GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2167

Geology and regional setting of major mineral deposits in southern British Columbia (Field Trip 12)

edited by

A. Legun
R.E. Meyers
H.P. Wilton

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GEOLOGY AND REGIONAL SETTING OF MAJOR MINERAL DEPOSITS IN SOUTHERN BRITISH COLUMBIA

[FIELD TRIP 12]

EDITED BY

A. LEGUN, R.E. MEYERS and H.P. WILTON

With Contributions from:

N. Berg, G.L. Dawson, G.D. Delaney, A.D. Ettlinger, J.T. Fyles, T. Hoy, S.J. Juras, A. Legun, W.J. McMillan, D. McMurdo, R.E. Meyers, K.E. Northcote, C.A. Pearson, V.A. Preto, P.W. Ransom, G.E. Ray, R. Simpson, W.A. Taylor and H.P. Wilton

8TH IAGOD SYMPOSIUM

FIELD TRIP GUIDEBOOK

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Chapter 1
GENERAL INTRODUCTION

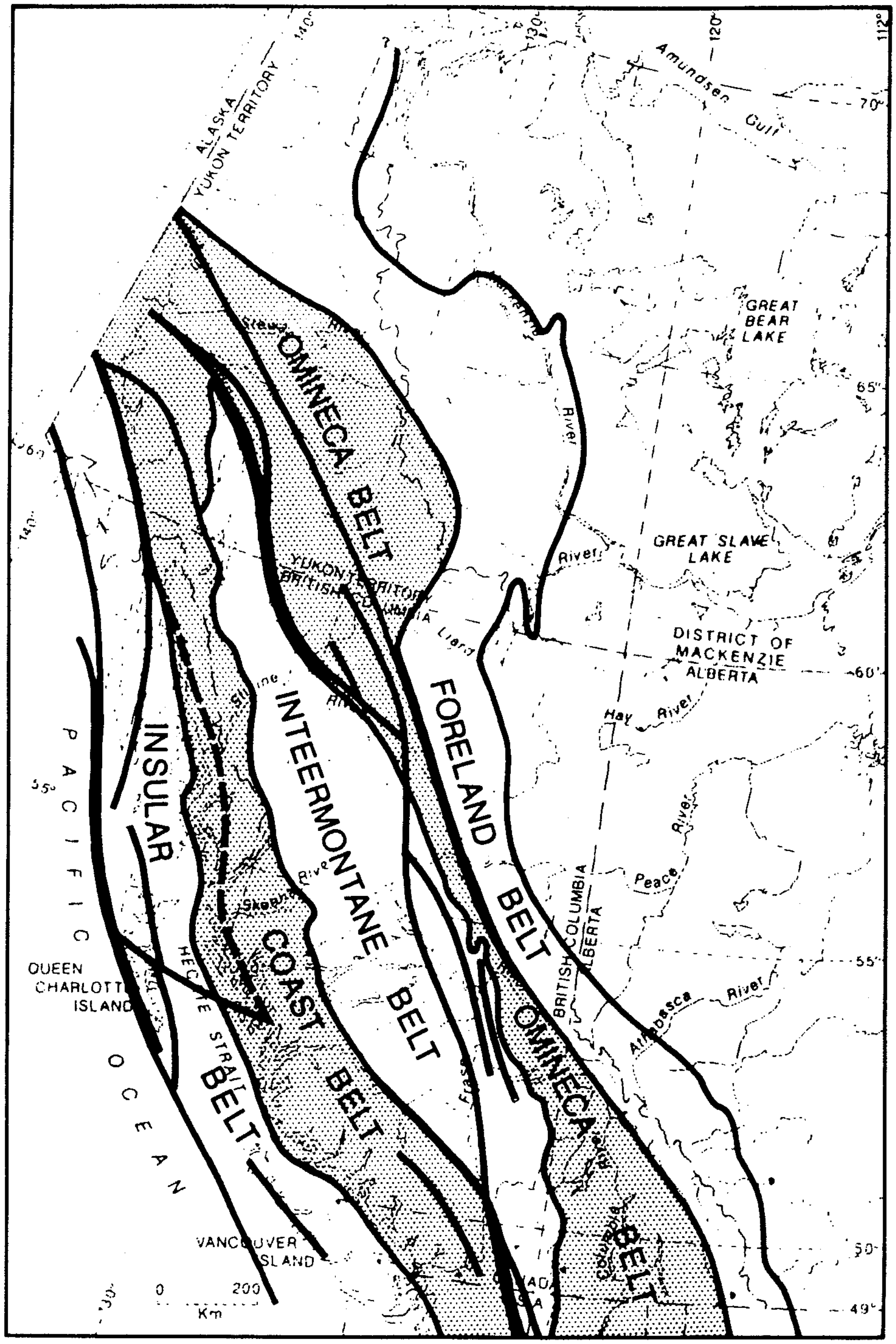
H.P. WILTON
BRITISH COLUMBIA GEOLOGICAL SURVEY
200-756 Fort Street
Victoria, B. C. V8W 3A3

GENERAL INTRODUCTION

The Canadian Cordillera is comprised of five major northwesterly trending morphogeological belts in contact with the western margin of the North American craton (Fig. 1). It has been further subdivided into a very large number of terranes each of which is believed to have had its own unique place of origin, stratigraphic development and tectonic history (Fig. 2). It follows that the individual superterranes and many of the lesser terranes each demonstrate their own particular metallogeny and major mineral deposit types. Furthermore, some specific mineral deposit belts and camps are genetically related to the regional strike-slip faults separating morphogeological belts and superterranes as well as with many of the sutures connecting accreted or displaced terranes. In other words, the metallogeny of the Canadian Cordillera is varied and complex and our knowledge of it has been changing rapidly in recent years as our new understanding of the tectonic evolution unfolds and new mineral discoveries are made. An excellent recent compilation of current thinking about the tectonic evolution of the Canadian Cordillera was published by H. Gabrielse and C.J. Yorath of the Geological Survey of Canada in 1989. The complete reference is cited at the end of this note and Figures 1 and 2 have been drawn from their paper.

On this field trip across southern British Columbia, we shall cross all of the morphogeological belts and many of the major terranes. The route of our transect from Calgary to Vancouver Island has been superimposed on Figure 2. All of the overnight stops and the four major mineral deposits to be visited have been plotted. We shall visit the Sullivan polymetallic sedex deposit in Precambrian rocks of Ancestral North America, the Nickel Plate precious metal skarn deposit and the Highland Valley Copper porphyry deposit, both in the Quesnellia terrane, and finally the volcanogenic polymetallic massive sulphide deposits at Buttle Lake in the Wrangellia terrane.

With the exception of the 1990 original contribution from Juras and Pearson describing the Buttle Lake camp, the mine descriptions in this guidebook have been drawn, with occasional modifications, from previous publications. Much of the regional descriptions have also been assimilated by the editors from existing publications. Each section is headed with an indication of its source and original authors and each has its own reference list.



EXPLANATION

Regional Strike-slip Faults

Coast Range Megalineament

Dominantly Igneous and Metamorphic rocks

Figure 1: *Morphogeological belts and regional strike-slip faults of the Canadian Cordillera.*

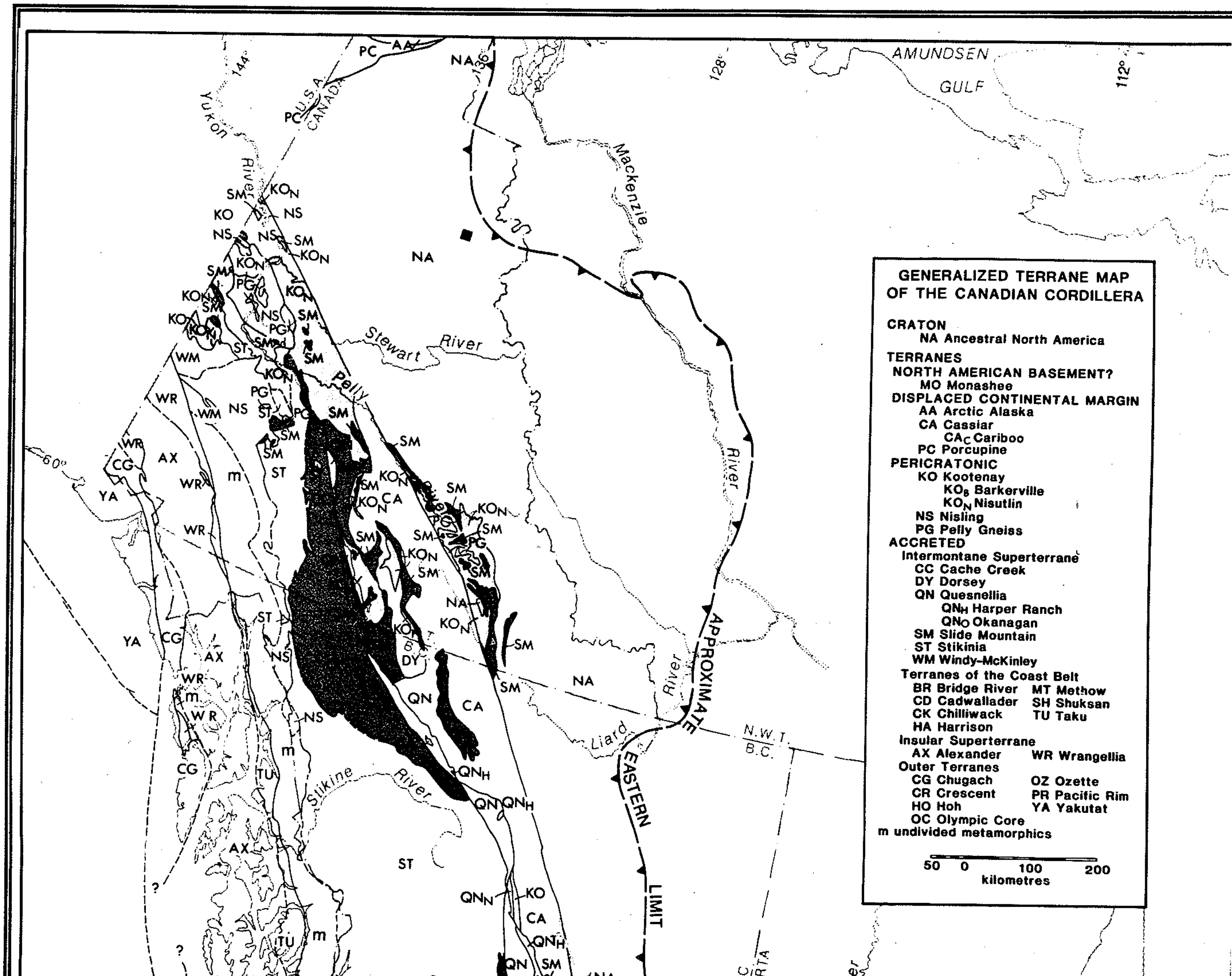


Figure 2 *Simplified terrane map of the Canadian Cordillera. **PR & CR**, Pacific Rim and Crescent terranes; **CG & YA**, Chugach and Yakutat terranes; **WR**, Wrangellia; **AX**, Alexander Terrane; **GN**, Gravina-Nutzotin Terrane; **CP & MRX**, Coast Plutonic and Metamorphic Rocks; **BR-CD-SH-HA-CK-MT**, Bridge River, Cadwallader, Shuksan, Harrison, Chilliwack and Methow terranes; **ST**, Stikinia; **CC**, Cache Creek Terrane; **QN**, Quesnellia; **SM & DY**, Slide Mountain and Dorsey terranes; **KO**, Kootenay Terrane; **NA**, North American Terrane (ancestral North America); **MO**, Monashee Terrane (North American Basement); **PG & NS**, Pelly Gneiss and Nisling Terrane.*

REFERENCE

Gabrielse, H. and Yorath, C.J. (1989): DNAG #4. The Cordilleran Orogen in Canada, Geoscience Canada, Volume 16, Number 2, pp. 67-83.

Chapter 2
GEOLOGY AND REGIONAL SETTING OF MAJOR MINERAL DEPOSITS IN THE KOOTENAY DISTRICT

Andrew Legun
District Geologist
B.C. Geological Survey Br.
310 Ward St., Nelson, B.C.

MAJOR GEOLOGICAL AND PHYSIOGRAPHIC SUBDIVISIONS OF CANADIAN CORDILLERA

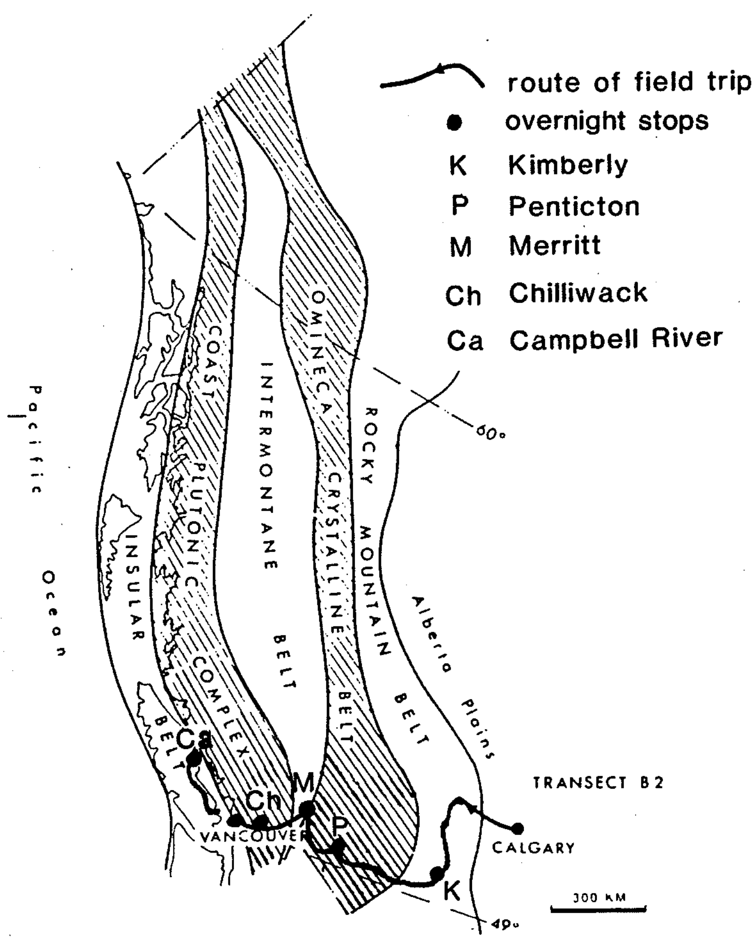


Figure 1: The five major geologic-physiographic belts of the Canadian Cordillera, and the field trip route.

TECTONIC SETTING

The Canadian segment of the Cordillera has been divided on the basis of contrasts in metamorphism, plutonism and volcanism, deformational style and physiography into five longitudinal belts. Two of these belts, the Rocky Mountain Belt and the Omineca Crystalline Belt are represented in the Kootenay District and traversed in the first two days of the field trip (Fig. 1). The Rocky Mountain Belt includes dominantly miogeoclinal rocks that were deposited on the western cratonic edge of North America from mid Proterozoic to Mesozoic time, and displaced eastward during the Mesozoic and Tertiary. The western part of the belt is intruded by Mesozoic age granitic rocks of mostly Cretaceous age. The Omineca Crystalline Belt comprises variably metamorphosed Proterozoic and Paleozoic miogeoclinal rocks of pericratonic (rifted?) origin and younger volcanic and pelitic rocks which appear to be ensimatic ; they are intruded by Mesozoic age granitic rocks.

The highway route through the Kootenay District thus transects cratonic and pericratonic rocks of ancient North America and passes into accreted terranes. On the first day the highway route crosses the Rocky Mountain fold and thrust belt, descends into the Rocky Mountain trench and climbs out into the tectonic belt of the Purcell Anticlinorium, still in the cratonic rocks of ancestral North America. After the Sullivan mine visit the main transect of the Purcell Anticlinorium is completed and at Summit Pass near Stagleap Provincial Park the descent is made into the metal-rich and transitional tectonic belt of the Kootenay Arc. Near Salmo the route passes into the Omineca Belt and volcanic rocks of the Rossland Group representing accretionary terrain.

For the purposes of this guide mineral deposits and mineral camps are grouped according to tectonic belts (Fig.2). The Shuswap Metamorphic Complex is rather peripheral to the Kootenay District and excluded. The Kootenay Arc more or less forms the border with the Omineca Crystalline Belt. It is a structure that may have been superimposed on more than one terrain (Lambert, 1989). The general stratigraphy for the Kootenay District (with the exception of the Greenwood area) is presented in Figure 3.

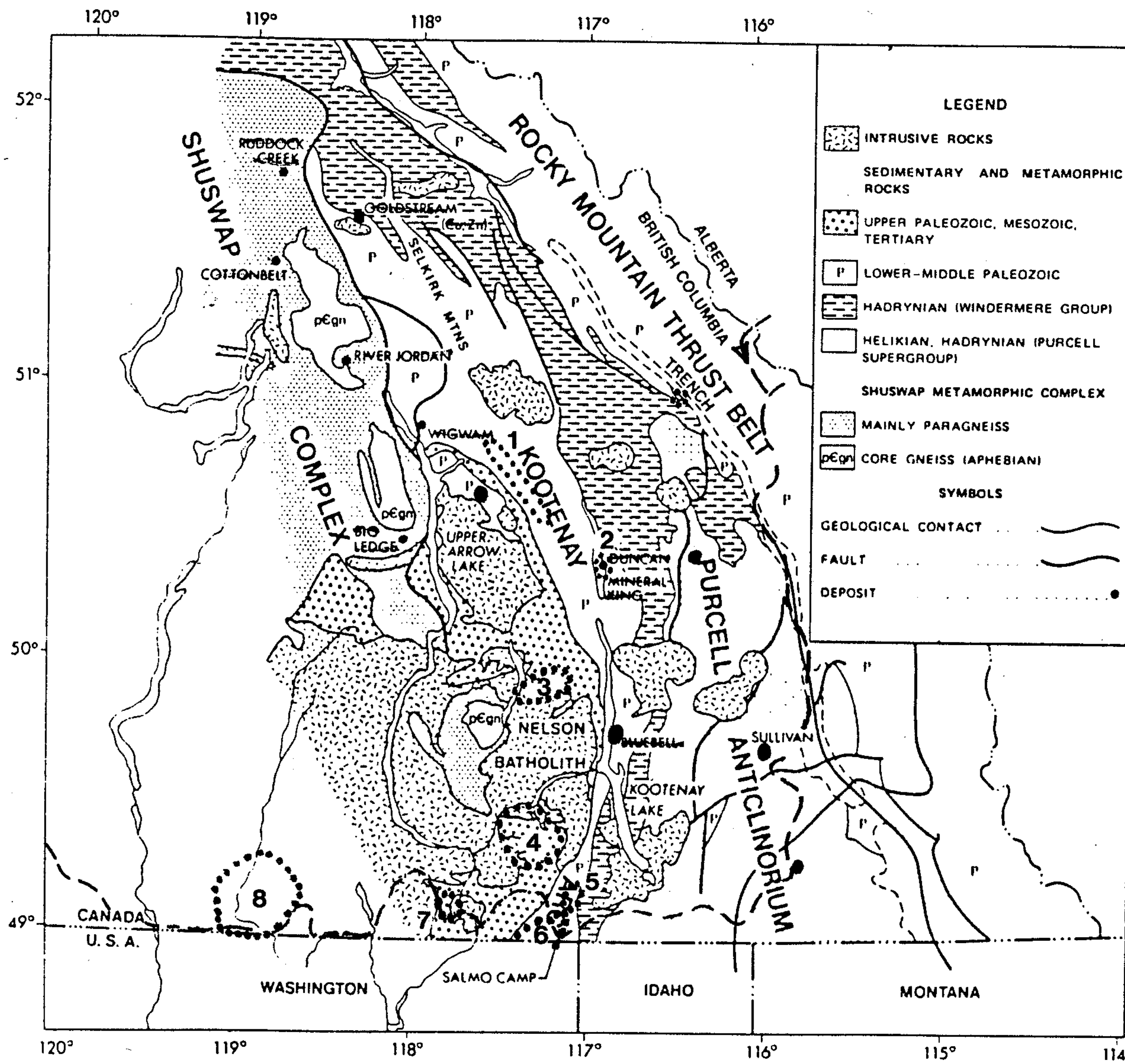


Figure 2: Regional map of southeastern British Columbia showing main tectonic belts, selected mineral deposits and camps. After Hoy et al. (1985).

Camps

1. Trout Lake
2. Duncan
3. Slocan
4. Nelson-Ymir
5. Sheep Creek
6. Salmo
7. Rossland
8. Greenwood

Highway Route

• Selected Deposits

General Stratigraphy Kootenay District

PALEOZOIC	Tertiary	44 ROSSLAND MONZONITE	
		43 [m] McGregor Plutonic Rocks [s] Sheppard Plutonic Rocks [c] Coryell Plutonic Rocks	
	Cretaceous	41 GRANITES (S.L.) a Lower Caribou Ck. Stock b Snowslide & Wragge Ck. Stock c Ruby Ronge Stock d Box Mt. Stock e Kuskanax Batholith f Fry Creek Stock White Creek Batholith g Biotite Granodiorite h Hornblende-biotite granodiorite i Porphyritic granodiorite j Quartz-Monzonite k Fine grained granodiorite l Aplite/Pegmatite n Nelson Plutonic Rocks v Valhalla Plutonic Rocks	
		40 Ultramafics	
		39 Sophie Mt. Formation	
		38 Marron Formation	
	Jurassic	ROSSLAND GROUP 37 Hall Formation 36 Elise Formation 35 Archibald Formation	
	Triassic-Jurassic	34 YMIR GROUP	
	Triassic	33 SLOCAN GROUP 32 KASLO GROUP	
	Permian		
	Carboniferous – Pennsylvania	30 Mt. Roberts Formation	
	Carboniferous – Mississippian	28 MILLFORD GROUP	29 Banff Formation
	Devonian		27 Burnais Formation 27a Starbird Formation 27b Mt. Forster Formation
	Silurian		
	Ordovician	22a Active Formation 22 LARDEAU GROUP	26 Beaverfoot-Basco Form. 25 Mt. Wilson Form. (Wonah) 24 Glenogle Formation 23 McKay Group
	Cambrian	17 BADSHOT-MOHICAN GROUP a Laib Formation b Nelway Formation c Reeves Formation 15 HAMILL GROUP a Quartzite Range Form. b Reno Formation	21 Jubilee-Ottertail Form. 20 Chancellor Formation 19 Tanglefoot Formation 18 Eager Formation 16 CRANBROOK GROUP
PROTEROZOIC – Hadrynian	Windermere	14 HORSETHIEF GROUP a Monk Formation b Three Sisters Formation 13 Irene Volcanics 12 Toby Formation	
PROTEROZOIC – Helikian	Purcell or later	11 Moyie Intrusions	
	Purcell	6 Mt. Nelson Formation 5 Dutch Creek Formation 4 Kitchener-Siyeh Form. a Kitchener Formation b Siyeh Formation 3 Creston Formation 2 Aldridge Formation [a] Upper [b] Middle [c] Lower 1 Fort Steel Formation	10 Roosville Formation 9 Philips Formation 8 Gateway Formation 7 Sheppard Formation

Fig. 3
after Grant (1985)

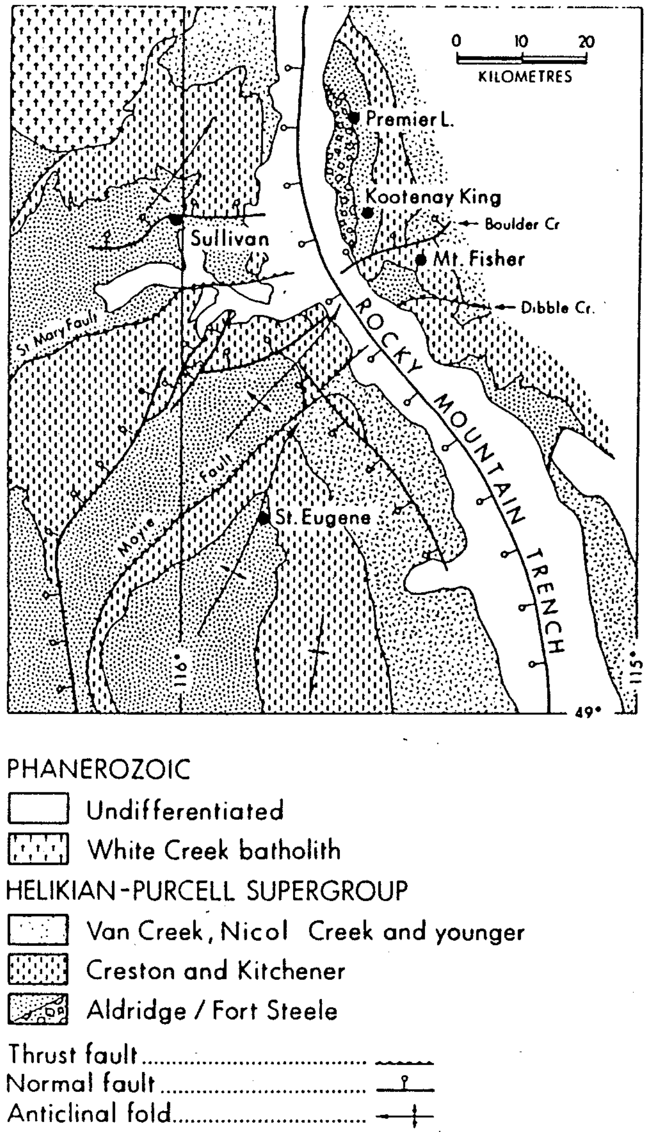


Figure 3a Geological map of the Purcell Supergroup in Fernie west half map sheet and part of Nelson east half.

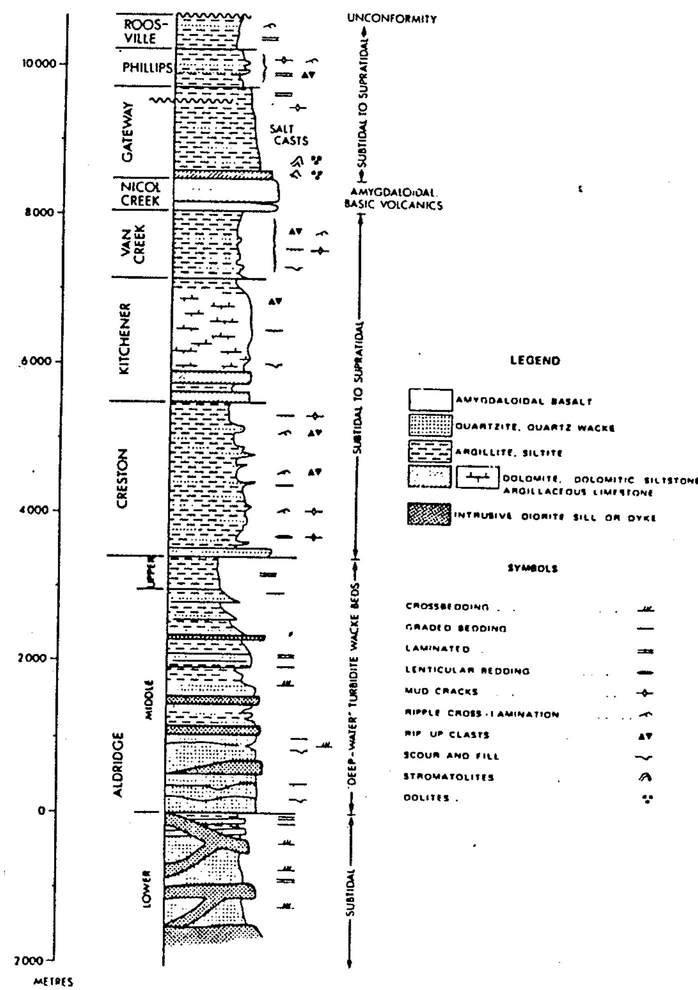


Figure 3b Composite stratigraphic column of the Purcell Supergroup in the Moyie Lake area.

GEOLOGIC HISTORY: JURASSIC TO TERTIARY

The recent geologic history of southeastern B.C. spans two orogenies in the Cordillera (Columbian and Laramide).The summary below is adapted from Price et al. (1985).

Rocks of the Omineca Crystalline Belt carry paleontologic and paleomagnetic indications that they are displaced with respect to cratonic North America and evolved somewhere outboard from the North American continental margin. Devonian to Lower Jurassic volcanics, clastics and carbonate represent a collage of off-shore arcs known as Quesnellia. The latest Jurassic volcanism and sub-volcanic intrusive activity is recorded in the 190Ma Rossland Group. In the early Jurassic these arcs still lay well offshore (Poulton and Aitken, 1989). The sea separating Quesnellia from North America was partly floored by oceanic crust, and partly by a thick sequence of rifted, continental terrace wedge rocks comprising the Purcell Supergroup and overlying Paleozoic sequence. A marginal basin with a fill of Triassic sediments collapsed in the mid-Jurassic. In the area of the Kootenay Arc during mid-Jurassic to Cretaceous, late-synkinematic to post kinematic granodioritic plutons(170-165Ma) were emplaced and accompanied by amphibolite-facies regional metamorphism and significant deformation. At this time allochthonous terrain converged with the western part of the miogeocline and compressed it. The Purcell Anticlinorium fan structure was a product of the compression. Mid-Cretaceous granitic plutons were emplaced in the deformed miogeoclinal prism. Subsequently(Late Cretaceous to Paleocene) the prism was displaced more than 100 km northeast across the edge of the continent.

Substantial uplift with erosional and/or tectonic unroofing occurred from mid-Jurassic to mid-Cretaceous. Extensional tectonics, strike slip faulting and substantial erosion occurred in the Tertiary with a notable heating event in the Eocene.

METALLOGENIC TRENDS AND GROUPINGS

The Rocky Mountain Belt is host to significant base metal deposits. Most significant are stratabound deposits in clastic rocks of Helikian age and replacement deposits in carbonates of Hadrynian age and Cambrian age. Base metal vein deposits of probable Proterozoic age are also represented. The earliest major stratabound and syngenetic mineralisation is that of the Sullivan deposit dated at 1.43 b.y. from biotite associated with alteration (LeCouteur, 1979). Most deposits are believed to relate directly or indirectly to rifting events that provided structural controls for igneous activity and localised areas of high geothermal heat flow in which convective hydrothermal cells formed (McMillan et al., 1987).

The transitional Kootenay arc tectonic belt is metallogenically very significant. It hosts major and complex (remobilized syngenetic?) lead-zinc deposits in Cambrian carbonates (eg. Salmo camp), gold veins in quartzites (Sheep Cr. camp) skarn tungsten, stockwork molybdenum and some vein deposits peripheral to Cretaceous intrusions (Trout Lake camp). The metallogeny of the arc in relationship to pericratonic rifting, the collapse of a postulated marginal oceanic basin, and accretion of Quesnellia is not well understood. Only a few workers have done direct research related to metallogeny(eg.Linnen and William Jones, 1987) Major known periods of mineralisation include a Lower Cambrian age for some of the lead-zinc deposits showing syngenetic features and a Jurassic-Cretaceous-Tertiary(?) age for the veins and skarns. Linnen and Jones(1987) argue a postkinematic granite-related metallogenic event during an episode of Middle to Late Cretaceous uplift formed the stockwork Mo deposits, skarn W deposits, and remobilised the stratiform Pb-Zn-Ag deposits into discordant vein-types.

The Omineca Crystalline Belt in the Kootenay District is host to copper-gold skarns and mesothermal polymetallic veins associated with Jurassic plutons. Porphyry molybdenum has been mined in one large deposit at Red Mt. near Rossland. The Rossland, Greenwood and Nelson-Ymir mining camps lie within this Belt.

Jurassic plutons range from pre to syn to post kinematic in relation to a metamorphic and deformational event in the mid-Jurassic. Older plutons are coeval with Lower Jurassic volcanism (Rossland Group) and represent island arc plutonism of subalkaline affinity. The younger plutons are characterised by Nelson and Valhalla batholithic rocks. Ages of mineralisation are not well established. One period of mineralisation probably coincides with the older subvolcanic intrusions, a second represented by epigenetic vein mineralisation post-dates intrusion of the Nelson batholith. In addition a Tertiary hydrothermal event is well documented by potassium-argon age dates but its relative metallogenetic significance is uncertain.

Metallogenic trends in relation to plate tectonics can be grossly summarised as follows: pre-accretionary mineral deposits are predominantly stratiform types and the majority of granitoid-related porphyry, skarn and vein deposits are syn- or post-accretionary.

ROCKY MOUNTAIN FOLD AND THRUST BELT

This belt is lacking in obvious intrusive related deposits and major known deposits exhibit a stratigraphic control or are sedimentary in nature. There are however some alkaline igneous rocks with potential for rare earths(Pell, 1987). Major commodities mined in this belt include Jurassic-Cretaceous coal formed in foreland molasse basins; Devonian age evaporite deposits of gypsum; barite and lead-zinc in platformal Cambrian carbonates; magnesite in Cambrian dolomites. Economically coal is by far the single most important commodity. The lead-zinc deposits, the world class magnesite deposit, and barite are briefly reviewed below. The reader is referred to Grieve (1990,in press) and Butrenchuk(1989) for the geology of the coal and gypsum deposits respectively.

Lead-zinc deposits occur in dolomitized breccias with low precious metal content and simple mineralogy. In the east the only mined deposit of any size is the Monarch near Field, B.C. It and other prospects parallel a Middle Cambrian carbonate bank margin trending southeast near the Alberta border (Hoy, 1982a). They are considered to be typical Mississippi valley type occurrences.

Further to the west near the Rocky Mountain trench lead-zinc deposits occur in similar-looking breccias but the gangue is barite rather than dolomite. According to Bennett(1986) the mineralisation is preferentially located in karst features formed beneath middle and upper Devonian regional unconformities. The principal past producer deposit is the Silver Giant. It is on the overturned west limb of the Purcell Boundary Syncline. Massive barite with disseminated galena and sphalerite replaces the upper part of the middle to Upper Cambrian Jubilee Formation at the crest of a fold. Barite was recovered from the tailings after the orebody was mined out.

Major barite deposits without sulphides are found as well within the trench region. They range in age from Paleozoic to Proterozoic and are hosted in brecciated dolomites. Significant tonnages of high quality white barite have also been mined from fissure veins related to faults (eg.Brisco mine).

The Mt. Brussilof magnesite deposit, brought into production in 1982 is one of the largest in the world. It occurs in the southern Main Ranges of the Rocky Mountains in the Middle Cambrian Cathedral Formation. The magnesite is stratabound, forming bands 65 to 75 metres thick separated by well-bedded limestone and dolomite. The main deposit is currently defined as an area about 790 by 500 metres on a northwest axis with a maximum thickness of at least 120 metres within the main magnesite zone. High grade magnesite (97% pure) occurs in the main pit. Current reserves in all categories stand at 40 million tons grading 92.44 percent or better MgO.

Magnesite is the main mineral with minor amounts of dolomite, calcite, quartz, and pyrite. Trace minerals include pentlandite, talc, sericite, illite, leuchtenbergite , phlogopite, muscovite and palygorskite.

The discrete beds have led to speculation whether the magnesite is primary in origin. According to MacLean(1989), from whom this summary is drawn, open pit operations have exposed a sharply defined discontinuous dolomite/limestone lens in the centre of the main mass of magnesite. Original bedding remains visible, with coarse-grained magnesite crystals replacing dolomite. This suggests the lens is a remnant of an original complete sequence which has been almost totally replaced. Further evidence for the magnesite being secondary is the presence of pyrite-filled veins.

PURCELL ANTICLINORIUM

The Purcell Anticlinorium is situated between the Rocky Mountain thrust and fold belt to the east and the Kootenay Arc to the west.The Anticlinorium is a broad north-plunging structure cored by rocks of the Purcell Supergroup. Coarser clastic rocks of the Hadrynian Windermere Supergroup unconformably overlie the Purcell rocks on the western flank and northern crest. The Anticlinorium is transected by a number of steep longitudinal and tranverse faults. The tranverse faults appear to have been active intermittenly since at least Hadrynian time and played an important role in controlling the type, distribution and thickness of late Proterozoic to early Paleozoic sediments (Lis and Price,1976).

The Purcell Supergroup is host to a number of deposits, two of which exceed 50 million tonnes; the Sullivan lead-zinc deposit occuring along the eastern edge of the Purcell Anticlinorium in Helikian age turbidites and across the U.S.A. the diagenetic

(Troy-Spar Lake) copper-silver deposit in younger fluvial and lacustrine sedimentary rocks. Other deposits of significant production include the Mineral King, a replacement deposit in Purcell platform carbonates, the St. Eugene, a base metal vein and Estella, a vein deposit adjacent to a syenite intrusion. The workings of the St. Eugene are visible on the east side of highway 3 opposite Moyie Lake.

Stratigraphic setting

Exposures of Purcell rocks are not confined to the Purcell Anticlinorium but are present immediately east of the Rocky Mt. trench in the Hughes, Lizard and Galton ranges and further east in the Clark Range in the southeast corner of B.C. and the southwest corner of Alberta. The oldest rocks exposed in the core of the Purcell Anticlinorium are quartzites, silstones, and argillites of the Aldridge Formation.

On the east side of the Rocky Mountain Trench north of Boulder Creek the Aldridge Formation is underlain by coarse fluvial sandstone of the Fort Steele Formation. The Boulder Creek fault (Fig. 3a) coincides approximately with a marked transition in the character of lower Purcell rocks: from the dominantly fluvial, shallow-water, and minor turbidite deposits to the north into a thick succession of turbidites to the south that are similar to those in the Purcell Mountains west of the Rocky Mountain Trench. This indicates that in lower Purcell time, the area east of the trench was near the edge of a deep, structural basin that lay to the south and west. Evidence suggests the basin edge developed by growth faulting (Hoy, 1979; 1982). Middle Aldridge time is marked by the introduction of extensive and thick accumulations of turbidite deposits. The basin of turbidite deposition expanded and, during Middle Aldridge time, overlapped inner fan deposits east of the present Rocky Mountain Trench.

Laterally extensive sills, which are predominantly gabbroic in composition (Hoy, 1984), intrude the Lower and Middle Aldridge Formation. Moyie intrusions are apparently restricted to early Aldridge time, dying out in late-middle Aldridge time at the same time as the volume of coarse turbidites decreased. The abundance, volume, spatial distribution, and temporal restriction of Moyie intrusions to a stratigraphic interval dominated by turbidite deposition and the geochemistry of the intrusive rocks (Hoy,unpub. data) suggest that Lower Aldridge and early middle Aldridge sedimentation took place during a period of continental rifting.

Overlying the Aldridge Formation are upper Purcell rocks which are generally platformal in nature. The Creston Formation consists of shallow-water argillaceous quartzite, siltstone and argillite. It is overlain by platformal carbonate rocks of the Kitchener Formation. Shallow-water argillite, siltstone, dolomite and quartzite of the overlying "Siyeh" and Dutch Creek formations, give way upward to dolomite and dolomitic limestone of the Mount Nelson Formation, host of the Mineral King deposit. Basic volcanics of the Nicol Creek Formation are exposed along the southeastern margin of the Purcell Anticlinorium.

KOOTENAY ARC

The Kootenay Arc is an arcuate belt of deformed and metamorphosed rocks that has had a complex history of deformation overprinted by Eocene extensional tectonics. It has developed in a succession of rocks ranging in age from Hadrynian to early Mesozoic. Windermere Supergroup rocks are overlain by early Cambrian platformal quartzites and an extensive Lower Cambrian platformal carbonate called the Badshot or Reeves Formation. These units are overlain by Paleozoic rocks of the Lardeau Group, which are overlain unconformably by the Milford Group of late Paleozoic age. Basaltic volcanic rocks of the Triassic Kaslo Group and shales and quartzites of the Triassic to Jurassic Slocan Group are in tectonic contact with the Milford Group. The rocks of the Kootenay arc are believed to represent both a distal continental margin and part of a late Paleozoic to early Mesozoic back-arc basin (Klepacki,1986; Parrish et al., 1988).

Strata on the western side of the Purcell Anticlinorium steepen in dip and pass westward into isoclinally folded rocks of the Arc. The western boundary is complicated by high grade metamorphism and repeated faulting. The Arc has a pronounced north-south structural grain due to the dominance of north trending phase two folds. Intrusion of synkinematic and post-kinematic plutons indicates a mid Jurassic age for this deformation.

Lead-Zinc Deposits of the Kootenay Arc

The first lead deposit in B.C., the Blue Bell was discovered on the east side of Kootenay Lake by an Americain, Henry Doan in 1868 and relocated by Robert E. Sproule in 1882.

Many of the other lead-zinc deposits, eg. the Reeves Macdonald and the Jersey were located prior to 1900. Major development did not occur until the late 1940's because they were low grade and contained mainly zinc. These large stratabound lead-zinc deposits are restricted to a "platformal" carbonate unit of Lower Cambrian age within the Kootenay Arc. The unit known as the Badshot or Reeves Fm. extends from the Lead Point area, near Northport, Washington to north of Revelstoke. (Fig.4). In B.C. major deposits are concentrated in two areas, the Salmo camp at the southern end of the arc and the Duncan camp north of Kootenay Lake. The Bluebell deposit, described as a vein replacement deposit (Ransom, 1977b; Hoy, 1980), is situated at Riondel between the Duncan and Salmo camps. General characteristics, as well as details of deposits, in the Salmo camp have been described by Fyles and Hewlett (1959) and Fyles (1970b). Deposits in the Duncan area have been described by Muraro (1962, 1966) and Fyles (1964). None of the deposits remain in production but in some deposits(eg. Duncan Lake) large reserves remain in strike extensions to the orebodies at depth.

Kootenay Arc deposits are hosted by intensely deformed Lower Cambrian marble or limestone. The deposits generally range in size from 6 to 10 million tonnes and contain 1-2% Pb, 3-4% Zn, about 0.4% Cadmium and trace silver (Hoy, 1982 b). They consist generally of lenticular, banded, massive or disseminated bodies of pyrite, shalerite and galena in dolomite or chert zones (Fyles, 1970a). They are irregular in outline and commonly elongated parallel to the regional structural grain. Contacts with country rock may be sharp or gradational. Dolomitization and associated brecciation of the limestone is common.

Salmo Camp

A fine-grained dolomite hosts deposits in the Salmo camp. The dolomite is texturally different from the barren, generally well-banded limestone (Fyles and Hewlett, 1959). It may be poorly banded, flecked with black, irregularly streaked or crackled. More massive dolomite contains only sparse mineralization. Obvious breccia zones with dolomite fragments surrounded by sulphides are common features of the Salmo deposits.

Sections and one plan of the deposits is illustrated in Figure 5. The Reeves orebody at the Reeves MacDonald mine is in a steeply plunging secondary syncline on the south limb of the Salmo River anticline. The Jersey orebodies follow secondary folds and locally bedding faults on the right-side-up limb of the Jersey anticline. The H.B. orebodies plunge parallel to primary and secondary fold axes and some are along gently dipping faults. The largest mineralised zones are a few thousand feet long, a few tens of feet thick, and a few hundred feet wide.

Many of the lead-zinc deposits are deeply oxidized and include carbonates, sulphates and minor phosphates.

Duncan Camp

Mineralization in Duncan-type deposits is in dolomite or a siliceous rock that Muraro (1966) interprets as recrystallized chert, but which may be silicified carbonate. The dolomite may be massive or textured like dolomite in the Salmo camp. According to Hoy(1982a) mineralization is localized in a particularly thick section of the Badshot Fm. The thick section may represent an extensively brecciated and locally dolomitized, bank margin facies developed on a shoal complex.

Bluebell

The Bluebell ore deposit consists of three main zones spaced approximately 500 metres apart along the strike of the Badshot marble which hosts the sulphide mineralization. The zones are localized along steep cross-fractures. The ore was predominantly massive coarse pyrrhotite, sphalerite and galena; however, disseminated sulfides, narrow bands of medium to coarse sulfides in quartz and marble and sulfide-filled fractures were also mined. Ransom (1977) described the geometry and genesis of individual ore shoots within the zones:

"They ranged in size from irregular pods of a few thousand tons to continuous masses of up to one million tons that extended down-dip as much as 500m In cross-section, an average ore shoot was mushroom-shaped, the stem representing cross-cutting keels 1 to 30 m wide and the cap representing a bedding-conformable horizon up to 6 m thick that extended laterally as much as 50 m from the keel zone. The keel zones extended below the conformable ore some 10 to 20 m, narrowing and grading into a series of steep mineralized fractures that became uneconomical to mine. Some of the fracture zones and keels of the larger ore shoots extended to the footwall.

Underground observations indicate that hydrothermal ore solutions entered steep east-west tensional fractures in the limestone from the footwall, ascended along these fractures into dilatant zones, and spread out below impermeable barriers such as the hangingwall schist, hangingwall pegmatite, the lamprophyre and diabase dikes and mid-limestone

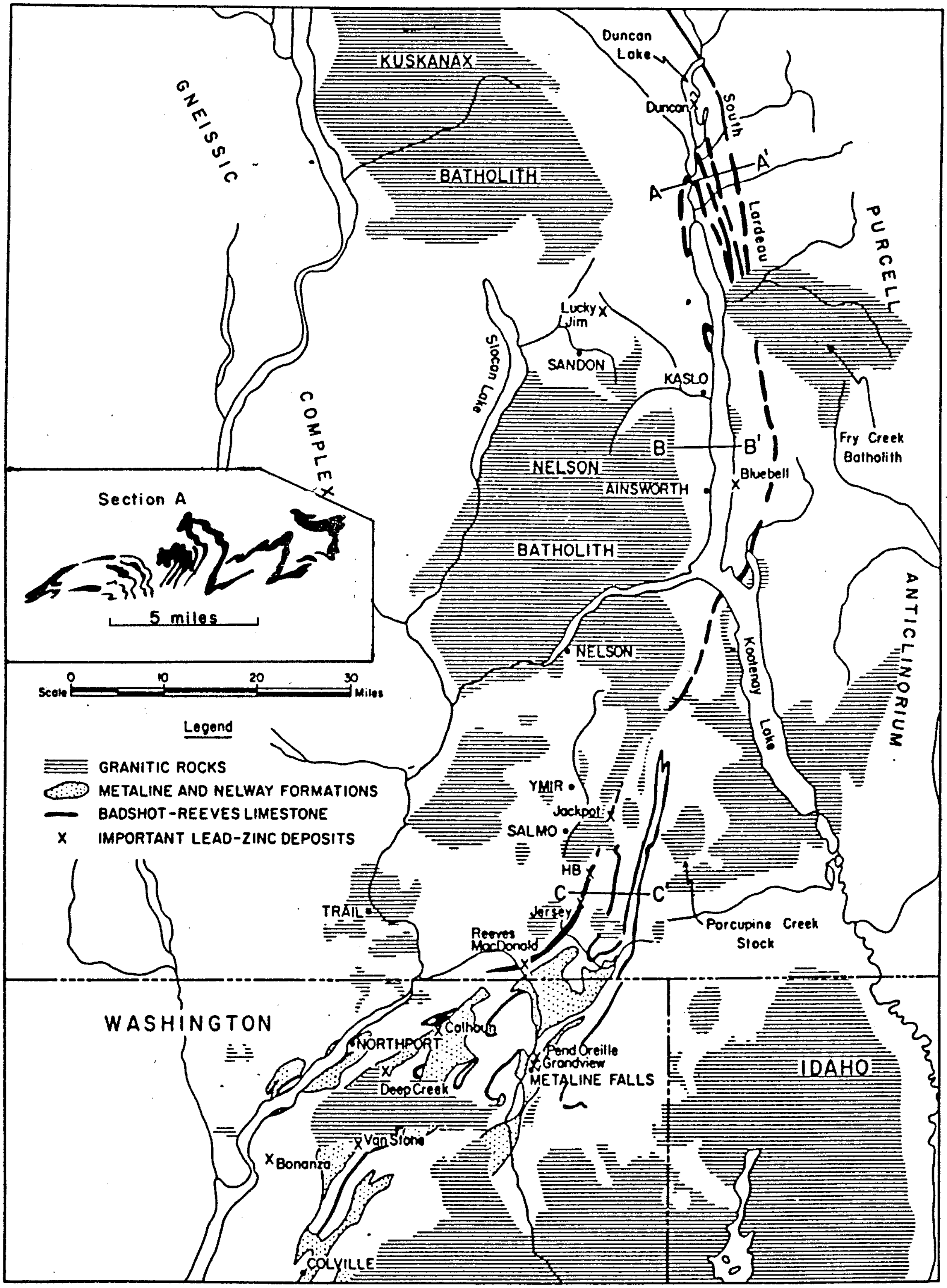


Figure 4 Geologic map of the southern Kootenay arc (after Fyles, 1970).

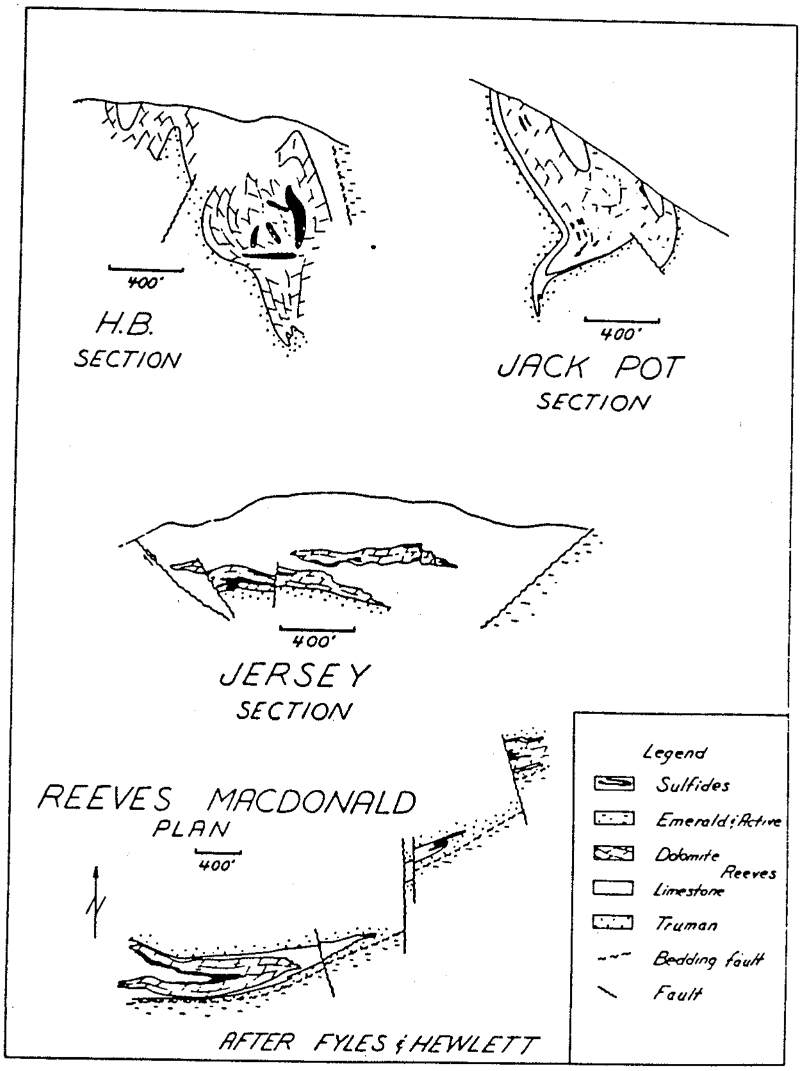


Figure 5 Three vertical sections and one plan of four deposits in the Salmo camp. Modified after Fyles and Hewlett, 1959. From Munro, 1966.

schist.

Regional metamorphic studies indicate that metamorphism took place at depths between 18 and 28 km. Detailed fluid inclusion studies infer ore formation to have taken place at a depth of 7 km. If these interpretations are correct, ore formation ocurred after the metamorphic culmination (in mid Jurassic)."

General Features and Origin of the Lead-Zinc Deposits

Hoy(1982a) summarises the features of the deposits and various theories as to their origin:

1) The deposits are localized in a specific limestone unit, the Badshot Formation or its equivalent, even though chemically and megascopically similar limestones occur locally in the underlying Mohican Formation.

2) Some of the deposits are well layered (essentially stratiform) and, according to Muraro (1966), are deformed and metamorphosed along with the enclosing host rocks.

3) Dolomite envelopes completely or partially surround the sulphide deposits. Dolomite is obviously brecciated, or has a textured appearance suggestive of early brecciation.

4) Lead-zinc zoning in Duncan deposits is consistent with stratigraphic tops regardless of the structural position; zinc is concentrated in the stratigraphically lower dolomite, and lead and zinc in the upper dolomite (Muraro, 1962).

Fyles and Hewlett (1959) describe the deposits as replacement deposits controlled by Phase 2 folds and locally, faults. They describe the close spatial association of mineralization to structures and the brecciated nature of some of the ore. Sangster (1970) and Addie (1970) describe the deposits as syngenetic, with sulphides accumulating in small basins in a deep-water carbonate platform. Muraro (1962), based on detailed studies of the Duncan deposit, suggests that Kootenay Arc deposits are hydrothermal replacement deposits, controlled by stratigraphy and formed before deformation and metamorphism, whereas Hoy (1982b) suggests the deposits span the syngenetic-diagenetic interval, in part accumulated along with shallow water carbonates, but also locally accumulated in cavities or collapsed breccia zones in lithified Reeves/Badshot marble. Recently the deposits have been investigated from the point of view of a possible sedimentary exhalative process(Sabin, 1987).

It is probable that the genesis and history of these deposits is not uniform. The Bluebell deposit in particular is distinct in regard to geometry, mineralogy and apparent timing of mineralization.

The other deposits as well show evidence of overprinting events.For example skarn is found below the ore zone at the Jersey mine and talc occurs locally within the ore zone at the H.B. This overprinting (eg. skarn) relates to the intrusion of the Nelson Batholith and is younger than the dolomitization. The relative age of the sulphides and the stocks, however is uncertain according to Fyles and Hewitt(1959).

Sheep Creek Camp

The following summary is adapted from Hardy(1990):

The Sheep Creek Camp straddles the eastern boundary of the Kootenay Arc. The Yellowstone and Queen veins of the Sheep Creek Camp, located about 18 kilometres south of Ymir Creek were staked in 1896 and since that time the camp has produced approximately 28900 kg of gold, 15500 kg silver and modest amounts of silver and zinc. In 1986 the camp was ranked seventh of British Columbia's gold camps in terms of total historic production (Schroeter, 1986).

The productive rocks of the district are a sedimentary series of Lower Cambrian age, overlain unconformably by Triassic(?) volcanic rocks and intruded by intrusive bodies including: granites, quartz monzonites, quartz porphyry sills and dikes and lamprophyre dikes (Matthews,1953; Fyles and Hewlett, 1959). The Lower Cambrian consists of the Quartzite Range Reno and Laib Formations which comprise quartzite, argillite and quartzite, and limestone and argillite.

Gold at Sheep Creek occurred almost exclusively in narrow ore shoots in steeply dipping quartz veins occupying east- to northeast-trending dextral strike-slip faults. The veins cross-cut quartzite, argillite and limestone contained in two northerly trending anticlinal structures. The ore was almost entirely confined to parts of the fault zones in which one or more walls are composed of quartzite. Most of the gold production has been from the Quartzite Range Formation, however a quartzite unit in the Reno Formation is hostrock for extensive mineralization in the Reno vein. Veins extending into the overlying Reno argillite and Laib limestone have been generally barren or too low grade to mine.

Gold occurs as small isolated particles within the veins and is most often associated with sphalerite, pyrite or galena. Significant pyrite is present in the wallrocks and in some areas, particularly the Reno mine, extends for many metres away from any known veins.

Trout Lake Camp

Trout Lake mining camp is in southeastern British Columbia, about midway between Revelstoke and the north end of Kootenay Lake (Fig. 2). The history, general geology, and property descriptions have been summarized by Emmens (1915a), Walker et al. (1929), Fyles and Eastwood (1962), and Read (1973,1975,1976,1977). The following summary is essentially an abridgement of Goldsmith et al. (1986).

Discoveries of lode deposits of silver and gold in the Trout Lake mining camp were made in the early 1890's and sporadic exploration and production have continued to the present. Historically, silver has been the most important commodity economically. Precious-metal vein deposits are contained chiefly in the lower Paleozoic Lardeau Group and to a lesser extent in the Lower Cambrian Badshot Formation. The metavolcanic rocks of the Jowett Formation outline the two most important folds, Finkle Creek synform and Silvercup antiform, which pass through the mining camp. The north-westerly trending structures and stratigraphy result in north-westerly trending belts of mineral deposits.

In the economically important Central mineral belt, past producers lie close to the Cup Creek and Bonanza fault zones, which cut near the crest and on the flanks of Silvercup antiform. The mineral occurrences and past producers are dominantly veins along fault splays located within several hundred metres of their major fault zones. The veins develop in the faulted competent units of the Lardeau Group. Near Incomppleux River, where the northwestern end of Cup Creek fault zone truncates metavolcanic rocks of the Jowett Formation and associated metadiorite, gold-silver deposits occur.

Spider, the largest past producer in the camp, is an intermediate type between the Ag-rich producers to the southeast and the Au-rich past producers to the northwest.

None of the individual lodes of the Ag-rich veins of the Central mineral belt is continuously mineralized (Fyles and Eastwood, 1962). Quartz is the main gangue, but siderite is present. Pyrite, sphalerite, and galena are the most abundant sulphides, although tetrahedrite is widespread and chalcopyrite and pyrrhotite occur locally. Silver grades are in excess of 100 oz/ton in some ore shoots. A generalized paragenetic sequence from oldest to youngest is quartz-carbonate-pyrite-(gold)-sphalerite-tetrahedrite-chalcopyrite-galena. Tetrahedrite and chalcopyrite are locally contemporaneous or reversed in order, and quartz deposition apparently continued intermittently to the final stages of mineralization. The larger production veins commonly attained widths of 1-2 m. and rarely up to 5 m. Veins are sinuous in both plan and section, with substantial thickening and thinning.

At the northern end of the Central mineral belt, the "large" tonnage gold deposits consist of either subparallel principal veins with intervening cross-veins and stringers, or massive veins, which give way to reticulated, quartz-filled fractures in the surrounding phyllite (Emmens, 1915b).

Quartz is the dominant gangue mineral, with minor siderite and sulphides consisting of pyrite, galena, and sphalerite. Visible gold occurs locally, especially along selvedges of the vein or at the margin of wall-rock inclusions.

Based on lead-isotope determinations and the relationship of vein-filled faults to the 76 Ma Trout Lake stock in the South-west mineral belt, the age of mineralization in the Trout Lake camp is probably Late Cretaceous to early Tertiary.

The Trout Lake Camp appears to be part of a large metallogenetic province of Pb-Zn-Ag deposits genetically related to quartz monzonite intrusions of this age (Andrews, 1986).

Trout Lake Molybdenum

The Trout Lake deposit is located in the Selkirk Mountains, 50 km. southeast of Revelstoke, British Columbia, and contains 50 million metric tons of 0.23 percent MoS2 (Boyle and Leitch, 1983). Molybdenum mineralization occurs in a quartz vein stockwork centered on the Trout Lake stock. The bulk of the quartz veins are hosted by metasediments, but the highest molybdenum grades occur in the stock.

The Trout Lake stock is a composite granodiorite-tonalite intrusive body. It occurs in a northwest-trending antiform containing several synclinal and anticlinal structures.

The stock has variably altered the surrounding schists, argillites and marbles of the lower Paleozoic Lardeau Group to hornfelsic biotite schists and skarn. The intrusive is composed of a small stock and an intersecting network of northeast and northwest-trending dykes at surface that coalesce downward into a larger stock. There are two main phases of intrusion. The earlier quartz pophyritic granodiorite is cut by an intra-mineral "quartz diorite" porphyry. A strong sub-vertical north-trending fault controls the distribution of the mineralized stockwork.(Fig. 6).

Molybdenite, as fine to medium flakes and rosettes accompanied by pyrite and pyrrhotite, is mainly present along the margins of veins in a quartz stockwork. Occasionally, in higher-grade zones (in excess of 1% MoS_2), the molybdenite is strongly disseminated in microfractured intrusive bodies up to 20 m wide by 200 m long. These are accompanied by larger (over 10 cm) quartz veins and intense quartz flooding. The quartz vein stockwork is best developed in and around the margins of the intrusive and its dyke-like apophyses. Thus, the major control of molybdenum grades is the location of the schist-intrusive contact.

The principal zoning established is a strong center silica-potassic zone with molybdenite, outward to a quartz-sericite-pyrite (phyllic) zone. Both the central silica high, measured by total % quartz, and the potassic enrichment, measured as a ratio of K-feldspar to plagioclase, correlate well with the best molybdenum grades.

From a geological viewpoint, the Trout Lake deposit is unusual in its location in the Canadian Cordillera, well into the Omineca belt. The granodiorite to quartz diorite composition contrasts with the usual quartz monzonite to granite intrusives found in these systems. As well the Trout Lake deposit does not fit the classical "multiple shell" model in its shape or alteration features. The strong vertical attenuation leads to a sausage or cigar shape rather than a shell.

OMINECA CRYSTALLINE BELT

Slocan Camp

On a regional scale the Slocan Camp is located between the Kootenay Arc to the east and southeast and the Shuswap and Monashee Metamorphic Complexes to the west and nothwest.

The first claims in the area, known as the Payne Group were located by Eli Carpenter and John L. Seaton in 1891. The following year 750 locations were recorded and the area of the Slocan supported the operation of 16 mines. In 1895, the Slocan Mining Camp became the most productive in the province. Peak production occurred in 1918 and has been sporadic since 1929. At present only one mine, the Silvana is active.

Mineral deposits of this camp have been investigated in detail by many geologists and form the basis of comprehensive reports by C.E. Cairnes (1934) and M.S. Hedley (1945, 1952). Fyles (1967) and Little (1960) also provide useful insights into the nature of Slocan mineral deposits in addition to describing mineral deposits in the adjacent camp of Ainsworth-Kaslo. Recent research on the camp includes Logan and Sinclair(1988) and Beaudoin and Sangster (1990)

The camp is underlain by rocks of the Late Triassic Slocan Group which form a huge complex recumbent fold trending northwesterly and open to the southwest. Silver-lead-zinc mineralization in the camp is hosted in calcite, siderite or quartz gangue in simple or complex breccia and vein systems associated with faults. The faults cross-cut deformed argillites, quartzites and limestone of the Slocan Group. Northeasterly strikes and southeasterly dips are prevalent.

Ore deposits vary widely in character. At the Lucky Jim, Whitewater and Cork-Province mines a significant portion of the lead-zinc ore was mined from replacement bodies in limestone beds intersected by veins. Variations in deposit characteristics are complex manifestations of stress related responses incurred by host rocks during major periods of deformation. For example, Fyles(1967) noted that in incompetent rocks folding accompanied movements on the shear zones. Resultant orebodies were localised in the shear zones near the folds.

Field evidence points to deposition of ore minerals during a late stage of folding.

The principal ore minerals are galena and widespread sphalerite. Arsenopyrite, tetrahedrite, chalcopyrite, pyrite, pyrrhotite and ruby silver may or may not be present in varying amounts. Lead, zinc and copper sulphides are generally argentiferous, much less commonly auriferous. Silver content varies widely but may attain 200 oz/ton in coarse grained galena, although a portion of this silver may be accounted for by minor argentiferous copper sulphides.

The general paragenetic sequence of ore deposition is pyrite-sphalerite-tetrahedrite-galena-silver sulphosalts and native silver (Cairnes, 1934). It is generally accepted that the mineralization is the same age as and related to the Middle Jurassic age Nelson Batholith(165 m.y.) (Reynolds and Sinclair, 1971; Andrew et. al, 1984).

According to Logan and Sinclair(1988) fine-grained clastic rocks of the Slocan Group could have been the source for metals in the veins. Metamorphogenic hydrothermal fluids, either generated or modified through additions during contact metamorphism by intrusion of the Nelson batholith, were likely sulphide-rich solutions. Fluid inclusion studies of late-stage minerals (12 deposits) suggest that ore fluids

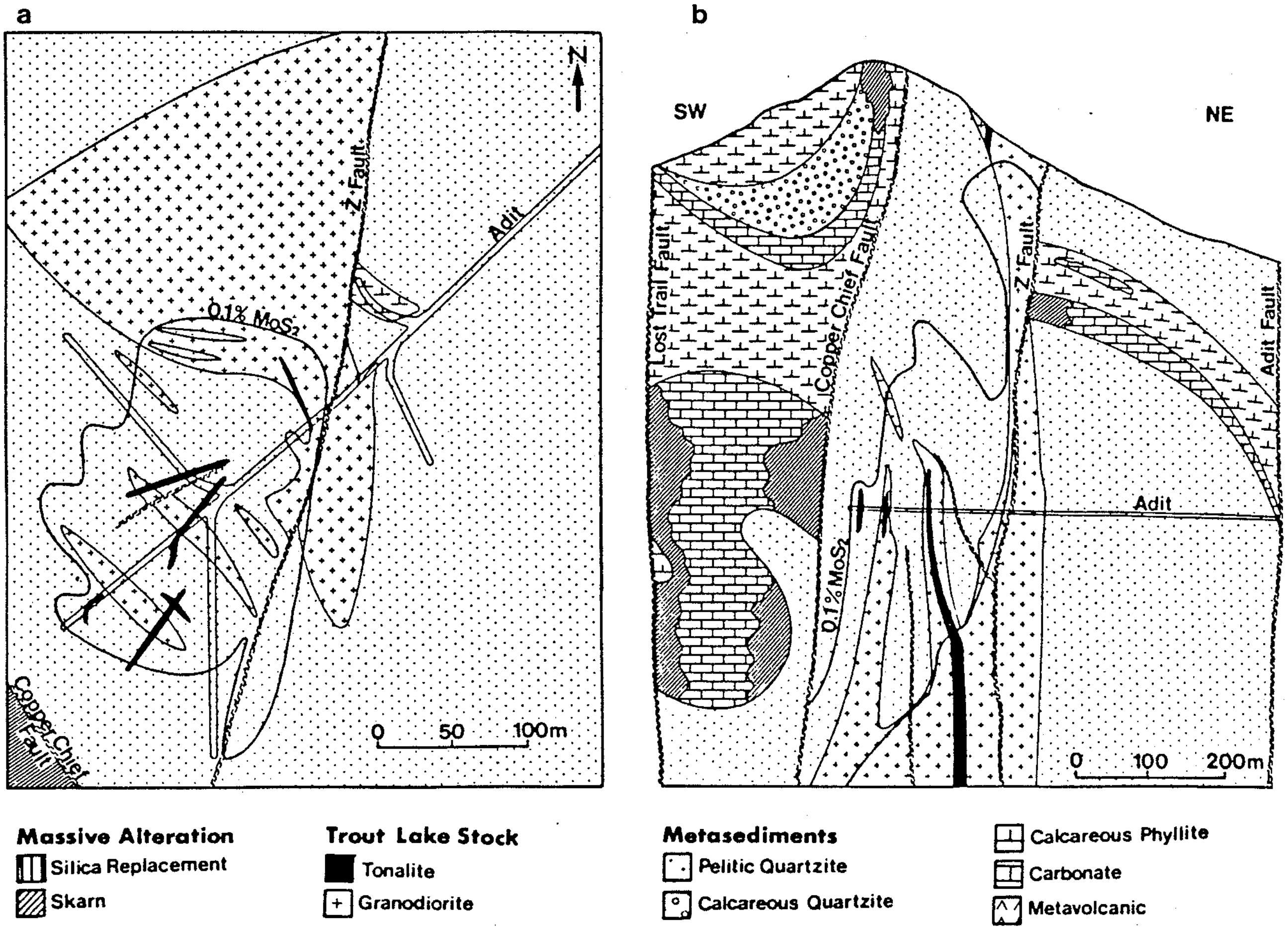


Figure 6 Geology of the Trout Lake deposit. (a) Plan view of the adit level: (b). Vertical cross section through the adit, no vertical exaggeration after Linnen and William-Jones (1987).

were dilute brines (Reinsbakken, 1968).

Silvana

The Silvana mine is located near Sandon, about 10 kilometres east of New Denver. Cumulative production as of June, 1988 was 376,750 tonnes of ore from which 194 million grams of silver (514.7 g/t), 21.7 million kilograms of lead (5.8% Pb), and 19.3 million kilograms of zinc (5.1% Zn) were recovered.

The Silvana mine orebodies occur in a "lode fault". This obscure, sinuous, shallow to steeply dipping fault can be interpreted over a 7 mile strike length between Silverton Creek on its west end and Sandon on its east. A lode was defined by Cairnes(1934) to mean any single body of fractured ground in which an ore-bearing vein or veins may occur. At Silvana lode structure thickness varies from a few inches to a few tens of feet and the fault itself may show braiding or multiple-stranding. Rocks within the lodes are mostly breccias cut by graphitic shears. Silicification of lode rocks is a pre-graphitization event. This alteration often also appears in adjacent rocks, principally the hangingwall, and occurs with a more or less similar distribution to the mineralization.

The ore mineralization occurs as veins, lenses, pods, shreds, breccia infillings etc. Most ore occurrence boundaries show shearing and/or slickensiding. En echelon lenses and pods show tectonic boundaries. Much of the galena mineralization shows the presence of a folded, gneissic, foliated texture. These are the principal reasons for postulating considerable redistribution of previously-existing, largely vein-type mineralization. The shearing of principally argentiferous galena also appears to have led to some redeposition of silver as ruby silver on slickensides.

Intrusive rocks are entirely pre-lode. They consist mostly of biotite-rich diorites and biotite/feldspar porphyries which widen down to the lowest mine level. The latest tectonic disruptions occur as clay-gouge-filled normal faults that slice through or drag the lodes and any contained ore.

Nelson Camp

In 1886 the Hall brothers staked the Silver King Group at Toad Mt. and with the establishment of a smelter in 1895 the city of Nelson was born

The larger known deposits in this camp are polymetallic (Ag-Au-Cu-Pb-Zn) veins. Vein deposits are widely distributed throughout the Elise and Archibald Formations, the Ymir Group and Nelson granitic rocks. Characteristically they occur near the contacts of granodiorite intrusives and sheared fragments of granodiorite are evident in some of the veins. Copper is a significant component of some vein deposits and is absent in others. Hoy and Andrew(1989) note that in the area vein mineralogy appears to have a lithologic control. They found that veins which carry lead and zinc in addition to gold and silver are preferentially distributed in metasedimentary rocks of the Ymir Group or correlative Archibald Formation and within or adjacent to Nelson granitic rocks. Copper-gold-bearing veins are more common in Elise volcanic rocks.

The Silver King deposit is underlain by highly schistose volcanics of the Lower Elise Formation which are intruded nearby by the coeval and subvolcanic Silver King porphyry. Mineralization is confined to three major shear controlled vein systems parallel to the regional schistosity. A gangue of quartz with some carbonate and siderite hosts pyrite, chalcopyrite, and galena with minor amounts of sphalerite, bornite, tetrahedrite, malachite, and azurite. The main silver mineral is "stromeyerite".

The mineralization at the Yankee Girl and Ymir mines was also in shear veins but cutting Triassic or older Ymir Group argillites. It comprised pyrite, galena and sphalerite with some values in gold and silver. A number of narrow quartz veins cutting Nelson granodiorite was mined mainly for gold with silver at the Granite-Poormann. Veins at the Second Relief carried pyrite, pyrrhotite, chalcopyrite and minor molybdenite. Skarn minerals in the country rock include coarse-grained garnet, epidote, biotite , quartz and magnetite. The deposit has recently been viewed as a gold skarn.

Rossland Camp

Large deposits in the Rossland camp comprise:

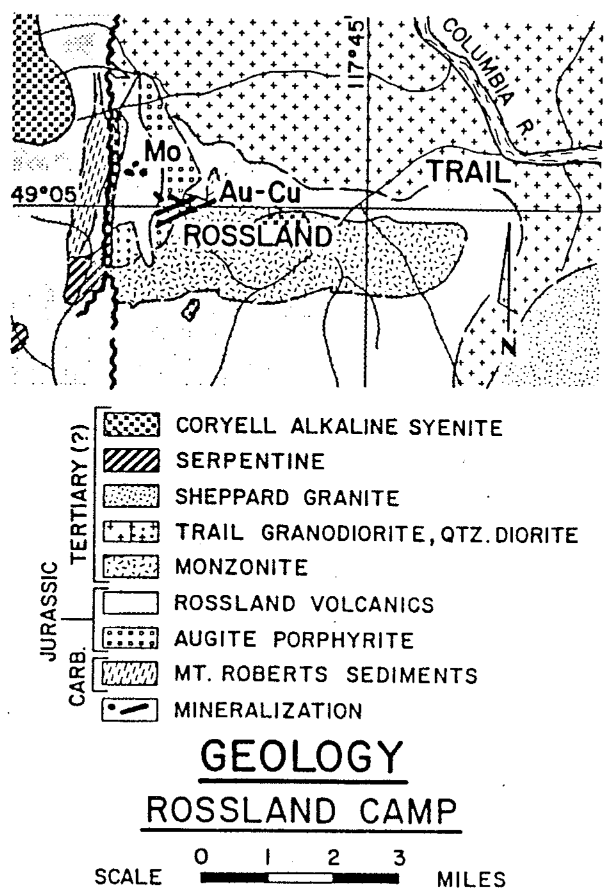
(1) copper-gold veins with minor lead and zinc

(2) porphyry molybdenum

The large deposits occur in the small area of Red Mountain on the outskirts of the present town of Rossland. The first claims were staked in 1887 on the copper-gold veins and production commenced in 1894. Cominco originated here as a copper producer and constructed the Trail smelter which later was to handle most of the lead-zinc ore from the Sullivan deposit. Total output until production ceased in 1941 was 2.7 million ounces of gold from 6200000 tons milled, with a recovered grade of 0.47 oz. gold per ton, 0.6 oz. silver per ton and 1 per cent copper.

Barr(1980) provides an excellent overview of the camp in relation to other gold camps in the cordillera. Recent reviews of the camp include Fyles(1984). The summary below is drawn from both sources.

The Rossland Camp in general lies within an area in which plutons and dykes intrude a sequence of Late Paleozoic and Lower jurassic volcanic and sedimentary rocks which strike northerly and dip to the west (Fig. 7). The Jurassic Rossland Group comprises mainly intercalated andesitic volcanic breccia, lapilli tuff, augite porphyrite, volcanic sandstones and conglomerate, and lenses of siltstone. The Carboniferous Mount Roberts Formation consists of several hundred feet of siltstone, sandstone, conglomerate, and minor limestone. These rocks are metamorphosed to a variable degree and intruded by three principal plutons: the Rossland Stock, the Trail Batholith and the Coryell Stocks, and by a large number



AFTER GILBERT 1948, & B.C. DEPT OF LANDS & FORESTS. PROJ. 229, JUNE 1970

FIGURE 7 Geology of the Rossland Camp.

after Barr (1980)

of diorite, lamprophyre and syenite dykes, as shown in the more detailed geologic plan of the mine area (Fig 8).

Copper-Gold Veins

Early development on the copper-gold veins of Red Mt. recognized three main groups of veins of which the main group represented 98% of production. The core of the main group lies on Red Mountain in an area of 2000 by 4000 feet and exploited in 4 interconnected mines (Le Roi,Centre Star,War Eagle,Josie). The Le Roi vein was mined almost continuosly for one kilometre.

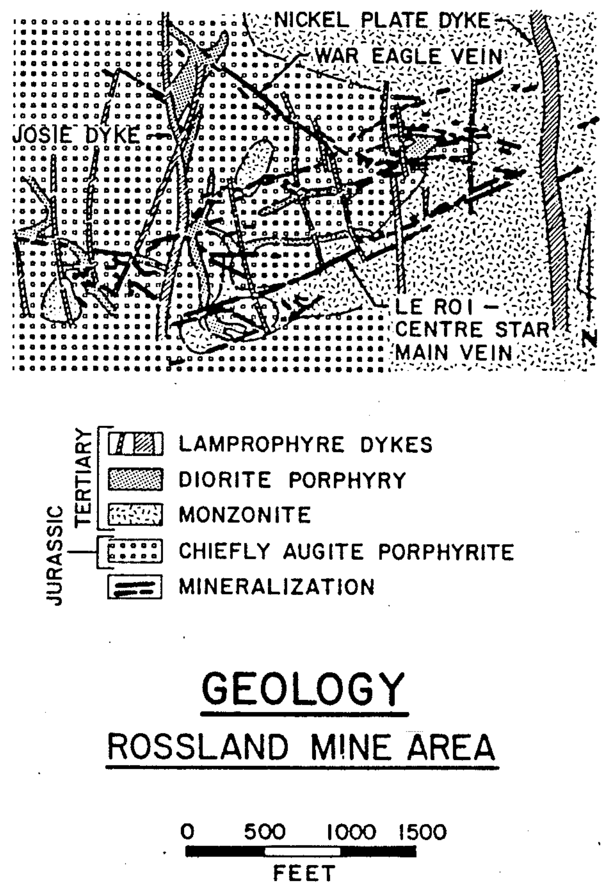


FIGURE 8 Geology of the Rossland mine area.

The principal veins are located on the northwest border of the Rossland monzonite in northeast and southwest trending fracture systems. The pattern of veins and mineralized fractures suggests that one period of fracturing developed by east-west compressive stresses resulting in shear failures in the 115 and 065 degree directions and tension fracture in the 90 degree direction. The veins are hosted both by Jurassic Rossland Group augite porphyries and the Rossland monzonite.The western margin is highly irregular and seems to consist of east dipping tongue-like protrusions with sharp to gradational contacts. Ore shoots in the veins commonly (but not exclusively) terminated against northerly trending lamprophyre dikes of Tertiary age. The Trail batholith lies to the north of the camp but dips to the south and underlies the mine workings at depth.

Ore minerals in the veins total 50-70 per cent by volume in a gangue of quartz, calcite and altered wall-rock. The minerals consist of native gold, pyrrhotite, chalcopyrite, minor pyrite and other sulphides. Rosettes of actinolite and crystals of garnet are associated with pyrrhotite and chalcopyrite.

The veins vary from a few inches to over 130 feet in width and extend for 4000 feet or more in length. Individual ore shoots tended to be short and narrow, the greatest dimension being down-dip. Most veins are made up of a series of shoots which are en echelon in strike and dip. In general gold values correlate with copper grade.

A genetic relationship of mineralization to the intrusive bodies is suspected. The Trail Batholith is mid to late Jurassic and predates Rossland monzonite. Any mineralization associated with these intrusions would then seem to be demonstrably pre-Tertiary. However, cross-cutting mineralization indicates that at least part of the copper-gold mineralization is later than the Tertiary dikes.

Porphyry Molybdenum

The Rossland area principal molybdenum deposits on Red Mountain were known from the early days of the camp when copper and gold were being mined nearby. The principal deposit, the Coxey Mine, lies within Lower Jurassic Rossland Group hornfelsed siltstone and breccia complex. The hornfels and hornfelsic siltstones are thinly laminated and massive, hard cherty rocks which locally contain brown garnet and epidote. The siltstone is intruded by lenticular masses of andesite, irregular bodies of quartz diorite and quartz diorite breccia, and late steeply dipping dykes which trend northward. The quartz diorite is assumed to be part of the Tertiary-Cretaceous Trail Pluton.

The molybdenum mineralization occurs essentially within the Rossland Group breccia complex. The hornfels and hornfelsic siltstone comprises a breccia with angular blocks ranging up to 30 metres across. The matrix between the blocks is comprised of fine silicates, quartz, calcite, garnet or scheelite. Molybdenite, usually without other sulphides, occurs in randomly oriented fractures in all types of hornfels breccia and in the quartz diorite breccia. Commonly, it lies along the margins of breccia blocks and locally is concentrated at junctions between the blocks. These junctions may also contain rare drusy quartz, scheelite, hornblende or epidote. Pyrrhotite, chalcopyrite and pyrite are disseminated in the hornfels, occur in fractures and as massive lenses between breccia fragments. The sulphide distribution seems independent of the distribution of molybdenite.

Production figures indicate that almost a million tonnes with an average grade of about 0.2 per cent was milled.Substantial reserves remain.

According to Fyles(1984) the high concentrations of molybdenite in the highly fractured hornfels breccia near feldspathized fracture zones and quartz dykes suggests a porphyry type of mineralization.

Greenwood Camp

Most of the mineral production in the Greenwood camp has come from copper-bearing skarns. Lode mineralization was first recorded in the Greenwood area near Boundary Falls in 1884 and in 1891 the future of the camp was firmly established when William McCormack and D. Thompson staked the Mother Lode mine, a copper skarn. By 1900 most of the major deposits had been found and a major smelter was constructed at Grand Forks. Production from the mines at Phoenix peaked in 1913. It was not until 1957 and 1959 when an increase in copper prices combined with new mining technology resulted in large scale open-pit production from the Motherlode and Phoenix orebodies. A total of 31,788,743 tonnes of ore has been produced from skarn rocks of the Phoenix, Oro Denoro, Motherlode, Greyhound and Marshall mines. This has yielded 35,976 kilograms of gold, 117,216 kilograms of silver, and 269,604 tonnes of copper. This mining camp ranks in the category of a significant world producer. The Greenwood camp ranks 6th in B.C. gold production mostly from the Phoenix mine as a byproduct of copper mining. The metallogeny of the camp was most recently reviewed by Church(1986) and is presented in Figure 9.

The area is underlain by a variety of sedimentary, volcanic, and metamorphic rocks and igneous intrusions of Paleozoic, Mesozoic, and Tertiary ages. Mineralization in the Triassic age Brooklyn Group is the source of most of the ore produced from the Greenwood area. The Brooklyn Group consists basically of sharpstone conglomerate, limestone, and volcanics. The target for mineral exploration is commonly the Brooklyn limestone, although the sharpstone conglomerate and associated argillites have also undergone some local skarnification.

The Oro Denoro mine presents a classical model for skarnification which sheds light on ore emplacement in other skarn deposits of the area which are not in direct contact with any significant igneous body. The geology of the Oro Denoro mine is relatively straightforward. Mineralization consists of pockets of pyrite, chalcopyrite, and magnetite in a garnetite skarn. This skarn is mostly a replacement of limestone caused by intrusion of the Lion Creek granodiorite, which is the most easterly lobe of the Wallace Creek pluton. It is argued that since other orebodies in the area have similar mineralization, they probably formed at the same time with the Jura-Cretaceous stocks being the source for the ore-forming fluids.

Chalcopyrite is the most abundant ore mineral in all the deposits. Other metallic and sub-metallic minerals are pyrite, specular hematite, and magnetite; non-metallic minerals are epidote, carbonate, amphibole, chlorite, quartz, garnet, pyroxene, and earthy hematite. Bedding, indicated by bands with varying concentrations of the above minerals, is well preserved locally in most of the deposits. The relative percentage of the minerals listed above varies considerably along strike and down dip in each deposit. Some of the minerals are far more abundant in some deposits than in others. Almost all the deposits, particularly those which are more flat-lying, have a hanging-wall of skarn as much as 200 feet thick. Chalcopyrite mineralization is most abundant in the carbonate-rich bands and in narrow carbonate veinlets traversing the banding.

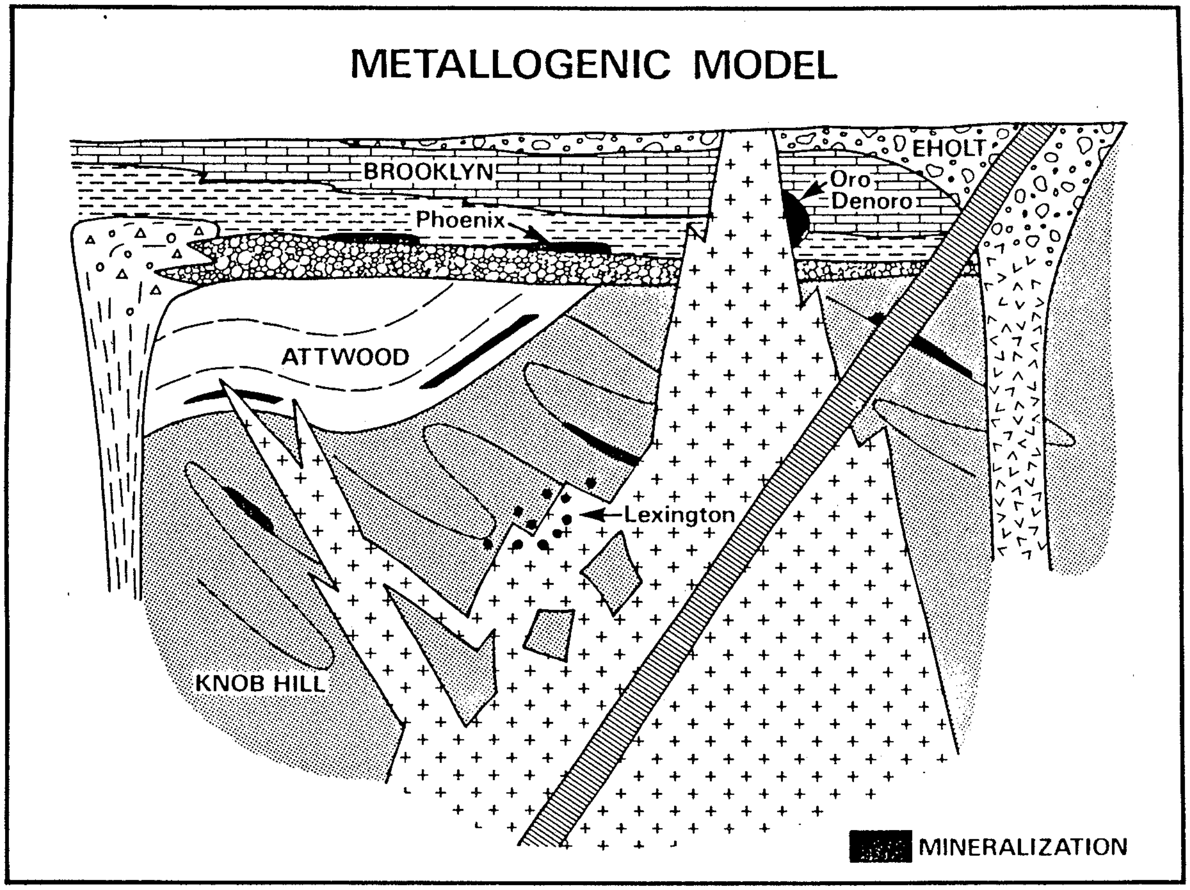


Figure 9 Metallogenic model for the Greenwood area (after Church, 1986).

IGNEOUS INTRUSIONS (GREENWOOD AND WALLACE CR. GRANODIORITE)

TRIASSIC

BROOKLYN GROUP

EHOLT FORMATION: VOLCANISTICS

LIMESTONE AND INTERCALATED ARGILLITE

SHARPSTONE CONGLOMERATE, SANDSTONE, SHALE

PERMO-CARBONIFEROUS

ATTWOOD GROUP

MAINLY ARGILLITE WITH LIMESTONE, CHERT PEBBLE CONGLOMERATE AND METAVOLCANICS (GREENSTONE)

BASEMENT COMPLEX

KNOB HILL GROUP

METACHERT AND MICA SCHIST, AMPHIBOLITE, MARBLE

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Chapter 3: THE SULLIVAN OREBODY[1]

T. Hoy, N.Berg, G.D. Delaney, J.T. Fyles, D. McMurdo and P.W. Ransom

INTRODUCTION

The Sullivan sulphide orebody, hosted by the Middle Proterozoic Aldridge Formation, is estimated to have originally contained 160,000,000 tonnes of 6% lead, 6% zinc, 28% iron and 67 gm per tonne silver. The ore-body overlies a feeder system, represented by a zone of fragmental rocks, boron alteration, and sulphide-rich veins. The feeder system formed as result of penecontemporaneous tectonic disturbance and submarine hydrothermal activity within an otherwise stable sedimentary environment. Pyrite-chlorite alteration of ore and albite-chlorite-pyrite alteration of hanging wall rocks indicate hydrothermal activity continued subsequent to deposition of sulphides.

GEOLOGICAL SETTING (Fig. 2)

The Aldridge Formation in the Purcell mountains is divided into Lower, Middle and Upper. The Lower Aldridge comprises at least 1500 m of rhythmically graded thin- to medium-bedded very fine grained wacke. The Middle Aldridge contains 2000 m of medium to thick-bedded wacke and quartzitic wacke. Most of these rocks were deposited as turbidites. The Upper Aldridge consists of 300 m of thin-bedded to laminated argillite. The Aldridge Formation has been metamorphosed to lower and middle greenschist facies. It has been folded into generally broad, open north-plunging folds of the Purcell Anticlinorium. The Sullivan orebody lies conformably at the top of the Lower Aldridge on the east side of the Purcell Anticlinorium (Fig. 1).

The Moyie gabbroic intrusions total up to 700 m of thickness in the Lower Aldridge and up to 400 m in the Middle Aldridge. Some gabbro bodies are coarse-grained and thick, indicating intrusion at substantial depths; others are chilled and erratic in a manner that suggests intrusion into wet sediment (Hoy, 1984a).

Zircons from differentiates of a sill near the top of the Lower Aldridge have uranium-lead ages of 1433±10 Ma (Zartman et al., 1982). LeCouteur (1973) determined lead isotope ages of 1200 to 1400 Ma on galena from the Sullivan orebody; Godwin (1982) subsequently reinterpreted this data and obtained an age of 1490 Ma. Biotite in the zone of associated hanging wall alteration has a K/Ar age of 1436 Ma (LeCouteur, 1979).

PRE-ORE FEATURES

Bedded Sediments

The interval of Lower Aldridge sediments immediately underlying the orebody consists of 150 m of thin and medium-bedded, very fine grained wacke. The main mineral constituents are quartz, sericite, biotite, pyrrhotite and minor carbonate. Near the top these rocks are interbedded with pyrrhotite laminated wacke.

Fragmentals

Bodies of discordant and conformable fragmental sedimentary rocks underlie much of the orebody and extend several kilometres south. Where unaltered, composition of matrix and clasts of the fragmentals is indistinguishable from enclosing Lower Aldridge strata.

Isolated near-vertical discordant fragmental bodies up to several metres wide and transecting several tens of metres of strata have been mapped adjacent to a major and central fragmental complex that is almost 1 km wide and cuts in excess of 100 m of strata under the central part of the orebody (Figs. 3 and 4; Delaney and Hauser, 1983). Clasts in these

[1] modified from Hoy et al., 1985

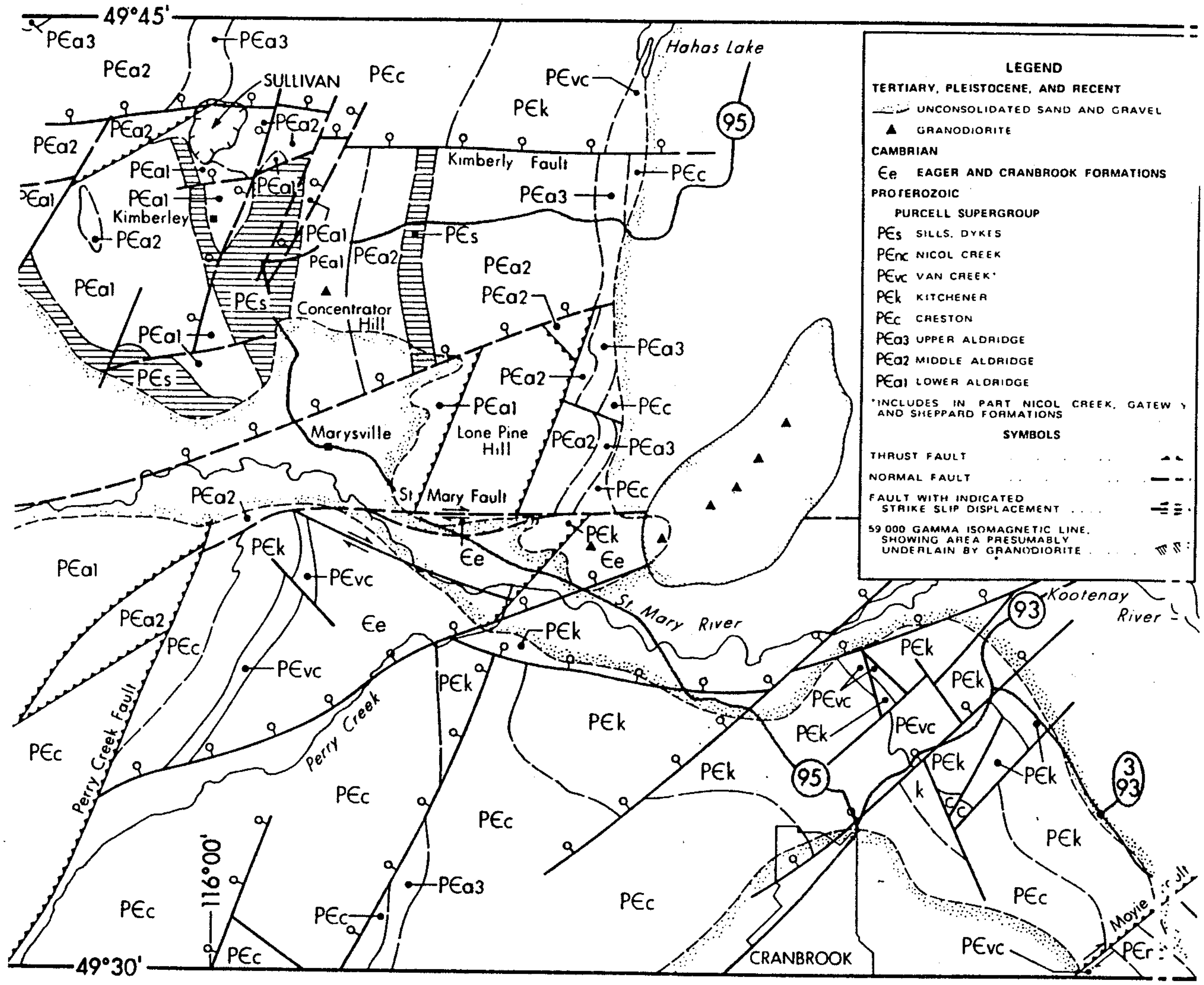

Figure 1 Geological map of the Kimberley area, showing excursion route.

fragmentals are sand- to cobble-size and are angular to rounded. Where discordant fragmental bodies have coalesced, blocks of bedded sediment up to 10 m across have been incorporated. Bodies of these large blocks have been named chaotic breccia (Jardine, 1966). Most chaotic breccia is found in north-trending zones up to 150 m wide and 1000 m long (Fig. 4).

The central discordant fragmental merges into a conformable body (conglomerate) that underlies most of the eastern part of the orebody. From a maximum thickness of about 50 m the conformable fragmental tapers to the east where it averages 15 m (Fig. 5). In the central area it is separated from ore by up to 12 m of laminated wacke; to the east the overlying wacke thins out and ore rests on the fragmental. Clasts in this fragmental are sand to cobble-size and are typically pebble-size; most are rounded to subrounded.

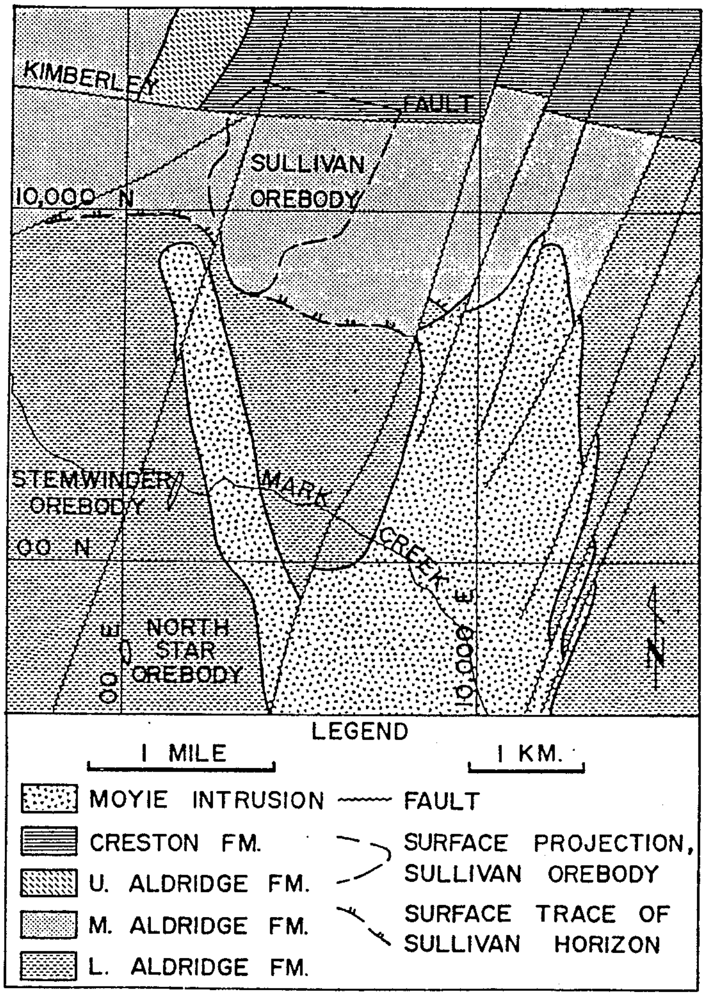

Figure 2 General geology in the vicinity of the Sullivan orebody.

The discordant fragmentals are interpreted to have resulted from localized release of pore overpressure within the sedimentary pile. Once initiated, the release of hydraulic pressure was probably rapid and violent. As ascending turbulent fluids stoped through the sedimentary pile fragments of sediment were incorporated and abraded. The resulting slurry was expelled through discharge centres onto the sea floor and accumulated as a mound that ultimately slumped toward the east. The conspicuous, generally north-south alignment of chaotic breccias, which flank the dislocation zones reflect prevailing tectonic forces acting within the basin of deposition. As material was withdrawn from depth a depression developed, possibly in conjunction with larger downwarp of this part of the basin to form a sub-basin. The lower parts of the irregular topography were filled by bedded sediment prior to the onset of ore deposition. The discharge pipes became the conduits for upwelling hydrothermal solutions. Fragmentals are evidence that substantial cross-strata permeability developed prior to deposition of sulphides.

Pre-ore Alteration

The western half of the orebody is underlain by a funnel-shaped zone of tourmalinite that extends at least 450 m below the sulphide footwall (Figs. 3 and 4); within this zone, matrix and clasts of discordant fragmentals are intensely tourmalinized.

Although rare, tourmalinite clasts are present within the concordant fragmental at sites remote from the discharge centre. Boron-rich lenses have been recognized in sediments adjacent to the tourmalinite 'funnel' as much as 50 m below the sulphide footwall (Shaw and Hodgson, 1980). In hand specimen tourmalinite resembles black or dark brown chert. Most tourmalinite appears to have resulted from the addition of boron to unlithified sediments, however Shaw and Hodgson have cited synsedimentary deposition of boron-rich muds (op. cit.). Recent oxygen isotope data (Nesbitt et al., 1984) is interpreted to indicate that tourmalinite was formed by low temperature (<100°C) solutions.

Extensive tourmalinization of the discordant fragmentals and proximal footwall strata show that large volumes of hydrothermal fluids rich in boron passed through the discharge pipes prior to sulphide deposition. The presence of tourmalinite in clasts in the concordant fragmental is convincing evidence that the tourmalinization process was active before completion of fragmental formation. Synsedimentary tourmalinite lenses in footwall strata suggest the combined tourmalinization fragmental development process was prolonged.

SULPHIDE DEPOSITS

The principal sulphide deposit is a stratiform upwardly convex lens and subordinate bands covering an area 1.6 x 2.0 km composed almost entirely of pyrrhotite, sphalerite, galena and lesser pyrite. Associated silver is economically important. Trace metals include Mn, As, Cu, Sn, W, Sb, Cd, Bi, In, Tl, and Hg, some of which are recovered commercially. The

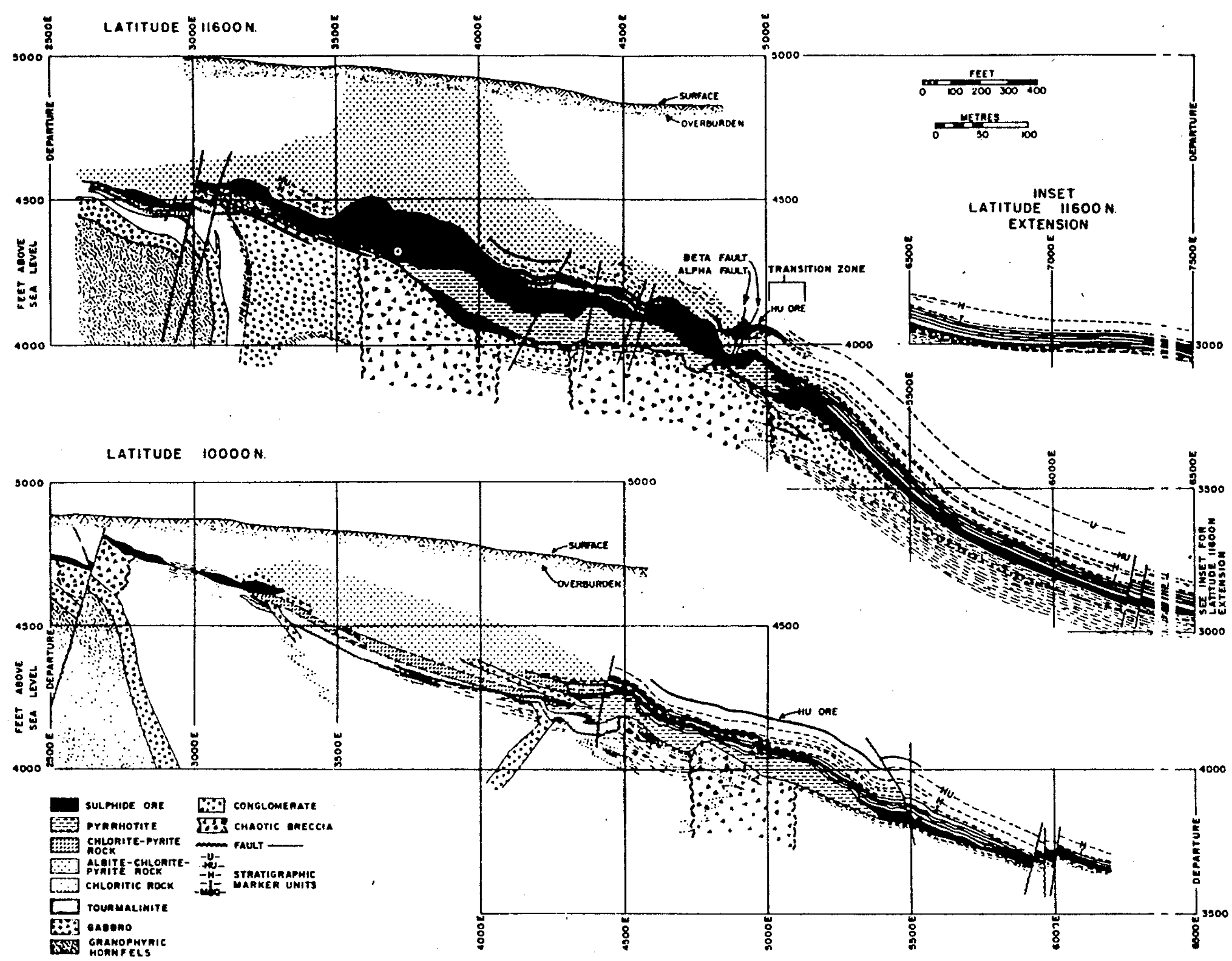

Figure 3 East-west vertical sections through the Sullivan orebody.

orebody overlies a system of sulphide veins and is in sharp conformable contact with adjacent clastic sediments. It is truncated on the north by the Kimberley Fault.

The sulphide deposits are conveniently described in three parts; footwall sulphide veins, a thicker western zone of continuous sulphides that are either massive or internally banded, and an eastern zone of bedded sulphides and intercalated clastic sediments.

Veins

A system of north-trending sulphide veins is

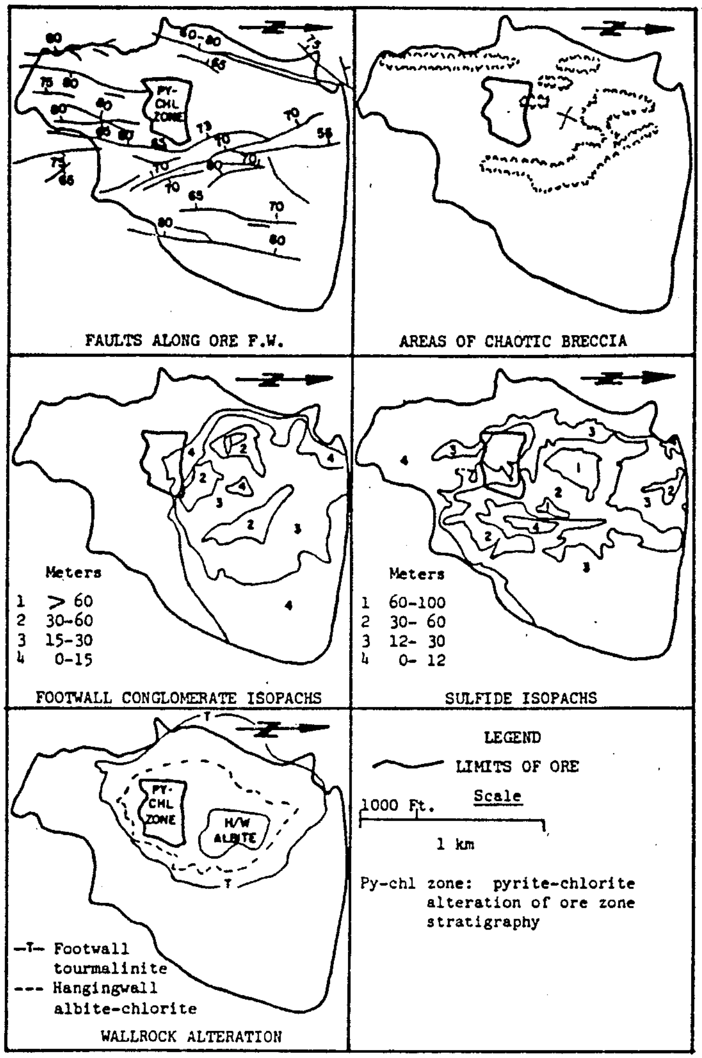

Figure 4 Faults, breccia distribution, conglomerate and sulphide isopachs, and wallrock alteration, Sullivan orebody.

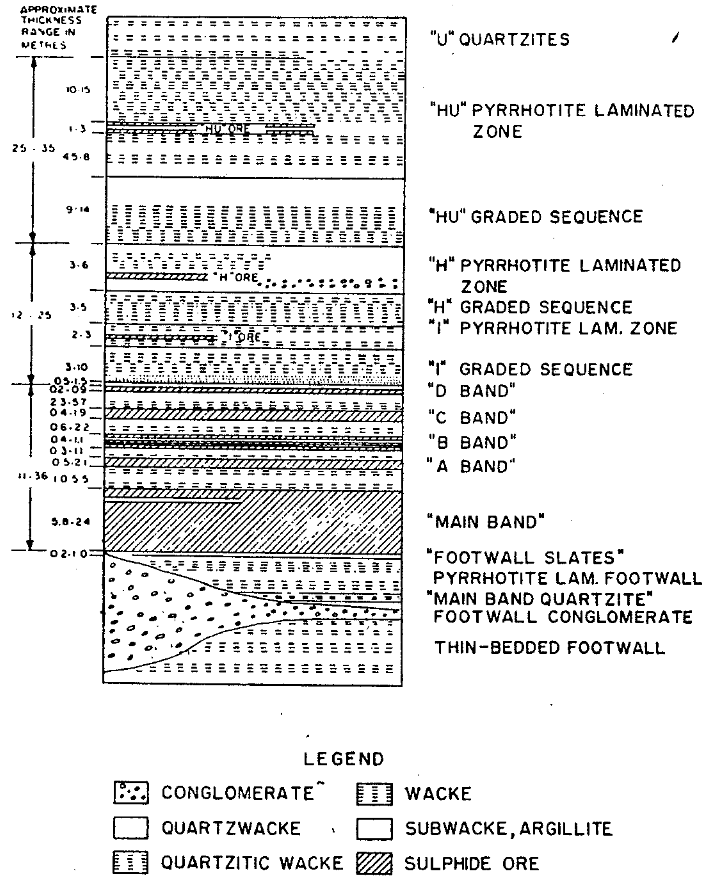

Figure 5 Ideal geological column

associated with the discordant fragmentals and tourmalinite beneath the orebody. Massive veins are less than 1 m wide but sulphide stringer zones occur which are several tens of metres wide. Both inter- and intra-clast sulphide impregnations occur within the fragmentals. The veins typically contain pyrrhotite, galena and sphalerite. Some veins contain quartz, arsenopyrite, chalcopyrite, cassiterite, tourmaline or scheelite. The network of veins is persuasive evidence of an underlying feeder system to the Sullivan orebody.

Western Part of the Orebody

The thicker western part of the Sullivan orebody overlies the discordant fragmentals, tourmalinite and sulphide veins. Its average thickness is 50 m; the range in thickness is 10 to 100 m (Fig. 4). In general it is about twice as thick as the eastern ore zone. In the northern part the lower two-thirds of the sulphide mass is a subeconomic pyrrhotite lens up to 35 m thick and 350 m long that contains sphalerite and galena disseminations, fracture fillings and veins. The pyrrhotite grades upward and laterally into ore of massive pyrrhotite containing laterally discontinuous layers of galena and sphalerite. This is overlain by higher grade ore of well banded galena, sphalerite and pyrrhotite with clastic interbeds. In some locations massive galena is up to 10 m thick. Much of the uppermost western ore is extremely deformed.

Sulphide veins within the pyrrhotite lens indicate an extension of the discordant footwall feeder structures through initial stages of mineralization. The thick section of internally homogeneous sulphides containing only a minor clastic component is indicative of rapid accumulation which may have been sufficient to create a sulphide mound over the vent. Some pyrrhotite has transgressed well-laminated galena and sphalerite; Shaw and Hodgson (1980) proposed that formation of the pyrrhotite lens was by replacement of lead-zinc sulphides by pyrrhotite.

Layering of sulphides and the presence of intercalated clastic beds near the top of the western part of the ore zone indicate a relatively reduced rate of sulphide deposition.

A transition zone between the western and eastern ores overlies the eastern margin of the footwall tourmalinite (Fig. 3). This zone is up to 75 m wide and is characterized by a thinning of the ore and by complex folding of bedded sulphides.

Eastern Part of the Orebody

The eastern ore sequence averages about 30 m in thickness (Fig. 4) and consists of five laterally persistent bedded sulphide units ("Bands") in sharp contact with interbedded wacke (Fig. 3). From base to top the sulphide bands are named "Main Band", "A", "B", "C", and "D Bands". A stratigraphic section through this sequence is shown on Figure 5. The basal one-half to two-thirds of the "Main Band" is a succession of fine grained pyrrhotite, sphalerite and galena in beds in which one of the minerals is predominant. The beds are generally less than 3 cm thick but may be as thick as 30 cm.

The upper portion of the "Main Band" and the overlying bands have up to 15% interbedded wacke. Individual sulphide layers are thin beds or laminae and almost monomineralic. Laterally persistent intervals up to 20 cm thick of nearly monomineralic lamellae .3 to 10 mm thick are common in the eastern ore zone. One or two thick graded, turbiditic wacke beds separate each of the five ore "Bands" and make up to 25 to 40% of the eastern ore section or about 60% of that part of the interval above the "Main Band".

Eastern ore is believed to represent distal accumulations of metallic sulphides derived from a brine cell which spread from the central feeder. Delicate and laterally extensive monomineralic bands of galena, sphalerite and pyrrhotite are indicative of rhythmic precipitation caused by minor changes in physical-chemical conditions within the inferred brine cell. Composition of the brine fluctuated both as individual sulphides were precipitated and as metals continued to be replenished through the feeder system. The basal part of the "Main Band" most likely postdates the early rapid accumulation of sulphides over the vent area.

Metal Distribution

The zonal distributions of Pb, Zn, Ag,and Sn are shown in Figure 6. The distributions show concentration of these metals and the highest ratios of silver to lead and lead to zinc are central to the western part of the orebody. Vertical metal distribution in the western part of the orebody trends toward increasing Pb and Zn and decreasing Fe up-section. In contrast, vertical metal variations through portions of the Eastern ore sequence show a general decrease in lead, zinc and silver and relative enrichment in iron up-section (Fig. 7; Hamilton et al., 1983).

The concentricity of metal distributions and, coincidence of metal concentration over footwall features described in this paper support the hypothesis of a central feeder system. Theories of evolution of the metalliferous brine and of physical-chemical conditions in the inferred brine cell are complicated by contrasting vertical trends of mineralization. These phenomena themselves may be indicative of distinct physical-chemical conditions in the brine cell or the mode of origin of the basal pyrrhotite.

POST-ORE FEATURES

Stratigraphy

Three distinct stratigraphic intervals, I, H, and Hu conformably overlie the eastern ore and parts of the western ore. The base of each interval is a very thick (1 to 5 m) bed that grades from quartzitic wacke to argillite. The top of each interval is 2 to 6 m of argillite characterized by disseminations and thin laminae of pyrrhotite. Distinctive pyrrhotite-laminations have been matched (Freeze, 1966) over distances of 1000 m. Up dip and to the south pyrrhotite laminae pass into ore grade material.

Beneath the H sulphide laminae is the Hanging Wall Conglomerate which has an average thickness of 4 m and has been traced about 1000 m along the southern margin of the orebody. In contrast to

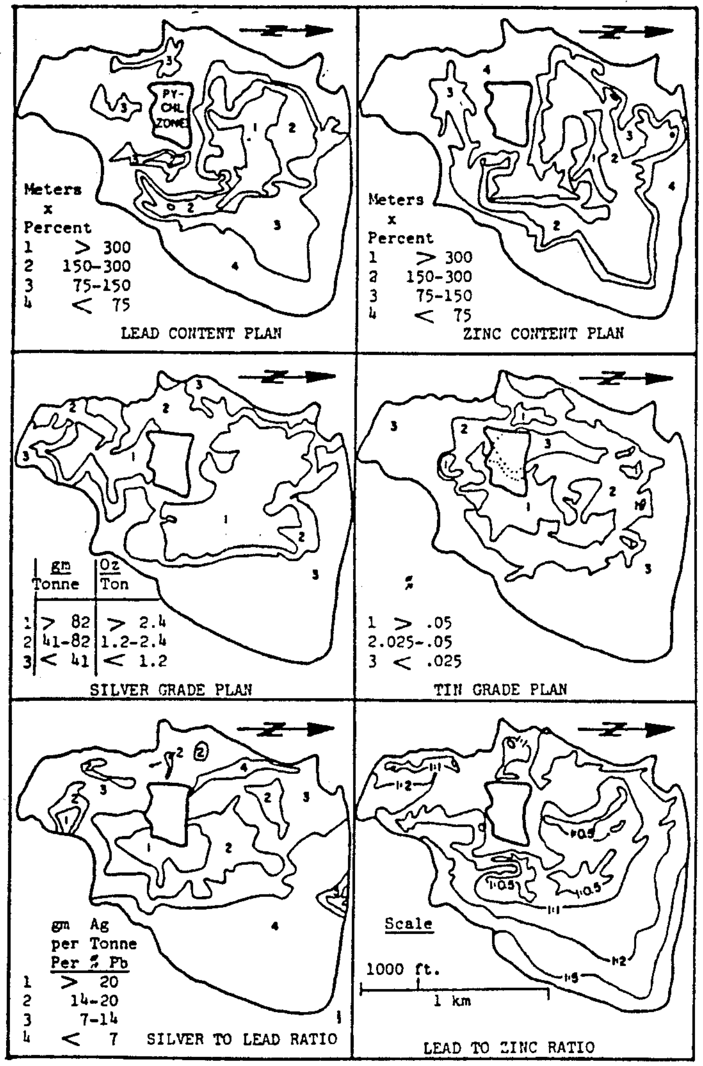

Figure 6 Metal distribution maps, Sullivan orebody.

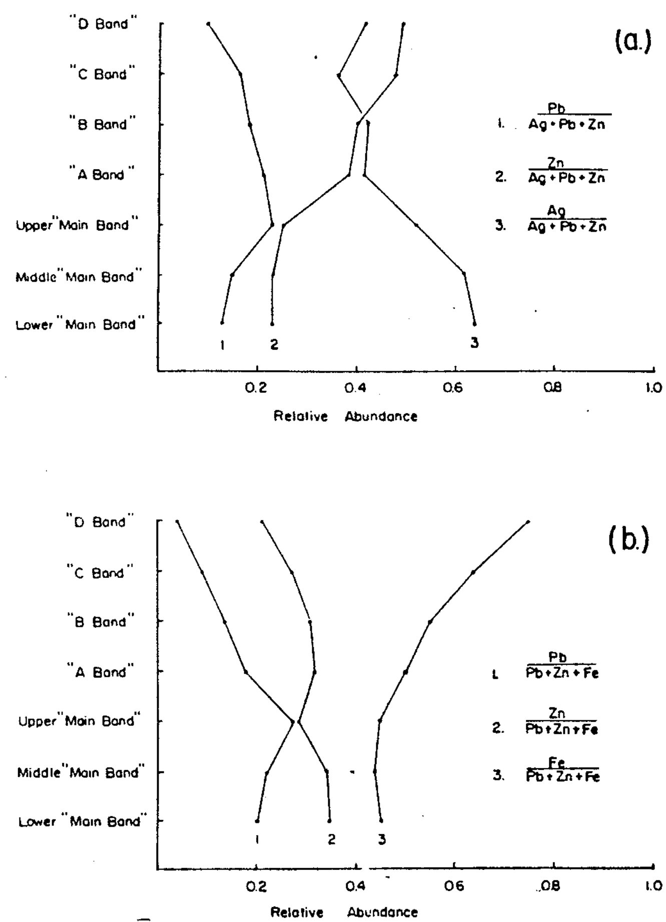

Figure 7 Vertical metal variations, eastern part of the orebody.

fragmental rocks in the footwall, it contains some ore grade clasts.

The Hanging Wall Conglomerate overlies a north-trending discordant fragmental that crosscuts the southwest part of the orebody to this stratum. Where the Hanging Wall conglomerate is absent, up to 2 m of strata at this horizon appear to have been subjected to soft sediment deformation. The Hu stratigraphic interval is overlain by the U Quartzites which are regarded as the base of the Middle Aldridge (Fig. 5).

Post-ore Alteration

Chlorite alteration is found along the eastern margin of the footwall tourmalinite zone. Below the centre of the orebody chlorite also occurs both in crosscutting zones of large vertical extent and in a conformable layer up to 10 m thick which is in contact with sulphides. Albite veins are present in the vertical zones of chlorite alteration.

The western ore sequence is cut by a cylindrical zone of pyrite-chlorite-calcite alteration approximately 350 by 250 m across that overlies albite-chlorite alteration in the footwall. In the core of this zone pyrrhotite is almost completely replaced by pyrite; galena and sphalerite are essentially absent. Enveloping the core is an outer shell in which replacement of pyrrhotite by pyrite is incomplete and some sphalerite and galena remain. Chlorite and calcite are present throughout the entire zone (Shaw and Hodgson, 1980).

Hanging wall rocks above the western portion of the orebody are altered to an albite-chlorite-pyrite assemblage as much as 125 m thick (Fig. 4). Massive albitite grades outward into albitic and chloritic rock in which original sedimentary layering is preserved. The albitite core is 225 m northeast of the pyrite-chlorite-calcite alteration assemblage of the ore zone. That this relationship represents a decollement is supported by displacements on gabbro dykes.

The coincidence of all footwall alteration features, both pre- and post-ore together with sulphide veins, indicate continued use of a footwall hydrothermal feeder system. The hanging wall alteration represents the extended development of this system and the final phase of hydrothermal activity which continued beyond deposition of sulphides.

Moyie Intrusions

Beneath eastern ore and also to the immediate west of the orebody, broadly conformable Moyie gabbro intrusions are present 450 m below the ore horizon. These intrusions comprise a 60 m thick basal gabbro and a 15 m thick upper gabbro, separated by 90 m of recrystallized sediment. Below the western side of the orebody the gabbro units abruptly transgress the footwall sequence and form a 1 km wide north plunging arch, the crest of which is in direct contact with western ore. Apophyses of gabbro transect the orebody as small dykes. Regional field observations and age dating show some of the Moyie intrusions were being emplaced in the Aldridge basin at or about Sullivan time.

Structural History

Complex structures within the Sullivan orebody amplify regional tectonic events due to ductility contrast between sulphides and clastic rocks (McClay, 1982a,b). Initial overriding of the hanging wall to the east, displayed by offset of the hanging wall alteration zone, and segmentation of gabbro dykes in the orebody, caused recumbent isoclinal folds in the sulphides. Continued deformation caused asymmetric folds, commonly overprinting isoclinal folds, and thrust faults at the orebody, as similar structures developed regionally. This phase of deformation probably included displacement on the Kimberley Fault. Subsequently lamprophyre dykes were intruded. Later structures include relatively minor west-verging thrusts and folds. All these deformational events are ascribed to the Laramide orogeny. Crustal extension during the Eocene (Price et al., 1981) resulted in west-dipping normal faults. Where they offset the orebody (Figs. 3 and 4) these faults have displacements of up to 30 m.

ORE GENESIS

The ore-Moyie gabbro age and spatial relationships have led several authors (Hamilton et al., 1982 and 1983; Hamilton, 1984) to speculate that the heat dissipated from a parent magma body could be sufficient to cause widespread convective leaching and transportation of metals from Lower Aldridge sediments. Additional or alternate sources of heat have been cited as radioactive decay and exothermic reactions in Lower Aldridge sediments, and high heat flow through an area of thin crust (op. cit.).

Essential to the formation of a mineral deposit by any heat related process of intraformational elemental scavenging and transportation is a feature to focus solution flow and provide an outlet to an environment where prevailing conditions will cause precipitation of transported elements. Such a feature is seen below the Sullivan ore body in the form of north-trending, near-vertical fragmental bodies. These and the localized discordant gabbro arch in proximity are evidence of lines of crustal weakness.

SUMMARY

The Sullivan orebody is interpreted as a hydrothermal synsedimentary sulphide deposit which formed in a sub-basin on the Aldridge marine floor. It is located directly over cross-cutting bodies of fragmental rocks, products of pore overpressure release along lines of crustal weakness. Dislocation zones so formed became conduits for boron-rich fluids which permeated sediments in and adjacent to them and discharged onto the sea floor. Composition of the fluids changed and sulphides were deposited.

The initial sulphide assemblage comprised pyrrhotite and unknown amounts of galena and sphalerite. Sulphide deposition near the vent area was rapid. Galena and sphalerite were remobilized from parts of the basal sulphide accumulation and were redeposited with pyrrhotite in layers throughout the western part of the orebody.

The distal eastern ore is considered to be slightly later than the basal sulphide accumulation and to be derived from a brine cell emanating from the vent.

Continued deposition resulted in well layered sulphides interbedded with wacke to form the upper parts of the entire orebody. Infilling of the sub-basin was completed with deposition of the I, H and Hu stratigraphic intervals. Although clastic sedimentation was predominant there was further deposition of some sulphides.

Some chlorite alteration in the footwall and above the feeder took place during the early stages of sulphide mineralization. A post-sulphide phase of hydrothermal activity produced, albite-chlorite-pyrite alteration in the footwall, pyrite-chlorite-calcite alteration in the ore zone and albite-chlorite-pyrite alteration of the hanging wall. Hydrothermal solutions are believed to have resulted from widespread convective leaching of Lower Aldridge sediments. Possible sources of thermal energy include high heat flow from magmatic intrusion or region of thin crust and radioactive decay and exothermic reactions in the sedimentary pile. Focused discharge of hydrothermal solutions was along lines of crustal weakness.

ACKNOWLEDGMENTS

Observations and conclusions on genesis of the Sullivan orebody and associated unique rocks have been made by several generations of geologists and the authors wish to acknowledge that it is mostly on the work of others that this field guide is based. Many of the concepts presented in this paper are embodied in Geology of the Sullivan Deposit, Kimberley, B.C., Canada (Hamilton et al., 1983). Some of the new thoughts on origin of fragmental rocks and the relationship of these to genesis of the Sullivan orebody are from G.D. Delaney and R.L. Hauser (1983). Most figures that accompany this article have appeared in previous publications by Sullivan geological staff. We wish to thank E.D. MacDonald and M.E. Knapp for reviewing the manuscript and Cominco Ltd. for permission to publish this field guide.

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Chapter 4
REGIONAL GEOLOGY AND SUMMARY OF GOLD MINERALIZATION IN THE OKANAGAN VALLEY

Modified from Meyers, R.E. and Taylor, W.A.(1989): Metallogenic Studies of Lode Gold-Silver Occurrences in South-Central British Columbia: A Progress Report (82E,82L), B.C. Ministry of Energy Mines and Petroleum Resources, Geological Fieldwork 1988, Paper 1989-1

REGIONAL GEOLOGY

The Okanagan Region is underlain by a diverse assemblage of rocks, ranging in age from late Paleozoic to early Cenozoic (Bostock, 1941; Jones, 1951; Little, 1961). The region is bisected by the Okanagan Valley, which represents a major tectono-stratigraphic break separating high-grade metamorphic rocks of the Okanagan metamorphic complex to the east from lower grade Carboniferous to Triassic metasedimentary and metavolcanic rocks to the west. The fault system is projected from Washington State along the full length of the Okanagan Valley to north of Shuswap Lake (Tempelman-Kluit and Parkinson, 1986; Parrish et al., 1988).

The Okanagan metamorphic complex occupies the western flank of the Omineca Belt and includes amphibolite-grade orthogneiss and paragneiss intruded on a broad scale by deformed granitoid plutonic rocks of the middle Jurassic Nelson suite and the Jura-Cretaceous Valhalla suite. The age of the gneiss complex was previously thought to be as old as Precambrian (Bostock, 1941; Little, 1961; Okulitch and Woodsworth, 1977), however, studies by Medford (1975), Mathews (1981), Parkinson (1985) and Parrish et al. (1988) have produced fission-track, uranium-lead and potassium-argon isotopic ages as young as late Eocene.

On the west side of the Okanagan Valley, late Paleozoic to middle Mesozoic sedimentary and volcanic rocks of island arc and oceanic derivation have preserved Mesozoic penetrative deformation and are metamorphosed to greenschist facies. As on the eastern side, these rocks are intruded by Nelson and Valhalla plutonic rocks but contrast dramatically in their metamorphic history.

Pre-Tertiary rocks on both sides of the Okanagan Valley are unconformably overlain, in places, by thick accumulations of Eocene volcanic and sedimentary rocks that are generally unmetamorphosed. Church (1982) and Tempelman-Kluit (1989) have correlated outliers of the Eocene sequence, and Parrish et al. (1988) interpret them as remnants of a continuous depositional basin that covered the southern Okanagan.

Recently presented evidence (Parrish et al.,1988; Tempelman-Kluit and Parkinson, 1986; Bardoux, 1985) indicates that the Okanagan fault system formed as a series of low-angle, west-dipping normal faults with east to west movement, placing lower grade rocks to the west against higher grade rocks to the east.

METALLOGENIC STUDIES OF LODE GOLD-SILVER OCCURRENCES IN SOUTH-CENTRAL BRITISH COLUMBIA: A PROGRESS REPORT (82E, 82L)

By R.E. Meyers and W.A. Taylor

KEYWORDS: Economic geology, metallogeny, lode gold-silver, epithermal, mesothermal, Okanagan.

INTRODUCTION

The recent success experienced by the exploration industry in newly discovered mining camps in northwestern British Columbia, combined with new discoveries and the successful regeneration of historical mining camps of the Canadian Shield and in the Western United States has encouraged industry re-assessment of the potential for precious metal lode deposits in southern British Columbia.

The objective of this study is to provide the explorationist with a review of precious metal occurrences in south-central British Columbia, their geologic setting and their character. Attention is drawn to the nature and potential of current exploration targets and the contrasts between them, and the type of deposits that have been historically exploited. The initial focus is in the Okanagan region, specifically on map sheets 82E/W and 82L/SW (Figure 1), where two recent epithermal discoveries have prompted a substantial increase in exploration activity.

This preliminary report summarizes the results of field observations and compilation of data from 127 precious metal lode occurrences in the Okanagan region. Other types of gold occurrences, such as copper-gold porphyries and gold-bearing skarns are not dealt with in this study, although a few skarn-related vein deposits are included.

SOURCES

Information has been compiled from 31 property visits, property descriptions researched from British Columbia Minister of Mines Annual Reports, MINFILE, assessment reports, Geological Survey of Canada publications and district property files, as well as from some earlier compilations (Dawson et al., 1984). Occurrences were selected on the basis of having a "reasonable" tenor of mineralization. Very small, isolated veins with only geochemically anomalous values were avoided. In most cases the historic property names have been used in preference to more recent claim names. All properties are tabulated and plotted at 1:250 000 scale in Open File 1989-5 (Meyers et al., 1989).

The geology of the Okanagan region is presented in the context of new interpretations by Parrish et at. (1988) and others. Geological information for the Penticton map sheet (82E/W) has been primarily derived from Tempelman-Kluit (in press) and for 82L/SW from Wheeler and McFeely (1987).

REGIONAL GEOLOGY

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Recently presented evidence (Parrish et al., 1988, Tempelman-Kluit and Parkinson, 1986, Bardoux, 1985) indicates that the Okanagan fault system formed as a series of low-angle, west-dipping normal faults with east to west movement, placing lower grade rocks to the west against higher grade rocks to the east.

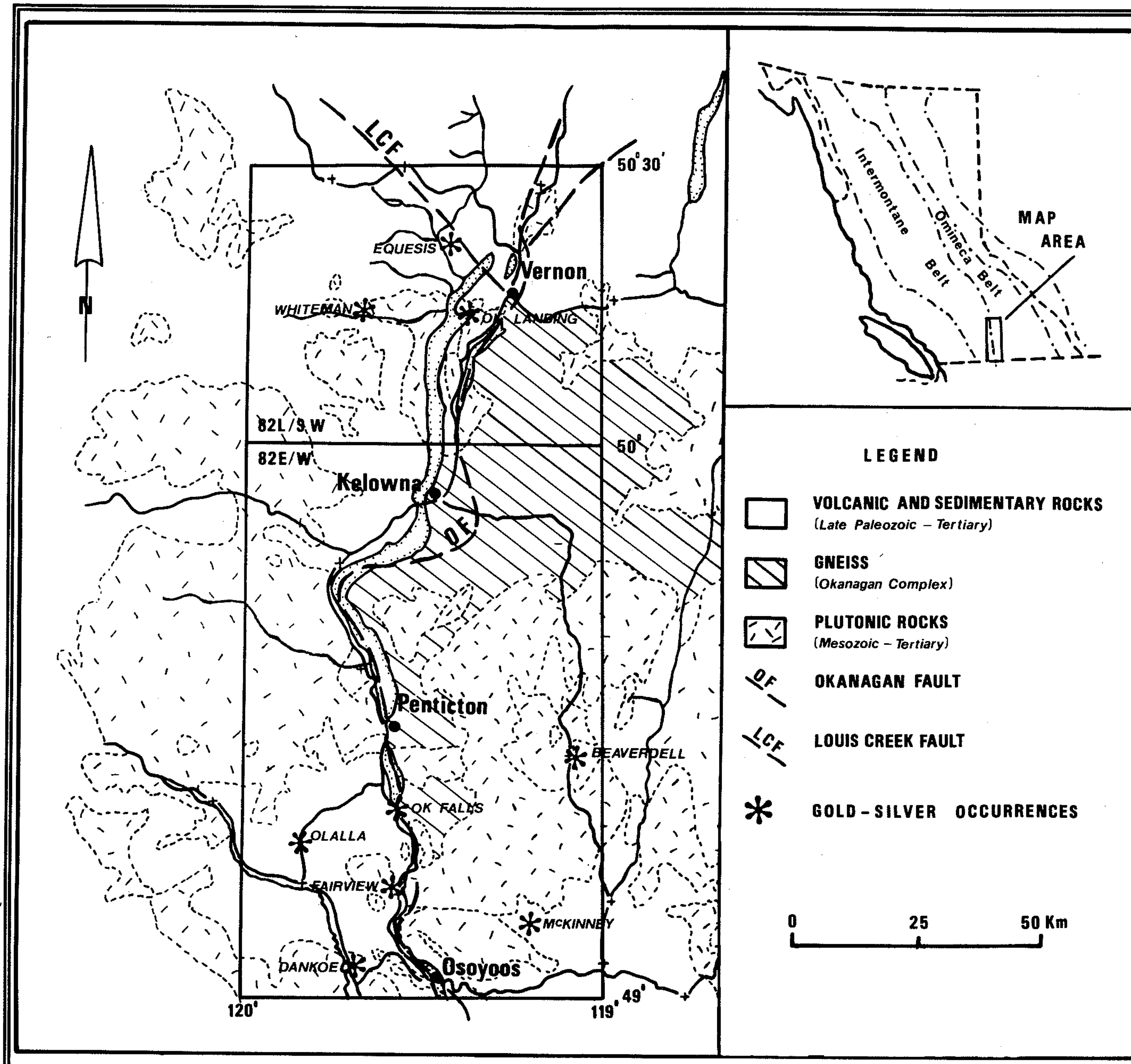

Figure 1 Okanagan region showing location of study area and main localities of lode gold-silver occurrences. Geology simplified after Wheeler and McFeely (1987) and Parrish et al. (1988)

DISTRIBUTION, SETTING AND CHARACTER OF PRECIOUS METALS DEPOSITS

NORTHERN OKANAGAN

In the northern Okanagan region (82L/SW) most occurrences are centred around Vernon, at

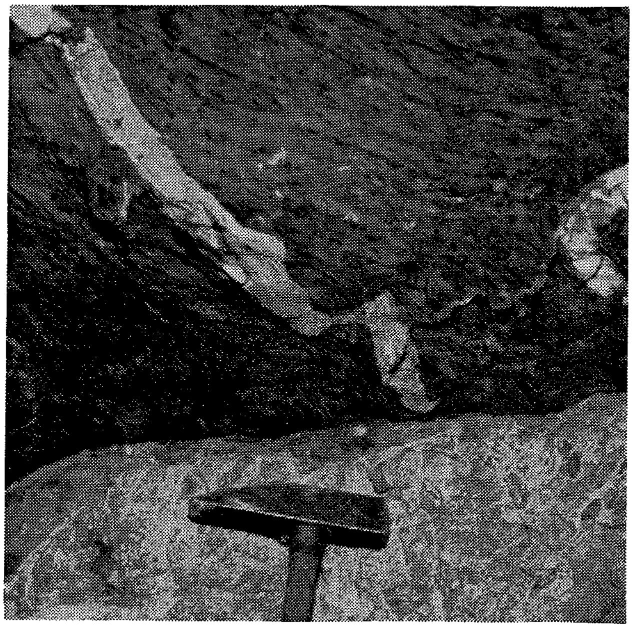

Plate 1 Imperial property. Deformed quartz vein and felsic dyke in schistose, chloritized metasedimentary rocks, which are truncated by lower grey breccia zone.

Okanagan Landing, Equesis Creek and the Whiteman Creek - Terrace Mountain area. The majority of these prospects occur in greenschist facies, Upper Triassic to Lower Jurassic Nicola Group volcanic and sedimentary rocks and in metasedimentary rocks of the Upper Triassic Slocan Group (Okulitch, 1979), while comparatively few occurrences have been discovered in Tertiary rocks.

OKANAGAN LANDING AND VERNON

Mineralized veins in this area are mesothermal in character and associated with north, northwest and west-trending structures that may be splays of the northern Okanagan fault system or the Louis Creek fault. The veins are gold-bearing with secondary silver, copper, lead and zinc. Some veins occur in fractures oriented oblique to foliation (Plate 1). Alteration is graphitic, with clay and limonite. On the east shore of Okanagan Lake, near the Ruby Gold prospect, the stratified rocks have a strong northwest-dipping penetrative fabric that is distinctly mylonitic in texture.

EQUESIS CREEK

Several precious metal bearing quartz-vein prospects occur in chloritic volcanic rocks and phyllitic sedimentary rocks of the Nicola and Slocan groups, between Equesis Creek and the Salmon River The veins are subparallel to host-rock foliation and are mainly gold-rich with low silver values. A minority, however, are silver-rich, gold-poor veins that contain galena and sphalerite. Alteration is variable and generally not well defined over large areas. Chlorite, limonitic carbonate, sericite and weak graphitic alteration are the most common.

WHITEMAN CREEK

In contrast to the areas described above, gold-silver mineralization in the Yctshiteman Creek - Terrace Mountain area occurs within, or close to relatively unmetamorphosed volcanic rocks of the Eocene Kamloops Group. The most notable occurrence is the Brett property, which is characterized by bladed and vuggy, epithermal gold and silver-bearing quartz veins (Plate 2) associated with illite, sericite and silica alteration (Meyers, 1988a). The veins occur in northwest-striking, highly fractured fault zones, which tend to coincide with feldspar porphyry dykes. A broad silicified breccia zone (Plate 3) northeast of the mineralized areas is believed to represent a major epithermal system. Recent drill-hole data indicate that silicification and gold mineralization in the main shear zone may extend laterally into porous tuff units, where they are intersected by the steeply dipping, mineralized fault zones. Southeast of the mineralized area, the volcanic sequence is intruded by a syenitic stock dated at 50.3 Ma (Church, 1980a).

The White Elephant property, which was exploited briefly in the 1920's and 1930's, is several kilometres south of Whiteman Creek. Precious metals occur in fractured and faulted quartz-rich and sulphide-rich veins that are hosted in propylitically altered middle Jurassic granodiorite. The deposit is exposed a few hundred metres east of Eocene volcanic rocks and the veins are cut by basaltic dykes.

SOUTHERN OKANAGAN

Occurrences in the southern Okanagan region (82E/W) are grouped in several well-known mining camps, where a number of past producers are still being explored. The Fairview Camp, Orofino Mountain, Olalla, Camp McKinney and Beaverdell are of particular note. In most areas, mesothermal veins

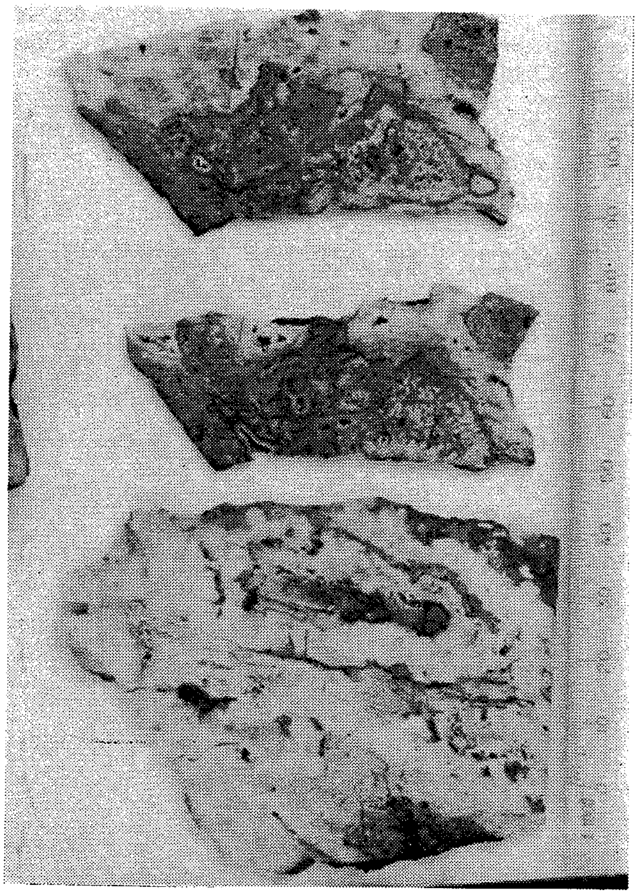

Plate 2 Brett property. Banded, vuggy and brecciated quartz veins. Wallrock material is silicified and clay (illite) altered; Trench No. 1, Main Shear Zone.

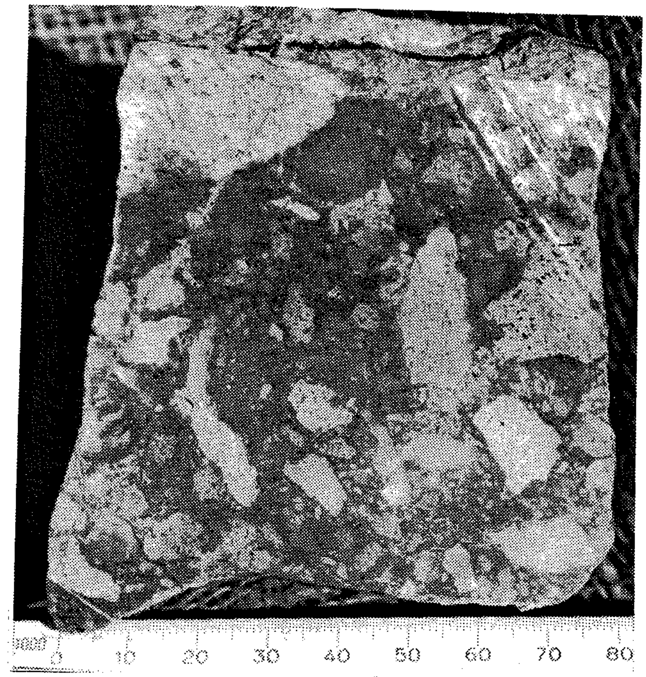

Plate 3 Brett property. Silicified and pyritized breccia, Gossan Zone.

occur in deformed late Paleozoic to Mesozoic sedimentary-volcanic sequences. At Okanagan Falls, however, Eocene volcanic rocks of the Marama and White Lake formations host epithermal gold mineralization.

OKANAGAN FALLS

At the south end of Skaha Lake epithermal mineralization at the Dusty Mac mine occurs in quartz-vein breccia in laharic deposits of the Eocene White Lake Formation (Church, 1969; 1973). The geology of the area is dominated by a northwest-trending fault system and dissected locally by numerous normal and reverse faults. Fracture-controlled veins are commonly banded (Plate 4), or exhibit cockscomb quartz intergrowths. The deposit was mined briefly between 1969 and 1975 and is currently undergoing further exploration.

Several kilometres southeast, at the Venner property, gold-silver mineralization is related to quartz-carbonate breccia and veining within Eocene Marama andesitic breccias, rhyolitic flows and crystal tuffs. This unit underlies the White Lake Formation.

A new epithermal gold-silver prospect has been discovered recently northwest of Okanagan Falls, at the Vault property. Mineralization is characterized by crustiform-banded chalcedonic quartz veining (Plate 5) and widespread silicification in brecciated and tuffaceous trachyandesites of the lower Marama Formation. Normal faulting is a complicating structural feature.

FAIRVIEW CAMP

At the Fairview mine, deformed gold-silver veins (Plate 6) occur in refolded and faulted Kobau metaquartzites of Carboniferous to Permian age (Okulitch, 1969; 1973) that are wedged between Oliver granite and the Fairview granodiorite. Renewed exploration has been hampered by the structural complexities of early polyphase folding and super-

Plate 4 Dusty Mac property. Multiple banding in quartz vein in laharic breccia.

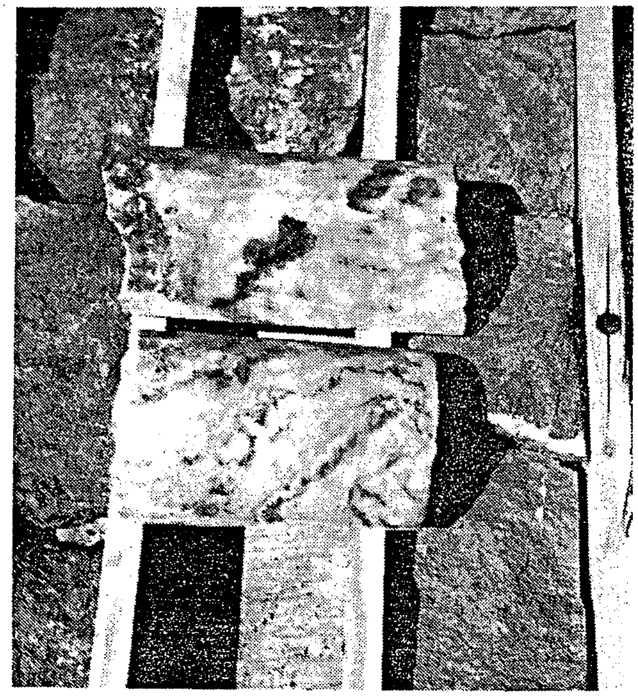

Plate 5 Vault property. Banded gold-bearing quartz vein in tuffaceous trachyandesite. Core is 4.5 cm in diameter.

imposed normal and reverse faulting (Meyers, 1988b). Veins are typically mesothermal, with precious metals associated with iron, lead, zinc and copper sulphides. The Stemwinder and Morning Star mines lie immediately southeast of the Fairview property and are interpreted to be part of the same quartz lode system cutting the Kobau stratigraphy. Operations in the Fairview camp were intermittent between 1895 and 1961, with total production amounting to 473 000 tonnes of ore which yielded 1944 kilograms of gold and 23 021 kilograms of silver.

A similar setting exists at Orofino Mountain where the host rocks are greenschist metasedimentary rocks of the Upper Triassic Old Tom and Shocmaker groups, intruded by dioritic and gabbroic rocks. Northeast and northwest-trending quartz veins carry gold and silver associated with polymetallic sulphides and chlorite-sericite alteration.

The host strata and mineralization are cut by a number of northeast-oriented normal faults.

Other deposits in the same area, such as the Suzie mine and Standard prospect, occur in northeast and northwest-trending dilatent fracture zones within the granitoid rocks of the Oliver intrusion (Plate 7).

OLALLA

Veins in the Olalla area occur within or peripheral to the mid-Jurassic Olalla pyroxenite and related syenitic rocks, where they intrude hornfelsed Upper Triassic Shoemaker Group metasedimentary rocks. Most structures trend east-northeast and are sheared or brecciated. Gold-silver mineralization is associated with base metals in quartz veins, quartz breccia zones and weakly mineralized gold and copper-bearing skarns. Alteration is variable, but predominantly silica, carbonate, clay and minor sericite. At least two properties (Sunrise, Juniper) are associated with skarn mineralization.

Plate 6 Fairview mine. Cleavage development in quartz vein, oriented parallel to S_1 foliation in wallrocks. Crossfracturing is subperpendicular to cleavage; No. 6 level.

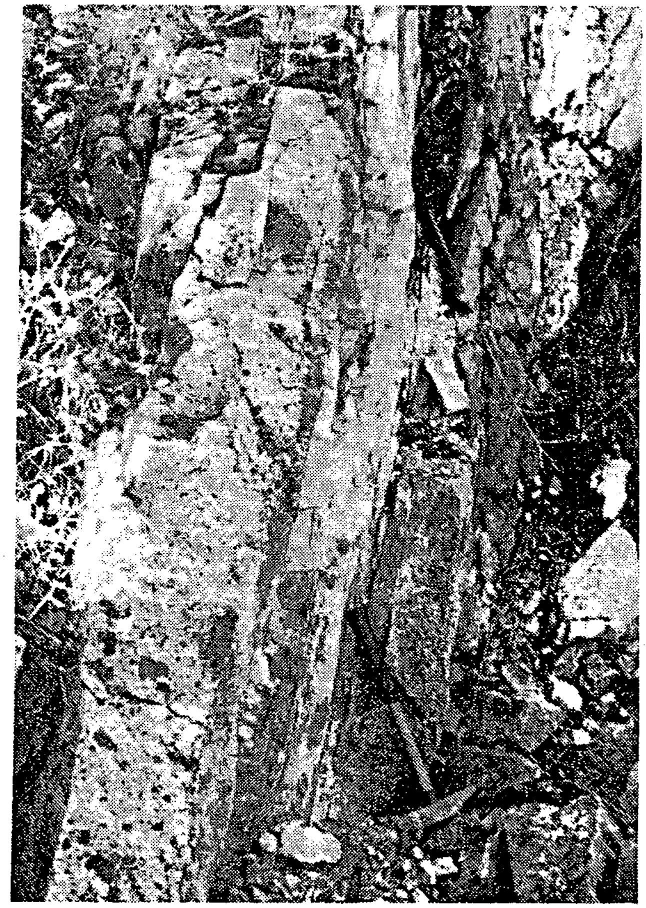

Plate 7 Standard property. Steeply dipping quartz vein enclosed in granodiorite (Jog) adjacent to adit portal.

DANKOE

In the Dankoe (Hom Silver) mine area, south of Mount Kobau, flat-lying quartz veins are generally oriented east-west subparallel to shearing. They occur within the Kruger syenites, monzonites and related pegmatites (Plate 8). Precious metals occur with pyrite, chalcopyrite, galena and tetrahedrite. Native silver, argentite, pyrargyrite and silver halides have also been reported from this deposit. Some veins display banded and bladed sulphides and quartz, suggesting open-space filling. Alteration is strongly propylitic in character. During intermittent operation between 1915 and 1984 the Horn Silver mine produced 391 111 tonnes of silver-gold ore, containing 333 kilograms gold and 127 194 kilograms silver.

CAMP McKINNEY

Camp McKinney deposits occur in greenstones, amphibolites, minor ultramafic rocks and schistose metasedimentary rocks of the Carboniferous to Permian Anarchist Group. The veins are generally conformable to the northwest and west-trending regional foliation and are reported to have similarities in structure and texture to the deformed mesothermal veins in the Fairview Camp (Cockfield, 1935). However, a few banded and vuggy veins are present, suggesting that low-temperature epithermal activity may have had an effect on vein development. Gold is by far the dominant precious metal, although modest silver values were reported, together with appreciable quantities of lead, zinc and copper. At the War Eagle property, fractured and brecciated veins contain zones partially replaced by massive sulphides. Alteration is quartz-carbonate rich, with associated sericite and chlorite. The Caribou-Amelia mine produced 124 452 tonnes of ore containing 2538 kilograms gold and 1009 kilograms silver between 1894 and 1962.

BEAVERDELL

The Highland-Bell mine, an amalgamation of the former Highland Lass, Bell and Beaver properties, is the oldest continuously operating mine in British Columbia. Between 1900 and 1988 the mine has produced 1278 tonnes of silver and approximately 500 kilograms of gold from 830 743 tonnes of ore.

In the Beaverdell - Carmi district, silver and gold vein mineralization occurs in predominantly northeast and east-trending structures in the Middle Jurassic Westkettle granodiorite. The batholith also contains pendants of the Wallue Formation, a volcanic-sedimentary component of the Anarchist Group (Fig. 2). The granodiorite is intruded by the Beaverdell quartz monzonite, an Eocene Coryell-type intrusion, dated at 58.8 Ma, which has been correlated with the timing of silver-rich mineralization at the Highland Bell mine (Godwin et al., 1986). Watson and Godwin (1983) reported arsenopyrite, tetrahedrite, pyrargyrite, chalcopyrite, polybasite, acanthite and pyrrhotite associated with the silver-lead-zinc mineralization. Alteration in the camp is mainly propylitic with accessory sericite and clay.

In contrast with the Beaverdell area, vein mineralization at Carmi is gold-rich, with generally lower sulphide content (Watson et al., 1982). No major production has come from this area.

DISCUSSION

The majority of lode gold-silver occurrences compiled for this study are mesothermal and occur in remnants of late Paleozoic to early Mesozoic eugeosynclinal rocks. The fact that many of them lie within well known established mining camps, reflects the historical exploration bias toward pre-Tertiary rocks.

Only five of the properties occur in Tertiary volcanic rocks. Most of these have distinct epithermal characteristics and were discovered during the last twenty years. The more recent discoveries are particularly significant in that they reaffirm the potential for epithermal gold mineralization related to Tertiary volcanism in the Okanagan region. The deposits fall into three general settings:

(1) Greenschist-hosted Deposits. Deposits occurring in sedimentary and volcanic sequences, metamorphosed to greenschist grade, occur as intrafolial veins parallel to bedding or cleavage, breccia fillings, multiple veins and stringers in ductile shears, and in discordant brittle cross-fractures. Host-rocks are deformed, foliated rocks originating as accretionary arc or oceanic assemblages (Wheeler and McFeely, 1987). Precious metals are usually intimately associated with base metals, and the sulphide and alteration mineral assemblages are typical of mesothermal lode deposits (Hodgson , 1985). Deposits of this type are common in greenschist terranes, particularly in the Archean of central Canada (Colvine et al., 1984, 1988) and Western Australia (Barley et al., 1986). They are believed to have formed from metamorphogenic fluids contemporaneous with ductile deformation and syntectonic plutonism.

However, to avoid direct comparisons between Cordilleran and Archean terranes, a better analogy might be drawn with lode deposits in the Juneau gold belt of southeastern Alaska, where Goldfarb et al. (1988) have determined a subduction-related metamorphic origin for mesothermal vein mineralization in greenschist to amphibolite-grade rocks of late Paleozoic to Cretaceous age.

(2) Intrusive-hosted Deposits. Except for the Beaverdell deposits, intrusive-hosted occurrences in the region are generally less well known. They occur in faults, dilational fractures or fissures, shear zones and breccia zones. The most significant of these are the Beaverdell deposits, which are fault and fissure controlled and silver rich. Although they occur in Jurassic granodiorite of the Westkenle batholith, they are considered to be Tertiary in age (Godwin et al., 1988). The Sunrise/Shepherd veins at Olalla occur within the Olalla pyroxenite and are breccia and skarn-related. The latter association suggests that metasomatic activity related to intrusion may have been important during vein development.

(3) Epithermal Deposits. The important epithermal prospects in the region occur at Okanagan Falls and Whiteman Creek. They are hosted by Eocene volcanic and sedimentary sequences that are inferred to be related in time, to "detachment-type" extensional tectonics associated with the Okanagan fault system (Parrish et al. ,1988).

Mineralization is best developed in porous tuffs, tectonic fracture zones, and laharic and

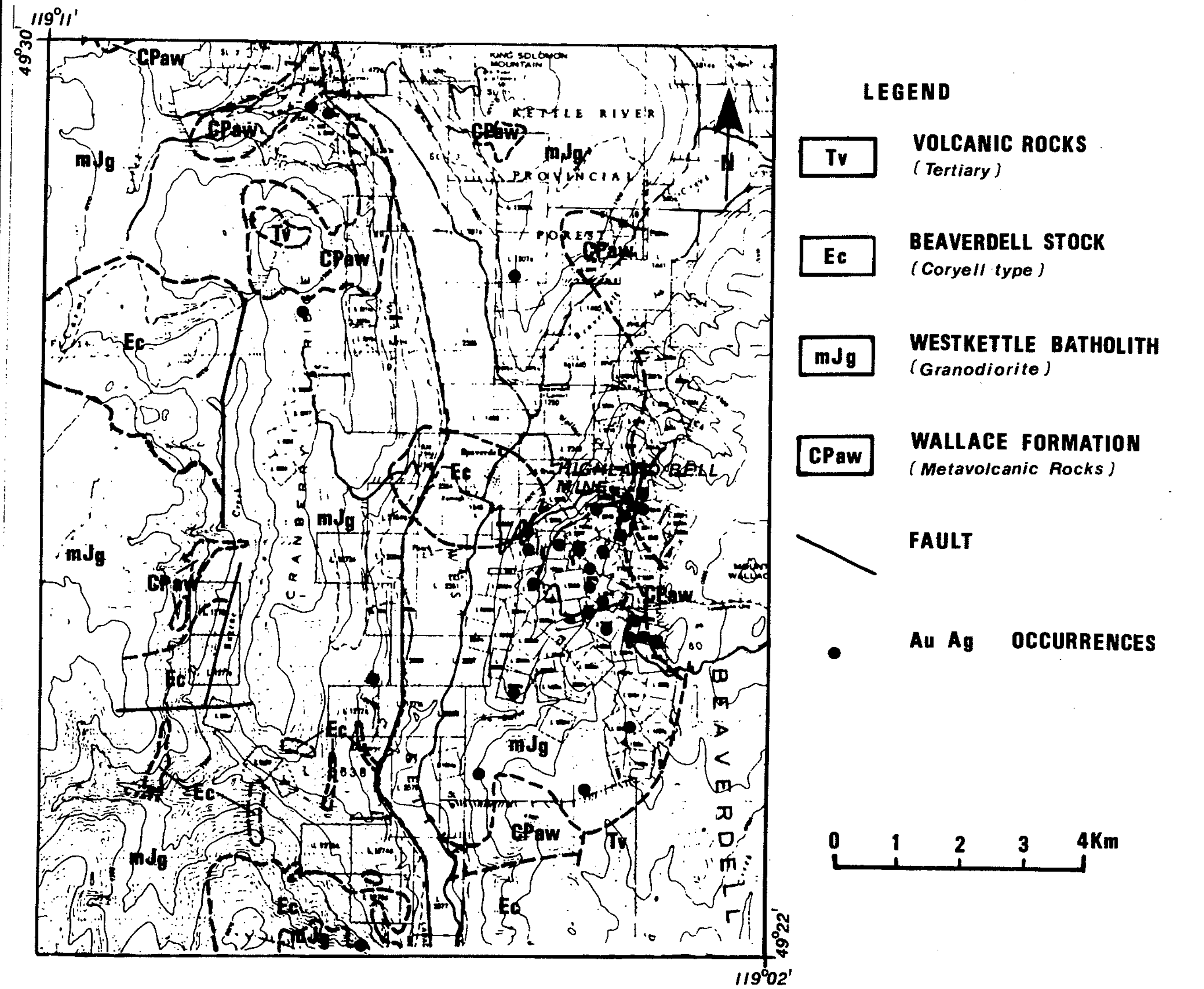

Figure 2 Distribution of silver and gold occurrences in the Beaverdell-Carmi district. Geology after Watson et al. (1982) and Godwin et al. (1986).

epiclastic breccias. It is associated with faulting, intense brittle fracturing, widespread silicification and moderate to strong pyritization of adjacent wall rocks. Clay (illite), sericite and to a lesser extent, carbonate are common alteration products. Quartz veins are vuggy, banded, bladed and rebrecciated, all of which are features characteristic of boiling in a hotspring environment (Buchanan, 1981).

Relationships between epithermal mineralization and extensional deformation have been proposed for deposits in the western United States (Spencer and Welty, 1986) and in Spain (Doblas et al., 1988). The fact that normal faulting is widespread throughout Eocene sequences in the Okanagan (Church, 1979; 1980a, b) and is spatially related to Eocene volcanic centres and mineral deposits, is

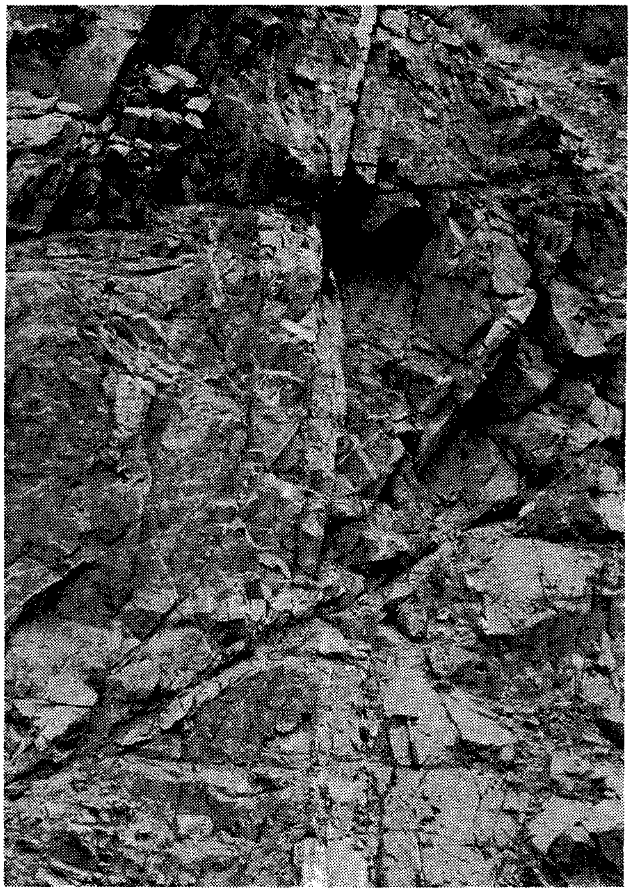

Plate 8 Dankoe mine. Pegmatite dykes cutting Kruger syenite (mJg) near adit portal.

indicative that extensional tectonism likely gave rise to Eocene volcanism. The open-space textures in epithermal quartz veins are further evidence, on a local scale, that dilatent deformation took place. Consequently, one can expect that the evolving models for extensional tectonics and Eocene volcanism in the region will have important and far-reaching genetic implications for epithermal precious metals exploration in the Okanagan.

ACKNOWLEDGMENTS

This study benefited from a number of property visits and on-site discussions with company project geologists. We acknowledge permission to visit several inactive properties and we thank Dirk Tempelman-Kluit for access to his data for the Penticton map sheet. Field assistance, property research and drafting assistance was enthusiastically provided by Todd Hubner.

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Chapter 5
GEOLOGY OF THE HEDLEY GOLD-SKARN CAMP

Modified from

1. **Ettlinger, A.D. and Ray, G.E. (1989): Precious Metal Enriched Skarns in British Columbia: An Overview and Geological Study, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1989-3, 128 pages.**

and

2. **Ray, G.E., Dawson, G.L. and Simpson, R. (1988): Geology, Geochemistry and Metallogenic Zoning in the Hedley Gold-Skarn Camp (9211/08; 82E/05), B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1987, Paper 1988-1.**

HEDLEY CAMP

The Hedley camp, situated approximately 40 kilometres east-southeast of Princeton in southern British Columbia, is the largest and economically most important PME-skarn district in the province. It has had a long history of intermittent gold mining (Camsell, 1910; Billingsley and Hume, 1941; Dolmage and Brown, 1945; Simpson, 1986, 1987, 1988) and between 1902 and 1955 approximately 51 million grams of gold were won from at least four gold-bearing skarn deposits. More than 95 per cent of the gold production in the camp came from one very large deposit which was worked at the Nickel Plate and Hedley Mascot mines. Smaller amounts of gold were recovered from the French, Goodhope and Canty auriferous skarn deposits. In addition to these deposits, there are numerous small gold-bearing skarn occurrences in the Hedley district including the Peggy which has had some underground work but no reported production. In the eastern part of the Hedley district, at Mount Riordan, there is also a large tungsten-copper-bearing skarn which contains some silver but only very low gold values (Ray et al., 1988). Exploration interest in the Hedley gold camp has been revitalized by the recent reopening of the Nickel Plate mine by Mascot Gold Mines Limited (now Corona Corporation) as a 2450 tonne per day open-pit operation.

The gold-bearing skarn mineralization is hosted in Upper Triassic Nicola Group rocks and is genetically related to a suite of subalkalic, calc-alkaline dioritic intrusions of Early Jurassic age. A series of facies changes recognized within the Nicola succession is related to deposition across a fracture-controlled basin margin; it is economically important as the gold mineralization in the Hedley district is lithologically, stratigraphically and structurally controlled.

A district-wide metallogenic zoning may exist in the Hedley camp with gold and arsenic-rich skarns developed to the west and tungsten-rich, gold and arsenic-poor skarns to the east. This type of zoning may have exploration significance elsewhere in the North American Cordillera.

GENERAL GEOLOGY

The Hedley camp lies within the Intermontane Belt of the Canadian Cordillera and the geology of the district is presented in Figure 1. The geology has been described by Camsell (1910), Bostock (1930, 1940a, 1940b) and more recently by Ray et al. (1986b, 1987, 1988), Simpson and Ray (1986), Ray and Dawson (1987, 1988), and Ettlinger and Ray (1988).

Most of the area is underlain by the Upper Triassic Nicola Group which contains three distinct stratigraphic packages. The oldest, the Peachland Creek formation largely comprises mafic tuffs and minor conglomerate; while the youngest, the Whistle Creek formation is essentially an andesitic to basaltic volcaniclastic sequence. Between these two formations is a predominantly sedimentary succession that hosts most of the gold-bearing skarns in the camp. Several east-to-west facies changes are recognized in this sequence, which progressively thickens from 100 metres in the east to over 700 metres in the west (Figure 2). These facies changes probably reflect deposition across the tectonically controlled margin of a Late Triassic marine basin which deepened to the west.

The easternmost and most proximal facies, the French Mine formation (Figs. 1 and 2), has a maximum thickness of 150 metres and comprises massive to bedded limestone interlayered with thinner units of calcareous siltstone, chert-pebble conglomerate, tuff,

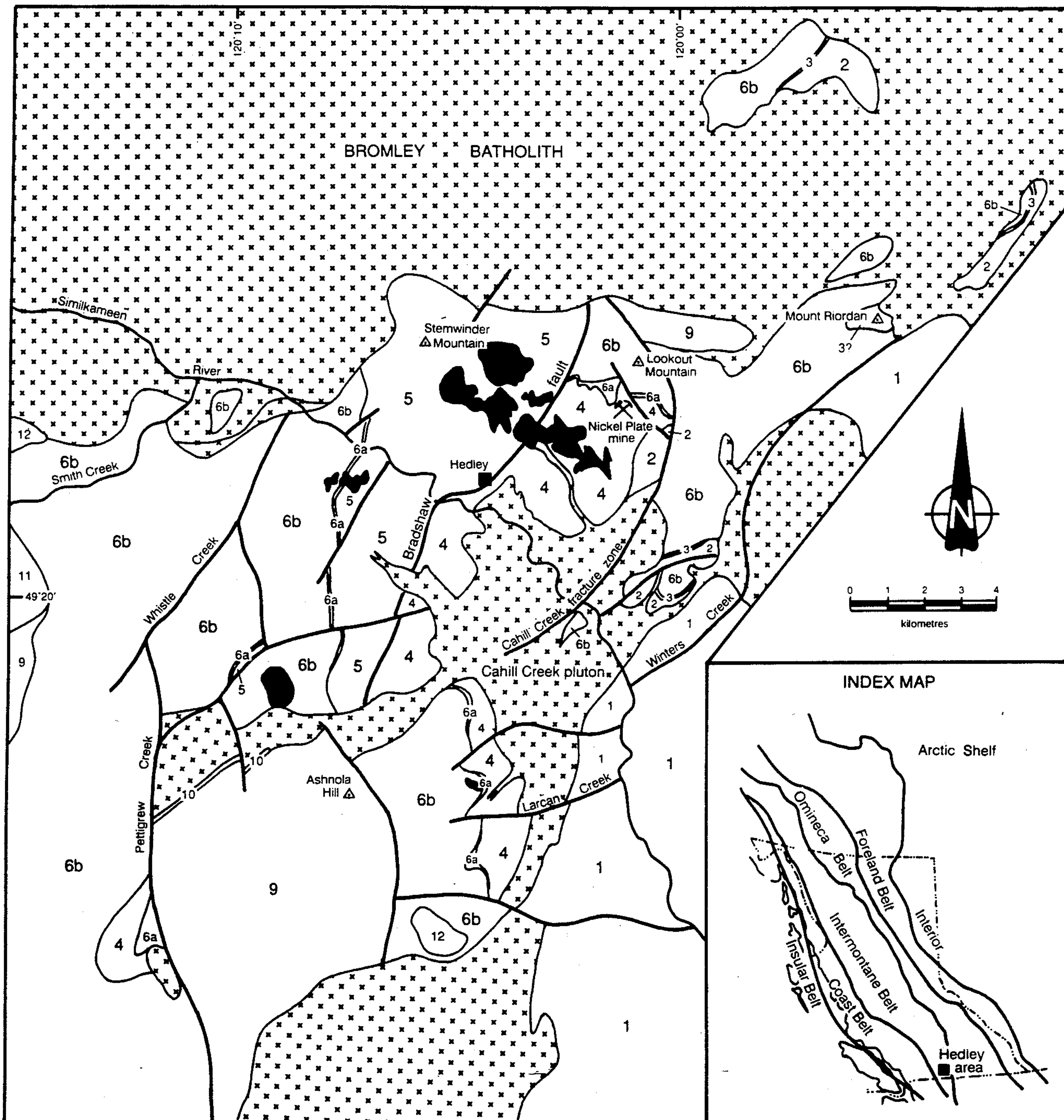

Figure 1 Regional geology of the Hedley district, southern British Columbia (after Ray et al., 1988). For legend see page 61

LEGEND

TERTIARY

12 Basaltic flows

EROSIONAL UNCONFORMITY

EARLY CRETACEOUS

11 VERDE CREEK INTRUSION – *granite and microgranite*

10 RHYOLITE INTRUSION – *quartz porphyry*

9 SPENCES BRIDGE GROUP – *andesitic to dacitic pyroclastics and flows with minor sediments*

CONTACT UNCERTAIN

EARLY JURASSIC

8 BROMLEY BATHOLITH AND CAHILL CREEK PLUTON – *granodiorite to quartz monzodiorite*

7 HEDLEY INTRUSION – *quartz diorite, diorite, and gabbro*

INTRUSIVE CONTACT

NICOLA GROUP

LATE TRIASSIC

6b WHISTLE CREEK FORMATION – *bedded to massive ash and lapilli tuff, minor tuffaceous siltstone*

6a Copperfield Conglomerate – *limestone boulder conglomerate*

5 STEMWINDER MOUNTAIN FORMATION (WESTERN FACIES) – *thinly bedded argillite and limestone*

4 HEDLEY FORMATION (CENTRAL FACIES) – *thinly bedded siltstone, thick limestone beds and minor tuffs*

3 FRENCH MINE FORMATION (EASTERN FACIES) – *limestone, limestone breccia and pebble conglomerate*

2 PEACHLAND CREEK FORMATION – *basaltic ash tuffs and flows with minor limestone and chert-pebble conglomerate*

CONTACT OCCUPIED BY CAHILL CREEK PLUTON

PALEOZOIC

1 APEX MOUNTAIN COMPLEX – *ophiolite sequence of cherts, greenstones, siltstones, argillites and minor limestones*

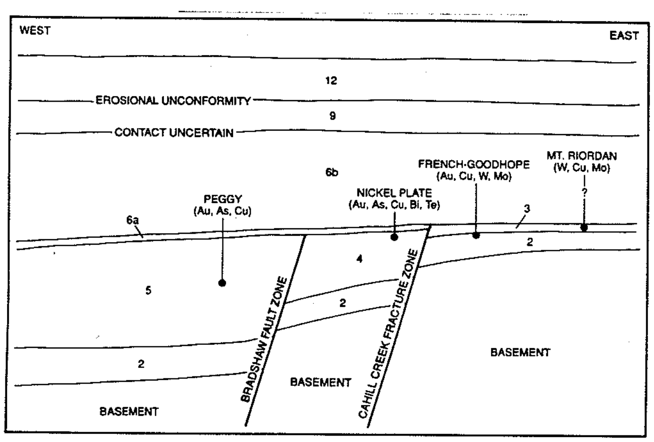

Figure 2 Schematic stratigraphic section of the Hedley district showing location of skarn mineralization in relation to sedimentary facies changes (after Ray et. al, 1988). See legend for Figure 1.

limestone-boulder conglomerate and limestone breccia. It hosts the auriferous skarn mineralization at the French and Goodhope mines (Fig. 2).

Further west, rocks stratigraphically equivalent to the French Mine formation are represented by the Hedley formation which hosts the gold-bearing skarn at the Nickel Plate mine. The Hedley formation is 400 to 500 metres thick and characterized by thinly bedded, turbiditic calcareous siltstones that display some soft sediment structures, and units of pure to gritty, massive or bedded limestone that reach 75 metres in thickness and several kilometres in strike length.

The most distal facies to the west is represented by the Stemwinder Mountain formation (Figs. 1 and 2) which is at least 700 metres thick and characterized by a monotonous sequence of black, organic-rich, thinly bedded calcareous argillite and turbiditic siltstone, and dark impure limestone beds that seldom exceed 3 metres in thickness.

Conodonts of late Carnian to late Norian age were obtained from limestones in the Hedley and Stemwinder Mountain formations (M.J. Orchard, personal communications, 1985, 1986; Ray and Dawson, 1987). Paleocurrent measurements suggest that the rocks in the Stemwinder, Hedley and Whistle Creek formations were derived from an easterly source. The French Mine formation was laid down in a proximal, shallow, possibly forereef marine environment that received deposition of angular limestone breccias and chert-pebble conglomerates. Deposition of the more distal Hedley formation involved slower, more turbiditic sedimentation with the occasional influx of coarser conglomerate, tuff and coarse gritty limestone. The limestones and calcareous siltstones are characterized by a general absence of both bioturbation and shelly fossils, although some crinoid ossicles, rare solitary corals, bivalve fragments and belemnites are present.

Deposition of the Stemwinder Mountain formation was characterized by slower sedimentation rates than that prevailing further east. This resulted in fine-grained, generally organic-rich argillaceous rocks, and only very minor limestones. Although laid down in deeper water, the formation is not considered to be oceanic, but was probably deposited within the deeper part of a relatively shallow back-arc basin that formed east of the main Nicola volcanic arc.

The sedimentary rocks of the Stemwinder Mountain, Hedley and French Mine formations pass stratigraphiclally upward into the Whistle Creek formation (Figs. 1 and 2) which is probably also Late Triassic in age. The formation is 700 to 1200 metres thick and distinguishable from the underlying rocks by a general lack of limestone and a predominance of andesitic to basaltic volcaniclastic material. The base of the Whistle Creek formation is often marked by the Copperfield conglomerate (Figs. 1 and 2), a limestone-boulder conglomerate 1 to 200 metres thick that forms and important stratigraphic marker horizon in the district. The conglomerate is well developed west of Hedley where it forms a northerly trending, steeply dipping unit that is traceable for over 15 kilometres along strike. The same conglomerate outcrops in small areas within upfaulted slices along Pettigrew Creek to the south, and as outliers near Nickel Plate and Lookout mountains to the east (Fig. 1).

Two Jurassic plutonic suites are recognized in the area. The oldest, the subalkalic, calc-alkaline Hedley intrusions, is economically important and Early Jurassic in age. It forms major stocks up to 1.5 kilometres in diameter and swarms of thin sills and dikes up to 200 metres in thickness and over 1 kilmetre in length. The sills and dikes are mostly coarse-grained, massive diorites and quartz diorites with minor gabbro, while the stocks range in composition from gabbro through granodiorite to quartz monzonite. Many of the sills and dikes are porphyritic and characterized by coarse phenocrysts of hornblende and zoned plagioclase. When fresh, they are dark coloured, commonly contain minor disseminations of pyrite and pyrrhotite and are often rusty weathered. By contrast, the skarn-altered diorite intrusions are usually bleached.

The Hedley intrusions invade the Upper Triassic rocks over a broad area. Varying degrees of sulphide-bearing calcic skarn alteration are developed within and adjacent to many of these intrusions, particularly the dike and sill swarms. Some previous workers (Billingsley and Hume, 1941; Dolmage and Brown, 1945) considered this plutonic suite to be genetically related to the skarn-hosted gold mineralization in the district, including that at the Nickel Plate, Hedley Mascot, French and Goodhope mines; the geochemical and mapping results presented by Ray et al. (1988) support this conclusion.

The second plutonic suite comprises coarse-grained, massive biotite hornblende granodiorite to quartz monzodiorite, of Early to Mid Jurassic age. It generally forms large bodies, such as the Bromley batholith which outcrops northwest of Hedley, and the Cahill Creek pluton which generally separates the Nicola Group rocks from the highly deformed Apex Mountain complex further to the southeast (Fig. 1). Country rocks up to 1.5 kilometres from the margins of the Bromley batholith and Cahill Creek pluton are hornfelsed; some minor skarn alteration is also locally present adjacent to the pluton, but it is generally sulphide poor and not auriferous.

Following lithification of the Nicola Group rocks, two distinct phases of folding took place. The youngest phase resulted in a major north-northeasterly striking, easterly overturned asymmetric anticline which is the dominant structure in the district; the axial plane of this fold dips steeply west. A related, but poorly developed, northerly striking axial planar cleavage is present in some argillites and the axes of smaller scale folds related to this deformation dip gently north and south.

The oldest phase of folding occurred during the emplacement of the Hedley intrusions but is only recognized in the Nickel Plate mine area. It produced small-scale northwesterly striking, gently plunging fold structures that are an ore control at the Nickel Plate mine (Billingsley and Hume, 1941; Dolmage and Brown, 1945) as well as a series of westerly to north-westerly trending fractures. Although there was little movement along these structures, they apparently controlled the emplacement of the Hedley intrusive dikes and the elongate Banbury, Stemwinder and Toronto stocks.

The sulphide-bearing auriferous skarn alteration is commonly developed in the Hedley and French Mine formations, and less frequently in the stemwinder and Whistle Creek formations. The alteration exhibits a strong spatial association with the Hedley intrusion and occurred during or shortly after their emplacement as many sills and dikes, as well as the Toronto stock, are altered to endoskarn.

GEOLOGY OF THE NICKEL PLATE MINE

The Nickel Plate and Hedley Mascot mines were largely developed on a single, very large, westerly dipping skarn-related gold deposit (Figs. 4 and 5). It was discovered in 1898 and mined in several underground operations until 1955; it produced approximately 48 million grams of gold from 3.6 million tonnes of ore. Mining resumed in April 1987 at a rate of 2450 tonnes of ore per day from an open pit; in December 1988 Corona Corporation reported ore reserves of 8.25 million tonnes grading 3.02 grams gold per tonne.

The gold deposit is hosted in the upper part of the Hedley formation (Fig. 2) where a discontinuous zone of garnet-pyroxene skarn alteration, up to 300 metres thick and 6 square kilometres in area, is developed peripherally to the Toronto stock and swarms of Hedley intrusion dikes and sills (Fig. 3 and 4). The alteration zone on surface is subcircular in shape and westerly dipping. It lies subparallel to, but locally crosscuts, the gently dipping host rocks which comprise calcareous and tuffaceous siltstone with interbeds of impure limestone. The bulk of the zone extends a considerable distance north and northeast of the Toronto stock within an area of more intense deformation, but to the south the skarn alteration only extends 30 to 150 metres beyond the intrusive contact.

Swarms of Hedley diorite porphyry sills, 1 to 25 metres in thickness, locally make up 40% of the skarn-altered section. In addition, several diorite porphyry dikes have followed west to northwest-trending fault zones (Fig. 4); mineralization and alteration tend to follow these dikes, forming deep keels of skarn that locally extend below the main alteration envelope. Skarn development is mostly confined to the Hedley formation, but alteration extends locally up into the overlying Copperfield conglomerate.

The main episode of skarn development occurred during a period of folding that accompanied and immediately followed the emplacement of the diorite sills and dikes. Most of the sills and dikes within the skarn envelope are bleached and altered. The exoskarn is dark green to brown coloured and typically consists of alternating layers of garnet-rich and clinopyroxene-rich alteration which reflect the original sedimentary bedding. Overall however, the Nickel Plate skarn is pyroxene dominant compared to garnet.

The concentric mineralogical zoning commonly observed in the small skarn envelopes in the district (Ray et al., 1987, 1988) is not clearly defined at the Nickel Plate mine, probably due to large-scale multiple and complex overprinting of the skarn alteration. Garnet-rich skarn is usually found in the cores of the alteration envelopes but metasomatic overprinting has eliminated most of the initial biotite hornfelsing, resulting in a generally sharp transition from pyroxene skarn to unaltered sediment. This transition represents the economically important "marble line" described by Billingsley and Hume (1941). Preliminary studies suggest that at least two stages of mineral grwoth are present in the skarn. The main minerals formed during the early stage were biotite, orthoclase, iron-rich pyroxene, garnet, quartz, wollastonite and carbonate. The pink to brown coloured garnets are generally anhedral but are euhedral where they grew adjacent to carbonate. They are markedly birefringent and range between Ad 25 and Ad 80 mole per cent (Figure 6A). Like garnets developed in all the gold-bearing skarns in the Hedley district and a Mount Riordan, the Nickel Plate garnets generally contain less that 1 per cent MnO. The pyroxenes at Nickel Plate usually form small anhedral crystals that are also low in manganese and commonly range between Hd 40 and Hd 75 mole per cent (Figure 7A).

The later stage of skarn alteration at Nickel Plate is largely restricted to the outer and lower margins of the envelope, normally within 100 metres of the skarn front. This late-stage alteration is rarely seen in the central or upper parts of the skarn zone, except along fractures or dike sill margins. It resulted in the introduction of sulphides and gold, accompanied by abundant scapolite, calcite and quartz with minor amounts of epidote, chlorite, clinozoisite, prehnite, orthoclase and local axinite. Dolmage and Brown (1945) describe the scapolite as dipyre, while XRD analyses indicate some mizzonite is also present (Ray et al., 1986b). The ferromagnesian minerals at the Nickel Plate mine, and in other skarns throughout the district, are remarkably fresh and show little evidence of widespread retrograde alteration.

The gold-bearing sulphide zones normally form semi-conformable, tabular bodies situated less than 100

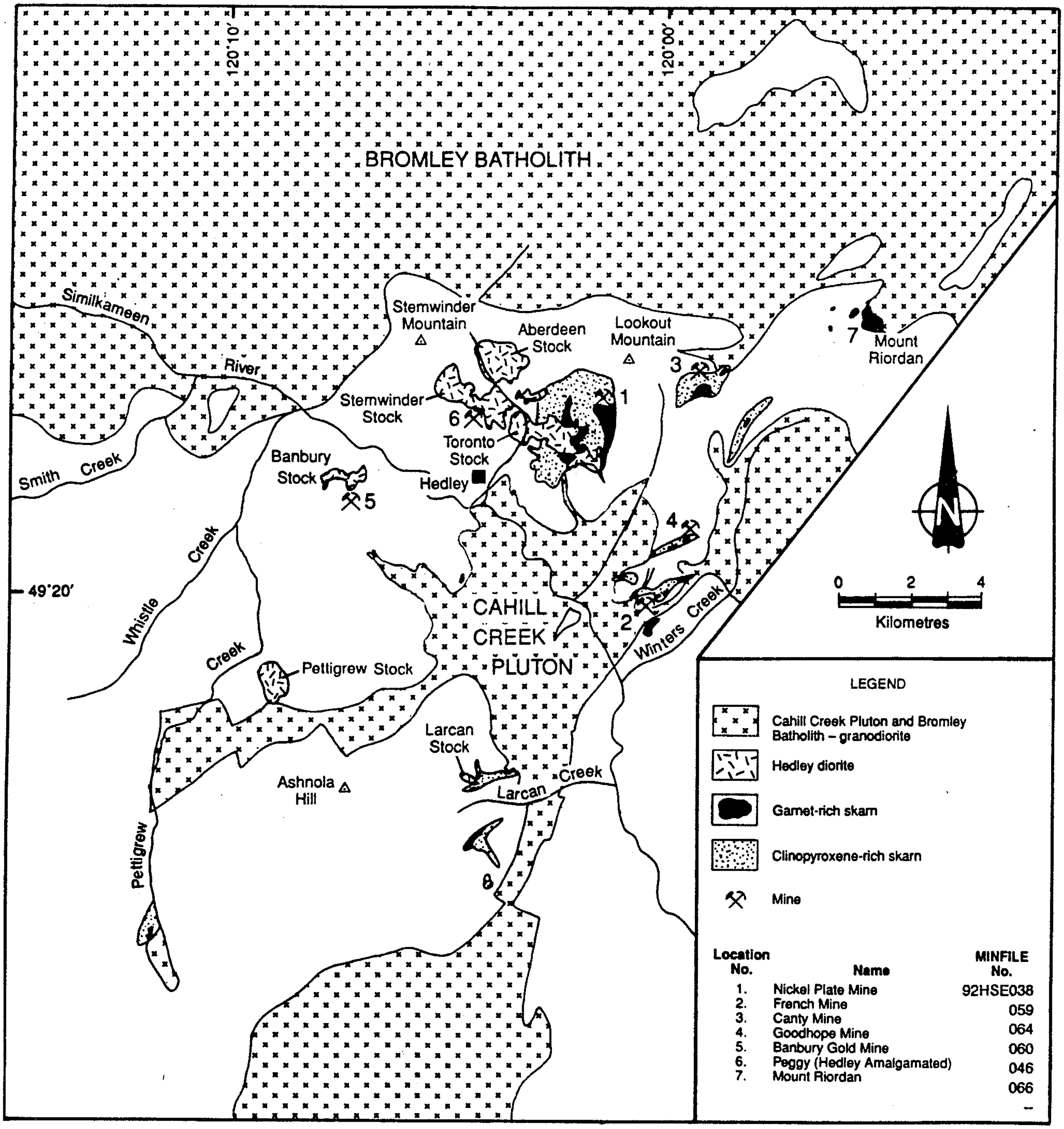

Figure 3 Areas of major skarn development in the Hedley district (after Ray et al., 1988).

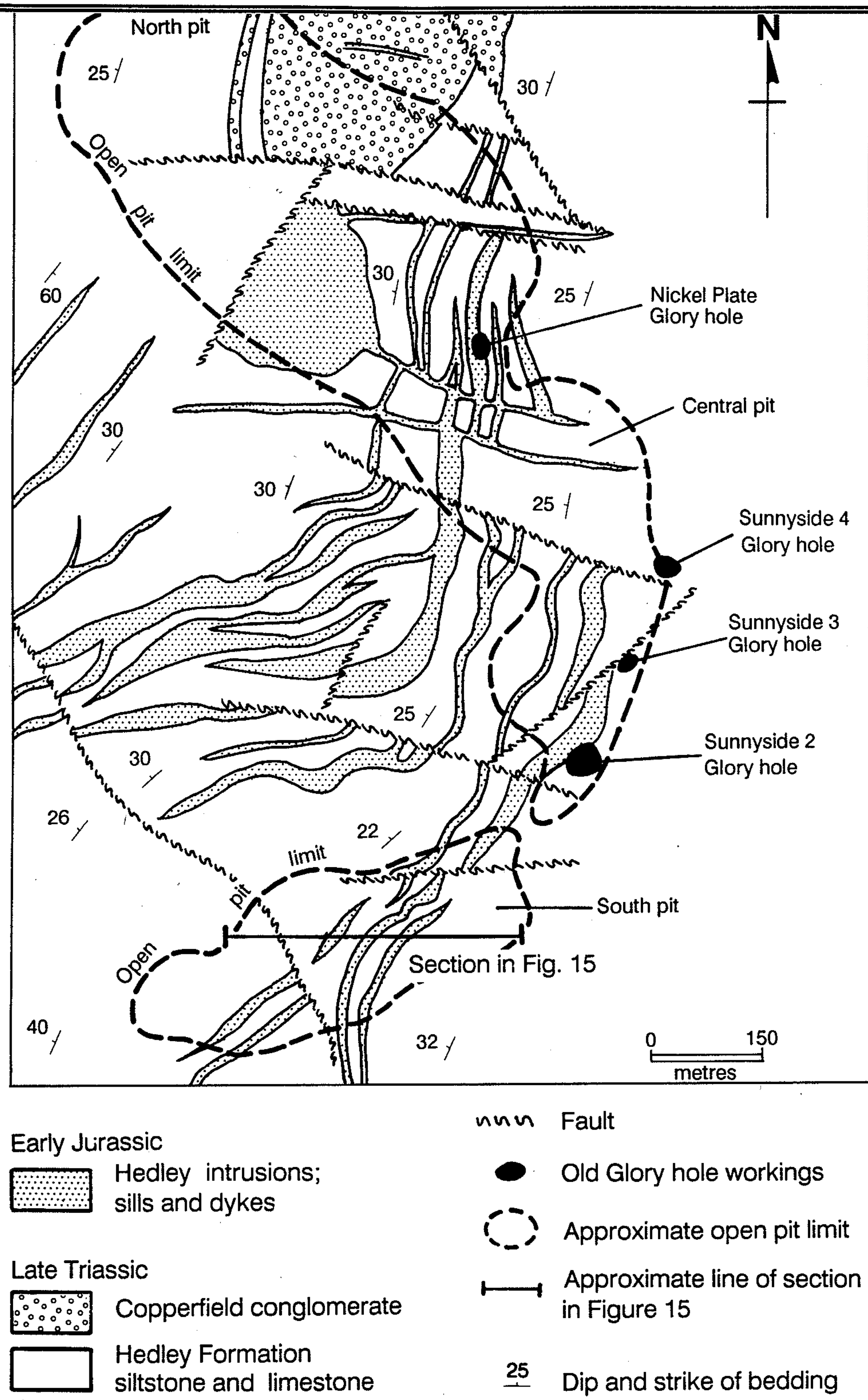

Figure 4 General geology of the Nickel Plate deposit, Hedley camp. (Compiled from Bilingsley and Hume, 1941; Lee, 1951; Ray and Dawson, 1988; Simpson, 1988.)

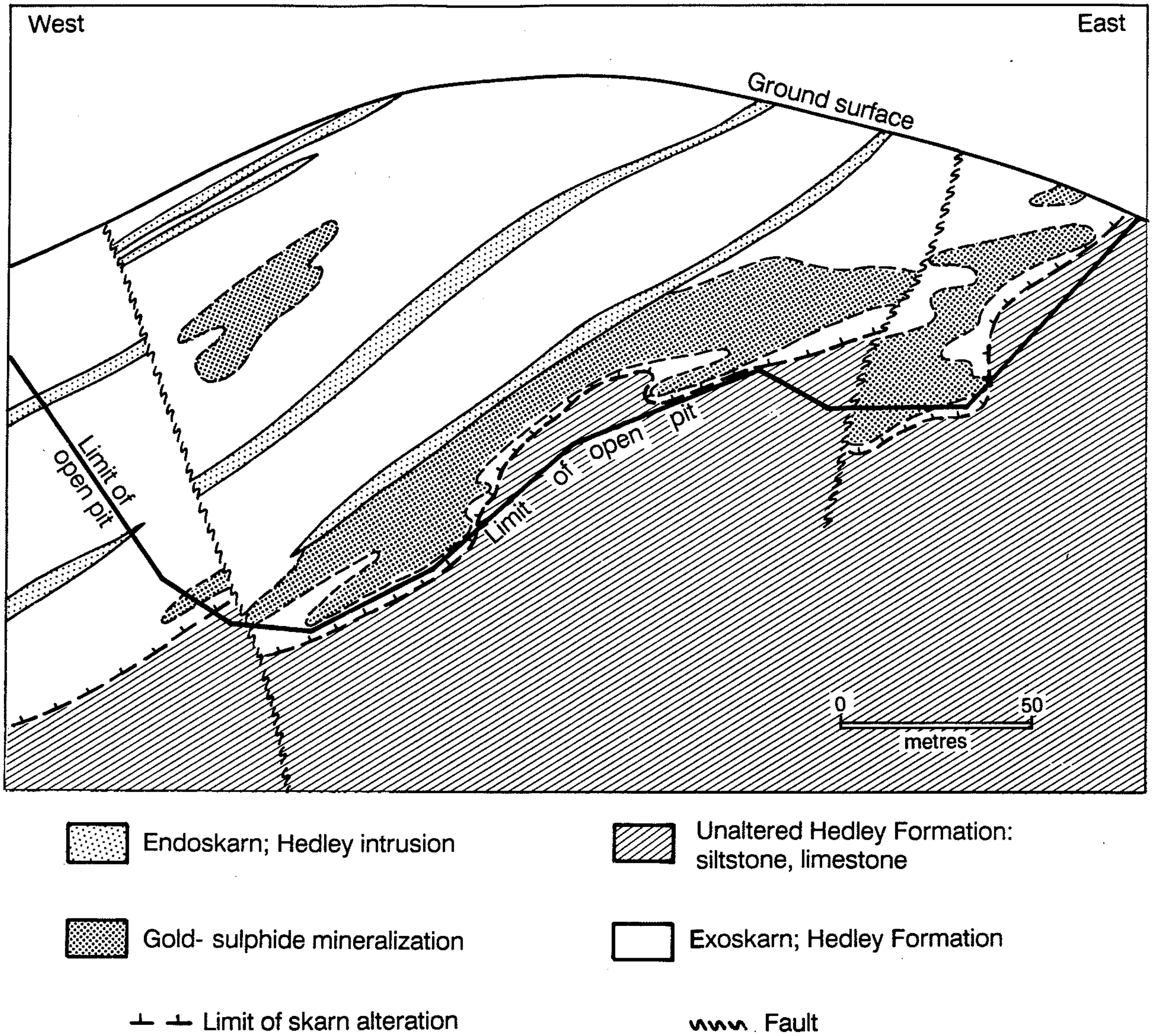

Figure 5 Generalized section through the southern part of the Nickel Plate deposit, Hedley camp. For location see Figure 4. (Compiled from Simpson, 1988 and unpublished reports and drill sections, courtesy of Mascot Gold Mines Ltd.)

metres from the outer and lower skarn margins (Fig. 5). They are both lithologically and structurally controlled along northwesterly plunging minor folds, fractures and sill-dike intersections (Billingsley and Hume, 1941; Dolmage and Brown, 1945).

There are significant geochemical and mineralogical variations throughout the deposit. The main Nickel Plate ore zone near the Nickel Plate glory hole (Fig. 14), in the northern part of the deposit, consists primarily of arsenopyrite, pyrrhotite and chalcopyrite with carbonate, pyroxene, scapolite, garnet and quartz. Arsenopyrite often forms coarse, wedge-shaped crystals up to 1 centimetre in length and the sulphides occur as disseminations and fracture fillings within the exoskarn. The Sunnyside ore zones in the central part of the deposit (Fig. 14) are strongly

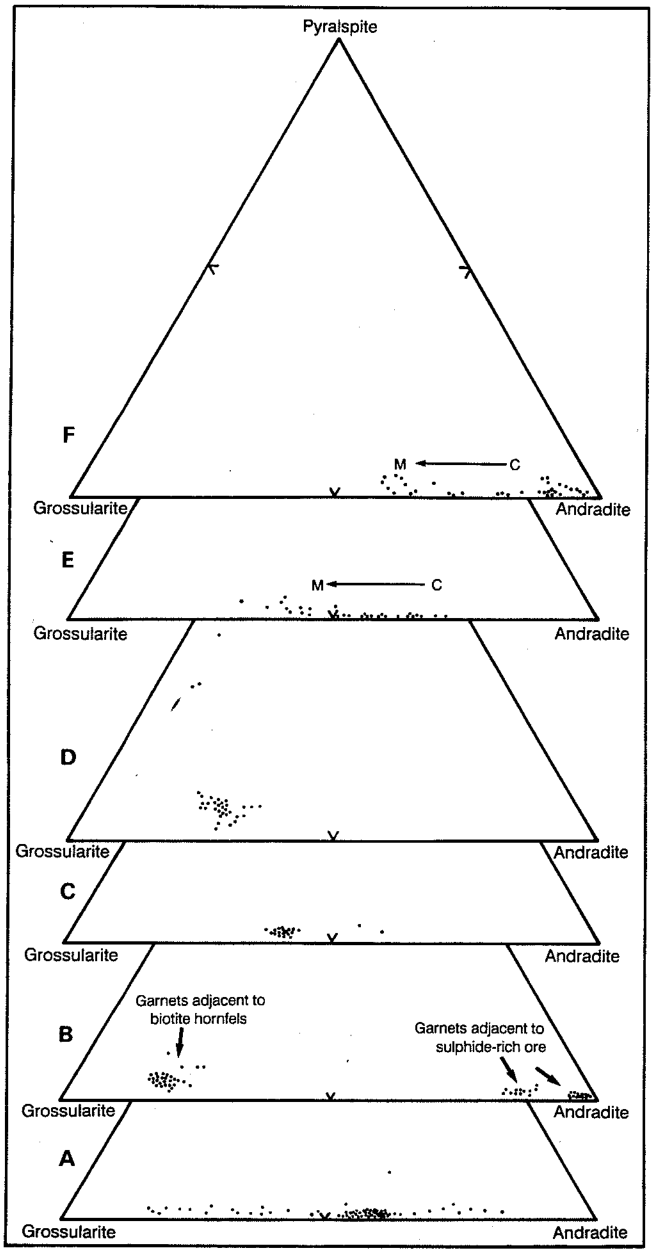

Figure 6 Composition of exoskarn garnets from the Hedley camp.*
A = Nickel Plate mine (65 analyses).
B = French mine (56 analyses).
C = Canty mine (20 analyses).
D = Goodhope mine (33 analyses).
E = Peggy (29 analyses).
F = Mount Riordan (35 analyses).
Arrows in Figures 6E and 6F indicate direction of crystal growth from cores (C) to margins (M).
*Analyses by G.E. Ray and G.L. Dawson at the University of British Columbia, Vancouver, except in Figure 6A which includes 25 analyses by A.D. Ettlinger at Washington State University, U.S.A.

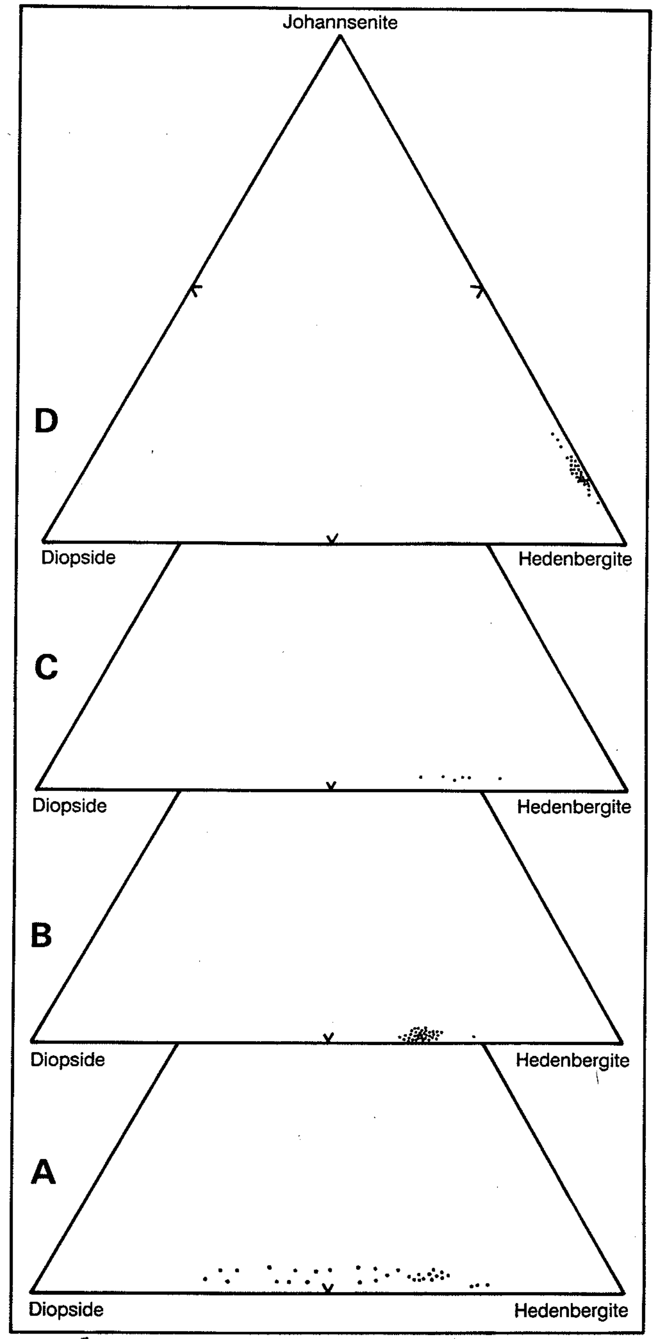

Figure 7 Composition of exoskarn pyroxenes from the Hedley camp.*
A = Nickel Plate mine (38 analyses).
B = French mine (35 analyses).
C = Canty mine (5 analyses).
D = Goodhope mine (29 analyses on coarse, tabular pyroxene crystals).
*Analyses by G.E. Ray and G.L. Dawson at The University of British Columbia, Vancouver, except in Figure 7A which includes 23 analyses by A.D. Ettlinger at Washington State University, U.S.A.

controlled by either sill-dike intersections or fold hinges. Although the sulphide mineralogy and textures resemble those in the Nickel Plate zone, pyrrhotite dominates in the Sunnyside zones. The mineralization in the southern part of the deposit comprises lenses and pods of massive to semi-massive sulphide mineralization; it is noticeably richer in chalcopyrite and contains higher silver and zinc values.

Grain boundary relationships suggest the following three stage of sulphide deposition: (1) pyrite; (2) arsenopyrite and gersdorffite (NiAsS); and (3) pyrrhotite, chalcopyrite and sphalerite (R. Simpson, personal communication, 1987). Gold mineralization is related to the latter two stages, and minor amounts of magnetite are associated with the first and last sulphide phases. Pyrrhotite and arsenopyrite are the most common sulphides. Present in lesser amounts, but locally dominant, are pyrite, chalcopyrite, and cadmium-rich sphalerite with minor amounts of magnetite and cobalt minerals. Trace minerals include galena, native bismuth, gold, electrum, tetrahedrite, native copper, gersdorffite, marcasite, molybdenite, titanite, bismuth tellurides (hedlyite, tetradynite), cobaltite, crythrite, pyrargyrite, and breithauptite. Trace amounts of maldonite (Au_2Bi) have recently been identified (Ettlinger and Ray, 1988) but no scheelite has been seen in the deposit. The native gold, with hedleyite, occurs as minute blebs, generally less than 25 microns in size, within and adjacent to grains of arsenopyrite and gersdorffite. In the South pit area (Fig. 4), electrum occurs in close association with chalcopyrite, pyrrhotite, sphalerite and native bismuth; it tends to be concentrated in microfractures within and around the sulphides.

A recent preliminary statistical study (Simpson, 1987) based on analyses of over 300 mineralized samples from various ore zones in the Nickel Plate deposit, showed the following correlation coefficients: Au:Bi, 0.94; Ag:Cu, 0.84; Bi:Co, 0.62; Au:Co, 0.58; Au:As, 0.46; Au:Ag, 0.28; and Au:Cu, 0.17. The strong positive correlation between gold and bismuth reflects the close association of native gold with hedleyite, while the moderate positive correlation between gold, cobalt and arsenic confirms the observed association of gold, arsenopyrite and gersdorffite. The high positive correlation between silver and copper may indicate that some silver occurs as a lattice constituent in the chalcopyrite. The gold and silver values are relatively independent of each other despite the presence of electrum, and there is generally a low correlation between gold and copper. Gold:silver ratios in the Nickel Plate and Sunnyside zones are greater than 1 with silver averaging 2 ppm. By contrast, in the southern part of the deposit where electrum is present, the Au:Ag ratio is less than 1, with silver averaging 17 ppm.

Bismuth averages 20 ppm but may reach concentrations of several hundred parts per million in areas with higher gold values. Nickel and cobalt values normally range from 100 to 200 ppm but both locally exceed 2 per cent in areas containing abundant visible erythrite and high gold values. Copper commonly exceeds 0.5 per cent over intervals of several metres, particularly in the sulphide-rich South pit area (Fig. 4). Secondary gold enrichment is also present in some weathered, near-surface, oxide-rich zones and along certain faults. The resulting red hematitic clay zones may carry gold grading over 34 grams per tonne.

MINERALOGICAL ZONING IN THE HEDLEY SKARNS

Skarn and skarn-related alteration containing pyroxene-garnet assemblages are common and widely distributed in Nicola group rocks throughout the Hedley district. Alteration varies from narrow veinlets or irregular patches only centimetres or metres in diameter, up to huge alteration envelopes several hundred metres thick, such as that associated with the Nickel Plate deposit (Fig. 8).

On an outcrop scale, a consistent concentric zoning of gangue mineralogy is recognized which is described by Ray et al.(1987). These small-scale zones are commonly the result of reaction between carbonate-rich beds and the skarn-forming fluids and range from the inner, coarse-grained, more intensely altered skarn assemblages, to the outer, finer grained margins of the envelope. In the ideal form the alteration zones initially develop along fractures adjacent to carbonate-rich beds or marble clasts. A central carbonate-rich core is commonly surrounded by a pinkish brown, garnet-rich section which passes outwards across a sharp contact to a green-coloured wider, clinopyroxene-rich section. The clinopyroxene-rich zone may be separable into an inner, dark green, coarser grained assemblage and an outer pale green, siliceous, finer grained portion consisting largely of fine-grained clinopyroxene quartz. The clinopyroxene-rich zone may pass outwards to a narrow section containing pink potassium feldspar and quartz. This potassium feldspar zone is often only a few centimetres thick and is absent in many

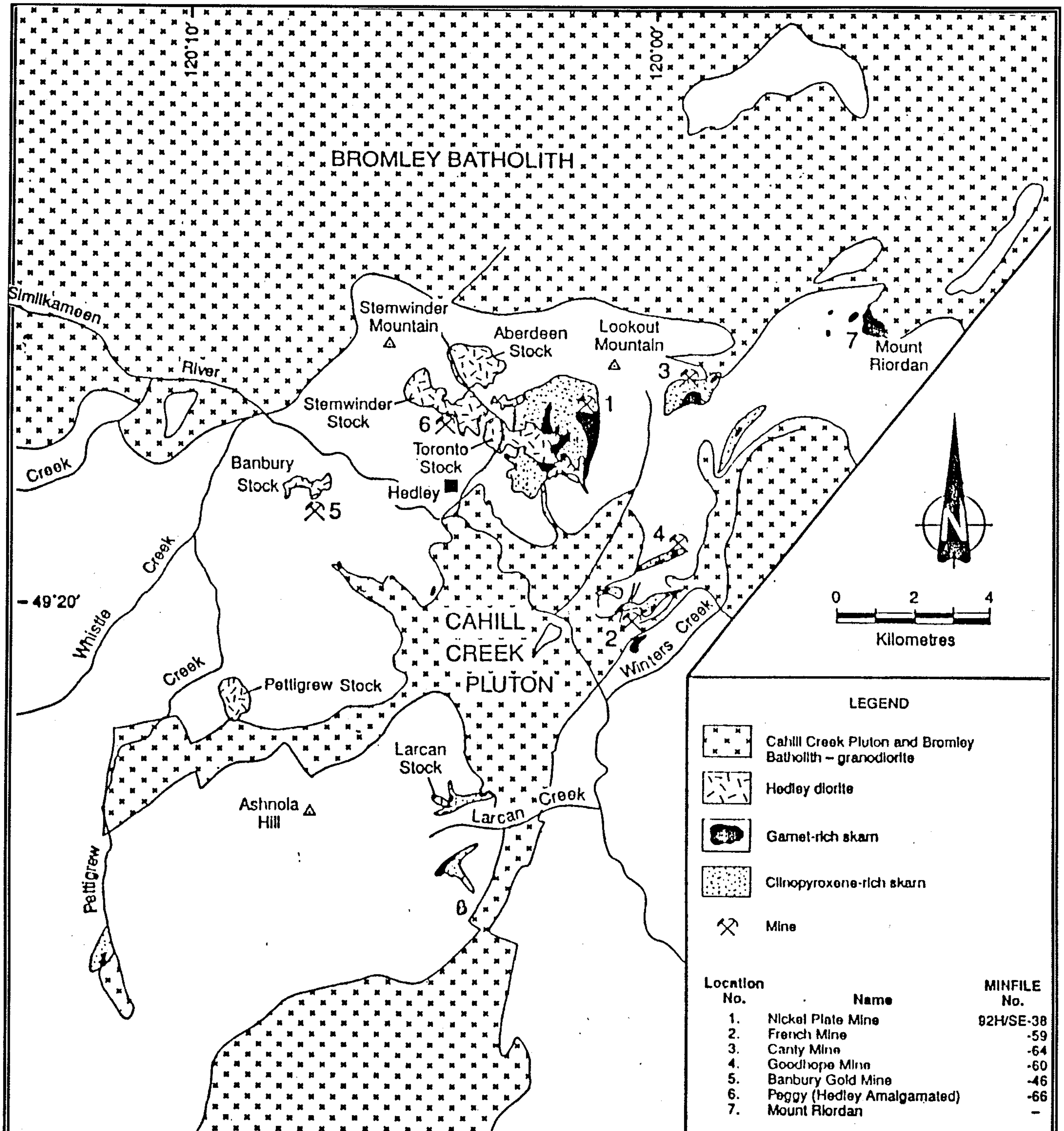

Figure 8 Areas of major skarn development in the Hedley district.

outcrops.

The outermost alteration zone is of variable thickness and characteristically comprises a dark brown, siliceous, massive and fine-grained biotite hornfels. Contacts between the inner clinopyroxene-rich and outermost biotite hornfels zones are generally sharp, except where they are separated by thin reaction zones containing potassium feldspar and quartz. The outermost biotite hornfels is commonly cut by a network of thin, light-coloured veinlets of pyroxene and minor amphibole. These fine-grained pyroxene-rich veinlets may be irregular, but in many outcrops they show a preferred orientation and have followed pre-existing microfractures.

A temporal sequence of skarn development is recognized in the Hedley district and is illustrated in Figure 9. Initiation of the skarn process on a small scale commenced with formation of the siliceous biotite hornfels as an irregular patch of alteration (Fig. 9A) often centred about a bedding plane fracture or crosscutting fault. It is emphasized that this hornfels alteration is **not** a thermal metamorphic feature related to the intrusion of the Hedley sills and dykes, but represents the preliminary stage of the skarning process and results from passage of the early, very hot, skarn-forming fluids along pre-existing fractures. Locally, some Hedley intrusions are also overprinted by the biotite hornfels-type alteration which emphasizes the post-magmatic, rather than the syn-magmatic, nature of this alteration. The initial fracture control suggests that parts of this early hornfels-type alteration did not form under isochemical conditions.

As skarn-forming fluids continued to pass through the sedimentary host rock, clinopyroxene-rich alteration began to develop and the surrounding biotite hornfels aureole grew slowly outward (Fig. 9B). With time, the area affected by the clinopyoxene-rich alteration grew steadily larger and development of a central zone of garnet-rich alteration began (Fig. 9C). The garnet-rich alteration, which also steadily expanded outward, always began within the pre-existing pyroxene-rich zone, developing either along a fracture or as a reaction rim adjacent to an original carbonate-rich sedimentary bed.

When the biotite hornfelsic aureole reached a certain diameter, which in some outcrops can be measured in tens of metres or less, its development either slowed or stopped. However both the garnet-rich and pyroxene-rich alteration zones continued their steady growth until they overprinted and completely replaced the hornfelsic aureole. This replacement often resulted in the development of the thin reaction zones of pink potassium feldspar and quartz that separate the pyroxene and biotite hornfelsic zones (Figs. 9B and C). The larger skarn envelopes, in contrast to the outcrop-sized skarns, have no peripheral biotite hornfelsic aureoles and the pyroxene-rich alteration passes directly outward into unaltered host rocks. In many cases the envelope of pyroxene-rich alteration contains small, irregularly distributed remnants of the earlier biotite and potassium feldspar alteration (Fig. 9D).

Most of the very fine-grained, pyroxene-rich alteration in the Hedley district resembles what some geologists call "calc-silicate hornfels". However, the fracture-controlled nature of the pyroxene alteration suggests that metasomatism occurred on a local scale and thus it is regarded as "skarn" *sensu lato*. Alteration of this type is particularly well developed within the hangingwall portions of the larger skarn envelopes. An example of this hangingwall alteration is the "upper siliceous beds" which lie above the Nickel Plate deposit and are characterized by very fine-grained clinopyroxene, quartz and occasional potassium feldspar replacement of the thin-bedded sedimentary rocks. The presence of similar widespread alteration elsewhere in the district, such as that currently being explored by Chevron Minerals Ltd. east of Ashnola Hill (L. Dick, personal communication, 1987), may mark the presence of major skarn systems at depth.

GEOCHEMICAL CHANGES ASSOCIATED WITH SKARN ALTERATION AND MINERALIZATION

Many previous workers including Camsell (1910), Billingsley and Hume (1941) and Dolmage and Brown (1945), noted a spatial association between the Nickel Plate auriferous skarn Mineralization and the Hedley intrusions, leading them to suggest a genetic relationship. Preliminary geochemical data presented in this report indirectly support this conclusion and suggest that the iron in the skarns was derived from the intrusions.

Many major elements including calcium, aluminum and titanium show little or no variation between the unaltered and skarn-altered dioritic Hedley intrusions. Some elements, however, notably total iron, and to a lesser extent silica, potassium and sodium, exhibit progressive compositional changes during the skarning process. Figure 10 shows that, compared to unaltered Hedley diorites, the skarn-altered (endoskarn) intrusions gain

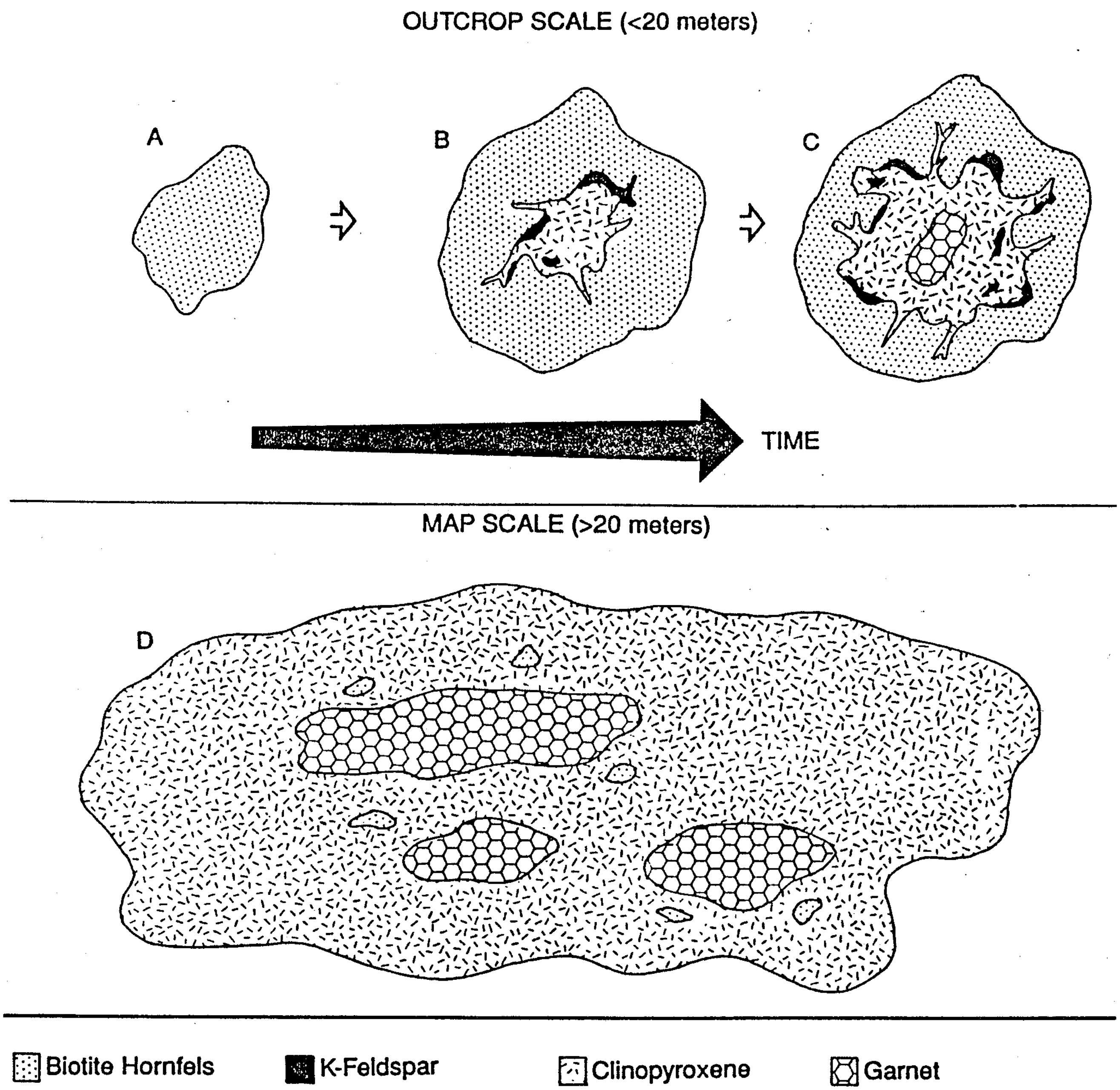

Figure 9 Progressive development of mineralogical zones in the Hedley gold skarns.

potassium and sodium. Likewise, Figure 11A illustrates that the skarning process results in a considerable loss of total iron and a modest gain in silica; this conclusion is supported by a plot of total iron/titanium (Fig. 11B). The genetic implications of this

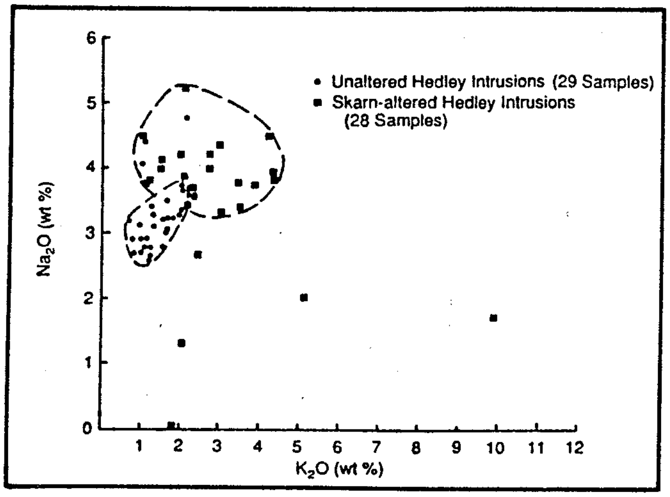

Figure 10 Plot of the Na_2O versus K_2O illustrating increases in sodium and potassium in skarn-altered Hedley intrusions compared to unaltered Hedley intrusions.

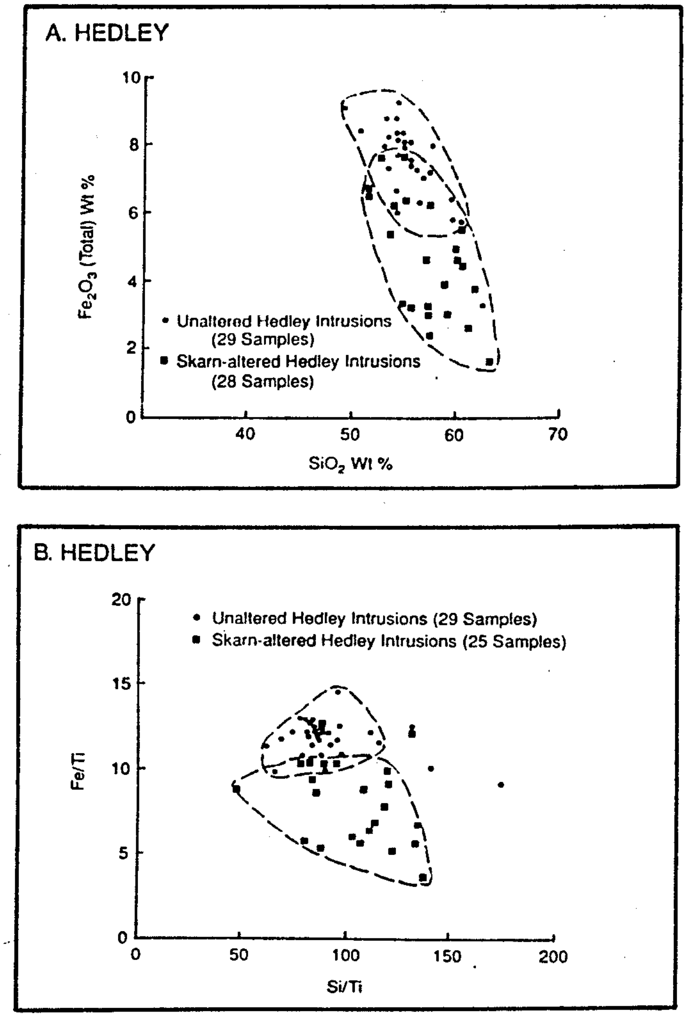

Figure 11 Comparing unaltered and skarn-altered Hedley intrusions; A = Fe_2O_3 (total) versus SiO_2 weight per cent; B = Fe/Ti versus Si/Ti.

iron loss are illustrated by Figure 2 which compares endoskarn and exoskarn samples from three drill holes that intersect different parts of the Nickel Plate deposit. All the samples collected from these holes exhibit varying degrees of skarn alteration; the endo-skarn samples are dioritic Hedley intrusions while the exoskarn is largely represented by altered calcareous siltstones and limestones of the Hedley formation (Table 1). Note that DDH 401 was collared outside the open-pit perimeter and intersected barren, generally fine-grained pyroxene-rich skarn; DDH 73 intersected subeconomic skarn-hosted mineralization west of the open-pit boundary; while DDH 261 contained ore-grade skarn mineralization and was collared within the planned open-pit area (Fig. 12A).

Within the barren intersection (Fig. 12B) the two fields outlining the iron-silica contents of the exoskarn and endoskarn are relatively close together, and the endoskarn is the more iron-rich. By contrast, in the subeconomic and economic intersections (Figs. 12C and 12D) the iron content of the exoskarn greatly exceeds that of the endoskarn. In these two holes the exoskarn shows a major increase in iron and decrease in silica, matched by a corresponding drop in iron and rise in the silica in the endoskarn.

To summarize, progressive skarn alteration of the Hedley diorite intrusions results in no change in the calcium content, a modest increase in the sodium, potassium and silica contents and a major decrease in total iron. The adjacent skarn-altered sedimentary rocks (exoskarns) are correspondingly enriched in iron and depleted in silica. These preliminary results suggest three things. First, that relatively few metasomatic geochemical changes took place in the outer parts of the Nickel Plate skarn envelope and that the most dramatic metasomatism occurs in the mineralized parts of the skarn where there was presumably greater fluid movement. Second, the Hedley intrusive dyke and sill swarm was the source of the iron enrichment in the adjacent exoskarn, and thus may also be the primary source of the skarn-hosted gold. Third, outlining areas containing iron-enriched exoskarn adjacent to iron-

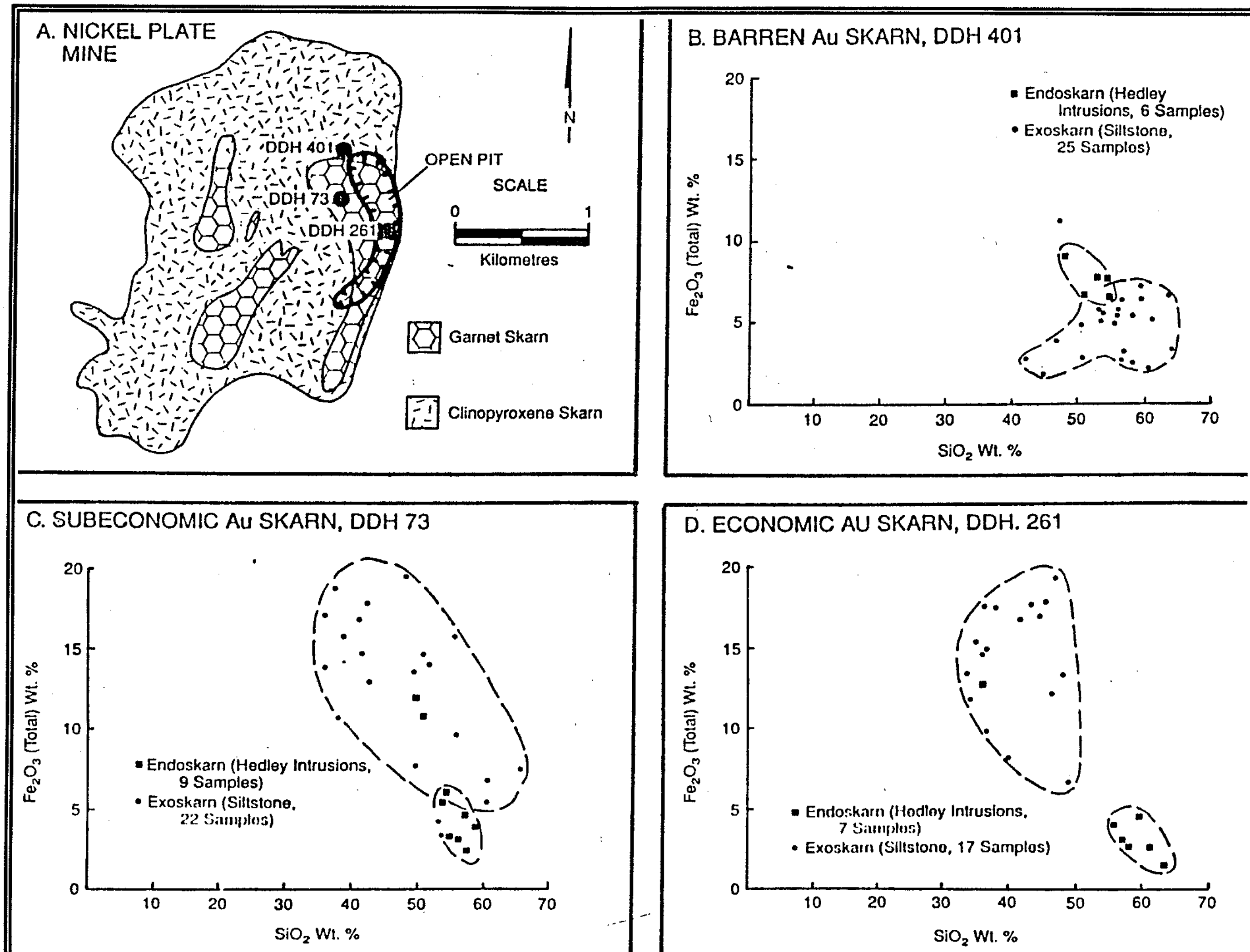

Figure 12 Plot of Fe_2O_3 (total) weight per cent versus SiO_2 weight per cent comparing barren, subeconomic and economic skarn from three diamond-drill holes at Nickel Plate mine: A=Nickel Plate mine showing location of drill holes in relation to the open pit and skarn zone; B=barren skarn, DDH 401; C= subeconomic skarn, DDH 73; D=economic skarn, DDH 261. Note: passage from barren to auriferous skarn is accompanied by a decrease in iron in the endoskarn Hedley intrusions and a corresponding increase in iron in the exoskarn sedimentary rocks.

depleted endoskarn may provide a useful exploration tool for recognizing close proximity to auriferous skarn mineralization in the Hedley district.

GEOLOGY OF THE MOUNT RIORDAN TUNGSTEN-COPPER SKARN

During this study interesting tungsten-copper skarn mineralization was outlined within and adjacent to several Crown-granted mineral claims on Mount Riordan, approximately 7 kilometres east-northeast of the Nickel Plate mine (Figs. 1 and 8). Although there are numerous old prospect pits on Mount Riordan, it was uncertain at first whether the scheelite mineralization had been recognized by the earlier workers, particularly since there was no evidence of past

Table 1
Skarn-Altered Hedley Formation (Exoskarn)

Field No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O
401.01	47.27	0.51	8.77	11.14	0.20	6.40	17.92	0.00	3.18
401.02	58.17	0.57	16.06	2.56	0.08	3.46	6.91	2.19	7.11
401.03	53.36	0.73	15.21	5.69	0.16	4.75	13.38	1.87	3.30
401.05	56.59	0.66	17.04	6.35	0.13	3.33	7.26	3.91	3.14
401.06	57.97	0.63	16.18	5.42	0.08	3.98	6.59	4.12	1.90
401.07	53.68	0.55	13.21	5.55	0.18	4.17	11.52	1.18	5.66
401.08	55.75	0.58	13.82	5.49	0.13	3.48	10.25	0.51	7.72
401.09	55.97	0.54	14.38	5.79	0.12	2.94	8.69	0.61	8.60
401.10	53.45	0.47	14.41	5.11	0.12	3.08	10.42	0.87	7.63
401.11	56.56	0.66	17.75	2.69	0.07	2.76	8.48	3.43	4.97
401.13	58.36	0.59	15.67	3.75	0.10	4.03	8.12	2.42	5.76
401.14	55.28	0.67	18.00	4.80	0.07	4.89	9.57	4.24	1.29
401.15	56.83	0.74	17.23	3.26	0.07	4.27	10.27	2.85	3.76
401.17	51.04	0.68	16.81	6.52	0.11	5.85	14.91	2.89	0.23
401.18	55.88	0.60	16.83	5.52	0.07	3.82	7.11	2.52	4.65
401.19	59.19	0.87	12.62	7.12	0.08	4.05	6.03	1.54	4.67
401.20	63.42	0.86	13.06	6.65	0.07	3.30	4.16	1.80	5.05
401.22	42.02	0.23	4.59	2.77	0.19	3.80	27.62	0.00	1.04
401.25	63.95	0.33	6.12	3.29	0.12	3.20	11.24	0.12	3.82
401.26	59.20	0.90	17.93	6.42	0.12	2.15	4.44	3.14	3.11
401.27	44.77	0.20	4.89	1.84	0.06	2.59	27.73	0.71	0.85
401.28	60.54	0.25	4.99	2.21	0.06	3.85	15.91	0.65	1.04
401.29	50.80	0.32	6.41	2.77	0.05	2.71	18.62	0.81	1.54
401.31	61.06	0.41	8.66	5.15	0.09	3.57	9.50	0.55	4.63
401.32	46.68	0.28	6.17	3.88	0.10	7.50	24.21	0.48	1.62
73.01	60.52	0.77	11.36	5.40	0.15	3.46	8.84	1.39	6.76
73.02	52.11	0.57	7.89	12.43	0.34	4.79	16.36	1.93	2.48
73.03	42.80	0.52	10.71	12.93	0.48	3.78	25.68	0.75	0.67
73.04	41.61	0.42	9.01	14.65	0.46	2.48	28.04	0.07	0.54
73.05	38.89	0.34	7.10	15.80	0.42	2.32	31.25	0.02	0.01
73.06	41.25	0.39	6.01	16.81	0.51	2.73	28.42	0.06	0.02
73.07	65.68	0.29	5.43	7.48	0.25	4.44	11.80	0.23	3.95
73.08	51.53	0.30	7.20	14.08	0.50	3.60	17.37	0.55	3.99
73.09	53.58	0.65	18.03	3.45	0.12	4.21	12.79	2.02	4.02
73.10	49.63	0.88	19.24	7.73	0.18	4.15	9.74	1.22	4.55
73.11	60.44	0.37	8.53	6.78	0.24	2.36	13.51	0.94	3.66
73.12	50.70	0.30	4.99	14.68	0.63	4.99	20.96	0.76	2.01
73.16	49.21	0.28	7.92	13.58	0.52	2.21	21.79	0.71	2.91
73.18	55.62	0.32	0.44	15.78	0.73	4.17	12.95	1.22	0.84
73.20	55.71	0.47	9.01	9.56	0.41	3.56	13.55	0.49	6.10
73.22	38.16	0.35	9.78	10.79	0.56	2.94	30.51	0.38	0.35
73.23	37.39	0.13	5.65	18.67	0.34	1.67	31.73	0.03	0.01
73.24	42.48	0.22	6.15	17.77	0.62	2.55	27.77	0.02	0.01
73.25	36.07	0.15	6.73	17.08	0.43	1.28	30.28	0.01	0.01
73.27	48.19	0.46	2.95	19.48	0.79	4.04	22.38	0.29	0.80
73.29	36.16	0.30	5.07	13.90	0.45	2.39	27.35	0.63	0.88
73.30	53.18	0.29	5.73	4.26	0.11	3.13	23.65	0.89	1.06
261.01	38.10	0.27	8.03	17.46	0.37	1.31	32.43	0.06	0.05
261.02	36.66	0.13	9.26	14.88	0.32	0.44	33.73	0.05	0.80
261.06	41.61	0.57	5.71	16.79	0.60	2.36	28.61	0.04	0.02
261.07	36.42	0.16	7.16	17.53	0.27	0.77	34.20	0.01	0.33
261.08	35.06	0.18	7.63	15.27	0.29	0.84	34.27	0.01	0.71
261.09	46.28	0.17	2.77	12.20	0.47	1.94	27.04	0.01	0.64
261.10	34.14	0.33	3.99	11.90	0.48	2.02	31.83	0.41	0.93
261.12	43.23	0.36	7.19	17.64	0.61	2.13	26.13	0.06	1.27
261.13	45.36	0.20	3.65	17.85	0.76	3.88	23.94	0.14	0.60
261.14	46.86	0.37	4.19	19.42	0.74	4.12	22.75	0.31	0.45
261.15	33.82	0.11	2.23	13.43	0.46	1.57	26.89	0.01	0.81
261.16	35.99	0.26	6.91	14.60	0.35	2.20	21.83	0.22	2.47
261.18	47.90	0.26	5.42	13.41	0.35	2.40	20.52	0.27	1.26
261.19	44.46	0.41	6.39	16.97	0.35	2.91	16.44	0.21	2.54
261.20	36.67	0.27	5.15	9.84	0.35	2.67	27.16	0.01	1.10
261.21	48.82	0.22	4.64	6.72	0.22	1.53	22.51	0.01	1.50
261.22	39.84	0.41	6.39	8.13	0.22	3.46	23.71	0.12	3.09

drilling and the mineralization was not listed in the Ministry of Energy, Mines and Petroleum Resources' MINIFILE. Subsequent literature search indicated that the Mount Riordan occurrences were briefly described by McCammon (1953), although the mineralization was largely ignored by industry, even throughout the tungsten boom of the 1970s. W.J. Bromley (personal communication, 1987) indicates that some bulk sampling was undertaken in the 1950s, but since that time little exploration has taken place.

The outcrop geology of the Mount Riordan area is shown on Figure 13. A massive, fresh biotite hornblende granodiorite, that is characterized by coarse hornblende phenocrysts and sparse pyrite, outcrops to the northeast and east of the mountain. To the south, and presumably separated from the rocks on Mount Riordan by an east-northeastly trending fault, are the highly deformed ophiolitic rocks of the Apex Mountain complex. A very large elongate mass of mainly garnetite skarn, which reaches 900 metres in length and 500 metres in maximum width, is centred on Mount Riordan. The surrounding rocks are mostly obscured by glacial overburden, but to the west are several small exposures of skarn and one of massive, coarse-grained marble (Fig. 13). South of the summit, within the skarn, are minor remnants of altered microdiorite, while the extreme eastern edge of the skarn is in contact with altered epidote-veined outcrops of hornblende-porphyritic granodiorite similar to that occurring further northeast.

Apart from rare marble remnants, the nature of the protolith to the Mount Riordan skarn is uncertain; alteration is also so complete and exposure so poor that the stratigraphic relationship between the protolith and the sequences recognized elsewhere in the district is uncertain, although it probably lies within the limestone-rich French Mine formation. The rare marble layers in the garnetite are flat to gently dipping.

The Mount Riordan skarn differs considerably in appearance from the Nickel Plate skarn and mainly comprises massive, coarsely crystalline andraditic garnetite; almost no original textures are recognizable. Unlike the gold-bearing skarns to the west, no mineralogical zoning or biotite-hornfels rocks have been seen within the Mount Riordan skarn. The garnets vary considerably in colour; black, red, pink, brown, green and yellow-green varieties are present. In a few cases the crystals exceed 6 centimetres in diameter and show prominent growth zonations. Some massive outcrops also display sharply defined, subparallel zones of different coloured garnetite and in one outcrop the pale-coloured garnetite matrix contains "clasts" of dark-

Table 2
Analysis of Selected Grab Samples From Mount Riordan

Location No.	Lab. No.	W%	Cu ppm	Mo ppm	Au ppb	Ag ppm	Zn ppm
1	33668	0.1	850	5	475	7	75
2	33666	0.25	840	15	339	0.8	210
3	33661	>5.0	600	250	187	0.7	105
3	33662	3.0	0.7%	106	<20	10	357
3	33663	0.1	0.3%	19	161	15	321
3	33664	0.5	0.2%	33	99	9	111
3	33665	0.35	75	310	498	0.5	270
3	33667	0.25	150	145	<20	0.5	258
3	33672	4.0	0.35%	152	122	5	106
3	33673	2.0	0.16%	36	37	1.3	50
4	33670	0.9	118	6	<20	0.6	159
4	33671	0.7	117	17	40	0.5	307
5	33669	0.1	45	5	<20	0.5	73
5	33674	0.1	84	30	<20	0.5	52
6	33676	<0.1	75	5	14	3	138
6	33677	<0.1	0.74%	7	1690	19	0.11%
7	33675	<0.1	0.13%	6	29	0.7	118

Note: W by semi-quantitative emmission spectrophotometry; Cu, Mo, Au, Ag and Zn by AAS analysis).

coloured garnetite up to 1 metre long and 0.2 metre wide. These clasts have sharp contacts and it is uncertain whether they represent remnants of either an original conglomeratic texture, a tectonic boudinage feature, or the results of two different episodes of garnet growth.

Quartz and epidote together with variable amounts of carbonate, hedenbergite, clinopyroxene and actinolite, and traces of chlorite and wollastonite are also present in the garnetite. Some epidote forms coarse euhedral crystals. Locally, particularly near the summit of Mount Riordan, the skarn is cut by veins, blebs and stringers of either white quartz or coarsely crystalline carbonate that may exceed 1 metre in width. In some veinlets, where the quartz and carbonate are intergrown, the quartz forms elongate, well-terminated crystals up to 3 centimetres in length.

Locally the skarn contains pockets, irregular veinlets and disseminations of magnetite intergrown with variable amounts of pyrrhotite, pyrite, chalcopyrite and trace bornite. Magnetite is present within and adjacent to a short adit on the eastern side of Mount Riordan and in the most westerly outcrop of skarn in the area (Fig. 13). Generally the gold values in the skarn are very low (see Table 2), however, the highest assays (up to 1.69 ppm gold) are found in the magnetic-sulphide-rich portions of the skarn.

Visible traces of scheelite are seen over a wide area, both throughout the skarn and as minute detrital fragments in the soils. However, the best developed tungsten mineralization occurs close to the summit of the mountain where numerous old pits and trenches have been dug in an area of approximately 40 by 100 metres. In this area, where the garnet skarn contains abundant coarse quartz and/or carbonate veining and disseminated massive pyrite-pyrrhotite, it is extensively weathered to jarosite.

The scheelite occurs in two forms. The commonest and probably earliest is found as small crystals, generally less than 1 millimetre in diameter, sparsely disseminated or clustered in zones throughout the garnetite. The other, possibly later generation, forms spectacular blebs, coarse crystalline masses and irregular veinlets up to 5 centimetres wide and associated with quartz and carbonate veining and in some instances both the quartz and carbonate enclose rounded masses of scheelite. The distribution of the coarse scheelite is generally irregular, however, in one trench the veinlets form an irregular stockwork. Some scheelite-rich outcrops may also contain minor amounts of powellite [Ca(Mo, W)O_4] although this has not been positively identified, together with coarse axinite. Analyses of various mineralized grab samples collected throughout the Mount Riordan skarn are listed in Table 2.

The age and origin of the Mount Riordan skarn is unknown and it is uncertain whether the microdiorite remnants within the skarn, and the porphyritic granodiorite further east, are related to the skarn alteration and tungsten-copper mineralization. However, epidote veining and alteration indicate that both these intrusions predate the skarn.

DISTRICT-WIDE METALLOGENIC ZONING IN THE HEDLEY DISTRICT

The location and distribution of areas underlain by major skarn alteration in the Hedley district are shown in Figure 8. All these areas lie within the central and eastern, more proximal facies, lime-rich supracrustal rocks, while skarns are only poorly developed in the deeper basinal facies to the west. The largest area of skarn alteration covers approximately 6 square kilometres and surrounds the Nickel Plate deposit. Other substantial alteration zones include those associated with the Canty. Goodhope and French mines, as well as areas cast of Ashnola Hill and at Mount Riordan.

The auriferous deposits in the Hedley camp have formerly been regarded as relatively uniform gold (copper-cobalt-arsenic) skarn mineralization (Camsell,

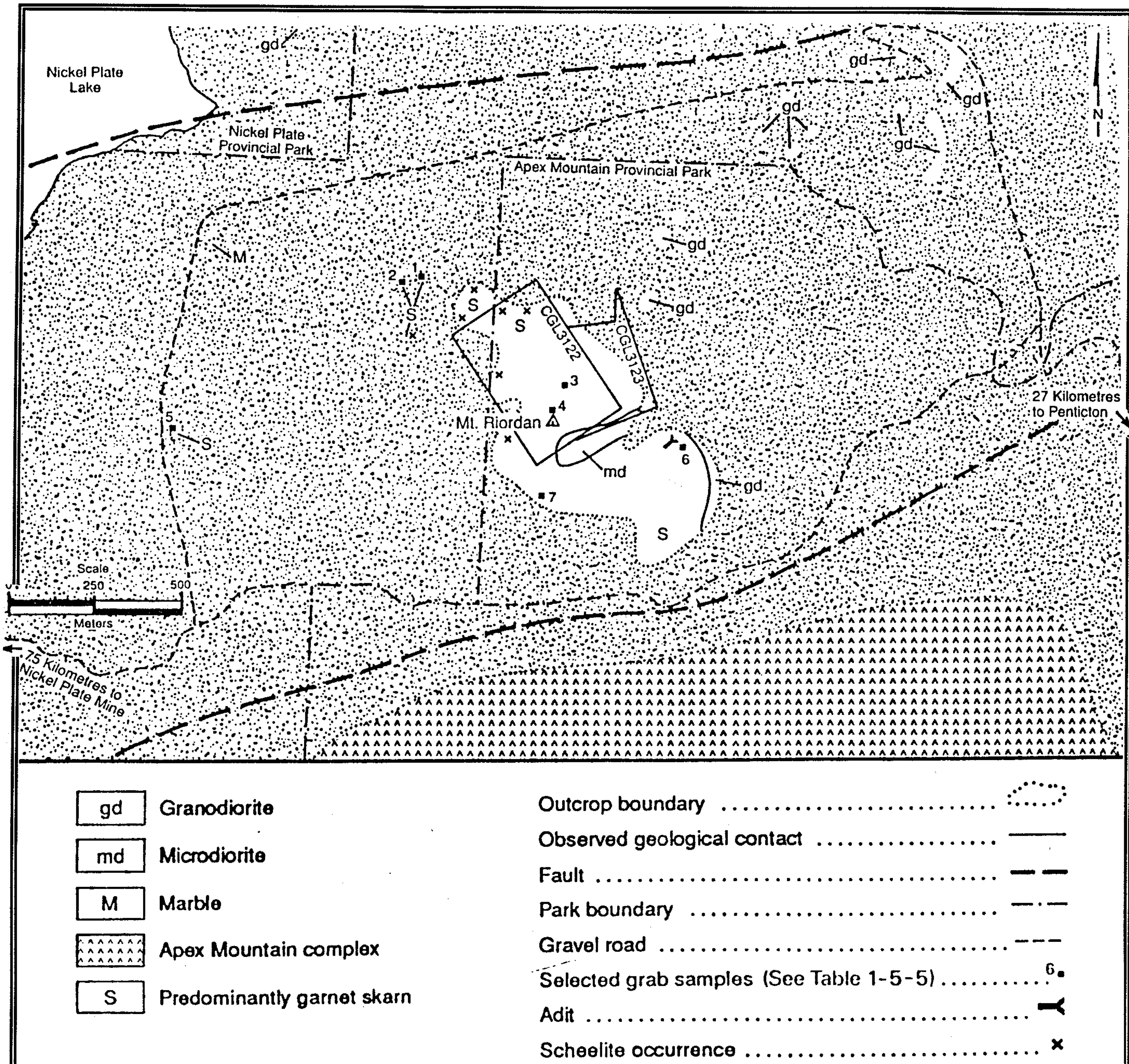

Figure 13 Outcrop geology of the Mount Riordan area. Note: for assay results of selected grab samples from locations 1 to 7 see Table 2

1910; Billingsley and Hume, 1941; Ray et al., 1987). However, the Mount Riordan skarn is distinct in being gold-poor, tungsten and copper-rich, and garnet-dominant in contrast to the pyroxene-dominant Nickel

Table 3
Characteristics of East-West Skarn Variation Across the Hedley District

FEATURES	WEST NICKEL PLATE MINE	FRENCH AND GOODHOPE MINES	EAST MOUNT RIORDAN
Skarn mineralogy	Banded, clinopyroxene-dominant skarn. Garnets – generally noncrystalline and brown	Locally clinopyroxene or garnet-dominant skarn. Crystalline and noncrystalline garnet	Massive, garnet-dominant skarn. Crystalline garnet with highly variable colour
Degree of skarn overprinting	Sedimentary structures often preserved in skarn	Sedimentary structures locally preserved	No sedimentary structures preserved
Skarn metallogeny	Au, As, Cu, Co, Bi, Te, Ag, Ni	Au, Cu, W, Co, Mo, Bi, As, Ag	W, Cu, Ag
Skarn-related intrusions	Associated with I-type dioritic Hedley intrusions	Associated with I-type dioritic Hedley intrusions	Associated with I-type granodiorites that do not resemble the Hedley intrusions
District hostrock geology	Siltstones and limestones of the Hedley formation	Limestone breccia and limy sediments of the French Mine formation	Probably massive limestone of the French Mine formation

Plate skarn. The following possible relationships are considered:

(1) The Mount Riordan skarn is unrelated to the gold-rich skarns further west and their relatively close proximity is coincidental.

(2) The two skarn types are related and derived from a common basement source, but were emplaced at different, possibly widely separated times.

(3) The Mount Riordan skarn is temporally and genetically related to the Nickel Plate skarn and other gold skarns in the district.

The third alternative is tentatively favoured, partly because the mineralization and mineralogy in the vicinity of the French and Goodhope mines exhibit geochemical and mineralogical characteristics intermediate to the Mount Riordan and Nickel Plate skarns. For example, the Goodhope skarn contains crystalline, variably coloured garnet similar to Mount Riordan while other skarn occurrences close by are magnetite rich. Both the Goodhope and French mines locally contain abundant fine-and-coarse grained scheelite together with the gold and copper. Underground chip sampling along a 35-metre, gold-rich skarn section at the French mine averaged 0.68 per cent WO_3 with maximum values of 1.32 per cent over 3 metres (Westervelt Engineering Ltd., unpublished report, January 12, 1978). Thus, the Hedley camp probably possesses a district-wide metallogenic zoning with gold-rich, tungsten-poor skarns in the west through to tungsten-rich, gold and arsenic-poor skarns in the east. This has important implications elsewhere in the Cordillera, as some tungsten skarn districts, particularly those associated with fracture-related basin margins, may have gold skarn potential. The east-to-west metallogenic zoning is also accompanied by changes in skarn mineralogy, hostrock geology and composition of the skarn-related intrusions (Table 3). The skarns in the western and central parts of the district are clinopyroxene-rich and epidote-poor, while the Mount Riordan skarn is garnet and epidote-rich and clinopyroxene-poor. the nature and colour of the garnets also vary across the district; in the western skarns, including those at the Nickel Plate mine, they are generally poorly crystalline and uniformly pink to brown coloured, while at the Goodhope mine and Mount Riordan they are coarsely crystalline and highly variable in colour.

The composition of the skarn-related intrusions varies across the district from diorite at the Nickel Plate, Canty, Goodhope and French mines to possible granodiorite at Mount Riordan (Table 3). These variations in skarn mineralogy and intrusion composition probably reflect east-to-west changes in the basement rocks that underlie the Nicola Group which presumably represents the source of the skarn related intrusions.

CONCLUSIONS ON THE HEDLEY DISTRICT

The Upper Triassic Nicola Group rocks of the Hedley district contain a recognizable stratigraphic succession. At the bottom and top of this succession are volcaniclastic rocks of the Peachland Creek and Whistle Creek formations. Separating these tuffaceous sequences is a 100 to 700-metre sedimentary succession which paleocurrent indicators and facies changes suggest was deposited across the northeasterly trending, tectonically controlled margin of a northwesterly deepening, shallow marine basin. From east to west, the progressively thickening facies sequences are represented by the predominantly carbonate-bearing French mine, siltstone-dominant Hedley and argillite-dominant Stemwinder Mountain formations.

The two main intrusive episodes in the district, the older dioritic Hedley intrusions and the younger granodioritic Cahill Creek pluton, may be genetically related and were emplaced shortly after one another during a folding episode. Intrusion took place post-225 Ma (the age of the hosting sedimentary rocks based on Carnian-Norian microfossils) and pre-200 Ma (the preliminary $^{207}Pb/^{206}Pb$ zircon date obtained from the Cahill Creek pluton).

The Hedley intrusions are spatially associated associated with higher level, tension-fracture quartz-carbonate vein systems. The volume of skarn alteration developed throughout the district varies in scale from narrow, fracture-related halos only centimetres in thickness to huge alteration envelopes several hundred metres in width similar to that surrounding the Nickel Plate-Hedley Mascot deposit.

A small-scale, consistent, concentric zoning of gangue mineralogy is present at many skarn outcrops and a temporal sequence of skarn alteration is recognized. On the small scale the initial skarn process involves development of a biotite hornfels-type alteration which may locally overprint both the sedimentary rocks and the Hedley intrusion sills. This is followed by the sequential development of pyroxene-rich followed by garnet-rich assemblages which, as the alteration envelope enlarges, eventually replace and obliterate the earlier biotite hornfelsic aureole. Replacement of the biotite aureole by the pyroxene alteration often results in development of a thin intervening reaction zone containing potassium feldspar. It is uncertain whether the potassium was introduced with the skarn forming fluids or represents remobilized and concentrated potassium that was orginally present in the sediments.

The economic auriferous skarn mineralization is structurally, lithologically and stratigraphically controlled. The Hedley intrusion sills and dykes are more often associated with the skarn mineralization than the larger stocks. Economic gold values tend to be confined to the exoskarn while the endoskarn is generally barren. Most of the auriferous skarns are confined to the shallower marine, limestone-bearing Hedley and French Mine formations and are more commonly developed in flat-lying or gently dipping beds. Other controlling features include sill-dyke intersections, fractured sill margins and small-scale fold hinges, as noted by Billingsley and Hume (1941) at the Nickel Plate mine, as well as close proximity to the Copperfield conglomerate, a limestone-boulder olistostrome which overlies the Hedley formation.

Both the skarn-related Hedley intrusions and the Cahill Creek pluton represent I-type, calcalkaline intrusions. During the skarning process, the altered diorite sills (endoskarn) gain sodium, potassium and silica but undergo a considerable loss of total iron. Comparative whole-rock geochemistry suggests the Hedley intrusions are the source of the iron enrichment present in the exoskarns and may also be the source of the gold.

The Nickel Plate gold deposit is hosted in calcareous and tuffaceous siltstones in the upper part of the Hedley formation. It is associated with a skarn envelope that exceeds 300 metres in thickness and 6 square kilometres in outcrop area. The gold-bearing and arsenopyrite-rich zones normally occur as semiconformable tabular bodies situated less than 100 metres from the outer and lower skarn margin. There is significant geochemical and mineralogical variation throughout the deposit and the gold and sulphide mineralization postdates the garnet-clinopyroxene-carbonate skarn alteration, although there is surprisingly little propyllitic alteration of the ferromagnesian minerals. Three stages of sulphide deposition took place, namely: (i) pyrite; (ii) arsenopyrite and gersdorffite; (iii) pyrrhotite, chalcopyrite and sphalerite. Gold, occurring as blebs less than 25 microns in diameter, was introduced with the latter two phases and is associated with the bismuth telluride, hedleyite. Statistically, gold shows a strong to moderate positive correlation with bismuth, cobalt and arsenic and a low correlation with silver and copper.

The Hedley camp does not, as formerly believed, consist solely of uniform, gold-copper-arsenic-cobalt-enriched skarn mineralization. An east-to-west district-wide metallogenic zoning of the skarns may exist with gold-cobalt-arsenic-rich skarns occurring in the west (Nickel Plate) and tungsten-copper-magnetite-rich gold-poor skarns developing in the east (Mount Riordan). Mineralization in the central part of the district (French and Goodhope mines) has some intermediate mineralogic and metallogenic characteristics. The metallogenic zoning, which also parallels changes in the original geological environment (deeper basinal in the west, shallower marine to the east) probably reflects east-to-west changes in the composition of the basement rocks which underlay the Nicola Group and controlled the Late Triassic basin margin. This suggests that some tungsten skarn camps in the North American Cordillera, particularly those developed along fracture-controlled, island arc-related marine-basin margins, could have the potential for gold-skarn mineralization similar to the Nickel Plate deposit.

GENERAL CONCLUSIONS ON GOLD SKARNS

A comparison between the gold skarns at Tillicum Mountain (Ray et al., 1986b) Texada Island and the OKA property (Ettlinger and Ray, 1988,) and Hedley suggests the following features:

All are hosted in island-arc sequences that include limy sediments and either volcanic or volcaniclastic rocks of andesitic to basaltic composition. Regionally, the volcanic rocks at Tillicum Mountain (Rossland Group), Hedley and OKA (Nicola Group) include potassium-rich shoshonites.

Fault controlled marine-basin margins may have good exploration potential for gold skarns because:

(a) They often contain sedimentary lithologies (calcareous sediments, limestone boulder conglomerates) suitable for skarn development.

(b) The deep basement structures localize intrusive activity that may result in auriferous skarn formation.

Gold in skarn varies from very coarse grained and visible (Tillicum Mountain) to micron sized (Hedley).

To date, all of the gold skarns studied in British Columbia are associated with calcalkaline I-type intrusions and it is not known whether there are any gold skarns in the province related to alkalic rocks. However, some alkalic, high level intrusions in the Nicola Group are associated with a class of gold-bearing porphyry copper deposit, such as Copper Mountain (Fahrni et al., 1976) that locally contain some garnet-pyroxene-epidote-scapolite skarn-like alteration features.

The Hedley, Tillicum Mountain and OKA areas involved similar intrusive sequences characterized by early skarn-related intrusions of generally small volume and dioritic to gabbroic composition, followed by large amounts of barren granodioritic material forming major batholiths which enclose the skarn-hosting sequences and leave them as roof pendants. Preliminary dating suggests these two sequences at Hedley (the Hedley intrusions and the Cahill Creek pluton) are close together in age; it is possible that they are related and originated from the same magma source.

At the Hedley, Tillicum Mountain and Texada Island gold camps there are suggestions that the skarns are metallogenically zoned on a district scale. Metallogenic zoning is also reported at some other skarns such as the large Fortitude deposit in Nevada (G. Myers and A. Ettlinger, personal communication, 1988). However, the Hedley area is believed to be the first major skarn camp in which gold-to-tungsten zoning is recognized.

There is a highly variable trace element association with the gold in gold skarns. Some are enriched in cobalt, arsenic, antimony, tellurium, bismuth, molybdenum, tungsten and copper. Some, such as those in the Hedley camp, contain most or all of these elements, while in others these elements may be absent. At present no general rule can be made concerning trace element enrichment in gold skarns.

The amount of skarn alteration associated with gold mineralization varies considerably from the narrow alteration envelopes present at Texada Island, Tillicum Mountain and the OKA properties, up to the immense volumes of alteration developed in the Hedley camp. Generally the amount of skarn alteration developed appears to be proportional to the amount of gold present in the system. Thus, large tonnage gold deposits are more likely to be found in areas containing large skarn alteration envelopes.

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Chapter 5
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Chapter 6
INTERMONTANE BELT: REGIONAL GEOLOGY OF THE SOUTHERN NICOLA BELT

B.A. Preto[1] and K.E. Northcote[1]

MODIFIED FROM

Preto, V.A. and Northcote, K.E. (1977): Nicola Volcanic Rocks, Related Plutons and Mineral Deposits, Geological Association of Canada, Annual Meeting, 1977: Field Trip No. 5: Guidebook, pp 8-26

INTRODUCTION

The region between Princeton and Merritt covers the central part of the Nicola Belt of Southcentral British Columbia, a terrain of Upper Triassic volcanic, sedimentary and intrusive rocks approximately 40 kilometres wide that extends from near the International Boundary 180 kilometres northward to Kamloops Lake. Rocks of the Nicola assemblage continue northward beneath an extensive cover of tertiary strata into the Quesnel Trough, and extend along the full length of the Intermontane Zone into northern British Columbia and Yukon where they are known as the Takla and Stuhini volcanic assemblages.

The Nicola Belt is overlain to the north by an extensive cover of Tertiary volcanic rocks, and is invaded to the south by granitic rocks of the Similkameen Batholith. To the west it is bounded by granitic rocks of the Eagle Complex and by Jurassic and Younger strata and to the east is intruded by granitic rocks of the Okanagan Batholith and related plutons. Between Princeton and Merritt the Nicola rocks can be divided into three roughly parallel, north-trending belts, the boundaries between which are marked largely by high-angle faults that are part of large regional systems. Each belt comprises units of varied lithology and uncertain correlation, but of roughly similar composition, mode of origin and environment of deposition.

CENTRAL BELT

The Central Nicola Belt assemblage occurs along the full length of the area covered by figures 1 and 2. It is bounded to the east by faults of the Summers Creek-Quilchena system and to the west by faults of the Allison system. This assemblage includes the oldest Nicola rocks within the map area and is typified by an abundance of massive pyroxene and plagioclase-rich flows of andesitic and basaltic composition, coarse volcanic breccia, conglomerate and lahar deposits and by lesser amounts of fine-grained pyroclastic and sedimentary rocks. Intrusive rocks of gabbroic and dioritic composition, but including some monzonite and syenite, are abundant throughout the belt. The character and composition of these intrusions and lithologic changes in the surrounding extrusive rocks indicate that at least in some cases these stocks are the eroded remains of upper Triassic volcanics.

Rocks of alkalic and calc-alkalic composition (Figs. 3 and 4) and of sub-aerial and sub-marine origin occur in the Central Belt. In general most of the red and purple flows and associated red laharic breccias, such as are found on Fairweather Hills east and southeast of Aspen Grove are considered to be of sub-aerial origin, whereas greenish flows and breccias, generally with associated small lenses of calcareous sandstone and impure limestone, such as are found in the vicinity of Missezula mountain, are considered to be of sub-marine origin most stocks in the Central Belt are elongated in a northerly direction and occur along northerly trending faults. It is apparent that areas of stronger volcanic activity, such as Fairweather Hills, contain a much greater number of faults and more intrusive rocks than areas of less intense volcanism. Many of these faults are subsidiary to and part of the major systems and yet are intimately associated with and dependent on the volcanic history of the Nicola rocks.

EASTERN BELT

Rocks of the Eastern Belt crop out east of the Summers Creek-Quilchena fault. To the north they are lost under extensive overburden and are intruded by

[1] British Columbia Geological Survey, 756 Fort Street, Victoria, B.C., V8V 1X4

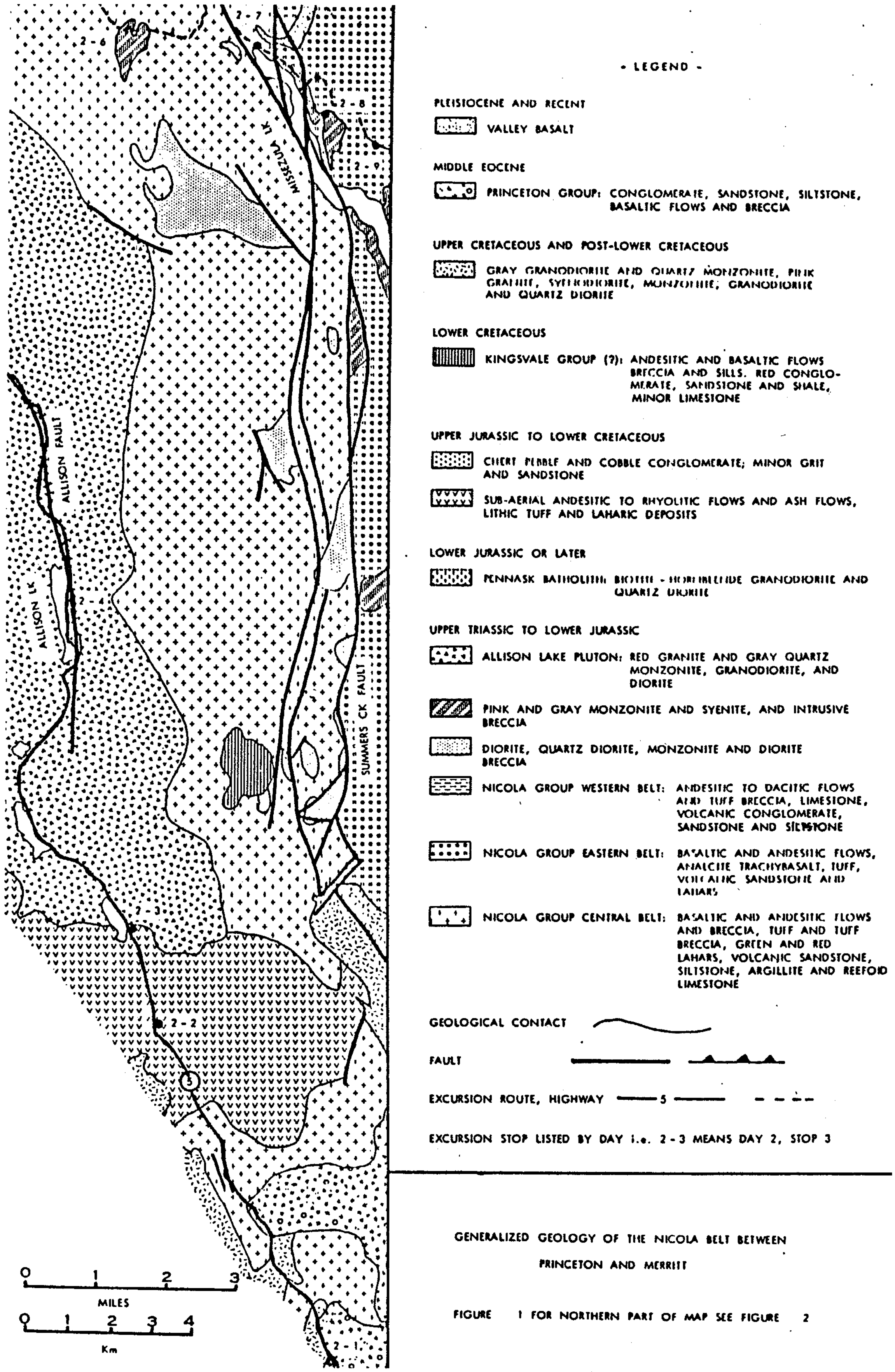

Figure 1 for northern part of map. See Figure 2

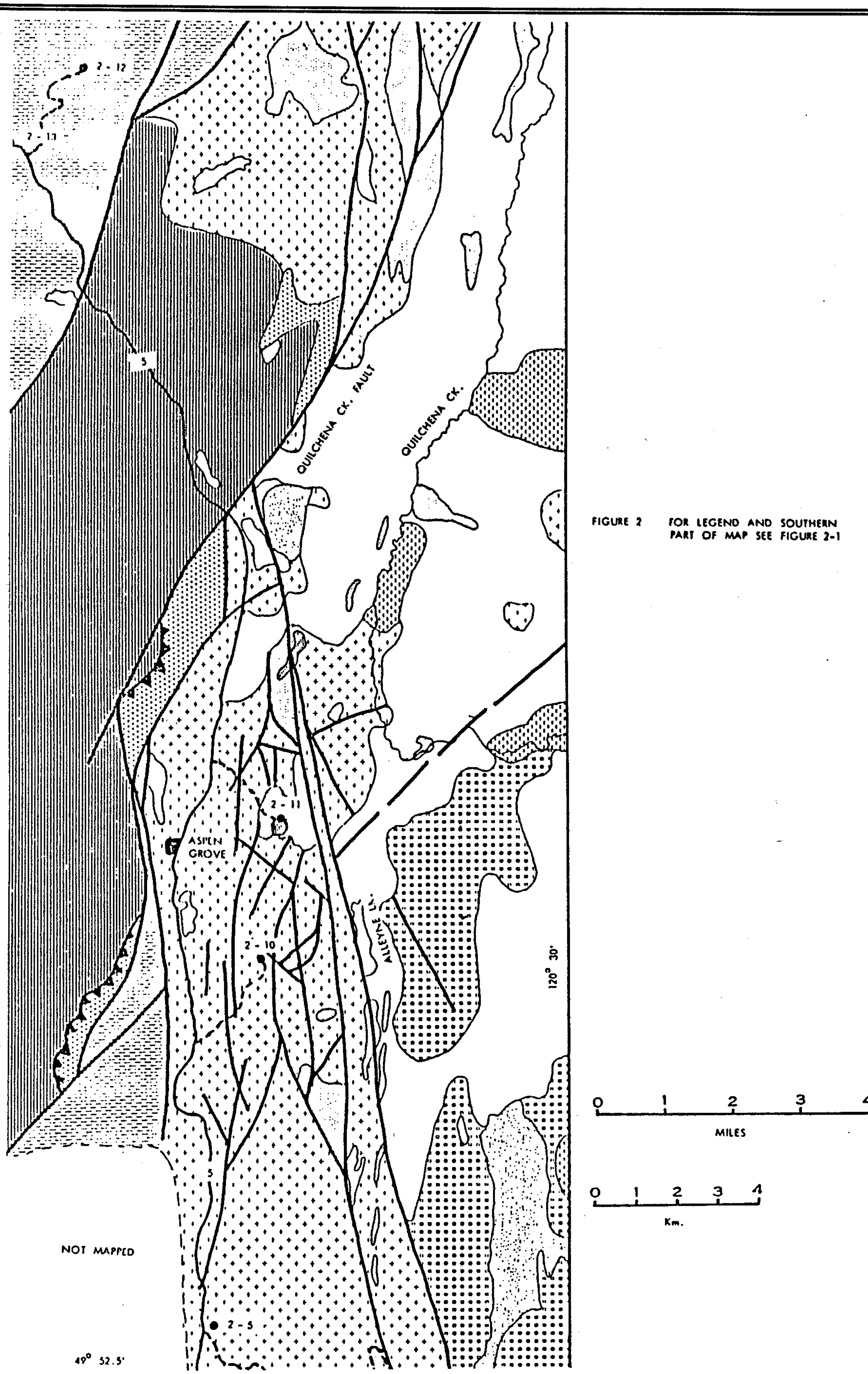

Figure 2. For legend and southern part of map see Figure 1.

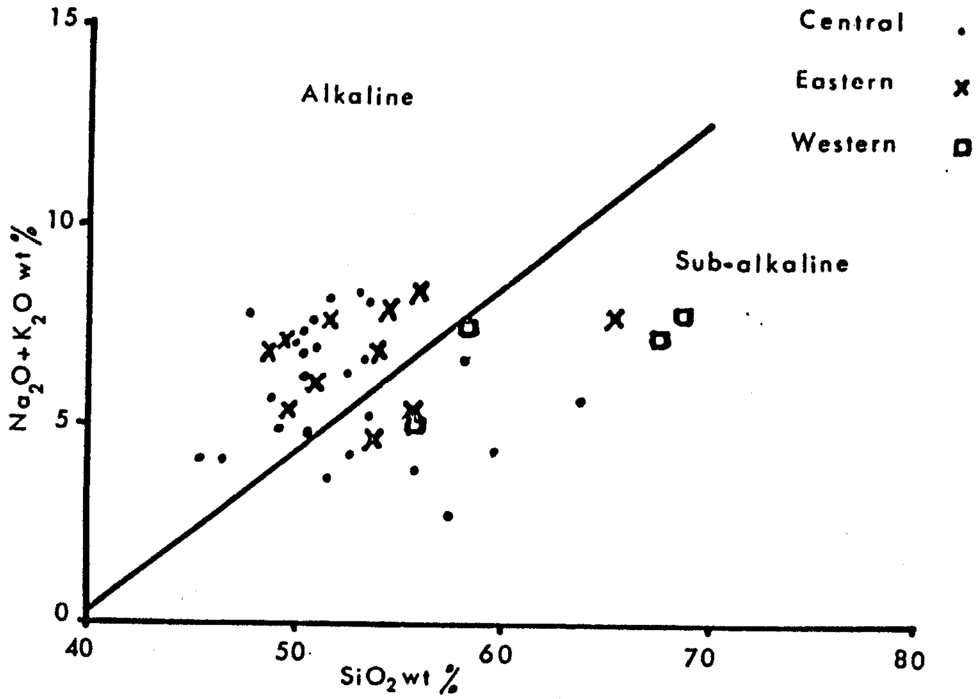

Figure 3 Silica-total alkali plot for Nicola volcanic rocks.

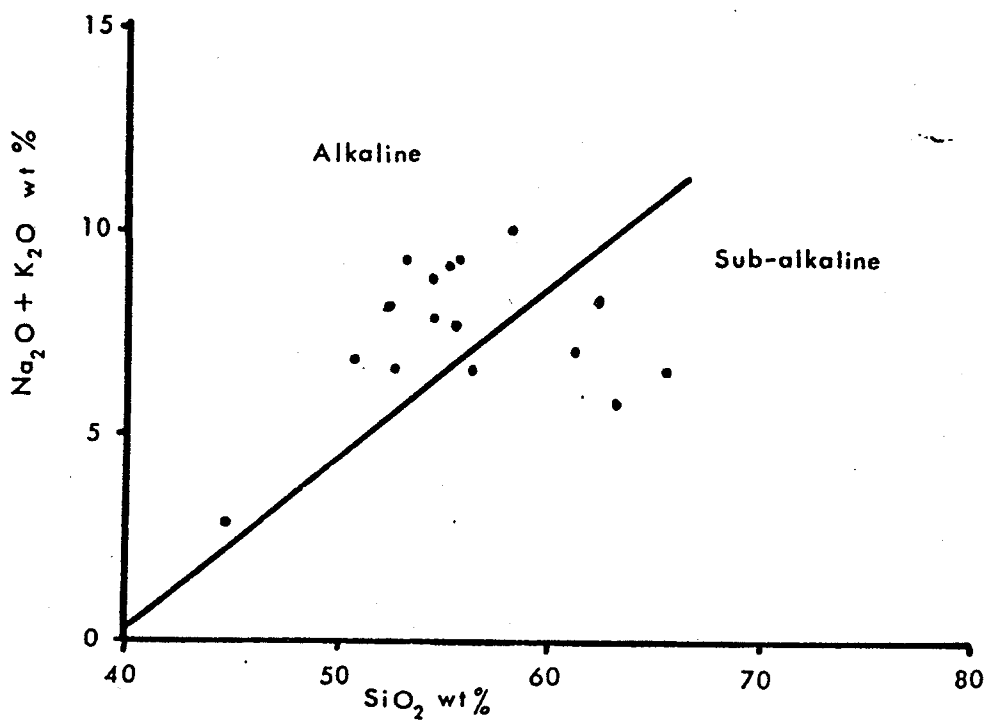

Figure 4 Silica-total alkali plot for Nicola intrusive rocks.

granitic rocks of the Pennask pluton. The belt can be described in terms of a northern and a southern assemblage, the boundary between which is marked by a facies change east of the northern end of Missezula Lake. The northern assemblage consists of a well-bedded, westerly dipping succession of volcaniclastic rocks that range from thinly layered volcanic siltstone and sandstone in the lower parts of the section to coarse volcanic conglomerates and some massive green breccia in the upper part. This part of the Eastern Belt is characterized by a lack of intrusive rocks and of mineralized showings. East of the north end of Missezula Lake, the sedimentary rocks quickly grade southward into a sequence of crystal and lapilli tuff, lahar deposits with clasts of syenite and monzonite, and some flows of analcite-bearing trachybasalt and trachyandesite. These deposits occur within a radius of roughly 3 kilometres of a northerly elongated stock of micromonzonite porphyry and breccia that is believed to represent a shallowly eroded volcanic dome. There is a similarity in composition between intrusive and extrusive rocks in this area and rock fragments in all the clastic units around this dome are clearly derived from it. To the south of this succession, the remainder of the Eastern Belt consists of massive to crudely bedded, reddish to grey, lahar deposits that contain abundant clasts of pink and red microsyenite and micromonzonite porphyry and of purple trachyandesite. Three other stocks of fine-grained monzonite cut these strata but none is surrounded by the assemblage of flows, tuffs, and volcaniclastic deposits that surrounds the stock northeast of Missezula Lake. This probably means that if the three southern stocks ever broke to the surface as volcanic vents they did so at a higher level and their extrusive products were removed by erosion.

WESTERN BELT

Rocks of the Western Belt form an easterly dipping sequence that occurs only in the northwestern corner of the map area and in a fault wedge south of Aspen Grove. In the north they are in fault contact to the east with rocks of the Central Belt and with volcanic and sedimentary rocks which may be as young as Lower Cretaceous. In the south they are separated by the Allison fault from rocks of the Central Belt to the east and are in fault contact to the west with a unit of chert pebble conglomerate of probably Jurassic to Cretaceous age and with the same succession of volcanic and sedimentary rocks of probably Lower Cretaceous age. Thus the Western Belt is an assemblage whose top is truncated by faults, and whose bottom is not exposed within the map area.

Flow and pyroclastic units consisting of grey-green and grey plagioclase andesite and dacite and of reddish to maroon volcanic breccia and lapilli tuff form the lower part of the succession, whereas greenish fine-grained flows, greenish to grey, generally calcareous fine-grained volcaniclastic rocks, and massive to well-bedded fossiliferous limestone make up the upper part. The volcanic rocks of the Western Belt, as contrasted with those of the other two belts, appear to be entirely calc-alkalic and contain considerably more dacite and rhyolite but very little basalt (Fig. 5). Most of the flow units in the upper part of the succession are rhythmically interlayered with limestone and thus are considered to be of subaqueous origin. However, lower in the section widespread flow laminations in the lavas and eutaxitic textures in the pyroclastic units suggest a predominantly subaerial environment of deposition. In contrast with the generally upper Triassic fossil ages obtained from the Central Belt, the Western Belt assemblage in the northwestern corner of the map area has yielded mainly fossils which range in age from Lower Norian in the mid part to Lower and possibly mid-Jurassic in the uppermost exposed part.

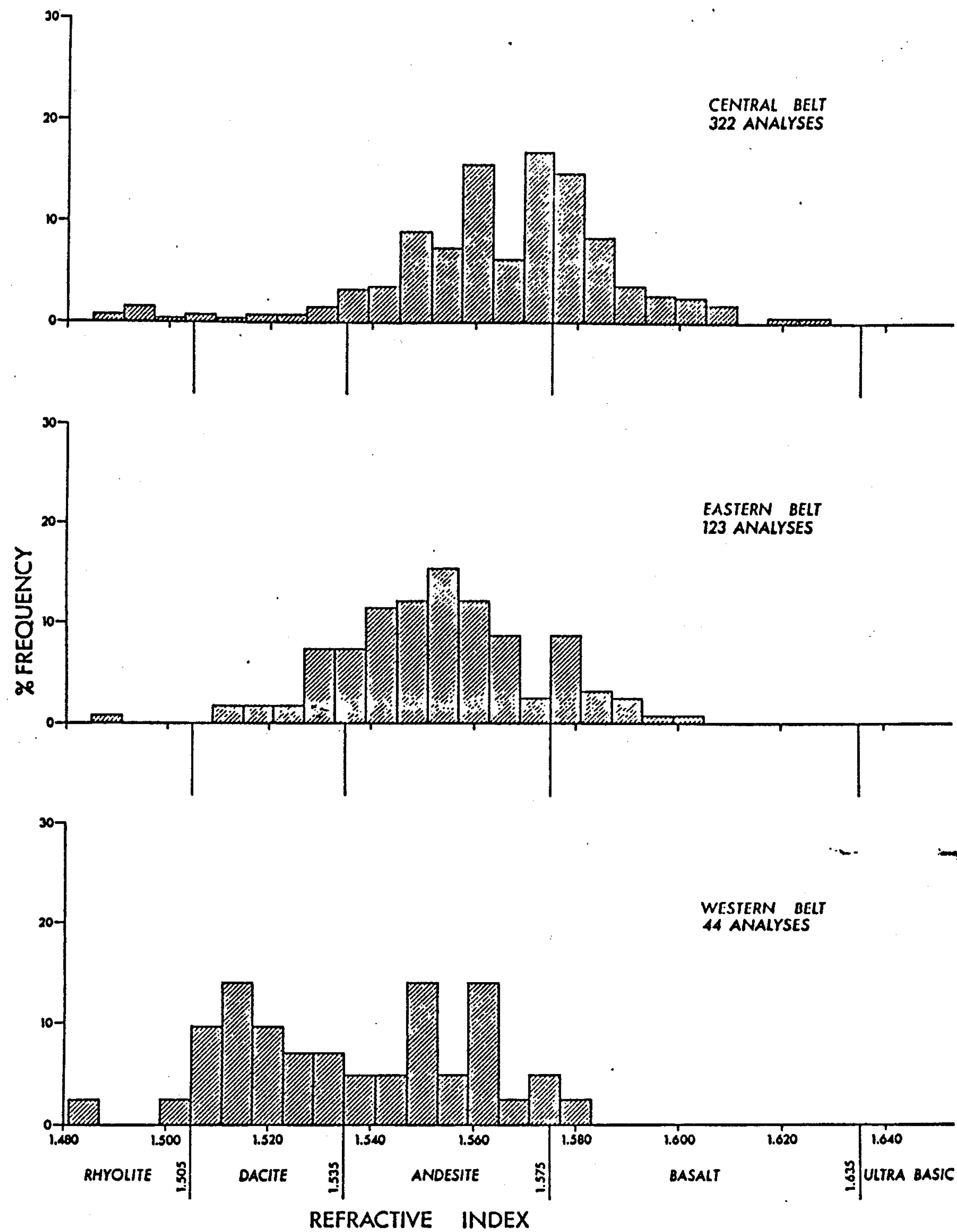

Figure 5 Refractive Indices of Nicola Rocks.

Chapter 7a
GEOLOGY AND ORE DEPOSITS OF THE HIGHLAND VALLEY COPPER MINE

W.J. McMillan[1]
British Columbia Geological Survey
756 Fort Street
Victoria, B.C. V8V 1X4

INTRODUCTION

The Highland Valley district, known for its large low-grade open pit porphyry copper-molybdenum mines, is situated in south-central British Columbia about 350 kilometres northeast of Vancouver (Fig. 1).

Five major deposits constitute the heart of the Highland Valley district. These are: Lornex, Highmont, and Valley Copper, which are operating mines; Bethlehem Copper, which closed in 1982 due to metal prices; and the J.A. deposit which is a potential producer. Two other deposits, Krain and South Seas, which have similar grades but smaller tonnage potential, have also been tested extensively. Numerous small, high-grade vein deposits first attracted attention to the district, and several, OK (Alwin), Snowstorm and Aberdeen, are former small-scale producers.

Aggregate ore reserves for the 13-square-kilometre central part of the Highland Valley district are nearly 2 billion tonnes of 0.45 per cent copper equivalent. This figure includes former production and proven reserves (Table 1), as well as geologically inferred reserves.

HISTORY AND EXPLORATION METHODS

Prior to Bethlehem Copper coming on-stream in 1957 there were no producing porphyry copper deposits in British Columbia. The success of Bethlehem spurred intense exploration. Within a few years exploration companies discovered Lornex, Valley Copper and the J.A. deposit, and many showings in the district were evaluated thoroughly.

Copper was not a new commodity in the area. What is now Bethlehem Copper mine was first staked in 1899. Work at that time and into the early 1900's explored small high-grade veins of the Snowstorm zone, with shipment of 90 tonnes of hand-cobbed ore during 1915 and 1916. Diamond drilling of Snowstorm began in 1917 and underground testing of what is now the Iona zone began in 1919. Eighty-five metres (280 feet) of 0.64 per cent copper were cut in the Iona zone but at that time the copper price was too low for the zone to be of economic interest. A few more holes were drilled in 1942 then the property lay idle until 1954 when the area was staked by the Huestis-Reynolds-McLellan syndicate. In 1955 work by American Smelting and Refining Company outlined large tonnage, low-grade copper deposits; the exploration focus shifted, the hunt for porphyry copper deposits in Highland Valley began in earnest.

Exploration was intense and exciting in those early years. In 1964 bulldozer trenches spotted by veteran prospector Egil Lorentzen opened up the Discovery zone at Lornex. In 1966 and 1967 an extensive percussion drill program at Highmont outlined the No. 1 orebody. Valley Copper was discovered in 1967 and the J.A. deposit in 1971.

Soaring costs accompanied by low copper prices over the last few years delayed production decisions at Cominco Ltd.'s Valley Copper deposit and Teck Corporation Limited's Highmont deposit. However, Highmont was brought into production in 1980 and Valley Copper in 1982. No production plans appear likely for the J.A. deposit in the near future.

The main exploration tools effective in these discoveries were prospecting, geology, and geophysics (mainly induced polarization). Glacial deposits, particularly till, and lacustrine and glaciofluvial sediments, cover many areas and mask geochemical responses, although auger samples taken in till overlying

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[1] modified from McMillan (1985)

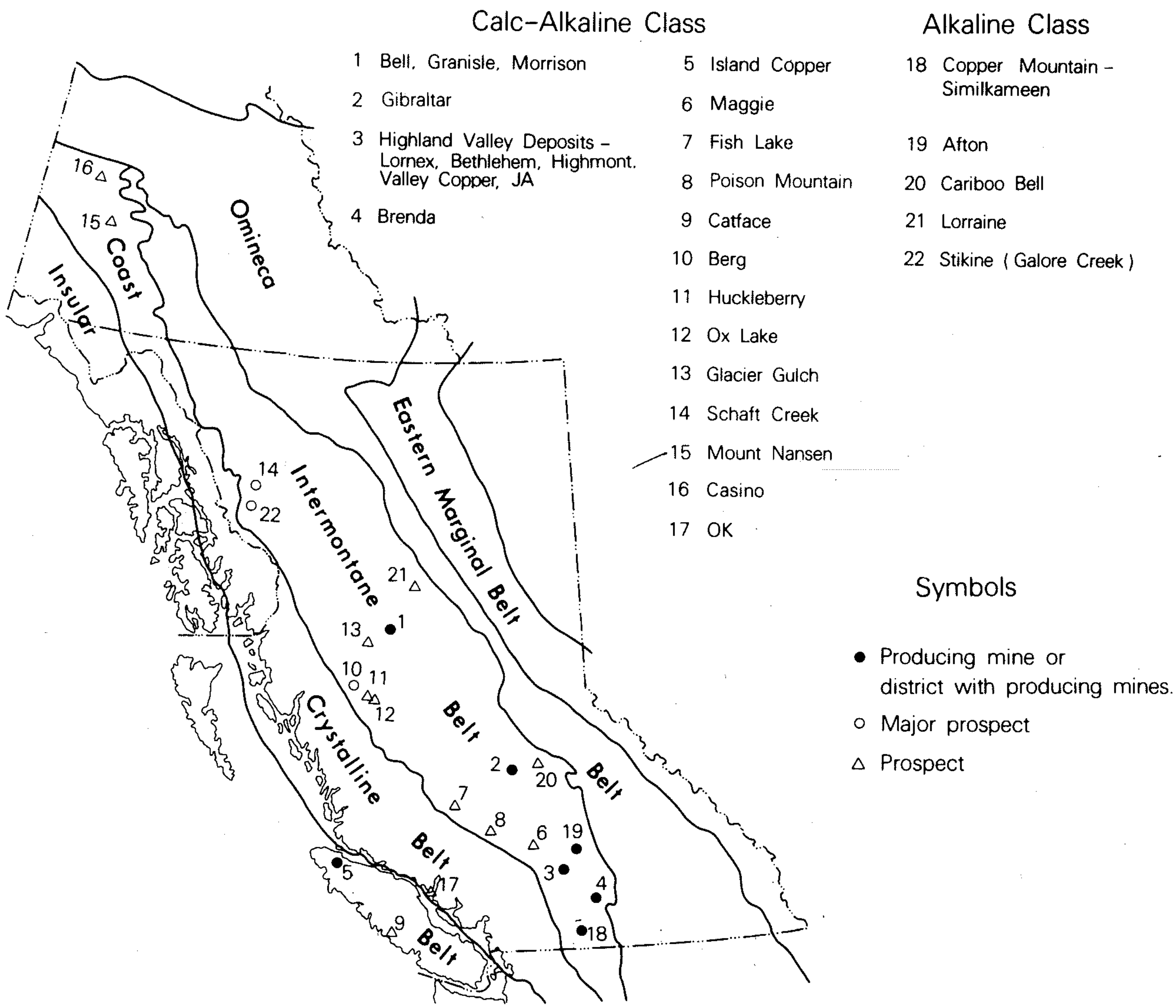


Figure 1 Distribution of porphyry copper deposits of the calc-alkaline and alkaline classes in the Canadian Cordillera relative to tectonic belts. Most are in the Intermontane Belt.

the bedrock surface gave meaningful geochemical anomalies. In areas of thin glacial cover bulldozer trenching was an important method of revealing geology and checking geophysical or geochemical anomalies. Generally trenching was followed by percussion or diamond drilling to delimit mineralization.

As is pointed out later in the text, the ore deposits have geochemical dispersion halos and peripheral alteration that can provide exploration 'vectors' (see also Table 2). All the major deposits are related to younger phases of the host Guichon Creek batholith.

TABLE 1. MINING STATISTICS FOR MAJOR PORPHYRY COPPER-MOLYBDENUM DEPOSITS, HIGHLAND VALLEY, NTS 92I/6, 7

Deposit (Start of Production)	Orebody	Ore Mined to Dec. 1984 (million tonnes)	Mined Grades Cu%	Mined Grades Mo%	Strip Ratio (waste /ore)	Daily Rate (Tonnes)	Reserves (Cutoff) (million tonnes)	Grades Cu%	Grades Mo%	Status*
Bethlehem	East Jersey	8.96	0.60	-	-	-	20.6	0.40		N
Copper	Jersey	53.16	0.50	-	-	-	22.9	0.40		(1982)
(1962)	Huestis	29.46	0.52	-	-	-	-	-		
	Iona	1.43	0.40	-	-	-	6 (oxide)	0.40		
	Combined Total	105.87	0.502	-	1.93:1	Combined Total	37.67	0.40		
Krain	-	-	-	-	-	-	9.1	0.53	appx.	P
							4.9 (oxide)	0.64	0.01	
Highmont	West Pit	14.2	0.15	0.048	2:1	-	0.8	0.15	0.048	N
(1980)	East Pit	20.5	0.26	0.021	2.2:1		87.6	0.26	0.021	(1984)
J.A.	-	-	-	-	-	-	286 (1983)	0.43	0.017	P
Lornex (1972)	Lornex Pit	228**	0.421	0.159	2.3:1	76 000	350 (appx) (0.25)	0.374	0.0129	0
Valley Copper (1983)	Valley Pit	15.6	0.51	-	0.7:1	20 000	559 (Indicated)	0.471		0
							141.6 (Inferred)	0.482		

*0 - Operating Open Pit Mine; N - Former Producer, temporarily closed (and when); P - Potential Producer
**calculated from average daily production; grades refer to material produced to December 31, 1983 - they may change slightly when data from the 28 million tonnes mined in 1984 becomes available

Probably the best indirect exploration tool is induced polarization. Deposits, like Lornex, with shallow cover give distinct anomalies; even those with deeper cover may respond. The J.A. discovery hole, for example, penetrated 100 metres of overburden; it was drilled on an induced polarization anomaly. Anomalous zones are generally subtle, overall sulphide content is low, and pyritic halos poorly developed - pyrite abundance is typically less than 1 per cent in the halos.

REGIONAL SETTING OF THE GUICHON CREEK BATHOLITH

Highland Valley porphyry copper deposits occur within the Guichon Creek batholith, one of several large plutons in the southern Intermontane Belt (Fig. 1) that are associated and possibly comagmatic with Late Triassic volcanic rocks. These intrusive and volcanic rocks occur in a belt the length of the Cordillera; they are variously interpreted to be products of island arc volcanism (Gabrielse and Reesor 1974) or rifting in an island arc environment (Preto, 1977); they display both calc-alkaline and alkaline (Barr et al., 1976) differentiation trends. Monger (1982) argues that these rocks, derived from melting of subducted oceanic crust, were deposited on Late Paleozoic oceanic and arc rocks (Cache Creek Group and Harper Ranch Group). Fossil and paleomagnetic evidence indicates that the

TABLE 2. GEOLOGIC CHARACTERISTICS OF HIGHLAND VALLEY

Name	Location	Size*	Grade %Cu	Grade %Mo	Relative Age	Host Rock	Estimated proportion of ore contained
Bethlehem Copper	50°29.5'; 120°59'	143	0.48	only recoverable in times of high prices	After Bethlehem Before Bethsaida	Guichon granodiorite Bethlehem granodiorite Breccia & dacite porphyry dykes	35% 45% 20%
Krain	50°35'; 120°58	14	0.56	0.01	After Bethlehem	Guichon granodiorite Dyke-like stock of Bethlehem (?) granodiorite	
Highmont	50°26'; 120°35'	116 in two main zones	0.246	0.025	Late stage Bethsaida	Skeena granodiorite Gnawed Mountain quartz feldspar porphyry	95% 5%
J.A.	50°28.5'; 120°58.5'	286	0.43	0.017	Late Stage Bethsaida ?	Guichon granodiorite Bethlehem granodiorite J.A. porphyry stock	47% 50% 3%
Lornex	50°27'; 121°03'	578	0.393	0.014	Late stage Bethsaida	Skeena granodiorite Quartz±feldspar porphyry dyke Bethsaida quartz monzonite	93% 7% 0%
Valley Copper	50°29'; 121°02'	716	0.474	not significant	Late stage Bethsaida	Bethsaida quartz monzonite Quartz feldspar porphyry dykes	99% 1%

Note: K - potassic, sil - silicic, phyl - phyllic, arg - argillic, prop - propylitic, Fr - fresh rock,
*million tonnes (includes mined ore and reserves)

PORPHYRY COPPER-MOLYBDENUM DEPOSITS

Alteration and Cu mineralization: Core	Medial	Rim	Relative age of alteration types	Associated minerals	Oxide zone	Comments
K (bio) bo	phyl/ arg ch >0.3% Cu	prop Fr py sp	Main stage potassic (biotite & sericite) - phyllic/argillic-propylitic Late calcite zeolite	Specularite Tourmaline Zeolites	Generally weakly developed, no enrichment blanket, deep in part of Iona deposit	Small subequant to elongated orebodies Zoning concentric
phyl bo cp	prop/ arg cpy	prop Fr py	Main stage propylitic-argillic to propylitic		Significant tonnage, slightly enriched	Oxide zone unconformably overlain by Tertiary lavas
K (bio, Kspar) bo	phyl/ arg ch >0.3% Cu	prop Fr py	Early biotite, propylitic Main stage potassic (k-feldspar) phyllic Later argillic-propylitic Late calcite	Tourmaline Actinolite Zeolites	Thin, no enriched blanket	Zoning outward from Gnawed Mountain dyke, linear trends
bo K (bio, Kspar)	ch phyl/arg? >0.3% Cu	py prop	Early potassic (biotite after mafics; potassic feldspar related to stock) Main stage phyllic-argillic propylitic Late calcite, gypsum	Actinolite Gypsum Tourmaline	Not certain due to drilling method	Elliptical deposit elongated parallel to Highland Valley; zoning related to central stock
sil patchy K (bio, Kspar) bo	phyl/arg ch >0.3% Cu	prop py	Early potassic Main stage phyllic-argillic-propylitic Late fracture-controlled argillic calcite, gypsum	Some tourmaline gypsum	Best developed at south end, minor enriched zone locally	Ore zone elliptical, zoning sub-concentric Cut off by younger fault on west side
sil K (kspar very weak bio) ch bo	phyl/ arg ch >0.3% Cu	prop (narrow) py (weak)	Early potassic-propylitic (?) some silicic Main stage phyllic-argillic-propylitic Late main stage silicic ±phyllic Late fracture-controlled argillic, calcite, gypsum	Gypsum Anhydrite	Overall thin	Subequant deposit, zoning concentric

bio - biotite, py - pyrite, bo - bornite, ch - chalcopyrite, sp - specularite entire Late Triassic volcanic belt is allochthonous; it originated over 1,000 kilometres south of its present location (Irving, et al., 1980). In this plate tectonic interpretation, the Cordillera is seen as a collage of allochthonous terranes 'plastered' onto the western margin of North America by convergent and transform plate motions (Monger, et al., 1982).

A melange that is part of the Cache Creek terrane lies along the western side of the Guichon Creek batholith. The melange consists largely of Late Paleozoic clasts but has local Nicola clasts (Shannon, 1981). Clasts range from several centimetres to hundreds of metres in size and lie in a sheared chert and argillite matrix of Triassic age (Travers, 1978). If the melange represents the time when collision locked these two areas together, then they have been in their present relative positions since some time during the Triassic. However, it is not certain when this composite terrane moved northward to its present geographic location; possibly it was as late as Early Tertiary time (Irving, et al., 1980). Continuing geological and paleomagnetic analyses are under way to attempt to clarify some of the uncertainty of present interpretations.

AN OVERVIEW OF HIGHLAND VALLEY ORE DEPOSITS

INTRODUCTION

Petrologic and chemical evidence indicate that crystallization of the source magma of the Guichon Creek batholith took place at depth under relatively high partial pressures of water. This factor was probably instrumental in allowing saturation and subsequent separation of a fluid phase to occur. Geochemical evidence argues that metals in Highland Valley deposits were derived from granitic rocks of the younger phases; calculations, using estimated volumes of depleted rock (Fig. 2), indicate that this depletion model more than adequately accounts for all known copper reserves estimated for the batholith.

The host magma was injected along and localized by basement structures; subsequently it was fractured during periodic reactivation of these regional structures. A strong pattern of northerly and northwesterly faults and fracture swarms and northerly trending dyke swarms resulted. Early ore deposition, such as that at Bethlehem Copper, was controlled by faults and porosity caused by brecciation during dyke swarm emplacement. As the copper lithogeochemical distribution map shows (Fig. 2), younger ore deposits, such as Highmont, Lornex, and Valley Copper, were deposited north of the depleted source magma from which the ore fluids were derived. Mineralization in the deposits is dominantly fracture controlled.

GEOLOGIC SETTING

All known major Highland Valley ore deposits cluster in the central part of the batholith. They occur in younger phase rocks, in dyke swarms, or in intrusive breccias associated with younger phase rocks (Fig. 3; Table 2). If post-ore fault movements are removed, the major deposits lie close to the surface projection of the root or feeder zone of the batholith that underlies Highland Valley (Fig. 2).

Ore deposits of Bethlehem Copper Corporation include the East Jersey, Jersey, Huestis, and Iona deposits; they occur near contacts where Bethlehem phase granodiorites intrude more mafic Guichon variety granodiorites. They are associated with dacite porphyry dykes and intrusive breccias. Ore occurs in the country rock, the dykes, and the breccias, although not all dykes are mineralized. The Highmont and Lornex deposits are largely in Skeena granodiorite adjacent to or near the large, composite Gnawed Mountain dyke. Breccia bodies occur at Highmont but are not significant in the ore reserve picture. Lornex is also adjacent to the Bethsaida quartz monzonite contact but the Bethsaida is not mineralized. The Gnawed Mountain dyke is largely pre-ore; it is weakly to moderately well mineralized in the ore zones. The Valley Copper ore deposit is entirely within Bethsaida quartz monzonite; porphyry dykes are volumetrically insignificant and no breccia bodies are known.

North of Bethlehem Copper there are many showings and two moderate-sized deposits, South Seas and Krain. South Seas deposit is a breccia pipe cutting Guichon granodiorite and is associated with porphyry dykes like those at Bethlehem Copper. Krain is also in Guichon granodiorite; it is allied with a sheet-like body of Bethlehem granodiorite.

Breccia bodies associated with Highland Valley ore deposits are intrusive, normally multilithic, and commonly mineralized; they generally show evidence of explosive release of volatiles (Carr, 1966). Tourmalinized breccias at Bethlehem and Highmont represent both

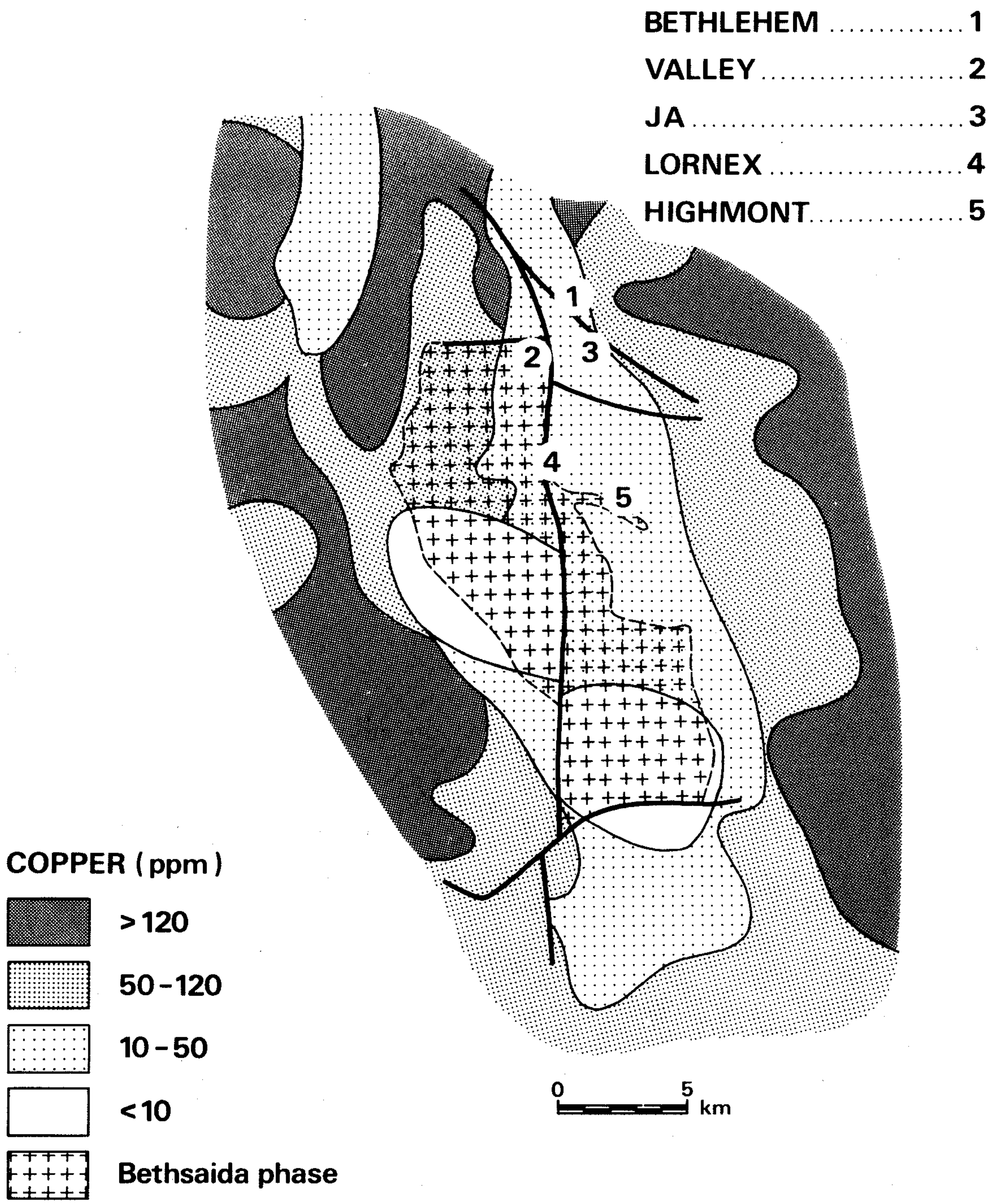


Figure 2 Simplified geological map of the Guichon Creek batholith showing copper abundances; strong depletion occurs in the Bethsaida phase south of the major ore deposits (modified after McMillan and Johan, 1981).

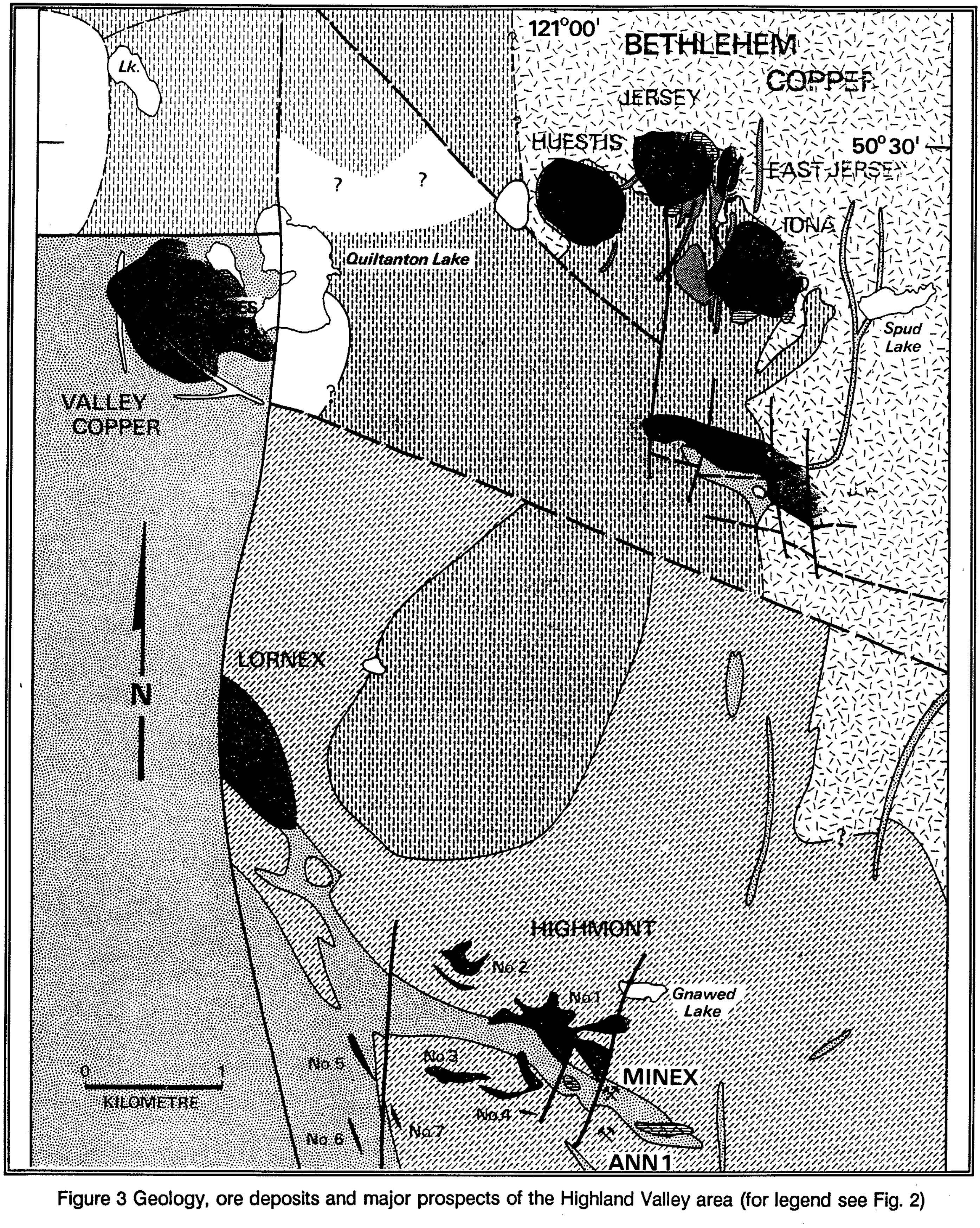


Figure 3 Geology, ore deposits and major prospects of the Highland Valley area (for legend see Fig. 2)

syn-ore and late-stage events.

STRUCTURAL SETTING

Almost all the sulphide mineralization in Highland Valley deposits is either in or closely associated with veins, fractures, faults, or breccias. Fracture density was apparently the most important single factor influencing ore grades, although mineralized breccias are important at Bethlehem, South Seas and, to a lesser extent, at Highmont, and mineralized fault zones are significant local ore controls at Bethlehem. Typically grades are higher where swarms of fractures occur and higher still where sets of fracture swarms overlap. At Bethlehem northeast and lesser north-trending fracture sets predominate; consequently, better grade zones are elongated northeastward. In the Highmont area ore grades occur where swarms of northeast and northwest-trending fractures overlap in a general zone of fracturing adjacent to the Gnawed Mountain dyke (Bergey, et al., 1971; Reed and Jaimbor, 1976; McMillan, 1984). At Lornex, which occupies a closely fractured area at the contact of Skeena granodiorite with Bethsaida quartz monzonite, north-northeast, northeast, and east-trending mineralized fractures predominate; the best grades occur where all three sets overlap (Waldner, et al., 1976). The predominant fracture sets at Valley Copper strike north-northwest and east-southeast (McMillan, 1971); the orebody occupies a shatter zone in which fractures are more evenly distributed than those in the other deposits.

These fractures, fracture swarms, shatter zones, breccias, and, to a lesser extent, faults, represent permeable, porous zones; they provided migration paths, 'the plumbing system,' for hydrothermal, metal-rich brines, and sites for sulphide deposition. Economically interesting deposits formed where the plumbing system was best developed; subeconomic, widely spaced mineralized fractures are nearly ubiquitous in the Highland Valley area.

ALTERATION AND VEINING

The following synopsis of the types of alteration and veining in Highland Valley deposits is based on work done by the writer, but also draws heavily on data From the various deposits presented in Canadian Institute of Mining and, Metallurgy Special Volume 15, Porphyry Deposits of the Canadian Cordillera. The synopsis will begin by comparing the distribution of silicic, then potassic, phyllic, argillic, propylitic, and other types of alteration. Subsequently, vein and alteration chronology will be considered (see also Table 2).

Silicic Alteration

Silicic alteration is expressed both as quartz veins without flaky sericite (muscovite) halos, and as quartz flooding in the host rocks. Where quartz stockworks are well developed, flooding is also prominent. At Valley Copper, for example, the deposit is outlined by the 10 per cent secondary quartz contour and areas of greater than 0.5 per cent copper have between 10 and 20 per cent secondary quartz (Osatenko and Jones, 1976).

Only Valley Copper and Lornex have well-developed quartz stockworks. That at Valley Copper forms an elliptical, dome-like zone which plunges northwestward (McMillan, 1971). Throughout this poorly mineralized quartz core, veins are less than 30 centimetres apart and the country rock is silicified; in the ore zone, quartz veins are 60 to 150 centimetres apart; the contact between the zones is gradational. The quartz stockwork zone at Lornex also forms an elliptical dome with an axis which apparently plunges northwestward. However, there are two differences: the vein frequency at Lornex is lower; and the zone at Lornex is relatively well mineralized. Most other Highland Valley deposits have only relatively widely spaced quartz veins and patchy zones of silica flooding.

Potassic Alteration and Occurrence of Hydrothermal Biotite

Potassic alteration is characterized by deposition of hydrothermal biotite or hydrothermal potassic feldspar; its abundance is highly variable in Highland Valley deposits. At Valley Copper, fracture-controlled potassic feldspar alteration is moderately well developed in the central, deeper part of the deposit, where most is in or adjacent to quartz veins. J.A. is the only other deposit with a pervasive zone of potassic feldspar alteration. Adjacent to the deposit the carapace of the porphyry stock is flooded and veined by potassic feldspar, however, the zone may be more closely allied to stock emplacement than to ore-forming processes. Potassic alteration at Lornex forms spotty zones of replacement or vein potassic feldspar or biotite. Such zones are apparently becoming more common as mining penetrates deeper into the orebody; they may represent remnants of an early, pervasive potassic alteration zone. At Bethlehem, Highmont, and within the J.A. deposit, only hydrothermal biotite is present. This biotite is typically greenish brown in thin sections; it occurs in fractures, as overgrowths on mafic minerals, and as crystal aggregates that replace mafic minerals. At Bethlehem Copper the Jersey deposit has a higher grade core zone in which hydrothermal biotite is distributed widely. Secondary biotite zones at J.A. and Highmont are less prominent, and largely overprinted by later propylitic alteration; occurrences at Lornex and Valley Copper seem to be sporadic.

Phyllic Alteration

Phyllic alteration in Highland Valley is characterized by fracture-associated zones or vein envelopes of mixed quartz and 'flaky sericite.' Although it is called 'flaky sericite,' the 'flakes' are generally several millimetres in size and the mineral should be called muscovite (2MJ). Phyllic alteration is particularly important at Valley Copper where it is widespread and abundant; the majority of the associated sulphide is bornite. Phyllic alteration is less well developed at Lornex. There, vein envelopes predominate and quartz-sericite alteration zones are uncommon; vein envelopes also tend to be thinner. Phyllic alteration characterizes the ore zone at Lornex. At Highmont and J.A., phyllic alteration is generally weakly developed, although Reed and Jambor (1976) found a fairly good correlation at Highmont between phyllic alteration and areas of greater than 0.2 per cent copper equivalent. The average intensity of phyllic alteration decreases from Valley Copper to Lornex to Highmont and J.A.; it is poorly developed at Bethlehem Copper.

Argillic Alteration

The term 'argillic alteration,' as used in Highland Valley, describes alteration of feldspars and, less commonly, mafic minerals to an assemblage typified by microscopic sericite and kaolinite with or without montmorillonite. This alteration occurs throughout the ore deposits and can extend for significant distances beyond the 0.3 per cent copper isopleth. Judging from data on Bethlehem Copper Corporation's Jersey deposit, argillic alteration is ,still mappable where copper grades are as low as 0.1 per cent (Briskey and Bellamy, 1976).

The relationship between argillic alteration and ore grades is not consistent. At Krain moderate to intense argillic alteration occurs in the higher grade core zone (Christie, 1976). At J.A. it encloses the potassic core and coincides with the phyllic alteration zone; at Highmont it is adjacent to the Gnawed Mountain dyke, and in the borders of the dyke itself, which is not of ore grade. Elsewhere in the J.A. and Highmont ore zones argillic alteration is present but weakly developed. At Lornex and Valley Copper the orebody and the zone of moderate to intense argillic alteration virtually coincide. However, the most intense zones of argillic alteration in all the deposits occur along and adjacent to late-stage faults, where the country rock is totally altered to a soft, white mixture of kaolinite and sericite.

Propylitic Alteration

All Highland Valley deposits have propylitic alteration zones of varying width, location, and intensity. In general, there is a gradation between propylitic and argillic alteration zones. In hand specimen, epidote is the characteristic mineral for propylitic alteration. Chlorite is almost ubiquitous in all the deposits except Valley Copper, so is not generally a useful indicator mineral. Feldspars in propylitic zones are altered to sericite, carbonate, and some clay minerals; mafic minerals alter to chlorite and carbonate with associated epidote.

At Krain and Jersey, fairly well-defined propylitic halos enclose the orebodies; immediately outside the propylitic halo the rock is almost fresh, albeit cut by local fracture-coatings and veinlets of quartz, chlorite, and epidote. At J.A. and Highmont, propylitic facies assemblages occur throughout most of the mineralized zones. At J.A. the intensity of propylitic alteration is greater in the more mafic-rich Guichon quartz diorite than in the Bethlehem granodiorite country rock. At Lornex there is a narrow propylitic alteration zone peripheral to the orebody. At Valley Copper such alteration is weakly developed and ill-defined in the leucocratic host rocks. Propylitic alteration is more prominent where host rocks are more mafic.

Tourmaline Distribution

At Bethlehem, South Seas, and Highmont, tourmaline occurs in and near breccia bodies, where it forms crystalline aggregates, replaces clasts, or replaces comminuted rock of the matrix. It is commonly associated with quartz, specularite, epidote, calcite, copper sulphides, and, locally, actinolite. At South Seas, specularite, quartz, and chalcopyrite fill openings in the breccia and are generally slightly younger than quartz and tourmaline in the matrix. At Bethlehem and Highmont quartz and tourmaline-bearing breccias are mineralized, but also contain clasts that were mineralized with copper sulphides prior to brecciation. Thus, some brecciation and associated tourmaline deposition occurred after the initiation of sulphide deposition. Tourmaline is uncommon at Lornex and Valley Copper.

Late-stage Vein and Alteration Minerals

Typical late-stage veins in Highland Valley deposits are calcite and zeolite or gypsum. These minerals occur as minor components of main-stage mineral assemblages, but typically they are post-ore and were deposited during collapse of the hydrothermal system.

Zeolites occur primarily as veins and fracture coatings, but also form pervasive alteration halos around fractures and zeolite veins. Laumontite is the most common zeolite present but some stilbite and uncommon chabazite, heulandite, and other species occur (White, et al., 1957). Zeolites frequently are intergrown with calcite; in places they are intergrown with gypsum. Zeolites are abundant at Bethlehem and J.A., less common at Highmont, and sparsely distributed in the other deposits.

Calcite forms veins, coats fractures, and replaces feldspars in all the deposits. Replacement calcite accompanies propylitic alteration; fracture and vein calcite is generally late stage and predominantly post-ore; much of it also post-dates zeolite deposition. Gypsum, which is also largely post-zeolite, is abundant as veins and fracture fillings at J.A. and Valley Copper. It occurs at Lornex but is of local extent; it has been reported at Highmont. Rarely, main-stage quartz-sulphide veins at J.A. have vugs filled with fibrous gypsum. Anhydrite occurs in a similar setting in several deep drill holes at Valley Copper, therefore such fibrous gypsum may be derived from anhydrite.

Age Relationships of Alteration Types

Age relationships of alteration types in Highland Valley apparently vary from deposit to deposit (Table 2). At Jersey (Briskey and Bellamy, 1976) ore fluids are thought to have moved upward and outward. Thus, formation of the potassic core and the fringing argillic and propylitic zones are interpreted to have been virtually synchronous. At J.A. there may have been a pre-ore stage of weak propylitic alteration. During the main stage of sulphide mineralization at J.A., weak potassic and phyllic with associated argillic alteration was followed by propylitic with associated argillic alteration. At Highmont, Reed and Jambor (1976) concluded that an early phase of hydrothermal biotite alteration accompanied by propylitic alteration occurred and was followed successively by phyllic, argillic, and additional propylitic alteration.

They infer that most of the metals were introduced during the early phase of alteration. At Lornex (Waldner, et al., 1976) argillic alteration apparently initiated prior to main-stage sulphide mineralization and continued for a short time after it; phyllic alteration and quartz stockwork formation occurred primarily during mainstage mineralization; propylitic alteration was later. At Valley Copper, the indicated sequence of alteration (Osatenko and Jones, 1976) is propylitic, then argillic, phyllic, and potassic; the quartz stockwork post-dates potassic alteration. The various alteration types overlap in time but the main period of sulphide deposition at Valley Copper occurred during the phyllic stage. In a contrasting interpretation, Reed and Jambor (1976) concluded that alteration sequences at Valley Copper and Lornex followed the sequence described at Highmont. Zeolites in the deposits are predominantly later than sulphide deposition, and calcite and gypsum veins and fracture fillings are younger still.

In all cases, age sequences are based on crosscutting features; however, disagreement remains. It seems likely that the discrepancies are caused in part by overlapping of alteration types in time, in part by variations related to permeability and travel distances of the hydrothermal solutions, in part by repetition of alteration types in response to new influxes of hydrothermal fluid, or influx of meteoric water, and in part by the effects of country rock composition on the alteration assemblages generated. The system is complex and three-dimensional; it changes with time and is subject to external influences; local variations are to be expected.

METALLIC MINERAL ZONING

In most Highland Valley deposits there is a fairly well developed metallic mineral zoning, but, because grades are structurally controlled, these patterns do not everywhere correlate closely with grade distribution patterns (Table 2). That is, although most of the deposits have zones in which bornite and then chalcopyrite and then pyrite are the predominant sulphide minerals, not all bornite zones are ore and parts of ore zones may extend into the pyrite zone. At Krain, in the Jersey deposit, at Valley Copper, and at Lornex, the core zones, which have better than average grades, are enriched in bornite relative to chalcopyrite. In contrast, most of the better grade zones at J.A. and a significant proportion of the ore zones at Highmont are in the chalcopyrite dominant zone.

At Valley Copper and Jersey sulphide zoning is almost concentric, with a central bornite zone giving way outward to chalcopyrite then pyrite zones, although the pattern at Valley Copper is complicated by superposition of younger chalcopyrite in the central quartz stockwork. Inside the 0.3 per cent copper isopleth at Valley Copper, bornite abundance equals or exceeds that of chalcopyrite. Outside it, there is a narrow zone dominated by chalcopyrite, then a narrow, very weak pyritic halo. Pyrite in the halo is much less than 1.0 per cent by volume (Osatenko and Jones, 1976). At Jersey grades exceed 0.5 per cent copper in the bornite zone and there are fringing chalcopyrite, pyrite, and specularite zones. On the north side of the orebody, the pyrite and specularite zones are discontinuous. At Highmont, Lornex, J.A., and Krain, sulphide zoning is not concentric. Zoning at Highmont is subparallel to the Gnawed Mountain dyke, that at Lornex is elongated and symmetric about either the quartz porphyry dyke or the structure along which it was emplaced. Zoning at J.A. is related to a quartz monzonite porphyry stock and that at Krain is related to a quartz diorite porphyry stock.

Sulphide deposits and areas of hydrothermal alteration virtually coincide; however sulphide zoning and associated alteration zones vary from deposit to deposit. Bornite dominant zones at Valley Copper and Lornex are in areas with phyllic and argillic alteration, those at Highmont and Jersey are associated with hydrothermal biotite, and those at J.A. and Krain are in areas with argillic alteration. Chalcopyrite zones generally are associated with argillic alteration, although those at J.A. and Krain partially overlap into the propylitic alteration zone. Pyritic zones generally have associated propylitic alteration.

The distribution and abundance of molybdenite varies widely in Highland Valley deposits. Molybdenite grade is below economically recoverable levels at Krain, marginally economic at Bethlehem, and slightly lower at Valley Copper. It is economically significant at J.A. and Lornex and very important at Highmont. Molybdenum distribution in the deposits is similar, but not identical, to that of copper. Molybdenite occurs with quartz in veinlets in the central bornite zone at Krain; it is in the chalcopyrite zone at Bethlehem; it occurs sparsely along the southwest side of the orebody in the pyrite zone at Valley Copper. However, at Lornex, J.A., and Highmont molybdenite is sparsely but widely distributed. Most molybdenite in these deposits occurs in quartz and sulphide veins. That at J.A. is most abundant in the zone with best copper grades, but it is also concentrated along the southern edge of the orebody near and in the stock. At Lornex zones with grades exceeding 0.02 per cent molybdenum occur in both the bornite and chalcopyrite zones and locally extend out into the pyrite halo. Molybdenite and copper zones overlap considerably at Highmont, but the top of the molybdenite zone is below that of copper and its base extends below that of copper (Reed and Jambor, 1976).

GEOCHEMICAL ZONING PATTERNS

Zonal arrangements of major and trace elements also occur in Highland Valley ore deposits. Olade (1974) studied geochemical variations around the Valley Copper, Lornex, Highmont, and J.A. deposits. Osatenko and Jones (1976) conducted a detailed geochemical study of the Valley Copper deposit. Both studies found variations in chemical elements in the different alteration zones, and both found progressive changes from the edge to the centre of each deposit studied.

In general, lithophile elements, Ca, Na, Mg, Sr, Ba, and Mn, decrease from the borders of deposits to their centres. At Valley Copper the most depleted zone is characterized by phyllic alteration; less depletion occurred in zones of propylitic and argillic alteration. Osatenko and Jones (1976) report that argillic alteration locally extends more than 300 metres beyond the 0.3 per cent copper isopleth. The writer found that Alteration of plagioclase to sericite and clay also occurred well out into the country rock at the Lornex, Highmont, and J.A. deposits. Geochemically, this alteration causes depletion in Na and Ca relative to background values.

Other elements, notably Si, K, Rb, Fe, and Ti, are enriched in the Valley Copper deposit. Highest K values occur in areas of phyllic alteration, which correspond to areas with the best grades of mineralization. Copper is, of course, enriched and the border of the deposit is an assay boundary. Zinc and Mo form halos that are primarily outside the deposit and Mn forms a distinct halo roughly 300 metres in width around it.

Olade reports similar elemental distribution patterns for the other Highland Valley deposits. In contrast to Osatenko and Jones, he reports that the deposits are depleted in iron. Olade found that potassic alteration zones were enriched in Rb, Ba, Si, K, and S, but lost Ca, Mg, Fe, Na, and Al. In general Olade found that lithophile element distribution was controlled by alteration; zoning more or less coincided with alteration zones. Ferric elements (Zn, Mn, Ti, V, Ni, Co, Fe, and Mg) are largely controlled by primary lithology; hydrothermal redistribution of these elements is minor.

Sulphur, Cu, and, locally, Hg and B distributions were interesting from an exploration point of view. Sulphur and Cu both formed halos up to 500 metres wide around deposits, but the sulphur distribution was more consistent. Mercury formed a broad halo around the J.A. deposit, but not around Valley Copper. Boron anomalies marked Lornex and Highmont, but boron was inconspicuous at Valley Copper and J.A. Patterns defined by Rb and Sr distribution and Rb/Sr ratios also outline some ore deposits. At Valley Copper and J.A., Rb contents were highest and Sr contents lowest in the potassic core zones; contours of Rb/Sr ratios at the 0.1 level broadly delineated both deposits (Olade and Fletcher, 1975).

INTERPRETATION OF THE CHARACTER OF THE ORE-FORMING FLUIDS

As Beane (1982) indicated, hydrothermal solutions derived from a magma are initially in equilibrium with igneous minerals; injection along fractures into cooler rocks causes cooling and disequilibrium. With cooling, potassium in the solution crystallizes in veins and replaces plagioclase or produces overgrowths on primary biotite. With continued cooling potassic feldspar becomes unstable and Muscovite (sericite) begins to replace feldspars and perhaps biotite; eventually the muscovite becomes unstable and kaolinite begins to replace feldspar and earlier alteration minerals. That this simple model is partly correct can be seen on vein-scale in all Highland Valley deposits. At Valley Copper in particular many veins have alteration selvedges with inner potassic feldspar grading out through muscovite-quartz to sericite-kaolinite to relatively unaltered rock; this sequence may reflect decreasing temperature outward from the vein. However, other veins display apparently reverse zoning; at Valley Copper quartz-potassic feldspar veins cut muscovite-quartz zones. As a generalization, the deposits have early 'potassic' alteration, intermediate phyllic alteration, and late argillic alteration. In detail the system is multiphase and overlapping in space and time; many generations of hydrothermal solutions operated on the systems. Boiling, venting to surface, brecciation, and varying salinity influenced some of the alteration patterns.

Isotopic data indicate that sulphur in the hydrothermal systems had a mantle source (see also Christmas, et al., 1969; Johan, et al., 1980). Sulphur and oxygen isotopic data from Valley Copper (Jones, 1975) indicate that alteration temperatures increased from 260°C in the early stages of alteration to 480°C during the main stage of mineralization. These data also suggest that 70 per cent of the hydrothermal water had an oceanic source during early pervasive argillic alteration; 80 per cent of the hydrothermal fluid was of magmatic origin during early main stage mineralization; but 94 per cent of the water was oceanic during gypsum vein deposition. Presumably the system was quenched by the large influx of oceanic water. If, however, pervasive argillic alteration is late stage (Reed and Jambor, 1976), the data indicate a progressive decrease in temperature and increase in oceanic water content with time; that is, early in main-stage mineralization magmatic water at 480°C dominated, during late pervasive argillic alteration 70 per cent of the water was oceanic at 260°C, and later, during gypsum deposition, 94 per cent of the water was oceanic. It is uncertain which interpretation is correct; the writer favours the idea of two main periods of argillic alteration - one early, one late.

Although there is disagreement in detail, both Osatenko and Jones (1976) and Olade (1974) concluded that acidity in the hydrothermal system gradually decreased with time. Osatenko and Jones argue that during passage from conditions of argillic to phyllic to potassic alteration, sulphur fugacity first increased then decreased and oxygen fugacity gradually decreased. In several deposits the alteration sequence was potassic (+ propylitic ?) to argillic/phyllic to propylitic to late argillic. This sequence argues for swings in acidity during early and main stage events and relatively acid conditions during late stage alteration. According to Beane (1982) pH values in porphyry systems are generally between 3 and 5.

Fluid inclusion data are sparse. However, Jones (1975) reported a few halite, sylvite and carbonate crystals as well as liquid CO2 in some fluid inclusions. The fluid inclusions are small and occur along linear zones, which suggests that most may be secondary. However, some containing solid phases or liquid CO2 may be primary. Liquid CO2 suggests main stage pressures in the range of 100 to 300 bars, which would occur at a depth of I to 2 kilometres.

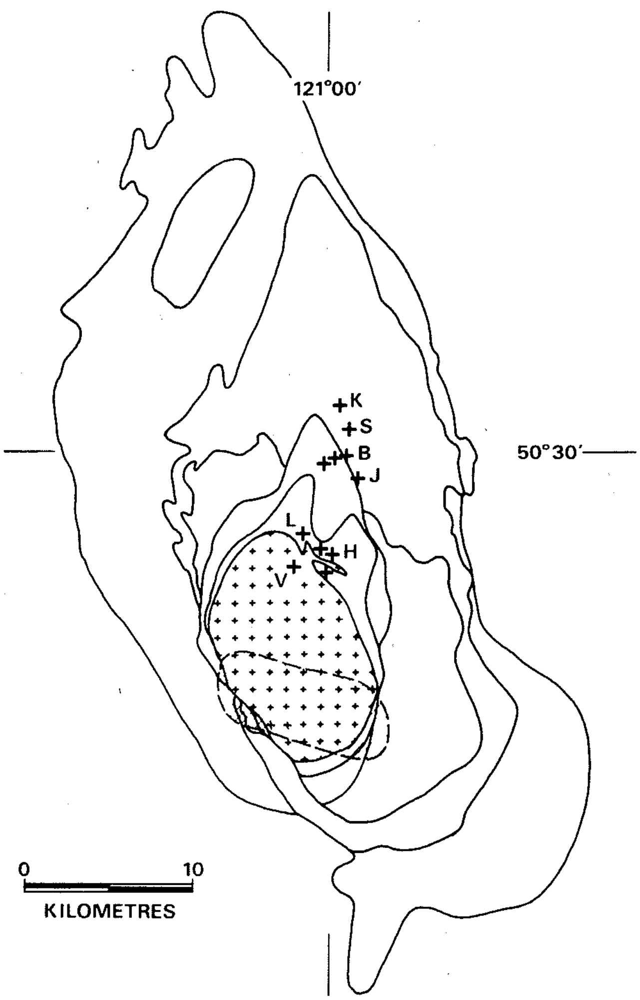
Alteration and sulphide mineralogy in all the deposits is similar, geologic settings are alike, and the deposits occur in close proximity to one another. Therefore oreforming fluids in all the deposits were probably similar. That being the case, the fluid must have been a chloride brine, probably containing HCl, H3BO3, HF, HS, H2SO4, and other volatiles (Olade, 1974). It would be partly of deep-seated origin; at least in part, it would be derived from the Guichon Creek magma, although conceivably the metal and part of the hydrothermal fluid could be from a deep-seated but separate source than the magma.

Alteration initiated during the influx of hydrothermal fluids into structurally favourable areas. Initial intermixing with oceanic waters might be caused by formation of convective cells. Apparently proportions of magmatic and oceanic water and temperature varied across the deposits (Osatenko and Jones, 1976); host rock mineralogy, temperature, and water composition controlled alteration types and intensity (see, for example, Taylor, 1974). Main-phase mineralization was dominated by upwelling magmatic fluids and this stage probably consisted of several waves of hydrothermal fluid of varying composition. As magmatic supply waned, oceanic water proportionally increased, which diluted and cooled the ore-forming brines. Finally, oceanic water predominated, the hydrothermal system collapsed, and mineralization ceased.

ORE DEPOSIT MODEL

Highland Valley porphyry copper-molybdenum deposits are interpreted to be dominantly of orthomagmatic origin. Most of the metal was apparently concentrated into hydrothermal solutions that were derived from the relatively water-rich, more evolved, 'younger' phases of the batholith. These metals were subsequently deposited in structural traps adjacent to subvolcanic source cupolas (Fig. 4a). Initially, the ore fluid consisted primarily of magmatic water; later, as the hydrothermal system collapsed, a large component of meteoric (oceanic) water was involved (Fig. 5).

Relative depth and temperatures of the deposits were inferred from tectonic setting, intensity of alteration, temperature information, presence of porphyry dyke swarms and intrusive breccias, and their present locations and elevations. From deepest and hottest to shallowest and coolest the deposits sort as follows: Valley, Lornex, Highmont and J.A., Bethlehem and South Seas, then Krain (Fig. 4b).



LEGEND

VALLEY COPPER V

LORNEX L

HIGHMONT...................... H

J.A. .... J

BETHLEHEM .... B

SOUTH SEAS.................... S

KRAIN........................... K

COPPER DEPLETED AREA ...

BETHSAIDA PHASE

Figure 4a Diagrammatic representation of the geologic setting of major porphyry copper-molybdenum deposits in the Guichon Creek batholith (younger cover rocks and effects os strike-slip fault movements removed).

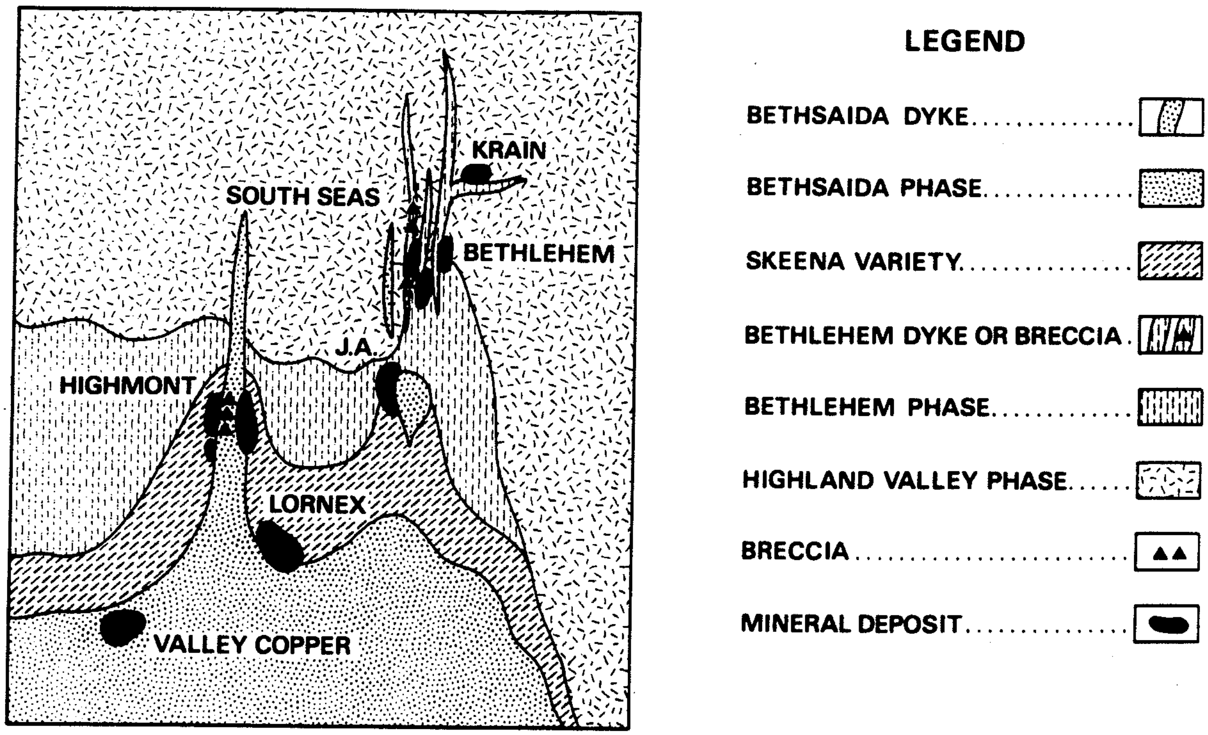


Figure 4b Schematic cross-section showing major deposits and their inferred geologic settings at time of formation.

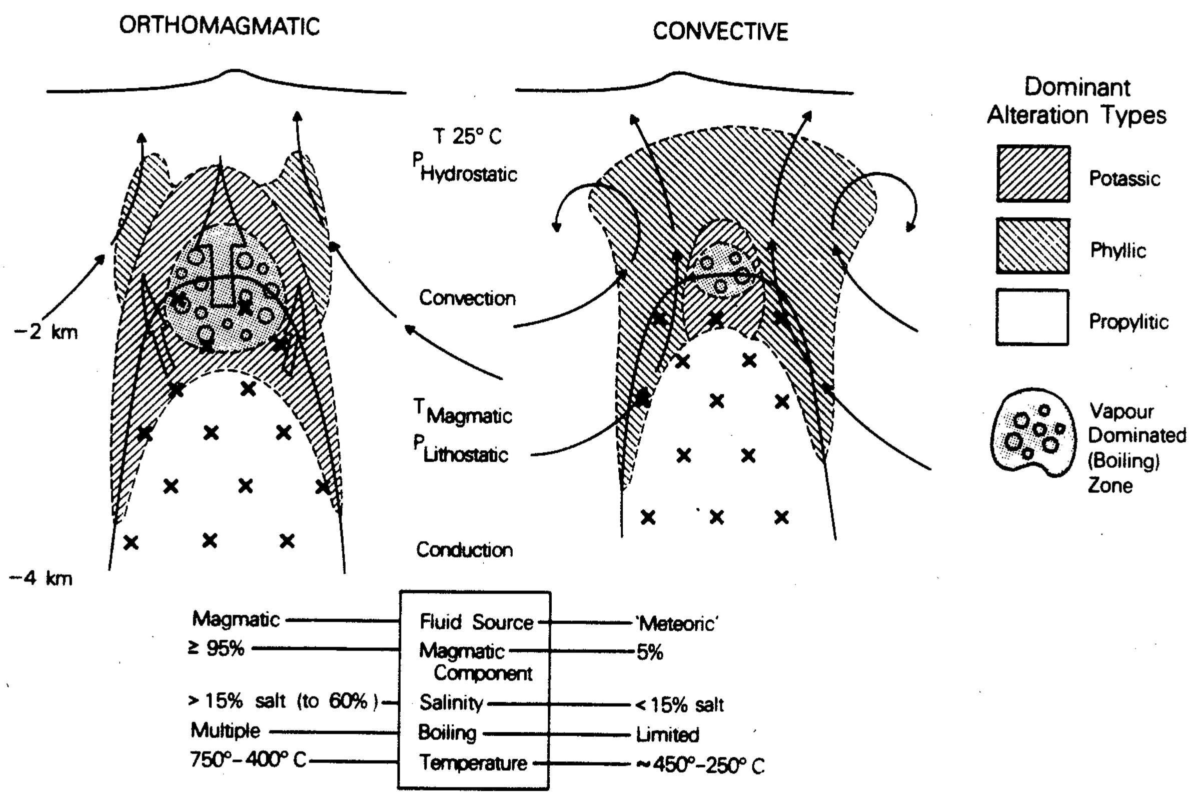


Figure 5 Model of hydrothermal systems with contrasting orthomagmatic and convective fluid flow patterns (after McMillan and Panteleyev, 1980).

Chapter 7b
THE LORNEX DEPOSIT[1]

W.J. McMillan
British Columbia Geological Survey
756 Fort Street
Victoria, B.C. V8V 1XR

INTRODUCTION

This report is mainly after a description published by M.W. Waldner, G.D. Smith, and R.D. Willis in 1976; it includes updated geological plan and section maps courtesy of Lornex Mining Corporation Ltd.

The Lornex copper-molybdenum deposit is in the interior plateau of British Columbia on the southern slope of the Highland Valley at latitude 50027' north, longitude 121003' west, NTS 921/6E. The pre-mining surface of the orebody was about 1 550 metres above sea level. The property is 42 kilometres by road southeast from Ashcroft and 72 kilometres by road from Kamloops.

HISTORY

Copper mineralization was discovered in bulldozer trenches spotted by Egil Lorentzen in 1964. Mr. Lorentzen formed Lornex Mining Corporation Ltd., and in 1965, under agreement with Lornex, Rio Tinto Canadian Exploration Limited began an investigation of the property. A program of geochemical, induced polarization, magnetometer, and geological surveys followed. The induced polarization survey outlined two zones where chargeabilities were in excess of 5 milliseconds - twice mean background. Subsequent diamond drilling of the anomalous zones returned encouraging copper grades. A total of 26 200 metres of surface diamond drilling and 27 000 metres of percussion drilling were completed by 1967. An underground bulk sampling and a small open pit provided feed for a pilot mill at 90 tonnes per day.

The developed orebody, which contained an estimated 266 million tonnes of mineable ore, was put into production in the spring of 1972 by Lornex Mining Corporation Ltd., which is controlled by Rio Algom Mines Limited. During the period from 1973 to 1974, additional reserves were outlined by 20 700 metres of diamond drilling.

The mill was initially designed to process 34 500 tonnes of ore per day; however, actual throughput attained 43 500 tonnes per day. In 1979 expansion was initiated and increased design capacity to 84 000 tonnes per day.

GEOLOGY

Lornex copper-molybdenum deposit is approximately 1 900 metres long, 500 metres wide, and plunges northwesterly to a depth in excess of 750 metres (less than 850 metres above sea level). The ore deposit is mantled by 2 to 75 metres of overburden, which gradually thins eastward from a maximum depth in Award Creek Valley, the surface expression of the Lornex fault.

The orebody occurs within Skeena variety, a slightly porphyritic, medium to coarse-grained granodiorite (Fig. 6). It consists of quartz (20 per cent), plagioclase (50 per cent), orthoclase (10 per cent), biotite (5 to 20 per cent), and hornblende (5 to 10 per cent), with accessory sphene, apatite, zircon, and magnetite. Quartz occurs interstitially, as subhedral grains that show undulatory extinction. Plagioclase is twinned with complex oscillatory zoning; crystal cores are generally An30-35. Orthoclase is interstitial and perthitic. Biotite is subhedral to euhedral; hornblende is irregular, anhedral, and commonly poikilitic.

A pre-mineral quartz porphyry dyke (Fig. 6), which probably is related to the Bethsaida phase (McMillan, 1976), trends northwesterly through the Highmont property and pinches out in the Lornex orebody. Contacts of the dyke are indistinct because

[1] modified from McMillan (1985)

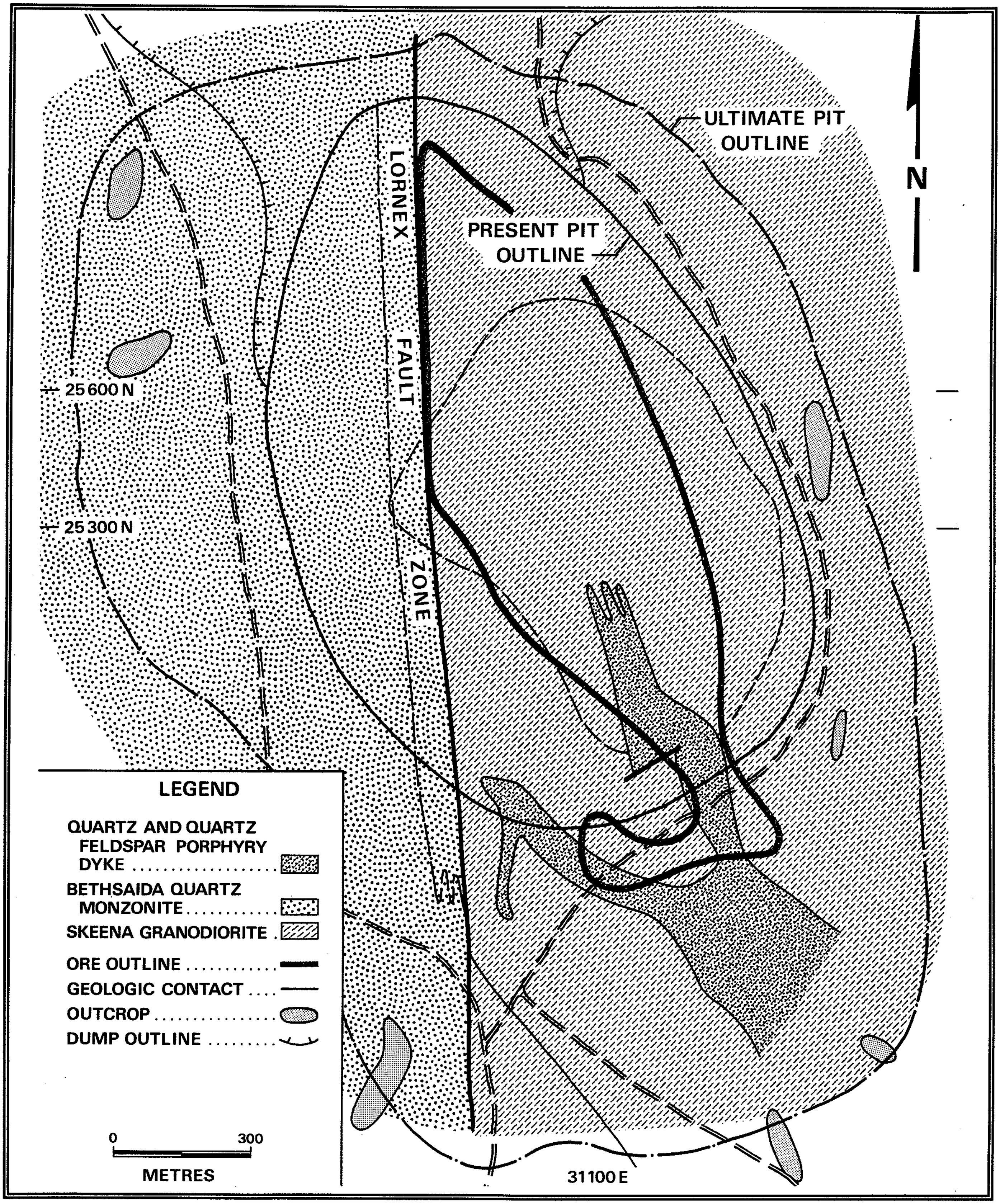


Figure 6 General geologic setting of the Lornex copper-molybdenum deposit (modified after Waldner et al., 1976).

adjoining Skeena quartz diorite is silicified and sericitized. The dyke is presumed to have intruded one of a series of structural zones parallel to Highland Valley (Bergey et al., 1971). Quartz phenocrysts normally compose 20 to 25 per cent of the dyke and plagioclase phenocrysts occur locally. The grey aphanitic matrix is composed of 60 to 70 per cent plagioclase (An 40) and 10 per cent quartz.

STRUCTURE

Mineralization is controlled by the distribution and density of fracture sets. Mineralized and post-mineral fractures formed during at least three periods of deformation. More than 11 000 structural measurements from mineralized veins in the Lornex pit defined three major sets of copper-molybdenum veins: 022°/55° southeast, 064°/57° southeast, and 090°/58° south. Certain of these veins are dominant in distinct zones of the orebody. The veins striking 022° are concentrated in the southern and southeastern zones. In the central and western zones all three vein sets overlap, which results in a greater concentration of veins and higher copper grades (Fig. 7).

Two post-mineral fault and fracture systems have been recognized in the open pit. One system has two sets of fractures: one set trends 0940/520 to 092°/62° south, the other 021°/46° to 032°/54° southeast; these are subparallel to the northeast and east-striking copper-molybdenum veins. A second system, which offsets the first, has three dominant trends: 112°/69° southwest, 036°/66° southwest, and 172°/68° west. Where faults cut vein mineralization, displacements are from 1 centimetre to 2 metres.

The most prominent structural feature in the area is the Lornex fault (Figs. 6 and 7); it has been exposed by mining and intersected by diamond-drill holes. The fault, which strikes northerly and dips 55 to 85° westward, truncates the north-western part of the ore deposit and juxtaposes Bethsaida quartz monzonite and Skeena quartz diorite in the vicinity of the orebody. In general, the dip is lowest in the south and steepens toward the north. Black gouge, which forms on the footwall of the fault zone, varies in thickness from 10 centimetres to 1.5 metres. Mylonite forms discontinuous pods 1 to 50 metres wide in the hangingwall of the fault zone; it has been exposed in the pit over a strike length of 75 metres.

ALTERATION

Five main types of hydrothermal alteration related to quartz and sulphide mineralization occur at Lornex: silicic, potassic, phyllic, argillic, and propylitic (Fig. 8).

Silicic Alteration

Pervasive silicification appears to be related to the pre-mineral quartz porphyry dyke. This dyke is weakly affected by hydrothermal alteration, in contrast to the Skeena quartz diorite host, which is altered pervasively. The silicic alteration zone is marked by closely spaced quartz veins with associated quartz alteration. Unlike that at Valley Copper, the silicic alteration zone at Lornex is moderately to well mineralized with copper.

Potassic Alteration

Potassic alteration is distributed erratically and no well-defined potassic zone exists at the levels explored in the Lornex orebody. hydrothermal potassic feldspar occurs sporadically in thin discontinuous veinlets and hydrothermal biotite locally replaced mafic minerals in zones of intense argillic alteration.

Phyllic Alteration

Phyllic alteration consists of grey quartz-sericite envelopes as borders on quartz-copper sulphide and quartz-molybdenite veins within the argillic alteration zone. These envelopes, which commonly form sharp boundaries with pervasive, moderate to intense, argillic alteration, average approximately 3 centimetres in width.

Argillic Alteration

Argillic alteration, which is pervasive throughout the ore zone (Fig. 8), is characterized by the presence of quartz, sericite, kaolinite, montmorillonite, and chlorite. Sericite and kaolinite, with minor amounts of montmorillonite and chlorite, form pseudomorphs after plagioclase. The cores of the plagioclase crystals are generally more intensely altered than the rims, but in intense stages of argillic alteration the entire plagioclase crystal is replaced by sericite and clays. Kaolinite, sericite, and lesser montmorillonite also

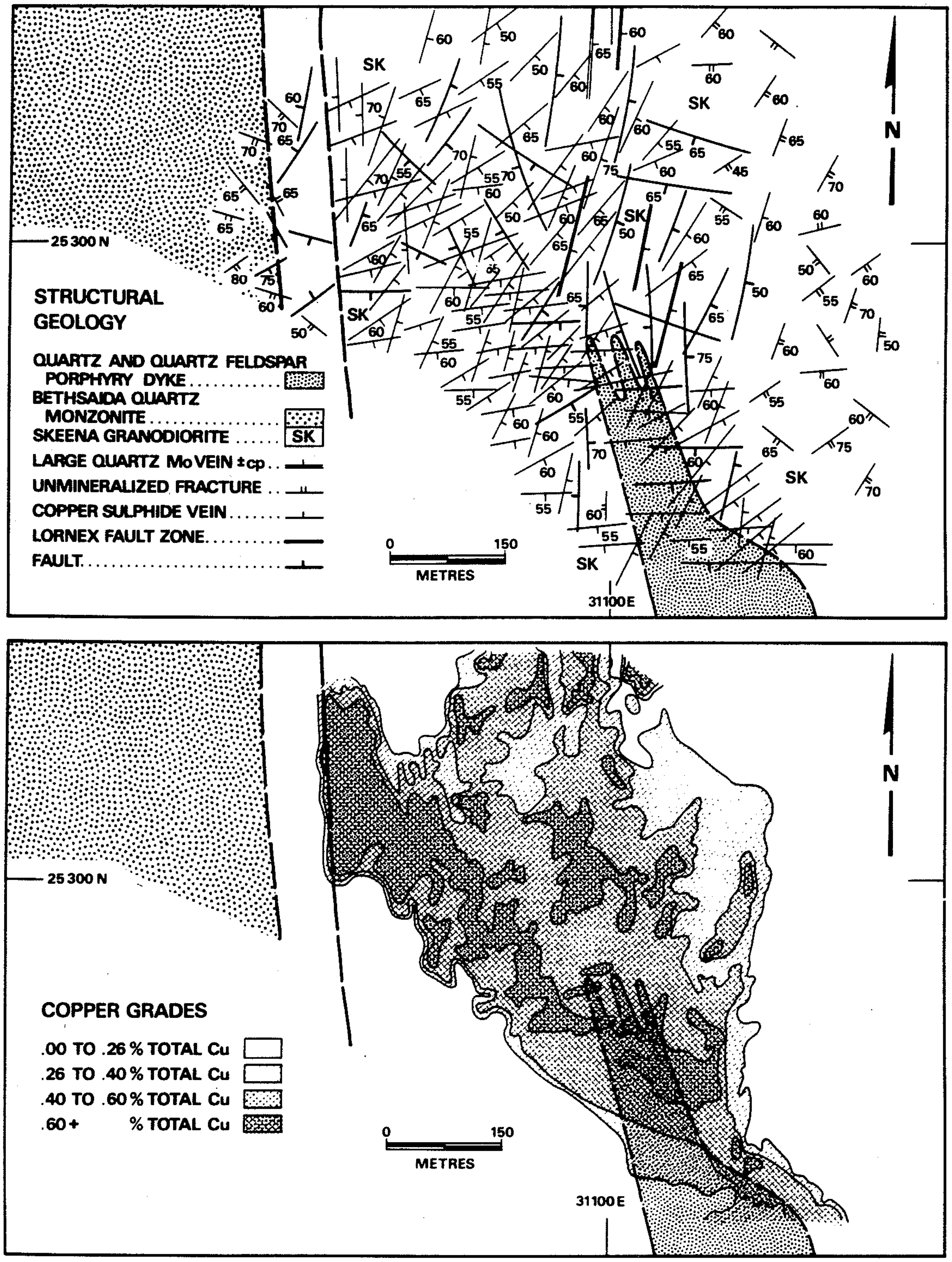


Figure 7 Composite maps of the 1426-metre and 1524-metre benches, Lornex mine, illustrating structural trend and copper grade distribution (after Waldner et al., 1976).

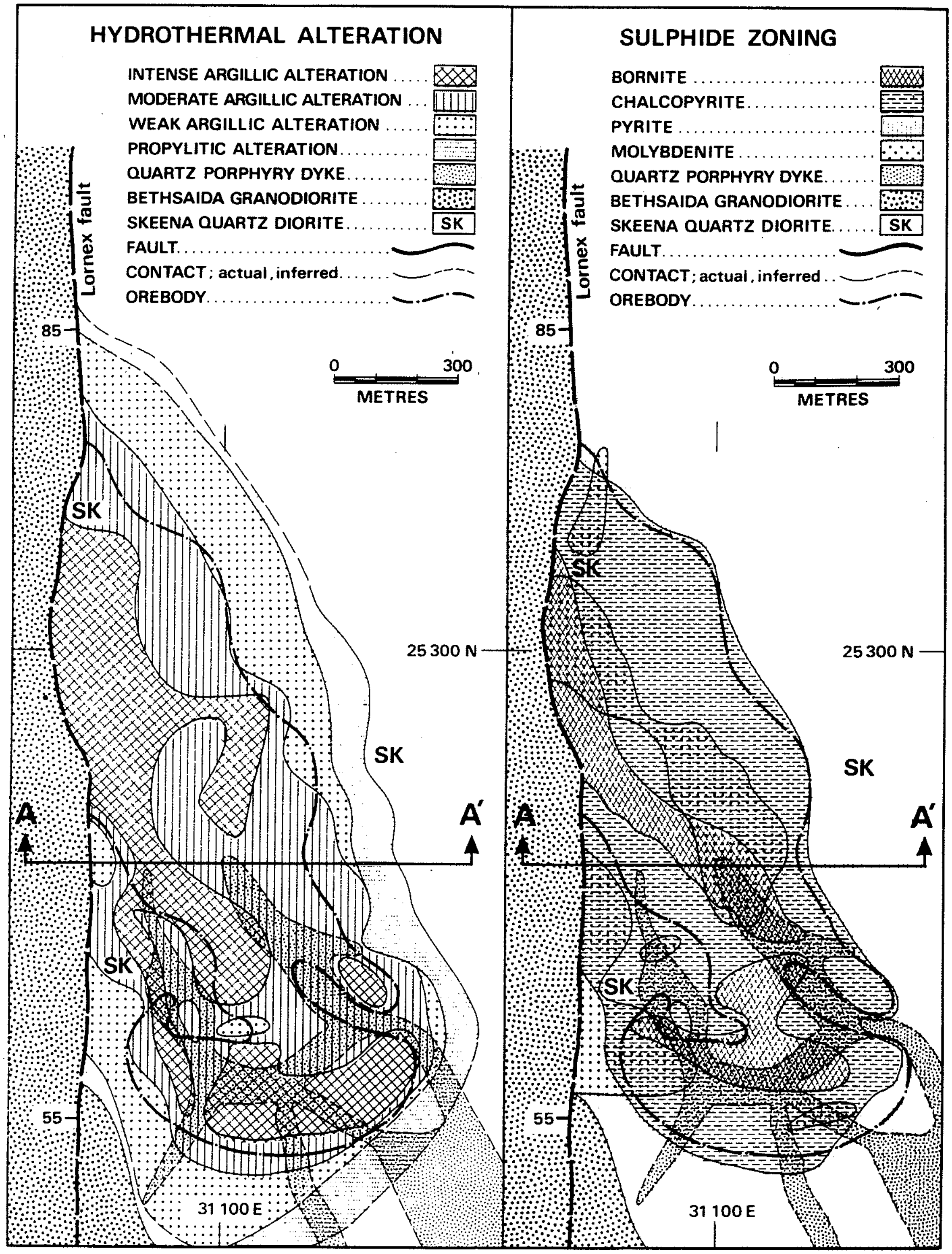


Figure 8 Plan views of the Lornex deposit illustrating alteration and hypogene sulphide zoning patterns (modified after Waldner et al., 1976).

replace primary orthoclase; alteration progresses from the rim toward the core with increasing intensity of argillic alteration. Primary biotite and hornblende alter to chlorite and sericite. Pervasive argillic alteration of Skeena quartz diorite produces a cream or apple green rock. In the cream varieties kaolinite predominates over sericite, in the apple green variety sericite predominates. Generally, copper grades increase as the intensity of argillic alteration increases.

Propylitic Alteration

Pervasive propylitic alteration is peripheral to the argillic alteration; typically it consists of epidote (zoisite), chlorite, and carbonates (calcite), with minor amounts of sericite and hematite. Epidote and calcite are most common in veins. Quartz and orthoclase in the host rock are unaltered, but plagioclase, which has a fresher appearance than in the argillic alteration zone, is altered to calcite and epidote with minor amounts of sericite and chlorite. Mafic minerals alter to chlorite, calcite, and sericite, with lesser hematite and epidote.

Gypsum Distribution

An erratic zone of late-stage gypsum occurs at elevations below approximately 1 100 metres. The gypsum is generally at a higher level on the fringe of the orebody and deeper in its centre. Gypsum is post-ore and occurs mainly as 5 to 10-millimetre-thick veins.

MINERALIZATION AND METALLIC MINERAL ZONING

The predominant hypogene sulphide minerals, in order of abundance, are chalcopyrite, bornite, molybdenite, and pyrite. Minor amounts of sphalerite, galena, tetrahedrite, and pyrrhotite also occur. Total sulphide content averages 1 to 1.5 weight per cent in the ore zone, but gradually decreases from the central part of the orebody toward its periphery. Common gangue minerals include quartz, calcite, epidote, hematite, magnetite, and gypsum.

Sulphides occur primarily with quartz as fracture fillings and as fracture coatings. Only an estimated 5 per cent of the total bornite, chalcopyrite, and pyrite occur as disseminations or partial replacements of mafic constituents of the host rock. Veins average 5 to 15 millimetres in width, but vary in width from 'hairline' to more than a metre. Larger veins, some of which have been mapped for more than 200 metres of strike length, commonly are composed of quartz, molybdenite, and chalcopyrite. Molybdenite normally occurs as thin laminae in banded quartz veins, although it may occur as rosettes in vuggy quartz veins. Drummond and Kimura (1969) describe similar veins at Endako and suggest that these types of vein structures represent repetitive pulses of mineralization. Molybdenite veins more than a metre in width are prominent on the eastern side of the orebody (Fig. 7). Post-ore faults are prevalent along these veins.

Sulphide zones illustrated on Figures 8 and 9 are defined as follows:

Bornite Zone: bornite > chalcopyrite > pyrite

Chalcopyrite Zone: chalcopyrite > bornite > pyrite

Pyrite Zone: more than 0.05 per cent pyrite and 60.26 per cent copper

Molybdenite Zone: molybdenum ->0.02 per cent

Total sulphide content averages 1 to 1.5 per cent in the bornite, chalcopyrite, and molybdenite zones, but only 0.25 to 0.5 per cent in the pyrite zone. According to Olade (1974) an increase of pH could cause the sulphide zonation if the rate of decrease of copper caused by deposition of copper sulphide was less than the rate of decrease of H^+ activity caused by hydrothermal alteration.

Trace-element studies of the orebody and the Lornex fault zone discovered anomalous values for several elements. Anomalously high amounts of Zn, Ag, and Bi, and, according to Olade (1974), Pb, Mn, Hg, Cd, and Ca exist in the Lornex fault zone where it truncates the orebody. Zinc values as high as 1 200 ppm have been determined from analyses of Lornex fault gouge. Sphalerite and discontinuous pods of massive pyrite occur in the zone, but chalcopyrite, bornite, and molybdenite have not been observed. Assays of over 70 ppm Bi in the fault are probably due to the presence of bismuthinite, which was identified by microprobe analyses of copper concentrate. The orebody is enriched in B, Ti, and V, but is low in Mn, Sn, and Ba.

Weathering and Supergene Characteristics

The oxide zone averages 3 to 30 metres in thickness and contains only minor amounts of recoverable copper sulphides. It is thickest on the west side of the orebody and thins toward the east. The

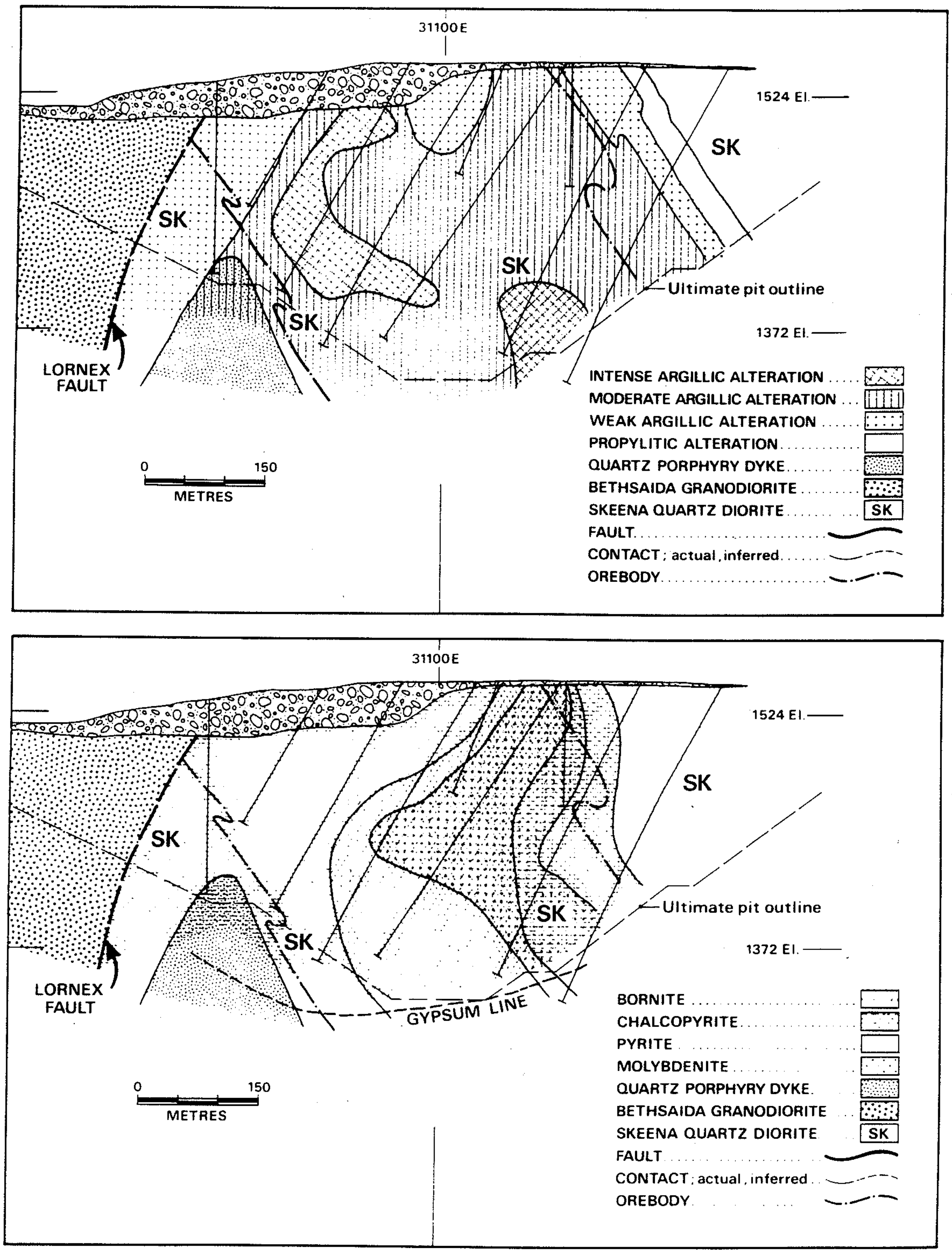


Figure 9 Section A-A', looking north, through the Lornex orebody showing zones of hydrothermal alteration and sulphide mineral distribution patterns (modified after Waldner et al., 1976).

depth of the zone is irregular, apparently controlled by local fracture density. Malachite is the predominant copper mineral in the oxide cap, but azurite, cuprite, chalcocite, covellite, and native copper are common. Limonite and pyrolusite are also abundant in this zone. No molybdenum oxide minerals have been identified. Copper enrichment in the oxide zone is not important economically, although a discontinuous 5 to 10-centimetre-thick layer of chalcocite occurs at the oxide-sulphide interface.

GENESIS

Relative ages of mineralization have been determined from crosscutting relationships, polished section exsolution features, and vein zoning. The stages of mineralization and related alteration types are illustrated on Figure 10. Quartz is ubiquitous in all but the two youngest stages of mineralization. Molybdenite occurs in stages 2 to 5, but is most abundant in stages 4 and 5. Copper mineralization generally is confined to stages 3, 4, and 5. Pyrite mineralization is mainly in stage 7 and peripheral to the ore zone. Calcite veining is associated with propylitic alteration as a late-stage alteration product. The final stage of mineralization, gypsum, has no associated alteration. It occurs mainly below the 'gypsum line' near the 1 200-metre elevation on Figure 9.

Plan and section views show concentric zonal distributions of principal sulphides and major hydrothermal alteration types at Lornex (Figs. 8 and 9). Sulphide and alteration zones plunge northwesterly at 30 to 400 and terminate abruptly against the footwall of the Lornex fault. Bottoms of zones have been determined by drilling in the south-central portion of the orebody and by interpretation in the northern part. The shallow depth of the zones in the south-central area coincides with the highest level of quartz porphyry dyke intrusion.

Hydrothermal alteration in the dyke is weak; sulphide content is also relatively low. This may be due in part to the very fine-grained nature of the dyke matrix, in part to low fracture density, and in part to its halo of silicified rock. These factors may have impeded flow of hydrothermal fluids into the dyke.

The following general statements regarding the mineral and alteration zoning of the orebody can be made:

(1) The principal sulphides form a concentric pattern, with bornite in the centre, chalcopyrite outside bornite, and a molybdenite zone overlapping portions of the bornite and chalcopyrite zones. Pyrite forms a halo around the ore zone.

(2) Copper grades and total sulphide content decrease outward from the core of the orebody to its periphery.

(3) Sulphide and alteration zones continue to depth in the northern portion but are shallow in the southern portion of the orebody, indicating a 30 to 40°-northwest plunge to the orebody.

(4) Zones of moderate to intense argillic alteration correspond to grades higher than 0.26 per cent copper and total sulphide content greater than 1 per cent.

(5) The propylitic alteration zone occurs on the margin of the orebody; it is associated with subeconomic copper grades, the pyrite zone, and a total sulphide content of less than 0.5 per cent.

Any interpretation of the genesis of the orebody must take the following factors into account:

(1) Mineralization is slightly younger than the Bethsaida phase.

(2) The Lornex fault and the quartz porphyry dyke represent zones of weakness.

(3) The Skeena quartz diorite and the ore zone are truncated by the Lornex fault.

(4) Right-lateral and reverse movement occurred on the Lornex fault.

(5) Sulphide mineralization occurs primarily as fracture infillings.

(6) Copper-molybdenum veins are mainly in discrete sets of fractures.

(7) The density and spatial distribution of veins in the orebody control grades.

(8) There are two post-mineral structural systems.

(9) Hydrothermal alteration related to stages of mineralization changes with time.

(10) Hydrothermal alteration is weaker and sulphide

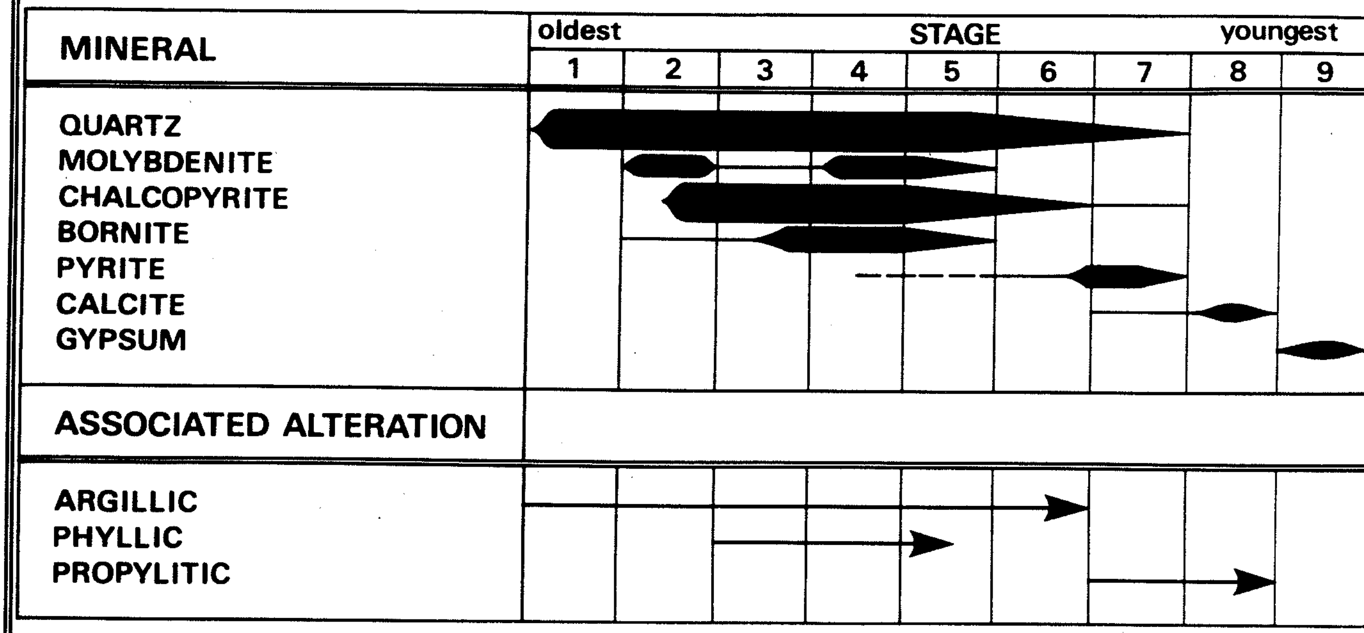


Figure 10 Stages in the paragenetic sequence showing relative abundance of metallic and non-metallic hypogene minerals and related alteration facies (after Waldner et al., 1976).

content lower in the quartz porphyry dyke.

(11) Sulphides and phases of hydrothermal alteration

are concentrically zoned.

(12) The ore deposit plunges 30 to 40° toward the northwest.

Emplacement of the Guichon Creek batholith appears to have been controlled by major, deep-seated zones of weakness (Carr and McMillan, 1970). The Lornex fault may be the rejuvenated supracrustal expression of one of these deep-seated structures. The quartz porphyry dyke, which probably was derived from the Bethsaida phase, was emplaced along a northwest-trending zone of weakness which intersects the Lornex fault.

Pre-mineral tectonic stresses are thought to have formed a conjugate shear system at the intersection of the Lornex fault and the quartz porphyry dyke. Maximum principal stresses from the east-northeast and west-southwest produced shear fractures striking 022° and 090°, and extension fractures striking 064° . Ore-bearing hydrothermal fluids, which may have developed by late-stage fractionation from the batholith, migrated along the fractures and formed an epigenetic ore deposit with sulphide minerals and hydrothermal alteration concentrically zoned around a more permeable core zone (Fig. 8).

Following mineralization, it is thought that regional stresses, with maximum principal stresses from the east-northeast and west-southwest, produced further shearing subparallel to and along 022° and 090°-striking veins. It is probable that right-lateral displacement took place on the Lornex fault during this period of deformation. Apparently, the Lornex orebody (the portion east of the fault) was tilted down in the north and relatively up in the south at this time. This tilt is invoked to explain why mineralized fractures now dip in a southerly direction and why sulphide and alteration zones plunge 30 to 40° northwesterly.

A late-stage deformation produced by maximum principal stresses, oriented from the northwest and southeast, developed a conjugate shear set oriented 115° and 172°, and extension fractures striking 136°. Displacements related to this period of deformation are generally small.

Tertiary weathering and Pleistocene glaciation and other geomorphological processes developed the present oxide cap and cover of glacial, fluvial, and lacustrine sediments.

Chapter 7c
VALLEY COPPER DEPOSIT[1]

W.J McMillan
British Columbia Geological Survey
756 Fort Street
Victoria, B.C. V8V 1X4

INTRODUCTION

The Valley Copper porphyry deposit (latitude 50°29' north, longitude 121°02' west, NTS 92I/6E) has been explored extensively by drilling and underground workings; development began in spring, 1982. Published reserves, to a depth of 442 metres, are 790 million tonnes of 0.48 per cent copper. A historical summary of the discovery of the deposit may be found in Allen and Richardson (1970). Except where otherwise acknowledged, data in this paper are mainly after Osatenko and Jones (1976).

HISTORY

In the 1920's shallow shafts were sunk on high-grade chalcopyrite veins on the Bethsaida claims southwest of the Valley Copper deposit. After the second World War, Western Beaver Lodge Mines Ltd. acquired the claims and performed geochemical surveying and trenching. Kennco Explorations, (Canada) Limited optioned the Bethsaida claims in 1957 and after performing a wide-spaced induced polarization survey, one line of which crossed the western edge of the Valley Copper deposit, Kennco relinquished its option. In 1964 and 1965 most of the mineral claims that comprise the Valley Copper property, including the Bethsaida claims, were acquired by Cominco Ltd. through agreements with Northwest Ventures Ltd., Huestis Mining Corporation Ltd., Buttle Lake Mining Company Limited, B.X. Mining Company Limited, and various individuals. As part of the agreement, Valley Copper Mines Limited was incorporated. Also in 1964, three holes were drilled on the Bethsaida claims. Subsequent drilling of 10 additional holes in 1966 indicated large amounts of sub-ore grade copper mineralization just southwest of the Valley Copper deposit. This find, in addition to information gained from a geologic study of the Guichon Creek batholith and discovery of the Lornex orebody, nearby to the south-southeast, indicated that the Valley Copper site warranted more intense exploration. Favourable results obtained from an induced polarization survey and percussion drilling over the Valley Copper site in 1967 were followed by a large-scale drilling program that led to discovery of the orebody and to its continuous exploration and development through 1970; production began in the spring of 1982.

GEOLOGY

The rocks that contain the Valley Copper deposit are mainly porphyritic quartz monzonites and granodiorites of the Bethsaida phase of the Guichon Creek batholith (Fig. 11). These rocks are medium to coarse grained with coarse phenocrysts of quartz and biotite. Accessory minerals are hornblende, magnetite, hematite, sphene, apatite, and zircon.

Feldspar porphyry and quartz feldspar porphyry dykes occur in the western, central, and southern parts of the deposit. These dykes, which vary in width from about 0.6 to 35 metres, dip steeply eastward in the western and central areas, and northward in the southern area. Feldspar porphyry dykes consist approximately of 60 per cent medium to coarse-grained plagioclase and a small number of quartz phenocrysts in a fine-grained matrix consisting of quartz, potassic feldspar, and lesser plagioclase, with trace amounts of magnetite, hematite, and biotite. Quartz feldspar porphyry, which ranges from fine to coarse grained, contains 50 per cent plagioclase and 8 per cent quartz phenocrysts in a fine-grained matrix of quartz and plagioclase that contains minor amounts of potassic feldspar, magnetite, and hematite. These (dykes are invariably cut by mineralized fractures and quartz veinlets. A single potassium-argon determination on biotite gave an age of 204+-4 Ma (Osatenko and

[1] Modified from McMillan (1985)

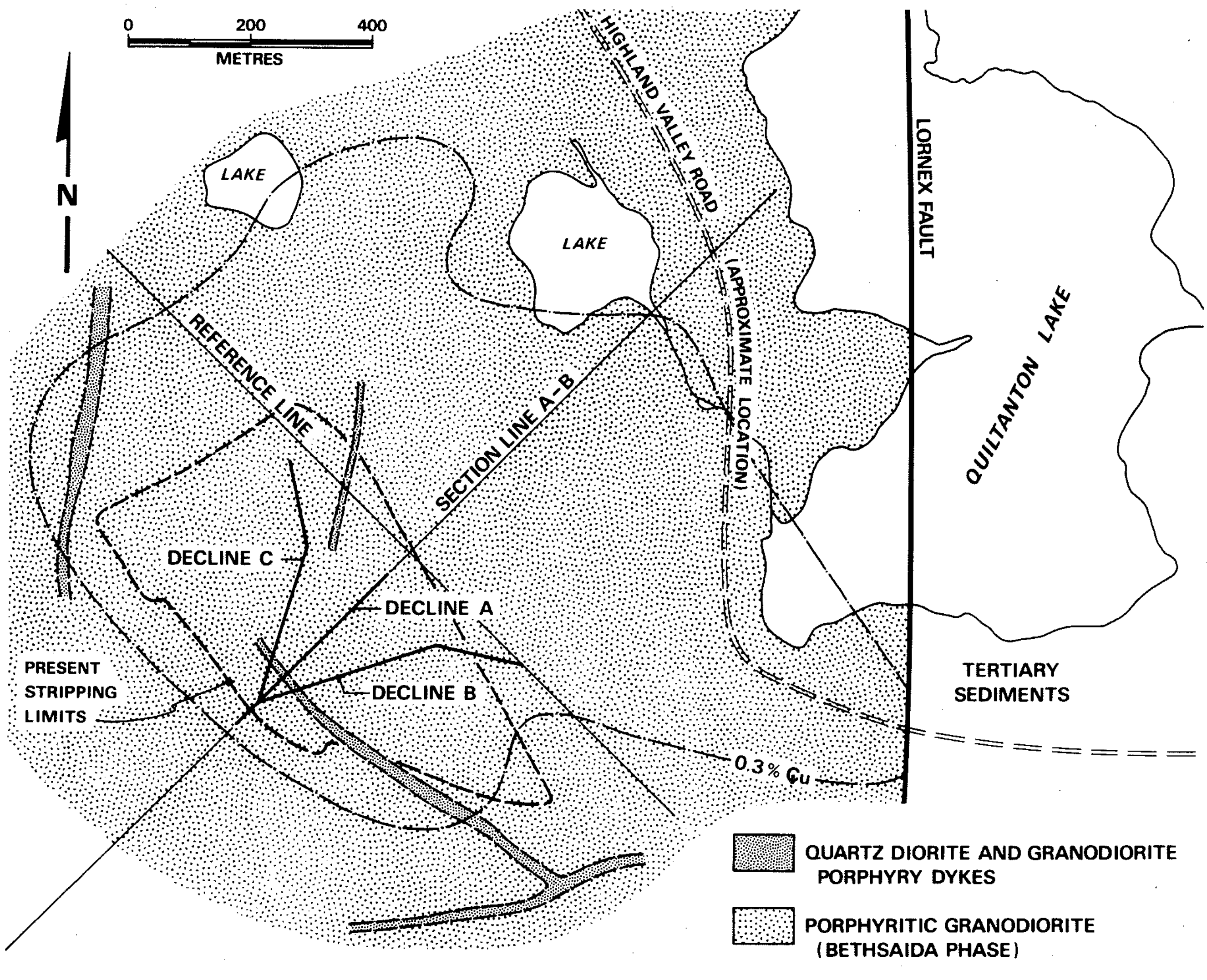


Figure 11 Plan view showing the geology and the ore outline in the Valley Copper deposit (after Osatenko and Jones, 1976).

Jones, 1976).

Aplite dykes, up to 0.3 metre in width, occur throughout the deposit. They consist of potassic feldspar and quartz with lesser amounts of plagioclase and biotite. The aplite dykes are invariably cut by mineralized fractures.

A swarm of tan-coloured felsite porphyry dykes intrude the Bethsaida granodiorite in the northwestern part of the deposit. These dykes, which are up to 4.5 metres in width, are characterized by a higher proportion of matrix (about 80 per cent) than the other porphyry dykes. Their matrix is light tan in colour and consists primarily of potassic feldspar and quartz. Phenocrysts make up 20 per cent of the rock and include quartz, plagioclase, potassic feldspar, and biotite.

Tan felsite porphyry dykes may have been intruded during the waning stages of mineralization. Some unaltered dykes contain inclusions of sericite-veined Bethsaida granodiorite, but others contain disseminated chalcopyrite and bornite and are sparsely veined by mineralized quartz.

Three types of lamprophyre dykes - spessartite, hornblende vogesite, and vogesite - were intersected in drill holes. Alteration and mineralization are cut by these younger dykes. Further, the vogesite lamprophyre has a potassium-argon age of 132±3 Ma (Jones, 1975).

STRUCTURE

Cominco Ltd. geologists made about 14 000 structural measurements on faults, fractures, and quartz veinlets in the exploratory declines. Faults comprise four distinct sets, represented by the following orientations: 173°/75° east, 004°/90°, 108°/84° south, and 000°/16° east. Fractures include corresponding sets at 169°/80° east, 000°/90°, and 108°/85° south, and additional sets at 073°/18° south and 035°/70° northwest. Quartz veinlets show well-developed sets at 161°/80° east and 111°/79° south that are subparallel to the earlier formed principal sets of fractures and faults (McMillan, 1971). The main structural orientations that occur in the declines are parallel to the Lornex and Highland Valley faults respectively (Allen and Richardson, 1970).

ALTERATION

Introduction

Alteration types recognized at Valley Copper are: silicic, potassic, phyllic, argillic, and propylitic. In general, alteration types are associated intimately, even at hand specimen scale. A generalized diagram of the distribution of dominant alteration types is depicted on Figure 12. A major zone of potassic feldspar alteration in the west-central part of the deposit is associated with and enveloped by an extensive zone of moderate to strong phyllic and pervasive argillic alteration. These grade outward into a zone dominated by weak to moderate pervasive argillic alteration fringed by a peripheral zone of weak to moderate propylitic alteration. Locally this peripheral zone contains minor amounts of phyllic and pervasive alteration as well as quartz veining. An area of well developed barren quartz veinlets occurs in the southeastern part of the deposit. Elsewhere, quartz veinlets (commonly mineralized, but some barren) are only moderately abundant within the 0.30 per cent copper isopleth.

Silicic Alteration and Veining

Quartz veinlets in the form of a stockwork are a common feature at Valley Copper; typically veinlets are about 1 to 2 centimetres in width, although some are up to 25 centimetres. The term silicic alteration refers to quartz veining and secondary quartz produced as a by-product of sericitization and kaolinitization of plagioclase.

The quartz stockwork consists of two main classes of quartz veinlets. The first, which is commonly vuggy, usually has envelopes of medium-grained sericite, or intergrown sericite and potassic feldspar, or potassic feldspar. Veinlets of this class are closely associated with mineralization. They vary in grain size from 0.4 to 2.5 millimetres (average 1.5 millimetres). These veinlets frequently contain minor amounts of sericite, sericitized plagioclase, secondary potassic feldspar, calcite, hematite, bornite, chalcopyrite, pyrite, molybdenite, digenite, and covellite.

The second class of quartz veinlets have no alteration envelopes and carry essentially no sulphides. Veinlets of this class are most abundant in the southeastern part of the deposit, where they comprise two types: a fine-grained variety, varying in grain size from 0.02 to 1.0 millimetre (average 0.5 millimetre); and a medium-grained variety with grain sizes of from 1.0 to 1.5 millimetres (average 1.3 millimetres). Both types have sharp contacts with the unaltered or pervasively altered country rocks and generally contain minor amounts of potassic feldspar; muscovite is notably absent.

The distribution of silicic alteration and quartz veinlets on the 1 097-metre level shown on Figure 32 is based on the abundance of secondary quartz. Quartz content is expressed as the actual percentage minus the background primary quartz content of the unaltered country rock (29 per cent). The 10 per cent secondary quartz contour outlines the deposit. In areas of greater than 0.50 per cent copper, levels of secondary quartz range up to about 20 per cent. The very low grade zone in the southeastern corner of the deposit is highly silicic, with secondary quartz content ranging from 19 to 27 per cent. It should be stressed that these secondary quartz percentages comprise both barren and mineralized

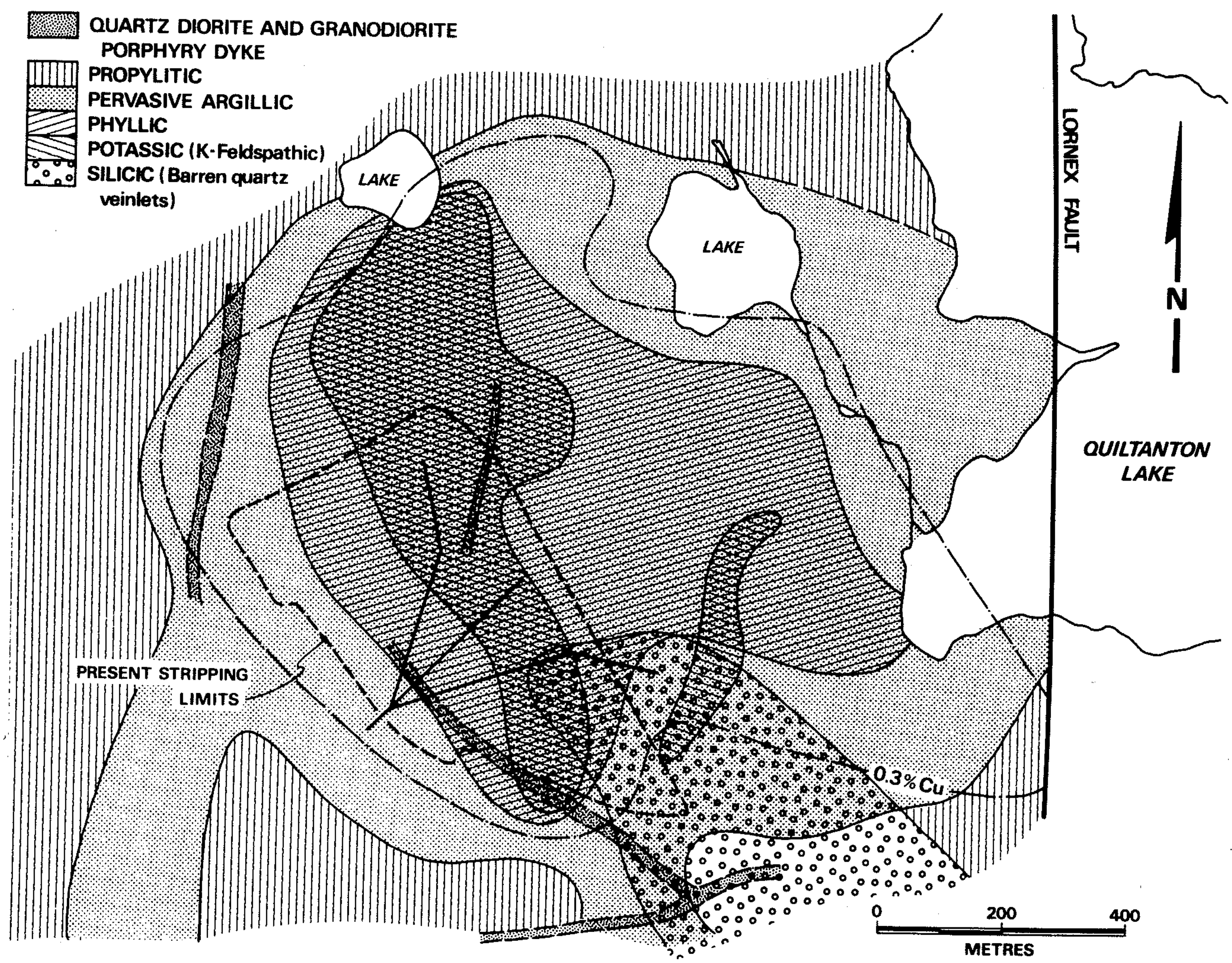


Figure 12 Plan view showing the distribution of major alteration types in the Valley Copper deposit (after Osatenko and Jones, 1976).

quartz veinlets and a component, which is approximately three-quarters of the total, of secondary quartz that formed from silica liberated during alteration of plagioclase to sericite and kaolinite.

Potassic Alteration and Hydrothermal Biotite Formation

Potassic feldspar alteration is common at Valley Copper, especially at deeper levels (Fig. 13). It occurs in association with vein sericite (muscovite) in some replacement zones, as veinlet envelopes, along fractures, and disseminated in quartz veinlets.

Potassic feldspar associated with vein sericitic (phyllic) alteration typically forms thin, discontinuous selvedges (about 1 millimetre thick) at the outer margins of sericitic replacement zones, where it apparently

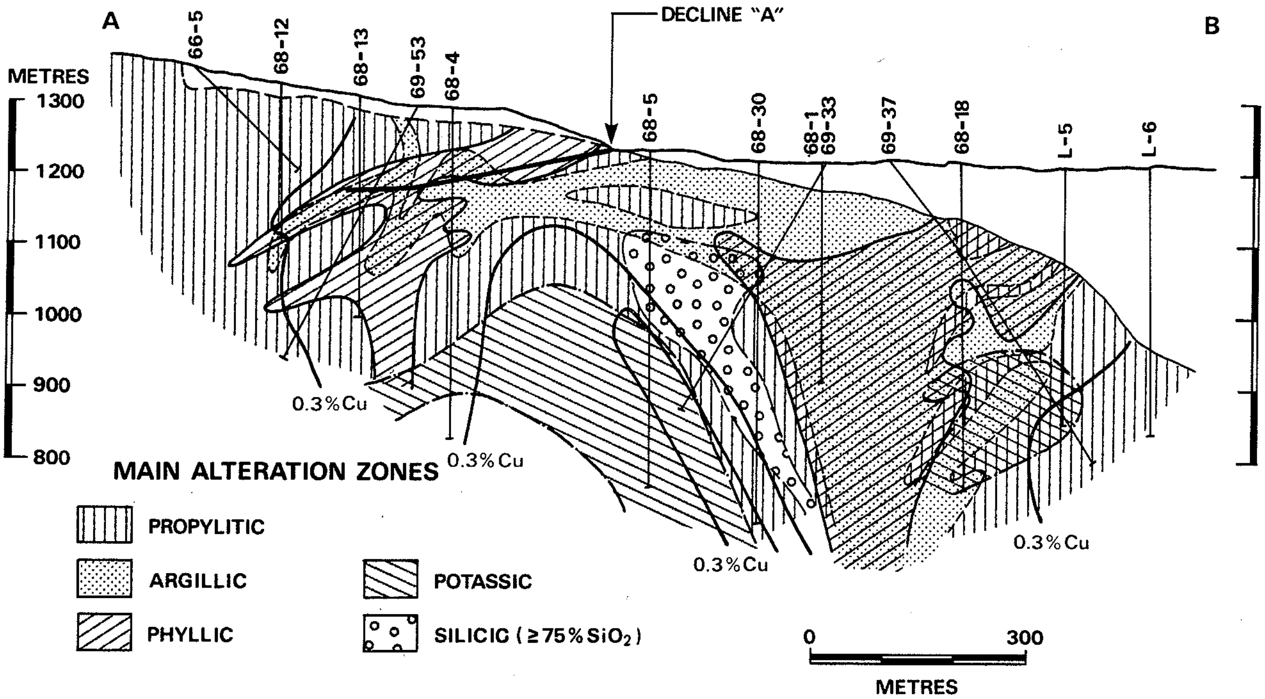


Figure 13 Cross-section A-B through the Valley Copper deposit showing geology and major alteration types (after Osatenko and Jones, 1976). For location see Figure 11.

replaces sericitized plagioclase or vein sericite. Secondary potassic feldspar is most common in quartz veinlets but also occurs as thin, fracture-controlled replacement zones. Copper mineralization is typically sparse with this type of alteration, and consists of chalcopyrite with trace amounts of bornite and molybdenite.

The upper part of the zone of moderate potassic alteration (5 to 15 per cent) forms a lensoid or mushroom-shaped body. Its upper surface is largely below the 1 036-metre level and conforms closely to the gypsum line. Within the lens are found scattered areas of more intense alteration (15 to 35 per cent). The low-grade copper zone in the central part of section AB (Fig. 13) is a clear expression of the poor correlation between copper mineralization and potassic alteration.

Minor amounts of hydrothermal biotite (brown to green) replace primary biotite and less commonly plagioclase, or form thin veinlets and replacement patches. Secondary biotite does not appear to form distinct alteration zones.

Phyllic Alteration

Phyllic alteration consists of flaky sericite (muscovite) and quartz both as replacement zones and as envelopes around quartz veinlets. It is the mst common alteration type associated with copper mineralization at Valley Copper. Sericite replacement zones follow fractures and range in width from about 0.5 to 30 millimetres. They typically show irregular, diffuse contacts with adjacent rock and are commonly vuggy. Locally they contain narrow, discontinuous quartz veinlets and grade into the veinlet envelope type. Sericitic borders on quartz veinlets range in width from 0.5 to 25 millimetres but widths do not correlate closely with the thickness of associated quartz veinlets.

Flaky sericite replacement zones and veinlet envelopes consist predominantly of fine-grained quartz and medium-grained muscovite (2M1 type). Minor constituents are calcite, brick-red hematite, highly sericitized and kaolinitized feldspar, sericitized biotite, bornite, chalcopyrite, and trace amounts of pyrite and molybdenite.

The relationship of phyllic alteration zones to adjacent, argillically altered rock is not entirely clear. It might be argued that the two represent different products of the same process. The fine-grained pervasive argillic alteration zones, which grade outward from phyllic areas might constitute transitional zones between phyllic and weakly propylitized rocks. Locally, however, replacement zones and veinlet envelopes have sharp contacts against and apparently crosscut pervasively altered rock. This suggests that solutions causing pervasive argillic alteration preceded solutions causing phyllic alteration; however, both followed the same channelways.

The zone of moderate phyllic alteration (5 to 15 per cent) closely follows the 0.30 per cent copper isopleth, but extends slightly beyond it. The areas of strongest phyllic alteration (greater than 15 per cent) are closely coincident with areas of greater than 0.50 per cent copper.

Argillic Alteration

Argillic alteration, characterized by pervasive alteration of feldspar, is gradational to propylitic alteration. X-ray and thermogravimetric analyses show kaolinite to be the dominant clay mineral species in the deposit, although some montmorillonite occurs on its west side (Jones, 1975). Pervasive alteration is strongest where fractures are most closely spaced, whereas propylitic alteration characterizes areas of little or no fracturing. Where pervasive argillic alteration is most intense, plagioclase is completely altered to a green or white, soft mixture of sericite, kaolinite, quartz, and calcite. In these areas, biotite has been completely altered to sericite, siderite, kaolinite, and quartz; primary potassic feldspar has been weakly altered to sericite and kaolinite; and magnetite has been oxidized to hematite. Chalcopyrite, pyrite, and sphalerite are present in trace amounts.

Where moderate to strong pervasive argillic alteration occurs copper content exceeds 0.30 per cent. Propylitic alteration characterizes the peripheral regions of the deposit and, to some extent, the area below the 853-metre level on the west side of the deposit.

Propylitic Alteration

Propylitic alteration occurs in relatively small areas within the deposit and in zones peripheral to it. It is characterized by weak to moderate alteration of plagioclase to clay, some sericite, epidote, clinozoisite, and calcite, and alteration of biotite to chlorite and epidote. Thermogravimetric analyses of composite samples suggest that a calcite-rich zone, with calcite contents of up to 4.2 per cent, surrounds the deposit. By comparison, calcite contents within the deposit are about 1 per cent. Despite these data, a zone of propylitic alteration spatially associated with the Valley Copper deposit is difficult to define because propylitic minerals have been developed in the country rocks on a regional scale.

Post-mineralization Veining

Late-stage gypsum, anhydrite, kaolinite, and fluorite veinlets occur at Valley Copper. Gypsum veinlets, which are the most common type, are fracture fillings that are generally less than 2 millimetres in width. They form white to orange, fibrous crystal aggregates which are oriented perpendicular to wall rock contacts. Gypsum is most common in areas with potassic feldspar alteration; it is rare above the 1 036-metre level (Fig. 12).

Paragenesis

The main alteration types at the Valley Copper deposit display, to some extent, overlapping periods of formation. However, crosscutting relationships defined certain general trends: (i) fracture-controlled vein sericitic (phyllic) alteration appears to be younger than pervasive sericitic and kaolinite (argillic) alteration, but is consistently crosscut by quartz veinlets with vein sericitic (phyllic) alteration envelopes; (ii) pervasive argillic alteration and phyllic alteration are typically cut by quartz veinlets with associated secondary potassic feldspar; (iii) gypsum veinlets cut all alteration types.

The age of barren quartz veinlets with no alteration envelopes is uncertain. They generally cut both phyllic and potassic feldspar replacement zones, but in some cases are cut by phyllic alteration; there are at least two generations of barren quartz veinlets.

Potassium-argon ages of hydrothermal muscovite range from 198±4 Ma (Jones, 1975) to 189±6 Ma and 186±8 Ma (Blanchflower, 1971). These results suggest that the age of the hydrothermal alteration (average 191 Ma) is slightly younger, but not significantly different than the age of crystallization of the batholith, which is 202±8 Ma (Northcote, 1969).

MINERALIZATION

Introduction

Sulphides in the Valley Copper deposit occur chiefly as disseminations in quartz veinlets and in phyllic and potassic alteration zones. The greater part of the copper sulphides are in areas with abundant phyllic alteration and associated quartz veinlets. Bornite is the dominant sulphide in this association, whereas chalcopyrite is the dominant sulphide associated with potassic alteration.

Oxidized Zone

Typical minerals in the oxidized zone are limonite, malachite, pyrolusite, digenite, native copper, and possibly tenorite. The zone generally varies in thickness from 0.3 to 14 metres and averages 4.5 metres; however, in the southeastern corner of the deposit, where the thickness ranges from 18 to 98 metres, it averages 33 metres.

Profiles of copper grades in the southeastern area show depletion of copper from 0.45 per cent in the unoxidized to 0.35 per cent in the oxidized zones. Grades range up to 0.65 per cent copper in a zone 3 to 6 metres thick that occurs just below the oxidized zone; this probably represents a poorly developed zone of supergene enrichment.

Hypogene Sulphides

Hypogene sulphides in the Valley Copper deposit are bornite and chalcopyrite, with minor amounts of digenite, covellite, pyrite, pyrrhotite, molybdenite, sphalerite, and galena. Petruk (1970) reported minor amounts of gudmundite (FeSbS) and native gold. According to Osatenko and Jones (1976) the sequence of the sulphide formation, based on crosscutting, filling, and riming relationships, is as follows: pyrite I; chalcopyrite I; bornite; molybdenite, pyrite II, and chalcopyrite II; sphalerite with minor pyrrhotite and galena; digenite and covellite. The position of sphalerite, pyrrhotite, and galena in the sequence is not certain.

Bornite/chalcopyrite ratios and pyrite contents on the 1 158-metre level plan are shown on Figure 14. Bornite/chalcopyrite ratios on the 1 158-metre level show a distinct high zone (greater than 3.0) in the central part of the deposit; small highs occur in the southern and southwestern parts. Bornite/chalcopyrite ratios decrease progressively away from the centre of the mineralized zone until, outside the 0.30 per cent copper isopleth, bornite is uncommon.

Pyrite abundance on the 1 158-metre level in the central part of the deposit (Fig. 14) is less than 5 per cent of the total sulphides. There is a very subtle pyrite halo around the deposit; in it, pyrite rarely exceeds 1 per cent by volume.

Geochemical Patterns

Geochemical data were obtained by the analysis of assay pulp composites from various percussion and vertical diamond-drill holes. Percussion hole composites represent the bottom 15 metres of each hole. In the diamond-drill holes, 30-metre composites were made at 76-metre intervals down the holes. Copper sulphide ratios and pyrite contents were found by point-counting polished sections made of sulphide concentrates from the composites (Osatenko and Jones, 1976).

Contents of major and trace elements in fresh Bethsaida granodiorite relative to those in composite samples of different alteration types from various parts of the deposits (Osatenko and Jones, 1976) show that CaO, Na_2O, MgO, Sr, Ba, and Mn decrease from the peripheral zone of the deposit, where propylitic and argillic alteration are present, to the central area where phyllic and argillic alteration are best developed. In contrast, contents of $Si0_2$, K_20, Rb, and TiO_2 increase from the peripheral regions of the deposit to its centre. K_20, which varies from 2.0 to 3.8 per cent, and Rb, which varies from 35 to 69 ppm, show the most pronounced increases.

Copper distribution for the 1 158-metre level (Fig. 14) shows a zone containing greater than 0.30 per cent copper that is roughly oval in plan (1 370 metres by 915 metres, long axis striking 130*). Several areas of greater than 0.50 per cent copper occur within the 0.30 per cent copper isopleth and a zone about 300 metres

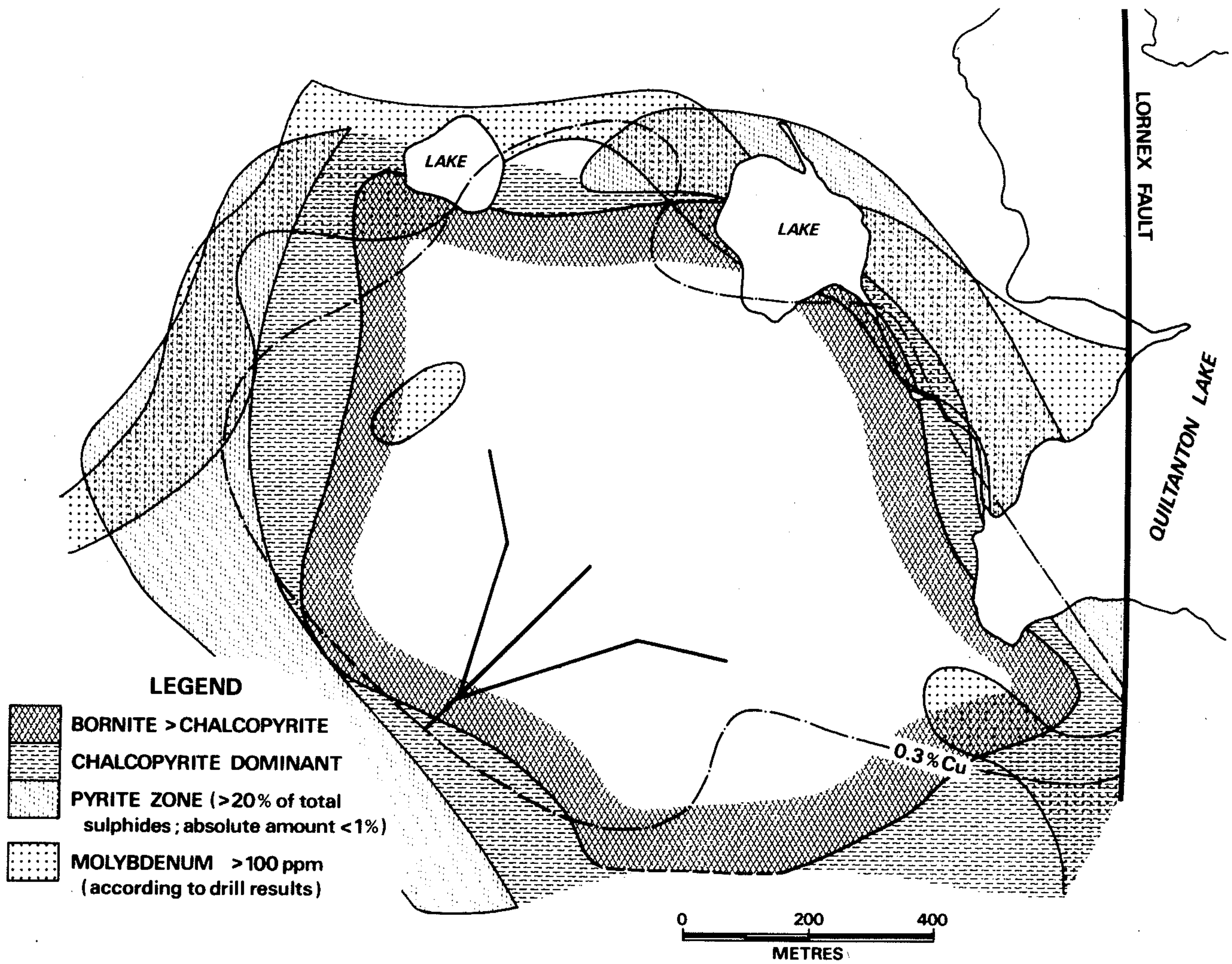


Figure 14 Plan view showing hypogene sulphide zoning in the Valley Copper deposit (after Osatenko and Jones, 1976).

in width, containing between 0.10 and 0.30 per cent copper, is peripheral to it. In vertical section (Fig. 13), the zone of greater than 0.30 per cent copper shows two distinct extensions to depths around a west-central low-grade zone.

Molybdenum and zinc (Fig. 14) form distinct halos marginal to and generally outside the 0.30 per cent copper contour. Values in the molybdenum halo range from 50 to 530 ppm over a width of 300 metres; values in the zinc halo range from 50 to 1 700 ppm. Within the deposit, molybdenum averages about 30 and zinc 20 ppm respectively.

Silver values are less than 1 ppm outside the deposit and range to 2.4 ppm in the zone of strong vein alteration. Analyses of sulphide concentrates suggest that silver is concentrated in bornite, which contains about 270 ppm, relative to chalcopyrite with 30 ppm.

Elements referred to by Olade (1974) as 'pathfinder' elements are Hg, B, Cl, and F. Mercury values range from 1 to 51 ppb and average 3 ppb. Boron dispersion is erratic, although values exceeding 11 ppm are generally confined to the outer margins of the deposit, especially along its northwestern fringe. Chlorine values are generally in the range of 160 to 350 ppm, whereas the regional background is 115 ppm. Fluorine values exceeding 564 ppm occur principally in the area immediately northwest of the deposit; elsewhere, fluorine contents are generally between 250 and 500 ppm. Regional background is about 188 ppm.

Isotopic Analyses

Sulphur isotopic compositions of Valley Copper sulphides are characteristic of Cordilleran hydrothermal deposits with magmatic associations that formed at relatively high temperatures. Mean values are near zero per mil with small standard deviations (Field, 1966; Jensen, 1967; Field et al., 1971). A deep or mantle source (typical range of δS34 values for mantle sulphur is -0.3 to +3.0 per mil) for the sulphur in sulphides is consistent with the probably deep source of the Guichon Creek magma based on Sr^{87}/Sr^{86} ratios (Christmas, et al., 1969; Preto, et al., 1979).

The σS34 value in the sulphates are about +13.6 per mil which precludes their derivation by supergene oxidation of sulphides. Alternatively, the sulphates may have precipitated from a hydrothermal solution that contained seawater sulphate.

Analyses of coexisting chalcopyrite-pyrite pairs from other Highland Valley deposits gave temperatures ranging from 294°C (Fiddler prospect), to 327°C (Highmont), to 477°C (Bethsaida showing); average formation temperatures were near 400°C (Johan et al., 1980).

Equilibration temperatures calculated from oxygen isotope pairs of coexisting minerals (Jones, 1975) suggest a range of temperatures from 260°C for early pervasive sericitic alteration to 480°C for potassic alteration. Temperatures calculated from three sulphur isotope pairs range from 266°C for pyrite-sphalerite in a zone of argillic alteration to 480*C for anhydrite-bornite in secondary potassic feldspar. The bulk of the phyllic alteration and mineralization apparently took place at about 400°C, with a range from 370°C to 500°C, over a depth interval of 550 metres. Temperatures ranged from about 500°C in the deeper, central part of the deposit to about 300°C near the periphery.

The isotopic compositions of hydrothermal fluids and average magmatic water at Valley Copper were calculated from the oxygen and hydrogen isotopic values of six samples of sericite and two samples of primary biotite, respectively. The Valley Copper hydrothermal waters plot on or near a line that connects SMOW with the average composition of primary magmatic water. That is, the hydrothermal fluid was apparently a mixture of seawater and magmatic waters. The degree of mixing is estimated to range from 16 to 44 per cent SMOW for the main period of sulphide deposition (average is about 25 per cent).

Fluid Inclusion Analysis

Fluid inclusions in mineralized quartz veinlets from the Valley Copper deposit are extremely small, about 0.005 millimetre in diameter; they tend to occur in planar clusters and linear zones and may not be primary. Most are composed of 70 to 80 per cent liquid and 20 to 30 per cent gas phases, although daughter crystals of chloride and carbonate have been identified. Average salinity, as indicated by freezing techniques, is 5 weight per cent (Osatenko and Jones, 1976). A few inclusions contain liquid CO_2, indicating pressures between 100 and 300 bars and a depth of formation of about 1 to 2 kilometres.

The structurally dependent arrangement and low homogenization temperatures (<200°) of the fluid inclusions suggest formation by dominantly secondary processes, perhaps during the waning stages of hydrothermal activity.

GENESIS

The sequence of major events leading to formation of the Valley Copper deposit are believed to have been as follows:

(1) The Bethsaida granodiorite was intruded in Late Triassic time about 200 million years ago.

(2) Movement on the Lornex and Highland Valley faults initiated a zone of intense fracturing in Bethsaida

granodiorite near the fault intersection.

(3) Pre-mineralization aplite, and feldspar and quartz feldspar porphyry dykes were injected along northerly and easterly trends.

(4) Hot saline fluids moved upward in the zone of fracturing and mixed with downward-percolating seawater to produce a fluid with a temperature of about 260•C (Osatenko and Jones, 1976). This fluid reacted with wall rocks, leaching Na_2O and CaO while adding K_20 and H_2O. This stage of alteration produced extensive pervasive sericitic and kaolinitic (argillic) alteration, with associated trace amounts of pyrite and chalcopyrite.

(5) A continued influx of magmatic hydrothermal fluids and seawater gave rise to a hydrothermal fluid with a temperature of about 400•C, and a slightly higher pH and sulphur fugacity. These fluids reopened many of the access channelways used by previous hydrothermal fluids and produced phyllic alteration. Deposition of main-stage copper mineralization occurred, probably as a result of increased sulphur ion concentration. Tan felsite dykes, of syn-mineralization age, were also intruded at this time.

(6) In the main part of the deposit, a further influx of fluids again reopened the old channelways and formed quartz veinlets containing vugs lined by or filled with bornite and chalcopyrite.

(7) Continued fracturing of the rock mass occurred, along with the formation of quartz veinlets containing disseminations and envelopes of secondary potassic feldspar. Mineralization of this stage was limited to minor amounts of chalcopyrite, probably as a result of decreased sulphur fugacity. Chemically, this stage is characterized by a pronounced addition of K_20 and SiO_2 and a marked depletion of H_2O, relative to zones with argillic and phyllic alteration.

(8) Further fracturing occurred, followed by the deposition of essentially barren quartz veinlets.

(9) In close spatial association with previously formed secondary potassic feldspar, fractures were reopened and gypsum deposited. The hydrothermal solutions were rich in seawater sulphate.

(10) Lamprophyre dykes were intruded about 132±3 Ma ago.

(11) During subsequent uplift and erosion, the overlying rocks and the upper part of the deposit were removed; an oxidized zone and weak supergene blanket developed. Glaciation followed by glaciofluvial deposition and continued erosion produced the present-day surface.

Plate I

Rock types in the batholith form distinguishable, areally mappable units. Distinguishing criteria are grain size, mineralogy, colour index, and texture. The plate illustrates the major mapped units - called phases or varieties - and some of the variations within each unit. Plates Ia to Ic portray the 'older phases'; Id and Ie the 'younger phases; and If some porphyry dykes.

Ia (i to iii) Border phase - diorite to quartz diorite, generally fine to medium grained, relatively high colour index, mafic minerals are amphibole, biotite, and local pyroxene (as cores in amphiboles).

Ib (i to iii) Guichon variety of Highland Valley phase - quartz diorite to granodiorite, mafic minerals are amphibole and biotite; locally potassic feldspar is as much as 15%; contacts with Border phase and Chataway variety are gradational; characteristically mafic minerals are subhedral and distributed in clusters of crystals; quartz is generally interstitial - as wedge-shaped areas.

Ic (i to iii) Chataway variety of Highland Valley phase - granodiorite, mafic minerals are amphibole and lesser biotite; locally it contains coarse poikilitic potassic feldspar; characteristically mafic crystals are sub- to euhedral, relatively evenly distributed, and poikilitic; quartz crystals are rounded.

TOUR 6

Tour 6 complements Tour 5; it looks at the Gump Lake quartz monzonite, another granitic body at the periphery of the Guichon Creek batholith. Start about 2 kilometres west of Logan Lake on the Highland Valley highway at the Lower Nicola turnoff. Take the south road and go about 10 kilometres to the north end of Mamit Lake, where a branch road leads westward; at kilometre 10.8 a second road heads north then up the powerline. At kilometre 12.1 take the north branch road to kilometre 13.0 then roads that lead up the slope toward large, blocky outcrops.

STOP 6-1 (6-1 to 4, 17-59A) exposes Gump Lake quartz monzonite that is locally cut by porphyry dykes. The Gump Lake quartz monzonite is locally porphyritic and well to poorly foliated. The strike of the foliation varies from northeast to southeast and the dip from 50 to 80° easterly. Phenocrysts are plagioclase, quartz, amphibole, and biotite; the matrix is quartzo-feldspathic. Quartz is generally 25 to 30 per cent by volume; mafics are 8 to 17 per cent. Locally aplite or quartz feldspar porphyry dykes cut the quartz monzonite. At least locally, foliation results from cataclastic deformation; in extreme cases the rock is gneissic. In some of the eastern exposures, xenoliths of Nicola metasedimentary rock consist of biotite chlorite schist with quartz, chlorite, epidote, and magnetite layers. Dominant steep-dipping joint sets strike easterly and south-southeasterly; a set with moderate dips strikes northeasterly.

To see the northern edge of the Gump Lake stock, where it cuts Late Triassic Nicola Group metasedimentary and metavolcanic rocks, return to the paved road and follow it north to the Highland Valley highway. One-half kilometre west of the junction follow a dirt road that branches southwestward off the highway. Keep left at the first junction (0.7 kilometre). To see the Nicola country rock keep on straight at the first split in the road (kilometre 1.0) or follow the west branch at kilometre 1.7. To reach Gump Lake intrusive outcrops follow the road southward to kilometre 3.2 where it swings westward.

STOP 6-2 (7-99) is at kilometre 3.3. Outcrop south of the road is foliated Gump Lake quartz monzonite; foliation strikes 045° and dips 60° southeast. The outcrop is cut by aplitic dykes that strike southeasterly and contains inclusions of metasedimentary rock. The quartz monzonite is porphyritic with plagioclase, quartz, and amphibole phenocrysts. Mafic minerals average 10 per cent; biotite is a lesser component. Potassic feldspar averages 10 per cent by volume. Locally there are schistose, layered metasedimentary xenoliths. The dykes are variably aplite to granite pegmatite, commonly in the same dyke; some carry accessory molybdenite. Dominant joints strike southeasterly and dip steeply.

Other outcrops of Gump Lake rocks can be seen by hiking 500 metres west along the creek from the end of the road at kilometre 4.0. There also the rock is foliated (100°/70° northeast) and cut by aplitic dykes. Rare fractures striking 095° and dipping 75° south contain blotches of chalcopyrite associated with green sericitic feldspar alteration.

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Chapter 8
GEOLOGY AND MINERAL DEPOSITS OF VANCOUVER ISLAND

H.P. Wilton
British Columbia Geological Survey
756 Fort Street Victoria, B.C. V8V 1XR

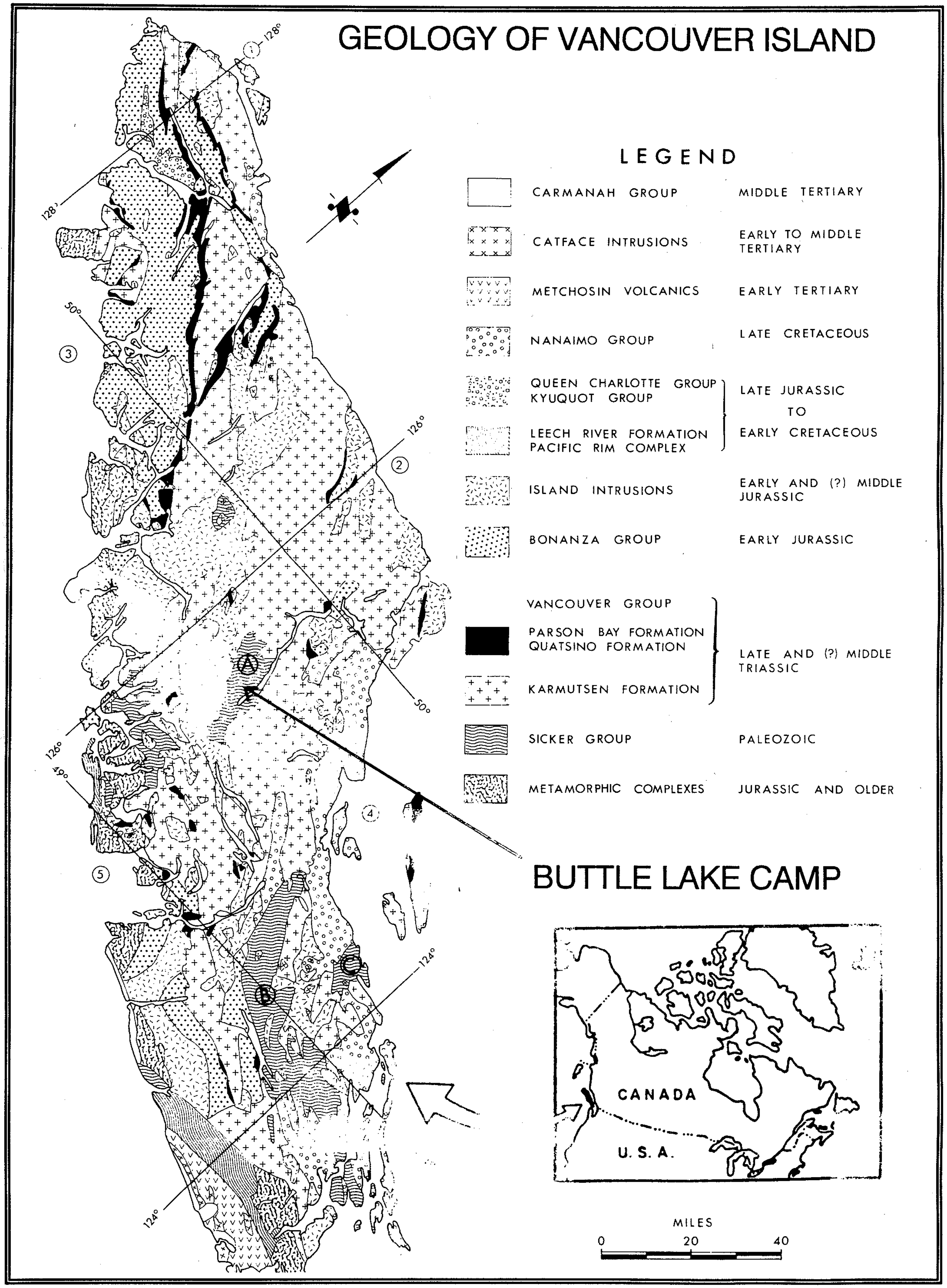
Vancouver Island is the major land component of the Insular morphogeological belt within Canada and is comprised mainly of the Wrangellia terrane with small segments of the Pacific Rim and Crescent terranes accreted to its western margin and southern tip. Figure 1 illustrates the main geological components of the island as well as the location of the Myra Falls Operations of Westmin Mines Ltd. (formerly Westmin Resources). The map in Figure 1 is modified from the identically numbered figure in a previously published guidebook by J.E. Muller (1977).

The oldest rocks on Vancouver Island comprise the Sicker Group which ranges from Devonian to Permian in age, and is exposed in at least five fault-bounded uplifts. The Sicker Group can be subdivided into a lower volcanic package overlain by a sedimentary package capped in most areas by a crinoidal limestone formation of Permian age. Most of the significant volcanogenic massive sulphide deposits on Vancouver Island, including the major H-W deposit to be visited on this field trip, occur within felsic volcanic rocks of the lower volcanic sequence in the Sicker Group. Exploration in recent years has identified chert and jasper horizons within the Sicker Group which are locally enriched in gold. All of the small but economically significant rhodonite deposits of Vancouver and Saltspring Island occur within the upper sedimentary part of the Sicker Group.

Overlying the Sicker Group with an angular unconformity is a thick sequence of Late Triassic rocks referred to as the Vancouver Group and comprising the Karmutsen Formation of tholeiitic basalt flows, pillow breccias, and minor tuffs overlain by a thick, massive limestone unit called the Quatsino Formation which is overlain in turn by the Parson Bay Formation of calcareous black argillite, calcareous greywacke and shaley limestone. The Karmutsen Formation alone is up to 6000 metres thick and underlies a very major part of the island. It is a copper-rich unit within which is found innumerable uneconomic concentrations of chalcopyrite and bornite in shear zones and on fracture surfaces. More significantly, the Quatsino Formation and thinner limestone and calcareous tuff members common to the upper part of the Karmutsen host the abundant magnetite and copper sulphide skarn deposits of the Insular belt (e.g. Argonaut, Texada, Coast Copper). Some of the skarn deposits on Vancouver and Texada Islands are presently being re-examined for their locally significant gold content. Dykes and sills of diorite to ultramafic composition intrude the Sicker Group extensively and are believed to represent feeders to the Karmutsen. In at least one locality, an ultramafic phase of the suite contains Ni-Pt-Pd-rich magmatic sulphides.

The Early Jurassic Bonanza Group is a thick, poorly bedded pile of mainly subaerial basaltic to rhyolitic tuffs and breccias with minor flows and with intercalated marine argillites, greywacke and water-laid tuffs at and near the base. It generally sits disconformably on top of the Vancouver Group and occurs mainly in the western and northwestern part of the island. Some of the skarn deposits are partially hosted within the lowest sedimentary sections of the group and there are a limited number of small stratabound polymetallic massive sulphide occurrences in water-laid tuff beds of the Bonanza. Otherwise, the only economic significance of the Bonanza Group has been as a host for the Island Copper and other porphyry copper-molybdenum-gold deposits at the north end of the island.

Island Copper is the only operating metal mine on the island besides Myra Falls. It is a major 50,000 tonne per day open pit operation with pre-production ore reserves of 257 million tonnes at 0.52% copper, 0.017% Mo, and approximately 0.24 grams/tonne Au (see Fleming, et.al., 1983). The Island Copper orebody is associated with the intensely brecciated and altered contact between Bonanza Group andesitic tuffs and a quartz-feldspar porphyry dyke of Middle Jurassic age. The latter is representative of the widespread suite of Middle to Late Jurassic, felsic to intermediate plutons collectively known as the Island Intrusions. Metamorphic complexes including the Wark-Colquitz


GEOLOGY OF VANCOUVER ISLAND
LEGEND
CARMANAH GROUP
MIDDLE TERTIARY
CATFACE INTRUSIONS
EARLY TO MIDDLE TERTIARY
METCHOSIN VOLCANICS
EARLY TERTIARY
NANAIMO GROUP
LATE CRETACEOUS
QUEEN CHARLOTTE GROUP
KYUQUOT GROUP
LEECH RIVER FORMATION
PACIFIC RIM COMPLEX
LATE JURASSIC TO EARLY CRETACEOUS
ISLAND INTRUSIONS
EARLY AND (?) MIDDLE JURASSIC
BONANZA GROUP
EARLY JURASSIC
VANCOUVER GROUP
PARSON BAY FORMATION
QUATSINO FORMATION
KARMUTSEN FORMATION
LATE AND (?) MIDDLE TRIASSIC
SICKER GROUP
PALEOZOIC
METAMORPHIC COMPLEXES
JURASSIC AND OLDER
BUTTLE LAKE CAMP
CANADA
U. S. A.
MILES
0
20
40
128°
126°
124°
50°
49°
A
B
C
1
2
3
4
5

gneisses around Victoria and the Westcoast Complex along the west-central coast are composed of Sicker and Vancouver Group protoliths which were metamorphosed during the Jurassic plutonic event.

Queen Charlotte and Kyuquot Group clastic sedimentary rocks occur in patches along the west edge of Wrangellia and are Late Jurassic to Early Cretaceous in age. Unrelated rocks of the Pacific Rim terrane are of the same age but, mainly in the Leech River metamorphic complex at the south end of the island, they were metamorphosed in the Tertiary. The Leech River gneisses and schists of southern Vancouver Island contain ubiquitous gold-bearing quartz veins and gave rise to the placer gold of the Leechtown placer camp.

The Late Cretaceous Nanaimo Group sedimentary rocks, remnants of which are widespread along the east coast of Vancouver Island and the Gulf Islands, contain the coal resources of Vancouver Island. Coal mining was the first mining activity to become significant on Vancouver Island and is presently undergoing a mild resurgence with the present expansion occurring at the 200,000 tonne/annum Quinsam thermal coal mine near Campbell River.

Felsic to intermediate plutons and volcanic centres of Early Tertiary age in various parts of the island have proven to be important producers of porphyry copper (e.g. Catface and Mount Washington) and mesothermal to epithermal gold-quartz vein camps such as Zeballos, Kennedy River and, recently discovered, at Mount Washington. The Crescent terrane at the extreme south end of the island continues across the Strait of Juan de Fuca to the Olympic Mountains of Washington State. It is composed primarily on Vancouver Island of a partial ophiolitic assemblage of Eocene-age Metchosin basaltic flows, tuffs, and breccias with a basal complex of Sooke gabbro stocks and sheeted dykes. No mineral deposits have yet been found in the Crescent terrane except a few replacement deposits of massive chalcopyrite in shear zones cutting the Sooke gabbros and adjacent basalt flows.

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Chapter 9
THE BUTTLE LAKE CAMP, CENTRAL VANCOUVER ISLAND, B.C.

S.J. Juras and C.A. Pearson
Westmin Mines Ltd.
P.O. Box 8000
Campbell River, B.C. V9W 5E2

INTRODUCTION

The Buttle Lake Camp, a volcanogenic massive sulphide district with Paleozoic host rocks and ore, is 85 km southwest of Campbell River at the south end of Buttle Lake within Strathcona Provincial Park, central Vancouver Island, British Columbia (Fig. 1). The ore deposits are currently being mined by Westmin mines Ltd. through the operation of two underground mines, the H-W and Lynx. Proven and indicated ore reserves as of January 1, 1989 (Westmin Resources Ltd. Annual Report 1988) were 294,600 tonnes at 2.62 9 Au/t, 76.8 g Ag/t, 1.37% cu, 0.78% Pb, and 7.61% Zn for the Lynx Mine, and 11,597,600 tonnes at 2.30 g Au/t, 33.0 g Ag/t, 2.39% cu, 0.33% Pb, and 5.07% Zn for the H-W Mine. Production to the end of 1988 comprised 9,170,600 tonnes (approximately 65 percent of which was Lynx and Myra ore) at 2.16 gAu/t, 81.0 gAg/t 1.83% cu, 0.78% Pb, and 6.58% Zn.

The first claims in the Buttle Lake Camp region were staked in 1917 when Strathcona Park was opened for prospecting. Three showings were staked: the Lynx, Price and Paw (Myra) claims. Sporadic work continued on the ground until 1925. The property then remained dormant until 1946 when renewed interest brought about various examinations by individuals and companies. Western Mines acquired the claims in 1961 and concentrated their exploration in the Lynx claim group which had the best showings within the camp. By mid-1964, after potential ore zones consisting of 1.5 million tonnes were defined on five levels, a decision was made to begin production. Production, largely open pit, began in early 1967. From 1969 to the end of 1974 the Lynx open pit was gradually phased out in favour of underground ore development. The total tonnage produced from the Lynx open pit was 1.6 million tonnes. The Myra deposit (formerly the Paw group) was evaluated in 1970 and put into production as a separate mine by 1972. Mining at the Myra Mine terminated in late 1985 due to depletion of reserves. The Price showings received serious attention during the period from 1979 to 1981, which resulted in the discovery of the Upper Price zone. Reserves of 209,500 tonnes at 1.23 g Au/t, 53.1 g Ag/t, 1.10% cu, 1.07% Pb, and 8.31% Zn were blocked out but a production decision for this deposit has been put on hold indefinitely. The large H-W deposit was discovered in late 1979 and the decision to mine made shortly after in early 1980. The H-W mine officially come on stream in September of 1985. Also during this time period (in 1981), Western Mines changed their corporate name to westmin Resources Ltd. Divestiture of their oil and gas holdings in late 1989 resulted in a further name change to Westmin Mines Ltd.

GEOLOGICAL SETTING

Buttle Lake Camp ore deposits consist of many individual massive sulphide lenses grouped into several major zones within two main felsic volcanic stratigraphic intervals in the Paleozoic sicker Group within the Buttle Lake uplift (Fig. 2). The sicker Group is represented in the Buttle Lake Camp by four formations (Juras, 1987): the Late Devonian or older Price Formation, the sulphide deposit-bearing Late Devonian myra Formation, the Early Mississippian (?) Thelwood Formation, and the Mississippian(?) Flower Ridge Formation. The first three formations are also referred to as the Footwall H-W Andesite, the mine Sequence, and the Sharp Banded Tuff unit respectively. Four composite geologic cross sections form the basis of the lithologic and facies variation descriptions. The cross sections cover the length of the mine property at the following mine coordinates (mine north is 45° east of true north): 183+00 E (Fig. 3), 124+00 E (Fig. 4), 60+00 E (Fig. 5) and 5+00 E (Fig. 6). Descriptions below will be relative to true north.

Price Formation (Footwall H-W Andesite)

The lowermost unit exposed in the mine-area

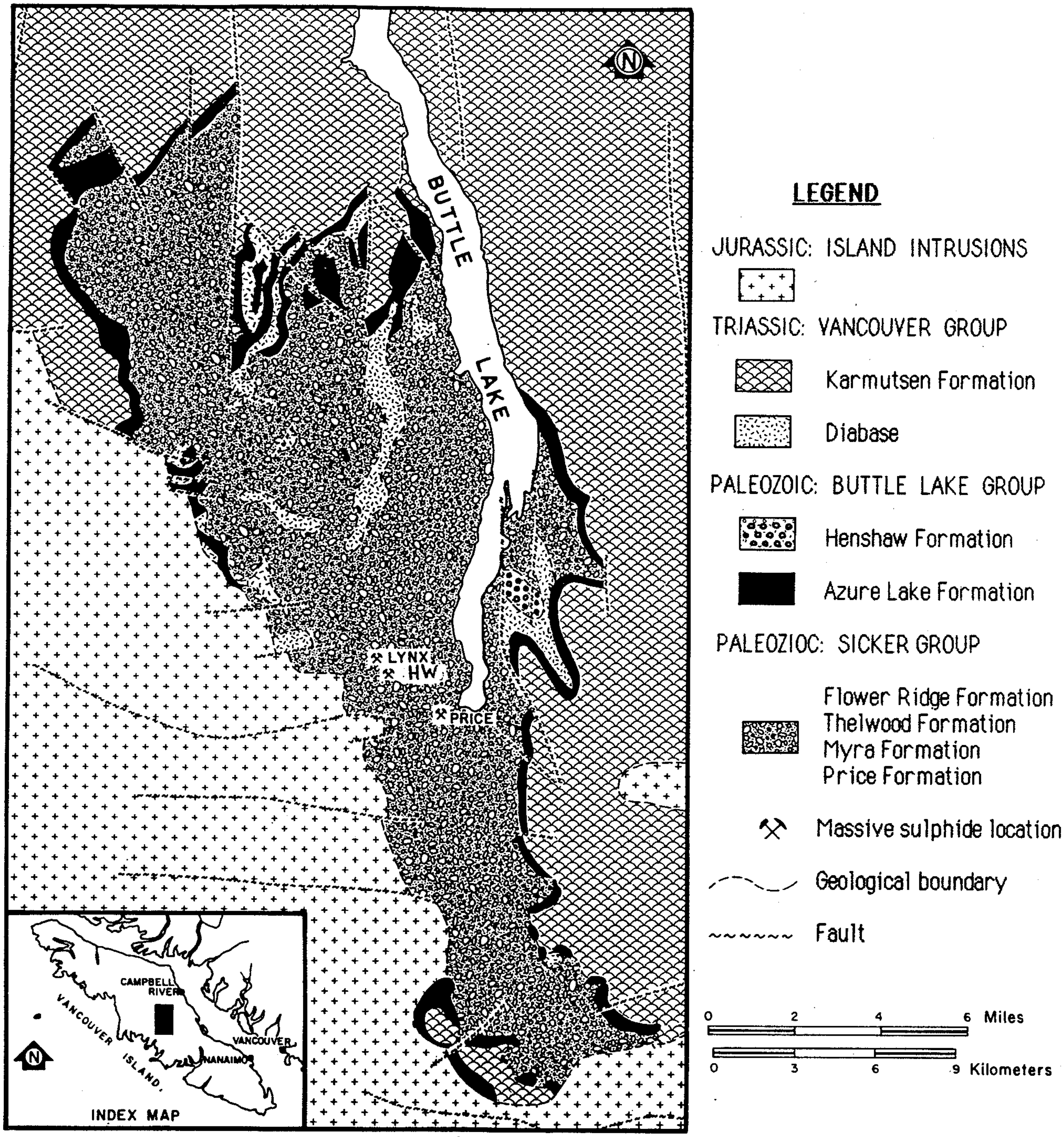

Figure 1. Geology of the Buttle Lake Uplift (modified after Muller, 1964).

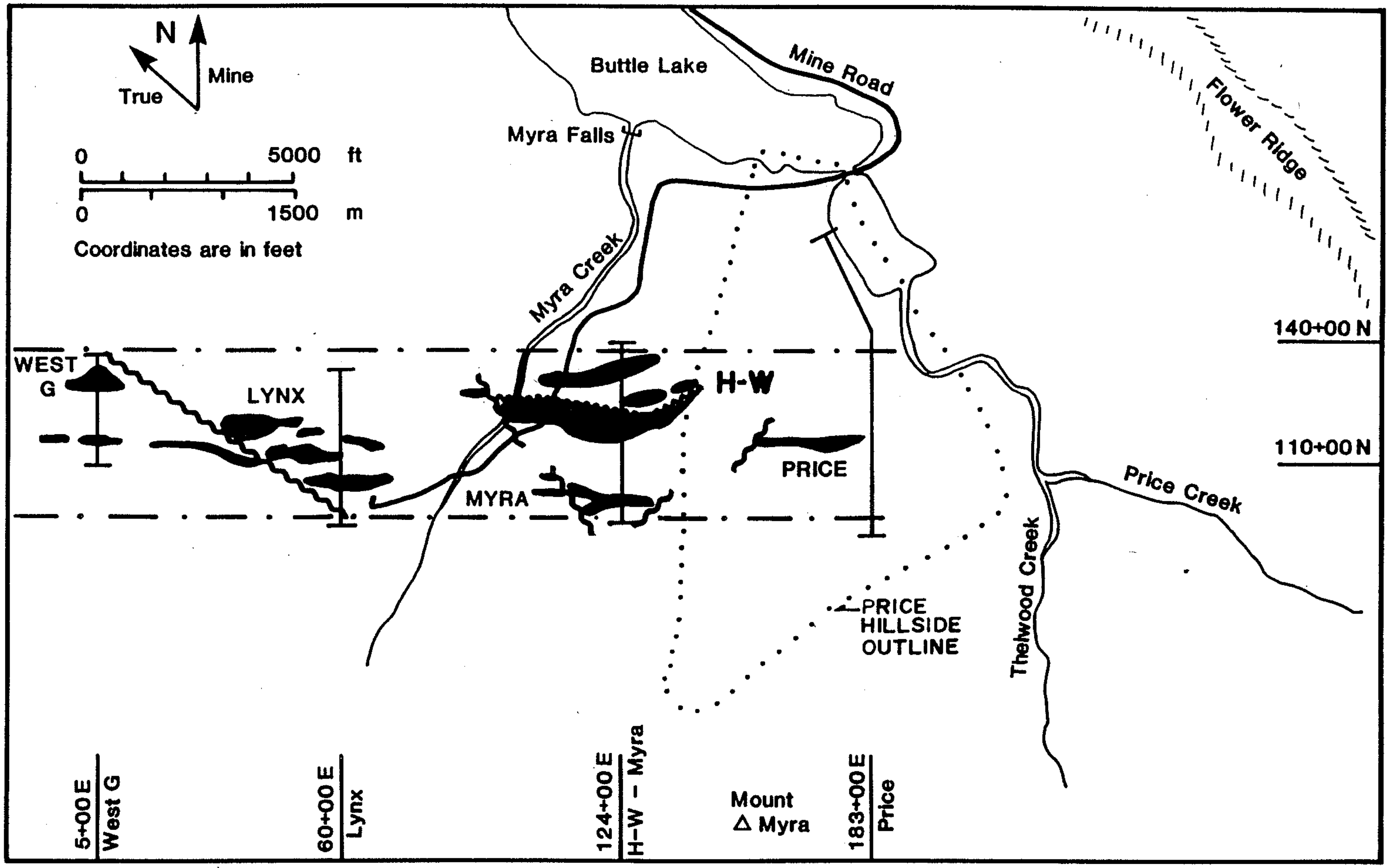

Figure 2: Orientation diagram for geological descriptions, Buttle Lake Camp, Vancouver Island, B.C. Descriptions in text are made relative to the northwestern trend of the massive sulphide ore zones (shown in plan projections as solid patterns: Walker, 1985). The area around the ore zones between the dashed-dot lines is defined as the central region. Lengths of section lines represent area covered in the respective cross sections: Price, H-W—Myra, Lynx, and West G.

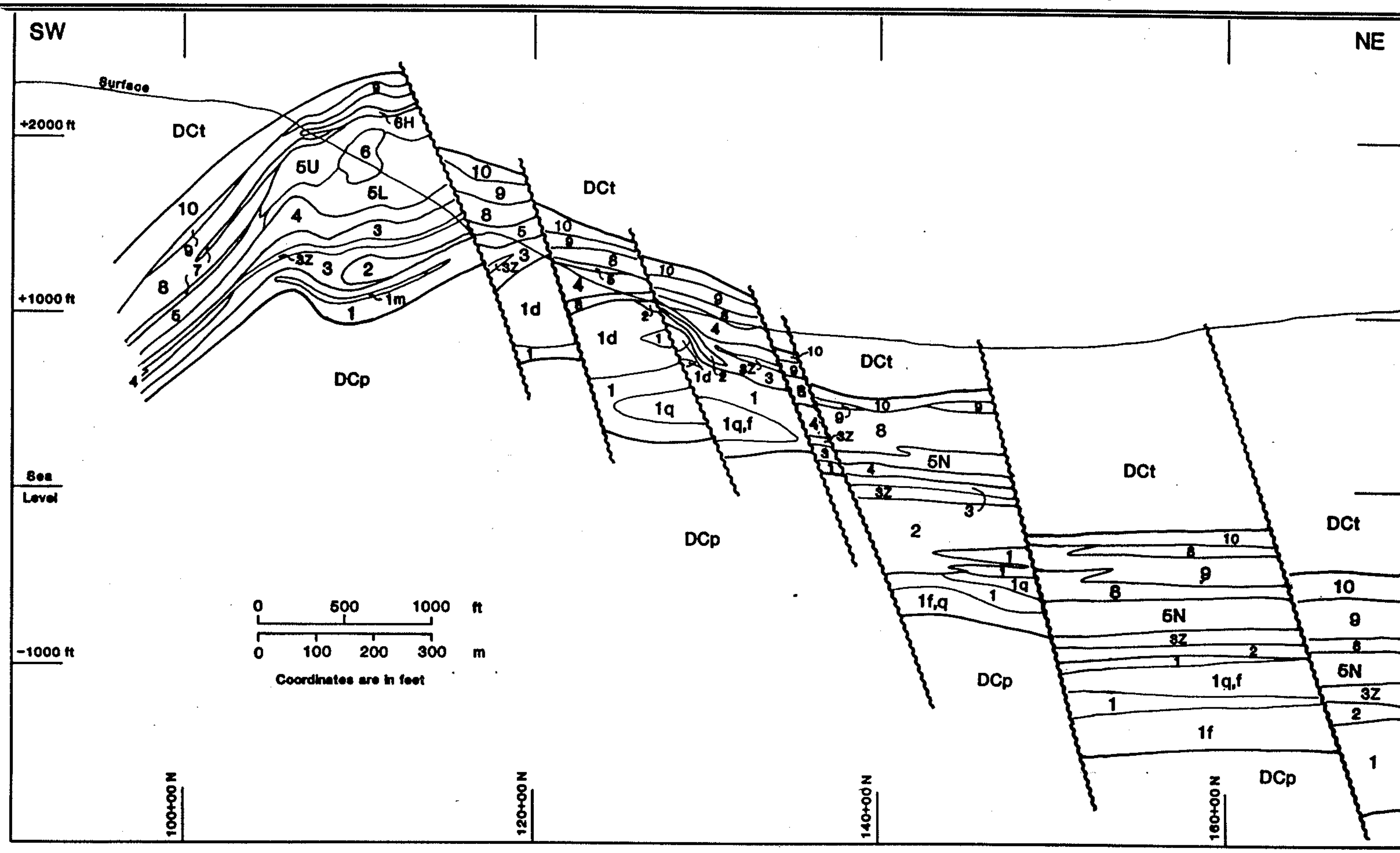

Figure 3: Generalized composite geology along Price section (183+00 E: after Juras, 1987), Buttle Lake Camp, Vancouver Island, B.C. Rock unit symbols are: DCp = Price Formation; 1 = H-W Horizon; 1d = H-W Horizon, dacite; 1f = H-W Horizon, feldspar porphyritic rhyolite; 1m = H-W Horizon, mafic flow member; 1q = H-W Horizon, quartz + feldspar porphyritic rhyolite; 2 = Hanging Wall H-W Andesite; 3 = Ore Clast Breccia unit; 3Z = Ore Clast Breccia unit, Interzone Rhyolite; 4 = Lower Mixed Volcaniclastics; 5L = Upper Dacite, lower member; 5U = Upper Dacite, upper member; 5N = North Dacite; 6 = Lynx-Myra-Price Horizon, G-Zone; 6H = Lynx-Myra-Price Horizon, G-Hanging Wall Zone; 7 = G-Flow unit; 8 = Upper Mixed Volcaniclastics; 9 = Upper Rhyolite unit; 10 = Upper Mafic unit; and DCt = Thelwood Formation.

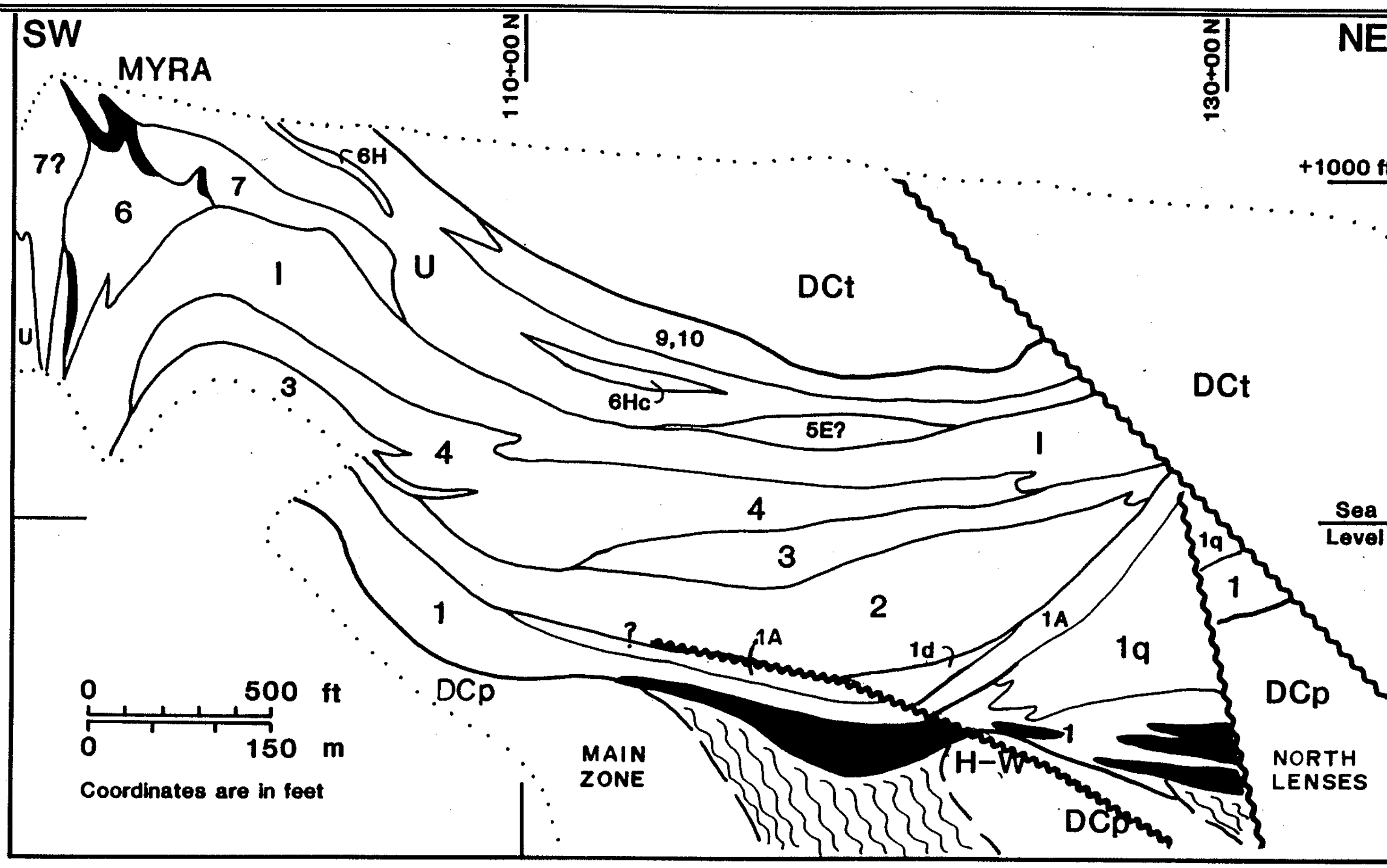

Figure 4: Composite geology along H-W—Myra section (124+00 E: after Walker, 1985). Rock unit symbols are the same as for Figure 3 except: 1A = H-W Horizon, argillite member; 5E = 5E Andesite; I = undifferentiated Myra Formation interzone units (Ore Clast Breccia unit, Lower Mixed Volcaniclastics, Upper Dacite); and U = undifferentiated Myra Formation upper units (Upper Mixed Volcaniclastics, Upper Rhyolite unit, Upper Mafic unit). Solid patterns represent massive sulphide bodies and wavy pattern represents hydrothermal alteration associated with sulphide mineralization. Letter "c" denotes chert. Fault separating the Main Zone and North Lenses is called the H-W Flat Fault.

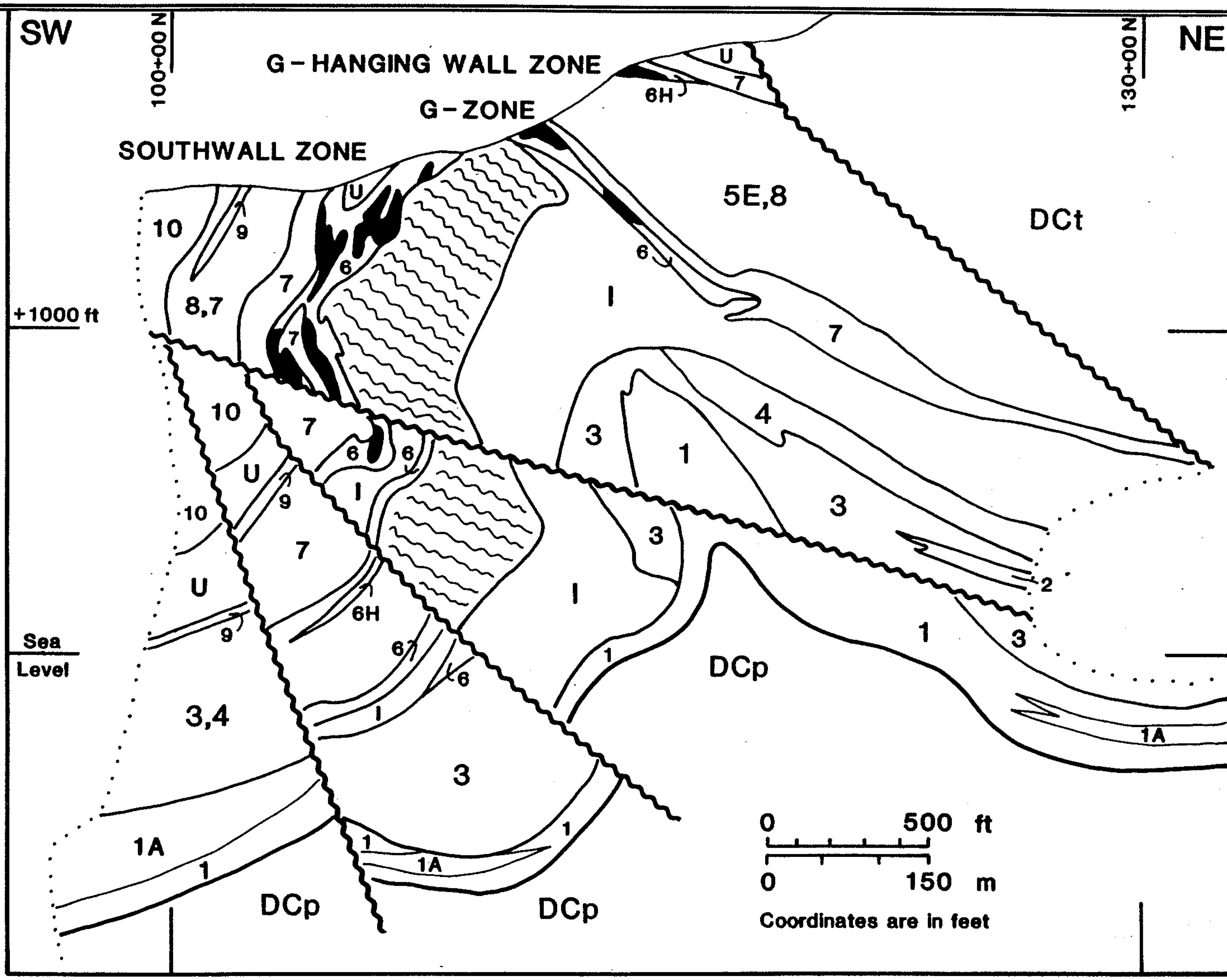

Figure 5: Composite geology along Lynx section (60+00 E: after Walker, 1985).
Rock unit symbols are the same as for Figures 3 and 4.

and in the Buttle Lake uplift is a thick sequence (> 300 m) of massive to pillowed basaltic andesite flows and flow breccias, and minor associated fine to coarse pyroclastic rocks. The Price Formation has been intersected in drillcore throughout the property but is exposed at surface only in a small region southwest of the mouth of Thelwood Creek. The base of this formation is not known. The formation is characterized by alternating, 30 to 150 m thick sequences of variably amygdaloidal,feldspar-phyric and pyroxene + feldspar porphyritic flow units.

Myra Formation (Mine Sequence)

The Myra Formation consists of a 310 to 440 m thick sequence of complex volcanic - dominant stratigraphy. Myra Formation lithologic units exhibit remarkable linear continuity (>7 km) along the northwestern trend of the ore zones, but abrupt lateral northeast to southwest facies changes. The Myra Formation is divided into ten general lithostratigraphic units (in decreasing relative age: Juras, 1987): H-W Horizon, Hanging Wall H-W Andesite, Ore Clast Breccia unit, Lower Mixed Volcaniclastics, Upper Dacite / 5E Andesite / North Dacite, Lynx-Myra-Price Horizon, G-Flow unit, Upper Mixed Volcaniclastics, Upper Rhyolite unit, and Upper Mafic unit.

H-W Horizon

The lowermost Myra Formation unit is the predominantly rhyolitic H-W Horizon. This horizon varies in thickness from approximately 15 m to 200 m and occurs throughout the mine-area. it consists of dacitic to rhyolitic flows, pyroclastic deposits, argillite, and sulphide mineralization. H-W Horizon units vary laterally from bedded argillite and felsic tuffs towards the southwest to complex felsic flow assemblages towards the northeast. It can be divided into five general parts: (1) an argillite member, (2) a felsic flow member, (3) a pyroclastic and volcaniclastic member, (4) a mafic flow member, and (5) a massive sulphide member. It is this unit that hosts the large H-W massive sulphide deposit.

The 1.5 to 45 m thick, argillite member is a more or less continuous unit. It consists of massive to thinly laminated beds of black siliceous argillite and normally graded, thinly bedded, fine to coarse rhyolite tuff and beds made up of varying mixtures of argillite and tuff (tuffaceous argillite to argillaceous tuffs) and minor chert. The argillites are composed of quartz, lesser feldspar, and variable but minor chlorite and carbonaceous matter. The tuff beds comprise quartz and feldspar crystals and a former vitric-rich host. Sedimentary structures observed include scour marks, load casts and rip-up clasts but no cross laminated structures were observed. The bedded sequences within this member reflect A-E and A-B-E turbidite deposits. Minor but ubiquitous sulphide mineralization consists of thin laminae or lenses of pyrite, or less commonly pyrrhotite, in the argillite beds, and pyrite or pyrrhotite disseminations and pebble-size clasts in some tuffaceous units.

The felsic flow member can be divided into three types: a quartz + feldspar porphyritic (QFP) rhyolite, an aphyric to feldspar porphyritic rhyolite, and a feldspar porphyritic (FP) dacite. Chemically, the first two are rhyolites whereas the dacite spans the dacite-rhyolite division. The FP and QFP rhyolite flow units occur throughout the H-W Horizon in the northeast region and parts of the central region (Figs. 3 and 4), but disappear towards the southwest. The feldspar porphyritic dacite flow units are present only in the central region and appear to have a different source area from the rhyolites. Unlike the distribution of the rhyolites, the dacite flows thicken southeastward towards the Price section (Fig. 3) and not towards the northeast area. The felsic flow units consist of autobrecciated to massive flows. Massive phases are predominant in the FP rhyolite and dacite flow types, and brecciated phases are more common in the QFP rhyolite flow types.

The pyroclastic and volcaniclastic member makes up most of the H-W Horizon in the central region. The rock units consist of medium to thin bedded, fairly well sorted, normally graded sequences of quartz + feldspar crystal-lithic-vitric lapilli-tuff, and coarse to fine tuff. They occur throughout the H-W Horizon becoming generally finer grained towards the southwest. Other units in this member include unwelded to welded subaqueous pyroclastic flow deposits, heterolithic rhyolite-dominant debris flow deposits and unsorted and ungraded tuff-breccia deposits. The pyroclastic flow deposits extend to all regions. The debris flow deposits are constrained laterally, occurring only in the central region. The coarser felsic lapilli-tuff and tuff-breccia deposits predominate around and between the various felsic flow units in the northeast region. Massive sulphide clasts can be a common occurrence in all flow to breccia deposit types.

The mafic flow member in the H-W Horizon consists of aphyric to pyroxene-phyric komatiitic basalt flows and hyaloclastite. It is usually associated with the argillite member in the central region. Flows commonly overlie or are replaced by a hyaloclastite zone. It is characterized by feathery shard-like ultramafic clasts. They may be mixed with up to 40 percent fine to coarse felsic tuff, felsic tuff clasts, feldspar and quartz crystals, argillaceous material, and the occasional massive sulphide fragment. The matrix is fine-grained and has been silicified. This apparently chaotic deposit probably represents a peperite formed by the interaction of rapidly extruded, hot lava with the underlying, water-saturated and unlithified sediments (Juras, 1987).

Hanging Wall H-W Andesite

Hanging Wall H-W Andesite is an up to 100 m thick unit consisting mainly of basaltic andesite to andesite flows and related breccias. Less common pyroclastic deposits are made up of massive, lapilli-tuff, tuff-breccia, and bedded feldspar-crystal, fine to coarse tuff. The proportion of pyroclastic deposits relative to the flows and related breccias varies from 20:80 in the central region to approximately 60:40 in the northeast. In the H-W Myra and Price sections (Figs. 3 and 4), the H-W Horizon felsic flow member has influenced the distribution of Hanging Wall H-W Andesite rock units. The discontinuity of the Hanging Wall H-W Andesite in the Price section is caused by the formation of a paleo-barrier by the H-W Horizon dacite. However, in the H-W Myra section, the H-W Horizon dacite is quite thin and consequently has not affected the distribution of the overlying andesite flows. Instead, in that section the andesite flows encountered another paleo-barrier built by a series of H-W Horizon QFP rhyolite flows.

Ore-Clast Breccia Unit

The Ore Clast Breccia unit represents a series of volcaniclastic submarine debris flow deposits and lesser subaqueous pyroclastic deposits. The unique feature of this unit is the presence of massive sulphide clasts and lenses or 'rafts' (olistoliths) of pyrite-mineralized rhyolite coarse tuff to lapilli-tuff. The unit is up to 90 m thick and is found throughout the mine-area. Excellent exposures are present on the Price Hillside. The Ore Clast Breccia unit can be divided into three mappable members: (1) a rhyolite-rich volcaniclastic breccia having from 10 to 50 percent non-andesite or mafic volcanic constituents (average is 25 percent); (2) a rhyolite-poor volcaniclastic breccia with less than 10 percent non-andesite or mafic volcanic constituents; and (3) the Interzone Rhyolite, a rhyolite pyroclastic horizon. Generally, the rhyolite-rich member occurs in the lower to middle parts of the unit whereas the rhyolite-poor member is found in the middle to upper portions. The Interzone Rhyolite generally is found in the middle to upper portions of the Ore Clast Breccia unit.

Clast types present in the volcaniclastic breccia members can be highly variable. Generally, they comprise andesite, aphyric to weakly pyroxene-phyric mafic volcanics, dacite, QFP rhyolite, massive sulphide (pyrite > > sphalerite > chalcopyrite > galena), rhyolite fine tuff, chert and argillite. Clast sizes in the breccia members are also highly variable ranging from 1 cm to 1.5 m with rhyolite 'rafts' obtaining dimensions of up to 50 m long by 15 m wide.

Lower Mixed Volcaniclastics

The Lower mixed Volcaniclastics represent and e site dominant volcaniclastic deposits. The unit is up to 90 m thick and occurs throughout the property. It contains volcaniclastic breccias, tuff-breccia, bedded lapilli-tuff and coarse to fine tuff, and minor subaqueous pyroclastic flow deposits. Thin feldspar porphyritic andesite flows are present locally. The coarse clastic deposits occur mainly in the central region in the Price end and the West G end of the mine-area, whereas the Lynx and H-W Myra sections contain relatively greater sequences of finer grained, bedded deposits. The subaqueous pyroclastic flow deposits are most prevalent in the northeast region. Generally the Lower mixed Volcaniclastics thicken from the Price area to the H-W Myra section, before gradually thinning towards the Lynx and West G sections.

The bedded clastic sequences are largely made up of aphyric to plagioclase-phyric andesite cognate lithic fragments and plagioclase crystals. Towards the northeast region both clast and crystal components contain ubiquitous pyroxene grains. Coarse clastic deposits are made up of andesite and dacite with the andesite component by far the most common. It occurs as two types: variably feldspar-phyric cognate lithic clasts and strongly feldspar glomeroporphyritic flow clasts. The clast sizes (long axes) vary from 1 to 60 cm, averaging around 10 cm.

Upper Dacite / 5E Andesite / North Dacite

The Upper Dacite / 5E Andesite / North

Dacite units represent three approximately contemporaneous yet different eruptive events which occurred in non-overlapping relationships throughout the mine property. The upper Dacite unit, up to 60m thick, is best documented in the Price section (Fig. 3) and comprises two general parts: the Upper Dacite lower member and the Upper Dacite upper member. The lower member consists of resedimented deposits of dacite to rhyolite hyaloclastite and flow breccia, and subaqueous pyroclastic deposits. The upper member is made up of feldspar porphyritic intermediate flows containing variably rounded felsic blocks, and subaqueous pyroclastic deposits. The main difference between the two members is in the low amounts of hyaloclastite in the upper member. The 5E Andesite is best developed at the West G end (Fig. 6) and consists of up to a 250 m thick sequence of massive to pillowed, feldspar porphyritic basaltic andesite to andesitic flows and lesser flow breccia and lapilli-tuff deposits. Both the Upper Dacite and the 5E Andesite units are thickest in their respective central regions; they thin markedly towards the middle sections (Lynx and H-W - Myra) of the mine-area. Both units are absent in the northeast region. The North Dacite, a feldspar porphyritic felsic flow unit, is only present in the northeast area where it occupies the same general stratigraphic position as the other two lithostratigraphic units.

Lynx Myra Price Horizon

The upper massive sulphide mineralized felsic volcanic units in the mine-area comprise the Lynx-Myra-Price Horizon. This horizon consists of two spatially distinct units: (1) the G-Zone member, and (2) the G-Hanging Wall Zone member. The two are separated by units from upper parts of the 5E Andesite in the West G and Lynx sections, and by the Upper Dacite upper member in the Price section and possibly the H-W-Myra section. In the West G and Lynx areas the separation is 30 to 150 m whereas in the Price end, it is 10 to 60 m. Both G-Zone and G-Hanging Wall Zone members can be traced throughout the mine property. The difference between the two lies in their lateral extent. The stratigraphically lower G-Zone member can be traced for at least 300 m in the West G section, over 825 m in the Lynx section, and only 300 m in the H-W-Myra and Price sections.

The overlying G-Hanging Wall Zone member is at least 1000 m wide in both West G and Price sections. No estimates can be made for the Lynx and H-W-Myra areas because of limited data. Extrapolation between the West G and Price sections suggests similar widths throughout the mine-area. Both zones vary in thickness from 1 to 45 m, but generally the G-Zone member is thicker than the G-Hanging Wall Zone member.

Both Lynx-Myra-Price Horizon members consist mainly of massive to bedded, fine to coarse quartz + feldspar crystal vitric rhyolite tuff and lapilli-tuff, and massive sulphide mineralization. The rhyolite tuffs commonly occur as normally graded, moderately to well sorted, thin to thick beds. They usually contain 5 percent disseminated pyrite and lesser sphalerite grains. Most samples also contain grey rhyolite accessory lithic clasts.

The G-Hanging Wall Zone member contains two additional lithologic units. They are a vitrophyric rhyolite coarse tuff to fine lapilli-tuff unit, and a chert unit. The tuffs locally are associated with bedded tuffaceous siltstone and mudstone deposits. Total thickness of tuff unit is usually less than 3 m. The chert unit occurs in the central regions in the Price and H-W-Myra sections. It is composed of thin to medium laminated beds of white to light green Chert, jasper, and, less commonly, black argillaceous chert. Thickness of this unit varies from 1 to 3 m.

G-Flow Unit

The G-Flow unit represents a number of thin (2 to 15 m thick) but widespread ultramafic (komatiitic basalts: cf. Juras, 1987) flows and flow breccia and hyaloclastite deposits overlying the two members of the Lynx-Myra-Price Horizon (Figs. 3, 4, 5 and 6). At the Price end, this unit consists of medium to dark green, pyroxene porphyritic, amygdaloidal, massive to pillowed flows, and lesser lapilli-tuff and coarse tuff deposits. In the H-W-Myra, Lynx and West G sections, the G-Flow unit is characterized by distinctly purple zones. These zones mainly consist of hyaloclastite and flow breccia and are moderately to intensely altered by carbonate and hematite. Associated massive to pillowed flows are less affected by this alteration and remain medium to dark green. The unit, thickest in the West G and Lynx areas, becomes steadily thinner towards the Price section. Laterally, it disappears towards the northeast region but thickens towards the southwest area.

Least altered flow units consist of 5 percent, augite glomerocrysts and trace chromite microphenocrysts. The flows are always amygdaloidal

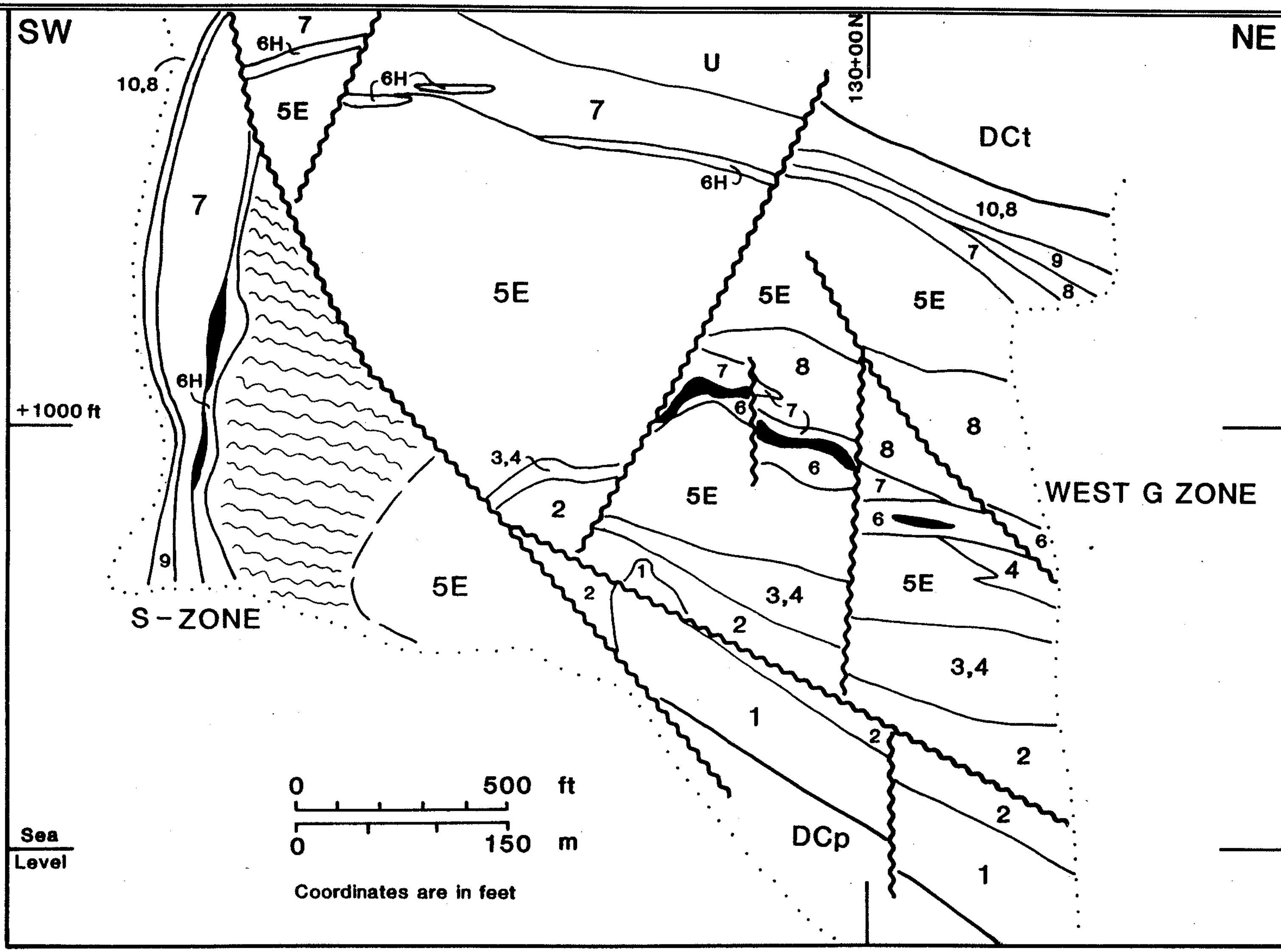

Figure 6: Composite geology along West G section (5+00 E: after Walker, 1985). Rock unit symbols are the same as for Figures 3 and 4.

with generally 3 percent (up to 15 percent) chlorite, epidote and calcite amygdules. Flow units in the Lynx and West G sections have distinctly more calcite and less chlorite amygdules. Pillowed flows contain magnetite-rich (price area) or hematite-rich (West G section), fine-grained relict selvages, and jasper in pillow interstices.

Upper Mixed Volcaniclastics

The Upper Mixed Volcaniclastics represents a mafic to intermediate volcanic dominant volcaniclastic unit consisting of bedded fine to coarse tuff and lapilli-tuff sequences, and massive coarse lapilli-tuff to tuff-breccia deposits. The unit is up to 50 m thick and occurs throughout the mine property, being best developed in the central regions of all four sections. Bedded tuff sequences are thinly to medium bedded, moderately well sorted and normally graded, and consist largely of feldspar crystal intermediate to mafic tuffs. In places, maroon fine tuff beds mark the tops of the graded deposits. Tuffs in these sequences are composed of broken plagioclase crystals and aphyric to occasionally plagioclase porphyritic mafic volcanic vitric clasts. Massive lapilli-tuff and tuff-breccia deposits contain plagioclase crystals and a wide variety of vitric and flow clasts. Main clast types (in decreasing order of relative abundance) comprise weakly plagioclase porphyritic mafic to intermediate volcanic cognate lithic clasts, aphyric to plagioclase-phyric, felsic cognate lithic clasts, plagioclase + pyroxene porphyritic basaltic cognate to accessory lithic clasts, and strongly epidotized andesite accidental clasts. A lateral compositional variation of the clast types is recognized. Intermediate and felsic volcanic constituents are uncommon towards the southwest region but become increasingly more abundant towards the northeast area. The mafic volcanic clast distribution generally follows the reverse of the above pattern.

Upper Rhyolite Unit

The Upper Rhyolite unit is the stratigraphically highest rhyolite horizon in the Mine Sequence. Distribution of rock types in the Upper Rhyolite unit consists of two general parts: (1) a pyroclastic deposit-rich member; and (2) a siliceous argillite - chert dominant member. In most areas the siliceous argillite - chert member underlies the pyroclastic member.

The pyroclastic deposit member is up to 50 m thick and made up of thin to medium bedded, normally graded, crystal-lithic-vitric coarse tuff to lapilli-tuff, and lesser fine tuff and tuff-breccia deposits. This member displays a distinct lateral facies variation from the northeast region to the southwest area. It is thickest towards the northeast region, being approximately 50 m in thickness, where it consists mainly of lapilli-tuff deposits with subordinate coarse tuff and tuff-breccia beds. The sequence is generally coarsening-upward. The member in the central region (in all sections) is composed of moderately well sorted, fine to coarse tuff and fine lapilli-tuff, and a heterolithic tuffaceous breccia deposit which can form up to 25 percent of the sequence. The pyroclastic member in the southwest region is finer grained and markedly thinner (approximately 10 m) where it eventually disappears. Generally the deposits are crystal-rich comprising plagioclase, lesser quartz and trace amphibole. main lithic components are: QFP rhyolite accessory clasts, mica-poor weakly phyric to sericite-rich QFP felsic cognate lithic clasts, and mafic volcanic accidental clasts.

The siliceous argillite - chert member consists of thin to medium laminated beds of grey to black siliceous argillite, white to pale green chert, green to gray rhyolite fine tuff, and minor jasper. This member ranges from 1 to 15 m in thickness and is largely confined to the central regions of all sections. siliceous argillite is the most common rock type in this member.

Upper Mafic Unit

The Upper Mafic unit is the uppermost lithostratigraphic unit in the Myra Formation. it is present throughout the property being thickest (> 200 m) in the southwest region and thinning to approximately 5 to 20 m towards the northeast area. The main rock types present are basaltic in composition and occur mainly as hydroclastic and pyroclastic deposits. Flow and flow breccia, and mixed sedimentary and pyroclastic units are less common.

Hydroclastic and pyroclastic deposits are poorly to moderately sorted and form generally coarsening-upward sequences. Lower parts consist of normally graded coarse tuff to lapilli-tuff deposits. Up section the main deposits become composed of lapilli-tuff and tuff-breccia units. Clast sizes vary from 1 mm to 50 cm but more commonly range from 2 to 15 cm. The main clast type is a strongly pyroxene + feldspar porphyritic basalt. Non-volcanic clasts include jasper ± magnetite, chert, mafic fine tuff and epidote-rich mudstone.

Mixed sedimentary and pyroclastic deposits are found in the middle to lower parts of the Upper Mafic unit. They are only sporadically present in the southwest region, but are equal to or greater in abundance than the hydroclastic deposits towards the northeast area. The deposits are 2 to 7 m thick and consist of thinly bedded, massive to laminated cherty tuff, jasper and chert, and epidote-rich mudstone. Fine to coarse tuff and fine lapilli-tuff deposits are also present. Primary sedimentary structures, such as scours and flames, are common.

Thelwood Formation (Sharp Banded Tuff)

The Thelwood Formation is a 270 to 500 m thick bedded sequence of siliceous tuffaceous sediments, subaqueous pyroclastic flow deposits and penecontemporaneous mafic sills (Juras, 1987). This unit is present throughout the mine property but the best exposures occur on the west side of the mouth of Thelwood Creek and around Myra Falls. The rock units can be grouped into three general, repetitive lithologies: (1) tuffaceous sediment units, (2) pyroclastic deposit units, and (3) mafic sills. Components of all three occur within each generalized unit. Tuffaceous sediment units range from 5 to 30 m in thickness and consist of massive to thinly bedded tuffaceous mudstone and siltstone, mudstone, and vitric ± crystal fine tuff. Minor chert layers occur locally. Also present are up to 20 percent coarse grained subaqueous pyroclastic deposits. Pyroclastic deposit units, intermediate in composition, range from 4 to 25 m in thickness and consist of vitric-lithic, lapilli-tuff to coarse tuff beds intercalated with up to 50 percent tuffaceous sediment deposits. Tuffaceous mudstone rip-up clasts are common and generally are concentrated in the lower portions of a deposit mafic sills consist of 1 to 90 m thick, massive basaltic to basaltic andesite sills. They are found throughout the Thelwood Formation but are generally more common in the lower portions. They also seem to be associated with the tuffaceous sediment units. Contacts of sills can be finer grained than the interiors and reflect chilled margins. Locally, flame-like protrusions of tuffaceous sediment into sills and hyaloclastitic margins are observed, and are interpreted to be the result of intrusion into wet unlithified sediment (Juras, 1987).

Flower Ridge Formation

The Flower Ridge Formation is the uppermost Paleozoic unit exposed in the mine-area. The unit is basaltic in composition and consists mainly of moderately to strongly amygdaloidal feldspar + pyroxene porphyritic basaltic lapilli-tuff, tuff-breccia and pyroclastic breccia deposits (Juras, 1987). Other rock types of this formation are fine to coarse tuffs, basalt flows and flow breccias, and bedded tuffaceous mudstone. The top of the Flower Ridge Formation is not on the mine property where only the lower 650 m can be observed. The contact with the underlying Thelwood Formation is conformable and characterized by the first appearance of abundant scoriaceous volcanic clasts in either pyroclastic or sedimentary beds.

Intrusive Rocks

Intrusive phases on the mine property, from oldest to youngest, are: (1) Paleozoic or Triassic diabase dikes, (2) Triassic basaltic sills and dikes related to the Karmutsen Formation, (3) Jurassic feldspar porphyry and quartz diorite dikes related to the Island Intrusions, and (4) Jurassic or younger quartz + feldspar porphyritic rhyolite and hornblende gabbro dikes. Paleozoic or Triassic diabase dikes are the second most abundant intrusive unit. They are usually less than 1 m wide, dark brown, aphyric and always strongly carbonate altered. There are several sets of dikes, but all have been affected by the major Jurassic deformational event, which constrains the age of their intrusion as Paleozoic, Triassic or both. certain mafic sills and dikes in the Thelwood and Flower Ridge Formations are inferred, on the basis of lithologic similarity, to represent dikes related to the Triassic Karmutsen Formation. These basaltic sills and dikes are thick (up to 300 m), coarse to very coarse grained, and contain relatively unaltered pyroxene and plagioclase grains. Jurassic feldspar porphyry and quartz diorite dikes are the most abundant intrusive phase on the mine property. They are intermediate in composition, up to 25 m wide, and crosscut all Sicker Group lithologies and fold-related fabrics in the mine-area. The latest event (Jurassic or younger) is represented by rare quartz + feldspar porphyritic rhyolite dikes, and a coarse to very coarse grained hornblende gabbro dike. These dikes crosscut all other intrusive rocks as well as most faults.

DEFORMATIONAL HISTORY OF THE MINE-AREA

The main deformational event in the Buttle Lake Camp is mesozoic in age and affected all pre-Mesozoic stratigraphy in the area. It is expressed in the Thelwood Formation as northwest trending, horizontal to shallowly northwest plunging, upright open folds. No foliations or lineations attributable to this event are recognized in Thelwood Formation lithologies. However, there is a distinct northeast striking, vertical joint set perpendicular to fold axes defined by bedding. Effect of the Mesozoic event on the Myra and Price Formations resulted in the development of second-order or parasitic folds relative to folds in the Thelwood Formation. The resultant structures, confined largely to the anticlinal cores (defined by folds in the Thelwood Formation), are northwest trending asymmetric open folds with steep southwest- to northeast-dipping axial surfaces, and, less commonly, symmetrical, tight to isoclinal folds with vertical axial planes. This is reflected by the range of steep northeast to steep southwest dips in the predominant foliation on the mine property. Plunges of these structures are shallow and vary in direction from northwest (Lynx area) to southeast (Price area) . Relative to the folding style in the Thelwood Formation, myra Formation structures can be classified as disharmonic, reflecting contrasting ductilities between the two units (Myra Formation was more ductile: Juras, 1987).

Lithologies in the Buttle Lake Camp also experienced at least two deformational phases after the main mesozoic episode. The first is characterized by rotation of bedding due to later intrusion of batholiths of the Jurassic Island Intrusions. The second phase might be represented by the north-northeast and east-northeast trending joint sets observed in the mine-area. These joints may have formed as a result of Cretaceous to Tertiary tectonics related to uplifting of the Buttle Lake area.

Faulting

Most of the numerous mine property faults are high angle, normal faults; some are strike-slip. Flat dipping thrust-like structures are also present. Though the faults occur with many different orientations, the main trends are northeast, north, northwest and east-southeast. Many of the more significant faults are associated with schistose zones commonly characterized by gouge, breccia, schistosities parallel to the fault, and abundant kink bands. Bedding, foliations and joints have been rotated near some faults. Fault displacements range from centimetres to hundreds of meters. Most offsets are less than 100 M. The largest measured offset occurs on the Myra-Price fault with an estimated net slip of 850 m (Walker, 1985).

Metamorphism

Rock units in the Price and myra Formations are characterized by lower greenschist mineral assemblages similar to those attributed to regional submarine hydrothermal metamorphism (cf. Reed, 1983, 1984). The metamorphic mineral assemblages are diverse, reflecting the bulk composition of rock types (ultramafic to rhyolite) in the Myra Formation and whether the unit is flow dominant or clastic dominant. Alteration of ultramafic to intermediate volcanic flows and clasts generally formed either epidote-dominant or chlorite-dominant assemblages of which the former is more common. Additionally, ultramafic volcanic rocks contain actinolite. Variations in epidote and chlorite in the ultramafic to intermediate volcanic rocks generally can be explained by the presence of multiple water/rock ratios in the hydrothermal system (Reed, 1983). Alteration and metamorphism of felsic volcanic rocks in the myra Formation formed numerous mineral assemblages that generally comprised varying proportions of sericite, albite and quartz.

Later superimposed burial metamorphism or dynamothermal metamorphism recrystallized phyllosilicate phases to coarser grain sizes and created local pressure shadow development. These effects are most pronounced in the hinge areas of Mesozoic structures and in schist zones related to faulting. Best evidence that the area experienced a later event is in reset K -Ar and, to a lesser degree, Rb- Sr isotopic dates (Juras, 1987).

Rock units in the Thelwood and Flower Ridge Formations are characteristically metamorphosed to sub-greenschist and lower greenschist facies. The Thelwood Formation contains a lower greenschist metamorphic mineral assemblage of chlorite, clinozoisite/epidote, quartz and albite. Flower Ridge Formation units contain similar assemblages except for the presence of actinolite and pumpellyite. The latter phase, indicative of a sub-greenschist facies, is present only in the mid- to upper parts of the formation.

MINERALIZATION AND ALTERATION H-W

The massive sulphide member of the H-W Horizon consists of a number of massive sulphide deposits (Main Zone, North Lenses, Upper Zones) that are collectively known as the H-W deposit (Figs. 4, 7). The H-W massive sulphide bodies are typical fine grained, massive to thin bedded assemblages of pyrite,

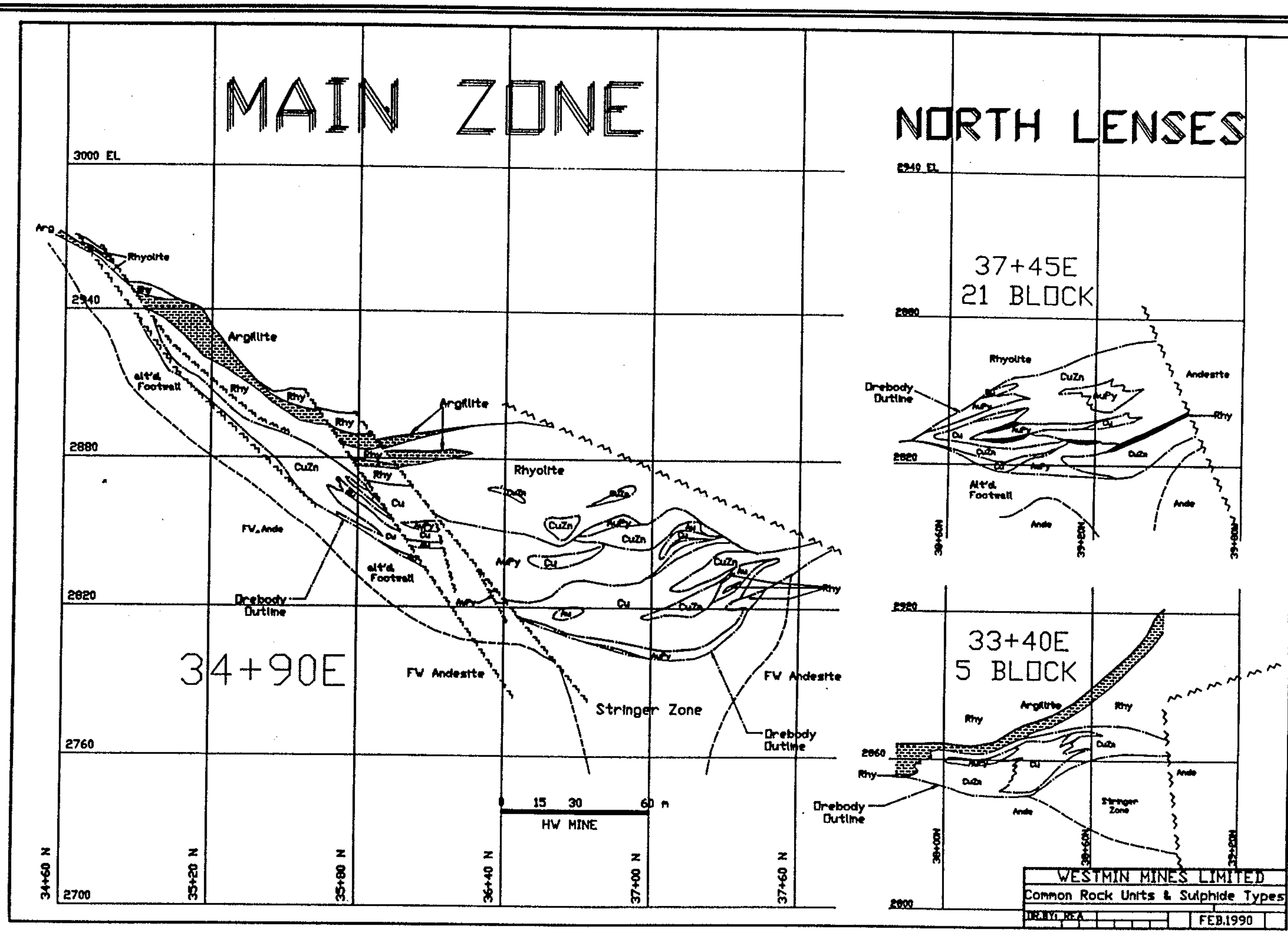

Figure 7. Sections through typical H-W Horizon massive sulphide deposits (coordinates are in meters). Sulphide and rock type symbols are: Au, AuPy = auriferous pyrite; Cu = pyrite + chalcopyrite; CuZn = sphalerite + chalcopyrite + pyrite; Rhy = rhyolite; Ande = andesite; alt'd = altered.

sphalerite and chalcopyrite with subordinate bornite, tennantite, galena. Trace native gold and argentite are recognized. Non-sulphide phases include barite, quartz and sericite. The deposits are commonly located at the base of the H-W Horizon.

The H-W Main Zone massive sulphide body, the largest of the H-W deposits, is an elongate, essentially flat lying lens some 1200m long by up to 500m wide. Thicknesses range from 3m along the 40° north dipping "fringe" zone to 80m in the flat lying central zone (Fig. 7) . The Main Zone sulphides exhibit a strong lateral zonation from the pyrite-rich central zone, having chalcopyrite and sphalerite-rich areas, to the barite-rich and pyrite-poor fringe zone containing significant sphalerite, chalcopyrite, galena and bornite. Cu/Zn ratios mimic the mineral zoning and define a copper-rich central region and a zinc-rich fringe area. mineral zonation on a smaller scale is more complex necessitating seven discrete sulphide types for mine planning purposes. Also within the Main Zone are regions of barren pyrite. However, because of relatively uniform gold distribution throughout the deposits (Walker, 1985), these base metal-poor areas contain mine average gold values and are consequently called auriferous pyrite.

The H-W North Lenses are a diverse group of commonly overlapping massive sulphide, semi-massive sulphide and clastic sulphide lenses north of the main Flat Fault (Figs. 4 and 7). The lenses range from precious metal-rich, pyrite-poor sphalerite, chalcopyrite and galena deposits, to precious metal-poor sphalerite and pyrite deposits, to strongly metal zoned pyritic lenses similar to the H-W Main Zone. The clastic sulphide deposits comprise massive sulphide clasts (all ore types) amongst varying types of rhyolite clasts. Individual clasts are up to one meter in size.

L-M-P

The Lynx-Myra-Price Horizon massive sulphides are composed of banded sphalerite, chalcopyrite, pyrite, galena and minor tennantite. Bornite was present in the Southwall Zone. Non-sulphides include barite, quartz and sericite. The deposits are largely located on or near the uppermost contact of the horizon. The L-M-P massive sulphide deposits do not vary greatly in composition and are not significantly zoned. Precious metal grades vary between the various L-M-P ore zones, from a high in the Myra deposit and the G and West-G Zones, to a comparative low in the S-Zone and Price orebodies.

Alteration

The Price and Myra Formations contain two main zones of hydrothermal alteration associated with massive sulphide mineralization. One occurs below the H-W deposit and a smaller one is found beneath the Southwall Zone of the L-M-P Horizon in the Lynx Mine. Both feeder zones lie in andesitic volcanic rocks which have been completely altered to assemblages of quartz + sericite + pyrite ± chlorite. Pyrite content varies from several to over 30 percent (Walker, 1985). it is distinctly coarser grained relative to the overlying massive sulphides. Chlorite-bearing rocks appear to be more common in less intensely altered areas, marginal to the central parts of the zones. The H-W alteration zone has an additional flanking zone consisting of moderate to strong albitization and silicification, such that the final assemblage consists of albite + quartz + sericite. This alteration assemblage also occurs irregularly within the upper units of the Price Formation outside the feeder zone areas.

DEPOSITIONAL HISTORY

The Price and Myra Formations represent volcanism and volcanogenic sedimentation in an intra-arc rift environment within an oceanic island arc system (Juras, 1987). More specifically, most of the preserved Price and myra stratigraphy in the mine property indicates that deposition occurred in a northwest-southeast trending rift basin (minimum dimensions being 2 to 3 km wide and 10 km long), named here as the Buttle Lake Camp basin (BBSN). The rifted nature is implied by the marked linear distribution of many of the lithologic units in the Myra Formation, including the ore deposits and the presence of rift related volcanic rocks (komatiitic basalts and basalts). Deposition into the rift basin followed a general sequence of events: (1) mafic to intermediate arc volcanism, (2) rifting, hydrothermal convection and sulphide mineralization, (3) felsic arc volcanism, (4) ultramafic to mafic rift volcanism, and (5) volcanogenic sedimentation. This sequence was repeated at least twice forming two massive sulphide mineralized horizons: H-W and Lynx-Ryra-Price.

The first series of events in the development of the Buttle Lake deposits involved periods o f mafic to intermediate arc volcanism (e.g. Price Formation and 5E Andesite). Rifting, marked by high-angle normal faults, created complex patterns of ridge and trough structures along the rift basin floor (based on topography necessitated by drawing of reconstructed cross sections). Little if any volcaniclastic or epiclastic sedimentation occurred during the opening of the rift basin. This initial lack of sedimentation on basin or trough floors could indicate that a subaqueous environment existed for the entire island arc system and that rifting took place in a marginal region of the volcanic arc (Hawkins et al., 1984) instead of in the topographically higher central area (Karig, 1971; Carey and Sigurdsson, 1984). As a consequence of numerous faults (documented normal fault spacing in modern rift basins can average 50 m: Arcyana, 1975) and a relatively high thermal regime, submarine hydrothermal convection occurred. The driving mechanism for hydrothermal fluids could be from shallowly emplaced magma chambers or cupolas (Cathles, 1983; Alabaster and Pearce, 1985). Locally, hydrothermal fluids discharged along high angle faults onto the sea floor. The discharge or vent areas were within trough structures and are characterized by development of crosscutting, conically to cylindrically shaped, moderately to strongly altered zones. These evolved hydrothermal fluids ponded in existing depressions giving rise to the characteristic elongate nature of the Buttle Lake massive sulphide lenses (lateral extent much greater than thickness: cf. Lydon, 1988). Explosive and effusive felsic arc volcanic activity accompanied the mineralization events, resulting in formation of massive sulphide hosting, rhyolite-rich units. Timing of the felsic volcanism played an important role in determining the thickness of massive sulphide bodies. If the concomitant felsic volcanism preceded the ponding of the ore solutions and deposited pyroclastic material within the trough structures, relief was decreased. Subsequent ponding of the hydrothermal fluids was thinner and more spread out (L-M-P Horizon orebodies). The much thicker H-W deposits, for the most part, formed before significant deposition of felsic pyroclastic material.

The final events of a general sequence consisted of ultramafic to mafic rift volcanism (e.g. G-Flow unit), and volcanogenic sedimentation. The rift-related lavas, if voluminous enough, influenced the life of contemporaneous sulphide-generating geothermal systems. Sudden covering by the flows prevented further sulphide mineralization by choking hydrothermal activity (e.g. G-Zone and G-Hanging Wall Zone, Lynx area) or filling in existing depressions. Volume of the ultramafic to mafic lavas, which increased in successively younger cycles, was governed by the growth of the intra-arc rift zone. Volcanogenic sedimentation commonly coincided with another phase of mafic to felsic arc or mafic rift volcanism. Resulting mixtures of volcaniclastic debris and flows buried previously deposited massive sulphide deposits and generally preserved them.

Thelwood and Flower Ridge Formations indicate a major change in depositional style and environment from the underlying Myra Formation (Juras, 1987). The Thelwood Formation is a sediment-sill complex consisting of siliceous tuffaceous sediments, subaqueous pyroclastic deposits and penecontemporaneous mafic sills. The Flower Ridge Formation, the final main Sicker Group volcanic phase in the Buttle Lake Camp, represents basaltic explosive to effusive activity from a back-arc (?) spreading centre system. The Thelwood sills are probable early, intrusive equivalents to the Flower Ridge units.

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