i - \bar{X})^2 \quad \sum_i W_i (Y_i - \bar{Y})^2 \right|^{1/2}}$$

where:

$r$  = correlation coefficient

$W_i$  = weight of the  $i^{th}$  observation

$X_i$  = value of the  $i^{th}$  observation of  $X$

$\bar{X}$  = sample mean of  $X$

$Y$  = value of the  $i^{th}$  observation of  $Y$

$\bar{Y}$  = sample mean of  $Y$

TABLE 5.1  
Fifteen Hydrothermal Minerals Used in Statistical Analysis of  
Alteration and mineralization at Poplar Porphyry Deposit.

---

<u>ALTERATION MINERALS</u>	<u>ORE MINERALS</u>
quartz	chalcopryite
K-feldspar	bornite
biotite	molybdenite
sericite	
chlorite	
clay	
epidote	
carbonate	
gypsum	
pyrite	
hematite	
magnetite	

---

Table 5.2 shows the correlation matrix, and the means and standard deviations of 14 economic and alteration minerals observed at the Poplar porphyry.

The standard deviation of most minerals is as large or larger than their mean. This is because the number zero was recorded in the field when a particular mineral was absent in an interval of core; therefore zero does not represent a missing observation, but instead a numerical value. Except for quartz,

sericite, and pyrite which occur to some extent in most intervals of core, zero is the most frequently recorded value for any mineral, hence the standard deviation calculated accounts for this skewness towards zero. Correlations which disregard observations of zero in the correlation equation (5.1) are discussed in detail in Section 5.2.2.

Correlation coefficients that are statistically significant have been underlined in Table 5.2 by either a single or double line, indicating significance at the 99.0 percent and 99.9 percent confidence levels, respectively. Based on 739 observations a minimum departure from zero of 0.094 for the 99.0 percent confidence level, and 0.127 for the 99.9 percent confidence level, is required for significance (Dixon and Massey, 1969). The term "statistically significant" means that correlation coefficients with values above those calculated for a specific confidence level are significantly different from zero (i. e. there is a definite correlation) at the probability of the confidence level.

Geologically significant correlations, with few exceptions, support correlations based on field observations (Chapter IV) and are shown classified by facies in Table 5.3. Alteration relationships defined by these correlation groupings are not only very similar to those in the field, but statistically substantiate the alteration facies of Lowell and Guilbert

CONTROL CARD NO. 1 ** INMSDC **** INMSDC **** INMSDC **** INMSDC **** INMSDC **** INMSDC **** INMSDC ** CONTROL CARD NO. 1  
FORMAT CARDS

(30X,6(1X,F1.0),1X,3(1X,F1.0),5X,7(1X,F1.0))

CORRELATION MATRIX

	<u>QUARTZ</u>	<u>K-SPAR</u>	<u>BIOTIT</u>	<u>SERICT</u>	<u>CHLCRT</u>	<u>CLAY</u>	<u>EPIDOT</u>	<u>CARBS</u>	<u>GYP SUM</u>	<u>PYRITE</u>	<u>HEMATT</u>
QUARTZ	1.0000										
K-SPAR	-0.0872	1.0000									
BIOTIT	-0.0825	0.4318	1.0000								
SERICT	0.1139	-0.3306	-0.3002	1.0000							
CHLCRT	-0.1519	-0.0080	0.1250	-0.0333	1.0000						
CLAY	-0.0660	-0.0651	-0.1108	0.3315	0.0288	1.0000					
EPIDOT	-0.0422	0.0366	0.0287	-0.0872	-0.0034	-0.0134	1.0000				
CARBS	-0.0416	-0.0078	-0.0600	0.1281	-0.0162	0.0533	-0.0372	1.0000			
GYP SUM	0.0691	-0.0611	0.0592	-0.0975	0.0920	-0.1778	-0.0220	-0.3389	1.0000		
PYRITE	0.3646	-0.2215	-0.0144	0.0648	-0.0162	-0.2026	-0.0204	-0.2594	0.3095	1.0000	
HEMATT	-0.1245	-0.1506	-0.1260	0.1220	0.0364	-0.0510	-0.0165	0.1453	-0.1485	-0.0867	1.0000
CHALPY	-0.0317	0.2497	0.1970	-0.1966	-0.0168	0.0148	0.0125	0.1117	-0.0981	-0.3008	0.0280
BORNIT	-0.0614	-0.0105	-0.0127	0.0288	-0.0133	0.0162	-0.0052	0.0105	-0.0852	-0.0549	0.0086
MAGNTT	-0.2634	0.1376	-0.0063	-0.2182	0.0127	-0.0364	-0.0129	0.1740	-0.1517	-0.2753	0.0859
MCLY	0.1577	0.1353	0.1134	-0.0429	-0.0339	0.0407	0.0750	0.0550	-0.0816	-0.1271	-0.1087

CORRELATION MATRIX

	<u>CHALPY</u>	<u>BORNIT</u>	<u>MAGNTT</u>	<u>MCLY</u>
CHALPY	1.0000			
BORNIT	0.0139	1.0000		
MAGNTT	0.2474	-0.0119	1.0000	
MCLY	0.2624	-0.0789	-0.1284	1.0000

NAME	MEAN	STANDARD DEVIATION
QUARTZ	4.40054	2.09446
K-SPAR	1.62111	2.39520
BIOTIT	0.703654	1.66508
SERICT	4.70907	1.98928
CHLCRT	0.324763E-01	0.347700
CLAY	0.338295	0.932277
EPIDOT	0.270636E-02	0.735712E-01
CARBS	1.76049	1.74165
GYP SUM	1.13261	1.89744
PYRITE	3.09202	1.97263
HEMATT	0.489851	1.09611
CHALPY	1.45467	1.60505
BORNIT	0.243572E-01	0.170928
MAGNTT	0.510149	1.45886
MCLY	1.02842	1.45874

739 OBSERVATIONS TOTAL  
739 OBSERVATIONS ARE COMPLETE  
738 DEGREES OF FREEDOM

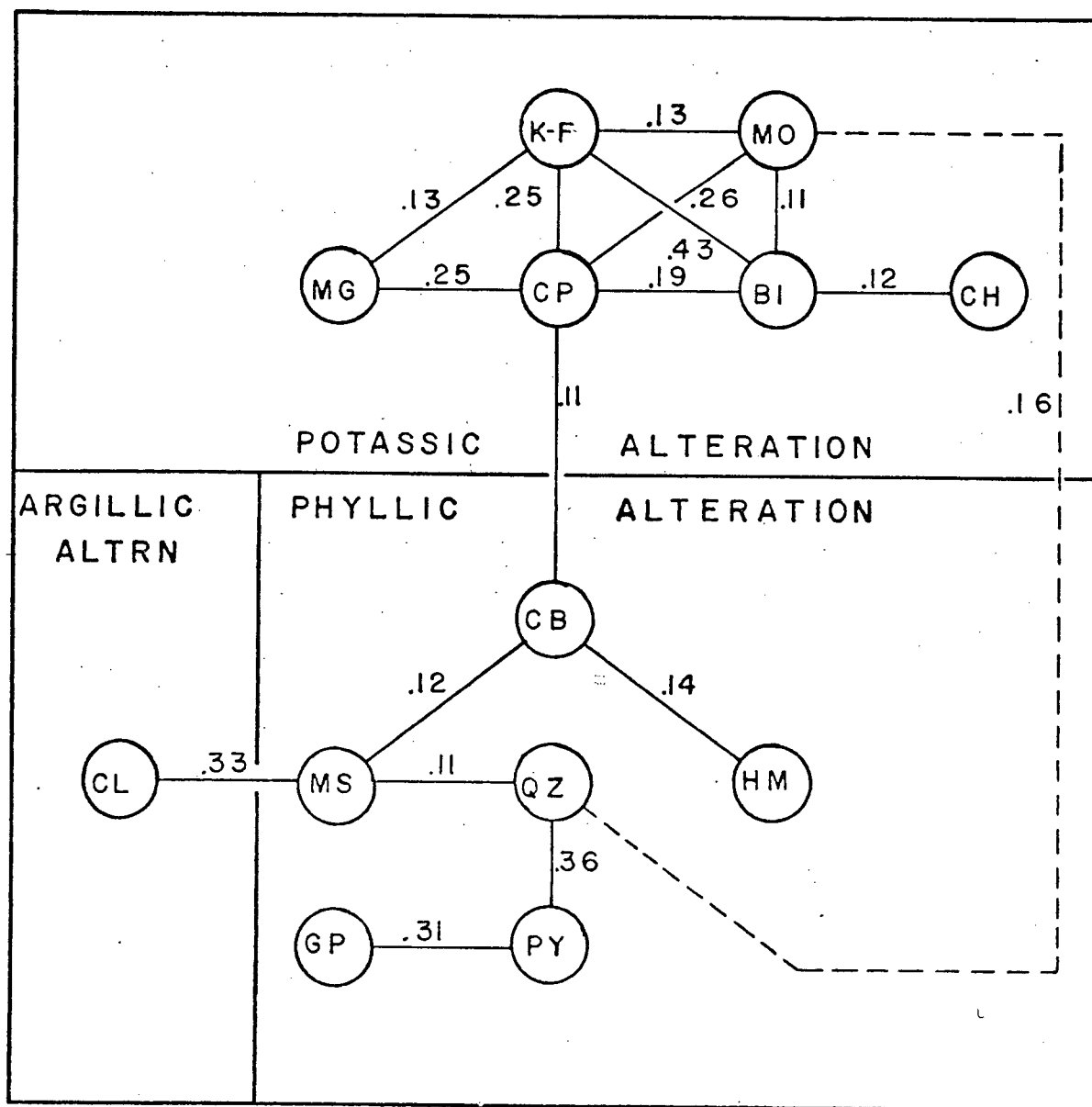


Figure 5.1: A positive correlation "cluster", based on alteration facies between minerals which are significantly correlated. Divisions between potassic, phyllic, and argillic facies are shown.

(1970).

Figure 5.1 is a Correlation 'Cluster' diagram showing mineral correlations grouped according to alteration facies.

One significant correlation which was not identified in the field is carbonate - pyrite. A correlation which was expected to be significant, but cannot be shown here to be so, is sericite - pyrite. The significant negative correlation (-0.1284) between molybdenite and magnetite is anomalous, since both are positively correlated with K-feldspar (Table 5.2), and both occur within the potassic alteration zone. However, molybdenite is largely restricted to quartz veins, and quartz is negatively correlated with magnetite. Therefore, the relationship between molybdenite and magnetite, may be due to the absence of magnetite near quartz veins, rather than its true spatial relationship to just molybdenite alone.

The most useful correlation for the economic evaluation of the deposit are those that not only define alteration facies, but also establish which minerals are the most useful in predicting the occurrence and abundance of chalcopyrite and molybdenite. Chalcopyrite is correlated positively with potassic alteration minerals, and negatively with phyllic alteration minerals (Table 5.2). Molybdenite, less well defined in terms of facies relationships, is correlated positively with the potassic alteration facies minerals K-feldspar and biotite, and with quartz in the phyllic alteration facies. It is

TABLE 5.3

Correlations Between Minerals Based on Alteration Facies¹

<u>FACIES</u>	<u>MINERAL</u>	<u>+CORRELATION</u>	<u>-CORRELATION</u>
Potassic	K-feldspar	biotite chalcopyrite magnetite molybdenite	sericite pyrite hematite
	biotite	chalcopyrite molybdenite K-feldspar	sericite clay hematite
	magnetite	carbonate chalcopyrite K-feldspar	quartz sericite gypsum pyrite molybdenite
Phyllic	sericite	quartz clay carbonate hematite	chalcopyrite magnetite K-feldspar biotite gypsum
	quartz	pyrite sericite molybdenite	hematite magnetite
	pyrite	gypsum quartz	K-feldspar magnetite chalcopyrite molybdenite clay carbonate
Argillic	clay	sericite	gypsum biotite pyrite
	carbonate	hematite chalcopyrite magnetite sericite	gypsum pyrite

¹This table is a summary of analytical results shown in Table 5.2

correlated negatively with pyrite and hematite in the phyllic alteration facies, and with magnetite in the potassic alteration facies.

### 5.2.2 One-way Correlation Matrix

One-way correlation is calculated using Equation (5.1); if a principle variable  $X$ , is zero for a particular observation,  $i$ , that observation is excluded from the regression; the secondary variable,  $Y$ , is considered regardless of its value for a particular observation. The purpose of such a calculation is to distinguish those correlations which occur between variables because both, though unrelated, maintain mutual values of zero in a number of observations, and are consequently assigned a correlation coefficient that may not indicate their true spatial relationship.

The one-way correlation matrix (Table 5.4) is nonsymmetrical, indicating that two variables have different correlation coefficients, depending on which is chosen as the principle variable,  $X$ . This shows that the inter-dependence of the two minerals is unequal (i. e. the occurrence of mineral A is more dependent on the occurrence of mineral B, than vice versa). For example, Table 5.4 shows that although chalcopyrite does not correlate significantly with occurrence of the principle variable K-feldspar; K-feldspar does significantly correlate with the occurrence of the principle variable chalcopyrite.

TABLE 5.4

## One-way Correlation Matrix of Alteration and Economic Minerals

	Quartz	K-feldspar	Biotite	Sericite	Chlorite	Clay	Epidote	Carbonate	Gypsum	Pyrite	Hematite	Chalcopyrite	Bornite	Magnetite	Molybdenite	N ^a	r _{99.0} ^b
Quartz	1.0	-.146	-.1297	.1567	.0387	-.092	-.057	-.106	.1017	.3897	-.054	-.095	.010	-.1932	.0769	692	0.098
K-feldspar	.0459	1.0	.3439	-.045	-.085	-.055	-.005	-.058	-.143	-.008	-.099	-.029	-.064	0.063	+.109	286	0.151
Biotite	-.137	.2082	1.0	-.1949	.2625	0.1212	-.0985	-.0498	.3327	.2055	-.078	.0511	-.0519	-.2073	.1069	133	0.223
Sericite	.114	-.3104	-.2745	2.0	.0745	.3333	0.0	.1191	-.0832	.0701	.1162	-.2054	.0244	-.2437	-.0438	727	0.095
Chlorite	0.0	-.0848	.967	-.4698	+.106	-.1446	0.0	-.536	.9670	.6926	-.1501	-.6954	0.0	-.2583	0.0	12	0.695
Clay	.0474	.0040	.1826	.4113	-.0602	1.0	0.0	-.0534	-.0379	-.1189	-.1083	.1083	-.1116	-.0951	-.0156	112	0.242
Epidote	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1	1.000
Carbonate	.0331	-.0699	-.0744	.1982	0.0332	.0448	0.0	1.0	-.2372	-.1016	.0886	.0686	.0421	.1433	.0079	484	0.115
Gypsum	-.0520	-.0818	.0806	.0299	.2272	-.0446	0.0	-.2492	1.0	.2947	.1360	-.0059	0.0	-.1398	.0363	230	0.170
Pyrite	.3156	-.2555	-.0723	.0735	.0154	-.1627	-.0357	-.1894	.2912	1.0	.0672	-.2241	-.226	-.1882	-.2017	646	0.101
Hematite	-.0411	-.1401	0.1052	.0646	.0473	-.1533	0.0	.1445	0.1456	.0325	1.0	-.0936	.0039	-.0029	.0062	184	0.188
Chalcopyrite	.0610	.1279	.1027	-.2535	-.0769	-.1627	-.0156	-.0902	.2018	-.0584	.1288	1.0	-.0276	.2263	.1170	439	0.122
Bornite	-.1471	.3388	-.1677	-.2275	0.0	-.2390	0.0	-.3962	0.0	.3797	-.1862	-.4467	1.0	-.1299	-.1690	16	0.623
Magnetite	-.1475	-.0113	0.1114	-.4473	-.1036	-.3072	0.0	.0623	-.0354	-.1289	-.1196	.1688	.0028	1.0	-.1069	109	0.256
Molybdenite	.1704	.0116	.0097	-.0046	.0358	.0144	.0700	-.0376	-.0466	.0549	.0153	.2841	-.0858	-.0479	1.0	312	0.145

Underlined correlation coefficient are statistically significant.

a) N = number of observations of a particular variable in Equation (5.1). Equal to the number of non-zero observations

b) r₉₉ = minimum correlation coefficient, for the number of observations, N, at the 99.0 percent confidence level. Calculated from Dixon and Massey (1969)

Results from the one-way correlation matrix (Table 5.4) in general corroborate results on the mineralogy of alteration facies presented in Sections 4.3, and 4.4. Quartz and sericite correlate positively with each other, and negatively with potassic alteration facies minerals and chalcopyrite. Chalcopyrite correlates significantly with K-feldspar, gypsum, hematite, and magnetite and negatively with sericite and chlorite. Molybdenite is positively correlated with quartz, and chalcopyrite. Inconsistencies between results from one-way (Table 5.4) and two-way (Table 5.2) correlation matrices include the lack of a significant positive correlation between K-feldspar and biotite, and between these minerals and chalcopyrite and molybdenite in the one way correlation matrix. The lack of a significant positive correlation between pyrite and sericite is also apparent in Table 5.4.

### 5.3 Multivariant Analysis

#### 5.3.1 General Statement

Univariant linear analysis (linear correlation between one dependent and one independent variable) is useful in evaluating what effect, if any, one variable has on another. Correlation coefficients presented in Section 5.2 are measures of this dependence between two variables. However, this approach is restricted since most geologic variables are the result of interactions between numerous other variables (Davis, 1973). Multivariant analysis allows one to consider changes in several properties of a system simultaneously, in order to sort out the

major factors determining the relative worth of variables.

$$(5.2) \quad Y = A_1 X(1) + A_2 X(2) + \dots + A_N X(N) + K$$

where:

$Y$  = dependent variable

$A_i$  = coefficient of the  $i^{th}$   
independent variable

$X_i$  =  $i^{th}$  independent variable

$K$  = a constant that is equal  
to the  $Y$ -intercept on  
the regression hyperplane

The multivariant regressions were performed using the subroutine STREG from the TRP statistical computer package (Le and Tenisci, 1978). Both frontwards and backwards stepwise regression techniques were employed, with equal results (Equation 5.3 and 5.4).

In backwards stepwise regression all independent variables are included in the equation (5.2) at the first step; a multivariant equation is calculated with a minimum variance in  $Y$  for those variables. Each variable is then tested for significance by computing the probability of obtaining an absolute value of the coefficient 'A' greater than the one calculated, if the variable  $X$  made no significant contribution. The greater this probability, the less significant  $X$  is to the

equation. If this probability is greater than 0.05 (five percent) the variable is eliminated from the equation. The least significant variable is dropped from the equation at each step and a new equation is calculated by minimizing the variance between the remaining variables. This routine is carried out until each independent variable left in the equation has an associated probability of less than 0.05.

### 5.3.2 Multivariant Equations for Chalcopryite and Molybdenite

Multivariant equations (5.3 and 5.4) are presented for the dependent variables chalcopryite or molybdenite versus the independent variables quartz, K-feldspar, gypsum, pyrite, and magnetite. Molybdenite was an independent variable in the chalcopryite equation (5.3), and chalcopryite was an independent in the molybdenite equation (5.4).

$$(5.3) \quad \begin{aligned} \text{Chalcopryite} = & 0.78 \text{ quartz} + 1.5 \text{ biotite} \\ & + 0.24 \text{ magnetite} + 0.25 \text{ molybdenite} - 0.07 \\ & \text{sericite} - 0.20 \text{ pyrite} + 1.59 \end{aligned}$$

$$r^2 = 0.229 \qquad \text{S.E.} = 1.415 \text{ R.I.}$$

$$(5.4) \quad \begin{aligned} \text{Molybdenite} = & 0.12 \text{ quartz} + 0.05 \text{ K-feldspar} \\ & + 0.23 \text{ chalcopryite} - 0.11 \text{ pyrite} \\ & - 0.20 \text{ magnetite} + 0.52 \end{aligned}$$

$$r^2 = 0.149 \qquad \text{S.E.} = 1.350 \text{ R.I.}$$

Where:

$r^2$  = multiple correlation coefficient; equal to the proportion of the variance of the dependent variable, Y, accounted for by the regression line.

S.E. = standard error; the estimate of the variance of the dependent variable Y, about the regression hyperplane (Le and Tenisci, 1978). Units of standard error are the "ranked abundance" used in logging drill core ( Appendix B).

R.I. Means Ranked Intensity. (see Section 5.3.2.1.)

Equation (5.3) indicates that the empirical relationship between chalcopyrite and the potassic and phyllic alteration facies is substantiated when the effects of the other variables are taken into account. The notable exclusion of K-feldspar from the equation is because its associated probability was greater than five percent. Even though K-feldspar and chalcopyrite are correlated positively at the 99 percent confidence level (Sections 5.2.1 and 5.2.2) K-feldspar is interdependent on the variables in the equation and forms a linear combination of the other independent variables (Le and Tenisci, 1978). Therefore K-feldspar does not contribute significantly to reducing the variance of the dependent variable (chalcopyrite).

The multivariant equation for molybdenite (Equation 5.4) is also consistent with previous observations (Sections 4.4, and 5.2.1) that molybdenite is associated with the potassic alteration facies, and negatively related to pyrite of the phyllic alteration facies. The absence of biotite from the equation (Equation 5.4) is surprising since there is a significant positive correlation between molybdenite and biotite (Table 5.2). A similar STPREG programme was run in which biotite was forced into the equation, with the result that K-feldspar was forced out; signifying the strong interdependence between K-feldspar and biotite. As with K-feldspar in the chalcopyrite equation (Equation 5.3), this does not necessarily mean that biotite is a poor "indicator" of molybdenite, but only that the inclusion of biotite into the equation does not account for any more variance of molybdenite than K-feldspar does singularly.

### 5.3.3 Estimation of Error in Multivariant Equations

The standard error of the multivariant equations in (5.3) and (5.4) is given in units of Ranked Intensity.

Ranked intensity of alteration and ore minerals is discussed in Sections 3.2, and 4.1, and Appendix B. The reason for using this ranking was to normalize all mineralogic variables so as to retain resolution between small absolute changes in sulfide, and oxide mineral abundance, and to compare these with larger absolute changes in the abundance of silicate,

carbonate, and sulfate minerals.

Although this ranking normalizes the changes in different minerals, it is difficult to understand the actual numerical value of the error. Figure 5.2 shows the absolute values of error associated with the standard errors for chalcopyrite and molybdenite. The ranking scale used for estimating abundances of chalcopyrite and molybdenite in the field is geometric (Appendix B, Table B.6, and therefore it should be noted that the absolute value of the error increases with the value of chalcopyrite and molybdenite in equations (5.3) and (5.4).

#### 5.4 Summary of Geostatistics

A simple two-way correlation matrix of 15 hydrothermal minerals from the Poplar porphyry demonstrates that statistical analyses supports empirical observations made in the field regarding alteration zoning and facies, and helps define relationships which were not readily apparent. A one-way correlation technique was used to help show (1) which mineralogical variable was more the dependent one in a given correlation, and (2) to help remove correlations that were significant only because two minerals were both absent in a number of given observation.

Finally, a stepwise multivariant regression technique was used to determine which variables were the most important for

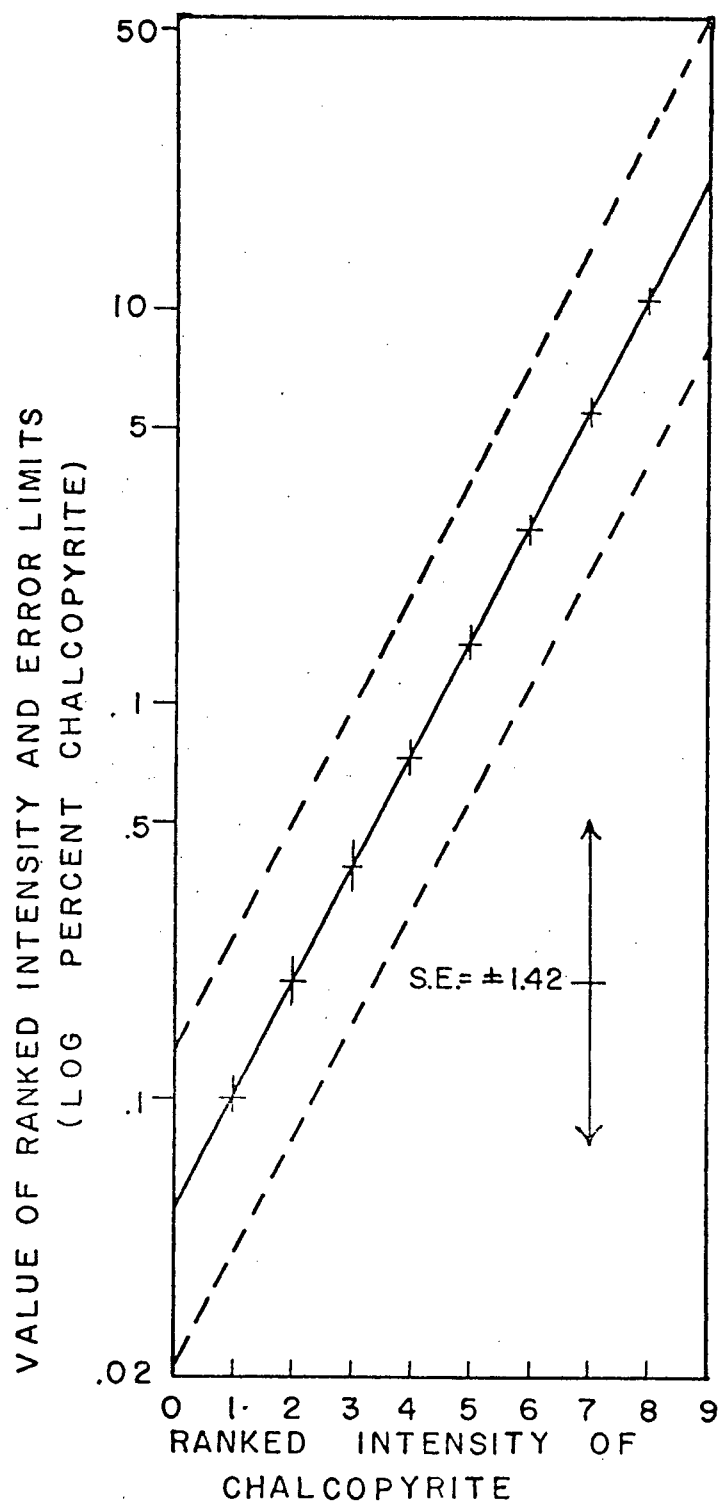


Figure 5.2: A graph of ranked intensity of chalcopyrite (as recorded on Poplarlog and used in the multivariant regression equation) versus the value of the midpoint of each rank in log percent chalcopyrite. The error limits associated with a standard error of 1.42 ranked intensity units are shown as dashed lines.

estimating the ranked intensity of chalcopyrite and molybdenite when all the other variables were considered together. The error associated with such estimations are fairly large. However, the equations serve to qualify the observation that certain alteration minerals can be used as a tool in estimating potential ore grade.

## CHAPTER VI

CONCLUSIONS

This study was undertaken to define and map petrologic units, and mineralization and alteration zones at the Poplar porphyry copper-molybdenum porphyry deposit. Due to sparse outcrop in the study area most of the field portion of the study involved the logging of diamond drill core. A computer-compatible logging format was used to expedite this work.

The following aspects of this study have been presented:

(1) the deposit is genetically and spatially related to a zoned calc-alkaline stock which ranges from hornblende quartz monzodiorite to biotite quartz monzonite in composition. The stock intruded the Lower Cretaceous Skeena Group, and the Upper Cretaceous Kasalka Group. These units consist of volcaniclastic and epivolcaniclastic, and clastic sedimentary rocks, respectively.

(2) Four K-Ar model ages have been determined and indicate that mineralization and alteration were geologically synchronous with intrusion. The term paramagmatic is used to describe this relationship. These ages range from 72.2 Ma to 76.9 Ma, placing

the event in late Upper Cretaceous time.

(3) Two mineralized zones and four alteration zones are defined. Chalcopyrite and molybdenite are the two most abundant economic minerals; minor amounts of other sulfide ore minerals are locally present. Potassic, phyllic, argillic, and propylitic alteration facies are defined based on the occurrence of the diagnostic minerals K-feldspar and/or biotite, sericite, clay, and epidote respectively. Chalcopyrite and molybdenite are most closely associated with the potassic alteration facies. Chalcopyrite occurs in an annular ring with potassic alteration which surrounds a core of argillic alteration and is bordered to the outside by an area of high- to low-intensity phyllic alteration.

(4) Argillic alteration occurs in two areas; at the center of the deposit, and in a more restricted area in a portion of drill core which is intensely fractured. Both areas occur within the larger potassic alteration zone. The central argillic zone occurs in rock that is sparsely mineralized, and is due to secondary alteration of a central "low grade core" because of local intense fracturing and consequent increased permeability.

(5) Based on the type of mineralization contained at the

Poplar porphyry, its age and its geographic location, it is considered here to belong to the Bulkley intrusive epoch, after Carter (1974, and 1976).

(6) Statistical analysis of mineralogical features from 12 drill holes logged in detail, show that most hypotheses made in the field, dealing with mineralization and alteration associations, were substantiated by statistical correlations. This was especially useful in defining alteration facies, and their relationship with molybdenite and chalcopyrite.

Multivariant regression analyses are used to show which minerals have the greatest effect on the observed values of chalcopyrite and molybdenite. However, certain inconsistencies in regression analysis indicate that statistical testing must be viewed in context of real field observations, or else misleading exploration parameters may be developed. The resolution of incompatibilities between field observation and statistical analysis can lead to a better understanding of the actual relationships between mineral variables.

## BIBLIOGRAPHY

- Beane, R.E., 1974. Biotite Stability in the Porphyry Copper Environment: Econ. Geol. v. 69, pp. 241-256.
- Blanchet, P.H. and Godwin, CI, 1972. "Geology System" for Computer and Manual Analysis of Geologic Data from Porphyry and Other Deposits: Econ. Geol. v. 67, pp. 796-813.
- Bowen, B., 1975. Geological and Geophysical Report on the Poplar Groups 1,2,3,5 and 6 Omineca Mining Division: B.c. Ministry of Mines Assessment Report no. 5679.
- Bowen, B., 1976. Geological, Geophysical, Geochemical and Drilling Report on the Poplar Groups 1 to 7 Omineca Mining Division: B.c. Ministry of Mines Assessment Report no. 6065.
- Burnham, C.W., 1962. Facies and Types of Hydrothermal Alteration: Econ. Geol. v. 57, pp. 768-784.
- Burnham, C.W., 1967. Hydrothermal Fluids of the Magmatic

Stage: in "Geochemistry of Hydrothermal Ore Deposits,"  
ed. H. L. Barnes, Holt, Rinehart, Winston, pp. 34-  
76.

Carmichael, I.S., Turner, F.J. And Verhoogen, J., 1974.  
"Igneous Petrology," McGraw-Hill, inc. 739 p.

Carson, D.J.T., and Jambor, J.L., 1977. Phyllic  
Overprinting: A Fundamental Cause of Variations in  
Zoning at Porphyry Copper Deposit: Geol. Ass. Can.  
/ Min. Assoc. Can., abstr., v. 2 pp. 11.

Carter, N.C., 1974. Geology and Geochronology of Porphyry  
Copper and Molybdenum Deposits in West-Central British  
Columbia: Univ. of British Columbia, Ph.D. Thesis,  
unpub. 326 p.

Carter, N.C., 1976. Regional Setting of Porphyry Deposits  
in West-Central British Columbia: in "Porphyry  
Deposits of the Canadian Cordillera," ed. A.  
Sutherland-Brown, Can. Inst. Min. Met. Spec. Vol.  
15, Harpells Press Coop. pp. 227-238.

- Cathles, L.M., 1977. An Analysis of the Cooling of Intrusives by Groundwater Convection which Includes Boiling: Econ. Geol. v. 72 pp. 804-826.
- Christopher, P.A., and Carter, N.C., 1976. Metallogeny and Metallogenic Epochs for Porphyry Mineral Deposits: in "Porphyry Deposits of the Canadian Cordillera," ed. A Southerland-Brown, Can. Inst. Min. Met. Spec. Vol. 15, Harpells Press Coop. pp. 64-71.
- Creasey, S.C., 1959. Some Phase Relations in the Hydrothermally Altered rocks of Porphyry Copper Deposits: Econ. Geol. v.54 pp. 351-373.
- Creasey, S.C., 1966. Hydrothermal Alteration: in "Geology of the Porphyry Copper Deposits Southwestern North America," ed. S.R. Titley and C.L. Hicks, University of Arizona Press. Pp. 51-74.
- Cunningham, C.G., 1978. Pressure Gradients and Boiling as Mechanisms for Localizing Ore in Porphyry Systems: Jour. Research U.S. Geol. Surv. V.6 pp. 745-754.

Davis, J.C., 1973. "Statistics and Data Analysis in Geology": John Wiley and Sons, Inc. 550 p.

Dixon, W.J., and Massey, F.J., 1969. "Introduction to Statistical Analysis" McGraw-Hill, Inc. 638 p.

Drummond, A.D., and Godwin, C.I., 1976. An Empirical Evaluation of Alteration Zoning: in "Porphyry Deposits of the Canadian Cordillera," ed. A. Sutherland-Brown, Can. Inst. Min. Met. Spec. Vol. 15, Harpells Press Coop pp. 52-71.

Duffell, S., 1959. Whitesail Lake Map-Area British Columbia: Geol. Surv. Can. Mem. 299, 119 p.

Eisbacher, G.H., 1977. Mesozoic - Tertiary Basin Models for the Canadian Cordillera and their Geological Constraints: Can. Jour. Earth Sci. v. 14 pp. 2414-2421.

Forester, R.W., and Taylor, H.P., 1972. Oxygen and Hydrogen Isotope Data on the Interaction of Meteoric Groundwaters with a Gabbro-diorite Stock, San Juan

Mountains, Colorado: Internat. Geol. Cong., 24th,  
Montreal sec.10, Geochemistry, pp. 254-263.

Gibbs, J.W., 1873. A Method of geometrical Representation  
of the Thermodynamic Properties of Substances by Means  
of surfaces: Trans. Conn. Acad., v.2 p. p.309-342

Godwin, C.I., 1976. Geology of Casino Porphyry Copper -  
Molybdenum Deposit, Dawson Range, Y.T.: University of  
British Columbia, Ph.D thesis, unpub., 245 p.

Godwin, C.I., Hindson, R.E., and Blanchet, T., 1977.  
GEOLOG; A Computer-Based Scheme for Detailed  
Stratigraphy, Especially as Applied to Data from Drill  
Holes in Coal Exploration or Development: Can. Inst.  
Min. Met., Bull., v. 70, pp. 1-10.

Gustafson, L.B., 1978. Some Major Factors of Porphyry  
Copper Genesis: Econ. Geol. v. 73 pp. 600-607.

Gustafson, L.B., and Hunt, J.P., 1975. The Porphyry Copper  
Deposit at El Salvador, Chile: Econ. Geol. v. 70 pp.  
856-912.

- Helgeson, H.C., 1964. "Complexing and Hydrothermal Ore Deposits": Pergamon Press Inc. 128 p.
- Helgeson, H.C., 1970. A Chemical and Thermodynamic Model of Ore Deposition in Hydrothermal Systems: Min. Soc. Am. Spec. Pap. 3, pp. 155-186.
- Hemley, J.J., 1959. Some Mineralogical Equilibria in the System  $K_2O-Al_2O_3-SiO_2-H_2O$ . Am. Jour. Sci. v. 257 pp. 241-270.
- Hemley, J.J., and Jones, W.R., 1964. Chemical Aspects of Hydrothermal Alteration with Emphasis on Hydrogen Metasomatism: Econ. Geol. v. 59 pp. 538-569.
- Hemley, J.J., and Meyer, C., and Richter, D.H., 1961. Some Alteration Reactions in the System  $Na_2O-Al_2O_3-SiO_2-H_2O$ : U. S. Geol. Surv., Prof. Paper 424-D, pp. 338-340.
- Holland, S.S., 1964. "Landforms of British Columbia A Physiographic Outline": Brit. Col. Ministry Min. Pet. Res., Bull. 48, 138 p.

- Holland, S.S., 1976, "Landforms of British Columbia A Physiographic Outline": Brit. Col. Min. Mines and Pet. Res., Bull. 48, 138 p.
- Hurlbut, C.S., 1971. "Dana's Manual of Mineralogy": John Wiley and Sons, Inc. 579 p.
- Hutchinson, W.W., 1970. Metamorphic Framework and Plutonic Styles in the Prince Rupert Region of the Central Coast Mountains: Can. Jour. Earth Sci. v. 8, pp. 523-548.
- Hyndman, D.W., 1972. "Petrology of Igneous and Metamorphic Rocks": McGraw-Hill, Inc. 533 p.
- International Union of Geological Sciences, 1973. Plutonic Rocks - Classification and Nomenclature Recommended by I.U.G.C. Subcommission on the Systematics of Igneous Rocks: Geotimes, v. 18, pp. 26-30.
- Jahns, R.H., and Burnham, W.C., 1969: Experimental Studies in Pegmatite Genesis; I. A Model for the Derivation and Crystallization of Granitic Pegmatites: Econ.

Geol. v. 64 pp 843-864.

Jambor, J.L., and Beaulne, J.M., 1978. Sulfide Zones and Hydrothermal Biotite Alteration in Porphyry Copper-Molybdenum Deposits, Highland Valley, British Columbia: Geol. Sur. Can. Pap. 77-12, 25 p.

Jones, H.M., 1972. Geological-Geochemical Report on the Poplar Mineral Claims, Tagetochlain Lake Area: Brit. Col. Ministry Mines Petrol. Res. Assessment Report no. 3665.

Le, C., and Tenisci, T., 1978. UBC TRP, Triangular Regression Package: Univ. Brit. Col. Computing Center, 197 p.

Lowell, J.D., and Guilbert, J.M., 1970. Lateral and Vertical Alteration - Mineralization Zoning in Porphyry Ore Deposits: Econ. Geol. v.65, pp. 373-403.

MacIntyre, D.G., 1976. Evolution of Upper Cretaceous Volcanic and Plutonic Centers and Associated Porphyry

Copper Occurrences, Tahtsa Lake Area, British  
Columbia: Univ. West. Ontario, Ph.D. Thesis, unpub.  
149 p.

Mesard, P.M., Godwin, C.I., and Carter, N.C., 1979.

Geology of the Poplar Porphyry Copper - Molybdenum  
Deposit: Brit. Col. Ministry Min. and Pet. Res.  
Fieldwork 1978, pp. 138-143.

Monger, J.W.H., Souther, J.G., and Gabrielse, H., 1972.

Evolution of the Canadian Cordillera, A Plate Tectonic  
Model: Am. Jour. Sci. v.272, pp. 577-602.

Moore, W.J., 1978. Chemical Characteristics of Hydrthermal  
Alteration at Bingham, Utah: Econ. Geol. v.73,  
pp. 1260-1269.

Norton, D., 1972. Concepts Relating Anhydrite Deposition  
to Solution Flow in Hydrothermal Systems: Internat.  
Geol. Cong., 24th, Montreal, Sec. 10, Geochemistry,  
pp. 237-244.

Norton, D., 1978. Source lines, Source regions, and

Pathlines for fluids in Hydrothermal Systems Related to Cooling Plutons: Econ. Geol. v.73 pp.21-28.

Norton, D., and Knapp, R., 1977. Transport Phenomena in Hydrothermal Systems; The Nature of Porosity: Am. Jour. Sci., v. 277, pp. 913:936.

Norton, D., and Knight, J., 1977. Transport Phenomena in Hydrothermal Systems; Cooling Plutons: Am. Jour. Sci., v. 277, pp. 937-981.

Roedder, E., 1971. Fluid Inclusion Studies on the Porphyry-Type Ore Deposits at Bingham, Utah, Butte, Montana, And Climax, Colorado: Econ. Geol., v. 66 pp. 98-120.

Rose, A.W., 1970. Zonal Relations of Wallrock alteration and Sulfide Distribution at Porphyry Copper Deposits: Econ. Geol., v. 65, pp. 920-936.

Schmidt, A.J., 1974. 1974 Drilling Report on the Poplar Lake Property: Brit. Col. Ministry Min. Pet. Res. Assessment Report no. 5360.

- Schmidt, A.J., 1975. 1975 Drilling Report on the Poplar Lake Property : Brit. Col. Ministry Min. Pet. Res., Assessment Report no. 5586.
- Sheppard, S. M. F., Nielsen, R. L., and Taylor, H. P., 1971. Hydrogen and Oxygen Isotope Ratios in Minerals from Porphyry Copper Deposits: Econ. Geol. v. 66, pp. 515-542.
- Streckeisen, A., 1967. Classification and Nomenclature of Igenous Rocks: Neues Jahrb. Mineral. Abhandl., v. 107, pp. 144-240.
- Taylor, H.P., 1974. The Application of Oxygen and Hydrogen Isotope Studies to Problems of Hydrothermal Alteration and Ore Deposition: Econ. Geol., v. 69, pp. 843-883.
- Tipper, H.W., and Richards, T.A., 1976a. Geologic Map of Smithers Map Sheet: Geol. Sur., Can. Open File Map 351.
- Tipper, H.W., and Richards, T.A., 1976b. Jurassic

Stratigraphy and History of North-Central British  
Columbia: Geol. Surv. Can. Bull. 270, 73 p.

Villas, R.N., and Norton, D., 1977. Irreversible Mass  
Transfer between Circulating Hydrothermal Fluids and  
the Mayflower Stock: Econ. Geol., v.72, pp. 1471-  
1504.

Wallace, S.R., Mackenzie, W.B., Blair, R.G., and Muncaster,  
N.K., 1978. Geology of the Urad and Henderson  
Molybdenite Deposits, Clear Creek County, Colorado,  
with a Section on a Comparison of these deposits with  
those at Climax, Colorado: Econ. Geol., v. 73, pp.  
325-368.

White, W.H., 1959. Cordilleran Tectonics in North America:  
Amer. Assoc. Pet. Geol., Bull., v. 43, pp. 60-  
100.

White, W.H., Harakal, J.E., and Carter, N.C., 1968.  
Potassium-Argon Ages of Some Ore Deposits in British  
Columbia: Can. Inst. Min. Met. Bull., v. 61, pp.  
1326-1334.

Wilton, D.H.C., 1978. A genetic Model for the Sustut  
Copper Deposit, North-Central British Columbia: Univ.  
Brit. Col. M.Sc. Thesis, unpubl., 215 p.

Witherly, K.E., 1975. 1974 Geophysical Report on the  
Poplar Lake Property: Brit. Col. Ministry Min. Pet.  
Res. Assessment Report no. 5361.

Woodsworth, G.J., 1979. Geology of Whitesail Lake Map  
Area, British Columbia:in Current Research, Part A,  
Geol. Surv. Can., Paper 79-1A, pp. 25-29.

APPENDIX A

Analytical Data

TABLE A.1

POTASSIUM-ARGON ANALYTICAL DATA^a FROM THE POPLAR PORPHYRY DEPOSIT, B.C.

Sample No.	Location	Rock unit; ^b	Mineral		$^{40}\text{Ar}^{*d}$	$^{40}\text{Ar}^{*d}$	Apparent ^e	
or Name	Lat. (N); Long. (W)	rock name	dated	%K±S ^c	$^{40}\text{Ar}$ total (10 ⁻⁵ cm ³ STP/g)		age (Ma)	Time ^f
G76TR22	54°01'126°50'	3b: biotite quartz monzonite	biotite	7.14±0.07	0.878	2.088	73.7±2.5	Late Cretaceous
POPLAR LAKE	54°01'126°50'	3b: biotite quartz monzonite	biotite	7.00±0.04	0.915	2.139	76.9±2.3	Late Cretaceous
PC-36	54°01'126°50'	4a: porphyritic dacite	biotite	5.875±0.29	0.846	1.683	72.2±3.0	Late Cretaceous
PT-115	54°01'126°50'	3a: hornblende quartz monzodiorite	hornblende	5.875±0.05	0.794	1.780	76.2±2.7	Late Cretaceous

^aAll analyses in the Geochronology Laboratory, Department of Geological Sciences, The University of British Columbia.

^bRock units correspond to Map A

^c"S" is one standard deviation of quadruplicate analyses

^d"Ar*" indicates radiogenic argon

^eDecay constants used:  $\lambda_e = 0.581 \times 10^{-10} \text{ yr}^{-1}$ ,  $\lambda_\beta = 4.96 \times 10^{-10} \text{ yr}^{-1}$ ,  $^{40}\text{K}/\text{K} = 1.167 \times 10^{-4}$

^fTime designed after Obradovich and Cobban, 1975

TABLE A-2  
 CHEMICAL ANALYSIS (% OXIDE WEIGHT PERCENT) AND C.I.P.W. NORMS  
 OF IGNEOUS ROCKS FROM THE POPLAR PORPHYRY

Sample: Rock unit	PT51: 8	PT60: 5	PT115: 3	30/132: 4	36/375: 5
Oxide					
SiO ₂	64.76	61.60	62.33	66.10	59.75
Al ₂ O ₃	15.38	15.16	16.59	16.55	15.62
Fe ₂ O ₃ *	8.89	4.91	5.55	5.41	4.98
MnO	0.09	0.09	0.12	0.05	0.12
MgO	1.33	2.09	2.60	1.69	1.91
CaO	2.43	3.84	3.75	3.38	5.40
K ₂ O	2.67	2.92	2.70	2.31	2.87
P ₂ O ₅	0.27	0.414	0.30	0.31	0.40
Na ₂ O	4.89	3.93	3.94	4.29	2.32
TiO ₂	0.37	0.54	0.624	0.515	0.525
L.O.I. [†]	2.94	4.103	1.94	1.64	7.29
TOTAL	98.97	99.58	100.29	102.26	101.18
quartz	19.47	15.18	13.70	15.99	16.63
orthoclase	16.36	17.74	15.83	13.02	17.22
albite	42.7	34.73	34.05	36.97	21.13
anorthite	10.84	15.32	16.52	14.07	23.51
magnetite	2.73	2.97	3.07	2.88	2.95
illmenite	0.73	1.05	1.18	0.93	1.01
apatite	0.59	0.99	0.69	0.69	0.95
corundum	0.70	0.0	0.88	1.06	0.0

* All Fe as Fe₂O₃

[†] L.O.I. = Loss On Ignition

## APPENDIX B

POPLARLOG

The Computer Compatible Drillcore Logging Format Used In This Study.

B.1 Introduction

The development of Poplarlog, as a computer compatible coding format for the logging of drill core, came about as a necessity to assure that geologic information be recorded in a standardized manner, and that each interval of core be examined for the same geologic parameters. Poplarlog was developed on the knowledge that the Poplar porphyry had an extensive alteration halo (Schmidt, 1978, pers. comm.; Bowen, 1976; and Carter, 1978, pers. comm.), and that outcrop made up less than one percent of the surface area on the property.

Many ideas and suggestions on the format of Poplarlog were offered by colleagues who has previously used other computer compatible logging systems (Wilton, 1978, and pers. comm., 1978 and Mortensen, pers. comm., 1978). The major part of Poplarlog was formulated along the lines of a previously developed coding format for porphyry copper deposit designed by Blanchet and Godwin (1972), and C. I. Godwin (pers. comm., 1978, and 1976). Most of the codes used during this study and described in Section B.3 and B.4 are taken directly from Blanchet and Godwin (1972).

## B.2 Description and Coding

A blank Poplarlog drillcore logging form is shown in Figure B.1. The characteristics and headings of the form will be described from left to right.

(1) Visual Log; This space was used to plot the attitudes with respect to drill core of veins, faults, fractures, rock unit contacts, bedding, foliation, and any other planar or linear feature. Paragenetic relationships between veins was also recorded. The appropriate symbol was plotted adjacent to the portion of a particular depth interval being described.

(2) Comments, Column 1: Column one was used to record one letter codes denoting discontinuous geologic features, or as a one letter "flag", used to denote lines which were used for criteria other than formatted geologic information. The comment codes used in Column one on Poplarlog are shown in Table B.1.

# VISUAL LOG

[illegible]

TABLE B.1

One Letter Comment Codes Used With Poplarlog  
(Column One)

---

<u>1 Letter Code</u>	<u>Meaning</u>
B	Bottom of hole-recorded with hole number and date; used as a flag in determining the end of a hole.
C	Comment - to denote lines used for comments about the drill core in addition to, and sublimating, normal coding; usually used to describe a particular geologic feature in more detail.
D	Dykes - used to denote the bottom of an interval consisting of a dyke unit.
K	Contact - used to denote contacts between rock units, superseded by D (=dyke) where appropriate.
S	Sample - sample taken at a particular depth (which was recorded in column 76-80).
Z	Zone of faulting, fracture, or a shear zone.
T	Top of hole - recorded with hole number and date; used as a flag in denoting the top of a hole.

---

(3) Depth to the bottom of the interval described on that line; Columns 2-5: usually in 10 foot (3 m) intervals, or less if geologic features changed (i. e. contact between rock units).

(4) Ore Zone; Columns 6-8: used to define which ore zone

that particular interval was in (i. e. hypogene (HYP), supergene sulfide (SUS), or supergene oxide (SUX)).

(5) Type Modifier and Rock Name; Columns 9-14: used in conjunction with each other to name the rock unit being described (Columns 11-14) using four letter code names which were developed as new units were intersected in drill core. Column 9 was used to record a one letter "flag", unique to each rock unit, to facilitate the rapid visual identification of the rock type in each interval (Table B.2). Column 10 was used to qualitatively describe with a one letter code the "condition" of the core with respect to the stability of biotite (determined to be a diagnostic mineral, sensitive to various types of alteration (Table B.3)).

(6) Colour; Column 15-16: a qualitative estimate of the Colour Index. DK-dark, >50% mafics; MD-medium, 25-30% mafics and; LT-light, <25% mafic minerals. Includes both primary and secondary minerals.

(7) Mafics; Columns 17-18: consists of a two letter (or letter and symbol) code for the type of mafic minerals present, and their relative abundance. HB-hornblende only; B<-hornblende greater than biotite; B>-biotite greater than hornblende and; BI-biotite only. Biotite and hornblende were the only mafic minerals observed at the Poplar porphyry.

Table B.2  
First Type Modifiers and Coded Names Used With Poplarlog  
(Columns 9, and 11-14)

Rock Unit	Field Name	Type Modifier	4 Letter Code	Comments
Skeena(1)	Hornfels	H	HORN	used for any country rock observed in drill core - not necessarily hornfels meta- morphosed.
Quartz Monzodiorite(3a)	Hornblende Diorite	D	DIOR	
Quartz Monzonite(3b)	Biotite Porphyry	P	PPBF	PP=Poplar porphyry BF=biotite-feldspar porphyry
Intrusive Breccia(3b)	Breccia	B	BRXX	Sub-unit of quartz monzonite
Quartz Latite-Andesite(4a)	Feldspar Porphyry	F	PPFL	FL-feldspar porphyry
Felsite Dykes(4b)	Felsite	F	FELS	Sub-unit of quartz latite andesite
Porphyritic Rhyolite(5)	Rhyolite	Q	PPFQ	FQ=Feldspar-quartz porphyry
Andesite	Tracyte	T	TRAC	T=Tracyte; originally named tracyte in field, later changed to andesite, but code kept to maintain consistency

(8) Qualifying Descriptor; Columns 19-21: a "catchall" heading used to denote unusual features in the core, or changes in the nature of the core which were too minor to describe under a new interval. Examples include; CNA-a change in alteration type; XEN-xenoliths; and PAT-patches.

TABLE B.3

Second Type Modifier Used With Poplarlog  
(Column 10)

---

<u>Type Modifier</u>	<u>Meaning</u>
D	Dark - Secondary biotite is observed in the interval described.
N	Normal - Biotite books are present, and thought to be original phenocrysts. rock is fresh or has undergone minor alteration.
L	Light - Original biotite books have been altered to pseudomorphs of chlorite or sericite.
O*	Obliterated - Biotite books are not observed and the texture is obliterated by alteration (generally phyllic). Identification of rock type is difficult and questionable.
X*	Extremely obliterated - The original texture has been destroyed by alteration. Rock type in doubt.

---

*For both designations the original rock type could be ascertained by correlation by gradational changes to fresh rock either up or down the drill core.

(9) Texture; Columns 22-30: a general heading which is subdivided into seven subheadings. Originally intended for recording criteria to be used in correlating sedimentary rocks from drill core. These criteria include; (a) grain size mode, (b) maximum grain size, (c) open or closed packing of grains, (d) degree of sorting, and (e) and (f) particular textural features which were determined in the field to be important criteria for correlation. Most of these headings were never used because of the high intensity to which most of the Skeena rocks were altered, and the textural nature of the unit itself, made such observations difficult, and too infrequent to be of any use. However, the subheadings Texture I, and Texture II were used to denote unusual or distinguishing textures encountered in the drill core such as FL for flow lineation or pilotaxitic texture, or AG for amygdaloidal texture.

(10) Alteration Minerals; Columns 31-54: this heading consists of the 16 subheadings listed in Table B.4. Each of 10 mineral subheadings consist of two columns (except for clay, and SUM ALT which are discussed below); the first of which (H) is used for a one numeral code describing "how" the mineral occurs, i. e. its relative dispersion (Table B.5, taken from Blanchet and Godwin, 1972). The second column (I) is used for a one letter code describing the "intensity", or percentage by volume, of the mineral (Table B.6).

The last subheading under Alteration Minerals on Poplarlog, SUM ALT, columns 52-54, was used to "summarize alteration" for that interval and to place that interval of core in one of 10 alteration zones in the Lowell and Guilbert Model of porphyry deposits, modified by Blanchet and Godwin (1972). Columns 52 and 53 (H and I) were used to summarize both how the alteration occurred (its degree of dispersion), and its intensity (volume percent). Column 54 was used to place the interval described in one of the 10 alteration facies of Lowell and Guilbert (1970) based on criteria found in Table B.7 (taken from Blanchet and Godwin, 1972), which is a "checklist" of relative intensities of silicate, and carbonate alteration minerals versus the 10 alteration facies. Figure B.1 is a cross-section through a typical porphyry deposit showing the spatial relationship of 10 alteration facies (taken from Blanchet and Godwin 1972).

(11) Mineralization; Columns 55-75: similar to the method for describing the degree of dispersion and intensity of silicate, carbonate, and sulfate alteration minerals; the mode of occurrence and intensity of 7 sulfide and oxide minerals in each interval of core was recorded in appropriate columns (Table B.8). However, because the degree of intensity to which oxide and sulfide minerals occur is generally a great deal less than that of alteration minerals, a geometric scale of abundances was used. Therefore the notation "PT" was used in the columns to describe intensity of mineralization, and distinguish it from the scale used to record intensities of alteration (Table B.6).

The method used to record degree of dispersion of sulfide and oxide minerals is exactly the same as for alteration minerals as shown in Table B.5.

The subheading SUM ORE is exactly analogous to the summary columns for alteration minerals, previously described in the previous sub-section (9). The checklist of relative mineral abundance versus mineralization facies taken from Blanchet and Godwin (1972) is shown in Table B.9. A corresponding cross-section through a typical porphyry deposit showing the spatial relationship between these facies is shown in Figure B.2.

(12) Sample Depth; Columns 76-80: These columns were used to record the depth at which samples were taken(c. f. 'S' in column 1; Table B.1).

TABLE B.4

Silicate, Carbonate and Sulphate Alteration Minerals  
(Columns 31-51)

---

Poplarlog		
<u>Abbreviation</u>	<u>Mineral</u>	<u>Comments</u>
QZ	Quartz	
KF	Potassium Feldspar	
BI	biotite	
MU	muscovite	
CH	chlorite	seldom used
CY	clay	Column 43 was intended to distinguish kaolinite from montmorillonite. it was never used.
EP	epidote	seldom used
CB	carbonate	includes calcite, siderite, and dolomite.
ALT 1	Anhydrate-Gypsum	Was used for these minerals after fieldwork indicated their importance
ALT 2	miscellaneous alteration	used for seldomly observed minerals.

---

TABLE B.5

Mode And Degree Of Mineralization And Alteration. V,E,D,P Refer To Modes Of Occurrence: Veins, Envelopes, Disseminations, And Pervasive, Respectively (from Blanchet And Godwin, 1972).

Mode of Occurrence Mineralization			Degree of Dispersion	Mode of Occurrence Alteration Assemblages			
Veins and macro - veins including stockwork and gouge	V	V	1	V	V or V	V	veins
Veins, veinlets, fracture fillings & minor disseminations	$\frac{1}{8}D + \frac{7}{8}V$	$D \ll V$	2	$E < V$ or $P \ll V$	$\frac{2}{8}E + \frac{6}{8}V$	$\frac{1}{8}P + \frac{7}{8}V$	veins and moderate envelopes or minor pervasive
Veinlets and some disseminations	$\frac{2}{8}D + \frac{6}{8}V$	$D < V$	3	$E \approx V$ or $P < V$	$\frac{4}{8}E + \frac{4}{8}V$	$\frac{2}{8}P + \frac{6}{8}V$	envelopes and veins equal or veins and moderate pervasive
Veinlets with moderate disseminations	$\frac{3}{8}D + \frac{5}{8}V$	$D \leq V$	4	$E > V$ or $P \leq V$	$\frac{6}{8}E + \frac{2}{8}V$	$\frac{3}{8}P + \frac{5}{8}V$	envelopes with some veins or pervasive with moderate veins
Veinlets and disseminations more or less equal	$\frac{4}{8}D + \frac{4}{8}V$	$D = V$	5	$E$ or $P \approx V$	$\frac{8}{8}E$	$\frac{4}{8}P + \frac{4}{8}V$	envelopes or pervasive equal to veins
Disseminations and moderate veinlets	$\frac{5}{8}D + \frac{3}{8}V$	$D \geq V$	6	$P < E$ or $P \geq V$	$\frac{2}{8}P + \frac{6}{8}E$	$\frac{5}{8}P + \frac{3}{8}V$	pervasive with some envelopes or moderate veins
Disseminations with some veinlets	$\frac{6}{8}D + \frac{2}{8}V$	$D > V$	7	$P \approx E$ or $P > V$	$\frac{4}{8}P + \frac{4}{8}E$	$\frac{6}{8}P + \frac{2}{8}V$	pervasive and envelopes or with some veins
Mostly dissemination with minor veinlets or micro-veinlets	$\frac{7}{8}D + \frac{1}{8}V$	$D \gg V$	8	$P > E$ or $P \gg V$	$\frac{6}{8}P + \frac{2}{8}E$	$\frac{7}{8}P + \frac{1}{8}V$	pervasive with some envelopes or minor veins
Disseminations	D	D	9	P	P	P	pervasive

TABLE B.6

One Letter Codes for Estimated Volume Percent of Silicate, Carbonate and Sulfate Alteration Minerals, and for Sulfide and Oxide Mineralization, from Poplarlog

---

<u>"Alteration"</u> <u>Mineral Abundances</u>	<u>One Letter</u> <u>Code</u>	<u>"Mineralization"</u> <u>Mineral Abundances</u>
>60%	X-extremely high	>16%
50-60%	V-very high	8-16%
40-50%	H-high	4-8%
30-40%	A-above medium	2-4%
20-30%	M-medium	1-2%
15-20%	B-below medium	0.5-1%
10-15%	F-fair	0.25-0.5%
5-10%	L-low	<0.25%
2-5%	E-extremely low	<<0.25%
<1%	T-trace	Trace
NIL	blank-none	NIL

---

TABLE B.7

Checklist of Relative Alteration Minerals Abundances Versus  
Alteration Facies in Porphyry Deposits (taken from  
Blanchet and Godwin 1972)

Alteration Facies	Quartz QZ	K-spar KF	Biotite BI	Muscovite Sericitic MU,MS	Clays CY		Chlorite CL	Epidote EP	Carbonates CB	Other	Remarks
					Kaolin KA	Montmorillonite MM					
Fresh Rock	0							and/or	and/or	and/or and/or	
Propylitic	1										
Montmorillonitic	2		Orig. BI							AB	ZE
Intermediate Argillic	3										
KF - Stable	4	Orig. KF stable	Mg-rich								
Sericitic (=Phyllic)	5										
Advanced Argillic	6									PP	TO
Potassic	7										
'Chlori-Potassic'	8									AH	
Silicic (Quartz Flooding)	9										
diagnostic & abundant = commonly present & moderate = infrequently present & minor =											

Also Adularia,  
Siderite  
AB=Albite  
ZE=Zeolite(s)

TO= tourmaline  
PP= pyrophyllite

AH= anhydrite

FIGURE B.2

Model of Alteration Facies in Porphyry Deposits after Lowell and Guilbert (1970), (taken from Blanchet and Godwin, 1972).

---

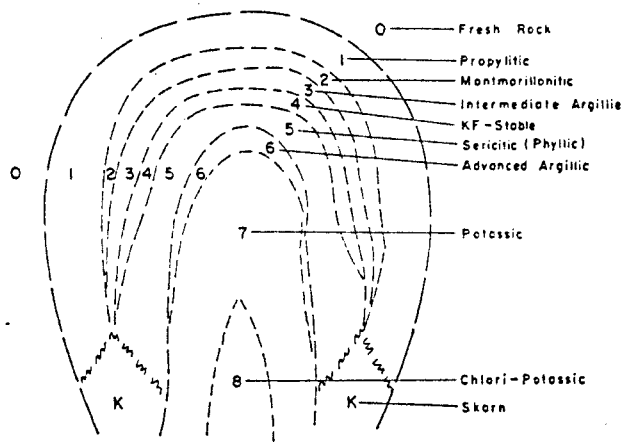


TABLE B.8

## Sulfide and Oxide Minerals

(Columns 55-72)

Poplarlog

<u>Abbreviation</u>	<u>Mineral</u>	<u>Comments</u>
PY	Pyrite	
HM	hematite	
CP	chalcopyrite	
BN	bornite	
CC	chalcocite	
MO	molybdenite	
MN1	magnetite	added in the field
MN2	covellite, tetrahedrite	only rarely used
MN3	galena, etc.	Only rarely used

TABLE B.9

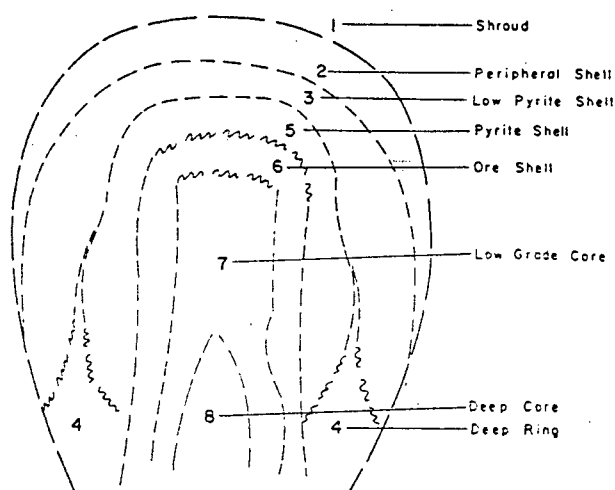
Checklist of Relative Sulfide and Oxide Mineral Abundances  
Versus Mineralization Facies in Porphyry Deposits (taken from  
Blancet and Godwin, 1972).

Mineralization Zones		Pyrite PY	Chalco- pyrite CP	Molyb- denite MO	Wolframite Covellite Digenite WF, CV, DG	Chalcocite CC	Hematite Magnetite HX	Galena- Sphalerite GX (Gold-Silver occurrence)	Pyrrhotite PR	Native Copper CU	Remarks
Shroud	1										
Peripheral Shell	2										
Low Pyrite Shell	3										
Deep Ring	4										
Pyrite Shell	5										
Ore Shell	6										
Low-Grade Core	7										
Deep Core	8										diagnostic & abundant = / / / / frequently present & substantial = / / / / usually present & moderate = / / / / sometimes present & minor = / / / / infrequently present & trace to minor = / / / /

FIGURE B.3

Model of Sulfide, Oxide Mineral Facies in Porphyry Deposits  
after Lowell and Guilbert (1970) (taken from Blanchet and  
Godwin, 1972). Compare with Table B.9, and Figure B.1.

---



### APPENDIX C

#### Computer Programs Used in the Study

```

C   A PROGRAM TO PLOT CHALCOPYRITE ON CROSS-SECTION A-A
C   FORMATING IS COMPATABLE WITH PLOTLARLOG
C   CPYI IS CHALCOPYRITE INTENSITY - CPYH IS ITS MODE OF OCCURENCE; BOTH ARE ON RANKED SCALES
C   ALL ELSE IS FOUND IN "U.B.C. PLOT"
INTEGER SYM,CPYI,CPYH
LOGICAL*1 COM,COMM(5)
LOGICAL*4 EQCMP
CALL PLCTRL('METRIC',0.0)
CALL SYMBOL(13.30,.75,0.25,'CROSS-SECTIONAL PLOT OF CHALCOPYRITE ALONG LINE A-A ',0.0,511)
CALL SYMBOL(9.5,0.25,0.25,'WITH SUPPERIMPOSED ZONES OF MOLYBDENITE,K-FELDSPAR,BIOTITE,PHYLIC AND ARGILLIC ALTERATION',0.0,901)
5 READ(5,10,END=999)COM,CPYH,CPYI,EASTG,DEPTH
10 FORMAT(A1,57X,211,22X,F8.3,2X,F8.3)
   IF(EQCMP(1,'3',COM)) GO TO 100
   UP=1100.00-DEPTH
   UP=(UP/528.0)*12.0*0.4-1.+.394
   ESTG=(EASTG/528.0)*12.0*0.4+2.12
   IF(CPYI.EQ.0)SYM=15
   IF(CPYI.EQ.1)SYM=16
   IF(CPYI.EQ.2)SYM=17
   IF(CPYI.EQ.3)SYM=18
   IF(CPYI.EQ.4)SYM=19
   IF(CPYI.EQ.5)SYM=20
   IF(CPYI.EQ.6)SYM=22
   IF(CPYI.EQ.7)SYM=23
   IF(CPYI.EQ.8)SYM=26
   IF(CPYI.EQ.9)SYM=27
   CALL SYMBOL(ESTG,UP,0.18,SYM,0.0,-1)
   GO TO 5
100 READ(5,110,END=999)(COMM(J),J=1,5),EL,RGT
110 FORMAT(5A1,8X,F5.2,F7.2)
   EL=1100.0-EL
   EL=(EL/528.0)*12.0*0.4-1.0+.394
   RGT=(RGT/528.0)*12.0*0.4+2.12
   CALL SYMBOL(RGT,EL,0.20,COMM,0.0,5)
   GO TO 5
999 CALL PLCTRL('METRIC',1)
   CALL AXCTRL('XCRIG',0.0)
   CALL AXCTRL('YORIG',0.0)
   CALL AXPLT('EASTING ALONG X-SECTION A-A (METERS);',0.0,93.726,11200.0,13.2)
   CALL AXPLT('ELEVATION ABOVE SEA LEVAL (METERS);',90.0,24.14,616.35,13.2)
   CALL PLOTND
   STOP
   END

```

C COMPUTER PROGRAM "SHLRK1" PLOTS THE GEOLOGY ALONG CROSS-SECTION A-A  
 C FORMATING IS COPATIBLE WITH POPLARLOG  
 C INFORMATION OF ROCK NAMES ARE GIVEN IN APPENDIX B  
 C ALL OTHER INFORMATION IS IN "U. S. C. PLOT"

INTEGER SYM  
 LOGICAL*1 COM(5),COM(1),RK1(2)  
 LOGICAL*4 EQCMP,RK2  
 CALL PLCTRL('METRIC',0)  
 CALL SYMBOL(13.3,9.5,0.25,'CROSS-SECTIONAL PLOT OF GEOLOGY ALONG LINE A - A ',0.0,48)

C

5 READ(5,10,END=999)COM,RK1,RK2,EASTG,DEPTH  
 10 FORMAT(4I,7X,2A1,A4,69X,F8.3,2X,F9.3)  
 IF(EQCMPI(1,'3',COM(1)))GO TO 100  
 UP=1100.0-DEPTH  
 UP=(UP/528.0)*12.0*0.4-1.0+0.394  
 ESTG=(EASTG/528.0)*12.0*0.4+2.12  
 SYM=30  
 IF(EQCMPI(4,'PPBF',RK2))SYM=0  
 IF(EQCMPI(4,'PPXX',RK2))SYM=11  
 IF(EQCMPI(4,'PPFQ',RK2))SYM=1  
 IF(EQCMPI(4,'PPFL',RK2))SYM=2  
 IF(EQCMPI(4,'BXIN',RK2))SYM=17  
 IF(EQCMPI(4,'HORN',RK2))SYM=43  
 IF(EQCMPI(4,'FELS',RK2))SYM=37  
 IF(EQCMPI(4,'TRAC',RK2))SYM=5  
 CALL SYMBOL(ESTG,UP,C.07,SYM,0.0,-1)  
 IF(SYM.NE.30)GO TO 5  
 WRITE(6,10)COM,RK1,RK2,EASTG,DEPTH  
 GO TO 5  
 100 READ(5,110,END=999)(COM(I),I=1,5),EL,RGT  
 110 FORMAT(5A1,9X,F5.2,F7.2)  
 EL=1100.0-EL  
 EL=(EL/528.0)*12.0*0.4-1.0+0.394  
 RGT=(RGT/528.0)*12.0*0.4+2.12  
 CALL SYMBOL(RGT,EL,0.20,COM,0.0,5)  
 GO TO 5  
 999 CALL PLCTRL('METRIC',1)  
 CALL AXCTRL('XORIG',0.0)  
 CALL AXCTRL('YCRIG',0.0)  
 CALL AXPLLOT('EASTING ALONG X-SECTION A-A (METRES);',0.0,93.726,11200.0,13.2)  
 CALL AXPLLOT('ELEVATION ABOVE SEA LEVEL (METRES);',90.0,24.14,616.35,13.2)  
 CALL PLOTNO  
 STOP  
 END

C A PROGRAM TO CHANGE FORTN CHARACTERS TO FORTRAN REAL NUMBERS  
 C THIS REQUIRES USE OF COMMAND 'EQUAC'  
 C FORMATTING IS COMPARABLE TO POPLARLOG

```

    LOGICAL EQUAC
    LOGICAL*1 COM(1)
    DIMENSION ALTI(50),XMINI(50),LTI(50),MINI(50)
10  READ(5,20,END=999)COM,(LTI(I),I=1,10),(MINI(J),J=1,9)
20  FORMAT(1A1,29X,6(1I1,1X),1X,4(1I1,1X),3X,9(1I1,1X))
    IF (EQUAC('T',COM)) GO TO 10
    IF (EQUAC('B',COM)) GO TO 10
C
    DO 100 I=1,10
      IF(LTI(I).EQ.0)ALTI(I)=0.0
      IF(LTI(I).EQ.1)ALTI(I)=2.5
      IF(LTI(I).EQ.2)ALTI(I)=7.5
      IF(LTI(I).EQ.3)ALTI(I)=12.5
      IF(LTI(I).EQ.4)ALTI(I)=17.5
      IF(LTI(I).EQ.5)ALTI(I)=25.5
      IF(LTI(I).EQ.6)ALTI(I)=35.5
      IF(LTI(I).EQ.7)ALTI(I)=45.5
      IF(LTI(I).EQ.8)ALTI(I)=55.5
      IF(LTI(I).EQ.9)ALTI(I)=65.5
100  CONTINUE
C
    DO 200 J=1,9
      IF(MINI(J).EQ.0)XMINI(J)=0.0
      IF(MINI(J).EQ.1)XMINI(J)=0.01
      IF(MINI(J).EQ.2)XMINI(J)=.13
      IF(MINI(J).EQ.3)XMINI(J)=.37
      IF(MINI(J).EQ.4)XMINI(J)=.75
      IF(MINI(J).EQ.5)XMINI(J)=1.5
      IF(MINI(J).EQ.6)XMINI(J)=3.0
      IF(MINI(J).EQ.7)XMINI(J)=6.0
      IF(MINI(J).EQ.8)XMINI(J)=12.0
      IF(MINI(J).EQ.9)XMINI(J)=24.0
200  CONTINUE
C
    WRITE(6,300)(ALTI(I),I=1,9),(XMINI(J),J=1,7)
300  FORMAT(9F5.2,1X,7F5.2)
    GO TO 10
999  STOP
    END
  
```

APPENDIX D

Thin Section Descriptions

Rock Unit: Skeena Group (Unit 1); crystal tuff.  
Thin Section No. 30; Sample No. PT-116  
Location: 5,440N; 11,617E

179

<u>Mineral</u>	<u>Mode</u>
quartz crystals	5%
chlorite (clots)	10%
clay (clots)	20%
groundmass	65%

Description: Broken 0.1-1.0 mm quartz crystals, locally spherulitic, in altered groundmass of clay, chlorite, and limonite. Pseudomorphs of chlorite after mafics (?) are 0.1-1.5 mm in diameter. Clay patches, pseudomorphic after plagioclase, are 0.5-1.5 mm in diameter.

---

Rock Unit: hornblende quartz monzodiorite (Unit 3a)  
Thin Section No. 29; Sample No. PT-115  
Location: 5,370N; 11,640E

<u>Mineral</u>	<u>Mode</u>
plagioclase phenocrysts	25%
hornblende phenocrysts	10%
quartz phenocrysts	2%
epidote	10%
magnetite	2%
groundmass	51%

Description: Propylitic alteration; hornblende phenocrysts are 1-3 mm in length, and are still fresh. Plagioclase phenocrysts ( $An_{31}$ ) range from 1-3 mm, and are altered to carbonate, albite, and epidote. Groundmass plagioclase (45%) is less than 0.1 mm in diameter. Magnetite ranges from 0.1-1 mm in width.

Rock Unit: biotite quartz monzonite (Unit 3b)  
Thin Section No. 1; Sample No. PT-1  
Location: 6,087N; 11,567E

180

<u>Mineral</u>	<u>Mode</u>
plagioclase phenocrysts	50%
quartz phenocrysts	15%
biotite phenocrysts	5%
groundmass	
plagioclase	15%
K-feldspar	10%
quartz	5%

Description: Crowded glomerophyritic plagioclase phenocrysts range from 0.5-4 mm in width and are locally zoned. Some plagioclase replaced by sericite and carbonate. No An determined. Anhedral quartz phenocrysts range from 0.5-2 mm in diameter. Biotite phenocrysts are mostly fresh; some are altered to chlorite. Minor biotite in groundmass is interstitial to quartz and plagioclase. Groundmass is equigranular 0.05-0.1 mm anhedral crystals of quartz, biotite, K-feldspar, and plagioclase.

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Rock Unit: intrusive breccia (Unit 3b)  
Thin Section No. 80  
Location: D. D. H. 24- 567 ft.

<u>Mineral</u>	<u>Mode</u>
Matrix	
biotite	30%
magnetite (?)	3%
plagioclase	40%
K-feldspar	17%
quartz	10%

Clasts: porphyritic quartz monzonite

Description: Euhedral to anhedral 0.01-0.5 mm brown biotite intergrown in mats. Plagioclase phenocrysts are zoned and glomerophyritic. Most are cloudy and are altered to albite and K-feldspar (?). Groundmass plagioclase is 0.025 mm in length, and is cloudy. Anhedral K-feldspar and quartz, 0.01-0.05 mm across in groundmass. Euhedral cubic magnetite (?) is interspersed in the groundmass with biotite.

Rock Unit: porphyritic dacite (Unit 4a)  
Thin Section No. 76  
Location: D. D. H. 36- 375 ft.

181

<u>Mineral</u>	<u>Mode</u>
plagioclase phenocrysts	10%
hornblende phenocrysts	2%
biotite phenocrysts	3%
quartz phenocrysts	10%
groundmass	75%

Description: Porphyritic texture; normal zoning in 1-4 mm glomeroporphyritic plagioclase, locally resorbed (rounded with reaction rim), and albitized. Extremely high carbonate alteration of plagioclase phenocrysts, and in groundmass. Hornblende phenocrysts altered to chlorite and clay magnetite sericite. 1-3 mm biotite phenocrysts are fresh. Groundmass is too fine grained to identify.

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Rock Unit: porphyritic rhyolite (Unit 5)  
Thin Section No. 56  
Location: D. D. H. 29- 154 ft.

<u>Mineral</u>	<u>Mode</u>
plagioclase phenocrysts	15%
biotite phenocrysts	5%
quartz phenocrysts	5%
groundmass	75%

Description: Clots of clay and carbonate, 0.5-2 mm across, replace plagioclase phenocrysts. Pseudomorphs after biotite are chlorite; replacements along cleavage is evident. Quartz phenocrysts are rounded and 1-5 mm in diameter. Quartz is locally polycrystalline. Groundmass consists of very fine grained anhedral quartz, orthoclase, and plagioclase (?).

Rock Unit: andesite (Unit 6)  
Thin Section: No. 72  
Location: D. D. H. 34- 435 ft.

182

<u>Mineral</u>	<u>Mode</u>
quartz phenocrysts	1%
chlorite after hornblende	5%
plagioclase phenocrysts	1%
groundmass	93%

Description: Quartz and plagioclase phenocrysts are 0.5-1 mm across. Plagioclase is altered to carbonate and clay. Clots of chlorite and carbonate replace hornblende. Groundmass consists of 0.1-0.2 mm plagioclase with minor quartz and magnetite. Plagioclase is altered to carbonate and clay or sericite.

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Rock Unit: Ootsa Lake Group (Unit 7)  
Thin Section No. 7; Sample No. PT-51  
Location: 5,900N; 10,800E

<u>Mineral</u>	<u>Mode</u>
plagioclase phenocrysts	20%
hornblende phenocrysts	3%
groundmass	
plagioclase	50%
K-feldspar	5%
quartz	20%
apatite	1%
opaques	1%

Description: Zoned 1 mm plagioclase phenocrysts ( $An_{28}$ ) are slightly altered to carbonate. Some plagioclase phenocrysts are albitized and some are stained from hematite inclusions. 1-2 mm hornblende is altered to chlorite and carbonate. Groundmass is fresh, opaques include limonite, hematite, and magnetite. Small carbonate vein cuts thin section.