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**GEOLOGICAL SETTING AND GENESIS OF THE HANGING WALL SULPHIDE
ZONES, SULLIVAN Zn-Pb DEPOSIT, SOUTHEASTERN BRITISH COLUMBIA**

by

Andrew George Conly, B.Sc.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Science

Ottawa-Carleton Geoscience Centre

and

Department of Earth Sciences

Carleton University

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GEOLOGICAL SETTING AND GENESIS OF THE HANGING WALL SULPHIDE ZONES, SULLIVAN Zn-Pb DEPOSIT, SOUTHEASTERN BRITISH COLUMBIA

submitted by Andrew G. Conly, B.Sc.

in partial fulfilment of the requirements

for the degree of Master of Science

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January 9, 1996

ABSTRACT

The Sullivan orebody is a Meso-Proterozoic, metamorphosed, poly-deformed, stratiform Zn-Pb-Ag deposit, situated at the lower - middle Aldridge Formation contact within the Purcell Anticlinorium, southeastern British Columbia. The Sullivan deposit formed within an intracratonic basin along the western margin of the Precambrian North American craton. The emplacement of the gabbroic Moyie sills, dated at 1467 ± 3 Ma (Anderson and Davis, in press), was contemporaneous with deposition of the lower Aldridge Formation, and very likely provided a local heat source to drive hydrothermal fluid circulation. The hanging wall of the deposit includes all meta-sedimentary, sulphide, and altered rock units that overlie the main ore zone stratigraphy. Evaluation of the sedimentary architecture has shown that the hanging wall consists of five large-scale (2-40 metres thick) meta-turbidite sequences (I, H, hu, Hu, and U), with laterally extensive zones of stratiform to stratabound sulphides within the uppermost semi-pelitic and pelitic units of the I, H, and Hu sequences. Macroscopic textures (*i.e.* interlaminated sulphide and silicate rock) and sedimentary architecture indicate that the hanging wall sulphide zones are syn-sedimentary in origin, formed by sulphides precipitating from a hydrothermal brine (?) during the waning stages of turbidite sedimentation and during pelagic sedimentation.

Formation of the hanging wall sulphide zones can be related to two hydrothermal events. The first event, the "ore-stage" resulted in the deposition of sedimentary sulphides (primarily pyrrhotite, sphalerite, and galena). Associated with sulphide deposition were the formation of: discordant tourmalinite breccias comprising the feeder pipe for hydrothermal up-flow and discharge; stratabound zones of disseminated tourmaline alteration; laterally extensive zones of chlorite + Fe-sulphide zones that envelop hanging wall sulphide zones; and extensive zones of muscovite alteration. The second hydrothermal event, formed extensive zones of albite + chlorite $\pm$ pyrite alteration within the hanging wall and resulted in further Zn and Pb enrichment

of hanging wall sulphides zones. The effects of metamorphism (*i.e.* recrystallization, metamorphic minerals) and tectonic deformation (block faulting and folding) are widespread, but do not appear to have affected significantly macroscopic textures, sedimentary architecture, or metal distribution within the deposit.

FRONTISPIECE

"The Miner"

sculpture by William A. Conly

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First and foremost the author would like to acknowledge gratefully the mine staff at Sullivan and Cominco Metals Ltd. for allowing the opportunity to visit the mine and for providing complete access to all mine records. In particular, thank-yous are extended to Norris Del Bel Bullez and Bruce Reid from the mine's geology office for their suggestions and assistance while at Sullivan. The author would also like to thank the Sullivan Working Group for all of their assistance, and informative and entertaining discussions (particularly over dinner).

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Completion of this project would not have been possible without the assistance of the following people: Anett Brigges and John Everest for making all 180+ thin sections; Ron Conlon for performing the X-ray diffraction; Peter Jones for all of his assistance on the SEM; John Stirling (Geological Survey of Canada) for his electron microprobe work; Richard Lancaster (Geological Survey of Canada) for photographing polished drill core samples; Pascal Mouchakkaa for digitizing and preparation of preliminary isopach and metal distribution maps; and, Joanne Treidlinger for some last minute data entry. A very special thanks to Sheila Thayer for all of her assistance during the my undergraduate and graduate years at Carleton (you saved my "butt" too many times to mention!).

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STATEMENT OF ORIGINAL CONTRIBUTION

All sampling and relogging of drill holes was completed by the author while visiting the Sullivan mine during the summer of 1993. Sample descriptions, petrographic analysis of thin sections, drafting of figures, and preparation of tables were also completed by the author. Sample crushing and milling for whole-rock geochemistry were completed by XRAL Laboratories, Don Mills, Ontario. Whole-rock geochemical analyses used in chapter 6 were performed by the Analytical Geochemistry Section of the Mineral Resources Division, Geological Survey of Canada, Ottawa, and by XRAL Laboratories. Scanning electron microscope analyses were performed by the author with the assistance of Peter Jones at the Carleton University Research Facility for Scanning Electron Microscopy (CURFEM). Electron microprobe analyses of tourmaline and some biotites were performed by John Stirling, Geological Survey of Canada, Ottawa.

Chapters 2 and 3 of this thesis represent a literature review of the regional and local geology. The information provided within these chapters is considered to be cited accurately, although the author does not take responsibility for the interpretations made therein.

The author is the sole contributor to chapters 4, 5, 6, and most of chapter 7 of this thesis and accepts full responsibility for the interpretations made therein.

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CHAPTER 1: INTRODUCTION

1.1 General Statement

A number of stratiform to stratabound Zn-Pb deposits in southeastern British Columbia are hosted within Mesoproterozoic to Middle Cambrian meta-sedimentary sequences. The largest of these deposits is the 160 million tonne Sullivan deposit, considered as one of the world's "super-giant" sedimentary-exhalative (SED-EX; Carne and Cathro, 1982) Zn-Pb sulphide orebodies. Understanding the formation of the Sullivan deposit is complicated by the modification of the original sulphide orebody by regional metamorphic, tectonic, and hydrothermal events. However, geologists have developed two models to explain its origin: *i*) epigenetic hydrothermal replacement (Swanson and Gunning, 1945; Freeze, 1966); and *ii*) syn-sedimentary or sedimentary exhalative (Owens, 1960). These models evolved primarily during the mining of the main ore sequence in the footwall, with very little emphasis being placed on understanding the hanging wall and its ores. Therefore, the focus of the present research is to develop a genetic model for the hanging wall sulphide zones (see below), and to link their development to the origin of the Sullivan deposit as a whole.

Hanging wall sulphide zones consist of interlayered, layered, to massive sulphide (comprised of >20 vol% pyrrhotite, sphalerite, and galena), that form locally discordant stratiform to stratabound lenses that are confined between the D ore band (uppermost ore zone of the footwall ore sequence) and the base of the U meta-sedimentary sequence of the Sullivan deposit (which in part comprise the hanging wall of the Sullivan deposit) (see Figure 3.2 and Chapter 4). Several hypotheses exist for the origin of the hanging wall sulphide zones, namely that they represent: *i*) sedimentary sulphides (syngenetic) formed during the waning stages of the Sullivan hydrothermal system; *ii*) sulphides that have been tectonically emplaced into the sedimentary rocks overlying the main orebody; or *iii*) sulphides that have been remobilized by late-stage hydrothermal fluids.

1.2 Objectives

The main objectives of this study are: *i*) to provide a detailed description of the hanging wall geology of the Sullivan deposit; *ii*) to document the sulphide, alteration, metamorphic, and sedimentary mineral assemblages and their textural relationships, in order to establish a paragenetic sequence; *iii*) to characterize the chemical composition of the lithostratigraphic units; *iv*) to compare the composition of hanging wall and footwall ore and meta-sedimentary (rocks composed of >80 vol% aluminosilicate minerals) units; and *v*) to develop a genetic model for sulphide deposition in the hanging wall.

1.3 General Methodology

Four weeks of field work were completed at the Sullivan Mine during July 1993. Cominco mine plans, sections, and diamond drill hole data were compiled and reviewed in order to select appropriate drill holes for re-logging. While it was not feasible to re-log and sample all suitable drill holes, a suite of drill core samples were obtained from 17 drill holes, totalling 675 metres (2,075 feet), that were considered representative of the vertical and lateral extent of the hanging wall sulphide zones. During core logging, approximately 460 sulphide and silicate rock samples were collected for petrographic examination, whole-rock geochemistry, and isotope geochemistry. Samples were taken at distinct changes in lithology and texture. Mine data (core logs and underground maps) were used in areas where re-logged drill hole coverage is sparse. Drill log data enable the identification of ore and alteration zone contacts, are useful for stratigraphic correlation, and provide assay data for the ore zones. Mine stope maps were an essential source of information, because underground access to hanging wall sulphide zones during the field season was impossible.

Sulphide and host rock mineral assemblages and textures were investigated in 184 thin and polished thin sections (Chapter 5). Samples were also analyzed for mineral chemistry (Chapter 5), and whole-rock geochemistry (Chapter 6).

1.4 Location and Access

The Sullivan deposit is located at 49°43'N latitude and 116°00'W longitude, on the eastern flank of the Purcell Mountains, west of the Rocky Mountain Trench, in southeastern British Columbia. The mine and concentrator are located within the city limits of Kimberley, British Columbia. [The Sullivan Mine is easily accessed by Highway 1, the Trans-Canada Highway, from Calgary to the junction with Highway 93 (approximately 145 kilometres), then south by Highway 93 to Radium, further south on Highway 95 to the junction of Highway 93-95 (approximately 100 kilometres), and then west into the city of Kimberley (approximately 30 kilometres)(see Figure 2.1).]

1.5 History and Mining of the Sullivan Deposit

The Sullivan deposit was discovered in 1892 by the prospectors, Sullivan, Smith, Cleaver, and Burchett. Extensive development of the property was not initiated until the completion of a Canadian Pacific Railway branch line in 1899, which connected Kimberley to Cranbrook. In 1900 the property was developed by a Spokane, Washington, mining group, who in 1903 built a smelter at Marysville nearby. Due to metallurgical difficulties the smelter was closed, and the property was acquired in 1909 by the Federal Mining and Smelting Company. The Consolidated Mining and Smelting Company of Canada Ltd. (now Cominco Limited) leased and optioned the property in late 1909. The following year they exercised their option, and sale of the property to them was finalized in 1913.

Early production was from the upper levels of the deposit (around the 4600 to 4800 foot levels) with ore being shipped to the Cominco Ltd. smelter at Trail, British Columbia. During

this period, deep drilling revealed the presence of an immense and complex sulphide orebody. In 1915 the main adit was started at the 3900 foot level, approximately 650 feet (200 metres) below the sulphide zone. By 1920, milling and metallurgical problems resulted in the development of a differential flotation process to concentrate Pb and Zn. In order to offset increasing production costs, conversion to mechanized milling began in 1978 and was completed in 1985.

From the date of acquisition by Cominco Limited until the end of 1981, the Sullivan Mine had produced a total of 115,900,000 tonnes of ore, with average grades of 6.7% lead, 5.8% zinc, and 79 gpt of silver (Hamilton *et al.*, 1983). From 1981 until the end of 1993, the mine had yielded another 16,500,000 tonnes (based on data from Canadian Mines Handbook, years from 1981 to 1993), to bring total ore production to over 130,000,000 tonnes. Cominco geologists have estimated that ore reserves are sufficient for mining operations to continue past the year 2000.

1.6 Previous Work

Early descriptions of the geology of the Sullivan deposit were published by Pentland (1943), Swanson and Gunning (1945), and Freeze (1966). Debate over the origin of the deposit has been ongoing since the 1960's, with geologists having argued for either an epigenetic (Freeze, 1966) or a syn-sedimentary/exhalative (Owens, 1960) origin, although the general consensus favours a stratiform, syn-sedimentary/exhalative model (Owens, 1960; Ransom, 1977; Ethier *et al.*, 1976; Campbell *et al.*, 1978, 1980; Hamilton *et al.*, 1982). Work during the late 1970's and early 1980's focused on isotope geochemistry (Ethier *et al.*, 1976; Campbell *et al.*, 1978, 1980; Nesbitt and Longstaffe, 1982; Nesbitt *et al.*, 1984) and structural aspects (McClay, 1983) of the orebody and encompassing meta-sedimentary units. Recent work on the deposit, including this study, involved a five year co-operative effort between Cominco Limited and a team of research scientists from the Geological Survey of Canada, the United States Geological Survey, and various Canadian universities. While other studies (*e.g.*, Hamilton *et al.*, 1982;

Shaw and Hodgson, 1986; Leitch *et al.*, 1991; Shaw *et al.*, 1993) have evaluated various aspects of hanging wall geology, in particular wall rock alteration, several internal mine reports (e.g. Jardine, 1966) have evaluated the genesis and economic potential of the hanging wall sulphides. Apart from the afore mentioned studies, this is the first academic study that focuses solely on the genesis of the various hanging wall sulphide zones.

CHAPTER 2: REGIONAL GEOLOGY

2.1 Introduction

Rocks of the Mesoproterozoic Purcell Supergroup outcrop within the Purcell Mountains and the Clark, Hughs, Lizard, and Galton Ranges of the Rocky Mountains in southeastern British Columbia (Figure 2.1), and are laterally correlative with the Belt Supergroup of western Montana, Idaho, and eastern Washington (Figure 2.2). Within the Purcell Mountains, rocks of the Purcell Supergroup form the core of the Purcell Anticlinorium. The Purcell Anticlinorium is located within the Columbian orogen, and is situated between rocks of the Rocky Mountain Foreland Thrust and Fold belt to the east and accreted rocks of the Kootenay arc to the west (see Figure 1 in Höy, 1982). The core of the Columbian orogen is the Shuswap Metamorphic Complex, a terrain of high-grade metamorphic rocks to the west of the Kootenay arc.

In Canada, the Purcell Supergroup consists of a thick wedge of dominantly shallow marine and non-marine sedimentary rocks that overlie basinal clastic rocks in the Purcell Mountains (Figure 2.3), and platformal clastic and carbonate rocks in the Rocky Mountains. The maximum thickness of sedimentary rocks of the Purcell Supergroup exceeds 11 kilometres (Reesor, 1958), with the base unexposed. Facies changes are more distinct near the basin margins (near the northeastern limit of exposure), but become less easily recognized towards the southwest. Facies variations are accompanied by an increase in stratigraphic thickness and subtle decreases in grain size, with sedimentary units becoming more argillaceous westward.

2.2 Purcell Supergroup Stratigraphy - Purcell Mountains

An idealized stratigraphic section of the Purcell and Windermere Supergroups is illustrated in Figure 2.3.

2.2.1 Fort Steele Formation

The Fort Steele Formation is a 200 metre-thick succession of at least three upward-fining fluvial/deltaic cycles, composed of quartz arenite, quartz wacke, and argillite. The base of each

		Northern Idaho ¹	Northern Purcell Mtns. ²	Hughes Range ^{3,4}	Lizard Range ^{5,6} / Clark-Galton Ranges ^{7,8,9}	Glacier Park Montana ¹⁰
Mesoproterozoic Purcell (Belt) Supergroup	Libby Fm.					
	Striped Peak Fm.					
		Missoula Gp.	Mt. Nelson Fm.			
			Roosville Fm.	Roosville Fm.	Roosville Fm.	-unnamed-
				Phillips Fm.	Phillips Fm.	Red Plume Qz.
			Gateway Fm.	Gateway Fm.	Gateway Fm.	Mt. Shields Rm.
	Wallace Fm.		Sheppard Fm.	Sheppard Fm.	Sheppard Fm.	Sheppard Fm.
			Van Creek Fm.	-- Nicol Creek Fm.	Purcell Lava	Snowslip Fm.
				Van Creek Fm.	Van Creek Fm.	
			Kitchner Fm.	Kitchner Fm.	Kitchner Fm.	Helena Fm.
						Empire Fm.
	St. Regis Fm.					Ginnell Fm.
	Revelt Fm.		Creston Fm.	Creston Fm.	Creston Fm.	Appakunny Fm.
	Burke Fm.					
					Aldridge Fm.	Altyn Fm.
						Prichard Fm.
		Prichard Fm.	Aldridge Fm.	Aldridge Fm.		Altyn Fm.
						Waterton Fm.
						Tombstone Mtn. Fm.
						Haig Brook Fm.
				Fort Steele Fm.		
		Base Not Exposed				

Figure 2.2. Nomenclature for classical Purcell (Belt) Supergroup (after McMechan, 1981; Aitken and McMechan, 1991).

Explanation: (1) Harrison and Jobin, 1963; (2) Reesor, 1958; (3) Hoy, 1979; (4) McMechan *et al.*, 1980; (5) Leech, 1958; (6) McMechan, 1980; (7,8) Price, 1962, 1964; (9) Fermor and Price, 1983; (10) Earheart *et al.*, 1983.

Figure 2.3. Stratigraphic section of the Purcell Supergroup and Lower Windermere Supergroup, from the Kimberley area, southeastern British Columbia (from Hamilton *et al.*, 1983).

cycle is characterized by cross-stratified quartz arenite that fines-upwards into finely laminated and mud-cracked argillite (Höy, 1978). The Fort Steele Formation is not exposed in the Purcell Mountains. The closest exposure is approximately 25 kilometres to the east of the Sullivan deposit, along the eastern edge of the Rocky Mountain Trench in the Kootenay King area (Figure 2.1).

2.2.2 Aldridge Formation

In the Purcell Mountains the Aldridge Formation is up to 4200 metres thick, and has been subdivided into three main sequences (Reesor, 1958; Edmunds, 1973, 1977), the lower, middle, and upper Aldridge Formation. The lower Aldridge Formation (1000 metres; Reesor, 1958; Edmunds, 1977) conformably overlies the Fort Steele Formation and consists of a rhythmic succession of rusty weathering, laminated to thin-bedded quartz sandstone, argillaceous sandstone, siltite, and argillite. Massive to poorly bedded, elongated lenses of intraformational conglomerate occur locally near the top of the lower Aldridge Formation (Hamilton *et al.*, 1982). Cross-stratification is very common in the sandstones and siltites (Reesor, 1958). Rocks of the lower Aldridge Formation probably represent C-E turbidite in the Bouma (1962) turbidite facies model (McMechan, 1981). The contact with the overlying middle Aldridge Formation is defined by a change in weathering colour, from rusty-brown to grey.

The middle Aldridge Formation (2700 metres thick) is characterized by interbedded to graded sequences of bedded quartz sandstone, argillaceous sandstone, laminated siltite, and laminated argillite. Middle Aldridge Formation rocks are interpreted as A-E turbidites in the Bouma (1962) turbidite facies model (Bishop *et al.*, 1970; Edmunds, 1973, 1977). Sole marks indicate a northward transport direction (Edmunds, 1973); however, depositional current features indicate an eastward current direction in the western Purcell Mountains, and a westward current direction in the eastern Purcell Mountains (*c.f.* Hamilton *et al.*, 1982).

The Upper Aldridge (300-500 metres thick) consists of rusty-weathering, laminated to thin-bedded carbonaceous siltite and argillite. The Upper Aldridge is interpreted to have been deposited in a subtidal environment (McMechan, 1981).

2.2.3 Creston Formation

Creston Formation strata consist of green, grey, and purple siltite and argillite, with minor quartzarenite, which locally contain mudcracks, ripple marks, and rip-up debris layers. The Creston Formation ranges from 920 to 2350 metres in thickness, with a gradual thickening to the northwest.

The Creston Formation is informally divided into three members. The lower member consists of grey-green siltite-argillite couplets, with load casts, scour-and-fill structures, continuous and discontinuous parallel laminations, ripple cross-laminations, and syneresis cracks. The absence of mudcracks indicates deposition in a subtidal environment that was intermittently affected by tidal currents and/or within reach of wave base (McMechan, 1981).

The middle and upper members consist of green-purple discontinuously to continuously laminated, siltite-argillite couplets and graded siltite-argillite beds. Scours-and-fill and pull-apart structures, mudcracks, ripple marks, and rip-up debris beds are locally abundant. The upper member contains tabular lenses of white to green cross-stratified quartzarenite that are interbedded with siltite-argillite couplets. The upper member is interpreted to have been deposited in an intertidal environment, with the quartzarenite lenses representing the infilling of migrating tidal channels (McMechan, 1981). The lack of quartzarenite in the intermediate member probably reflects a transition between the subtidal and intertidal environments (McMechan, 1981).

2.2.4 Kitchener Formation

The upper member of the Creston Formation grades into dolomitic argillite and siltite of the lower member of the Kitchener Formation. The lower member (17-500 metres thick) consists of laminated to thinly bedded, graded dolomitic and non-dolomitic siltite-argillite

couplets. Climbing ripples and mudcracks are found throughout the lateral extent of the lower member, with local occurrences of pyrite, lenticular bedding, scour-and-fill structures, and lenticular pods of micritic limestone. It is inferred from the lateral extent of mudcracks and local abundance of lenticular bedding, that the lower member was deposited in the lower intertidal zone (McMechan, 1981).

The upper member (1175-1500 metres thick) consists of platformal facies including thin- to thick-bedded, internally laminated silty dolomite and dolomite, sandy quartzose dolomite, and siltite-argillite couplets. Intraformational conglomerate, oolitic limestone, stromatolitic limestone, mudcracks, and ripple marked surfaces occur locally. Molar tooth structures and black argillite partings are common in carbonate units. Load casts, flame structures and syneresis cracks are common in siltite-argillite units. The sediments of the upper member were deposited in a shallow-subtidal environment (McMechan, 1981).

2.2.5 Van Creek Formation

The Van Creek Formation conformably overlies the Kitchener Formation, with the contact placed where the siltites and argillites change from a dolomitic to a non-dolomitic composition (McMechan *et al.*, 1980). In the Hughs Range and Purcell Mountains the Van Creek Formation is abruptly overlain by lava flows of the Nicol Creek Formation; however, along the western edge of the Purcell Mountains the Van Creek Formation is overlain by the Dutch Creek Formation. The Van Creek Formation thickens to the northwest (200-850 metres thick) and consists of green, and locally purple, laminated to thinly bedded siltites grading into argillites. Lenses of fine-grained quartzitic sandstone occur locally throughout the formation. Sedimentary structures include mudcracks, ripple marks, ripple cross-laminations, climbing ripples, rip-up debris beds, pull-apart structures, and scour-and-fill structures. The sedimentary structures and weakly bi-polar paleocurrent measurements (from ripple cross-laminations) indicate that the depositional environment varied from the intertidal zone of a tidal flat to a non-marine floodplain (McMechan *et al.*, 1980).

2.2.6 Nicol Creek Formation

The Nicol Creek Formation (60-750 metres thick) is composed of two distinct, interlayered lithological assemblages. One assemblage consists of green to purple siltite and argillite with subordinate volcanoclastic debris. The siltite and argillite units are typically laminated, graded, or arranged in siltite-argillite couplets. Lithological units and structures are similar to those observed in the underlying Kitchener Formation. Volcanoclastic sedimentary units are composed of very fine- to coarse-grained sandstone, and are typically thinly bedded.

The second assemblage of the Nicol Creek Formation consists of green or maroon, massive to amygdaloidal basaltic to andesitic flows (Daly, 1912; Hunt, 1964; McMechan *et al.*, 1980) that correlate with the 'Purcell Lavas' in the Hughs, Galton, and Lizzard Ranges (Schofield, 1915; Rice, 1937). The flows have been extensively altered to chlorite and sericite, with large altered plagioclase phenocrysts; amygdules are commonly infilled with quartz or chlorite.

The interlayered nature of the Nicol Creek Formation indicates that volcanic activity was intermittent, with sedimentary and volcanoclastic units being deposited between eruptions (McMechan, 1981). Sedimentary structures in the siltite and argillite units indicate sedimentation occurred in a non-marine floodplain or tidal-flat environment (McMechan, 1981).

2.2.7 Sheppard, Gateway, and Roosville Formations

The basal strata of the Sheppard Formation (115 metres thick) conformably to disconformably overlie the Nicol Creek Formation, with the contact defined by a quartzitic sandstone unit. The Sheppard Formation consists of stromatolitic dolomite, dolomite, interbedded grey and dark red sandstone, quartz sandstone, dolomitic siltite, and red laminated argillite. Ripple marks, mud cracks, cross-bedded oolites and intraformational conglomerate are locally abundant. Deposition is interpreted to have occurred in the intertidal zone with an intermittent supply of terrigenous material (McMechan, 1981).

Rocks of the Sheppard Formation grade upward into the lower siltite member of the Gateway Formation (1350 metres thick). The lower member of the Gateway Formation is

overlain by an upper siltite and dolomite member. Salt casts and ripple marks are abundant throughout the formation. The Gateway Formation was deposited in a shallow water, hypersaline environment, possibly a tidal flat (Price, 1964), or in a lagoon (McMechan, 1981).

The Roosville Formation (600 metres thick) conformably overlies the Gateway Formation in the Purcell Mountains, but is underlain by quartz arenites of the Phillips Formation (Daly, 1912, McMechan, 1981) in the Rocky Mountains. The Roosville Formation consists of laminated argillite and siltite that become more dolomitic and calcareous up-section. A tidal flat environment is inferred for the Roosville Formation (Price, 1964).

2.2.8 Mount Nelson Formation

The Mount Nelson Formation conformably to disconformably overlies the Roosville Formation. The Mount Nelson Formation is up to 1000 metres thick and consists of a lower white, green, to grey quartz arenite unit, overlain by a thicker, brownish red- to grey-weathering carbonate interbedded with argillite and siltite. Deposition is interpreted to have occurred in a shallow marine environment (Reesor, 1973).

2.3 Windermere Supergroup

In the Purcell Mountains, the Windermere Supergroup unconformably overlies the Mount Nelson Formation of the Purcell Supergroup (Little, 1960; Reesor, 1973). The basal Toby Formation ranges in thickness from a few metres to 500 metres and consists of pebble to boulder conglomerate, sandstone, argillite, and diamictite. Quartzite, slate, and dolostone clasts in the Toby Formation were derived from the Purcell Supergroup. The Toby Formation is interpreted as a glaciogenic deposit (*c.f.* Gabrielse and Campbell, 1991), and is conformably overlain by the basal argillites of the Horsethief Creek Group. The basal strata of the Horsethief Creek Group grade into quartzitic sandstone and pebble conglomerate, which in turn are overlain by purple and red siltite. The Horsethief Creek Group thickens westward from 1000 metres, near the

Rocky Mountain Trench, to more the 3000 metres in the western extremity of the area, and is interpreted to be a turbidite deposit (*c.f.* Gabrielse and Campbell, 1991).

2.4 Magmatic Events

Four discrete periods of magmatism have been documented within the Purcell Mountains. The first two events were dominated by the intrusion of gabbroic sills into Lower Purcell Supergroup strata, whereas the last two events involved the emplacement of granitoid stocks and batholiths.

The first magmatic event is represented by the subalkaline to alkaline gabbroic Moyie sills and dykes which were emplaced into unconsolidated to partially consolidated sediments of the lower to lower-middle Aldridge Formation (Höy, 1989). Previous U-Pb dates had indicated that intrusion occurred at 1433 ± 10 Ma (Zartman *et al.*, 1982) and 1455 ± 11 Ma (Höy, 1989); however, Anderson and Davis (in press) have reported an earlier age of intrusion, at 1467 ± 3 Ma. The youngest episode of gabbroic intrusion is considered to be co-magmatic with the eruption of the Nicol Creek Formation lavas and Purcell lavas, and is represented by gabbroic sills that intruded the Creston, Kitchener, and Van Creek Formations (Bishop, 1974).

Mesoproterozoic granites (*i.e.* Hellroaring Creek Stock; Figure 2.1) were intruded into Aldridge Formation strata and Moyie sills during the East Kootenay Orogeny (see Leech, 1962; Ryan and Blenkinsop, 1971). A second granitoid event consisted of the intrusion of Late Jurassic to Middle Cretaceous granites into strata of the Purcell and Windermere Supergroups (Archibald *et al.*, 1983).

2.5 Regional Structure

Precambrian strata within the Purcell Mountains have undergone several periods of deformation resulting in the formation of the Purcell anticlinorium. The anticlinorium is considered to have formed by uplift and arching during convergence between a collage of

accreted terranes and the North American craton in the Mesozoic and early Cenozoic (*c.f.* Cook and Van der Velden, 1995). The folds comprising the anticlinorium are open and gentle with north-plunging axes, with some that are overturned to the east and some that display axial planar schistosity (*c.f.* Hamilton *et al.*, 1982). The anticlinorium is cut by a number of steep transverse faults, separating large structural regions further affected by block faulting along longitudinal faults (Figure 2.1). Major transverse faults (*e.g.*, St. Mary-Boulder Creek faults and Moyie-Dibble Creek faults; Figure 2.1) have a complex history of movement, following the locus of Precambrian structures that controlled the deposition of the Windermere Supergroup (Leech, 1958; Price and Lis, 1975; Lis and Price, 1976; Höy, 1978). Furthermore, these faults could have been active during deposition of the Purcell Supergroup, resulting in local modification of facies trends, variations in thickness, cause and occurrence of intraformational conglomerate, localization of granitoid intrusions, and the siting of hydrothermal fluids that formed the stratiform Pb-Zn deposits (*c.f.* Höy, 1982).

2.6 Regional Metamorphism and Orogenic Events

Strata within the Purcell Anticlinorium have been affected by four distinct episodes of deformation and/or regional metamorphism. The oldest episode, the East Kootenay Orogeny (*ca.* 1360 Ma), was originally interpreted to be a compressional event that occurred at the end of Purcell Supergroup sedimentation, resulting in regional metamorphism, deformation, and granitic intrusion (McMechan and Price, 1982). Recent U-Pb dates of Moyie sills by Anderson and Davis (*in press*) imply that the East Kootenay Orogeny occurred prior to the deposition of upper Purcell strata (post-Van Creek Formation), and therefore, would likely have been an extensional event. The work by Anderson and Davis (*in press*) has also lead to the identification of a previously unrecognized "Grenville-age" (1050-1120 Ma) event. This latter episode is considered to have been primarily thermal in character (with no major accompanying deformation) and resulted in the recrystallization of the Moyie sills during either burial

metamorphism or high temperature - low pressure regional metamorphism. The second episode, the Goat River Orogeny (800-900 Ma), is characterized by regional uplift, block faulting, and low-grade regional metamorphism. McMechan and Price (1982) interpreted that this event involved the sedimentation of the Windermere Supergroup; however, Anderson and Davis (in press) consider it to have been post-Purcell and pre-Windermere in age. The final episode occurred during the Mesozoic-Cenozoic ("Laramide-age") and consisted of regional metamorphism, deformation, and plutonism that overprinted earlier Precambrian deformation and metamorphism (McMechan and Price, 1982).

Mesozoic-Cenozoic metamorphism increases in grade, from lower greenschist facies in the Rocky Mountains to a narrow belt of amphibolite-grade rocks along the western side of the Purcell Anticlinorium (in contact with the Kootenay Arc). Metamorphic grade also increases with stratigraphic depth (Reesor, 1973; Bishop, 1974; Edmunds, 1977), producing local areas of amphibolite-grade rocks at the lowest stratigraphic levels (Leech, 1962, 1967). Regional metamorphic conditions, estimated from Chl-Ms-Ab-Qtz and Bt-Ms-Ab-Qtz assemblages (mineral abbreviations after Kretz, 1983), indicate a maximum temperature of 375°C and pressure of 5 MPa ($\cong$ 17 kilometres depth) (McMechan and Price, 1982). Temperature and pressure estimates from metamorphic assemblages within the bedded sulphide zones of the Sullivan deposit indicate a peak pressure of 380 MPa $\pm$ 100 MPa and a temperature of 450°C $\pm$ 50°C (DePaoli and Pattison, in press).

2.7 Evolution of the Purcell (Belt) Basin

Meso- to Neoproterozoic rocks of the Purcell and Windermere Supergroups were deposited in the Belt-Purcell basin, which is interpreted to have existed as either an epicratonic or an intracratonic basin. An epicratonic model implies that deposition occurred in a large miogeocline re-entrant of the Mesoproterozoic sea, located off the western margin of ancestral North America (Price, 1964; Harrison, 1972; Sears and Price, 1978; McMechan, 1981), which

may have been floored by continental, transitional, or oceanic crust (Höy, 1989). However, the discovery of older Precambrian rocks in the Shuswap Metamorphic Complex (Wanless and Reesor, 1975), combined with recent paleotectonic reconstructions for the Proterozoic (e.g. Hoffman, 1991; Ross *et al.*, 1992) support the interpretations of Winston *et al.* (1984) and Roberts (1986) that the basin was intracratonic in character, and analogous to Lake Baikal (Russia) or the East African Rift.

Originally, the basin was thought to have a simple north-west trending margin (Price, 1964; Smith and Barnes, 1966; McKelvey, 1968; Harrison, 1972). However, thickness and facies trends dictate that the basin shape was more complex than was originally postulated, and in fact outlines a rectilinear north, west-northwest, and north-trending basin margin with a westerly offset of more than 200 km near the international border (McMechan, 1981).

The infilling of the Purcell basin commenced with the turbidite deposits of the Aldridge Formation, indicating rapid subsidence. The shallow-water sedimentary rocks overlying the Aldridge Formation record a subsequent basin-wide regression (Höy, 1993). Strata of the Creston, Kitchener, Van Creek, and Nicol Creek Formations exhibit a gradual thickening to the west and northwest indicating an increased rate of subsidence in these directions (McMechan, 1981). Similar trends may have been recorded in the overlying formations, but evidence was removed by pre-Cambrian and pre-Devonian erosion (McMechan, 1981).

Based on the results of whole-rock K-Ar and Rb-Sr geochronology, sedimentation in the basin was originally considered to have occurred between 1500 to 900 Ma (Hunt, 1962; Obradovich and Peterman, 1968; Obradovich *et al.*, 1984). Ages determined by magnetostratigraphy indicate that sedimentation occurred between 1500 to 1250 Ma, with younger ages produced by regional metamorphism (Elston and Bressler, 1980; Elston, 1984). Based on structural and geochronological relationships documented by McMechan and Price (1982), sedimentation of the entire Purcell Supergroup terminated before 1360 Ma (East Kootenay Orogeny), with younger ages produced by the Goat River Orogeny. Recent U-Pb ages

of zircon and titanite from Moyie sills by Anderson and Davis (in press) indicate that deposition of the Aldridge, Creston, Kitchener, and Van Creek Formations began prior to 1467 Ma (age of the sills) and ceased by 1360 Ma. Anderson and Davis (in press) also suggest that the East Kootenay Orogeny occurred prior to, or during, the deposition of the Nicol Creek, Sheppard, Gateway, and Roosville Formations, and that Upper Purcell sedimentation was terminated by *ca.* 1250 Ma. Rocks of the Windermere Supergroup were initially deposited around 760 Ma (Devlin *et al.*, 1988). Between the end of Purcell sedimentation and initial deposition of the Windermere Supergroup, Purcell rocks were uplifted and subsequently eroded, producing the Mount Nelson-Tobi unconformity (Lis and Price, 1976).

CHAPTER 3: GEOLOGY OF THE SULLIVAN - NORTH STAR CORRIDOR AND SULLIVAN OREBODY

3.1 Local Geology

The Sullivan-North Star Corridor lies at the intersection of the north-northwest-trending rift axis of the Purcell Basin and the northwest-striking Kimberley Fault (Figures 3.1 and 3.2). The north-trending corridor is formed by an elongate graben structure, over 7 kilometres in its north-south dimension, that is defined by the presence of syndepositional faults, bodies of discordant fragmental rocks, conglomerate, rock alteration, and sulphide mineralization (Leitch *et al.*, 1991).

The Sullivan orebody lies on the folded eastern limb of a broad north-trending anticline at its intersection with the Kimberley Fault. The anticline follows the region's structural grain, plunging to the north, and is locally asymmetrical and overturned to the east (Hamilton *et al.*, 1982). South of the Hidden Hand Fault (Figures 3.1 and 3.2), rocks along the eastern limb of the anticline are folded forming an "S"-shaped anticline-syncline structure. The North Star and Stemwinder deposits are situated within the syncline.

3.2 Geology of the Sullivan Orebody

The Sullivan deposit is a stratiform, inverted saucer-shaped, Fe-Zn-Pb-Ag sulphide orebody enclosed by metamorphosed turbidites of the lower Aldridge Formation, near the contact with the overlying middle Aldridge Formation. The geology and stratigraphy of the orebody have been described in detail by Hamilton *et al.* (1982). The maximum north-south dimension of the orebody is approximately 2000 metres and the east-west dimension is approximately 1600 metres (Figure 3.1). The orebody ranges from flat to gentle easterly dipping in the west, moderate easterly to northeasterly dips in the centre, and easterly to northeasterly dipping along its eastern fringe (Figure 3.3). The orebody has a maximum thickness of 100 metres near its centre, and thins outwards in all directions.

Figure 3.1. Generalized geological map of the Kimberly area (modified from Cominco Ltd.).

Figure 3.2. Generalized northeast-southwest geological cross-section at 10,000 NI: through the Sullivan - North Star corridor (modified from Cominco Ltd.).

c)

d)

Figure 3.3. c,d) East-west geological cross-sections at 10000 N and 11600 N, respectively, through the Sullivan orebody (after Hamilton *et al.*, 1982).

The Sullivan orebody has been modified by three phases of post-depositional folding and faulting (McClay, 1983). Most of the folds consist of east-verging isoclinal folds, associated with west-dipping, low-angle thrust faults, which resulted in the relative movement of the hanging wall over the footwall along décollements in the sulphide orebody (McClay, 1983). The sulphide ore zones and their encompassing meta-sedimentary rocks have been offset by a series of transverse and longitudinal normal faults, with subordinate thrust faults (see Figure 4.6). Transverse normal faults, which include the Kimberley Fault, are oriented parallel to northeast-striking regional transverse faults (*e.g.* Moyie and St. Mary). With approximately 3000 metres of stratigraphic displacement, the Kimberley Fault truncates the northern edge of the Sullivan orebody and juxtaposes rocks of the Creston and Kitchener Formations against the lower Aldridge Formation. Longitudinal faults within the orebody are commonly referred to as "Sullivan-type" faults, and named after the Sullivan Fault that offsets the western margin of the deposit. These south-striking faults transect the orebody and are characterized by west side down displacements of less than 30 metres. The footwall thrust faults are commonly located within the transition zone, and commonly pass upward into east-verging folds within the hanging wall (*e.g.* Jonel Thrust and associate folds, Figure 3.4).

3.3 Stratigraphy of the Sullivan Orebody

3.3.1 Footwall Sequence

An idealized stratigraphic section through the eastern part of Sullivan deposit is illustrated by Figure 3.4. The footwall rocks consist primarily of thin- to medium-bedded argillite with subordinate meta-quartz wacke, intraformational conglomerate, and discordant breccias. Intraformational conglomerate underlies the northern two-thirds of the orebody, and disconformably overlies lower Aldridge Formation meta-sedimentary rocks. Conformably overlying the conglomerate are pyrrhotite-laminated argillites and bedded meta-quartz wacke. Directly underlying the eastern region of the orebody is a thin unit of strongly sheared,

Figure 3.4. Idealized geological column (not to scale) of the bedded facies of the Sullivan orebody, east of the transition zone (from Hamilton *et al.*, 1982)

pyrrhotite-bearing siltite termed the "Footwall Slates". Underlying the slates in the northern, eastern, and southern regions of the deposit is the "Main Band Quartzite", a graded quartzitic psammite. The footwall rocks are cut by a several discordant breccia bodies, that are composed of Aldridge Formation-type fragments in a pyrrhotite-rich argillite matrix. Footwall alteration consists primarily of tourmalinite alteration in the western half of the orebody, with the local occurrence of albite-chlorite-pyrite-carbonate alteration.

3.3.2 Geology of the Ore Zone

Based on sulphide ore texture, the Sullivan orebody can be subdivided into two distinctive parts joined by a transition zone (Figure 3.3). West of the transition zone, the ores typically occur in a single conformable lens consisting of massive to poorly bedded pyrrhotite with an interspersed wispy layering of sphalerite and galena. The western part of the orebody ranges in thickness from greater than 60 metres to as little as 2 metres (Hamilton *et al.*, 1982). The eastern part of the orebody consists of a bedded ore sequence, subdivided into five ore bands (in ascending stratigraphic order): the Main, A, B, C, and D Bands (Figure 3.4). The A-D bands and the upper third of the Main Band consist of thinly bedded sulphide (pyrrhotite-sphalerite-galena) interbedded with fine-grained clastic material. The lower two-thirds of the Main Band consist of a massive band of fine-grained sulphide without intercalated clastics. The eastern part of the orebody is as much as 36 metres thick, and commonly has well preserved primary sedimentary textures (Hamilton *et al.*, 1982)

3.3.3 Geology of the Hanging Wall Sequence

Since the genesis of hanging wall sulphide zones (in terms of geological setting, petrography, mineralogy, and geochemistry) is the principal objective of this dissertation, these sulphide zones will be discussed in detail in the following chapters.

CHAPTER 4: GEOLOGICAL SETTING OF THE HANGING WALL SULPHIDE ZONES

4.1 Introduction

The major objectives of core logging, drill hole correlation, and mine map compilation were to:

- i)* establish a stratigraphic and structural framework for the hanging wall sulphide zones, and use the available sedimentary marker units to assist in stratigraphic analysis;
- ii)* determine the environment of deposition of sulphide ores and host meta-sedimentary rocks; and,
- iii)* determine the spatial distribution of the related hydrothermal alteration zones.

4.2 Methodology

Cominco mine plans, sections, and diamond drill hole data were compiled and evaluated in order to select appropriate drill holes for re-logging. Out of a total of 300 drill logs that were examined in a reconnaissance manner, core from seventeen drill holes was selected for detailed study. The drill core from these 17 holes was re-logged in order to record information such as changes in lithology, sedimentary structures and textures, grain size, mineralogy, and ore textures. Of the remaining drill holes that were not re-logged, approximately 78 were used to provide information on regions of the hanging wall that were sparsely covered by the re-logged drill holes. These 78 drill holes also provide valuable assay data that are used in Chapter 6. All of these data were recorded on-site directly into PC-compatible databases (MS-Excel or MS-Word) or graphic logs (Corel Draw) using a laptop computer.

4.3 Stratigraphy and Sedimentology

The hanging wall of the Sullivan deposit consists of five graded meta-sedimentary sequences called, in ascending stratigraphic order, I, H, hu, Hu, and U, that overlie the footwall ore zone (Figure 4.1). Each of the sequences consists of a large-scale fining-upward cycle, (although smaller fining- and coarsening-upward cycles are also present), that are interpreted as meta-turbidite deposits (McMechan, 1981; Hamilton *et al.*, 1982). McMechan (1981) determined that the bedforms present in the Lower Aldridge Formation correspond to the C-E turbidite facies of Bouma (1962) (Figure 4.2). However, this study shows that the hanging wall bedforms consist of the A to E turbidite facies. The A facies consists of a thin basal unit of normal or reverse graded to massive quartzite to quartzitic psammite, which grades locally into a succession of interlayered and convoluted psammite to semi-pelite, representing the B-C facies. More typically the A facies rapidly grades into a thick succession of laminated, convoluted to massive semi-pelite, representing the D facies. The upper beds of the D facies are commonly interlayered with pelite. The upper part of the turbidite sequence, the E facies, is marked by a succession of massive to foliated pelite. The total thickness of the hanging wall meta-sedimentary rocks ranges between 20-55 metres (60-180 feet), and these rocks thicken to the east in an arcuate pattern following the transition zone.

4.3.1 Hanging Wall Meta-sedimentary Sequences

The transition between the footwall D sulphide band and base of the I sequence, the lowermost of the hanging wall sequences, is marked by a thin (generally <2 metres) pyrrhotite-rich semi-pelite to pelite, that is overlain by the I quartzite/psammite. Although the I quartzite is only a few centimetres thick, its lateral continuity and composition (with medium- to coarse-grained quartz grains with porphyroblastic garnet and biotite) enable it to be a useful datum for

Figure 4.1. Idealized stratigraphic section through the hanging wall of the Sullivan orebody (not drawn to scale). Thickness measurements obtained from drill cores used for this study.

Unit		Description
E		Pelagic mud
D		Interlaminated silt and mud
C		Cross-stratified silt and sand
B		Planar laminated sand
A		Massive to graded sand and gravel

Bouma Model

Unit		Description
E		Massive to foliated pelite
D2		Interlayered semi-pelite and pelite
D1		Massive to layered semi-pelite
B-C		Intercalated psammite and semi-pelite
A		Massive to graded quartzite to quartzitic psammite

Hanging wall - Sullivan Deposit Model

Figure 4.2. A comparison of the turbidite model of Bouma (1962) with that of the hanging wall meta-sedimentary sequences.

stratigraphic correlation. The I sequence thickens to the east, from 2 to 16 metres (7-25 feet). Hamilton *et al.* (1982) reported that outside the economic limit of the Sullivan orebody the I sequence gradually thins to the east.

Overlying the I sequence is the basal quartzite to quartzitic psammite of the H sequence. The quartzite unit grades upwards into semi-pelite and pelite. The H sequence is laterally discontinuous, ranges in thickness between 0 and 25 metres (0-77 feet), and thins to the southeast. Hamilton *et al.* (1982) describe the occurrence of a thin (<5 metres) sporadic meta-conglomerate (which was not encountered during core logging for this study) occurring in the upper part of the H sequence

The Hu sequence directly overlies the H sequence, except locally where the hu sequence occurs (Figure 4.1). The hu sequence consists of a thin (1-3 m) graded quartzite to pelite unit. The Hu sequence thickens to the east from 5 to 40 metres (15-130 feet) near the eastern margin of Hu sulphide zone. The Hu sequence consists of a basal unit of fine- to medium-grained quartzite to quartzitic psammite that grades into the overlying semi-pelites and pelites.

The U sequence is defined by a series of quartzite to psammite beds interlayered with semi-pelite. Cominco geologists consider the U quartzite marker unit to represent the Lower-Middle Aldridge Formation contact (*c.f.* Hamilton *et al.* 1982). The U sequence contains no substantial occurrences of economic sulphides (Hamilton *et al.* 1982).

4.3.2 Meta-sedimentary Facies

The meta-sedimentary hanging wall rocks can be classified texturally on the basis of grain size into meta-conglomerate, quartzite, quartzitic psammite, semi-pelite, and pelite. This rock classification, which uses metamorphic rock names, is considered to be more appropriate than the pseudo-sedimentary classifications used in mine records and in the literature. The various rock classifications and protoliths are presented in Table 4.1.

Table 4.1. Classification schemes and protoliths for hanging wall meta-sedimentary rocks.

Metamorphic Classification* (this study)	Pseudo-sedimentary/Mine Classification	Sedimentary Protolith
Meta-conglomerate	Conglomerate	Conglomerate
Quartzite	Quartzite	Quartzarenite
Quartzitic psammite	Quartzitic wacke	Quartz wacke
Psammite	Subarkose, arkose, arkosic wacke	Arkose sandstone to grey wacke
Semi-pelite (sorted, coarse-grained variety)	Siltite or wacke	Medium- to coarse grained siltstone
Semi-pelite (poorly sorted, fine-grained variety)	Silty-argillite	Fine-grained siltstone to silty-mudrock
Pelite	Argillite, chloritite	Mudrock

* Based on terms used by Yardley (1989).

Most of the macroscopic structures are considered to be sedimentary, and include: planar laminations/bedding, normal and reverse graded-bedding, cross-bedding, ripple cross-laminations, and slump structures (*e.g.* soft-sediment folds and faults). Typically, the contacts between lithological units are gradational.

Meta-Conglomerate

A sporadic meta-conglomerate unit occurs above the H marker horizon in the eastern and southern parts of the deposit. This unit was not transected in cores examined in this study, although the unit has been described by Hamilton *et al.* (1982). The unit is less than 5 m thick and consists of fragmented meta-sedimentary rock as well as fragmented sulphides, some of which comprise material of ore grade.

Quartzite/Quartzitic Psammite (Meta-Sandstone)

Quartzite consists of well to moderately well sorted, fine- to medium-grained (0.05-0.1 mm) quartz and potassium feldspar grains, which comprise >90 vol% of the rock. The remaining <10% consists of sericitized and less commonly fine-grained chloritized matrix. Quartzitic

psammite consists of poorly to moderately sorted, fine- to coarse-grained (0.05-1 mm) quartz and potassium feldspar. Matrix contents vary between 15-30 vol% and are typically dominated by sericite, although chlorite is more abundant in comparison to quartzite samples. Colour for quartzite and psammite varies from light to dark grey.

The meta-sandstone (a collective term for quartzite and quartzitic psammite) units are typically massive in character, although grading and bedding occur locally. Bedding occurs as alternating colour bands, from grey to maroon to brownish-grey meta-sandstone. Maroon coloured beds are generally enriched in garnet porphyroblasts (<10 vol%), although some samples exhibit a similar coloration due to a relatively high abundance of disseminated sphalerite. Brownish-grey bands reflect the occurrence of intergrown biotite and tourmaline (<20 vol% combined). The meta-sandstone units are commonly intercalated with or grade into semi-pelite.

Semi-pelite

Semi-pelite rocks are the most voluminous lithology that occurs in the hanging wall. On the basis of grain size and sorting, semi-pelitic rocks can be subdivided into: *i*) moderately well to well sorted, coarser grained (<0.5 mm) semi-pelite; and *ii*) a poorly sorted, finer grained (<0.1 mm) semi-pelite. Colour varies from light to very dark grey or dark greenish grey, depending on the chlorite content.

The semi-pelite units are typically massive, although laminations and bedding occur locally. In a manner similar to the meta-sandstones, bedding is characterized by alternating biotite and tourmaline-rich beds with less altered beds. Laminae are defined by finely disseminated sulphides, primarily pyrrhotite, and by fine-grained chlorite. Soft-sedimentary deformation features are common. A vague to moderately well developed foliation occurs in

fine-grained, chloritic semi-pelite. Coarser-grained semi-pelite typically grades into poorly sorted semi-pelite, which subsequently grades into pelite.

Sulphides, primarily pyrrhotite with subordinate sphalerite, compose <10 vol% of the rock and commonly occurs as disseminations, but may be found as laminae and in veins. Pyrite porphyroblasts are typically more abundant (up to 10 vol%) in poorly sorted semi-pelites than in the coarser grained variety.

Pelite

Pelitic rocks are dominated by either chlorite or sericite alteration of clay minerals. Pervasively chloritized samples are referred to as "chloritites" (according to mine classification, Table 4.1). Sericite-dominated samples are uncommon, and are typically more abundant at higher stratigraphic levels (above hu). The colour varies from dark grey to dark greyish green.

The pelites are massive to well foliated, with fabric controlled by chlorite grain texture. Massive samples consist of radiating masses or ribbons ("bow ties") of acicular chlorite that are randomly oriented; whereas in the foliated rocks the foliation planes are defined by the parallel alignment of acicular chlorite. Sericite-dominated samples lack any internal fabric. Pelitic rocks are commonly interbedded with semi-pelite. Interbedded samples typically contain soft-sediment deformation structures. Other sedimentary structures (e.g. ripple cross-laminations) are rare.

Sulphides (<10 vol%) include pyrrhotite with subordinate sphalerite, which occur as disseminations and in veins. Pyrite occurs as euhedral porphyroblasts that are randomly distributed throughout the rock, or occur along foliation planes, and in veins.

4.4 Sulphide Zones

4.4.1 Spatial Distribution of Sulphides

Extensive zones of massive to layered sulphides are hosted within the finer-grained meta-sedimentary units (D-E facies, see above) of the I, H, and Hu sequences (Figure 4.1, 4.3, and 4.4). These sulphide zones are referred to as the I laminations, H "ore" and Hu ore, respectively. The majority of the sulphide occurrences in the hanging wall are not of ore grade and/or tonnage, with the following exceptions: *i*) regions of the Hu sulphide zone along the transition zone; and *ii*) a small region of the H sulphide zone in the southern part of the orebody (Hamilton *et al.*, 1982).

The sulphides in the hanging wall are laterally distributed in the following manner (Figure 4.5 and 4.6): *i*) as an arcuate band of concordant to discordant sulphide bodies following the crescent-shaped trend of the transition zone; and *ii*) as a series of stratiform/stratabound lenses situated north of the tourmalinized breccia bodies (*i.e.* feeder-vent complex, see Paakki *et al.*, 1995). All three sulphide zones in the hanging wall overlie, or are proximal to north-trending breccia zones (Figure 4.7). These breccias consist of altered clasts of host rock suspended in a matrix composed of hydrothermal silicates and sulphides. The breccia zones are likely the product of hydrothermal fluid up-flow responsible for the formation of sedimentary sulphides. Laterally discontinuous pods of hanging wall sulphide also overlie breccia bodies along the western edge of the Sullivan deposit; however, sulphides from this latter area were not included in this study due to the lack of drill hole exposure and difficulties in correlation over the vent complex.

Figure 4.8 shows the footwall trace of structural features which extend up into the hanging wall. Stratabound-stratiform lenses of hanging wall sulphides that lie north of the vent complex are truncated to the west by the eastern arm of the Sullivan fault, and to the east by the

Figure 4.5. Distribution of hanging wall sulphide zones and collar locations of drill holes selected for re-logging, Sullivan orebody (based on mine records). Sections A-A' and B-B' correspond to Figures 4.3 and 4.4, respectively.

Figure 4.6. West-east cross-section at 11600N showing distribution of hanging wall sulphides (after Hamilton *et al.*, 1982). Inset illustrates the discordant Hu sulphide structure located along the transition zone (from mine records).

Figure 4.7. Distribution of breccia zones with respect to hanging wall sulphide zones (modified after Hamilton *et al.*, 1982).

Figure 4.8. Structural features of the Sullivan orebody (after Hamilton *et al.*, 1982).

No. 2 fault. The arcuate band of sulphides along the transition zone is bounded to the west by the Burchett, Main Water Course, and No. 2 faults. Along the eastern flanks of the deposit, the sulphides roughly follow the trace of the transition zone, although the I and H sulphide horizons south of 10600 N are not limited by these features and extend laterally to the southeast and west. Faults and folds that cross-cut sulphide horizons have resulted in the local offset, thickening, and thinning of sulphides.

4.4.2 Textures and Structures of Sulphide Mineralized Units

4.4.2a I Laminations

The sulphide zone termed the I laminations (Plate 4.1) consist of interlaminated sulphide and quartzo-feldspathic layers which are laterally continuous across the north-south extent of the transition zone. This sulphide zone varies in thickness from < 1 to 11 m (1-35 ft), thinning outward in a concentric fashion from several north- to northwest-trending “high” points which are situated over the centre of the north-trending footwall breccia bodies (Figure 4.9). Thinning of the zone of I laminations corresponds to regions where the footwall breccia: *i*) extends to high stratigraphic level within the footwall, or *ii*) cross-cuts the hanging wall stratigraphy. Sulphide laminae within this zone range from 1 to 5 mm in thickness, with silicate bands ranging between 1 mm and 1 cm within laminated horizons (Plate 4.1), and up to several metres thick between laminated horizons. Laminae are planar-parallel, although soft-sediment deformation features are evident (Plate 4.1). Even though the hanging wall strata have been affected by regional metamorphism and deformation, the I laminations preserve a wide variety of sedimentary textures. However, minor replacement of sulphide by remobilized pyrrhotite, and by late-stage pyrite, is observed locally. The contacts of the sulphide laminae with silicate bands are sharp and straight, although some sulphide laminae are internally graded and have slightly gradational upper contacts. The contacts with the encompassing host rocks vary from sharp to gradational

Plate 4.1: Laminated sulphide-rich rock from the I sulphide zone (I laminations)

- a: Sample 93-C017, DDH 6839 - 115 ft (35 m)
Lower two-thirds of polished drill core sample consists of planar-parallel, interlaminated pyrrhotite (minor sphalerite) and semi-pelite which is abruptly overlain by a zone of soft-sediment folded interlaminated pyrrhotite and semi-pelite. Note the undeformed pyrite that cross-cuts the soft-sediment deformed zone.
- b: Sample 93-C018, DDH 6839 - 119 ft (36.3 m)
Representative polished drill core sample of the I laminated sulphide zone consisting of finely interlaminated pyrrhotite and semi-pelite/pelite. Note the wide lamination of recrystallized pyrrhotite in the centre of the sample.
- c: Sample 93-C020, DDH 6839 - 120 ft (36.6 m)
Polished drill core sample consisting of remobilized and recrystallized pyrrhotite that destroys the typical interlaminated nature of the I sulphide zone.
- d: Sample 93-C022, DDH 6839 - 121.3 ft (37 m)
Representative polished drill of the I laminated sulphide zone consisting of finely interlaminated pyrrhotite and semi-pelite/pelite.

Figure 4.9. Three-dimensional isopach map of the I sulphide zone (thickness is measured in feet). View is from the north, looking south.

(over a few tens of centimetres). Sulphide minerals include, in order of decreasing abundance: pyrrhotite, sphalerite, pyrite, galena, and chalcopyrite. The quartzo-feldspathic bands have similar compositions to the encompassing meta-sedimentary host rocks.

4.4.2b H “ore”

The H sulphide zone (commonly referred to as the H “ore”) is a laterally discontinuous zone consisting of stratiform to stratabound lenses of laminated, bedded, and massive sulphide (Plate 4.2). Laminated and bedded units are commonly intercalated with silicate bands, with the latter accounting for <25% of the rock. The sulphides in the H sulphide zone commonly exhibit evidence of extensive remobilization and replacement of primary sulphides and host rocks by pyrrhotite and pyrite. Sulphide mineralogy is variable and dependent upon location: H sulphide zone from the southern part of the hanging wall consists of >50% sphalerite with subordinate pyrrhotite, pyrite, galena, chalcopyrite, and arsenopyrite; H “ore” sampled from the central and northern areas is dominated by pyrrhotite, with <20% sphalerite, whereas the other sulphide minerals have abundances similar to those found in the southern part. The thickness of the H sulphide zone varies from <1 to 5 m (1-15 ft), and the unit thins in a concentric fashion from DDH 5063 outwards (Figure 4.3-4, 4.10). However, the sporadic distribution of the H sulphide zone and lack of drill hole intersections make it difficult to determine precisely the nature of its lateral variation. The H “ore” sulphides have been extensively modified by tectonic events resulting in the development of complex fold patterns, remobilization of sulphides, and ductile deformation of sulphides (*e.g.* durchbewegung structures, see below).

4.4.2c Hu ore

The Hu sulphide zone (referred to in the literature as the Hu ore) is the largest repository of sulphides in the hanging wall. The Hu sulphides are generally stratiform to stratabound, although locally they are discordant in character. The Hu sulphide zone varies from being

Plate 4.2: Laminated to banded sulphides from the H sulphide zone (H “ore”)

- a: Sample 93-C083, DDH 4501 - 223 ft (69 m)
Polished drill core sample with a basal zone of disseminated to weakly laminated pyrrhotite in pelite which grades into interlaminated pyrrhotite with minor pyrite and pelite.
- b: Sample 93-C154c, DDH 5063 - 193.3 ft (58.9 m)
Polished drill core sample of planar laminated sphalerite, pyrrhotite, and galena zone that is overlain by chloritized semi-pelite. Samples shows minor replacement of base metal sulphides by euhedral pyrite associated with the cross-cutting vein in the semi-pelite portion of the sample. Note that the pyrite at the top of the sample is distributed along the sulphide - semi-pelite contact.
- c: Sample 93-C156b, DDH 5063 - 197.2 ft (60.1 m)
Polished drill core sample of weakly folded banded to wispy sphalerite and galena that is overlain by extensively pyritized chlorite altered pelited. Note that the pyrite in the chloritic rock is distributed along cleavage planes producing a laminated appearance.

Figure 4.10. Three-dimensional isopach map of the H sulphide zone (thickness is in feet)
View is from the north, looking south.

pyrrhotite- to sphalerite-rich, although ores are typically more Zn-rich than either the I or H sulphide zones. The Hu sulphides form a series of discontinuous pods/lenses that extend along the transition zone and north of the vent complex (Figure 4.3 and 4.4). Sulphide thicknesses vary from 0.5 to >5 m (1.5-18 ft), with sulphides thinning outward in all directions along the transition zone in a manner similar to that observed for the I sulphide zone (Figure 4.11). Sulphides within the Hu ore zone typically consist of >50% pyrrhotite or sphalerite with minor to trace contents of pyrite, galena, chalcopyrite, and arsenopyrite. The sulphides can be subdivided on the basis of macroscopic textures into the following types (Plate 4.3): *i*) laminated sulphide; *ii*) bedded or banded sulphide; *iii*) interlayered sulphide and waste rock; *iv*) massive sulphide; and, *v*) colloform banded sulphide (?). Massive ore shows extensive evidence of deformation that includes the development of *durchbewegung* structures. *Durchbewegung* structures form in response to the progressive effects of tectonic processes such as detachment, dismemberment, fragmentation, rotation, and milling of competent wall rock in a flowing mass of ductile sulphide (Vokes, 1969, 1973). *Durchbewegung* structures observed in the hanging wall consist of silicate rock and pyrite clasts suspended in a matrix of primarily pyrrhotite or sphalerite. A single sample of relict colloform banded sulphide (93-C120f) is the only evidence of primary sulphide deposition, although even in this case the original texture has been modified somewhat. Extensive remobilization of sulphides, primarily galena, and the recrystallization and replacement of primary sulphides by pyrrhotite and pyrite are common within the Hu sulphide zone. Contacts with the encompassing meta-sedimentary host rocks are generally gradational and are defined by an increase in the abundance of disseminated sulphide grading into interlayered sulphides.

The Hu sulphide zone has an internal stratigraphy that is generally consistent throughout the hanging wall. The base of the zone is marked by disseminations of sphalerite and

Figure 4.11. Three-deminsonal isopach map of the Hu sulphide zone (thickness is in feet)
View is from the north, looking south.

Plate 4.3: Laminated, banded, durchbewegt, and massive sulphides from the Hu sulphide zone (Hu ore)

- a: Sample 93-C120c, DDH 3994 - 91.2 ft (27.8 m)
Polished drill core sample of durchbewegt sulphide consisting of poorly laminated to wispy pyrrhotite and sphalerite with granulated to interlaminaed quartzofeldspathic material.
- b: Sample 93-C110d, DDH 3976 - 81 ft (24.7 m)
Polished drill core sample of banded sphalerite with minor galena and intercalated quartzofeldspathic material.
- c: Sample 93-C098, DDH 3952 - 136 ft (41.5 m)
Polished drill core sample of durchbewegt sulphide consisting of chloritized pelite clasts in a matrix of massive pyrrhotite.

pyrrhotite (with a combined abundance of up to 40%) in semi-pelite to pelite. This unit grades into interlaminated sulphide and fine-grained meta-sedimentary rock. Sulphide laminae are up to 5 mm thick and vary locally from planar parallel to convoluted in form. Overlying the interlaminated sulphides is an interval of massive sulphide, typically displaying *durchbewegung* structures. The massive zone then changes into a banded sulphide unit, consisting of alternating bands of pyrrhotite with sphalerite and galena. The top of the Hu sulphide zone is characterized by either a semi-pelite/pelite with disseminated sulphides, or a second interlaminated (sulphide and silicate rock) zone. The thickness of each unit is variable, although the massive and banded zones typically account for more than 50% of the stratigraphic thickness of the Hu sulphide zone.

Discordant Sulphide Structures

Along the transition zone Hu ore occurs as discordant to concordant sulphide bodies. Laterally, the discordant bodies are discontinuous lenses that are situated between 10000N and 12000N (Figure 4.3). Outside of this area the sulphides are stratiform to stratabound in nature. The discordant structures have an anticlinal form consisting of a steep westerly dipping discordant zone and a moderate to gentle easterly dipping stratiform to stratabound zone (Figure 4.6). The discordant zone consists of convoluted folds of *durchbewegung* sulphides (see above) and altered wall rock. The sulphides of the discordant zone consist of a complex mixture of remobilized sulphide from the main ore zone and Hu ore horizon, which results in higher Pb and Zn grades in comparison to the concordant zones (see Chapter 6). The contact between main ore zones/footwall and hanging wall sulphides is obliterated in the discordant zone. The stratiform to stratabound zone consists of layered to massive Hu sulphides that exhibit little evidence of deformation. Hanging wall stratigraphy is generally preserved within the conformable zone; however, the basal quartzite marker units are rarely identifiable, proximal to, or within the discordant zone.

4.4 Distribution of Wall-rock Alteration

Wall-rock alteration is classified, following the mine classification scheme, on the basis of the dominant alteration mineral. The most abundant alteration minerals are albite, chlorite, tourmaline, and muscovite. Typically these minerals form disseminated to patchy zones of alteration, although more extensive zones of massive albite $\pm$ sulphide, albite + chlorite $\pm$ pyrite, chlorite + pyrrhotite, and tourmaline alteration also occur in the hanging wall. These latter alteration assemblages form zones that are: *i*) unique in their distribution and spatial association with the hanging wall sulphide zones; and *ii*) clearly related to cross-cutting fractures and discordant breccia bodies. In contrast, muscovite alteration is widespread and does not form discrete mappable zones. Furthermore, muscovite alteration is only accurately identified in thin section, although some hand samples do tend to have a bleached appearance. The following section discusses the distribution and nature of these alteration zones; their petrographic and chemical characteristics will be discussed in the following chapters. The spatial distribution of the above mentioned alteration zones are schematically illustrated in Figure 4.12.

Tourmaline Alteration

Tourmaline alteration of hanging wall meta-sedimentary rocks occurs in two forms: *i*) discrete massive "tourmalinite" zones (>80 vol% tourmaline) associated with the breccias of the vent complex; and *ii*) more laterally extensive disseminated zones (<20 vol% tourmaline). The intensity of tourmaline alteration decrease outward from the vent complex breccias: from massive tourmalinite adjacent to the breccia bodies to disseminated tourmaline in the peripheral regions. Discordant zones of massive tourmaline alteration in the hanging wall are distributed

Figure 4.12. Schematic section through the hanging wall, Sullivan Zn-Pb deposit, showing the spatial distribution and relations of the principal alteration zones (based on this study and Shaw *et al.*, 1993). Section not drawn to scale. Lateral extent of muscovite alteration is unknown due to limited distribution of drill core used for study and the widespread nature of the alteration.

Figure 4.13. Distribution of tourmalinite and tourmaline alteration (modified from Hamilton *et al.*, 1982).

along the perimeters of footwall breccia zones and surround the core of the zone of albite + chlorite $\pm$ pyrite alteration (Figures 4.3-4, 4.13). Disseminated tourmaline alteration zones surround the massive tourmalinite zone, bounded by the western economic limit for the Sullivan orebody to the west and by the transition zone to the east. With maximum north-south and east-west dimensions of 600 metres by 460 metres (2000 feet by 1500 feet), tourmaline alteration in the hanging wall is intermittent over a 50 m stratigraphic interval, extending from the top of the main band to the Hu sulphide horizon (Shaw *et al.*, 1993). In contrast, tourmaline alteration in the footwall is dominated by massive tourmalinite zones that underlie most of the western part of the Sullivan deposit (Figure 4.13 and Figure 3.3), with maximum lateral dimensions of 1470 metres by 980 metres (Shaw *et al.*, 1993) and a vertical extent of at least several hundred metres (based on DDH 6799; W.D. Goodfellow, *personal communication*, 1995). Footwall tourmalinites appear to have cross-cutting, conformable, and transgressive relations with the main ore zones (Hamilton *et al.*, 1982). The eastern most extent of the footwall tourmalinite is the transition zone, which is coincident with the best representation of hanging wall tourmalinite (Hamilton *et al.*, 1982). While not as volumetrically important as their counterparts in the footwall, hanging wall tourmaline alteration zones are similar in appearance and consist of a very fine-grained, black chert-like rock which is commonly brecciated. Cross-cutting tourmalinite breccias (Figures 4.3-4) consist of angular to round tourmalinized fragments (up to 80 vol%) suspended in a pyrrhotite matrix (typically 20-40 vol%) with subordinate sphalerite, galena, and chalcopyrite, although a siliceous (quartz + sericite or chlorite) matrix occurs locally. A rare buff-coloured or "blonde" tourmalinite is also present in the hanging wall. On the other hand, most tourmaline in the hanging wall occurs as disseminated grains or in small polycrystalline aggregates (<1-2 cm) associated with biotite. Disseminated and patchy tourmaline alteration is distributed erratically throughout the meta-sedimentary rocks of the hanging wall. Within

sulphide zones disseminated tourmaline is rare, although it is common within silicate interlayers (in particular those within the I laminations). Footwall tourmalinite zones are spatially related to the distribution of cross-cutting muscovite + Fe-chlorite + pyrrhotite veins; and therefore, tourmaline alteration is interpreted represent a hydrothermal product (Leitch and Turner, 1992; Leitch *et al.*, 1991).

Albite + Chlorite $\pm$ Pyrite Alteration

Albite + chlorite $\pm$ pyrite (Plate 4.4) alteration forms a cross-cutting alteration zone that extends upwards from the top of the I sequence into the U sequence (up to approximately 80 metres) (Figures 4.3 and 4.4), although it is more abundant at higher stratigraphic levels. Laterally this alteration zone is situated over the central part of the Sullivan orebody, extending to the west past the economic limit for the deposit, and bounded to the east by the transition zone (Figures 4.6 and 4.14), an area with maximum north-south and east-west dimensions of 1200 metres by 760 metres (4000 feet by 2500 feet). The hanging wall albite + chlorite $\pm$ pyrite alteration zone stratigraphically overlies, and extends outward from, the footwall pyrite-chlorite-carbonate zone (see Figure 29 in Hamilton *et al.*, 1982). Albite + chlorite $\pm$ pyrite alteration varies from disseminated to pervasive, forming both concordant and discordant alteration zones. Typically, this alteration is found to replace potassium feldspar and sericite (sedimentary matrix), with the gross sedimentary character of the rock being preserved. Contacts with surrounding hanging wall rocks are gradational.

The core of the hanging wall albite + chlorite $\pm$ pyrite alteration zone consists of nearly massive (>80 vol%) albite that grades outward to more chlorite-rich (>20 vol%) and pyrite-rich rock. The albite core has maximum north-south and east-west dimensions of 550 metres by 460 metres (1800 feet by 1500 feet). The albitized rock that forms the core of albite + chlorite $\pm$ pyrite zone has been termed "albitite", due to the pervasive nature of the alteration and

Plate 4.4: Polished drill core samples from the albite + chlorite $\pm$ pyrite alteration zones

- a: Sample 93-C157b, DDH 5063 - 203.5 ft (62 m)
Polished drill core sample of pervasively albitized pelite with minor chlorite alteration defining original bedding. Large (<0.5 cm) diffuse maroon clots are garnet aggregates.
- b: Sample 93-C158a, DDH 5063 - 210.3 ft (64.1 m)
Polished drill core sample of massive albite (= albitite) with patchy chlorite. Sample is cross-cut by quartz + chlorite + pyrite veins, with the pyrite being distributed along the vein-albite contact.
- c: Sample 93-C159e, DDH 5063 - 223.5 ft (68.1 m)
Polished drill core sample of a diffuse zone of massive albite that cross-cuts moderately chloritized semi-pelite. Sample contains approximately 1 vol% disseminated euhedral pyrite.
- d: Sample 93-C165b, DDH 4483 - 281 ft (85.6 m)
Albitized and chloritized semi-pelite that is cross-cut by a green-chlorite vein (see Chapter 5). Chlorite also occurs in fine fractures throughout the sample.

Figure 4.14. Distribution of albite-chlorite-pyrite/pyrrhotite alteration zones (modified after Hamilton *et al.*, 1982).

predominance of albite. South of the main albitite zone are smaller albitite zones that are spatially associated with the transition zone. Locally, albitites have been extensively fractured and brecciated. Albite alteration has pervasively affected the host sedimentary rock, obliterating many of the primary sedimentary textures and structures. Contacts with albite + chlorite $\pm$ pyrite altered rock are gradational, over several metres, to abrupt.

The zone of albite + chlorite $\pm$ pyrite alteration provides evidence of a hydrothermal event that affected hanging wall rocks. A hydrothermal origin for the alteration is inferred from the destructive nature of the alteration and the occurrence of albite $\pm$ Fe-sulphide, and albite + sphalerite $\pm$ chlorite $\pm$ carbonate veins that cross-cut unaltered and altered hanging wall rocks.

Chlorite + Fe-Sulphide (Pyrite/Pyrrohotite) Alteration

Based on mine records a localized zone of chlorite + pyrrhotite alteration (Plate 4.5) occurs in proximity to sulphides found in the central to western region of the hanging wall (Figure 4.14). This alteration zone is surrounded by an extensive zone of albitite and is not spatially associated with sulphide mineralization. However, examination of drill core indicates that chlorite + Fe-sulphide alteration is more extensive, although not as widespread as muscovite alteration (see below). Unlike muscovite alteration, chlorite + Fe-sulphide alteration zones are irregularly distributed making them difficult to map. Stratigraphically, there is no systematic distribution in the occurrence in chlorite + Fe-sulphide alteration, although this alteration is more common in pelitic units as compared to psammite and semi-pelite units. Zones of chlorite + Fe-sulphide alteration appear to be spatially related to the hanging wall sulphide zones, although the sulphide zones themselves are not extensively affected by this alteration. Unlike tourmaline and albite alteration zones, chlorite + Fe-sulphide alteration is generally not discordant and the overall sedimentary character (*i.e.* bedding) of the rock is typically preserved; although, discordant zones of chlorite + Fe-sulphide alteration is associated with the margin of the

Plate 4.5: Polished drill core samples from the chlorite + Fe-sulphide alteration zones

- a: Sample 93-C080, DDH 4501 - 212.5 ft (64.8 m)
Polished drill core sample of pervasively chloritized pelite (= chloritite) with pyrrhotite (oxidized rims surrounding pyrite) being replaced by euhedral pyrite.
- b: Sample 93-C156f, DDH 5063 - 199.2 ft (60.7 m)
Polished drill core sample of pervasively chloritized pelite (= chloritite) with fine-grained pyrite occurring as disseminations and in veins.
- c: Sample 93-C056, DDH 4495 - 30 ft (9.1 m)
Polished drill core sample of pervasively chloritized pelite (= chloritite) with a high abundance (10-15 vol%) of euhedral pyrite porphyroblasts.

"tourmalinite" breccia bodies. Chlorite contents are up to 80 vol% and sulphide abundances range between 1 and 20 vol%. Texturally, chlorite + Fe-sulphide altered rocks are massive to foliated. Sulphides are typically either pyrite or pyrrhotite, which occur as disseminated grains, porphyroblasts, and mono-mineralic veins; however, minor to trace amounts of sphalerite and galena are observed. Pyrrhotite tends to be finer grained and forms grain aggregates rather than porphyroblasts, unlike pyrite which forms large (up to 1 cm) euhedral grains which in places are observed replacing pyrrhotite.

Evidence of a hydrothermal origin for chlorite alteration is as follows: *i*) the occurrence of chlorite veins which cross-cut altered and unaltered hanging wall meta-sedimentary rocks; *ii*) chloritization of "tourmalinite" breccia matrices; *iii*) the presence of chlorite as a minor constituent in albite + sphalerite veins; and *iv*) significant volumetric increase within the deposit in comparison to regional meta-sedimentary rocks.

Muscovite Alteration

As discussed above, muscovite alteration is widespread throughout the hanging wall and does not form discrete mappable zones. Except for those altered rocks that have a bleached appearance (possible due to higher carbonate contents), muscovite altered rocks are similar in appearance to unaltered Aldridge Formation meta-sedimentary rocks. The degree of alteration is variable and is related to the nature of the protolith, with muscovite contents of <10 vol% in meta-sandstones, 10-20 vol% in semi-pelites, and >20 vol% (up to 80 vol%) in altered pelites. The muscovite content of altered hanging wall rocks shows no systematic variation in comparison to regional meta-sedimentary rocks. In contrast, footwall rocks display extensive zones of muscovite alteration that underlie ore stratigraphy, indicating a widespread potassium alteration event (Bishop, 1976; Shaw and Hodgson, 1980; Leitch and Turner, 1992; Shaw *et al.*, 1993). Muscovite alteration of hanging wall rocks results in the pervasive alteration of the

sedimentary matrix; and therefore, is likely a hydrothermal transformation of precursor diagenetic clays or early low-temperature hydrothermal phase(s) (*i.e.* illite, smectite-group minerals) and forms in response to the breakdown of detrital feldspars. Within hanging wall sulphide zones, muscovite alteration is principally restricted to the quartzo-feldspathic waste bands.

Muscovite is interpreted to be a hydrothermal phase based on its occurrence: *i*) in albite + sphalerite veins that cross-cut altered and unaltered hanging wall rocks (this study); *ii*) as muscovite + Fe-chlorite + pyrrhotite veins that cross-cut footwall "tourmalinite" (Leitch and Turner, 1992; Leitch *et al.*, 1991); and, *iii*) as alteration envelopes around pyrrhotite + sphalerite + galena + Fe-carbonate veins that cross-cut footwall "tourmalinite" (Leitch and Turner, 1992). Furthermore, the association of muscovite with albite + chlorite $\pm$ pyrite altered rocks and chlorite + Fe-sulphide altered rocks supports a hydrothermal origin.

4.6 Effects of Metamorphism and Deformation

Even without the benefit of petrographic analysis, there is clear evidence in drill core for the effects of deformation and metamorphism. For example the localized remobilization of sulphide (in particular galena), growth of garnet and biotite porphyroblasts, attenuation of disseminated sulphides and subsequent replacement by euhedral pyrite, presence of small-scale tectonic faults and folds, and development of foliation in pelitic rocks all attest to the effects of metamorphism and deformation.

The deformation history of the Sullivan deposit is discussed in detail by McClay (1983). The location of the major structural features identified by McClay (1983) is presented in Figure 4.8. Syntectonic deformation structures are rarely observed and consist primarily of convoluted slump-folds within intercalated sulphide and fine-grained meta-sedimentary rocks

which formed in response to sediment loading and dewatering. Soft-sedimentary faults are observed in unmineralized meta-sedimentary units, but are extremely rare.

The majority of deformation structures are tectonic in origin. McClay (1983) has recognized three phases of folding. Phase 1 folds are isoclinal, weakly east verging, and are restricted to ore bands primarily within the transition zone. McClay (1983) suggested that during phase 1 deformation sulphides from the main ore zone behaved in a ductile manner, with the ore zone acting as a décollement surface allowing the more silicate-rich and brittle hanging wall to be displaced over the footwall. Chlorite slickensides, grooving, and mineral stretching lineations on bedding slip and fault planes show movement directions to the north-northeast (McClay, 1983). The direction of movement corresponds to the displacement of the massive albitite zone in the hanging wall approximately 240 to 300 m northward relative to the of the centre of the pyrite-carbonate alteration in the main ore zone (McClay, 1983). However, Paakki *et al.* (1995) estimated displacement to be less than 150 m southwards, based on the displacement of gabbro dykes. Therefore, the pre-displacement upward continuation of the pyrite core is in the albite-chlorite-pyrite rock of the hanging wall, rather than in the massive albitite (Paakki *et al.* 1995).

Phase 2 deformation represents a continuation of phase 1 deformation and resulted in the refolding of phase 1 structures (McClay, 1983). Phase 2 also consisted of thrust faulting, producing east-verging folds that correspond to the regional fabric (McClay, 1983). Phase 3 folding is related to thrust faulting and deformation of earlier structures (McClay, 1983).

Several occurrences of normal and thrust faulting post-dated ductile deformational events. West-dipping, east-verging thrust faults in the footwall commonly extend into the hanging wall (*e.g.* Jonel thrust). Large-scale overturned folds are common in the hanging wall of these thrust faults. Late-stage normal or "Sullivan-type" faults cross-cut earlier deformation features and result in localized thickening and repetition of hanging wall ores (McClay, 1983).

Within the hanging wall the aforementioned deformation structures are localized, and therefore, the stratigraphic relationships observed in the hanging wall represent those of the initial stratigraphy at the time of deposition. The most prominent tectonic feature observed during core logging were normal faults that generally offset stratigraphy only by a few metres. While drill hole correlation (Figures 4.3 and 4.4) show these offsets, there has been no attempt to ascertain the direction of movement or displacement along these faults. Furthermore, these correlations imply that the various hanging wall sulphide zones are generally planar-tabular bodies; however, this is an over simplification for evaluation of detailed mine sections indicate that the sulphides zones have been folded to varying degrees. Whilst the vast majority of these folds are upright (*i.e.* stratigraphy is preserved), there are regions of the hanging wall where the folds have been overturned (see Figure 4.8); however, the lack of any substantial sulphide mineralization associated with these regions did not warrant further study.

CHAPTER 5: PETROGRAPHY AND MINERALOGY OF HANGING WALL ROCKS

5.1 Introduction

The primary objectives of hand sample and thin section analysis of hanging wall rocks were to:

- i)* determine the modal abundance and textural attributes of sulphide and non-sulphide minerals;
- ii)* document sulphide and hydrothermal mineral assemblages; and,
- iii)* document the distribution of sulphide and hydrothermal alteration minerals within the hanging wall meta-sedimentary units, sulphide zones, and hydrothermal alteration zones

5.2 Methodology

The petrography, mineralogy, and textural relationships of hanging wall rocks were determined from an analysis of 450 diamond drill core samples, and 180 thin sections using transmitted and reflected light microscopy. Extremely fine-grained samples whose mineralogy was not readily identifiable by petrographic techniques were analysed by powder X-ray diffraction. Trace minerals and micro-textural relationships were identified by scanning electron microscopy.

5.3 Meta-sedimentary Facies

Original grain textures have been overprinted by hydrothermal alteration and regional metamorphic events, resulting in the extensive recrystallization of framework grains and replacement of the original sedimentary matrix. Macroscopic structures are considered to be sedimentary, and include: parallel laminations/bedding, graded-bedding, normal and reverse

grading, cross-bedding, ripple cross-laminations, and slump structures (*e.g.* soft-sediment folds and faults). Typically, contacts between lithological units are gradational.

The petrography and mineralogy of meta-sedimentary lithological units are summarized in Tables A2.1-2.6 (refer to Appendix 2). It is important to note that there is no stratigraphic variation in mineralogy.

5.3.1 Quartzite/Quartzitic Psammite (Meta-Sandstones)

Quartzite consists of well to moderately well sorted, fine- to medium-grained (0.05-0.1 mm) quartz and potassium feldspar composing >90 vol% of the rock. The remaining 10% consists of sericitized and less commonly fine-grained chloritized matrix as well as other hydrothermal and metamorphic products, including tourmaline, biotite, clinozoisite, and garnet. Quartzitic psammite consists of poorly sorted to moderately sorted, fine- to coarse-grained (0.05-1 mm) quartz and potassium feldspar. Matrix contents vary between 15-30 vol% and are typically dominated by sericite, although chlorite is more abundant in psammites as compared to quartzites. Colour for quartzite and psammite varies from light to dark grey.

The quartz and potassium feldspar that compose the framework exhibit undulose extinction and have been extensively recrystallized producing a polygonal grain texture. Fine-grained (<0.1 mm) disseminated sulphide, primarily pyrrhotite, accounts for <10 vol% of the meta-sandstones. Euhedral pyrite porphyroblasts account for <1 vol% of the rock. Clinozoisite is commonly intergrown with sulphide. Anhedral to euhedral carbonate (Mn-calcite) infills vugs, bedding plane porosity and occurs in veins. Trace amounts of detrital (?) zircon are distributed throughout the matrix.

5.3.2 Semi-pelite

Semi-pelite rocks are the most voluminous of the meta-sedimentary rock types that comprise the hanging wall. They are typically composed of recrystallized quartz and potassium

feldspar in a fine-grained sericite- or chlorite-rich matrix. On the basis of grain size and sorting, semi-pelitic rocks can be subdivided into: *i*) moderately well to well sorted, coarser grained (<0.5 mm) semi-pelite; and, *ii*) a poorly sorted, finer grained (<0.1 mm) semi-pelite. Colour varies from light to very dark grey or dark greenish grey, depending on the chlorite content.

The quartz and potassium feldspar framework grains account for 30-70 vol% of the rock, with coarser-grained semi-pelites generally having higher framework contents. A chloritic matrix is more typical of finer-grained samples. The matrix of coarser-grained and sorted samples consists of <20 vol% sericite or $<<20$ vol% chlorite, whereas finer-grained semi-pelite may contain up to 50 vol% sericite or chlorite. Sulphides, primarily pyrrhotite with subordinate sphalerite, compose <10 vol% of the rock and commonly occur as disseminations, but also may be found as laminae and in veins. Pyrite porphyroblasts are typically more abundant (up to 10 vol%) in poorly sorted semi-pelites than in their coarser grained equivalents. Carbonate infills secondary porosity and veins. The matrix is variably altered to clinozoisite, coarser-grained white chlorite, muscovite, biotite, tourmaline, garnet, and albite.

5.3.3 Pelite

Pelitic rocks are typically composed of >70 vol% fine-grained (<0.05 mm) acicular chlorite, which is an alteration of the original sedimentary matrix. Due to the high chlorite content, these rocks have commonly been referred to as "chloritites". Sericite-dominated samples generally are uncommon, although they become more abundant at higher stratigraphic levels (above *hii*). Fine-grained ($<<0.01$ mm) quartz and potassium feldspar are not readily observed due to the pervasive nature of the chlorite and sericite alteration. Colour varies from dark grey to dark greyish green.

Other minerals account for <20 vol% of the rock and include muscovite, coarse-grained chlorite, biotite, tourmaline, clinozoisite, and albite. Sulphides (<10 vol%) include pyrrhotite

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with subordinate sphalerite, and occur as disseminations and in veins. Pyrite occurs as euhedral porphyroblasts that are randomly distributed throughout the rock, along foliation planes, and in veins.

5.4 The Nature and Distribution of Sulphide Minerals

5.4.1 Introduction

No attempt has been made to discuss the petrographic features of the sulphide minerals in the context of the three major hanging wall sulphide zones, because there is no evidence of any significant textural variation amongst the three sulphide zones. In fact the only major difference is in terms of the relative abundance of the sulphide minerals. Below, sulphide minerals are discussed in terms of their modal abundance, grain-size, crystallinity, texture, distribution, and relationship to hydrothermal alteration zones.

5.4.2 Pyrrhotite

Pyrrhotite (Plates 5.1 and 5.2) is the most abundant sulphide mineral in the hanging wall: abundances range between 20-50 vol% in bedded sulphide and intercalated units, >80 vol% in massive sulphide, and <20 vol% (typically <10 vol%) in meta-sedimentary rock. Pyrrhotite occurs as anhedral to euhedral grains, ranging from <0.01-0.5 mm in size. Two crystal habits are observed: *i*) tabular crystals are not uncommon and are often aligned parallel to bedding, typically in the finely laminated sulphide units; and *ii*) equant grains which show evidence of recrystallization, in the form of polygonal outlines, although there is no evidence of significant remobilization, and occur in all of the hanging wall rocks. Both forms of pyrrhotite are intergrown with sphalerite and chalcopyrite within hanging wall sulphide zones. Pyrrhotite forms laminated to banded units with sphalerite $\pm$ galena in sulphide-rich rock, and occurs in massive sulphides, as disseminations in meta-sedimentary rocks, and in veins. Pyrrhotite is

spatially associated with tourmaline alteration, forming the matrix (with subordinate sphalerite, galena, and chalcopyrite) of tourmalinite breccias. It is also commonly associated with chlorite and albite + chlorite alteration zones (see Chapter 4), although in the latter it is not as abundant as pyrite and its distribution is more localized.

5.4.3 Sphalerite

Sphalerite (Plates 5.1 and 5.2) abundance is variable, typically between 20-50 vol% in pyrrhotite-dominated sulphide-rich rock, up to 80 vol% in ore grade rock, and <<10 vol% in meta-sedimentary units. Sphalerite abundance increases stratigraphically upwards within the different sulphide zones. Sphalerite occurs as anhedral to subhedral grains, which typically range in size from <0.01-0.5 mm, but may obtain sizes >1 mm. Grains are equant to slightly elongate, with a weak alignment to bedding. Sphalerite grains show some evidence of recrystallization, but do not exhibit the well-developed polygonal texture associated with pyrrhotite. Optically, grains are dark red to reddish brown, contain intragranular fractures and do not exhibit any internal zonation. The corrosion of sphalerite aggregates by galena is common. The inclusion of other sulphides (primarily pyrrhotite) within sphalerite is common. Within sulphide zones, sphalerite forms laminated-bedded to massive sulphide units (with pyrrhotite and galena) and intercalated sulphide-silicate units (*i.e.* 1 laminations). In meta-sedimentary rocks, sphalerite occurs as disseminations and in albite + sphalerite and quartz + sphalerite veins. Sphalerite is commonly disseminated throughout muscovite and tourmaline altered rocks, but is generally absent within albite + chlorite altered rocks.

5.4.4 Galena

Galena (Plate 5.1 and 5.2) is an accessory sulphide phase in the hanging wall. Its abundance is typically <1 vol% in the meta-sedimentary rocks, but ranges up to 10 vol% in sulphide-rich rocks where the galena content increases stratigraphically upwards. The absence of

distinct grain boundaries, and the curvature of triangular cleavage pits are evidence of the extensive deformation and recrystallization of galena. Galena is commonly observed replacing and cross-cutting sphalerite and to a lesser extent pyrrhotite. Within sulphide-rich rock it occurs as bleb-like to dendritic masses infilling intragranular fractures (primarily in garnet), bedding plane porosity, intergranular porosity, and in albite + sphalerite veins (rare); although massive beds of galena within the H and Hu sulphide zones are not uncommon. Galena also occurs as very fine-grained (<0.01 mm) disseminations in meta-sedimentary rock. Galena distribution is directly proportional to the sphalerite content of the rock. Galena is primarily restricted to the hanging wall sulphide zones and is not spatially associated with alteration zones, except for the tourmalinite breccias whose clasts contain finely disseminated galena.

5.4.5 Pyrite

The abundance of pyrite (Plate 5.1 and 5.2) is generally <1 vol%, although can be as high as 30 vol%. While abundances are highly variable for all hanging wall rocks, pyrite is generally more abundant in the sulphide zones. Euhedral pyrite occurs as porphyroblasts in sulphide-rich rock, chlorite and albite + chlorite altered rock, and meta-sedimentary units. Pyrite forms cubes ranging between 0.1-2 mm in size, that typically cross-cut or replace other sulphide (primarily pyrrhotite) and aluminosilicate minerals: rounded inclusions of pyrrhotite, sphalerite, and galena, are quite common in the pyrite. Pyrite is generally distributed along bedding and cleavage planes, although in some places it is randomly distributed throughout the rock. Pyrite is also a common constituent of quartz - sphalerite and albite - sphalerite veins (see below). Pyrite shows a common spatial association with areas of pervasive albite and chlorite alteration.

5.4.6 Other Sulphides and Sulpharsenides

Chalcopyrite

Trace amounts (*i.e.* <1 vol%) of chalcopyrite occur as anhedral masses (<0.1 mm) along sulphide grain boundaries, as inclusions in pyrite, and as fracture-infillings. Although chalcopyrite forms inclusions in sphalerite, it does not occur as an exsolution phase. Chalcopyrite is most abundant in pyrrhotite-rich samples.

Arsenopyrite

Arsenopyrite (Plate 5.1) is typically a trace sulphide, but is locally abundant within tourmalinized breccias (up to 20 vol%) and within the H sulphide zone (5-10 vol%). It occurs principally as individual euhedral grains (<0.5 mm) replacing pyrrhotite and sphalerite, but also forms anhedral masses. Unlike pyrite, arsenopyrite appears to be restricted to the sulphide zones.

Tetrahedrite and Boulangerite

Minor amounts of tetrahedrite and boulangerite were identified only in sulphide-rich rocks from the Hu ore zone. Due to their low abundances and extremely fine grain size (<250 μm) petrographic determinations were not possible and these minerals were identified with scanning electron microscopy. Tetrahedrite occurs as anhedral grains and is intergrown with galena. Boulangerite (Pb-Sb sulphide) occurs as anhedral to subhedral grains intergrown with galena and pyrrhotite. Grains intergrown with pyrrhotite are commonly zoned from a boulangerite core to a very fine, discontinuous rim of berthierite or gudmundite (Fe-Sb sulphide). Identification of the very fine-grained rare sulpharsenides was extremely difficult due to the minerals having similar appearances to the major sulphides in backscattered electron images (*e.g.* tetrahedrite-sphalerite, boulangerite-galena).

Plate 5.1: Photomicrographs of sulphide textures observed in the hanging wall sulphide zones

- a: Sample 93-C017, DDH 6839 - 115 ft (35 m)
Photomicrograph from the I sulphide zone showing the sharp basal contact and diffuse upper contact commonly observed within laminated sulphide units (top is to the left). Reflected light (plane polarized). Base of laminae consists primarily of pyrrhotite (yellowish-white) with increasing abundance of sphalerite (grey) upwards. Field of view is 5 mm.
- b: Sample 93-C139c, DDH 5232 - 219.5 ft (66.9 m)
Photomicrograph of folded laminae of pyrrhotite (yellow), sphalerite (grey), and galena (white). Dark grey laminae are pervasively chloritized quartzofeldspathic bands. Reflected light (plane polarized). Field of view is 5 mm.
- c: Sample 93-C138f, DDH 804 - 112.5 ft (34.3 m)
Photomicrograph of laminated sphalerite (grey) and pyrrhotite (yellowish-white), with irregularly distributed quartzofeldspathic material (dark grey). Reflected light (plane polarized). Field of view is 2.5 mm.
- d: Sample 93-C047, DDH 2370 - 238.8 ft (72.8 m)
Photomicrograph of massive pyrrhotite (yellow), sphalerite (grey), and galena (white). Note large euhedral grain of arsenopyrite (bright white) near the lower edge of the photomicrograph. Polygonal grain texture of pyrrhotite indicates extensive recrystallization. Reflected light (plane polarized). Field of view is 5 mm.

Plate 5.2: Photomicrographs of sulphide textures observed in the hanging wall sulphide zones

- a: Sample 93-C154c, DDH 5063 - 193.3 ft (58.9 m)
Photomicrograph of pyrite (high relief mineral) replacement of sphalerite (grey) along sulphide bedding plane (also see Plate 4.2b). Disseminated within sphalerite bands are galena (white) and pyrrhotite (yellow). Reflected light (plane polarized). Field of view is 5 mm.
- b: Sample 93-C112a, DDH 3994 - 4.5 ft (1.4 m)
Photomicrograph of durchbewegt sulphide. Silicate clasts (dark grey) suspended in a matrix of pyrrhotite (yellow-white), sphalerite (grey), and galena (bright white). Reflected light (plane polarized). Field of view is 5 mm.
- c: Sample 93-C112a, DDH 3994 - 4.5 ft (1.4 m)
Photomicrograph of galena (white) corrosion of pyrrhotite (yellow). Reflected light (plane polarized). Field of view is 2.5 mm.
- d: Sample 93-C110c, DDH 3976 - 79.5 ft (24.2 m)
Photomicrograph *in-situ* brecciation of a silicate band (dark grey clast) resulting from galena (white) remobilization. Reflected light (plane polarized). Field of view is 5 mm.

5.5 Hydrothermal Alteration

5.5.1 Tourmaline Alteration

The abundance of tourmaline (Plate 5.3a,b) is variable, typically, >80 vol% in pervasively tourmalinized rocks, <20 vol% in intercalated sulphide and silicate rock. <20 vol% in meta-sandstones, <10 vol% in semi-pelite, and is rare in pelite; although some pelites have a significant (approximately 10 vol%) amount of fine-grained tourmaline. Laterally, tourmaline abundance decrease outward from the vent complex tourmalinite breccias, with contents of >80 vol% tourmaline, to contents of <10 vol% near the periphery of the tourmaline alteration zone (see Figure 4.13). Tourmaline abundance decreases stratigraphically upwards: it is almost non-existent within the U sequence (see Figures 4.2, 4.3, and 4.12). Two textural habits of tourmaline are observed: *i*) aphanitic and chert-like; and, *ii*) to fine- to coarse-grained crystals intergrown with biotite. Aphanitic tourmaline (<10 μm ; see Ethier and Campbell, 1977) occurs as a pervasive alteration of meta-sedimentary rock forming what is termed a "tourmalinite". Most tourmalinites are black in hand sample, although a rare light brown or "blonde" tourmalinite occurs locally. Basal hanging wall tourmalinites are often brecciated with the interstitial areas infilled with sulphides (primarily pyrrhotite) and/or hydrothermal silicates and carbonate. Fine- to coarse-grained tourmaline is commonly associated with biotite and forms variably sized clots (up to 1 mm) set in a quartzofeldspathic matrix, although grain sizes up to 5 mm have been identified adjacent to Moyie gabbroic intrusions at the mine (Slack, 1993). Individual tourmaline grains consist of fine-grained (<0.25 mm), anhedral crystals, that optically exhibit a weak orange to orange-brown pleochroism and lack internal zonation. Rare occurrences of subhedral to euhedral, prismatic crystals were observed in a few semi-pelite samples. Some tourmaline grains have an interstitial appearance, where they occur as a replacement of detrital feldspar and matrix component (this study; Slack, 1993). Within sulphide

rocks, tourmaline is generally restricted to silicate waste bands, although in sample (93-C089) it is associated with remobilized pyrrhotite.

5.5.2 Albite + Chlorite $\pm$ Pyrite Alteration

Albite (Plate 5.3c,d and 5.4a) abundance is highly variable: generally <1 vol% in meta-sedimentary rocks and sulphide-rich rocks, 20-40 vol% in sphalerite-albite veins, and in excess of 70 vol% in massive albitites. Albite forms subhedral to euhedral prismatic grains, 0.25-2.0 mm in size. Grains typically display undulose extinction, have a “cloudy” appearance in plane polarized light, display sutured grain contacts, and lack twinning. Albite occurs as disseminated grains replacing feldspar and sericite, as a major component in sphalerite veins, and as massive albitite. Albite associated with sphalerite veins (see below) is generally elongate with the long-axis perpendicular to the vein wall and represents the initial infilling stage. Albite grains are commonly intergrown with chlorite, and inclusions of sericite/muscovite are not uncommon.

Chlorite contents in this alteration assemblage are typically <20 vol% and consist of two textural forms that are discriminated on the basis of grain size, habit, and pleochroism-birefringence. The two forms will be referred to as green chlorite and white chlorite. Green chlorite is more abundant (>15 vol%) in the albite + chlorite $\pm$ pyrite alteration zone, and consists of acicular to rare laths (<500 μ m) with green to pale green pleochroism. Green-chlorite occurs as grain aggregates (up to 1 mm), forming “bow tie-” or ribbon-shaped masses, or as an interlocking grain mosaic pervasively replacing the original matrix of meta-sedimentary rocks. White chlorite generally accounts for <5 vol% of the rock, and occurs as a replacement or recrystallization of green-chlorite. Texturally, white chlorite consists of subhedral to euhedral, laths to tabular grains (<0.5 mm in size) that exhibit no pleochroism and have anomalous greyish-white to “Berlin blue” birefringence.

Pyrite abundances in this alteration assemblage are typically <1 vol%, although they can be as high as 5 vol%. Pyrite typically occurs as subhedral to euhedral porphyroblasts, up to 1 cm in size, disseminated throughout the albite + chlorite $\pm$ pyrite alteration zone and form cross-cutting veins. Pyrite is randomly distributed through the altered rock and is observed to overprint and cross-cut albite and chlorite.

5.5.3 Chlorite + Fe-Sulphide (Pyrite/Pyrrhotite) Alteration

Zones of chlorite + Fe-sulphide alteration (Plate 5.4c) are characterized by their high abundance of green chlorite (see above), with up to 80 vol% in pervasively altered pelites, 10-20 vol% in other altered meta-sedimentary rocks, and <1 vol% in sulphide-rich rocks. White chlorite (see above) which also occurs in this zone is typically less abundant, comprising <10 vol% of altered meta-sedimentary rock, although it is the dominant chlorite phase (up to 20 vol%) in sulphide-rich rocks. Texturally, both green- and white-chlorites are similar to the chlorites associated with the zones of albite + chlorite $\pm$ pyrite alteration. Green-chlorite appears to be a pervasive replacement of the original sedimentary matrix and commonly defines the foliation in altered pelitic rocks. White-chlorite appears to be a recrystallized form of green-chlorite, but also occurs as a replacement of biotite and carbonate and as minor component of veins. Within sulphide rocks, white-chlorite is primarily restricted to sulphide layers where it is commonly aligned parallel to bedding-cleavage planes. Regionally, green-chlorite is absent, except for samples that are proximal to the Sullivan deposit. On the other hand, white-chlorite is present in regional samples, although abundances are typically lower than those that are encountered within the hanging wall.

While pyrite and pyrrhotite are both associated with these chlorite alteration zones, the occurrence of pyrrhotite is rather limited, and pyrite is the primary Fe-sulphide associated with this alteration type. Pyrite abundance is typically < 1 vol%, although it can be as high as 10

vol%. Pyrrhotite abundance is similar to that of pyrite. Pyrite typically occurs as disseminated subhedral to euhedral grains, with sizes ranging from 0.1 mm to 1 cm, that cross-cut chlorite. Pyrrhotite tends to be finer grained <0.1 mm and occurs as recrystallized grain aggregates. Both sulphide minerals are also present in veins that cross-cut the chlorite + Fe-sulphide alteration zones. While pyrite and pyrrhotite rarely occur together in zones of chlorite + Fe-sulphide alteration, they two sulphide minerals can co-exist. Generally, there is no textural relationship between the two Fe-sulphides, with both occurring as disseminated grains or aggregates; however, in sample 93-C080 attenuated grains of pyrrhotite are overprinted by euhedral pyrite.

5.5.4 Muscovite Alteration

Two textural varieties of muscovite (Plate 5.4d) that are distinguishable on the basis of grain size and texture are present within hanging wall rocks. The first variety is a fine-grained (<25µm) muscovite, referred to here as sericite, with abundances ranging from 1-70 vol% for meta-sedimentary rocks and 10-40 vol% for sulphide zones. On the other hand, coarser grained muscovite (<1 mm) is much less abundant, generally 1-2 vol% (but as high as 10 vol%) for all rock types. Sericite occurs as acicular to very fine-grained laths that pervasively alter the sedimentary matrix and replace potassium feldspar. Muscovite consists of euhedral, lath-shaped grains that are commonly aligned parallel to bedding and/or cleavage. Coarse-grained muscovite appears to be a replacement or recrystallization of sericite. Within sulphide rock, sericite is principally restricted to the quartzofeldspathic waste bands, whereas muscovite is intergrown with sulphides, garnet, and tremolite.

Disseminated sulphides are commonly associated with muscovite alteration and consist primarily of pyrrhotite, although sphalerite and trace amounts of galena are not uncommon. Sulphide abundances are variable, ranging from <1 vol% in muscovite zones that are distant to hanging wall sulphide zones, up to 20 vol% in zones that are proximal to the sulphide zones.

Plate 5.3: Photomicrographs of hydrothermal alteration mineral assemblages associated with the hanging wall sulphide zones

- a: Sample 93-C089e, DDH 3952 - 29.8 ft (9.1 m)
Photomicrograph of tourmalinite breccia. Mottled texture of tourmalinite clasts (dark grey) result from the irregular distribution of finely disseminated galena (lighter part of clasts). Clasts of suspended in a matrix of sphalerite (grey), galena (white), pyrrhotite (yellow), and hydrothermal muscovite (dark grey laths). Reflective light (plane polarized). Field of view is 5 mm.
- b: Sample 93-C017, DDH 6839 - 115 ft (35 m)
Photomicrograph of disseminated tourmaline (orange-brown) in quartzofeldspathic band within the I sulphide zone. Note spatial association of biotite (light brown) with tourmaline. Transmitted light (plane polarized). Field of view is 2.5 mm.
- c: Sample 93-C054, DDH 4495 - -28.5 ft (-8.7 m)
Photomicrograph of massive albitite with euhedral grain of pyrite in the centre. Note dark green laths of chlorite that discontinuously rim the pyrite. Transmitted light (cross nicols). Field of view is 2.5 mm.
- d: Sample 93-C087b, DDH 4501 - 247.5 ft (75.4 m)
Photomicrograph albite-sphalerite vein. Elongate grain of albite (aligned perpendicular to the vein wall) represent the initial infilling stage of the vein with sphalerite (opaque) forming the core of the vein. Note the coarse grained carbonate (brownish-grey) along the albite-sphalerite contact. Transmitted light (cross nicols). Field of view is 5 mm.

Plate 5.4: Photomicrographs of hydrothermal alteration mineral assemblages associated with the hanging wall sulphide zones

- a: Sample 93-C076d, DDH 3385 - 153.5 ft (46.8 m)
Photomicrograph of albite + chlorite $\pm$ pyrite alteration. Albite grains are elongate and are overprinted by euhedral pyrite (opaque), forming a discrete zone that is in contact with fine-grained green chlorite. Transmitted light (cross nicols). Field of view is 5 mm.
- b: Sample 93-C076d, DDH 3385 - 153.5 ft (46.8 m)
Photomicrograph of albite + chlorite $\pm$ pyrite alteration similar to (A) above; however, pyrite (opaque) is associated with the fine-grained chlorite and albite grains are more equant. Transmitted light (cross nicols). Field of view is 5 mm.
- c: Sample 93-C166f, DDH 4483 - 294.5 ft (89.8 m)
Photomicrograph of chlorite + Fe-sulphide alteration. Fine-grained pyrite (opaque) is disseminated in a matrix of fine-grained green chlorite with recrystallized (?) laths of white chlorite. Transmitted light (cross nicols). Field of view is 2.5 mm.
- d: Sample 93-C033, DDH 2442 - 192.5 ft (58.7 m)
Photomicrograph muscovite alteration, consisting of fine-grained sericite replacement of the original sedimentary matrix with coarser grained laths of muscovite possibly representing a metamorphic recrystallization of the sericite. Transmitted light (cross nicols). Field of view is 1.25 mm.

5.5.5 Brecciation, Veining, and Fracture Infilling

Brecciation

Distributed with the western part of the Sullivan orebody, parallel to the transition zone, are several discordant hydrothermal breccia bodies that cross-cuts footwall and hanging wall stratigraphy, which acted as the feeder system that focused hydrothermal fluid upflow. The breccias consist of angular to rounded fragments of tourmalinite, and chloritized and sericitized meta-sedimentary rock. Unlike many of the sedimentary breccias (see Hamilton *et al.*, 1982), these discordant breccias do not contain fragmented sulphides. Tourmalinite fragments contain numerous fine-grained (<0.01 mm) disseminations of galena. The fragments are set in a matrix of primarily pyrrhotite with minor sphalerite, galena, pyrite, arsenopyrite, chalcopyrite, chlorite, muscovite, carbonate, and garnet that constitute up to 60-70 vol% of the rock, although sericite-rich and chlorite-rich matrices occur locally.

Other breccia bodies occurring in the hanging wall include the southwest sedimentary breccia and brecciated albite-chlorite-pyrite-carbonate rock. These breccia bodies were not examined during this study, so the reader is referred to Hamilton *et al.* (1982) for a description of the breccias.

Veining

Three main types of mineralized veins cross-cut hanging wall rocks: *i*) quartz + pyrite; *ii*) quartz + sphalerite $\pm$ pyrite; and *iii*) albite + sphalerite (Plate 5.3d). Compositionally, quartz + pyrite and quartz + sphalerite $\pm$ pyrite veins are homogeneous, consisting of nearly equal amounts of quartz and sulphide. In contrast, albite + sphalerite veins also contain minor (<20 vol% combined) amounts of carbonate, galena, chlorite, and sericite. Quartz + pyrite and quartz + sphalerite $\pm$ pyrite veins represent a single filling stage that is indicated by the interlocking grain texture; whereas albite + sphalerite veins exhibit a well developed comb texture, with

albite-carbonate representing a earlier filling stage followed by sphalerite $\pm$ galena mineralization. Within albite-sphalerite veins, pyrite commonly is disseminated along the vein-wall rock contact. Albite-sphalerite veins also contain variable amounts of chlorite alteration of albite that is localized along the albite-sphalerite contact. Quartz + pyrite and quartz + sphalerite $\pm$ pyrite veins are observed to cross-cut muscovite altered rocks and chlorite + Fe-sulphide altered rocks. Albite + sphalerite veins are observed cross-cutting the same alteration types as the quartz + sphalerite veins, but are also found to cross-cut albite + chlorite $\pm$ pyrite alteration. None of the vein types are observed cross-cutting sulphide-rich rock. Sulphide minerals within the two vein systems most likely originated from the remobilization of pre-existing sulphide by hydrothermal fluids that post-date the main ore-forming stage. Recrystallization of vein constituents indicates that veining occurred prior to peak metamorphism.

Other veins present in the hanging wall include non-sulphide bearing green chlorite and albite veins that cross-cut albite + chlorite $\pm$ pyrite alteration. Quartz veins (with no sulphide) are not uncommon and cross-cut all rock types, including sulphide-rich rocks. Veinlets of pure sulphide, not associated with the development of piercement veins, intersect sulphide rock and are commonly replaced by pyrite.

Bedding Plane Fractures

Bedding-cleavage plane porosity occurs as either fractures along bedding/cleavage contacts or as piercement veins (Marshall and Gilligan, 1989). Bedding parallel fractures may be the result of delamination or dissolution, and are primarily infilled with carbonate. Piercement veins are vein-shaped bodies of incompetent material (sulphide) that transgress layering of competent material (silicate rock). As a result, they are common in intercalated sulphide and meta-sedimentary rock. These veins consist of pyrite that replaced the original infilling

sulphides (pyrrhotite sphalerite, galena, and chalcopyrite). Pyrite also extends outwards from the veins and replaces sulphide along the contact of the sulphide laminae and host rock. These veins are formed by the flow of sulphide into dilatant fractures during extension (*i.e.* bedding plane shearing) of competent wall rock (Marshall, 1988). Flow of sulphide material is possible since under elevated pressures and temperatures during metamorphism sphalerite, galena, and pyrrhotite are less competent than either pyrite or the enclosing meta-sedimentary rock (Marshall and Gilligan, 1989).

CHAPTER 6: WHOLE-ROCK GEOCHEMISTRY

6.1 Introduction

Whole-rock geochemical analyses were made in order to: *i*) produce a compositional database for the hanging wall meta-sedimentary rocks, zones of hydrothermal alteration, and sulphide zones; and, *ii*) to address the following:

- i*) use trace element data for hanging wall meta-sedimentary rocks to corroborate the interpreted tectonic - depositional environment of Purcell sediments;
- ii*) identify probable provenance of host meta-sedimentary rocks using discriminant analysis;
- iii*) characterize the chemical composition of the I, H, and Hu sulphide zones and identify stratigraphic variations between and within these zones; and,
- iv*) characterize the chemical composition of zones of hydrothermal alteration and evaluate fluid sediment reactions.

6.2 Methodology

Crushing and milling of all samples were conducted by XRAL Laboratories, Don Mills, Ontario. Samples were dry crushed in agate to <3 mm and then subsequently milled in agate, resulting in an inherent contamination of up to 0.3 wt% SiO₂. Silica sand was used between each sample to reduce the risk of contamination from highly mineralized samples.

All analyses, with exception of Au, B, and Hg, were completed by the Geological Survey of Canada, Mineral Resources Division - Analytical Chemistry Section. Major elements (SiO₂, TiO₂, Al₂O₃, Fe₂O₃(t), MnO, MgO, CaO, Na₂O, K₂O, and P₂O₅) were determined with a Perkin-Elmer Optima 3000 inductively coupled plasma emission spectrometer (ICP-ES) equipped with an autosampler. Major element data were obtained from 0.5 g of sample treated with HNO₃ -

HF, HCl - HF - HClO₄, followed by a series of HCl treatments before fusing with lithium metaborate, with the sample then being diluted to 100 ml. More detailed descriptions of analytical techniques and equipment are available from the Analytical Chemistry Laboratory, Mineral Resources Division, Geological Survey of Canada. Loss on ignition (LOI), H₂O(t), CO₂(t), CO₂, and C were determined by chemical methods. S, F, and Cl were determined by pyrohydrolysis - DIONEX ion chromatography. FeO was determined volumetrically. Fe₂O₃ was calculated using:

$$\text{Fe}_2\text{O}_3 = \text{Fe}_2\text{O}_3(\text{t})(\text{ICP}) - 1.11134 \times \text{FeO (volumetric)} \quad (\text{eq 6.1})$$

Trace elements Ba, Be, Co, Cr, Cu, La, Ni, Pb, Rb, Sc, Sr, V, Y, Yb, and Zr were determined by ICP-ES. Trace metals Ag, Cd, Cs, Ga, Hf, In, Mo, Nb, Pb (<100 ppm), Rb (<100 ppm), Sn, Ta, Th, Tl, U, and Zr (<100 ppm) were determined with a Perkin-Elmer Sciex ELAN 5000 inductively coupled plasma - mass spectrometer (ICP-MS) with autosampler and a flow injection system for on-line dilutions and addition of internal standards. Trace element data were obtained from similar analytical techniques as described above, although samples analyzed with the ICP-MS were further diluted by a factor of 10 and a Rhenium internal standard was added.

Precision of both instruments is approximately 2% and the accuracy is based on the analyses for standard reference samples (*i.e.* BCR-1 and AGV-1). Data accuracy is also monitored by random duplication of samples (5% of the total number) and with the use of various internal control samples.

The elements of Au, B, and Hg were analyzed by XRAL Laboratories, Don Mills, Ontario. Gold values were obtained on 15 g of sample using fire assay and direct current plasma spectrometry (DCP) techniques. Boron was determined by using 0.5 g of sample, dissolved in

nitric aqua regia, and analyzed using ICP-ES spectrometry. Mercury was determined on 0.5 g of sample using a cold vapour technique.

6.3 Geochemistry of Hanging Wall Meta-Sedimentary Rocks

Although a number of modern geochemical methods exist for the classification of sediments and sedimentary rocks (*e.g.* Pettijohn *et al.*, 1972; Herron, 1988), it was unnecessary to classify chemically the hanging wall meta-sedimentary rocks, since the sediment textures and types are well preserved; and therefore, readily apparent. Furthermore, most major elements (with the exceptions of Ti and Al) and some trace elements are highly susceptible to remobilization during hydrothermal and metamorphic processes, resulting in significant variations from their initial abundances (*c.f.* Humphris, 1984).

The chemical analyses of 50 hanging wall meta-sedimentary rocks are summarized in Table A6.2 (Appendix 6. Iron is generally reported as Fe_2O_3 (total), although for some samples (with low Fe contents) as both Fe_2O_3 and FeO.

6.3.1 Chemical Composition and Tectonic Setting

The tectonic setting affects the bulk composition of sediments by influencing the provenance characteristics, and sedimentary and weathering processes. Therefore, sediments from different tectonic environments will have distinct chemical compositions due to the dominance of one or another parent (source) material (*i.e.* mature continental crust will yield sediment detritus enriched in Si, Al, and K). Bi-variant and multi-variant tectonic discrimination plots shown in Figures 6.1 allow for the differentiation between the following tectonic environments (after Bhatia, 1983): *i) oceanic island arcs*- including fore-arc and back-arc basins; *ii) continental island arcs*- arc systems developed on thick continental crust or along continental margins; *iii) active continental margins*- Andean-type basins developed on thick continental

margins (including strike-slip basins); and, iv) *passive continental margins*- rifted continental margins developed along the edges of continents and remnant ocean basins adjacent to orogens. The Belt-Purcell sediments are interpreted to have been deposited in either an epicratonic basin (Price, 1964; Harrison, 1972; Sears and Price, 1978; McMechan, 1981) or an intracratonic rift (Winston *et al.*, 1984; Roberts, 1986), and therefore, should fall within the passive continental margin field on the elemental discrimination plots. While trace element abundances may be highly variable in sedimentary rocks, certain trace elements are generally less mobile as compared to major elements during sedimentary processes (Holland, 1978), hydrothermal alteration (*e.g.*, Morgan and Wandless, 1980; Taylor and Fryer, 1980, 1983), and metamorphism (*e.g.*, Cullers *et al.*, 1974; Heier, 1973; Hower *et al.*, 1976; Rudnick *et al.*, 1985; Merriman *et al.*, 1986; Taylor *et al.*, 1986). Therefore, even in hydrothermally altered and metamorphosed rocks certain trace elements can be useful in the discrimination between tectonic environments.

For hanging wall unaltered and weakly altered meta-sedimentary rocks (not including the massive albitites or tourmalinites) certain trace elements (*e.g.* Co, Hf, Sc, Th, and U), that are considered to be immobile were used to corroborate previous regional tectonic setting studies (see above). On log Th versus log U (Figure 6.1a), log Th versus log Sc (Figure 6.1b), Th-Hf-Co (Figure 6.2a), and La-Th-Sc (Figure 6.2b) discrimination diagrams, the hanging wall meta-sedimentary rocks generally plot in the continental margin field, consistent with regional interpretations. However, these diagrams do not discriminate between active and passive margin settings: for the latter purpose the ternary Th-Co-Zr/10 and Th-Sc-Zr/10 diagrams (Figure 6.2c,d) are used. While the majority of data points in the Th-Co-Zr/10 and Th-Sc-Zr/10 diagrams plot within the passive continental margin field, a small population of data points plot outside. In both these diagrams the outlying samples plot in a linear trend towards the Co and Sc apexes in the Th-Co-Zr/10 and Th-Sc-Zr/10 diagrams, respectively. These trends are significant, for they

Figure 6.1. Plots of Th versus U (a) and Th versus Sc (b) for hanging wall meta-sedimentary rocks. Fields from McLennan *et al.* (1990). The Th/U and Th/Sc ratios are significantly higher than the upper crustal ratios of 3.8 and 1, respectively, typical of passive to active continental settings.

Figure 6.2. Ternary plots of Th-Hf-Co (a), La-Th-Sc (b), Th-Sc-Zr/10 (c), and Th-Co-Zr/10 (d) for tectonic setting discrimination of hanging wall meta-sedimentary rocks. Fields based on McLennan and Taylor (1984), Bhatia and Crook (1986) and McLennan *et al.* (1990). PAS is Post-Archean Australian shales. Symbols and abbreviations as in Figure 6.1.

indicate that both Co and Sc were mobile during post-sedimentation processes, while Th and Zr/10 remained immobile. Mobility of Co and Sc are also observed in Th-Hf-Co and La-Th-Sc diagrams, although the trends are not as obvious.

6.3.2 Provenance Signatures of Hanging Wall Meta-Sedimentary Rocks

Recent studies of sediment provenance have been directed at the relation of bulk-rock geochemistry to provenance, and in turn to tectonic setting (see references in Roser and Korsch, 1988). Standard oxide or elemental variation diagrams have limited use in determining provenance, due to the overlap of data as a result of chemical variation with sediment grain size (Roser and Korsch, 1988). A more viable means of determining sediment provenance that is largely independent of grain size effects is discriminant function analysis. Based on rocks from several sedimentary terranes of the Pacific margin, Roser and Korsch (1988) designed two sets of discriminant functions that clearly distinguish between provenance groups (*i.e.* quartzose sedimentary, felsic igneous, intermediate igneous, and mafic igneous). The discriminant functions are (after Roser and Korsch, 1988):

$$\begin{aligned} \text{discriminant function 1} = & -1.773 \text{ TiO}_2 + 0.607 \text{ Al}_2\text{O}_3 + 0.76 \text{ Fe}_2\text{O}_3(\text{t}) \\ & - 1.5 \text{ MgO} + 0.616 \text{ CaO} + 0.509 \text{ Na}_2\text{O} - 1.224 \text{ K}_2\text{O} - 9.09 \end{aligned} \quad (\text{eq. 6.2})$$

$$\begin{aligned} \text{discriminant function 2} = & 0.445 \text{ TiO}_2 + 0.07 \text{ Al}_2\text{O}_3 - 0.25 \text{ Fe}_2\text{O}_3(\text{t}) \\ & - 1.142 \text{ MgO} + 0.438 \text{ CaO} + 1.475 \text{ Na}_2\text{O} + 1.426 \text{ K}_2\text{O} - 6.861 \end{aligned} \quad (\text{eq. 6.3})$$

Results of discriminant function analysis using equations 6.2 and 6.3 are given in Figure 6.3a. It should be noted that these equations are only applicable to rocks that lack significant biogenic components. Rocks with a high abundance of biogenic sediments, notably biogenic SiO₂ and CaCO₃ (or for those analyses that cannot be corrected for these inputs) need to have their provenance signatures determined with a second set of functions (see equations 6.4 and 6.5), because samples that are CaO-rich samples will push data points up to the intermediate igneous provenance field of Figure 6.3a, and biogenic SiO₂ will pull data points down into the quartzose

Figure 6.3. Discrimination function diagram for the provenance signatures of hanging wall quartzite-pelite suites using major elements (after Roser and Korsch, 1988). See text for discrimination function formulae. Note how both plots indicate a quartzose sedimentary provenance. The mafic component is considered to be the result of chloritization and not reflective of the rock's provenance.

sedimentary field. These two functions are based on major oxide to Al_2O_3 ratios. The discriminant ratio functions that are used for rocks with a high biogenic component are (after Roser and Korsch, 1988):

$$\text{discriminant ratio function 1} = 30.638 \text{ TiO}_2/\text{Al}_2\text{O}_3 - 12.541 \text{ Fe}_2\text{O}_3(\text{t})/\text{Al}_2\text{O}_3 - 7.329 \text{ MgO}/\text{Al}_2\text{O}_3 + 12.031 \text{ Na}_2\text{O}/\text{Al}_2\text{O}_3 + 35.402 \text{ K}_2\text{O}/\text{Al}_2\text{O}_3 - 6.382 \quad (\text{eq. 6.4})$$

$$\text{discriminant ratio function 2} = 56.500 \text{ TiO}_2/\text{Al}_2\text{O}_3 - 10.879 \text{ Fe}_2\text{O}_3(\text{t})/\text{Al}_2\text{O}_3 + 30.875 \text{ MgO}/\text{Al}_2\text{O}_3 - 5.404 \text{ Na}_2\text{O}/\text{Al}_2\text{O}_3 + 11.112 \text{ K}_2\text{O}/\text{Al}_2\text{O}_3 - 3.89 \quad (\text{eq. 6.5})$$

Results of discriminant ratio function analysis using equations 6.4 and 6.5 are given in Figure 6.3b.

The majority of hanging wall rocks plot within the quartzose sedimentary provenance field of the two discriminant function plots (Figure 6.3). A quartzose sedimentary provenance is consistent with either an epicratonic (Price, 1964; Harrison, 1972; Sears and Price, 1978; McMechan, 1981) or an intracratonic (Winston *et al.*, 1984; Roberts, 1986) interpretation for the Purcell Basin, with Aldridge sediments being derived from the recycling of rocks of the North American Precambrian craton (*c.f.* Hamilton *et al.*, 1982). Discrimination diagrams based on equations 6.2 and 6.3 exhibit a stronger quartzose sedimentary provenance signature than do the diagrams based on equations 6.4 and 6.5. A large proportion of data points in Figure 6.3b plot along the boundary between the quartzose sedimentary field and the three igneous provenance fields, due to the overall enrichment of MgO and Fe_2O_3 in hanging wall rocks that are further attenuated by their large discriminant ratio function coefficients. In both diagrams a small population of data points plot within the mafic igneous field; however, this group is dominated by pelitic rocks characterized by high Fe_2O_3 and MgO contents, that result from chlorite and iron sulphide alteration.

6.4 Geochemistry of Sulphide Zones

Although geochemical analyses of a large number of elements were completed, the abundance of many elements in the hanging wall sulphide zones is uniformly low and invariable. This is not surprising given the inability of the sulphide structure to incorporate lithophile elements (*i.e.* Si, Al, Ca, Na) (Krauskopf, 1979). Therefore, the following discussion will confine itself to characterize the distribution of the potentially economic chalcophile elements (*i.e.* Pb, Zn, Ag), except in the circumstance when anomalously high abundances of lithophile elements are recorded.

The geochemical characteristics of the three hanging wall sulphide zones were examined from 28 whole-rock samples along with Cominco Ltd. assay data from 76 drill holes. Four whole-rock samples of undifferentiated main ore zones were analyzed for comparative purposes. The results of whole rock analyses are given in Table A4.3 (Appendix 4) and Cominco assay data are present in Table A5.2 (Appendix 5). Table 6.1 is comparative table of average concentration of economic chalcophile elements for hanging wall and main ore zones. Correlation coefficients are presented in Table 6.2. Lateral variations in metal grade had to be determined with Cominco assay data, since the limited number and distribution of drill holes for whole-rock chemistry were inadequate to draw meaningful contours. Contoured grade-foot maps were produced with the computer software package Mac-GRIDZO, a Macintosh-based contouring program. Contour (isopleth) maps were created using grade-foot data. Grade-foot values are produced by multiplying the assay value by the true thickness of the interval; however, in cases where true thickness could not be determined the apparent thickness was used. The advantage of using grade-foot values is that they limit the effects of anomalous grades or unit thickness and incorporate dilution effects by non-hydrothermal products. While the grade maps are considered to give a reasonable indication of lateral zonation, their accuracy is limited

Table 6.1. Comparative table of selected elements for the footwall, I, H, and Hu sulphide zones.

Footwall Ore n=4						I Laminations n=12					
		X	m	s	max	min	X	m	s	max	min
Fe ₂ O ₃ (t)	%	32.47	37.85	9.01	38.60	20.10	20.93	22.30	14.82	63.70	8.20
Pb	ppm	53262.81	100000.00	101836.47	199000.00	13000.00	14505.38	26000.00	79375.60	228000.00	42.00
Zn	ppm	23237.66	31000.00	85404.20	188000.00	2200.00	51069.48	66000.00	95430.82	254000.00	500.00
S (t)	%	22.90	24.85	10.78	37.70	12.00	14.20	19.15	9.30	31.00	3.72
Ag	ppm	54.55	164.00	176.82	340.00	3.10	18.48	18.50	106.68	350.00	0.11
Au	ppb	31.09	34.50	19.86	61.00	13.00	8.48	10.00	20.64	68.00	1.00
Cd	ppm	93.20	86.00	436.41	930.00	13.00	190.28	245.00	434.91	1200.00	1.80
Cu	ppm	235.87	340.00	206.97	490.00	64.00	150.64	145.00	91.99	350.00	59.00
Hg (ppb)	ppb	3419.93	4020.00	15486.33	33300.00	484.00	2025.43	1490.00	29959.51	106000.00	48.00
Sn	ppm	20.09	33.50	106.73	270.00	1.50	49.56	64.00	74.35	290.00	2.00

H "Ore" n=5						Hu Ore n=11					
		X	m	s	max	min	X	m	s	max	min
Fe ₂ O ₃ (t)	%	22.06	19.70	14.22	49.40	15.50	34.87	40.00	13.58	60.40	14.10
Pb	ppm	142819.63	262000.00	119489.33	299000.00	21000.00	25047.44	36000.00	26531.92	86000.00	93.00
Zn	ppm	69025.93	190000.00	98534.74	240000.00	790.00	73170.75	121000.00	73904.53	277000.00	110.00
S (t)	%	26.61	24.80	5.57	36.90	23.50	22.59	26.20	7.40	31.60	4.51
Ag	ppm	170.67	260.00	120.33	340.00	45.00	37.64	57.00	51.78	180.00	0.18
Au (ppb)	ppb	35.24	36.00	21.21	74.00	17.00	35.30	35.00	64.84	238.00	7.00
Cd	ppm	322.35	830.00	445.06	1200.00	4.80	400.36	335.00	348.62	1400.00	200.00
Cu	ppm	269.68	240.00	100.65	400.00	170.00	226.61	290.00	196.56	710.00	18.00
Hg (ppb)	ppb	875.62	8260.00	4671.70	8870.00	21.70	8245.76	16500.00	20358.45	64200.00	8.00
Sn	ppm	19.70	63.00	34.14	73.00	0.72	16.41	15.00	35.47	93.00	0.63

Explanation:

n = number of analyses

X = average

m = median

s = standard deviation

max = maximum value

min = minimum value

due to: *i*) an uneven distribution of drill holes, *ii*) limited stratigraphic control for some holes, *iii*) localized variations due to structure, *iv*) absence of a sulphide zone(s) in drill core, and *v*) incomplete assay records.

6.4.1 I Laminations

Relative to the main ore zones, the I laminations have lower average Fe_2O_3 (20.93 wt%), Pb (1.45 wt%), S (14.2 wt%), Ag (18 ppm), Au (8 ppm), Cu (150 ppm), and Hg (2025.45 ppm) contents (Table 6.1). By contrast, the I sulphide zone is enriched (on average by a factor of 2-3 x relative to the main ores) in Zn (5.1 wt%), Cd (190 ppm), and Sn (49 ppm). The distribution of Fe, Pb, Zn, and Cu is controlled by the distribution and abundance of pyrite, pyrrhotite, galena, sphalerite, and chalcopyrite. In contrast the distribution of Ag, Au, and Hg is not as easily discernible since these elements were below the detection limit of the SEM-EDS; therefore, statistical methods had to be incorporated in order to understand their distribution. The strong correlation of Ag with Pb ($r = 0.88$) and of Cd with Zn ($r = 0.93$) indicated that Ag and Cd are likely contained in galena and sphalerite, respectively. This inference is supported by SEM-EDS analysis of sphalerite (from all sulphide zones) which yielded Cd contents up to 0.36 wt% (A. Conly, unpublished data). Tin exhibits either a negative or no significant correlation with base metals and S, although it does show moderately positive correlations with lithophile elements (*e.g.* SiO_2 , TiO_2). These correlations imply that Sn is incorporated in a non-sulphide mineral phase and/or is associated with quartzofeldspathic interlayers. SEM-EDS analyses indicates that Sn is contained in cassiterite which is distributed within quartzofeldspathic sedimentary rocks. However, minor amounts of Sn are incorporated into sulphides such as sphalerite, which have Sn values up to 0.24 wt% (A. Conly, unpublished data).

Stratigraphic variations within the I laminations (Figure 6.4) were determined from two drill holes, DDH 6839 (along the transition zone) and DDH 4483 (stratiform lens northwest of

the transition zone). Internal stratigraphic trends are similar for both drill holes and are as follows: *i*) Fe, S, Cu, and Co (4483) contents increase up-section; and, *ii*) Pb, Zn, Ag, Au, B (in 6839), Cd, Sn (in 4483), and Hg contents decrease with up-section.

Grade-foot isopleth maps for Pb, Zn, and Ag have similar distribution patterns (Figure 6.5a-d). Iron, Pb, Zn, and Ag isopleths for the I sulphide zone generally reflect the thickness of the I sulphide zone and the lateral distribution of footwall breccias. The result is grade-foot values that are concentrically zoned and decrease toward the margins of the I sulphide zone (decreasing with the thinning of the sulphide zone), with maximum values that coincide with the area encompassed by the flanks of the two north-south trending breccia bodies (Figure 4.7 and 6.5).

Unlike the H and Hu sulphide zones, the I laminations contain high contents of lithophile elements (in particular SiO_2 and Al_2O_3) reflecting a greater frequency of intercalate quartzofeldspathic layers. Similarly B concentrations are substantially higher for the I sulphide zone, with contents ranging from 25-8680 ppm (average 264 ± 359 ppm). The high B content is due to the occurrence of disseminated tourmaline in the quartzofeldspathic interlayers. The quartzofeldspathic interlayers of the I sulphide zones have been variably sericitized; however, samples 93-C66b-67b (DDH 3385) and 93-C160b (DDH 4483) have elevated Fe_2O_3 (up to 23.6 wt%) and MgO (up to 10.6 wt%) abundances that correspond to a significant amount of chlorite alteration.

6.4.2 H "Ore"

Lead (14.28 wt%), Zn (6.9 wt%), Ag (170 ppm), and Cd (322 ppm) are nearly 2-4 times as abundant in the H sulphide zone as compared to the main ore zones (Table 6.1). Iron (22.06

Figure 6.4. Vertical distribution of metal and trace element concentrations within hanging wall sulphide horizons. (a) I laminations (DDH 6839), (b) I laminations (DDH 4483). Stratigraphic sections and symbols from Figure 4.3-4. Core lengths in feet, with scale of 1 cm = 1 foot. Data from whole-rock geochemistry presented in Table A5.3.

Figure 6. 5a. Iron ft-% isopleth map for the I sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

Figure 6.5b. Lead 8-% isopleth map for the I sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

Figure 6.5c. Zinc ft-% isopleth map for the I sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

Figure 6.5d. Silver ft-oz/t isopleth map for the I sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

wt%) is the only chalcophile element that is depleted with respect to the main ore zones, although its abundance is similar to the I sulphide zone. Metals are distributed in a similar fashion to that of the I sulphide zone, with Ag being concentrated in galena and Cd in sphalerite; Sn most likely occurs as cassiterite, although it may also be incorporated (in trace amounts) within sulphide minerals.

Vertical distribution trends (Figure 6.6) for the H "ore" zone were determined from DDH 5063. Iron, S, Cu, Co, and Au abundances increases up-section through the sulphide zone, whereas Pb, Zn, Ag, Cd, and Hg (although Hg has large variability between samples) decrease up-section. Tin contents in the H sulphide zone are highly variable, with the basal and upper samples having similar abundances, although both are depleted with respect to samples from the middle of the sulphide zone.

Grade-foot isopleth maps for Fe, Pb, Zn, and Ag were not created for the H sulphide zone due to the laterally discontinuous nature of the sulphide zone which is reflected by the limited number of drill hole intersections.

Sample 93-C154d has an anomalously high Na_2O content of 2.11 wt%, which is substantially greater than the average concentration (0.29 wt%) for the H sulphide zone. The elevated Na_2O content of this sample corresponds to the overprinting of the sulphide zone by albite alteration. The lack of any significant increase above the average value for MgO shows that the albite alteration is relatively free of any associated chlorite alteration.

6.4.3 Hu Ore

The content of many chalcophile elements within the Hu sulphide zone (including Fe, S, Au, and Cu) is similar to the main ore zones. However, whole-rock elemental

Figure 6.6. Vertical distribution of metal and trace element concentrations within the H sulphide zone (H "ore")(DDH 5063). Stratigraphic sections and symbols from Figure 4.3-4. Core lengths in feet. Data from whole-rock geochemistry presented in Table A4.3.

concentrations of Zn (7.3 wt%), Cd (400.36 ppm), and Hg (8245.76 ppb) are significantly elevated, and Pb (2.5 wt%), Ag (37 ppm), and Sn (16 ppm) are depleted within the Hu sulphide zone in comparison to the footwall ores. No Au- or Hg-bearing mineral phases were observed within the Hu sulphide zone. As discussed for the I sulphide zone, Ag is likely associated with galena, although the identification of tetrahedrite and boulangerite by SEM-EDS analysis indicates that Ag is not solely incorporated into galena. However, the extremely low abundances (<1 vol%) of these two minerals and the high whole-rock Pb content indicates that galena is likely the predominant Ag-bearing sulphide phase. Cadmium distribution is controlled by the relative abundance of sphalerite (see discussion on I laminations), and Sn most likely occurs as cassiterite, although trace amounts are also incorporated within sulphide minerals (see discussion on I laminations).

The well-defined stratigraphic variations present in the I and H sulphide zones are absent from the Hu ore zone (Figure 6.7). Stratigraphic variations within Hu are present as: *i*) an increase in Pb, Zn, Ag, Cd, Hg, and Sn from the basal laminated horizon to massive ore which then shows a decrease to upper laminated horizon; or *ii*) a decrease in Fe, Co, Au, and Cu from the basal laminated horizon to massive ore followed by a increase to the upper laminated horizon. Typically, in both distribution trends the basal and upper laminated horizons have either similar concentrations or the upper laminated horizon tends to be slightly enriched relative to the basal horizon. Sulphur shows a gradual decrease up-section.

Grade-foot isopleth maps for Pb, Zn, and Ag display similar distribution patterns to one another (Figure 6.8a-d), and generally correspond to the lateral distribution of footwall breccias. The result is grade-foot values that are concentrically zoned and decrease toward the margins of the Hu sulphide zone. Furthermore, Pb, Zn, and Ag grade-foot values are highest along the northwestern margin of the transition zone, which coincides with a small breccia body that

Figure 6.7. Vertical distribution of metal and trace element concentrations within the Hu sulphide zone (DDH* 3971, 3976, 3994). Stratigraphic sections and symbols from Figure 4.3-4. Core lengths in feet. Data from whole-rock geochemistry presented in Table A4.3.

* Due to small core diameters, samples for Hu sulphide zone had to be combined to provide enough sample mass for analysis. Therefore, in order to obtain a vertical distribution plot for the Hu sulphide zone, samples from proximal drill holes were plotted. Maximum distance between holes is approximately 485 feet (DDH 3971-3976). Lateral distances are not to scale.

Figure 6.8a. Iron ft-% isopleth map for the Hu sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

Figure 6.8b. Lead ft-% isopleth map for the Hu sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

Figure 6.8c. Zinc ft-% isopleth map for the Hu sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

Figure 6.8d. Silver ft-oz/t isopleth map for the Hu sulphide zone. Outline of tourmalinized breccia bodies (= feeder pipe) and drill hole collar locations are shown. Mine grid is in feet.

connects the two main north-south trending breccia zones (Figure 4.7 and 6.8). Iron grade-foot isopleths do not display the well-defined concentric zonation that is apparent with Pb, Zn, and Ag grade-foot contour maps. Whereas Fe grade-foot isopleths decrease outwards to the periphery of the Hu sulphide zone, they closely approximate the thickness of the Hu sulphide zone.

Lithophile element concentrations are typically low and do not show any systematic lateral or vertical variation within the Hu sulphide zone; however, sample 93-C075d-e (DDH 3385) contains 7.3 wt% Na₂O and 2.59 wt% MgO as compared to the average of 0.19 wt% and 0.83 wt%, respectively (Table 6.1). This dramatic increase in Na corresponds to overprinting of the Hu sulphide zone in DDH 3385 by late-stage albite + chlorite + pyrite alteration. Several samples (including 93-C104c-e, 93-C120e, and 93-C166b) have elevated CaO contents, ranging from 2.07-4.00 wt% (Hu ore average = 0.54 wt%) and CO₂ contents, ranging from 1.3-2.3 wt% (Hu ore average = 0.65), that reflect carbonate alteration.

6.4.4 Stratigraphic Variations using Pb-Zn-Fe and Ag-Pb-Zn Ratios

While absolute metal values are useful in evaluating the stratigraphic variation of Fe, Pb, Zn, and Ag, they are often susceptible to dilution of hydrothermal sulphides by ambient sediments and by the addition of minerals during hydrothermal alteration. In order to compensate for any localized effects, tri-element ratios were used to identify stratigraphic trends. Ratios were based on the Fe-Pb-Zn system and Ag-Pb-Zn system, with Fe, Pb, and Zn expressed in weight percent and Ag in parts per million. Average, median, maximum, and minimum values for element ratios calculated using whole-rock data are presented in Table 6.3, while ratios determined from Cominco Ltd. assay data are presented in Table A5.3 (Appendix 5). Stratigraphic trends using average ratios are illustrated in Figure 6.9.

Table 6.8. Whole-rock ratios (Ag-Pb-Zn and Pb-Zn-Fe systems) for footwall ore, I, H, and Hu sulphide zones.

	Pb/ Ag+Pb+Zn	Zn/ Ag+Pb+Zn	Ag/ Ag+Pb+Zn	Pb/ Pb+Zn+Fe	Zn/ Pb+Zn+Fe	Fe/ Pb+Zn+Fe		Pb/ Ag+Pb+Zn	Zn/ Ag+Pb+Zn	Ag/ Ag+Pb+Zn	Pb/ Pb+Zn+Fe	Zn/ Pb+Zn+Fe	Fe/ Pb+Zn+Fe
Footwall Ore	0.46	0.54	9.99E-04	0.04	0.05	0.90	average	0.56	0.44	9.14E-04	0.22	0.14	0.64
	0.99	0.01	1.83E-03	0.40	0.00	0.99	median	0.49	0.51	3.87E-04	0.31	0.18	0.78
	0.51	0.49	7.75E-04	0.38	0.36	0.27	stdev	0.31	0.31	7.35E-04	0.20	0.16	0.28
	0.27	0.73	4.84E-05	0.05	0.14	0.81	max	0.99	0.73	1.83E-03	0.40	0.36	0.90
	0.25	0.75	3.58E-04	0.12	0.36	0.52	min	0.27	0.01	4.84E-05	0.04	0.00	0.27
I Laminations	0.12	0.87	1.66E-04	0.02	0.15	0.83							
	0.08	0.92	2.03E-04	0.00	0.00	1.00	average	0.27	0.73	3.63E-04	0.16	0.28	0.59
	0.41	0.59	8.17E-04	0.33	0.48	0.19	median	0.24	0.76	3.55E-04	0.09	0.29	0.69
	0.02	0.98	3.45E-05	0.00	0.25	0.74	stdev	0.17	0.17	2.65E-04	0.14	0.16	0.27
	0.15	0.85	2.25E-04	0.05	0.28	0.67	max	0.59	0.98	8.54E-04	0.43	0.51	1.00
	0.59	0.41	3.86E-04	0.43	0.30	0.27	min	0.02	0.41	3.45E-05	0.00	0.00	0.19
	0.24	0.76	3.52E-04	0.04	0.12	0.84							
	0.41	0.59	5.48E-04	0.24	0.35	0.41	average	0.61	0.39	8.45E-04	0.34	0.29	0.37
	0.38	0.62	8.54E-04	0.07	0.12	0.81	median	0.55	0.44	5.95E-04	0.43	0.37	0.23
	0.24	0.76	3.70E-04	0.16	0.51	0.33	stdev	0.21	0.21	6.85E-04	0.17	0.17	0.33
	0.38	0.62	4.55E-05	0.26	0.41	0.33	max	0.96	0.58	2.06E-03	0.46	0.39	0.94
	0.55	0.44	6.30E-04	0.46	0.37	0.17	min	0.41	0.04	4.18E-04	0.06	0.00	0.17
H Ore	0.41	0.58	4.18E-04	0.28	0.39	0.33							
	0.52	0.48	5.19E-04	0.43	0.39	0.18	average	0.26	0.74	4.39E-04	0.09	0.29	0.62
	0.60	0.40	5.95E-04	0.46	0.31	0.23	median	0.28	0.72	3.45E-04	0.09	0.29	0.63
	0.96	0.04	2.06E-03	0.06	0.00	0.94	stdev	0.09	0.09	2.70E-04	0.05	0.15	0.19
	0.31	0.69	4.24E-04	0.11	0.25	0.63	max	0.46	0.86	9.34E-04	0.17	0.54	1.00
	0.33	0.67	9.34E-04	0.07	0.14	0.80	min	0.14	0.54	1.97E-04	0.00	0.00	0.33
	0.30	0.70	4.48E-04	0.17	0.39	0.44							
	0.46	0.54	8.86E-04	0.09	0.00	1.00	average	0.29	0.54	3.73E-04	0.08	0.15	0.59
	0.31	0.69	6.57E-04	0.15	0.33	0.52	median	0.31	0.69	4.02E-04	0.18	0.29	0.59
	0.16	0.84	2.58E-04	0.09	0.49	0.42	stdev	0.22	0.72	4.58E-04	0.15	0.16	0.26
	0.19	0.81	2.37E-04	0.13	0.54	0.33	max	0.99	0.98	2.06E-03	0.46	0.54	1.00
	0.14	0.86	2.09E-04	0.05	0.29	0.67	min	0.02	0.01	3.45E-05	0.00	0.00	0.17
	0.21	0.79	2.32E-04	0.06	0.24	0.70							
	0.28	0.72	3.45E-04	0.08	0.21	0.71							
	0.23	0.77	1.97E-04	0.09	0.31	0.59							

$$Pb/(Pb + Zn + Fe)$$

Cominco Ltd. assay data show a gradual decrease within the main ore zones, with a slight increase in the hanging wall with respect to the D ore zone. Hanging wall ratios (0.15 to 0.2) for the I, H, and Hu sulphide zones are similar to the A-C ore bands. Whole-rock data from this study show no systematic difference within the hanging wall, although the H "ore" displays a significantly higher ratio $Pb/(Pb + Zn + Fe)$ (>0.4 compared to <0.2 for the other sulphide zones); such elevated $Pb/(Pb + Zn + Fe)$ whole-rock values for the H sulphide zone correspond to anomalously high galena contents associated with the H sulphide zone in DDH 5063.

$$Zn/(Pb + Zn + Fe)$$

Cominco Ltd. assay data display a gradual decrease up-section in the $Zn/(Pb + Zn + Fe)$ ratio for the main ore zones, a trend which continues into the I and H sulphide zones of the hanging wall. However, the Hu sulphide zone of the hanging wall shows increase in $Zn/(Pb + Zn + Fe)$ with respect to the H sulphide zone. Zinc/(Pb + Zn + Fe) ratios for the hanging wall sulphide zones are similar those from the C and D Bands within the main ore zone. The higher in $Zn/(Pb + Zn + Fe)$ values for the Hu sulphide zone is consistent with petrographic observations that indicate an increase in the abundance of sphalerite as compared to the I and H sulphide zones. In contrast, whole-rock chemistry from this study shows an increase in $Zn/(Pb + Zn + Fe)$ for the hanging wall sulphide zones with respect to undifferentiated main ore zones, although between the hanging wall sulphide zones there is no systematic stratigraphic variation.

$$Fe/(Pb + Zn + Fe)$$

Cominco Ltd. assay data display an increase up-section in $Fe/(Pb + Zn + Fe)$ values throughout main ore zones, followed by a decrease between the D band and I laminations, with quite variable ratios in the hanging wall sulphide zones. Cominco Ltd. ratios for hanging wall sulphide zones are similar to the C and D bands of the main ore zones. Whole-rock $Fe/(Pb + Zn +$

Figure 6.9. Vertical distribution of metal ratios in the hanging wall and main ore zones of the Sullivan orebody; (a) Data from whole-rock geochemistry (this study) (Table A4.3), (b) Data from Cominco Ltd. assay records (Table A5.2). Ratios are calculated with Pb, Zn, and Fe expressed as weight percents, and Ag as parts per million.

Fe) values from this study also do not show any systematic variation between the hanging wall sulphide zones, although the H sulphide zone shows a significant decrease in Fe content due to the increased abundance of galena associated with DDH 5063.

$$Pb/(Ag + Pb + Zn)$$

Ratios calculated using Cominco Ltd. assays show a gradual increase in $Pb/(Ag + Pb + Zn)$ from the lower Main Band to the upper Main Band, followed by a decrease from the upper Main Band through to the Hu sulphide zone in the hanging wall. In contrast, whole-rock data from this study show no systematic change in the $Pb/(Ag + Pb + Zn)$ ratios in the hanging wall sulphide zones.

$$Zn/(Ag + Pb + Zn)$$

Cominco Ltd. assay data show an increase in $Zn/(Ag + Pb + Zn)$ values from the main ore zones through to the Hu sulphide zone, with a significant decrease between the main ore zones and the hanging wall sulphide zones. Whole-rock chemistry $Zn/(Ag + Pb + Zn)$ ratios show an increase for the hanging wall sulphide zones over the main ore zones, although within the hanging wall there is no systematic variation. However, whole-rock data show a decrease in $Zn/(Ag + Pb + Zn)$ for the H sulphide zone which corresponds to lower sphalerite contents due to the increase abundance in galena associated with DDH 5063

$$Ag/(Ag + Pb + Zn)$$

Silver/ $(Ag + Pb + Zn)$ ratios from Cominco Ltd. assay data display a decrease up-section from the Main Band to D Band in the main ore zones, with a significant increase between the D Band and the I sulphide zone, followed by a gradual increase between the I and Hu sulphide zones. Stratigraphic trends in $Ag/(Ag + Pb + Zn)$ ratios for whole-rock data from this study show a slight decrease from the main ore zones to Hu sulphide zones.

Summary

Discrepancies between whole-rock (this study) and Cominco Ltd. assay data sets originate primarily with the H sulphide zone and footwall ores. The conflicting data between the two data sets may be the result of sampling biases. Samples for this study were taken at locations where there was a distinct change in texture or sulphide mineralogy. Therefore, the bulk-compositions of the samples may not represent the entire sulphide zone, but rather reflect internal variations (see above). On the other hand, Cominco Ltd. assay data provide a weighted average for an entire sulphide zone, which is more representative. Furthermore, the large number of continuous samples collected from drill holes used to calculate the assay ratios makes ratios from Cominco Ltd. assay results statistically more reliable. Although, discrepancies between the two data sets may reflect localized stratigraphic trends, it is worth noting that vertical trends observed in SEDEX deposits are not generally as consistent as lateral trends (see above) or as comparable as the vertical trends for volcanogenic massive sulphide deposits (Lydon, 1983; Goodfellow *et al.*, 1993).

By comparing the stratigraphic trends using different ternary systems (Fe-Pb-Zn and Ag-Pb-Zn), overall trends can be identified for the hanging wall. Relative zinc abundances increase up-section in agreement with the bulk chemical trend for data from this study. Iron/(Pb + Zn + Fe) ratios decrease up-section; at variance with the overall increase in Fe abundance as indicated by whole-rock compositions. Overall trends of Pb and Ag ratios are enigmatic because ratios calculated from whole-rock analyses (this study) indicate a decrease with ascending stratigraphy, whereas ratios calculated from Cominco Ltd. assay data show an upward increase. This indicates that the whole-rock samples came from holes that are either more Zn-rich or have lower Ag and Pb contents.

6.5 Geochemistry of Hydrothermal Alteration

The sub-seafloor hydrothermal fluid discharge that affected the hanging wall during the formation of the I, H, and Hu sulphide zones resulted in the formation of discrete zones of sediment alteration, the distribution, textures, and mineralogy of which were described in Chapters 4 and 5. The chemical compositions of the different alteration zones are used to assess the relative chemical gains and losses that accompanied the formation of the major hydrothermal alteration assemblages. A fully comprehensive quantitative analysis, such as the isocon method (Grant, 1986) or Pearce element ratios (Pearce, 1968), of the hydrothermal alteration that affected the hanging wall was beyond the scope of this thesis; consequently the alteration assemblages were evaluated in a semi-quantitative fashion.

Analysis of hydrothermal alteration consisted of normalizing altered hanging wall meta-sedimentary samples to the average (n=62) bulk-composition of DDH 6464, a regional drill hole (see Figure 3.1), which is considered to represent "least" altered Aldridge Formation meta-sedimentary rocks. Such a plot of the DDH 6464-normalized major and trace element compositions for hanging wall meta-sedimentary rocks and albitites is presented in Figure 6.10. Chemical analyses from this hole were made available by Dr. Wayne Goodfellow, Geological Survey of Canada (Ottawa). In terms of stratigraphic position DDH 6464 extends from the "Sullivan horizon", strata considered contemporaneous with the formation of the Sullivan deposit, up into the basal units of the Middle Aldridge Formation. Thin section analysis of samples from the basal units of DDH 6464 indicated a moderate degree of hydrothermal alteration at the base, with the remainder of the drill hole being unaltered to very weakly altered. Alteration was measured by the presence of tourmaline, sulphide, albite, and chlorite. Muscovite was not included as a measure of alteration intensity since it does not exhibit any significant variation between regional (DDH 6464) and hanging wall samples. Altered samples near the

Figure 6.10. DDH 6464-normalized major and trace element average compositions of hanging wall meta-sedimentary rocks and albitites. DDH 6464 is considered to be representative of least altered Aldridge rocks (data provided by W.D. Goodfellow).

base were excluded before calculating the bulk-composition of DDH 6464. In order to evaluate the effects of hydrothermal alteration by normalizing hanging wall meta-sedimentary rocks to DDH 6464, it was necessary to make the following assumptions:

- i) That the original sediment composition of the hanging wall sediments was not chemically different than the DDH 6464 sediments; therefore, sedimentary processes (*i.e.* grain size effects and sedimentary sorting) were equal for both locations, and the sediments for both areas originated from either the weathering of the same source rock(s) or from different provenance areas that had similar chemical characteristics.
- ii) That diagenesis and weathering effects were the same for both locations.
- iii) That the effects of regional metamorphism were the same for both locations.

In assessing the gains and losses associated with hydrothermal alteration only those elements with DDH 6464-normalized values greater than 2 and less than 0.8 (on the log axis) in Figure 6.10 are considered in this discussion. Normalized data points that fall within this interval are considered to be within the range of analytical error, and therefore, are interpreted to similar elemental concentrations as the “least” altered regional meta-sediments.

Tourmaline Alteration

Tourmaline alteration has resulted in the formation of massive tourmalinite zones and disseminated tourmaline grains in meta-sedimentary rocks, both of which are characterized by a significant increase in B content. Boron contents for tourmaline altered rocks ranges from 1000 to 10100 ppm, as compared to unaltered meta-sedimentary rocks whose B contents are <100 ppm. The Fe_2O_3 content in tourmaline altered rocks is commonly elevated (although variable, ranging from 3.7-24.1 wt%) due to both the incorporation of Fe into the tourmaline structure and close spatial association of tourmaline with biotite. Boron contents are also commonly higher in pelitic rocks as compared to semi-pelites and quartzites/psammites. However, higher B values in

finer grained meta-sedimentary rocks do not coincide with a modal increase in tourmaline content, but are likely due to the absorption of B onto phyllosilicates during hydrothermal alteration (Schwarcz *et al.*, 1969; Spivack *et al.*, 1987; Ishikawa and Nakamura, 1993).

Albite + Chlorite $\pm$ Pyrite Alteration

The chemical gains and losses associated with albite + chlorite $\pm$ pyrite alteration were evaluated using the whole-rock chemistry of eight albitite samples. Albitite chemistry was used since they represented the most pervasively sodic altered rocks within the albite + chlorite $\pm$ pyrite alteration zones.

The chemical composition of hanging wall albitite alteration is characterized by the addition of significant Na, with Na₂O contents ranging from 1.1-8.3 wt%, by contrast the average Na₂O value for hanging wall meta-sedimentary rocks range from 0.13-0.32 wt%. The increase in Na abundance is accompanied by the loss of K, Ba, Rb, and Sr. The loss of these alkali elements is consistent with the replacement of potassium feldspar (of either detrital, diagenetic, or hydrothermal origin) and K-rich phyllosilicates by albite. The albite + chlorite $\pm$ pyrite alteration zone is also characterized by increases in Zn and Pb abundances, which reflect the occurrence of minor amounts of disseminated sphalerite and galena associated with the albite alteration.

Chlorite + Fe-Sulphide Alteration

The chemical characteristics of the chlorite + Fe-sulphide alteration zones were determined using the average composition of pelites. Whilst chlorite + Fe-sulphide alteration has affected the composition of the quartzitic psammites and semi-pelites, the effects of this alteration type are mostly discerned in the pelite samples because of their higher content of phyllosilicate minerals of detrital and/or diagenetic origin.

Chlorite + Fe-sulphide altered rocks are characterized by gains of Fe₂O₃, MnO, and MgO, and losses in CaO, Na₂O, K₂O, and Sr (Figure 6.10) which represent the decomposition of

potassium feldspar and K-bearing phyllosilicates (both of detrital, diagenetic, or hydrothermal origin). Chlorite + Fe-sulphide altered pelites also display a loss of SiO_2 , although the lower contents are not related to destruction of K-rich mineral phases and are likely due to the lower and more variable nature of SiO_2 content that is inherent in pelitic rocks. The chlorite + Fe-sulphide alteration zones are also characterized by elevated Cu, Pb, and Zn contents, which correspond to higher modal abundances of disseminated chalcopyrite, galena, and sphalerite.

Muscovite Alteration

The chemical gains and losses associated with widespread muscovite alteration were assessed using analyses of quartzite/psammite and semi-pelite samples, since muscovite alteration is most common in these rock-types. Although some meta-sandstones and semi-pelite samples have been substantially chloritized, the effect of this alteration is minimized due to the limited number of chlorite altered samples used to calculate the average elemental compositions the two rock types.

The abundances of most major and trace elements in muscovite altered quartzites/psammites and semi-pelites are similar to the average values of DDH 6464, and any variation that exists is within the range of analytical error (Figure 6.10). However, muscovite altered rocks do exhibit gains in MnO, Pb, and Zn, which are accompanied by loss of Na_2O and Sr. The depletion of Na_2O and Sr is consistent with the hydrothermal replacement of potassium feldspar by muscovite. The gain of MnO is largely due to the presence of spessertine garnet, formed as a metamorphic product, although a minor amount may be contributed by Mn contained in biotite, chlorite, and carbonate. Gains of Pb and Zn in the muscovite altered rocks coincide with increases in the modal abundance of galena and sphalerite.

CHAPTER 7: INTERPRETATIONS AND DISCUSSION

7.1 Introduction

There is considerable debate on the origin of SEDEX deposits with researchers favouring either a syn-sedimentary origin where the sulphides represent most sea-floor hydrothermal sediments (*e.g.*, Ramdohr, 1958; Large, 1983; Goodfellow and Jonasson, 1986; Goodfellow, 1987; Turner, 1990), or a post-sedimentary (epigenetic) origin with the sulphides being precipitated from a metal-rich fluid that infiltrated along bedding/cleavage planes and other permeable zones (*e.g.*, Williams, 1978; Neudert, 1984; Perkins, 1984). A similar debate has existed for the Sullivan deposits with arguments favouring an epigenetic origin arising during the mining of the western part of the orebody during the 1930's and 1940's (Swanson and Gunning, 1945; Freeze, 1966), which were followed by a syn-sedimentary model that was originally postulated by Owens (1966). Since the 1970's Cominco geologists have generally favoured a syn-sedimentary model for the origin of the Sullivan deposit (*c.f.* Hamilton *et al.*, 1982). Results from this study support a syn-sedimentary origin for the formation of the hanging wall sulphide zones; with evidence supporting this model presented in the following sections.

7.2 Depositional Processes Involved in the Genesis of the Hanging Wall Sulphide Zones

As stated in the introduction the laminated to bedded sulphides of the hanging wall sulphide zones are interpreted as sea-floor hydrothermal sediments that were most likely deposited contemporaneously with siliciclastic sedimentation. The following is evidence for a syn-sedimentary origin:

1) The lateral extension of mineralization at the Sullivan deposit for several tens of kilometres from the vent site mitigates against a model involving the lateral migration of fluids through the sedimentary pile outward from the zone of fluid up-flow.

2) The hydrothermal sediments that infilled the Sullivan sub-basin (see below) have been subjected to soft-sediment deformation (this study; Ransom, 1994). Examples include: *i*) the laterally continuous laminated pyrrhotite zone proximal to the Main Ore Band and thin quartzite/psammite beds within the hanging wall that represent slump and debris flows; *ii*) mud volcano activity represented by pyrrhotitic psammite unit that overlies the Footwall Conglomerate; and, *iii*) soft-sediment folds within laminated sulphide zones (Plate 4.1).

3) The nature and spatial relationship of the host meta-sedimentary rocks to the hanging wall sulphide zones favours a syn-sedimentary origin. The hanging wall sulphide zones are hosted in fine-grained semi-pelitic to pelitic rocks representative of the very fine-grained silts and pelagic muds associated with the upper part of the Bouma cycle. This lithological relation supports a syn-sedimentary origin on two lines of evidence: *i*) the association of the sulphides with the finer-grained ambient sediments due to the low-dilution effects; and, *ii*) the low permeabilities associated with the silts and pelagic muds that would not readily allow for the lateral movement of metalliferous hydrothermal fluids, as opposed to arenaceous sediments which have much higher permeabilities. Consequently, if hanging wall sulphides were formed by hydrothermal replacement it would only seem reasonable to find the great volume of sulphide mineralization in the most permeable rocks (*i.e.* sandstones and coarse-grained siltstones) (*e.g.* Mount Isa deposits, see Neudert, 1984). As stated above this is not the case, although it could be argued that infiltration of post-sedimentary hydrothermal fluids occurred along bedding planes within siltstone and shales.

4) The morphology or architecture of the hanging wall sulphide zones, in particular the Hu ore, favours a syn-sedimentary origin. The stratigraphic change in sulphide macro-texture from disseminated sulphides at the base of the sulphide zone grading into finely laminated sulphide and silicate rock to banded/massive sulphide in the middle of the sulphide zone that grade into a second laminated and disseminated sulphides at the top of the zone (see Chapter 4) is typically of sulphide precipitation from the water column. The increase in sulphide content up-section indicates a gradual increase in hydrothermal activity with the peak activity represented by the banded to massive part of the sulphide zone, with the second laminated-disseminated zone representing the waning and eventual cessation of sulphide precipitation. Hydrothermal replacement processes would not produce this well developed textural zonation, but rather would reflect the differential permeability of the host rock.

5) The tourmalinite breccia vent complex is restricted to stratigraphic levels containing stratiform sulphides (*i.e.* the tourmaline breccia does not extend above the Hu sulphide zone (Shaw *et al.*, 1993)) and to underlying footwall rocks. The stratigraphic relation indicates that hydrothermal activity corresponds to syn-sedimentary sulphide deposition, whereas if a post-sedimentary replacement model is assumed it would be expected that the feeder system would have extended into the overlying meta-sedimentary rocks (see Goodfellow *et al.*, 1993).

6) A syn-sedimentary origin for the alternating pyrrhotite-dominant bands with sphalerite + galena-dominant bands within hanging wall sulphide zones is consistent with Lydon (1983) who attributed the origin of mono-mineral banding to sulphide deposition from a brine.

7) The presence of sedimentary textures including compositional layering parallel to bedding in the enclosing meta-sedimentary rocks. While infiltration along bedding planes may produce a layer that resembles bedding, an infiltrational model is considered unlikely due to the morphology of many of the sulphide laminae/bands. Individual sulphide laminae commonly

have sharp bases which represent the rapid onset of hydrothermal fluid, although the tops are diffuse and grade into the overlying silicate band. This is consistent with sulphide precipitation from a sea-floor brine where the sharp bases represent the rapid onset of hydrothermal fluid discharge that caused a sudden precipitation of sulphides which settled to the sea-floor, followed by the slow settling of remaining sulphides in the water column. If the individual sulphide laminae represented post-sedimentary infiltration, they would be symmetrically distributed about the lateral conduit. The gradational nature of sulphide laminations from the hanging wall of the Sullivan orebody is similar to other deposits such as Howards Pass (Goodfellow and Jonasson, 1986) and the Red Sea deposits (*e.g.*, Bischoff, 1969; Hackett and Bischoff, 1973).

8) The asymmetric stratigraphic metal zonation within the hanging wall and within individual sulphide zones is consistent with a syn-sedimentary model (see Goodfellow *et al.*, 1993). This zonation consists of an upward increase of $Zn/(Pb+Zn+Fe)$ and a decrease in $Pb/(Pb+Zn+Fe)$ which reflects the relative abundances of sphalerite-galena-pyrrhotite/pyrite, and may be dependent on temperature, pH, and chloride/sulphide ratio of the fluid (*e.g.*, Anderson, 1973). Consequently this asymmetric zonation reflects the chemical evolution of an ore-forming fluid which precipitates higher temperature metal sulphide assemblages (chalcopyrite-pyrrhotite-galena) at the base of the sulphide zones and lower temperature assemblages (galena-sphalerite) at the top of the zones in response to decreasing temperature. This asymmetric zonation is not consistent with a replacement model, which would be more homogeneous.

7.3 Sulphide Formation and Overprinting Effects of Hydrothermal Alteration

7.3.1 Nature of the Mineralizing Hydrothermal Fluids

7.3.1a Composition of Sullivan Hydrothermal Fluids

Fluid inclusion work by Leitch (Leitch, 1991,1992; Leitch and Turner, 1991,1994) has identified at least five different fluids trapped within quartz, carbonate, sphalerite, albite,

cassiterite, and tourmaline. The composition of these fluids can be related to the ore-forming stage, post-ore hydrothermal alteration, and post-hydrothermal events.

Ore-Forming Fluids

Of particular interest for this study are the fluids responsible for ore deposition and subsequent hydrothermal alteration. The presence of Fe-, Pb-, Zn-, Ag-bearing sulphides and associated tourmaline alteration at Sullivan orebody indicates that the ore-forming fluids had to be enriched in Pb, Zn, Fe, Ag, B, Cl, and possibly S (see below). These mineralizing fluids (or slightly modified versions) are possibly represented in secondary or pseudosecondary inclusions in quartz, sphalerite and carbonate from pyrrhotite + quartz + Fe-carbonate veins that cross-cut the feeder zone tourmalinite (Leitch, 1992). These inclusions indicate high salinities for the ore-forming fluids (15-32 wt% NaCl $\pm$ CaCl₂ $\pm$ MgCl₂?) and yielded temperatures ranging from 200-415°C (Leitch, 1991, 1992; Leitch and Turner, 1994). Variations in the chemical composition of these inclusions may indicate that in places the fluids were diluted or reset by metamorphism (Leitch, 1992).

While the dispersive nature of the ore-forming fluids (see Sato, 1972) is uncertain, a brine pool model is generally favoured over a buoyant plume model (*i.e.* Lydon and Sullivan Project Working Group, 1994; Leitch, 1992). A stratified brine pool model, that is analogous to modern Red Sea metalliferous brines, is supported by the following lines of evidence:

- i) physio-chemical nature of Sullivan ore fluids with temperature of 200-300°C and salinities of 15-27 wt% are similar to the temperatures and salinities of Red Sea brines (<420°C, 13.5-25.6 wt%; Ramboz *et al.*, 1988);
- ii) sheet-like nature of the deposit as a whole and of the individual sulphide zones;
- iii) finely bedded to laminate nature of the hanging wall sulphide zones and bedded ore facies;

- iv) lateral continuity of sulphide beds and laminae (individual beds can be followed up to 2 km; Hamilton *et al.*, 1982); and,
- v) occurrence of mono-mineralic laminations/bedding that represent the slow cooling of a brine pool, as opposed to quenching in a "black smoker"-type systems (*i.e.* Middle Valley)

Post-Ore Hydrothermal Fluids

Post-ore hydrothermal fluids responsible for the extensive zones of albite + chlorite $\pm$ pyrite alteration were compositionally different than the ore forming fluids. The formation of the albite + chlorite $\pm$ pyrite alteration zones reflect a mixing between Na- and Cl-rich hydrothermal fluids and seawater during emplacement of Moyie sills (Shaw *et al.*, 1993; Leitch and Turner, 1994). Unlike the ore-forming fluids, these albitizing fluids were depleted in base metals, as indicated by the general absence of base metal sulphides within zones of albite + chlorite $\pm$ pyrite alteration zone. Secondary inclusions in quartz and primary inclusions in recrystallized tourmaline associated with albite + chlorite $\pm$ pyrite alteration indicate that these fluids had temperatures of 250°C and salinities ranging from 10-20 wt% NaCl $\pm$ KCl (Leitch, 1992; Leitch and Turner, 1994).

Post-Hydrothermal Fluids

Post-hydrothermal fluids are of syn- to post-metamorphic origin and consist of: i) secondary liquid-rich, low-temperature (90-150°C), inclusions, with salinities of 3-20 wt% NaCl (Leitch, 1992); and, ii) low-salinity (<5 wt% NaCl) and moderate temperature (300°C) inclusions with variable CO₂ + CH₄ found in quartz-carbonate veins that cross-cut Mesozoic folds and intrusive rocks (Leitch and Turner, 1994).

7.3.1b Origin of Sullivan Hydrothermal Fluids

Isotopic studies of $\delta^{18}\text{O}$ (Nesbitt *et al.*, 1984; Beatty *et al.*, 1988) and Pb-Pb (Godwin and Sinclair, 1982) indicate that the Sullivan ore-forming fluids were derived from the sedimentary pile or sialic crystalline basement. In order for metals to be leached the host mineral has to be destroyed or recrystallized either by metamorphic or metasomatic reactions within the reaction zone of the hydrothermal system (*c.f.* Goodfellow *et al.*, 1993). Metamorphic reactions respond to pressure-temperature changes and are driven by mineral-mineral disequilibrium. These reactions occur at low fluid/rock ratio and typically involved the transformation of muds/clays to more ordered micas (*i.e.* montmorillonite to illite-smectite). On the other hand, metasomatic reactions are driven by chemical disequilibrium and occur at high fluid/rock ratios. The difference between the two types of reactions is the concentration of metal that can leach from the host rock and be carried by the hydrothermal fluid. Metasomatic reactions produce low concentrations (1-2 ppm) of dissolved metals in the fluid (Lydon, 1986), whereas metamorphic reactions can produce a fluid with several thousand parts per million of dissolved base metals (Lydon, 1983, 1986). Consequently, Goodfellow *et al.* (1993) suggest that sialic crystalline basement rock would not be reactive enough (due to the stability of the quartz + feldspar + mica assemblage over a wide range of pressures and temperatures) under metasomatic conditions in order to produce sufficient metal contents for ore formation. Therefore, only the pore fluids associated with the sedimentary pile, undergoing the first phase of burial and metamorphism, are able to produce hydrothermal fluids with sufficient concentrations of Pb and Zn (Goodfellow *et al.*, 1993).

The Zn/(Zn+Pb) ratio is indicative of the nature of the deposit's hydrothermal reservoir (Lydon, 1983). Zn/(Zn+Pb) ratios >0.95 indicate that the hydrothermal fluids originate from an immaturely leached reservoir, with ratios ranging from 0.75-0.95 indicate leaching from a

maturely leached reservoir. While $Zn/(Zn+Pb)$ ratios were not calculated for the hanging wall sulphide zones, $Zn/(Ag + Pb + Zn)$ ratios are considered to be representative of the $Zn/(Zn+Pb)$ since Ag values are extremely low. Average $Zn/(Ag + Pb + Zn)$ ratios for the hanging wall sulphide zone range from 0.39 (H "ore") to 0.74 (I laminations and Hu ore) (values from Table 6.3), indicating that the hydrothermal fluids were derived from a maturely leached reservoir.

The stratigraphic association of metamorphosed evaporites, red alluvial fan paraconglomerates, tidal bedding, and shelf limestones (Goodfellow and Chandler, 1994), occurrence of syn-depositional faults within the deposit (Höy, 1982, 1989), and spatial association of gabbroic Moyie sills (and the likelihood of a co-existing mafic magma chamber) indicate that the ore-forming fluids for the Sullivan orebody could have evolved by the following scenarios (*c.f.* Goodfellow *et al.*, 1993):

i) Burial and compaction of evaporite-bearing argillaceous sediments, where thermal metamorphic reactions are driven by increasing burial temperature. Ore metals then would be leached from clay minerals during dehydration transformations with additional leaching from fluids that originated from the dissolution of evaporites.

ii) Metalliferous fluids that form within the sedimentary sequence that contains highly saline formation waters in which metal leaching reactions are driven by the heat arising from a high-level magma body.

iii) Subsidence of an intracratonic rift permitting a marine transgression where the syn-rift fill clastic sediments are overlain by marine argillaceous and carbonate sediments. Metals may be leached from oxide coating mineral grains of red beds within the rift-filled clastic sequence or from the marine sedimentary sequences proposed in scenarios (*i*) and (*ii*).

7.3.1c Fluid Flow

Fluid flow within a hydrothermal reservoir is slow and largely dependent on stratal zones of high permeability. Rapid up-flow and surface exhalation occurs when a cross-strata zone of permeability is formed (*i.e.* breccia pipes and/or syn-depositional faults). The up-flow of metalliferous fluids that formed the hanging wall sulphide zones of the Sullivan deposit can be explained by the following models:

Stratal Aquifer Model

The stratal aquifer (Lydon, 1983) model consists of a syn-rift clastic sequence that is capped by basinal argillaceous sediments (similar to the subsiding intracratonic rift model scenario above). The basinal sediments act as a relatively impermeable cap rock that restricts upward fluid flow from the more arenaceous clastic sequence, retards conductive and convective heat loss, and geopresses the hydrothermal reservoir (= clastic sequence). Up-flow occurs when the cap rock is ruptured by extensional faulting. Cathles and Smith (1983) determined that hydrothermal discharge would be episodic because of the increase of pore-fluid pressure during compaction, with fluid discharge coinciding with fault movement.

The stratal aquifer model is consistent with the geology of the Purcell Basin and Sullivan orebody in the following ways: *i)* argillaceous cap rocks may be represented by the argillaceous rocks of the lower Aldridge Formation; *ii)* since the base of the Purcell Supergroup is not exposed, the existence of arenaceous hydrothermal reservoir rock can not be ruled out; *iii)* the deposit occurs at the intersection extensional faults (*i.e.* Kimberley and north-trending faults; see Leitch *et al.*, 1991) which provide cross-stratal permeability; and, *iv)* the alternation of sedimentary sulphide units and meta-sedimentary rock with the Sullivan orebody is consistent with the episodic nature of fluid discharge, where the meta-sedimentary units representing

geopressuring of the hydrothermal reservoir and the sulphide representing periods of fluid discharge.

Seismic Pumping Model

The seismic pumping model (Sibson *et al.*, 1975) uses a tectonic energy source for the circulation of hydrothermal fluids. Fluid flow is initiated along active fault zones, where there is an increase in tectonic stress that causes dilation in adjacent rocks, allowing fluids to move into this low-pressure zone. Once in the low-pressure zone, fluids are forced upward along the fault plane and discharged onto the sea-floor.

The seismic pumping model is supported by the location of the Sullivan orebody, which is situated at the intersection of north-trending syn-depositional faults within the Sullivan-North Star corridor and the Kimberley fault (Höy, 1989; Leitch *et al.*, 1991; Ransom, 1994; Turner and Leitch, 1994). Turner and Leitch (1994) suggest that the vent complex underlying the Sullivan orebody was controlled by these north-trending syn-depositional faults.

Convection-Cell Model

The convection-cell model (Russell *et al.*, 1981; Russell, 1983) is based on the downward-movement of sea water along extensional faults where it becomes heated and undergoes chemical exchange with basin sediments and sialic rocks, producing the hydrothermal fluid. The hydrothermal fluids are then brought to the sea-floor along the upward-propagating flow path (*i.e.* along faults) of the convective cell. The convective-cell model does not require the occurrence of a high-level magma chamber to drive convection; however, this model has been modified with the addition of a magma body to describe the circulation pattern of hydrothermal fluids that formed the sulphide deposits in Middle Valley (Goodfellow *et al.*, 1990) and the Guaymas Basin (Einsele *et al.*, 1980).

While the remnants of a mafic magma chamber underlying the Sullivan orebody have not been identified, its existence can be inferred from the presence of gabbroic Moyie sills. Therefore, it can be inferred that the Sullivan hydrothermal system had a heat source that could drive convection. While there is a general lack of cross-stratal permeability associated with sediments, the presence of syn-depositional faults (Höy, 1989; Leitch *et al.*, 1991; Turner and Leitch, 1994) likely would have provided sufficient cross-stratal permeability to introduce seawater to the system and to discharge hydrothermal fluid onto the sea floor. Furthermore, it is possible that the fluids could have originated from several hundreds of kilometres away (analogous to the fluids associated with the Red Sea hydrothermal system) and migrate along zones of stratal permeability.

7.3.2 Role of Seawater

Present-day end-member ore-forming fluids that are venting at mid-ocean ridges are depleted in Mg and SO_4^{2-} (e.g., von Damm *et al.*, 1985; von Damm and Bischoff, 1987; Butterfield *et al.*, 1993). Therefore, an alternative source of Mg and reduced S are required, with seawater being the most likely source for these chemical constituents.

Assuming that Sullivan hydrothermal fluids were also Mg-depleted, the chlorite alteration must reflect the entrainment of Mg-rich seawater that mixed with the up-flowing hydrothermal fluid, or was conductively heated until Mg precipitated. The laterally extensive, semi-conformable nature of these alteration zones and their close spatial relation to hanging wall sulphide zones and tourmalinite breccia bodies support these two inferences. Further evidence for a seawater source of Mg is $\delta^{18}\text{O}$ (0-4‰) values for the chlorite + Fe-sulphide alteration assemblage, which are similar to present-day ocean water (Taylor *et al.*, 1994).

The ore-forming fluid may carry its own H_2S in order to form sulphides; however, this results in a decrease of the fluid's capacity to transport base metals in solution. Alternatively, the

reduced S originated from the ambient anoxic water column and metal sulphides were precipitated upon mixing of the hydrothermal fluid with seawater. Sulphur isotope studies by Campbell *et al.* (1978) yielded $\delta^{34}\text{S}$ values for individual sulphide minerals that ranged from -10.4 to 4.7‰ (average -2.2‰). They also recorded variations in $\delta^{34}\text{S}$ values at ore - waste contacts implying that sulphide deposition was controlled by the supply of H_2S rather than the supply of metals. Work by Goodfellow (Goodfellow and Chandler, 1994; Goodfellow, 1994) showed an upward increase in $\delta^{34}\text{S}$ values for pyrrhotite that occurred throughout several cycles (approaching 15‰ in one cycle), and indicated the following water column conditions: *i*) high sulphate levels (= marine conditions); and, *ii*) reducing H_2S bottom waters, with a temporal increase in the extent of sulphate reduction. Campbell *et al.* (1978) interpreted that the S source is the biogenic and chemical reduction of seawater sulphate at the time of sulphide deposition, with the isotopic composition being controlled by basin geometry and temperature. Isotopic studies of SEDEX deposits from the Selwyn Basin, Yukon, indicate a seawater source for S (see Goodfellow, 1987; Shanks *et al.*, 1987; Goodfellow and Rhodes, 1990). As for the Sullivan orebody the relative contributions of S from hydrothermal fluids and ambient seawater remain to be determined (Goodfellow and Chandler, 1994; Goodfellow, 1994), although it appears that none of the S or other elements enriched in Sullivan hydrothermal fluid are in whole or in part of magmatic origin (W.D. Goodfellow, *personal communication*, 1995). Further evidence for a seawater S source is the inverse relationship that exists between a fluid's capacity to transport Zn and Pb with its S content (*i.e.* more hydrothermal S = less metals in fluid) (*c.f.* Goodfellow *et al.*, 1993). Also in order for a hydrothermal fluid to transport metals and reduce S, fluid temperatures need to be in the order of 380°C (Large, 1983). However, in the case of Sullivan, ore-forming fluid temperatures are estimated to have been 300°C (Leitch, 1991; Leitch and

Turner, 1991), which would imply that the Sullivan ore-forming fluid temperature was not high enough to carry sufficient concentrations of reduced sulphide S.

7.3.3 Genetic Model for the Hanging Wall Sulphide Zones

Formation of the hanging wall sulphide zones and evolution of the Sullivan deposit can be describe in terms of four stages: *i*) basin formation and infilling; *ii*) ore-formation; *iii*) post-ore hydrothermal alteration; and. *iv*) post-hydrothermal sedimentation and metamorphism - deformation.

Stage 1: Basin Formation and Sedimentation

The Belt-Purcell is a Meso-Proterozoic intracratonic rift basin (supported by whole-rock trace element geochemistry, this study) that formed along the western margin of the Proterozoic North American craton (see Chapter 2). Normal faulting and subsidence within the basin created smaller second and third order basins, and triggered turbidity currents that deposited the sands, silts, and muds of the lower Aldridge Formation. During this time, a mafic magma ascended upward leading to the intrusion of Moyie sills into unlithified and wet Aldridge sediments (Höy, 1989).

Stage 2: Ore Formation (Figure 7.1a)

Boron-, Pb-, Zn-, Ag-, Fe-, Cu-, and Cl-rich hydrothermal fluids (see Leitch, 1991; Leitch and Turner, 1991) derived from deeply buried formational waters beneath the current stratigraphic level of the Sullivan deposit (see above) ascended upwards to the sea-floor along basin-parallel, north-trending faults. Developed along these north-trending faults were the tourmalinite breccia zones (= feeder zone) of the Sullivan orebody that formed in response to the up-flow of hydrothermal fluid (Figure 7.1a). The formation of massive tourmalinite is interpreted to represent the sub-surface lithification of sediment that was subsequently brecciated when pressures exerted by the up-flow of hydrothermal fluids were sufficiently high to hydraulically

Figure 7.1a. Idealized section showing the attributes of the Sullivan hydrothermal system during the "ore-stage" (see text), including hydrothermal up-flow along syn-sedimentary faults, development of the underlying tourmalinite breccia zones (feeder system), discharge of fluids as a stratified brine and precipitation of metal sulphide sediments, and the lateral and downward entrainment of seawater in the formation of muscovite and chlorite + Fe-sulphide alteration zones.

fracture the lithified crust and discharge ore-forming fluids onto the sea-floor. This lithification - brecciation cycle is analogous to the fracturing of lithified sediments at modern vent sites such as Middle Valley (W.D. Goodfellow, *personal communication*, 1995). On the other hand, stratiform zones of disseminated tourmaline alteration reflect the reaction between B-rich fluids entrained in the sub-surface and aluminous sediments (Slack, 1993). Tourmaline alteration (either massive tourmalinite or disseminated tourmaline) was primarily restricted to the intercalated siliciclastic sediments, since sulphide-rich hydrothermal sediments lack sufficient Al_2O_3 for crystallization of tourmaline. These discordant zones of massive to brecciated tourmalinite represent extensive replacement of host lower Aldridge Formation sediments.

The episodic discharge of metalliferous hydrothermal fluids occurred during periods of low turbiditic sedimentation, that is represented by the alternation of sulphide zones and meta-turbidite sequences. The origin of individual sulphide laminae within a sulphide zone can be attributed to cycles of hydrothermal discharge - quenching - differential nucleation and settling within a brine pool (Lydon, 1983). The silicate interlayers within sulphide laminated zones indicate periods where hydrothermal discharge was minimal and sedimentation was dominated by silts and pelagic muds. The presence of mono-mineralic sulphide laminae and the zonation within an individual sulphide zone (upward increase in Zn) is consistent with sulphides primarily being precipitated in response to conductive cooling within a brine pool (Lydon, 1983), which is analogous to the Red Sea hydrothermal system. If sulphides precipitated in response to the rapid mixing between seawater and hydrothermal fluid the result would be the creation of polymetallic sulphide laminae. The precipitation of metal sulphides is further influenced by: *i*) decrease in temperature on mixing with cooler seawater (Anderson, 1973; Russell, 1983; Lydon, 1983); *ii*) dilution of the solution, decreasing its chloride concentration (Anderson, 1973; Large, 1983); *iii*) increase in pH with seawater mixing (Anderson, 1973); and, *iv*) increase in the concentration

of reduced sulphur (Anderson, 1973; Large, 1983), provided from a stratified, H_2S -saturated water column (Goodfellow and Jonasson, 1986). The gradual upward increase in Zn within an individual hanging wall sulphide zone (Figures 6.4, 6.6, and 6.7) is interpreted to represent the thermal evolution and waning of a single episode of hydrothermal activity. Early stages of discharge are characterized by high-temperature fluids that precipitate the high temperature sulphide assemblages (chalcopyrite and pyrrhotite $\pm$ galena). The increased mixing of hydrothermal fluid with seawater, causes a gradual decrease of temperature with time and results in the precipitation of lower temperature sulphides (sphalerite + galena). Eventually, decreases in fluid discharge rates, temperatures, and metal concretions result in a termination of sulphide deposition and the hydrothermal system enters a period of low or zero hydrothermal discharge.

While a syn-sedimentary origin is favoured for the hanging wall sulphide zones there is evidence to indicate the outward flow from the feeder system of metalliferous fluids through the sedimentary pile. For example, the occurrence of euhedral pyrite distributed along bedding planes and in veins that cross-cut the meta-sedimentary interlayer between sulphide zones is supportive of infiltration processes. The occurrence of disseminated sulphides (primarily pyrrhotite and sphalerite) within meta-sedimentary units may have been precipitated as a result of fluid circulation through the sedimentary pile, although it is possible that some of these disseminated sulphides were precipitated from the water column during the initial and/or waning stages of hydrothermal discharge. Infiltration of metalliferous hydrothermal fluids along permeable zones appears to be temporally constrained by the on-set of ore deposition and ceased by the start of stage 3 (see below) due to the absence of base metal sulphides within the albite + chlorite $\pm$ pyrite alteration zones. While there are traces (<1 vol%) of base metal sulphides within the albite + chlorite $\pm$ pyrite alteration zones, their presence may be due to post-ore redistribution associated with zone refinement processes (see below).

On figure 6.5 and 6.8 localized areas that display a concentric zonation of grade-foot isopleths are interpreted to represent sea-floor vents for the discharge of hydrothermal fluid that formed the hanging wall sulphide zones. These “vent sites” coincide within the areas outlined by the tourmaline breccia, indicating that the breccia bodies acted as feeder pipes for hanging wall fluids that formed the hanging wall sulphide zones. The lateral offset between vent sites for the I and Hu sulphide zones (Figures 6.5 and 6.8) indicates that fluids followed different up-flow conduits. The apparent lateral migration of vent sites likely is the result of “choking” of the up-flow/discharge conduits by the precipitation of hydrothermal phases within permeable zones, resulting in the sealing of the discharge conduit. Re-opening of up-flow conduits would result when fluid pressures increased to a level necessary to fracture the rock. This migration of vent sites is consistent with the cross-cutting nature of tourmalinite breccia bodies (Shaw *et al.*, 1993). Based on isopach maps (Figure 4.9-10) and grade-foot isopleth maps (Figures 6.5,8) sulphides accumulated along the flanks of the breccia bodies and the area between the two north-trending breccia bodies along the transition zone. The thickest part of each sulphide zone corresponds to the location of the vent site, due to the precipitation of sulphides near the vents. The accumulation of sulphides along the flanks of the breccia bodies may represent the following: *i*) a sulphide apron formed by the slumping of sulphide down the sides of hydrothermal mound (analogous to Middle Valley, see Goodfellow *et al.*, 1993); or, *ii*) movement of a dense bottom-hugging brine that follows bathymetric contours depositing sulphides in areas of low sea floor relief (*i.e.* Red Sea brines, see Bischoff, 1969).

The formation of extensive muscovite and semi-conformable chlorite + Fe sulphide alteration zones represents the mixing of hydrothermal fluid with entrained seawater within the sedimentary pile, and formed after the initiation of hydrothermal circulation. However, their temporal constraints are not solely dependent on the sea floor expulsion of hydrothermal fluid,

but rather are related to the trapping of heated pore waters during sulphide sedimentation or to the lateral inflow of heat seawater through the sedimentary pile. While chlorite altered rocks display significant enrichment of Mg from seawater (see arguments above), muscovite altered rocks do not show any K-enrichment (see Figure 6.10). This lack of K-enrichment indicates that muscovite alteration resulted from the breakdown of detrital potassium feldspar, and transformation of detrital and diagenetic clays and early low-temperature phyllosilicates (*i.e.* illite) to muscovite, as opposed to the addition of K from hydrothermal fluids. This is analogous to the muscovite alteration associated with the hydrothermal vents at Middle Valley (Goodfellow and Peter, 1993; Leybourne and Goodfellow, 1993).

Stage 3: Post-Ore Hydrothermal Alteration (Figure 7.1b)

Post-ore hydrothermal alteration consisted of the up-flow of Na-rich fluids that upon mixing with entrained seawater resulted in the formation of extensive zones of albite + chlorite $\pm$ pyrite alteration. The association of albite + chlorite $\pm$ pyrite alteration with gabbro Moyie sills beneath the Sullivan orebody indicate that the sills may have been a source for Na and CO₂, and the sills may have acted as conduits for the flow of these albitizing fluids (Turner and Leitch, 1992; Shaw *et al.*, 1993). Zones of tourmaline alteration are cross-cut albite + chlorite $\pm$ pyrite alteration, indicating that the albitizing fluids likely used the tourmalinite breccia pipe as a conduit for the upward migration of albitizing fluids into the hanging wall (see Turner and Leitch, 1992). Furthermore, cross-cutting relations within the hanging wall sulphide zones support the interpretation that these albitizing fluids are a late-stage, post-ore hydrothermal event. During their ascent through the main ore zones within the western part of the deposit the albitizing fluids mobilized Pb and Zn, producing the massive pyrite replacement zone within the main ore zones (see Hamilton *et al.*, 1982; Shaw *et al.*, 1993; Paakki *et al.*, 1995) and localized Pb-Zn enrichment of the hanging wall sulphide zones. Lead-Zn remobilization is supported by

Figure 7.1b. Idealized section showing the attributes of the Sullivan "post-ore" hydrothermal stage (see text), including hydrothermal up-flow of Na-rich fluids (related to Moyie sill intrusion) along pre-existing faults and through the tourmalinite breccia zones (feeder system), and formation of zones of albite + chlorite $\pm$ pyrite alteration resulting from the mixing of hydrothermal fluid and entrained seawater. Note the cross-cutting relationship between albite + chlorite $\pm$ pyrite alteration and sulphide zones (both HWSZ and MOZ), tourmalinite, muscovite, and chlorite + Fe-sulphide alteration

Explanation:

HWSZ - Hanging wall sulphide zones

MOZ - Main ore zones

the occurrence of zoned albite + sphalerite $\pm$ galena veins which cross-cut albite + chlorite $\pm$ pyrite and chlorite + Fe-sulphide alteration zones and meta-sedimentary rock. The rare occurrence of base metal sulphides within albite + chlorite $\pm$ pyrite altered units indicates that these fluids did not carry significant amounts of base metal sulphides, and any sulphide associated with this event was locally mobilized from elsewhere in the deposit.

Stage 4: Post-Sullivan Sedimentation, Metamorphism, and Tectonic Deformation

Post-hydrothermal events involved the deposition of post-Aldridge Formation, Purcell Supergroup, post-Purcell Proterozoic, and Paleozoic sediments, and multiple episodes of regional metamorphism and tectonic deformation (see Chapter 2, *e.g.*, McMechan *et al.*, 1980; McMechan, 1981; McMechan and Price, 1982; Höy, 1982, 1989, 1993). The effects of regional metamorphism and tectonic deformation as they relate to the evolution of the hanging wall sulphide zones are discussed below.

i) Metamorphism

As described in Chapters 4-6, hanging wall sulphide zones have undergone variable modification that post-dates sedimentation, primary sulphide deposition, and subsequent hydrothermal activity. Regional greenschist metamorphism (see DePaoli and Pattison, in press) has affected the hanging wall sulphide zone in the following manner: *i*) an increase in grain size resulting from the extensive recrystallization of sulphide and non-sulphide minerals (*i.e.* pyrrhotite, sphalerite, and quartz) that have developed polygonal grain textures; *ii*) textural transformation of hydrothermal products (*i.e.* chlorite and muscovite; see below); *iii*) localized redistribution of sulphides (primarily galena redistribution along bedding/cleavage planes); and *iv*) growth of metamorphic minerals including spessartine, clinozoisite, biotite (partly detrital?), and tremolite.

The origin of the two textural varieties of hydrothermal muscovite and chlorite is considered to represent a metamorphic recrystallization of fine-grained hydrothermal minerals (sericite and green-chlorite) and did not originate by some other process. This inference is supported by mineral chemistry, where the chemical compositions of coarser grained muscovite is similar to that of sericite and white chlorite is compositionally similar to green chlorite (A. Conly, unpublished data).

While the textural and mineralogical effects of metamorphism are extensive, the chemical effects are relatively insignificant because the metamorphic reactions appear to behave isochemically (*i.e.* no significant change in whole-rock chemistry). Since metamorphic reactions are driven by mineral-mineral disequilibria, it is possible for these reactions to behave isochemically as long as system is closed to fluid transfer. Evidence for isochemical reactions include: *i*) the preservation of original metal within the hanging wall sulphide zones, that are consistent with other SEDEX deposits (see Goodfellow *et al.*, 1993); and, *ii*) lack of homogenization of hanging wall rocks and associated of discrete zones of hydrothermal alteration; for high fluid/rock reactions would be suspected to chemically homogenized hanging wall rocks and result in the obliteration of discrete hydrothermal alteration zones.

ii) Tectonism

Post-sedimentary tectonic activity (see Chapter 3 and 4; McClay, 1983) has affected the hanging wall sulphide zones in the following manner: *i*) vertical displacement of sulphide zones along "Sullivan-type" faults and thrust faults; *ii*) development of polyphase folds; and, *iii*) possibly, the injection of discordant Hu sulphides into host rocks along the transition zone. The first two structural features have been described in the body of the thesis and will not be commented on further; therefore, the discussion in this section will be restricted to the formation of the discordant Hu sulphide structures. The gross morphology and sulphide textures of these

discordant structures have been described in Chapter 4 as well as by Paakki *et al.* (1995). The development of these structures can be attributed to the nature of the transition zone, which marks the boundary between massive sulphides to the west and bedded sulphide to the east, as well as marking the eastern most extent of tourmalinite alteration. This change in sulphide texture also represents a change in the competency of the rock, where the massive sulphide ores to the west of the transition zone are more easily deformed (in response to the ductile behavior of sulphides) as compared to the bedded ores which are more competent due to the presence of silicate interbeds (see McClay, 1983). Unfortunately, the inaccessibility to stope_s that transect these structures and the lack of detailed structural data in Cominco Ltd. stope maps do not permit a precise interpretation of the development of these discordant structures. What can be clearly stated is that the eastern-most extent of these discordant zones consist of stratiform bedded sulphides of syn-sedimentary origin (see arguments above), while the western part of these structures consist of ductility deformed sulphides (*e.g.*, *durchbewegt* textures). Therefore, these structures appear to have formed by at a two-stage process, consisting of: *i*) the deposition of sedimentary sulphides; and, *ii*) the subsequent ductile deformation of these stratiform sulphides. The timing of this deformation event is uncertain. However, assuming that these discordant structures were formed in response to translation of the hanging wall over the footwall (see McClay, 1983), the timing can be constrained to post-Sullivan hydrothermal activity. The offset between footwall albite + chlorite + carbonate and hanging wall albite + chlorite ± pyrite alteration zones is interpreted to be the result of hanging wall translation over the footwall (see McClay, 1983; Paakki *et al.*, 1995).

7.4 Genetic Relationship Between the Hanging Wall Sulphide Zones and the Main Ore Zones

The formation of the hanging wall sulphides zones and associated hydrothermal alteration represents the waning stages of the "ore-forming" stage of the Sullivan hydrothermal system. Waning of sulphide depositional processes is inferred on two lines of evidence. First, Zn content and $Zn/(Pb + Zn + Fe)$ ratios display a gradual increase upward from the D Band within the main ore zones to the Hu sulphide zone in the hanging wall (see Figure 6.9). This asymmetric stratigraphic zonation is consistent with a gradual decrease in the thermal energy of the hydrothermal system. Therefore, sulphides within the main ore zones are more Cu-, Fe-, and Pb-rich than hanging wall sulphides which are more Pb- and Zn-rich, since the fluids responsible for depositing the hanging wall sulphide zones lack sufficient temperatures to transport higher temperature metals, such as Cu (see Lydon, 1983). A decrease in sulphide-forming hydrothermal activity is supported by the relative proportion of sulphide rock to intercalated meta-sedimentary rock. The main ore zones are dominated by sulphide rock with only thin accumulations (<2.5 m, see Figure 3.4) of sediment; however, the hanging wall is characterized by the development of thick (5-38 m) Bouma-cycle turbidite sequences with relatively thin (<5 m) accumulations of syn-sedimentary sulphide between the sequences. The difference in the distribution of detrital and hydrothermal sediments between the main ore zones and the hanging wall may be indicative of the following: *i*) siliciclastic sedimentation was more dominant during the formation of the hanging wall sulphide zones, with the influx of turbiditic sediments occurring during reactivation of faults during periods of tectonic instability within the Purcell basin; and, *ii*) periods of hydrothermal fluid discharge were relatively long and more frequent. The above arguments assume that the metalliferous fluids that were responsible for the deposition of the hanging wall

sulphide zone were derived from the same source reservoir, and therefore, represent a continual evolution of a hydrothermal system.

The formation of extensive zones of albite + chlorite + carbonate $\pm$ pyrite alteration in the footwall and main ore zones and albite + chlorite $\pm$ pyrite alteration in the hanging wall represents the termination of the Sullivan hydrothermal system. The absence of base metal sulphides within these zones possibly indicate that fluid temperature were insufficient to transport significant concentration of metals, or the fluid source reservoir was depleted. Although, as discussed above, the formation of the massive pyrrhotite core within the main ore zones in the western part of the deposit may be the result of up-flow of albitizing fluids that remobilized Pb and Zn, subsequently enriching the hanging wall. Assuming post-ore enrichment of the hanging wall occurred, the present metal zonations do not reflect the original sedimentary zonation. However, the asymmetric zonation defined by an upward increase in Zn is consistent with a temperature evolution of the ore-forming fluid.

CHAPTER 8: CONCLUSIONS

The Sullivan orebody is a Meso-Proterozoic, metamorphosed, poly-deformed, stratiform to stratabound, syngenetic, Fe-Zn-Pb-Ag sulphide deposit hosted within a succession of meta-turbidite deposits near the contact between the lower and middle Aldridge Formations.

The hanging wall of the Sullivan orebody consists of all sulphide, meta-sedimentary, and altered rock that stratigraphically overlie main ore zone (see Figure 3.4). Hanging wall meta-sedimentary rocks define five coarsening upward sequences (I, H, hu, Hu, and U sequences), and consist of high-energy turbidites, represented by thin basal quartzite to quartzitic psammite units that grade upward into semi-pelite rock, that were subsequently overlain by pelagic sediments, now represented by foliated pelites. Discrete sulphide zones consisting of layered to massive sulphide (primarily pyrrhotite, sphalerite, and galena) are hosted within semi-pelite to pelitic rock of the I, H and Hu sequences. The relation of the sulphide zones to periods of low-energy sedimentation is consistent with a sea-floor syn-sedimentary origin as opposed to formation *via* “infiltration” of hydrothermal fluid along permeable sandy to silty turbidites after the cessation of sedimentation.

Deposition of sulphides and the formation of hydrothermal alteration took place in two stages. The first hydrothermal event, the “ore-forming stage” consisted of the episodic discharge of B- and base metal-rich hydrothermal fluids between periods of turbiditic sedimentation, resulting in the formation of the various ore zones of the Sullivan orebody. Macroscopic textures and sedimentary architecture support a syn-sedimentary origin for the hanging wall sulphide zones, with sulphide deposition most likely from a dense, saline brine (also see fluid inclusion work by Leitch, 1991,1992). Pulses of hydrothermal discharge during episodes of elevated hydrothermal activity are represented by finely laminated sulphides, with individual sulphide

laminae characterized by sharp bases and diffuse tops. The up-flow of B-rich ore-forming fluids resulted in the extensive tourmalinization of sedimentary units and formation of discordant massive to brecciated tourmalinite zones representing the feeder pipe or up-flow zone for Sullivan hydrothermal fluids. Stratabound zones of tourmaline alteration are also associated with hanging wall sulphide zones, and likely represent the diffusive flow of hydrothermal fluid. Tourmaline alteration was restricted to sedimentary units intercalated with sulphides, since sulphide units do not contain sufficient Al_2O_3 for the formation of tourmaline. Diffusive lateral flow and mixing of hydrothermal fluids with entrained seawater within the sedimentary pile resulted in the formation of stratabound zones of chlorite + Fe-sulphide alteration that encompasses the hanging wall sulphide zones. A more widespread alteration effect resulting from the mixing of hydrothermal fluid with entrained seawater is widespread muscovite alteration, and likely represents a mineral transformation of detrital clays to diagenetic - early hydrothermal phyllosilicates (*i.e.* illite) to muscovite.

The second stage of hydrothermal activity is represented by extensive zones of albite + chlorite $\pm$ pyrite alteration that resulted from the up-flow of Na-rich fluids *via* the pre-existing feeder system during emplacement of Moyie sills within and proximal to the Sullivan orebody (inferred from the cross-cutting relationship between albite + chlorite $\pm$ pyrite alteration and tourmalinite alteration zones). These fluids likely remobilized Pb and Zn from the vent complex, hence forming the massive pyrite replacement zone within the western part of the orebody, and resulted in the enrichment of the hanging wall sulphide zones. Therefore, the current distribution of base metals reflect this zone refinement process, with the nature of the original protolith being somewhat uncertain.

Tectonic deformation within the hanging wall consisted primarily of block faulting, thrust faulting, and poly-phase folding (see McClay, 1983), although any disturbances in

stratigraphy are localized and therefore, the original stratigraphic relationships are interpreted to have been preserved. Translation of the hanging wall over the main ore zones may explain the formation of the discordant Hu sulphide structures that occur along the transition zone. Metamorphism is considered to have been behaved isochemically with no significant remobilization and redistribution of base metal sulphides, resulting primarily in an increase in grain size and growth of metamorphic minerals (garnet, biotite, tremolite, and clinozoisite). Therefore, the observed metal distributions reflect the original zonation after hydrothermal zone refinement processes.

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PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

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Appendix 1

Hand sample descriptions

Table A1.1. Whole-rock sample descriptions.

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	This section	Geo-chem	Isotope
93-C001	7027	46 (14)	disseminated	5-7% Po with minor Gr (1%) in semi-pelite to pelite	I		X	
93-C002	7027	61 (18.6)	disseminated	10-15% associated to lath-shaped grains of Po in Chl semi-pelite; foliation sub-parallel to core axis	I			
93-C003	7027	62.8 (19.1)	disseminated, veins	Chloritized pelite with finely disseminated Po and discontinuous Po veins (<1 mm thick), fine-grained Chl along vein margins	I	X		
93-C004	7027	63.8 (19.4)	disseminated, vein	Chl-Bt rich mu-pelite with minor (1%) disseminated fine-grained euhedral Py; sample is cross-cut by a medium-grained Py vein	I		X	
93-C005	7027	66 (20.1)	aggregate	Wisp of fine-grained Sp (40%) in semi-pelite to pelite; wisps are aligned parallel to core axis; very minor Po associated with Sp mineralization	I laminations			
93-C006	7027	77 (23.5)	disseminated to laminated	Disseminated to weakly laminated Po (5-7%) in semi-pelite; laminations are 1-2 mm thick; Po very fine-grained; minor Ccp associated with Po	I laminations			
93-C007	7027	79 (24.1)	disseminated	Disseminated fine-grained euhedral Py (<1%) in Bt-rich coarse-grained semi-pelite	H	X		
93-C008	7027	81.8 (24.9)	disseminated	Similar to 93-C007 except Py is finer grained and have patches (up to 1 mm in size) of Po	H			
93-C009	7027	93 (28.3)	disseminated aggregate	Disseminated fine-grained Py (<1%) in semi-pelite with patches (<1 cm) of fine-grained Po (<5%)	H			
93-C010	7027	113 (34.4)	disseminated	Similar to 93-C007 and C008 but have increase Py (5-7%) abundances	H			
93-C011	7027	120.8 (36.8)	disseminated	Fine- to medium-grained Po and minor (<<1%) Sp in semi-pelite to pelite	Hu	X	X	
93-C012	7027	126 (38.4)	disseminated, vein	Disseminated Py (<3%) in Bt-rich semi-pelite; cross-cut by a 3 mm wide Py-Sp vein (no internal zonation)	Hu			
93-C013	7027	124.5 (37.9)	disseminated	Semi-pelite to pelite containing medium-grained Po (1-4%) and fine-grained Sp (<5%)	Hu			
93-C014	7027	136 (41.5)	none to weakly disseminated	Bt-rich semi-pelite cross-cut by a 5 mm wide Ab vein; Bt variably distributed; <2% disseminated very fine-grained Po	Hu		X	
93-C015	6839	102.7 (31.3)	disseminated	Very fine- to fine-grained quartzite; Bt-rich very fine-grained disseminated Po (<5%)	I quartzite		X	

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C016	6839	110.5 (33.7)	laminated	Semi-pelite to pelite with vague Po laminations, laminations <3 mm wide and are laterally discontinuous	1			
93-C017	6839	115-115.8 (35-35.5)	laminated	Laminated Po, Py, and minor Sp. sulphides are very fine-grained. Laminations are 1-5 mm thick, semi-pelite interlaminated with sulphides. Base of sample consists of parallel laminations which are abruptly overlain by contorted laminations (2-3 cm), which are overlain by another parallel laminated zone	1 laminations	X	X	S
93-C018	6839	119 (36.2)	laminated	Parallel laminated Po, partially replaced by Py and semi-pelite to pelite laminations 1-5 mm thick. sulphides are very fine-grained and composes <25% of the sample	1 laminations	X		
93-C019	6839	119.6 (36.5)	laminated	Contorted Po+Sp-semi-pelite laminations, laminations 2-5 mm thick and highly disseminated, compared to underlying units. Po>Sp	1 laminations		X	S
93-C020	6839	120 (36.6)	banded	Single band (3 cm wide) of massive Po with minor Sp (<5%) and waste (10%) in semi-pelite to pelite	1 laminations	X		
93-C021	6839	120.5 (36.7)	none	Fractured pelite. Chl alteration along fractures	interbed to 1 laminations		X	S
93-C022	6839	121.3 (37)	laminated	Similar to 93-C018	1 laminations	X	X	S
93-C023	6839	124.5 (38)	aggregate	Bi-rich semi-pelite elongated Po patches <0.5 cm	1			
93-C024	2442	49.5 (15.1)	disseminated	Fine-grained quartzite with <3% disseminated Po, very fine-grained Bi associated with Po mineralization	Hu			
93-C025	2442	60 (18.3)	none to weakly disseminated	Fractured semi-pelite with Bi-Chl alteration along fractures. minor (<1%) disseminated Po	Hu			
93-C026	2442	65 (19.8)	none to weakly disseminated	Similar to 93-C025	Hu		X	
93-C027a	2442	83 (25.3)	none to weakly disseminated	Bi-rich semi-pelite to pelite. minor disseminated Po (1%)	Hu			
93-C027b	2442	99-99.5 (30.2-30.3)	massive	Massive Po+Sp+Gn	Hu ore	X	X	
93-C028	2442	101.5 (30.9)	laminated	Folded laminae of Sp+Po-semi-pelite laminations 0.1-1 mm thick. fine-grained Py disseminated along laminations	Hu ore	X		

Table A1 I -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C029	2442	101.8 (31)	laminated	Parallel laminated Po-Sp semi-pelite laminations 1-2 mm thick and have gradational contacts	Hu ore			
93-C030	2442	107 (32.6)	disseminated	Semi-pelite with <3% very fine-grained disseminated Po	Hu		X (50-52)	
93-C031	2442	117 (35.7)	laminated	Laminated semi-pelite laminations 1-7 mm thick, laminations are either Grt-rich or Grt-poor fine-grained. Py common in Grt-rich laminations sample has been variably Bt-Chl altered	Hu		X (50-52)	
93-C032	2442	110.5 (33.6)	none to weakly disseminated	Semi-pelite to pelite with very fine-grained Po (<<1%)	Hu		X (50-52)	
93-C033	2442	192.5-193 (58.7-58.8)	none	Fine-grained quartzite to coarse semi-pelite Bt-rich	U marker	X	X	
93-C034	2370	170.5 (52)	none to weakly disseminated	Partially tourmalinized pelite with minor disseminated Po (<<1%)	I	X		
93-C035	2370	170.5 (52.6)	laminated	Vague laminations of very fine-grained Sp (10-15%) in semi-pelite laminations up to 2 mm thick	I			
93-C036	2370	173.8 (53)	disseminated	Similar to 93-C034 disseminated fine-grained Py (<2%)	I			
93-C037	2370	175 (51.3)	disseminated	Similar to 93-C034 and C036. Po grains are acicular to lath-shaped	I		X	S
93-C038	2370	177.8 (54.2)	laminated	Laminated Po and semi-pelite laminations are 1-4 mm thick	I laminations		X	
93-C039	2370	180.5 (55)	disseminated aggregates	Po (5%) in semi-pelite to pelite. Po occurs as both fine-grained disseminated laths and as spinel to aggregates (2-3 mm in diameter)	H			
93-C040	2370	182.5 (55.6)	disseminated	Disseminated lath-shaped grains of Po (<3% very fine-grained) and euhedral Py (1%) very fine-grained in semi-pelite to pelite	H			
93-C041	2370	184 (56.1)	fracture	Psammite highly fractured with fractures aligned sub-parallel to core axis. Fractures infilled with carbonated and Po. Bt halo surrounds Po-rich fractures	I-	X		
93-C042	2370	187 (57)	banded	2 mm thick Po bands in semi-pelite cross-cut and offset by a <1 mm carbonate vein. Po= 3%	Hu		X	
93-C043a	2370	207 (63.1)	banded	Similar to 93-C042 no carbonate vein, increase Po up to 5%. Po bands are <1 mm thick	Hu			
93-C043b	2370	207 (63.1)	banded	Similar to 93-C042 and C043a, except sample has been extensively Bt and Chl altered	Hu			

Table A1.1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C044a	2370	223.5 (68.1)	massive	Massive Po	Hu ore		X	
93-C044b	2370	224 (68.3)	banded	Banded Sp (30%) and Gn (70%) Sp bands 2-3 mm Gn bands 5-10 mm	Hu ore			
93-C044c	2370	225.5 (68.7)	banded	Banded Po (55%) Sp-Gn (40%) and waste (5%) bands are 1-4 mm thick and undulatory	Hu ore			
93-C045a	2370	215.0 (65.6)	none to disseminated	Partially albitized semi-pelite with variable Bt-Chl alterations associated with Ab, very fine grained disseminated Py (<2%)	Hu			
93-C045b	2370	219 (66.8)	none to disseminated	Similar to 93-C045a	Hu			
93-C045c	2370	226.5 (69)	disseminated, aggregate	Similar to 93-C045a,b, fine- to fine-grained Po+Py (15%) forms small ovoid patches	Hu			
93-C046	2370	236 (72)	none to disseminated	Partially albitized (?) pelite very fine-grained disseminated Po+Py (<1%)	Hu			
93-C047	2370	238.8 (72.8)	banded	Banded Po (80%) and waste (20%) bands >1 cm thick	Hu ore	X	X	
93-C048	2370	253.6 (77.2)	none to disseminated	Similar to 93-C046	Hu			
93-C049	4495	-4.8 (-1.4)	none	Coarse-grain Qtz vein with minor Bt cross-cutting semi-pelite to pelite grain size increases away from the vein, host rock has been extensively Bt-Chl altered	Hu	X		
93-C050	4495	-17.8 (-5.4)	none	Semi-pelite cross-cut by a 1 mm carbonate vein, host rock has been variably Bt-Chl altered	Hu	X	X	
93-C051	4495	-19.3 (-5.9)	none	Bt-Chl altered semi-pelite Chl laths up to 5 mm long	Hu	X		
93-C052	4495	-6.2 (-1.9)	none	Albitized semi-pelite (?) sample also has been variably Bt and/or Chl altered indicated by the dark grey to maroon patches	Hu albitite	X		
93-C053	4495	-13.2 (-4)	none	Similar to 93-C051	Hu	X		
93-C054	4495	-28.5 (-8.7)	disseminated	Similar to 93-C052	Hu albitite	X	X	
93-C055	4495	-29.2 (-8.9)	disseminated	Chl-rich semi-pelite with 3% euhedral to slightly rounded Py grains	Hu			
93-C056	4495	-30 (-9.1)	disseminated	Pervasively Chl altered pelite, foliated ? medium- to coarse-grained euhedral Py (15%) grains disseminated throughout sample	Hu chloritite	X	X	

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C057	4495	-30.7 (-9.4)	disseminated	Chl and Ab altered semi-pelite disseminated fine-grained, euhedral Py (<2%), minor carbonate-Bt associated with Pv	no chloritite-albite	X		
93-C058	4495	-38.4 (-11.7)	none to disseminated	Pervasively Chl altered semi-pelite with minor Ab alteration (<1%) disseminated fine-grained euhedral Pv	no chloritite	X	X (58-59)	
93-C059	4495	-39 (-11.9)	none	Chl and Ab altered semi-pelite to silty-pelite small carbonate veins cross-cut sample	no chloritite-albite		X (58-59)	
93-C060	4495	-55.5 (-16.9)	none	Massive semi-pelite to pelite	H			
93-C061	4495	-63 (-19.2)	none	Similar to 93-C059	H chloritite			
93-C062a	4495	-66.7 (-20.3)	laminated to banded	Laminated Sp (15%) Po (15%) and waste laminations are 1-2 mm thick silty pelite laminations form bands up to 1 cm thick separated by semi-pelite	laminations			
93-C062b	4495	-69 (-21)	banded	Banded Gn (60%) Po (15%) and waste (25%) Bands are 0.5-1 cm thick and are irregular	laminations		X	
93-C062c	4495	-69.5 (-21.2)	disseminated	Disseminated Po (5-7%) in semi-pelite to pelite	interbedded to laminations			
93-C062d	4495	-70.5 (-21.5)	banded	Po (40-50%) bands separated by Chl altered pelite bands are 1-1 cm thick	laminations	X		
93-C062e	4495	-71.5 (-21.8)	laminated	Paralel laminated Po (50%) and pelite (50%) laminations are 2-10 mm thick pelite is Chl altered	laminations		X	
93-C063a	4495	-74.3 (-22.5)	disseminated aggregate	Semi-pelite to pelite with fine-grained disseminated Po (1-3%) Po also forms patches up to 2 cm in diameter				
93-C063b	4495	-78.4 (-24)	disseminated aggregate	Similar to 93-C063a				
93-C064	4495	-83.5 (-25.5)	disseminated aggregate	Similar to 93-C063a,b				
93-C065	4495	-84.8 (-25.8)	none	Sample is primarily massive semi-pelite top 1-2 cm consists of maroon very fine-to fine-grained quartzite Gn present in quartzite, contact between quartzite and pelite is sharp quartzite contains discontinuous lenses of pelite	laminations			
93-C066a	3385	2 (0.7)	banded	Banded Gn (60%), Po (25%) and waste (15%) bands are highly irregular in form, gradational contacts between bands	laminations			
93-C066b	3385	3.3 (1)	massive	Massive Po (85%) with minor Ga (15%)	laminations		X (66b-6*b)	

Table A1.1.-continued-

Sample	Drill Hole	Depth (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C067a	3385	5 (1.5)	disseminated	Disseminated Sp or Po (35-40%) in semi-pelite to pelite, sulphides are very fine-grained	interbed to l laminations		X (66b-67b)	
93-C067b	3385	9.3 (2.8)	banded	Similar to 93-C066a	l laminations		X (66b-67b)	
93-C067c	3385	12.5 (3.8)	banded	Similar to 93-C066a and C067b, except sample contains Sp and no Gn, minor Bt and carbonate associated with mineralisation	l laminations			
93-C068a	3385	21 (6.4)	banded	Folded (?) Po bands in Chl altered pelite, 1-2 mm wide Alb vein cross-cuts pelite but not Po bands	H "ore"	X		
93-C068b	3385	22.5 (8.7)	vein, disseminated	Bt-Chl altered pelite cross-cut by several thin (<5 mm) Qtz-Py veins very fine-grained Py (5%) disseminated throughout sample	H			
93-C069	3385	29.5 (9)	vein, disseminated	Medium- to coarse-grained Qtz-Py vein cross-cutting pelite, vein consists of 60% Qtz and 40% Py, fine-grained Po (7-10%) disseminated throughout pelite	H		X	
93-C070	3385	22.5 (6.9)	vein, disseminated	Disseminated fine-grained Po-Py (<2%) in Bt-Chl altered semipelite sample is cross-cut by a 1-2 mm Qtz vein	Hu		X	
93-C071	3385	33 (10.1)	vein, disseminated	Bt-Chl altered semi-pelite to pelite, with <2% very fine-grained disseminated Po/Py, sample is cross-cut by a 5 mm Qtz-Po-Py vein	Hu			
93-C072a	3385	40.6 (12.4)	banded	Irregular bands of Po (30%) in semi-pelite banding is vague due to sample being extensively oxidized bands <1 cm thick	Hu			
93-C072b	3385	41.5 (12.6)	disseminated	Bedded semi-pelite to pelite beds defined by alternating (Bt-Chl)-rich beds and (Bt-Chl)-poor beds fine-grained disseminated Py (3%)	Hu			
93-C072c	3385	43.8 (13.4)	banded	Banded Gn, Po, Py, Sp and waste sulphides= 70% waste= 30% Gn>Po>Py>>Sp, sulphides are very fine-grained except for Py (up to 1 mm)	Hu ore	X		
93-C072d	3385	46.8 (14.3)	banded, fracture	Apv band (>1 cm) in partially albitized semi-pelite minor Py infill fractures	Hu ore		X (72d-e)	
93-C072e	3385	48 (14.6)	fracture	Similar to 72c	Hu ore	X	X (72d-e)	
93-C073a	3385	53 (16.2)	vein	Qtz-Py vein cross-cutting albitite Vein is <3 mm wide and internally zoned with a Py core and Qtz edges, carbonate alteration rind at vein-host contact	Hu albitite			

Table A1.1. -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo- chem	Isotope
93-C073b	3385	61.5 (18.7)	disseminated	Pervasively albitized pelite with fine-grained disseminated Po (15%)	Hu albite		X	
93-C073c	3385	62.5 (19.3)	disseminated	Chl altered semi-pelite with irregular bands to lenses of Ab <5% fine- grained Po	Hu			
93-C074a	3385	66.5 (20.3)	none to disseminated	Pervasively chloritized pelite very minor (<<1%) medium- grained euhedral Pv	Hu chloritite		X	
93-C074b	3385	67.5 (20.5)	vein	Similar to 93-C073a. Qtz-Pv veins are cross-cut by a 5 mm wide Chl vein	Hu		X	
93-C074c	3385	71.5 (21.8)	none	Semi-pelite	Hu			
93-C075	3385	126.5 (38.6)	none	Semi-pelite to pelite cross-cut by a zoned carbonate+Ab vein zonation consists of an Ab core with carbonate along the outer rim; vein is offset by a hairline fracture	L	X		
93-C076a	3385	144.5 (44)	disseminated	Pervasively Ab altered pelite with Chl along fractures <2% disseminated Pv	L albite	X		
93-C076b	3385	148 (45.1)	none to disseminated	Similar to 93-C076a. Chl more abundant, occurring in discrete zones <1% medium-grained euhedral Pv	L albite- chloritite		X	
93-C076c	3385	148.5 (45.3)	disseminated	Similar to 93-C076b. Pv more abundant (5%)	L albite- chloritite			
93-C076d	3385	153.5 (46.8)	disseminated	Chl altered pelite with small (2-7 mm) patches of albite <10% medium-grained disseminated Pv sample is cross-cut by a 2-5 mm wide Qtz vein	L chloritite albite	X		
93-C077a	4501	198 (60.4)	disseminated	Disseminated Sp in (30-40%) pelite produces vague banding 1-2 cm wide; a 1 cm thick band of Po (5%) is bounded by Sp bands	I			
93-C077b	4501	201 (61.3)	none to disseminated	Bi-rich semi-pelite with minor (<1%) disseminated Pv (fine-grained and euhedral)	I	X		
93-C077c	4501	202 (61.6)	disseminated to aggregate	Disseminated Po (7-10%) forms small 2mm to 1 cm patches in semi-pelite	I			
93-C078b	4501	204.5 (62.6)	disseminated to aggregate	Patches (<5 mm) of disseminated Sp and Po (combined = 5%) semi-pelite to pelite disseminated fine-grained euhedral Pv (1%) associated with Sp and Po mineralisation; sample is cross-cut by several unmineralized Qtz veins <1 mm wide and randomly oriented	I		X (78a-b)	
93-C078a	4501	204.5 (62.3)	disseminated to aggregate	Semi-pelite to pelite with Po patches (similar to 93-C077c) medium-grained euhedral Pv replacing Po (?)	I		X (78a-b)	

Sample	Drill Hole	Depth (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C079a	4501	207 (63.1)	vein	Lower portion of a medium- to coarse-grained Qtz-Sp-Gn-Py vein. vein consists of 55% Qtz, 35% Sp, <5% Gn, and 5-7% Py. grains are subhedral to euhedral	I			
93-C079b	4501	212 (64.6)	vein	Upper portion of vein described by sample 93-C079a, have less sulphide (15-20%) with Py as the dominant sulphide phase	I		X	
93-C080	4501	212.5-213 (64.8-64.9)	none to disseminated	Pervarsely Chl altered pelite sample is foliated with foliation sub-parallel to core axis, minor (<<1%) medium-grained euhedral Py	I chloritite	X		
93-C081	4501	214.5 (65.4)	disseminated	Chl altered pelite with disseminated medium-grained Po (10%), minor euhedral Py (<1%) along fractures	I chloritite		X	
93-C082a	4501	221.8 (67.6)	disseminated, vein	Chl and Bt altered semi-pelite weakly foliated (?), disseminated very fine-grained Sp and fine-grained Py sulphide distribution highly variable ranging from 10-40%. Sample is cross-cut by a zone Sp+Qtz+Py vein. Sp forms core with thin Qtz rims. Py is associated with Sp	I			
93-C082b	4501	222.8 (67.9)	disseminated	Similar to 93-C082a, no Sp-Qtz-Py vein	H			
93-C083	4501	223 (68)	disseminated to laminated	Base of sample consists of highly disseminated Po and Py which rapidly grade into laminated Po laminations 0.5-1 cm thick, contact between Po laminations and interlaminated pelite marked by fine-grained euhedral Py total sulphide content= 20-25% with <5% being Py	H			
93-C084	4501	226 (68.9)	disseminated vein	Po-rich (40%) semi-pelite to pelite cross-cut by fine- to medium-grained Qtz-Py vein vein consists <5% Py	H			
93-C085a	4501	228.5 (69.6)	disseminated	Pervasively to weakly albited semi-pelite to pelite minor fine-grained Py (1%) associated with Ab-rich zones minor Chl alteration associated with Py mineralisation	H albite			
93-C085b	4501	230.5 (70.3)	disseminated	Chl altered ser-pelite to pelite with disseminated anhedral to subhedral, medium-grained Py (3%)	H			
93-C086a	4501	234 (71.3)	disseminated vein	Semi-pelite with disseminated fine-grained Py (<1%) Sample is cross-cut by a 3 mm wide fine- to medium-grained Qtz-Py vein vein has several <1 mm wide offshoots	H	X		
93-C086b	4501	234.5 (71.5)	aggregate	Pervasively Ab altered semi-pelite disseminated Py (<3%) form small (1-2 mm) aggregates	H albite	X		

Table A1 I -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C087a	4501	237.5 (72.4)	disseminated	Chl altered semi-pelite <2% disseminated fine-grained euhedral Py sample is cross-cut by a 1-2 mm wide Qtz+Sp vein	H chloritite			
93-C087b	4501	247.5 (75.4)	vein	4-5 mm wide zoned Qtz+Sp+Gn vein cross-cutting Chl-altered semi-pelite to pelite zonation consists of a Sp core with Qtz and Gn rims Sp zone ranges from 1-3 mm wide where as Qtz+Gn zone is <1 mm wide Sp and Gn are very fine-grained Qtz is fine- to medium-grained	H chloritite	X		
93-C088	4501	253.5 (77.3)	none	Chl altered semi-pelite	H chloritite	X	X	
93-C089a	3952	4 (1.2)	disseminated	Massive black tourmalinite with fine-grained disseminated Po and Pv (combined <5%)	F W tourmalinite		X	S
93-C089b	3952	13.5 (4.1)	disseminated	Blonde tourmalinite with very fine-grained Po (20-30%)	F W tourmalinite (blonde)	X		
93-C089c	3952	20 (6.1)	none to disseminated	Massive blonde tourmalinite with <1% disseminated fine-grained Pv	F W tourmalinite (blonde)			
93-C089d	3952	27.5 (8.4)	matrix	Similar to 93-C089c	F W tourmalinite			
93-C089e	3952	29.8 (9.1)	matrix	Brecciated black tourmalinite fragments are angular to sub-angular matrix consists of intergrown very fine- to fine-grained Po and Pv total sulphide content 25%	F W tourmalinite	X		
93-C089f	3952	31.5 (9.6)	matrix	Brecciated pelite fragments are 2mm to 1 cm in size and are angular to sub-rounded in shape matrix consists of very fine-grained Po	F W breccia			
93-C090a	3952	34.5 (12)	laminated	Interlaminated Po and semi-pelite laminae are 2-4 mm thick and have sharp straight contacts	F W			
93-C090b	3952	40.5 (12.3)	matrix	Brecciated semi-pelite angular to sub-rounded fragments range in size from mm to 1 cm matrix consists of very fine-grained Po	F W breccia		X (90b c)	
93-C090c	3952	42.8 (13)	disseminated	Semi-pelite with 5-7% disseminated very fine-grained Po	F W		X (90b c)	
93-C090d	3952	46 (14)	matrix	Brecciated semi-pelite to pelite angular to sub-rounded fragments range in size from 1 mm to 2 cm matrix consist of very fine-grained Po with 1-2% Pv total sulphide content <20%	F W breccia	X		
93-C091a	3952	50.2 (15.3)	disseminated	Very fine-grained quartzite with <5% disseminated Po	I marker			

Table A1 | -continued-

Sample	Drill Hole	Depth (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C091b	3952	52 (15.8)	vein	Semi-pelite cross-cut by a 5 mm wide Py vein. Py grains are anhedral to subhedral and are <1 mm in size (fine-grained)	I			
93-C091c	3952	58.2 (17.7)	disseminated to aggregate	Semi-pelite with 1-2% disseminated Po forming aggregates 1-2 mm in diameter	I			
93-C092	3952	66.2-67 (20.2-20.4)	laminated to banded	Interlaminated Po and waste (semi-pelite) laminae are 2-5 mm wide which coalesce into a 2 cm wide band of massive Po near the top of the sample. laminae contacts are sharp and straight, total sulphide 30-40%	I laminations	X	X (92-93)	
93-C093	3952	67-67.8 (20.4-20.7)	laminated	Laminated Gn and Po laminae range between 3 mm to 1 cm thick laminae are undulatory and have gradational contacts sulphides are very fine-grained Gn content increases up-section	I laminations		X (92-93)	
93-C094a	3952	70 (21.3)	laminated	Laminated Sp, Po and semi-pelite, laminae are 2-5 mm thick, with straight and sharp contacts sulphide content= 10% Sp and 15% Po Sp increase up-section	I laminations			
93-C094b	3952	71 (21.6)	laminated/banded	Pelite with a single 5 mm wide Po>Sp band	I laminations			
93-C095a	3952	75.5 (23)	banded	Bands of very fine-grained Po and Gn in semi-pelite, bands are irregular (undulatory) to lensoidal in form, and are laterally discontinuous sulphide content= 20% Po and 5% Gn	I	X		
93-C095b	3952	77.5 (23.6)	disseminated vein	Very fine-grained quartzite rapidly grading into a Fe-rich pelite, quartzite contains 1-2% disseminated Py a small 1 mm wide Qtz=py vein cross-cuts quartzite and pelite	top of H marker		X	
93-C096	3952	88 (26.8)	disseminated	Semi-pelite grading into pelite with 5-7% disseminated Po and Py sulphides form a weak banding in the semi-pelite	H			
93-C097a	3952	93 (28)	disseminated	Semi-pelite, <2% fine-grained disseminated Po, variable Chl-Bt alteration	Hu	X		
93-C097b	3952	99 (30.2)	none	Semi-pelite abruptly overlain by fine-grained quartzite, quartzite is extensively Chl-Bt altered	Hu	X		
93-C097c	3952	109 (33.2)	none	Laminated to thinly bedded siltite, laminations/beds range in size from 2 mm to 1.5 cm with carbonaceous partings	Hu			
93-C097d	3952	122 (37.2)	disseminated	medium- to fine-grained quartzite Bt forms small <1 mm. patches, fine-grained disseminated Py (<1-2%)	Hu		X	
93-C097e	3952	130 (39.6)	disseminated	Coarse- to medium-grained quartzite adjacent to fault zone, similar to 93-C097d	L marker			

Table A1.1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C098	3952	136-137 (41.5-41.8)	massive	Massive Po (85%) and Sp (10%), a weak banding exists in Sp-rich zones. samples contains 5% waste material primarily Bt	Hu ore (?)	X	X	
93-C099a	3971	1.5 (0.5)	massive	Massive Po with minor waste (<5%)	FW ore	X		
93-C099b	3971	5 (1.5)	massive	Similar to 93-C099a, variable replacement of Po by medium-grained euhedral Py	FW ore	X	X	S
93-C099c	3971	8.5 (2.5)	laminated	Laminated Sp-Po and pelite. laminae are 1-5 mm thick. sulphide content= 20% Sp 10% Po and 1-2% Py (replacing Po ?)	FW ore			
93-C100a	3971	10.5 (3.2)	disseminated	Disseminated very fine- to fine-grained Po (15-20%) in semi-pelite (<2% P., associated with Po	l marker			
93-C100b	3971	13.4 (4.1)	disseminated to aggregate	Similar to 93-C100a decreased sulphide content (<10%) Po=Py forms small (<5 mm) aggregates	l			
93-C101a	3971	26.5 (8.1)	laminated	Laminated Sp-Po and semi-pelite laminae are 2-8 mm thick sulphide laminae are generally thinner with respect to waste laminae. Sp content increases up-section from 5-40% whereas Po content decreases from 60-10% laminae contacts are straight and sharp but become more gradational up-section.	laminations	X		
93-C101b	3971	27.5 (8.4)	vein laminated	Base of sample consists of pelite cross-cut by a 1-2 mm wide Sp+Py vein. top of sample consist of laminated Sp and Py. total sulphide content= 30% Sp and ~10% Py.	top of l laminations	X		
93-C102a	3971	31.4 (9.6)	none	Medium-grained quartzite with a Chi-altered band of pelite	rl marker			
93-C102b	3971	38.1 (11.6)	none to disseminated	Fine-grained quartzite contains Chi-Bt=Gr., minor (<1%) disseminated Py	ru marker			
93-C102c	3971	41 (12.5)	disseminated	Similar to 93-C102b increased Py (2%) sample is cross-cut by a 2 mm carbonate vein. vein cross-cuts fractures infilled with Bt	Hu marker			S
93-C103	3971	55.5 (26)	disseminated	Chi-Bt altered semi-pelite ~2% disseminated Py. Bt associated with Py	Hu			
93-C104a	3971	90.2 (27.5)	none	Laminated Bt=Chi altered psammite	Hu	X		
93-C104b	3971	91.2 (27.8)	none	Similar to 93-C104a	Hu			
93-C104c	3971	91.5 (27.9)	disseminated to banded (?)	Similar to 93-C104a b with 30-40% disseminated Sp and 1-2% Py. Sp is banded in areas	base of Hu ore	X	X (104c-d)	

Table A1 1. -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C104d	3971	92 (28)	massive/banded (?)	Massive Po (45%) and Sp (35%) Gn (<10%) with <10% waste. vague internal banding, bands are >5 mm wide and have diffuse contacts, Gn associated with Sp	Hu ore	X	X (104c-d)	
93-C104e	3971	93 (28.3)	laminated	Single band of laminated Sp and Po in pelite, sulphide band is approx. 2 cm wide with laminae ranging from 1-3 mm, pelite is laminated defined by the alternating green/maroon colour banding	top of Hu ore			
93-C104f	3971	93.5 (28.5)	none	Semi-pelite	Hu			
93-C105a	3971	103.2 (31.5)	banded/ laminated	Base of sample has a 5 mm wide band of laminated Py and waste, band is slightly folded and is surrounded by 2-3 mm wide albite halos, the lower Ab zone is underlain by Ab altered semi-pelite, the upper Ab zone is overlain by Chi+Bt+Grt altered semi pelite (1.5 cm thick) the Chi+Bt+Grt band is overlain by a second Ab couplet, Grt decreases towards the Ab couplet (1 cm wide), the second Ab couplet is overlain by a Chi+Bt+Grt altered semi-pelite with patchy Ab alteration (representing top of sample)	top of Hu ore	X		
93-C105b	3971	103.8 (31.6)	aggregate	Semi-pelite grading into Grt+Bt-Chi altered semi-pelite, 3-5 mm blebs/ patches of very fine-grained Py+Bt+Chi in silty- pelite, total Py <3%	Hu		X	
93-C105c	3971	113.7 (34.7)	aggregate	Semi-pelite similar to sample 93-C105b	Hu			
93-C105d	3971	114.5 (34.9)	banded	Lower 3 cm of sample similar to 93- C105c, minus the Py patches the lower zone is abruptly overlain by a 2-3 cm band of very fine-grained Py+Bt+Chi+waste (Py content = 20%) the Py-bearing band is overlain by Chi+Bt altered semi-pelite, the top of sample is marked by a series of 3-4 Py bands, similar to the lower Py band	Hu			
93-C106a	3976	3.5 (1.1)	banded	Bands of Sp (15%) and Py (40%) in semi-pelite (45%) bands <5 mm wide with sharp contacts semi-pelite bands are Chi-Bt altered	1 laminations			
93-C106b	3976	4.5 (1.4)	aggregate	Semi-pelite with 3 mm to 1.5 cm patches of fine-grained Po	1			
93-C106c	3976	10 (3)	laminated	Semi-pelite with finely (1-2 mm) laminated Po and Sp sulphide content = 15% Po, <2% Sp semi-pelite is Bt+Chi altered	1 laminations			

Table A1 1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C107a	3976	18 7-19 (5 7-4 8)	disseminated	Medium- to fine-grained quartzite with variably disseminated Po and Sp, total sulphide content = 10-15%, sulphide-rich areas are Bi-free, but have Chl associated with mineralisation, sulphide-poor zones are Bi-rich and have minor Chl alteration	H marker			
93-C107b	3976	20 (6 1)	disseminated banded	Similar to 93-C107a, have a single band of very fine-grained Sp (5 mm wide)	H	X		
93-C107c	3976	21 8 (6 6)	disseminated	Similar to 93-C107a, increase abundance of sulphides, up to 20-25%	H			
93-C107d	3976	22 7 (6 9)	none to disseminated	Fine-grained quartzite with minor (<1%) disseminated euhedral Pv (fine-grained)	no marker			
93-C107e	3976	28 8 (8 8)	disseminated	Similar to 93-C107a	no		N	S
93-C108a	3976	30 2 (9 2)	none	Fine- to medium-grained quartzite, (Bi+Grt+Chl)-bearing	Hu			
93-C108b	3976	31 (9 4)	none to disseminated	Semi-pelite with <<1% very fine-grained disseminated Pv	Hu	X		
93-C108c	3976	33 (10 1)	laminated (?)	Thickly laminated to bedded (3 mm to 1.5 cm thick) semi-pelite laminae, beds are distinguished by colour and grain size variations (darker beds are more pelitic) darker beds have thin discontinuous laminae of Po and Pv, total sulphide content <2%	Hu			
93-C108d	3976	38 (11 6)	none	Quartzite with a 1-3 cm irregularly shaped zone of Ab-altered pelite, minor Chl associated with Ab, minor disseminated Pv (?)	Hu	N		
93-C108e	3976	39 5-40 2 (12-12 3)	none	Pelite cross-cut by several randomly oriented Qtz+Bi+Chl veins, veins are 1-2 mm wide	Hu			
93-C109a	3976	67 5 (20 6)	vein	Semi-pelite cross-cut by Po veins, veins <2 mm wide and are oriented near-parallel to core axis	Hu	X	N	
93-C109b	3976	76 (23 2)	none	Massive semi-pelite	Hu			
93-C109c	3976	77 8 (23 7)	none to disseminated	Semi-pelite with <1% disseminated Po	Hu	X		
93-C110a	3976	78 (23 8)	laminated	Laminated Po with minor interlaminated of Gr+Sp (<10%) and waste (<10%)	Hu ore	X	N	(110a-d)
93-C110b	3976	79 2 (24 1)	laminated	Similar to 93-C110a	Hu ore		X	(110a-d)

Table A1.1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C110c	3976	79.5 (24.2)	laminated	Laminated Po (75%), Sp (<5%) and Gn (20%), laminae 2-5 mm thick and are slightly uneven with diffuse contacts	Hu ore	X	X (110a-d)	
93-C110d	3976	81 (24.7)	banded to massive	Banded to near massive Sp with minor waste (<10%) Sp bands >1 cm wide	Hu ore	X	X (100a-d)	
93-C110e	3976	81.6 (24.8)	laminated	Laminated Sp, Po and semi-pelite. laminae are 1-3 mm thick, total sulphide content= 15-20%	Hu ore			
93-C110f	3976	81.8 (24.9)	laminated	Similar to 93-C110e	Hu ore			
93-C111a	3976	86 (26.2)	disseminated to laminated	Bi-Chl altered semi-pelite with disseminated to vaguely laminated Sp (15%), laminae are 1-3 mm thick with diffuse contacts	Hu			
93-C111b	3976	92.2 (28.1)	disseminated	Partially albited Bi-bearing semi-pelite. 1-2% disseminated very fine-grained Po	Hu	X		
93-C111c	3976	105 (32)	disseminated aggregate	Similar to 93-C111b. Po forms small, 1-2 mm, patches, sample is cross-cut an unmineralized Qtz vein, oriented sub-parallel to core axis	Hu	X		
93-C111d	3976	107.7 (32.8)	disseminated, aggregate	Similar to 93-C111b,c, no Qtz vein	Hu	X	X	
93-C112a	3994	2.5 (0.8)	matrix	Brecciated semi-pelite, sub-angular to sub-rounded fragments range in size from 2 mm to 1 cm, matrix represents 60% of sample, composed of Po (45%) and Sp (15%), Bi associated with Sp mineralisation	F W breccia	X	X	S
93-C112b	3994	4.5 (1.4)	matrix	Similar to 93-C112a, clasts are larger, 0.5-1 cm, lower abundance of sulphides (7-10%)	F W breccia			
93-C112c	3994	5.8 (1.8)	laminated	Laminated Sp (10%), Po (20%) and semi-pelite. Laminae are 1 mm to 1 cm thick, with abrupt straight contacts	F W ore			
93-C112d	3994	7 (2.1)	banded	Alternating bands of Gn and Po bands are >1 cm thick	F W ore			
93-C113a	3994	8 (2.4)	none	(Bi+Grt)-bearing fine-grained quartzite	I marker	X		
93-C113b	3994	8.8 (2.7)	none to disseminated	Bi altered semi-pelite with <1% very fine-grained disseminated Po	I	X		S
93-C113c	3994	12.2 (3.7)	none to disseminated	Similar to 93-C113b	I	X	X	
93-C113d	3994	10.2 (3.1)	laminated	Laminated Po and semi-pelite, laminae are 1-5mm thick, with abrupt and straight contacts, total sulphide= 20-30%	I laminations			

Table A1 1.-continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C113e	3994	14.5-14.8 (4.4-4.5)	laminated	Similar to 93-C113d	laminations	X		
93-C114a	3994	16 (4.9)	disseminated	(Gr+Bi)-bearing fine-grained quartzite finely disseminated Po (<5%)	H marker		X	S
93-C114b	3994	26 (7.9)	vein, disseminated	Chl altered semi-pelite with disseminated Po (3-5%), sample is cross-cut by a 2 mm wide Po vein, with minor Py (<10%) replacement of Po	H	X		
93-C115	3994	28 (8.5)	vein, aggregate	Semi-pelite to pelite with 1-2 mm patches of Po sample cross-cut by very thin (<1 mm) Sp veins total sulphide content = 3%	H	X		
93-C116a	3994	30 (9.1)	aggregate	Very fine- to fine-grained quartzite Bi and Chl abundant, Po (<5%) patches 1-2 mm in diameter surrounded by Chl	hu marker			
93-C116b	3994	34 (10.40)	disseminated	Semi-pelite with disseminated Po (<2%)	hu	X		
93-C116c	3994	37.8 (11.5)	none to disseminated	Lower 5 cm consists of interbedded/laminated (Bi-Chl)-altered and Ab-altered semi-pelite to semi-pelite, Ab-bearing beds are buff coloured, with (Bi-Chl)-bearing beds are deep maroon to greenish-grey Upper 2 cm consists of laminated Bi-rich and Chl-rich semi-pelite to semi-pelite, Chl-rich laminae have finely disseminated Ab Bi-rich laminae contain up to 10% fine-grained Po	hu			
93-C116d	3994	38 (11.6)	disseminated	Similar to upper 2 cm of 93-C116c sulphide less abundant (<5%)	hu			
93-C117a	3994	41.5 (12.6)	none	Quartzite	hu	X		
93-C117b	3994	44.5 (13.6)	disseminated	Similar to upper 2 cm of 93-C116c	hu		X	S
93-C118a	3994	45 (13.7)	disseminated	Medium-grained grading into fine-grained quartzite, Bi abundant in smaller grain size fraction, Disseminated fine-grained Po (<2%)	Hu marker	X		
93-C118b	3994	57.8 (17.6)	none	Bi and Chl altered semi-pelite with scattered Qtz grains (<5%)	Hu			
93-C118c	3994	61 (18.6)	none	Similar to 93-C118b	Hu		X	S
93-C118d	3994	69 (21)	none	Similar to 93-C118b	Hu			
93-C118e	3994	71.8 (21.9)	disseminated	Semi-pelite with 5% disseminated fine-grained Po	Hu			

Table A1 1. -continued-

Sample	Drill Hole	Depth (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C118f	3994	72.5 (22.1)	fault	Deformed Qtz grains form elongate lenses separated by thin (<2 mm) (Bt+Chl+Py) layers. Qtz lenses are variable in size and lateral extent	Fault zone			
93-C118g	3994	74 (22.6)	disseminated	Pelite with 2% disseminated Po (very fine-grained)	Hu	X		
93-C119a	3994	78.8 (24)	none to disseminated	Graded beds of medium-grained quartzite to semi-pelite, quartzite horizons contain abundant Po (10-15%), Bt and Chl. Po is significantly less abundant in semi-pelite horizons (<1%)	Hu	X		
93-C119b	3994	84 (25.6)	disseminated	Bedded (?) semi-pelite, bedding defined by alternating (Bt+Chl)-rich beds with pure semi-pelite beds, fine-grained disseminated Po (<5%)	I.			S
93-C119c	3994	89 (27.1)	disseminated, aggregate	Semi-pelite with Po (7%) disseminations and aggregates, disseminated Po very fine-grained, Po aggregates are variable in shape and size (up to 1 cm), aggregates surrounded by Ab+Chl halo	Hu			
93-C119d	3994	89.3 (27.2)	disseminated	Interlaminated semi-pelite and semi-pelite, laminae are 1-2 mm thick, argillaceous laminae are Bt-rich, semi-pelite laminae contain <2% fine-grained Po Abruptly overlying laminated horizon < 1 cm wide zone of Po-rich (10%), cross-laminated (?) semi-pelite Ripple cross-laminated horizon grades into a massive (Bt+Po)-bearing semi-pelite	Hu	X		
93-C120a	3994	90 (27.4)	laminated	Medium- to fine-grained quartzite with laminated Po, laminae are 3-7 mm thick, quartzite-Po contact is defined by high abundance of Bt	Hu			
93-C120b	3994	90.8 (27.7)	aggregate	Massive semi-pelite with Po aggregates, total Po content = 3-5%, aggregates are <5 mm in diameter and are extensively chloritized	Hu			
93-C120c	3994	91.2 (27.8)	banded, laminated	Contorted Po (65%) and Sp (25%) bands, laminae are 1-2 mm thick and form bands up to 1 cm wide, minor intercalated semi-pelite (10%)	base of Hu ore	X		
93-C120d	3994	91.5 (27.9)	massive	Massive Po with minor Sp (?)	Hu ore	X		
93-C120e	3994	91.8 (28)	laminated	Similar to 93-C120c	Hu ore		X	
93-C120f	3994	92 (28)	banded	Colloform (?) banded Sp (20%), Po (30%) and waste (50%), bands are 1-1.5 cm wide, with sharp and straight contacts, sulphide bands contain up to 50% waste, with gangue material being more abundant in Sp bands	Hu ore	X		

Table A1 1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C120g	3994	92.2 (28.1)	laminated, disseminated	Lower 2-3 cm consists of pelite with finely disseminated Sp Middle 2 cm consist of laminated Sp, Po and waste, similar to 93-C120f Upper 1.5 cm consists of fine- to medium-grained quartzite with disseminated Po and Sp	top of Hu ore	X		
93-C121a	3994	97 (29.6)	disseminated	Semi-pelite to pelite with finely disseminated Po (<2%), sample is cross-cut by two 3 mm Qtz=Chi+Py veins	Hu			
93-C121b	3994	98.8 (30.1)	disseminated	Graded beds of medium-grained quartzite to semi-pelite quartzite exhibits a weakly developed internal lamination, quartzite is (Bt=Grt)-bearing, sample contains 20% disseminated Po	L marker	X		
93-C121c	3994	100 (30.5)	disseminated	Interbedded semi-pelite and fine-grained quartzite Basal 4 cm consists of massive silty-pelite with very minor disseminated Po (<<1%) Basal zone grades into a 1 cm wide horizon consisting of interlaminated Po and Bt-rich pelite. Po laminae are laterally discontinuous A 2-3 cm zone of thickly laminated (Bt=Chi=Grt)-bearing quartzite abruptly overlies the interlaminated horizon, laminae 5 mm thick, Bt, Chi and Grt content decreases up-section <10% disseminated fine-grained po 1.5-2 cm wide horizon of laminated Po and pelite similar to the horizon underlying the quartzite Upper 1 cm consist of clean quartzite with 1-2 mm thick Po laminae	L	X		
93-C121d	3994	103 (31.4)	disseminated vein	Bedded semi-pelite, bedding define by colour variations purple-black beds alternating with grey beds, 1-2% disseminated Po sample is cross-cut by bedding parallel Qtz=Py veins veins are <1 mm wide and have Ab=Chi alteration halos	L	X	X	S
93-C121e	3994	106 (32.3)	disseminated	Soft-sediment deformed beds of semi-pelite beds are define by colour variation, similar to 93-C121d lighter coloured beds appear to have been partially albited, disseminated Po and Py (combine <3%) in Ab-bearing beds sample is cross-cut by a thin unmineralized Qtz vein Lower 1/3 of sample has a bleached structure cross-cutting beds structure is internally zoned consisting of of Py Po=Bt core and Ab rims, sharp contact with sedimentary units possible soft-sediment injection structure (?)	L Soft-sediment deformation structures (?)	X		

Table A1.1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C121f	1994	110 (33.5)	disseminated	Massive semi-pelite with disseminated Po (1-2%, very fine-grained)	U			
93-C122a	1866	0 (0)	banded	Banded Po and waste, band are 0.5-2 cm thick (sulphide bands are generally the thicker of the two) and have sharp and straight contacts with adjacent bands. Po content 60%	F W ore			
93-C122b	1866	1.5 (0.5)	massive	Massive Gn, grains are up to 1 mm in size, intermixed with Gn are thin wisps of very fine-grained Po (<5%)	F W ore		X	
93-C123a	1866	4.5 (1.4)	disseminated	Chl and Ab altered semi-pelite to pelite, alteration is patchy and discontinuous <2% disseminated Po	F W			
93-C123b	1866	8 (2.4)	aggregate	Massive semi-pelite with patches of disseminated Po (3-5%), patches are <5 mm in diameter and are irregular in shape. Bt intermixed with Po	I			
93-C123c	1866	9.2 (2.8)	aggregate	Similar to 93-C123b	I		X	
93-C123d	1866	10 (3)	disseminated	Semi-pelite, possible Bt and Grt (?), 10% disseminated Po and Py (replacing Po ?)	I			
93-C123e	1866	11.5 (3.5)	disseminated aggregate	Similar to 93-C123b	I			
93-C123f	1866	19 (5.8)	laminated	Semi-pelite with vague Sp-Po laminations, laminae 1-2 mm thick, total sulphide <3% (Sp>Po)	I laminations	X		
93-C123g	1866	13.8 (4.2)	disseminated, aggregate	Similar to 93-C123b, e have Sp mineralisation rather than Po	I			
93-C123h	1866	19.5 (5.9)	disseminated, aggregate	Similar to 93-C123g	I			
93-C124a	1866	21.5 (6.6)	disseminated	Fine-grained quartzite <2% disseminated Po. Bt and Grt present (?)	H marker			
93-C124b	1866	25 (7.6)	disseminated	Similar to 93-C124a	H			
93-C124c	1866	29.2 (8.9)	disseminated	Similar to 93-C124a, b	H		X	
93-C125a	1866	35 (10.7)	none to disseminated	Weakly bedded fine-grained quartzite bedding defined by presence/absence of Bt, <1% fine-grained Po	hu marker			
93-C125b	1866	40 (12.2)	none	Massive semi-pelite	hu			

Table A1 1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C125c	1866	44.5 (13.6)	none to disseminated	Similar to 93-C125b, have minor Po (<<1%)	Hu			
93-C125d	1866	48 (14.6)	laminated	Semi-pelite with finely laminated Po	Hu			
93-C125e	1866	54 (16.5)	none	Massive semi-pelite	Hu		X	
93-C125f	1866	62 (18.9)	disseminated	Semi-pelite, 1 mm Qtz grains scattered throughout sample, 2-3% fine-grained Po abundant Bt	Hu			
93-C125g	1866	67.5 (20.5)	disseminated	Bedded semi-pelite with cross cutting and patchy Ab alteration	Hu			
93-C125h	1866	72.5 (22.1)	disseminated	Graded bedding consisting of medium-grained quartzite to semi-pelite disseminated Po (2-5%) most abundant in quartzite horizons graded beds 1-2 cm thick	Hu			
93-C126a	1866	76.8 (23.4)	laminated	Laminated Po and medium-grained quartzite Po content 10-15%, quartzite consists of Bt-rich and Bt-free laminae	base of Hu ore	X		
93-C126b	1866	77.5 (23.6)	disseminated	Laminated fine-grained quartzite with <10% disseminated Po laminae are 0.5-1 cm thick define by relative Po content laminae contacts are gradational Po increase up-section	Hu ore			
93-C126c	1866	77.8 (23.7)	laminated	Laminated Po and fine-grained quartzite Po laminae are vague (diffuse contacts) and are Bt-rich Po content 10%	Hu ore	X		
93-C126d	1866	78.5 (23.9)	massive	Massive Sp (20-25%) and Po (>70%) with minor waste (<10%) sulphides are very fine-grained Po is generally slightly coarser than Sp	Hu ore			
93-C126e	1866	79.2 (24.1)	massive	Similar to 93-C126d	Hu ore		X (126e-h)	
93-C126f	1866	79.5 (24.2)	massive	Similar to 93-C126e	Hu ore			
93-C126g	1866	80.2 (24.4)	laminated	Laminated semi-pelite and Po, Po laminae 1-2 mm thick, semi-pelite laminae 3 mm to 1 cm thick	Hu ore		X (126e-h)	
93-C126h	1866	80.5 (24.5)	laminated	Similar to 93-C126c	Hu ore		X (126e-h)	
93-C126i	1866	81.2 (24.7)	laminated	Similar to 93-C126c	top of Hu ore			

Table A1.1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C127a	1866	88.2 (26.9)	none	Carbonated altered fine-grained quartzite, presence/absence of alteration defines bedding, beds 1 cm thick	Hu			
93-C127b	1866	91 (27.7)	disseminated	Bedded to laminated fine-grained quartzite to semi-pelite, bedding consist of alternating (Bt+Grt)-rich and (Bt+Grt)-poor beds, beds up to 1.5 cm thick. 5% disseminated Po, patchy Ab alteration that cross-cuts bedding	Hu			
93-C127c	1866	101 (30.8)	aggregate	Massive semi-pelite with rare blebs of Po or Py, aggregates up to 3 mm in size	Hu			
93-C127d	1866	102 (31)	none	Laminated to bedded fine-grained quartzite, beds/laminae are 5 mm to 3 cm thick, bedding defined by colour/mineralogical variation, dark (Bt+Chl)-rich beds and light (Bt+Grt)-poor beds, bedding contacts are sharp but irregular	U marker			
93-C128a	1866	106 (32.3)	disseminated	Interbedded fine-grained quartzite and semi-pelite, laminae contacts are sharp and straight, quartzite contains 5% disseminated Po, semi-pelite laminae are Grt-bearing	U	X		
93-C128b	1866	107 (32.6)	none	Coarse-grained Qtz vein in semi-pelite to pelite	U			
93-C128c	1866	111 (33.8)	none	Partially Ab and Chl altered pelite, alteration is irregularly distributed consisting of a massive Chl core with a diffuse Ab halo	U			
93-C128d	1866	124 (37.8)	none	Massive semi-pelite to pelite	U			
93-C128e	1866	126 (38.4)	disseminated	Similar to 93-C128f	U		X	
93-C128f	1866	129 (39.3)	disseminated	Altered semi-pelite, alteration is irregular consisting of a Bt+Chl+Py core surrounded by a diffuse Ab halo	U			
93-C128g	1866	134.5 (41)	none to disseminated	Bt+Grt altered semi-pelite, sample is cross-cut by thin Qtz veins (unmineralized), <<1% disseminated Py (very fine-grained)	U			
93-C128h	1866	136 (41.1)	none to disseminated	Similar to 93-C128g	U			
93-C128i	1866	140 (42.7)	none to disseminated	Massive semi-pelite with <<1% very fine-grained Py/Po	U			
93-C129a	804	31 (9.4)	disseminated	Bt altered semi-pelite, 5% fine-grained Po	I			
93-C129b	804	31.8 (9.7)	disseminated	Similar to 93-C129a	I			

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	This section	Geo-chem	Isotope
93-C130a	804	36 (10.9)	matrix	Brecciated semi-pelite matrix (65%) consists of very fine-grained Po, fragments (35%) are angular to sub-angular and are several millimetres in size	I			
93-C130b	804	36.2 (11)	none	(Bt+Grt)-bearing quartzite	I			
93-C130c	804	36.5 (11.1)	disseminated aggregate	Patchy to disseminated Sp (<5%) and Po (<10%) in fine-grained quartzite	I			
93-C131a	804	37.7 (11.5)	disseminated	Massive semi-pelite with <2% Po (very fine-grained)	I			
93-C131b	804	38.7 (11.8)	disseminated	Similar to 93-C131a	I			
93-C132a	804	39.7 (12.1)	laminated, disseminated	Laminated Sp in semi-pelite laminae are 3-5 mm thick and have gradational contacts. Sp content 15%, semi-pelite contains 5% disseminated Po	I laminations (?)			
93-C132b	804	39.8 (12.2)	laminated disseminated	Similar to 93-C132a, except have Po laminations rather than Sp	I			
93-C133a	804	41.5 (12.6)	none	Massive semi-pelite	I			
93-C133b	804	42 (12.8)	laminated	Laminated Po and semi-pelite laminae 1-5 mm thick. Po-pelite contacts sharp and straight. Po content 20-25%.	I laminations	X		
93-C133c	804	42.5 (13)	laminated	Similar to 93-C133b	I laminations			
93-C133d	804	44 (13.4)	laminated	Similar to 93-C133b	I laminations			
93-C134a	804	45 (13.7)	laminated	Laminated Po and fine- to medium-grained quartzite laminae <5 mm thick, quartzite laminae defined by colour/mineralogical variations; darker laminae are Grt-bearing. Po content 15-20%.	I laminations			
93-C134b	804	46.7 (14.2)	none	Massive semi-pelite	I	X		
93-C134c	804	48.3 (14.7)	banded	Semi-pelite with irregularly shaped Po bands. Po content <10%.	I			
93-C134d	804	49.2 (15)	none	Semi-pelite	I			
93-C134e	804	49.9 (15.2)	aggregate	Semi-pelite with Po patches. Po content <10% and patches <5 mm in size	I			
93-C135a	804	50 (15.2)	none	Massive semi-pelite	H			
93-C135b	804	53.2 (16.2)	none	Coarse semi-pelite	H			

Table A1 I -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C135c	804	57.3 (17.5)	none to disseminated	Semi-pelite with Chl and Bt specs. very minor disseminated Po (<<1%)	H	X		
93-C135d	804	58.5 (17.8)	none to disseminated	Similar to 93-C135c	H		X	
93-C136a	804	60.8 (18.5)	none to disseminated	Interbedded Po-rich quartzite and semi-pelite	hu marker soft sediment deformation			
93-C136b	804	62.8 (19.1)	disseminated	Fine- to medium-grained quartzite with Chl and Bt specs <<1% disseminated Po	hu		X (136b-137b)	
93-C136c	804	66.5 (20.3)	disseminated	Coarse semi-pelite with Qtz grains	hu		X (136b-137b)	
93-C137a	804	67.3 (20.5)	none to disseminated	Bt-rich very fine- to fine-grained quartzite, <1% fine-grained Po	Hu marker		X (136b-137b)	
93-C137b	804	70.8 (21.6)	disseminated	Bt-rich fine- to medium-grained quartzite, 2% disseminated Po sample is cross-cut by a small (1-2 mm thick) Qtz+Py vein	Hu		X (136b-137b)	
93-C137c	804	74.7 (22.8)	disseminated	Coarse semi-pelite to very fine-grained quartzite, 1-2% fine-grained Po	Hu			
93-C137d	804	78 (23.8)	disseminated	Similar to 93-C137c	Hu			
93-C137e	804	80 (27.1)	none to disseminated	Massive semi-pelite ~1% very fine-grained Po	Hu		X	
93-C137f	804	97 (29.6)	none to disseminated	Pelite with <<1% very fine-grained Po	Hu			
93-C137g	804	99 (30.2)	none to disseminated	Similar to 93-C137f	Hu			
93-C138a	804	108 (32.9)	none	Massive semi-pelite	Hu			
93-C138b	804	110.8 (33.8)	disseminated	Bt-rich, fine- to medium-grained quartzite, 3-5% disseminated Py (very fine-grained)	Hu			
93-C138c	804	111.3 (33.9)	none	Semi-pelite	Hu			
93-C138d	804	111.8 (34)	none	Semi-pelite	Hu		X	
93-C138e	804	112 (34.1)	disseminated	Very fine-grained Sp (30-35%) and fine-grained Po (5%) disseminated in semi-pelite	base of Hu ore			S

Table A1.1. -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C138f	804	112.5 (34.3)	laminated	Contorted laminations of Po and semi-pelite. Po laminae are 1-2 mm thick where as gangue laminae/beds are 1-2 cm thick. Po content = 20%. sily-pelite contains abundant fine-grained Bt	Hu ore	X		
93-C138g	804	112.5 (34.3)	laminated	Similar to 93-C138f	Hu ore		X (138g-hj)	
93-C138h	804	112.7 (34.3)	massive	Massive Po with 15-20% gangue	Hu ore		X (138g-hj)	
93-C138i	804	112.9 (34.4)	disseminated	Disseminated Sp (35%) in Bt-rich, coarse semi-pelite to fine-grained quartzite	Hu ore			S
93-C138j	804	113.3 (34.5)	banded	Weakly banded Po (15-20%) Sp (25-30%) and gangue (>50%) Sp increases up-section contacts are gradational, bands are >5 mm	Hu ore		X (138g-hj)	S
93-C138k	804	113.6 (34.6)	banded	Similar to 93-C138j	Hu ore			
93-C138l	804	114 (34.7)	massive	Massive Po with 15-20% gangue consisting of fine-grained Qtz	Hu ore	X		
93-C138m	804	115.8 (35.3)	laminated	Laminated Po (20-30%) Sp (50-55%) and gangue (15-20%) Po laminae are <1 mm thick. Sp and gangue laminae are 0.5-1 cm thick sulphides are very fine- to fine grained, contacts are sharp and straight	Hu ore			S
93-C138n	804	115.8 (35.3)	banded	Lower 1 cm consists of a single Po band in semi-pelite Upper 4 cm consists of laminated semi-pelite, laminae are 0.1 to 1 cm thick	Hu ore	X		
93-C138o	804	116.8 (35.6)	laminated	Semi-pelite with 2-3 thin (<2 mm) Po laminations, Po content 15-20%	top of Hu ore			
93-C139a	5232	217.5 (66.3)	laminated	Laminated Sp (50-60%), Po (25-30%) and semi-pelite (15-20%) laminae are <1 cm thick gangue laminae <5 mm, laminae contacts are sharp and straight	F.W. ore	X	X (139a-e)	
93-C139b	5232	218.5 (66.6)	laminated	Contorted laminae of Sp (40%), Gn (15%) and Po (30%) with minor waste bands (<15%) contacts are gradational	F.W. ore	X	X (139a-e)	
93-C139c	5232	219.4 (66.9)	laminated	Folded laminae of Po (20-25%) Sp (15-20%) Gn (<10%) and gangue (50%), laminae are 1-5 mm thick with abrupt contacts laminae are ordered, gangue-Gn-Sp-Po-Sp-Gn-gangue	F.W. ore	X	X (139a-e)	

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C139d	5232	221.3 (67.4)	disseminated to aggregate	Disseminated Po (5-10%), Sp (20-50%) and Gr (<5%) in semi-pelite to semi-pelite, sulphides are irregularly distributed, resulting in a patchy appearance. Po forms small (1-2 mm) wisps	F W ore	X	X (139a-e)	
93-C139e	5232	223.3 (68.1)	laminated	Similar to 93-C139c	F W ore	X	X (139a-e)	
93-C140a	5232	227.2 (69.3)	aggregate, vein	Chi-altered semi-pelite cross-cut by a zoned carbonate-Qtz vein, zonation consists of a Qtz core with carbonated rims, vein is 5 mm thick. Bt alteration along vein-semi-pelite contact, patches (<7 mm in diameter) of Po scattered through-out semi-pelite, carbonate-Qtz vein is cross-cut by a very thin Po vein and Po patch. Po content = 5-7%.	I chloritite			
93-C140b	5232	228.5 (69.6)	aggregate	Chi altered pelite with Po	I chloritite	X		
93-C141b	5232	240 (73.2)	vein	Pervasively Chi altered pelite, cross-cut by several 1-2 mm thick Po veins, veins have a dendritic form	I chloritite			
93-C141a	5232	239 (72.8)	disseminated to aggregate	Chi altered semi-pelite, Chi alteration is irregular, consisting of small wisps (several millimetres) to discontinuous lenses (several centimetres). Po occurs as very fine-grained disseminated grains to patches/lenses. Po content = 5%	I chloritite			
93-C142a	5232	241.8 (73.7)	none	Pervasively Chi altered pelite weak foliation parallel to core axis	I chloritite			
93-C142b	5232	242 (73.8)	none	Similar to 93-C142a	I chloritite	X	X	S
93-C142c	5232	244 (74.4)	none	Bt-rich coarse-grained quartzite	H marker			
93-C142d	5232	244.2 (74.4)	none	Similar to 93-C142c	H		X	
93-C143a	5232	246 (75)	none	Quartzite with Bt and Trm alteration	Hu marker	X	X	
93-C143b	5232	246.2 (75)	disseminated	Bt-rich, fine- to medium-grained quartzite 1% disseminated Po (fine-grained)	top of Hu marker			
93-C144	-	-	-	NO SAMPLE	-	-	-	-
93-C145a	5232	247.8 (75.5)	disseminated	Similar to 93-C145b	Hu			
93-C145b	5232	248.8 (75.8)	disseminated	Semi-pelite with 1% disseminated fine-grained Po, Bt associated with Po mineralisation	Hu	X	X	

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C146	5232	249.5 (76)	disseminated	(Chi-Bt-Grt)-bearing semi-pelite 7-10% disseminated very fine-grained Po, Qtz grains disseminated throughout sample	Hu			
93-C147	5232	252 (76.8)	disseminated	Similar to 93-C146	Hu			
93-C148a	5232	263 (80.2)	disseminated	Coarse semi-pelite to very fine-grained quartzite with irregularly shaped Chi-Bt patches, fine-grained Po (<5%) and very fine-grained Sp (<1%)	Hu	X	X	
93-C148b	5232	263 (80.2)	disseminated	Similar to 93-C148a	Hu			
93-C149a	5232	274.8 (83.8)	disseminated to aggregate	Irregularly shaped patches to disseminated Po (30%) and Sp (10-15%) in semi-pelite, patches have a high abundance of Bt, sulphides are fine-grained	Hu			
93-C149b	5232	276.5 (84.3)	vein	Sp-Po vein in fractured silty-pelite, vein cross-cuts a thin Chi band	Hu	X	X	
93-C149c	5232	276.5 (84.3)	disseminated to aggregate	Chloritized semi-pelite to pelite with quartzite lenses 10-15% Po occurring as disseminated grains and wisps quartzite lenses irregularly shaped and rimmed by Po sample is weakly foliated	Hu chlorite			
93-C150a	5063	156.5 (47.7)	disseminated	Pervasively chloritized pelite cross-cut by a 2 cm wide medium-grained Qtz vein, vein contains minor Chi and Bt fine-grained euhedral Py disseminated along vein-pelite contact	F W			
93-C150b	5063	158 (48.2)	disseminated	Chi and Ab altered pelite with disseminated euhedral Py (1-2%) Ab alteration is patchy	1 chlorite-albite		X	
93-C151a	5063	165 (50.3)	disseminated	Semi-pelite minor Po	1 chlorite-albite	X		
93-C151b	5063	165.9 (50.6)	disseminated	Similar to 93-C151a	1 chlorite-albite			
93-C151c	5063	169.8 (51.8)	disseminated	Similar to 93-C151a Ab less abundant	1 chlorite-albite			
93-C151d	5063	172.5 (52.6)	disseminated	Chi altered pelite high abundance of Bt 3-5% medium grained Py	1 chlorite			
93-C151e	5063	176.5 (53.8)	aggregate	Semi-pelite with wisps to patches of Py (3-5%), aggregates are 0.5-1 cm in size, sample is weakly foliated (?)	1			

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C152	5063	178.6 (54.4)	laminated, disseminated	<p>Lower 2 cm of sample consists of laminated Gn (60%) and Sp (40%), laminae are <5 mm, contacts are sharp and straight</p> <p>Overlying Gn and Sp laminations is a 1 cm wide horizon of interlaminated Py (50%), gangue (45%) and Sp (<5%), laminae are folded, <1 m thick and have diffuse contacts. Py laminae rapidly graded into a 1 cm horizon of weakly laminated Sp and gangue. Sp laminae are highly disseminated</p> <p>Upper 5 cm of sample consist of 2 series of graded fine-grained quartzite to semi-pelite, graded beds are >1.5 cm thick, quartzite horizons contain up to 5% disseminated medium-grained Py, 1-2 mm Qtz vein cross-cuts uppermost semi-pelite horizon, vein contact defined by medium-grained Py</p>	<p>I to H transition</p> <p>(1 laminations at 178.6 ft)</p>	X		
93-C153a	5063	180 (54.9)	vein, disseminated	Chloritized semi-pelite, cross-cutting zoned Qtz+Py vein (Py core), <2% disseminated Py (very fine-grained)	H chloritite			
93-C153b	5063	187.7 (57.2)	vein, disseminated	Similar to 93-C153c	H	X		
93-C153c	5063	191.7 (58.4)	aggregate	Semi-pelite with bands of very fine-grained Po (5-10%) lenses >1 cm in size, Bt and Chl mark Po-semi-pelite contact	base of H "ore"			
93-C154a	5063	192.2 (58.6)	laminated, disseminated, banded	<p>Lower 2 cm consists of interlaminated Po and gangue, laminae are 1-3 mm thick, Po content = 20-30%</p> <p>A 2 cm thick bed of semi-pelite abruptly overlies the interlaminated horizon, disseminated Po decreases in abundance up-section, ranging from 1-15%</p> <p>Top 1 cm consists of a massive band of Sp with 5% Po, Sp band gradationally overlies semi-pelite horizon, with contact consisting of interlaminated Sp and gangue (Sp laminae thicken up-section and gangue decrease)</p>	H "ore"			
93-C154b	5063	197.8 (58.8)	massive	Massive Sp with wisps of fine-grained Gn (5%) and Py, Bt associated with Gn mineralization.	H "ore"		X	S
93-C154c	5063	193.3 (58.9)	laminated, vein	<p>Laminated Sp (>50%), Gn (15-20%) and Po (<5%), medium-grained Py (<10%) along lamination planes, rare interlaminations of gangue material (10-15%), laminae are <1 mm and have diffuse contacts, sulphides very fine-grained</p> <p>Upper 1-2 cm of sample consists of semi-pelite cross-cut by a 1 mm wide Py vein, Py consists of euhedral, medium-sized grains, a thin Chl-rich alteration halo surrounds the vein</p>	H "ore"	X		

Table A1 1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	This section	Geo-chem	Isotope
93-C154d	5063	193.4 (58.9)	laminated	Similar to 93-C154c	H "ore"	X	X	
93-C154e	5063	193.9 (59.1)	laminated	Thickly laminated Sp (>50%) and Gn (20-25%) with thin gangue interlaminae (<10%). sulphide laminae are 0.5-1 cm thick, gangue laminae are <2 mm, euhedral Py (15%) grains disseminated through Gn laminae, laminae have sharp and straight contacts	H "ore"			
93-C155a	5063	194.9 (59.4)	fracture, disseminated, banded	Extensively fractured Chl altered pelite, fractures infilled by fine-grained Po and Py (possibly replacing Po), disseminated Py in pelite, top 1 cm of sample consists of a massive band of Sp and Gn with minor Py, band consists of 70% Sp, 20% Gn, 5% Py and 5% gangue, total sulphide in pelite <3%	H "ore"	X		
93-C155b	5063	195.2 (59.5)	massive	Massive Sp (>50%) and Gn (15-20%) with minor replacement Py (<10%), irregular patches of semi-pelite (<20%), up to 1 cm in size	H "ore"			
93-C155c	5063	195.7 (59.7)	massive	Similar to 93-C155b	H "ore"		X	S
93-C156a	5063	196.9 (60)	laminated to massive	Transition into a massive zone of folded Sp and Gn laminae, transition marked by (in stratigraphic order): 1) increase in disseminated Sp and Po (up to 7%), 2) a 5 mm wide banded of euhedral Py replacing Sp (?), 3) a 1 cm wide horizon of interlaminated gangue Sp and Ga, 4) edge of massive zone marked by a second band of Py, and 5) massive zone of laminated Sp and Gn	H "ore"	X		
93-C156b	5063	197.2 (60.1)	laminated to banded	Laminated/banded Po with minor intercalated Sp (<5%) and chloritized pelite (<15%), laminae/bands are <2 cm thick and are folded, laminated/banded Po grades into laminated Py, Py grains are euhedral and <1 mm in size	H "ore"			S
93-C156c	5063	197.5 (60.2)	laminated	Folded Py and pelite laminations, laminae are <1 cm thick, pelite is chloritized, Py content = 20-25%	H "ore"			
93-C156d	5063	198 (60.4)	disseminated	Pelite with disseminated fine-grained Sp (5%), medium-grained Py (25%) and Gn (<2%), Py replacement of Gn (?)	H "ore"			
93-C156e	5063	199.2 (60.7)	aggregate to massive	Chl altered pelite extensively replaced by fine- to medium-grained Py (60-70%), Py mineralisation has a patchy appearance	H "ore"	X	X	S
93-C156f	5063	201 (61.3)	disseminated, fracture	Pervasively chloritized pelite with fine-grained euhedral Py, disseminations Py also infills fractures, Py content = 1-2%	H "chlorite"		X	

Table A1.1. -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C157a	5063	202.3 (61.7)	disseminated, fracture	Pervasively albitized pelite with fine-grained euhedral Py disseminations. Py also infills fractures. Py content = 1-2%	H albitite	X		
93-C157b	5063	203.5 (62)	none to disseminated	Albitized pelite with minor Chl alteration and <1% disseminated Py. Chl is unevenly distributed	H albitite			
93-C158a	5063	207.5 (63.2)	disseminated, fracture	Similar to 93-C157b, have Chl and Py infilling fractures	H albitite	X		
93-C158b	5063	210.3 (64.1)	vein	Semi-pelite with minor to moderate Chl-alteration, consisting of disseminated Chl grains (1-5 mm in length). sample is cross-cut by a small fine-grained Py vein	H			
93-C159a	5063	215 (65.5)	disseminated	Similar to 93-C158b, no Py vein, sample contains 20-30% disseminated Py	H			
93-C159b	5063	216.8 (66.1)	none	Similar to 93-C158b	H	X		
93-C159c	5063	218 (66.4)	vein	Chloritized pelite cross-cut by several randomly oriented Py-Qtz veins	H chloritite			
93-C159d	5063	220.3 (67.1)	none to disseminated	Chl and Ab altered semi-pelite, Ab > Chl, <1% disseminated medium-grained Py. Chl most abundant along fractures	H albitite-chloritite	X	X	S
93-C159e	5063	223.5 (68.1)	none to disseminated	Semi-pelite, moderate Chl > Ab alteration, although Ab increases up section where it forms a massive 2 cm wide band near the top of the sample. <1% disseminated fine-grained Py	H chloritite-albitite	X		
93-C160a	4483	209 (63.7)	disseminated, aggregate	Chloritized semi-pelite, Bt and Grt in minor abundance, disseminated to patchy Po (3-5%). Po patches < 1 cm in size	I			
93-C160b	4483	211 (64.3)	laminated	Pelite (50%) grading into a massive zone of laminated Sp (45%) with interlaminated Gr+Po (<5%). sulphides are very fine-to fine-grained	I	X	X	
93-C160c	4483	215 (65.5)	disseminated	Chloritized pelite with disseminated Sp (<5%) and Po (<2%), minor (<1%) Py replacement of Po (?)	I chloritite		X	
93-C160d	4483	221 (67.4)	disseminated	Chloritized pelite with a foliation developed near-parallel to coreaxis disseminated Py (5%) observed along foliation	I chloritite			
93-C160e	4483	222 (67.7)	disseminated	Similar to 93-C160d	I chloritite			
93-C161a	4483	223 (68)	massive	Massive Sp with minor Po (5%), 25% gangue	I laminations			
93-C161b	4483	224.3 (68.4)	massive	Similar to 93-C161a	I laminations	X	X	

Table A1.1 -continued-

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C161c	4483	224.7 (68.5)	banded	Folded bands of Po (35%), Sp+Gn (20%) and gangue (45%), bands are >5 mm and have gradational contacts	I laminations			
93-C161d	4483	226.2 (68.9)	disseminated vein	Chloritized semi-pelite with disseminated Po (5%), sample is cross-cut by zoned Gn+Po+Py veins, zonation = Py (rim)-Po-Gn (core), edge of sample has a Grt-rich zone	interbed to I laminations	X		
93-C161e	4483	227 (69.2)	banded	Vague bands of Sp (25%), Gn (15%), Po (55%) and waste (<10%), bands are variable in size, irregularly shaped and have gradational contacts, banding is very obscure	I laminations			
93-C161f	4483	229 (69.8)	banded	Similar to 93-C161e	I laminations	X	X	
93-C162a	4483	232.5 (70.9)	disseminated	Chloritized argillite with disseminated medium- to coarse-grained euhedral Py (15%), foliation developed sub-parallel to core axis	I chloritite			
93-C162b	4483	235.2 (71.7)	disseminated	Similar to 93-C162a	I chloritite	X		
93-C163a	4483	238.2 (72.6)	none to disseminated	Chl and Ab altered semi-pelite to pelite. Ab is unevenly distributed consisting a diffuse zones of pinkish-white Ab (<1%), disseminated medium-grained Py	I chloritite-albitite			
93-C163b	4483	242 (73.8)	none to disseminated	Similar to 93-C163a	H chloritite-albitite		X	
93-C163c	4483	243.8 (74.3)	none	Chloritized pelite with disseminated grains of pinkish-white Ab (grains are 1-3 mm in size)	H chloritite-albitite	X		
93-C163d	4483	250.5 (76.4)	none	Similar to 93-C163c	H chloritite-albitite			
93-C164a	4483	257.3 (78.4)	none	Chloritized semi-pelite, foliation is aligned parallel to core axis	H chloritite			
93-C164b	4483	269 (82)	none	Similar to 93-C164a	H chloritite		X	
93-C165a	4483	271 (82.6)	none	Albitized semi-pelite to pelite containing fine-grained specs of Chl (15%)	H albitite-chloritite	X	X	S
93-C165b	4483	281 (85.6)	none	Similar to 93-C165a, have increased Chl content (20-25%)	H albitite-chloritite			
93-C165c	4483	290.5 (79.4)	none to disseminated	Chloritized semi-pelite to pelite with irregular shaped Ab patches disseminations of fine-grained euhedral Py (<1%)	Hu chloritite-albitite	X		
93-C165d	4483	289 (88.1)	vein, disseminated	Chloritized pelite cross-cut by a 1-5 mm wide Sp vein, medium-grained euhedral Py occurs as both disseminated grains and infillings of fractures	Hu chloritite			

Sample	Drill Hole	Depth ft (m)	Style of Mineralisation	Description	Comments	Thin section	Geo-chem	Isotope
93-C165e	4483	291 (88.7)	disseminated	Weakly foliated (?) chloritized pelite with disseminated medium-grained euhedral Py (5%)	Hu chloritite			
93-C166a	4483	291.5 (88.8)	laminated	Laminated Sp (30%), Py (10%) and chloritic pelite (60%). laminae are 1-5 mm thick. laminae contacts are defined by fine-grained Py	base of Hu ore			
93-C166b	4483	292 (89)	laminated	Similar to 93-C166a	Hu ore	X	X	S
93-C166c	4483	292.2 (89.1)	matrix	Brecciated semi-pelite. matrix represents 30% of the sample, consisting of 15% Po, 10% Sp and <5% Py. fragments are angular to sub-angular, ranging in size from <1 to 5 mm	Hu ore	X		
93-C166d	4483	293.2 (89.4)	matrix	Similar to 93-C166c	Hu ore	X		
93-C166e	4483	293.5 (89.5)	fracture	Fractured semi-pelite. fractures are oriented parallel to core axis, and infilled with fine- to medium-grained Po and Py sulphide content ~ 10-15% Po and 2-3% Py	top of Hu ore			S
93-C166f	4483	294.5 (89.8)	none	Chloritized pelite with 1-2 mm specs of Ab (5%)	Hu chloritite	X		
93-C166g	4483	295 (89.9)	none	Similar to 93-C166c	Hu chloritite	X	X	
93-C166h	4483	295.5 (90.1)	none	Foliated chloritic pelite. foliation parallel to core axis	Hu chloritite			
93-C167a	1972	183.5 (55.9)	matrix	Brecciated semi-pelite with Po (30%) and Py (10%) matrix. Po is fine grained and appears to have been replaced by euhedral, medium-grained Py. clasts are angular to sub-rounded, ranging in size from 0.2 to 2 cm	F W breccia			
93-C167b	1972	185.2 (56.4)	matrix	Similar to 93-C167a	F W breccia		X	
93-C167c	1972	188 (57.3)	none	Massive semi-pelite	F W			
93-C167d	1972	189.5 (57.8)	laminated	Laminated Po (25-30%) and gangue (70%) with minor Py (<5%) replacement of Po. laminae are 3-5 mm thick with straight and sharp contacts	F W ore			
93-C167e	1972	191 (58.2)	laminated	Similar to 93-C167d	F W ore		X	
93-C167f	1972	192 (58.5)	laminated	Contorted laminations of Po (35%) and gangue (60%). 1-2 mm patches of medium- to coarse-grained Py (5%) cross-cut Po laminae (replacement?). laminae <1 to 2 mm thick	F W ore			

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C166a	1972	195 (59.4)	none to disseminated	Coarse semi-pelite to fine-grained quartzite sample has been partially albitized, with Grt and Chi prevalent in these zones. Bt and Py (<1%) is common in Ab-poor zones.	I marker			
93-C166b	1972	198.5 (60.5)	none	Bt and Chi altered semi-pelite sample appears to have also been partially sericitized (?)	I			
93-C166c	1972	204.7 (62.4)	none	Similar to 93-C167b	I			
93-C166d	1972	209.3 (63.8)	none	Similar to 93-C167b	I		X	
93-C166e	1972	213.5 (65.1)	disseminated	Semi-pelite with disseminated very fine- to fine-grained Po (1-2%)	I			
93-C166f	1972	218.2 (66.5)	aggregate	Similar to 93-C166e, Po occurs as small (1-5 mm) aggregates	I			
93-C166g	1972	220.8 (67.3)	disseminated	Chloritized semi-pelite to pelite with 1-2% disseminated fine-grained Po, possible sericitization (?)	I chloritite			
93-C166h	1972	222.9 (67.9)	disseminated	Similar to 93-C166g	I chloritite			
93-C166i	1972	223.4 (68.1)	none	Semi-pelite with a vague (Bt-Grt)-rich band near the top of the sample				
93-C169a	1972	224 (68.3)	banded	Irregularly banded Po (15-20%) and Sph (50-60%) variable amount of gangue (<35%) disseminated throughout ore bands, contacts are sharp, commonly defined by Ch.	I laminations		X (169a-d)	
93-C169b	1972	224.3 (68.4)	laminated	Laminated Sp (20-25%), Po (30-35%) and Chi altered pelite (40-50%), sulphides are very fine-grained, laminae are 1-7 mm thick with abrupt and uneven contacts, laminations occur in a rhythmic pattern (pelite-Po-Sp-Po-pelite)	I laminations	X	X (169a-d)	
93-C169c	1972	225 (68.6)	laminated	Laminated Po (10%), Sp (40-45%), and Gn (25-30%) laminae are 1-3 mm thick, with gradational contacts, gangue (10-15%) occurs as 1-2 mm patches disseminated throughout the sample	I laminations		X (169a-d)	
93-C169d	1972	225.8 (68.8)	matrix or disseminated to massive	Disseminated (net-texture) to massive Sp (35-40%) and Po (20-25%) with 30-40% waste, sulphides are very fine-grained, sample may be a breccia (?) with sulphides forming matrix	I laminations		X (169a-d)	
93-C170a	1972	230 (70.1)	fracture	Chloritized semi-pelite to pelite with Po (<2%) in filling fractures	I chloritite			

Sample	Drill Hole	Depth ft (m)	Style of Mineralization	Description	Comments	Thin section	Geo-chem	Isotope
93-C170b	1972	230.5 (70.2)	laminated	Laminated Sp (40-45%), Po (20-25%), Gs (5%), gangue (20-25%) and Py (<2%). laminae are deformed and range in thickness from 1-3 mm. laminations are laterally discontinuous, sulphide are very fine-grained, except for Py (= medium-grained)	1 laminations			
93-C170c	1972	233.6 (71.2)	fracture	Alb altered pelite with Bt, Chl and Py infilling fractures	1 albite			
93-C170d	1972	234 (71.3)	disseminated	Similar to 93-C170c	1 albite		X	
93-C170e	1972	235 (71.6)	disseminated	Albitized pelite with 5% disseminated Py (very fine-grained), minor Chl alteration, forming small 5-10 mm lenses	1 albite			
93-C170f	1972	235.5 (71.9)	matrix	Fault breccia consisting of sub-angular to sub-rounded clasts in a siliciclastic+Py (<3%) matrix, fragments are 3 mm to 1 cm in size, and show no macroscopic evidence of strain (ϵ elongation), matrix has been partially albitized, clasts have been sericitized (?)	Fault zone		X	
93-C170g	1972	236.2 (72)	laminated, fracture	Laminated Sp (30-35%) and pelite (>60%), laminae are 1-5 mm thick, with sharp and straight contacts, fractures perpendicular to laminations are infilled with fine-grained euhedral Py (<5%), Py also observed along lamination planes	1 laminations	X		
93-C170h	1972	236.5 (72.1)	laminated fracture	Similar to 93-C170g	1 laminations			
93-C170i	1972	238.8 (72.8)	matrix	Similar to 93-C170f	Fault zone			

Explanation:

Mineral abbreviations (after Kretz, 1983): Ab= albite, Apy= arsenopyrite, Bt= biotite, Cal= calcite, Ccp= chalcopyrite, Chl= chlorite, Gs= galena, Grt= garnet, Kfs= potassium feldspar, Ms= muscovite, Po= pyrrhotite, Py= pyrite, Qtz= quartz, Sp= sphalerite, and Trm= tourmaline

Positive depths for core samples indicated that measurements were made from the base of the drill hole, with negative depths indicate measurement made from the top of the hole.

Analytical abbreviations: Geochem= whole rock geochemistry; "X" symbol denotes the method of analysis; "X (## - ##)" symbol denotes combined geochemistry samples.

Isotope abbreviations: S= δ^{34} sulphur whole-rock analyses).

Appendix 2

Summary tables for meta-sedimentary petrography

Table A2.1. Petrographic analysis of I sequence meta-sedimentary rocks.

Sample No. (DDH)	Mineralogy	Abundance	Comments
Quartzite/Quartz psammite			
93-C077b (4501)	Qtz/Kfs	>20	- fine-grained samples have lower matrix contents (<10%) as opposed to coarser varieties which have matrix contents up to 30%. - Qtz/Kfs recrystallised, undulose extinction, anhedral, 0.5 to 1 mm; Ser laths, up to 0.1 mm; Chl ² anomalous white-grey birefringence, subhedral to euhedral laths, <0.5 mm; Ms euhedral laths, <0.25 mm; Bt anhedral, orange-brown pleochroism, <0.25 mm, forms patches/clots; Trm anhedral, intergrown with Bt, orange-brown pleochroism; Carb. anhedral, <0.25 mm, infilling of intergranular porosity; Clz anhedral to subhedral, forms clots, intergrown with Sulph, <0.25 mm; Grt poikilitic, anhedral, <1 mm; Sulph. anhedral, disseminated, Po>Sp, recrystalized, <0.1 mm; Py euhedral, <0.25 mm; Zircon elongate rounded to well rounded grains, <0.05 mm.
93-C091a (3952)	Ser	<10	
93-C113a (3994)	Chl ²	<10	
	Ms	<1	
	Bt	10-20 (>20 in 77b)	
	Trm	10-20	
	Carb.	<10	
	Clz	10-20	
	Grt	<10	
	Sulph.	<10	
	Py	<1	
	Zircon	<<1	
Semi-pelite (well sorted)			
93-C123d (1866)	Qtz/Kfs	>20 (<10 in 134b)	- Qtz/Kfs anhedral, recrystallised, <0.5 mm, undulose extinction; Ser euhedral laths, <0.25 mm; Chl ² anomalous white-grey birefringence, euhedral to subhedral laths, <0.5 mm, forms clots up to .5 mm, replaces Bt; Ms euhedral laths, <0.3 mm; Bt anhedral to subhedral grains, <0.3 mm, orange-brown pleochroism; Trm anhedral, intergrown with Bt, <0.1 mm; Carb. anhedral to subhedral, <0.1 mm, intergrown with Sulph.; Clz anhedral, forms clots, intergrown with sulphides, <0.1 mm; Sulph. Po>Sp. anhedral, disseminated, <0.25 mm; Zircon anhedral, highly fractured, <0.05 mm.
93-C134b (804)	Ser	10-20	
93-C168e (1972)	Chl ²	<10	
	Ms	<1	
	Bt	<10	
	Trm	<10 (>20 in 134b)	
	Carb.	<10	
	Clz	<1	
	Sulph.	<10	
	Zircon	<<1	
Semi-pelite (poorly sorted)			
93-C113b (3994)	Qtz/Kfs	>20	- samples 113b and 113c are thickly laminated (0.5-1 cm) defined by disseminated Sulph. - sample 151a is extensive altered by cross-cutting Ab-Chl veins; sample is also foliated defined by Chl ¹ . - Qtz/Kfs undulose extinction, recrystallised, <0.5 mm; Ser acicular to lath-shaped, <0.025 mm; Chl ¹ acicular, defines foliation, <0.005
93-C113c (3994)	Ser	>20 (<10 in 151a & 162b)	
93-C151a (5063)	Chl ¹	<1 (>20 in 151a & 162b)	
93-C162b (4483)	Chl ²	<10	
	Ms	<1	
	Bt	<10	

Table A2.1. -continued-

Sample No. (DDH)	Mineralogy	Abundance	Comments
Semi-pelite (poorly sorted)			
-continued-	Trm	<10	mm, green-greyish green pleochroism, forms clots up to 0.25 mm; Chl ² lath- to tabular-shaped, white-grey birefringence, <0.5; Ms euhedral laths, <0.05 mm; Bt anhedral to subhedral, <0.05 mm; Trm intergrown with Bt, anhedral, orange-brown pleochroism, <0.1 mm; Clz anhedral to subhedral forms intergrown patches with Sulph. <0.25 mm; Grt subhedral to euhedral, poikiloblastic, <0.25 mm; Sulph. Po>Sp, disseminated, recrystallised, <0.1 mm; Ab occurs as veins and as matrix, subhedral grains, <1 mm; Py euhedral, <0.5 mm, associated with Ab and CChl ¹ alteration.
	Carb.	<10	
	Clz	<10	
	Grt	<1	
	Sulph.	<10	
	Ab	<1	
	Py	<10	
Pelite			
93-C003 (7027)	Chl ¹	>20	- Chl ¹ acicular to lath-shaped, green-greyish green pleochroism. <0.05 mm; Chl ² white to grey birefringence. euhedral laths, <0.5 mm; Ms euhedral grains, <0.1 mm; Bt brown to orange colour, lath-shaped, <0.5 mm; Trm anhedral, <0.1 mm, orange to brown grains, intergrown with Bt; Carb. subhedral to euhedral, 0.3-2 mm, infilling intergranular porosity; Clz anhedral, fractured, internal zoning (?). <0.25 mm; Sulph. Po>Sp, disseminated, <0.25 mm; Py euhedral, porphyroblastic, 1-2 mm.
93-C080 (4501)	Chl ²	<10	
93-C140b (5232)	Ms	<1	
93-C142b (5232)	Bt	<1	
	Carb.	<10 (>20 in 140b)	
	Clz	<10	
	Sulph.	<10	
	Py	<1	

Table A2.2. Petrographic analysis of H sequence meta-sedimentary rocks.

Sample No. (DDH)	Mineralogy	Abundance	Comments
Quartzite/quartz psammite			
93-C096 (3952)	Qtz/Kfs	>20 (<10)	<p>- no preserved bedding fabric, except for 107b which has alternating Bt-Trm rich beds.</p> <p>- 102a has an semi-pelitic interbed offset by a relict soft-sedimentary fault.</p> <p>- all samples except 124b are psammite, with matrix contents of 20-25%; 124b is a quartzite with <10% matrix</p> <p>- Qtz/Kfs recrystallised, undulose extinction, anhedral, <0.1 mm; Ser laths, up to 0.1 mm; Chl² anomalous white-grey birefringence, subhedral to euhedral laths, <0.5 mm; Ms euhedral laths, <0.25 mm; Bt anhedral, orange-brown pleochroism, <0.25 mm, forms patches/clots; Trm anhedral, rare dendritic grain shape, associated with Bt, orange-brown colour; Carb. anhedral, <0.25 mm; Clz anhedral to subhedral, forms clots, intergrown with Sulph, <0.25 mm; Grt poikilitic, anhedral, <1 mm, elongate (parallel to bedding ?); Sulph. anhedral, disseminated, Po>Sp, recrystallized, <0.1 mm.</p>
93-C102a (3974)	Ser	>20 (<10)	
93-C107b (3976)	Chl ²	<10	
93-C114a (3994)	Ms	<10 (>20)	
93-C124b (1866)	Bt	<20 (>20)	
93-C142c (5232)	Trm	<20 (>20)	
	Carb.	<1	
	Clz	<10	
	Grt	<1	
	Amp	<1	
	Sulph.	10-20	
		()- corresponds to 107b & 142c	
Semi-pelite (well sorted)			
93-C136a (804)	Qtz/Kfs	>20	<p>- Qtz/Kfs anhedral, recrystallised, 0.05-0.1 mm, undulose extinction; Ser euhedral laths, <0.05 mm; Chl¹ greyish-green pleochroism, acicular grains (50 µm); Chl² anomalous white-grey birefringence, euhedral to subhedral lath, <0.5 mm; Ms euhedral laths, <0.3 mm; Bt anhedral to subhedral grains, <0.25 mm, orange-brown pleochroism; Trm anhedral, intergrown with Bt, <0.1 mm; Clz anhedral, forms clots, associated with sulphides, <0.1 mm; Grt poikilitic, <0.3 mm; Sulph. Po>Sp, anhedral, disseminated, <0.1 mm.</p>
	Ser	<10	
	Chl ¹	10-20	
	Chl ²	<10	
	Bt	10-20	
	Trm	10-20	
	Clz	<10	
	Grt	<10	
	Sulph.	<10	
Semi-pelite (poorly sorted)			
93-C114b (3994)	Qtz/Kfs	>20	<p>- Qtz/Kfs undulose extinction, recrystallised, <0.05 mm; Ser acicular to lath-shaped, <0.025 mm; Chl¹ acicular, defines foliation, <0.01 mm, green-greyish green pleochroism; Chl² lath- to tabular-shaped, white-grey pleochroism, <0.05; Ms euhedral laths, <0.1 mm; Bt anhedral, poikilitic, <0.1 mm; Trm intergrown with Bt, anhedral, orange-brown pleochroism; Clz anhedral</p>
93-C115 (3994)	Ser	>20	
93-C135a (804)	Chl ¹	>20 (152)	
93-C152 (5063)	Chl ²	<10	
	Bt	>20 (135a)	
	Trm	>20 (135a)	
	Clz	<10	
	Grt	<10	

Table A2.2. -continued-

Sample No. (DDH)	Mineralogy	Abundance	Comments
Semi-pelite (poorly sorted)			
-continued-	Amp	<1	to subhedral fractured grains, associated with Sulph. <0.25 mm; Grt anhedral to subhedral, poikiloblastic, <0.5 mm; Amp anhedral to subhedral prismatic grains, associated with Sulph., <0.5 mm; Sulph. Po>Sp. disseminated, recrystallised, <0.1 mm; Ab occurs as veins and as matrix, subhedral grains, <1 mm; Py euhedral, , <2 mm.
	Sulph.	<10	
	Ab	10-20 (152 only)	
	Py	<10	
Pelite			
93-C007 (7027)	Chl ¹	>20	- Chl ¹ acicular to lath-shaped, green-greyish green pleochroism; Chl ² white to grey birefringence, euhedral laths, <0.25 mm; Ser acicular to lath-shaped, <5µm; Ms anhedral grains, <0.15 mm; Bt brown to orange colour, lath-shaped, <0.5 mm; Trm anhedral, <0.1 mm, orange to brown grains, intergrown with Bt; Grt subhedral to euhedral, poikiloblastic, .1-.2 mm; Sulph. consist of Po>Sp, disseminated; Ab porphyroblastic, anhedral, <2 mm, recrystallized, intergrown with Chl ¹ ; Py euhedral, porphyroblastic, 1-2 mm; Unkown rhombic form, high relief, highly fractured, <0.25 mm, possibly sphene or allanite.
93-C164a (4483)	Chl ²	10-20	
	Ms	<10	
	Bt	10-20	
	Trm	<10	
	Clz	<1	
	Sulph.	<1	
	Ab	<1	
	Py	<1	
	Unkown	<<1	

Table A2.3. Petrographic analysis of hu sequence meta-sedimentary rocks.

Sample No. (DDH)	Mineralogy	Abundance	Comments
Quartzite/quartz psammite			
93-C102b (3971)	Qtz/Kfs	>20	- samples 102b and 116d are bedded, with fabric defined by alternating Grt-rich and Grt-poor beds. - trace amounts of monazite/zircon, possibly detrital (?). - Qtz/Kfs undulose extinction, recrystallised, <0.3 mm; Ser acicular, distributed along Qtz/Kfs grain contacts, <0.01 mm; Chl ² subhedral laths, faint green-grey pleochroism; Ms euhedral laths, <0.25 mm; Bt anhedral to subhedral tabular grains; Trm intergrown with Bt; Carb. interstitial phase, subhedral; Clz anhedral to subhedral prismatic crystals, patchy occurrence; Grt anhedral to euhedral, poikilitic, < 1 mm; Sulph. recrystallised, anhedral, Po>Sp, disseminated; Py euhedral, disseminated; Zircon rounded to well rounded grains, <0.05 mm.
93-C116d (3994)	Ser	<10	
93-C117a (3994)	Chl ²	10-20	
93-C125a (1866)	Ms	<10	
	Bt	10-20	
	Trm	<10	
	Carb.	<1	
	Clz	10-20	
	Grt	10-20	
	Sulph.	<10	
	Py	<1	
	Zircon	<<1	
Semi-pelite (well sorted)			
93-C058 (4495)	Qtz/Kfs	>20	- Qtz/Kfs <0.1 mm, recrystallised, undulose extinction; Ser acicular to fine laths, <0.05; Chl ¹ green-greyish green pleochroism, occurs as patches (<0.25 mm) of intergrown acicular grains; Chl ² white-grey birefringence, subhedral to euhedral laths, <0.5 mm; Bt anhedral to subhedral, <1 mm; Trm intergrown with Bt, anhedral, <0.05 mm; Carb. subhedral to euhedral, matrix and vein constituent, <0.1 mm; Clz anhedral, forms clots that are intergrown with Sulph.; Grt anhedral, granular texture, up to 1 mm; Sulph. anhedral to subhedral, disseminated Po>Sp, <0.1 mm; Ab subhedral, <0.5 mm.
93-C097a (3952)	Ser	>20 (097a);	
	Chl ¹	<1	
	Chl ²	>20 (058); <1	
	Bt	<10	
	Trm	<1	
	Carb.	<1	
	Clz	<10 (058); <1	
	Grt	<10	
	Sulph.	<10	
	Ab	<10	
		<1	
Semi-pelite (poorly sorted)			
93-C116b (3994)	Qtz/Kfs	>20	- Qtz/Kfs <0.05 mm, recrystallised, undulose extinction; Ser acicular to fine laths, <0.05; Chl ² white-grey birefringence, subhedral to euhedral laths, <0.5 mm; Bt anhedral to subhedral, <0.1 mm; Trm intergrown with Bt, anhedral, <0.1 mm; Clz anhedral, forms clots that are intergrown with Po and Sp; Sulph. anhedral to subhedral, disseminated Po>Sp, <0.1 mm.
	Ser	>20	
	Chl ²	<10	
	Bt	<10	
	Trm	<10	
	Clz	<10	
	Sulph.	10-20	

Table A2.3. -continued-

Sample No. (DDH)	Mineralogy	Abundance	Comments
Pelite			
93-C011 (7027)	Ser	>20 (011);	- Ser acicular grains; Chl ¹ acicular o fine-grained laths, greyish green to green birefringence. pervasive alteration of matix; Chl ² occurs as radiating masses (<0.1 cm) of acicular grains (<0.25 mm); Ms subhedral to euhedral laths, <0.2 mm., commonly rims Py; Bt anhedral, <0.1 mm; Trm, anhedral, <0.1 mm, intergrown with Bt; Carb. anhedral to subhedral, <0.5 mm; Clz anhedral grains, forms patches intergrown with Po and Sp; Sulph. anhedral, <0.25 mm.; Ab anhedral to euhedral prismatic grains, <0.25 mm: Py euhedral, prophyroblastic, <0.5 cm.
93-C056 (4495)		<10 (056)	
	Chl ¹	>20	
	Chl ²	10 20	
	Ms	<10	
	Bt	<10	
	Trm	<10	
	Carb.	<10	
	Clz	<1	
	Sulph.	>20 (011); <1 (056)	
	Ab	<10	
	Py	<10	

Table A2.4. Petrographic analysis of Hu sequence meta-sedimentary rocks.

Sample No. (DDH)	Mineralogy	Abundance (%)	Comments
Quartzite/quartz psammite			
93-C097b (3952)	Qtz/Kfs	>20	<p>-all samples lack any bedding fabric except for: samples 97b and 104a with alternating Bt+Trm rich beds, and sample 157a which exhibits a weak foliation defined by Chl¹.</p> <p>- all samples except 118a are psammite, with matrix contents of 15-20%; 118a is a quartzite with <<5% matrix</p> <p>- Qtz/Kfs recrystallised, undulose extinction, anhedral, <0.1 mm; Ser laths, up to 0.1 mm; Chl¹⁻²</p> <p>green-grey and white-grey pleochroism, acicular to lath-shaped (rare), <0.05 -0.5 mm; Ms euhedral laths, <0.25 mm; Bt anhedral, orange-brown pleochroism, <0.25 mm, forms patches/clots; Trm anhedral, rare dendritic grain shape, associated with Bt, orange-brown colour; Carb. anhedral, <0.25 mm; Clz anhedral to subhedral, forms clots, associated with Sulph, blue-greyish blue pleochroism, <0.25 mm; Grt poikilitic, anhedral; Sulph. anhedral, disseminated, Po>Sp, recrystallized, <0.1 mm; Ab subhedral prismatic grains, <0.5 mm; Py porphyroblastic, euhedral, Up to 2 mm.</p>
93-C104a (3971)	Ser	10-20	
93-C108 (3976)	Chl ¹⁻²	10-20	
93-C118a (3994)	Ms	<10	
93-C137a (804)	Bt	<10-20	
93-C143a (5232)	Trm	<10	
	Carb.	<1	
	Clz	<1-10	
	Grt	<10	
	Sulph.	<10	
	Ab	<10	
	Py	<1	
Semi-pelite (well sorted)			
93-C050 (4495)	Qtz/Kfs	>20	<p>- a weak bedding fabric defined by alternating Bt+Trm rich beds is present in samples 051, 053, 111b, and 119d; other samples do not exhibit a bedding fabric.</p> <p>- Qtz/Kfs anhedral, recrystallised, 0.05-0.1 mm, undulose extinction; Ser euhedral laths, <0.05 mm; Chl¹ green-greyish green pleochroism, acicular grains (50 µm) form radiating and "bow tie" shaped patches (<0.25 mm); Chl² anomalous white-grey pleochroism, euhedral to subhedral laths, <0.5 mm; Ms euhedral laths, <0.3 mm, intergrown with Amp; Bt anhedral to subhedral grains, orange-brown pleochroism; Trm anhedral, associated with Bt, <0.05 mm; Carb. subhedral, <0.25 mm interstitial and vein occurrences; Clz anhedral, forms clots, associated with sulphides, <0.1 mm; Grt poikilitic, up to 1 mm; Amp anhedral to euhedral prismatic crystals, up to 2 mm; Sulph. Po>Sp, anhedral, disseminated, <0.1 mm; Ab prismatic (elongate crystals), <0.5 mm; Py associated with Ab, euhedral.</p>
93-C051 (4495)	Ser	>20	
93-C053 (4495)	Chl ¹	<10	
93-C086a (4501)	Chl ²	<10	
93-C111b (3976)	Ms	<10	
93-C119d (3994)	Bt	10-20	
93-C120b (3994)	Trm	<10	
	Carb.	<10	
	Clz	<10	
	Grt	<1	
	Amp	<10	
	Sulph.	<10	
	Ab	<10	
	Py	<1	

Table A2.4. -continued-

Sample No. (DDH)	Mineralogy	Abundance (%)	Comments
Semi-pelite (poorly sorted)			
93-C088* (4501)	Qtz/Kfs	>20	- samples are range from being massive to finely laminated, with laminae < 5 mm; Chl-dominated samples exhibit a weak foliation. - Qtz/Kfs undulose extinction, recrystallised, <0.05 mm; Ser acicular to lath-shaped; Chl ¹ acicular, defines foliation, <0.01 mm, green-greyish green pleochroism; Chl ² lath- to tabular-shaped, white-grey pleochroism, <0.05; Ms euhedral laths, <0.1 mm; Bt anhedral, poikilitic, <0.1 mm; Trm associated with Bt, anhedral, orange-brown pleochroism; Carb. occurs in veins and interstitial areas, subhedral; Cls fractured grains, associated with Sulph. and Carb. veins, <0.25 mm; Grt anhedral to subhedral, poikiloblastic, <0.3 mm; Amp anhedral, associated with Sulph.; Sulph. Po>Sp, disseminated, recrystallised, <0.1 mm; Ab occurs as vein in 153b, subhedral grains, <1 mm; Py euhedral. . <2 mm.h
93-C108b (3976)	Ser	10->20	
93-C109c (3976)	Chl ¹	>20	
93-C111c (3976)	Chl ²	<10	
93-C111d (3976)	Ms	<1	
93-C121d (3994)	Bt	10-20	
93-C137f (804)	Trm	<10	
93-145b (5232)	Carb.	<10	
93-C153b* (5063)	Clz	10-20	
93-C159b (5063)	Grt	1-20	
93-C159d (5063)	Amp	<1	
	Sulph.	<10	
* Chl-dominant samples	Ab	<10	
	Py	<1	
Pelite			
93-C109a (3976)	Qtz/Kfs	1->20	-no bedding fabric in Ser-rich samples. Chl-dominant have a weak foliation. - Qtz/Kfs recrystallised and overprinted by Ser, undulose extinction, <0.01 mm.; Chl ¹ acicular to lath-shaped, green-greyish green-Berlin blue pleochroism; Chl ² white to grey pleochroism, laths, <0.25 mm; Ser acicular to lath-shaped, <5µm; Ms subhedral grains, <0.25 mm; Bt brown to orange colour, lath-shaped, <0.25 mm; Trm anhedral, <0.1 mm, orange to brown grains, associated with Bt; Grt subhedral to euhedral, poikiloblastic, .1-.2 mm; Sulph. consist of Po>Sp, disseminated; Ab porphyroblastic, anhedral, <2 mm, recrystallized, intergrown with Chl ¹ .
93-C118g (3994)	Ser	>20	
93-C166f (4483)	Chl ¹	>20	
	Chl ²	<10	
	Ms	<10	
	Bt	<10	
	Trm	<10	
	Grt	<10	
	Sulph.	<1	
	Ab	10-20 (166f)	

Table A2.5. Petrographic analysis of U sequence meta-sedimentary rocks.

Sample No. (DDH)	Mineralogy	Abundance	Comments
Quartzite/quartz psammite			
93-C033 (2422)	Qtz/Kfs	>20	<p>- Samples 121b and 121c exhibit bedding defined by fine discontinuous lamination of Po and Sp, and by alternating Carb.-Clz rich and Bt-Trm rich beds; other samples are massive.</p> <p>- Samples 121b/c and 128a are quartzites, other samples are quartzitic psammites with up to 30% matrix.</p> <p>- Qtz/Kfs undulose extinction, recrystallised; Ser acicular to lath-shaped grains, < 0.01 mm; Chl² acicular (rare) to lath-shaped, white-grey birefringence, associated with Sulph. and Clz; Ms subhedral to euhedral lath-shaped, extensive alteration to Ser in 033; Bt anhedral grains forming patches; Trm intergrown with Bt, anhedral grains; Carb. subhedral to euhedral (veins), occurs interstitially and in veins; Clz anhedral to subhedral, associated with Sulph.; Grt poikilitic, subhedral, up to 5 mm; Amp subhedral to euhedral prismatic to acicular crystals; Sulph. disseminated Po>Sp.</p>
93-C121b (3994)	Ser	>20	
93-C121c (3994)	Chl ²	<10	
93-C128a (1866)	Ms	<10	
93-C128f (1866)	Bt	10-20	
	Trm	10-20	
	Carb.	10-20	
	Clz	<10	
	Grt	<1	
	Amp	<1	
	Sulph.	10-20	
Semi-pelite (well sorted)			
93-C121d (3994)	Qtz/Kfs	>20	<p>- Sample 121d is finely laminated; 121e lacks any bedding structures.</p> <p>- Qtz/Kfs anhedral, undulose extinction, recrystallized, <0.05; Ser lath-shaped grains, <<0.05; Chl² acicular to lath-shaped, anomalous white-grey birefringence, <0.1 mm, forms patches (<0.25 mm) of radiating grains; Ms subhedral to euhedral, <0.5 mm; Bt anhedral, 0.05-0.2 mm; Trm anhedral, <0.1 mm, intergrown with Bt; Carb. subhedral, occurs in veins and interstitially, 0.1-0.5 mm; Clz anhedral, <0.1 mm, patchy occurrence, associated with Sulph.; Amp anhedral to subhedral prismatic to acicular grains; Sulph. disseminated Po, <0.1 mm, also occurs in Carb. veins.</p>
93-C121e (3994)	Ser	<10	
	Chl ²	<10	
	Ms	<10	
	Bt	10-20	
	Trm	<10	
	Carb.	<10	
	Clz	10-20	
	Amp	<1	
	Sulph.	<1	

Table A2.5. -continued-

Sample No. (DDH)	Mineralogy	Abundance	Comments
Semi-pelite (poorly sorted)			
93-C075 (3385)	Qtz/Kfs	>20	- Qtz/Kfs <0.05 mm, recrystallised, undulose extinction; Ser acicular to fine laths, <0.05; Chl ¹ green-greyish green pleochroism, occurs as patches (<0.25 mm) of intergrown acicular grains; Chl ² white-grey birefringence, subhedral to euhedral laths, <0.5 mm; Carb. subhedral to euhedral, matrix and vein constituent; Sulph. anhedral to subhedral, disseminated Po>Sp, <0.1 mm.
	Ser	>20	
	Chl ¹	>20	
	Chl ²	<10	
	Carb.	<10	
	Sulph.	<1	

Table A2.6. Petrographic analysis of hanging wall albitites.

Sample No. (DDH)	Mineralogy	Abundance	Comments
H sequence			
93-C157a (5063)	Ms-Ser	<10	- samples consist of medium- to coarse-grain massive albite, cross-cut by small Chl veinlets; sample 165b is cross-cut by a 5-10 mm wide Chl vein. -Ms-Ser replaced by Ab, occur as fine-grained (<0.025 mm) inclusions; Chl ¹ green-greyish green pleochroism, <0.025 mm, occurs as veins and as matrix (infilling fractures and grain contacts), forms clots of radiating acicular grains up to 0.1 mm. Carb. anhedral to subhedral, <0.5 mm, infilling fractures; Ab anhedral to subhedral prismatic (elongated) grains, 0.25-2 mm, undulose extinction, sutured contacts; Py subhedral, rare cubes, <0.25 mm, disseminated.
93-C158a (5063)	Chl ¹	<10-20 (>20 in 163c)	
93-C159e (5063)			
93-C163c (4483)	Carb.	<10	
93-C165a (4483)	Ab	>70	
93-C165b (4483)	Py	<1	
hu sequence			
93-C057 (4495)	Chl ¹	10-20	- no preserved sedimentary textures in either sample. - Chl ¹ green-faint green pleochroism, acicular grains, <0.005 mm, grains form radiating clots (<0.1 mm), also forms small veinlets; Carb. subhedral, <0.25 mm, infilling intergranular porosity; Ab anhedral to subhedral prismatic (elongated) grains, 0.25-2 mm, undulose extinction, sutured contacts; Py euhedral, disseminated, <1 mm; Zircon elongate, slightly rounded with syntaxial overgrowths.
93-C076d (3385)	Carb.	<10	
	Ab	>80	
	Py	<1	
	Zircon	<<1	
Hu sequence			
93-C052 (4495)	Ms-Ser	<1	- no preserved sedimentary textures in either sample. - Chl ¹ green faint green pleochroism, acicular grains, <0.005 mm, grains form radiating clots (<0.1 mm), also forms small veinlets; Carb. subhedral, <0.05 mm (veins) to 0.25 mm (matrix), occurs as veins and infilling intergranular porosity; Ab anhedral to subhedral prismatic (elongated) grains, <0.5 mm, undulose extinction, sutured contacts; Py euhedral, disseminated, <1 mm.
93-C054 (4495)	Chl ¹	10-20 (>20 in 165c)	
93-C086b (4501)			
93-C165c (4483)	Carb.	<10	
	Ab	>70	
	Py	<1	

Appendix 3

Summary tables for sulphide zone petrography

Explanation of terminology and abbreviations for Tables A3.1-4:

Sample: corresponds to sample numbers in Table A1.1

DDH - diamond drill hole

Inteval - drill hole length corresponding to the base of the sample, first number represents the length in feet, the second is in metres

Mineralogy:

Min - mineral; abbreviations after Kretz (1983) with the following exceptions:

- a) Carb - carbonate (includes calcite and siderite)
- b) Sulph. - sulphide (not including pyrite or arsenopyrite)
- c) QF - quartzofeldspathic material

DS - Dominant Sulphide

% - modal abundance

E - essential >20 vol%

A - accessory 1-20 vol%

T - trace <1 vol%

Grain Habit:

Grain size - expressed in millimetres

Xln - crystallinity

E - euhedral

S - subhedral

A -anhedral

Shape-

eq - equant

el - elongate

pr - prismatic

ac - acicular

bl - bladed

t - tabular

rnd - rounded

rhomb - rhombic-shaped

agg - aggregates

Grain Textures:

Dtl - detrital

Col - colloform banding

Rxt - recrystallized

Rpl - replacement

Fxt - infills fractures

Brx - brecciate, either forms clasts or matrix

Pok - pokiolitic

Fab - defines are is oriented parallel to rock fabric

Table A3.2. Petrography summary table for the I sulphide zone (I laminations).

Sample	DDH	Interval f/m	Mineralogy		Grain Habit			Grain Textures							Inclusions	Comments				
			Min	DS	%	Grain Size	Xln	Shape	Primary		Secondary									
			Qtz/Kfs	E		0.025-0.5	S,A	eq-irreg	Dtl	Col	Rst	Rpl	Fst	Brx	Pot	Fab				
93-C017	6819	115/35									X						- bimodal size distribution; undulatory extinction			
			Ser	A		<<0.01	E,S	ac-l				X					X	- inclusions at Qtz/fields contacts		
			Ms	A		0.05-0.2	E	l									X			
			Chl	A		0.05-0.3	E-A	ac-bl					X					X	-restricted to Sulph laminae; anomalous white-grey birefringence	
			Carb	T		0.05-0.2	E	rhomb							X				- intergrown with Bt, restricted to silicate laminations	
			Trm	A		0.05-0.2	E-A	pr, r-lit												
			Bt	A		0.05-0.3	E,S	l												
			Grt	A		0.3-1.5	S,A	eq-el							X		X	QF	- elongated parallel to laminations, highly fractured	
			Amp	A		<0.1	E-A	pr-bl												
			Ccp	T		<<0.1	A	bleb												- restricted to Sulph. laminations
			Gn	A		-	A	-												
			Sp	A		<0.15	S	eq-el												- remobilized along laminations
Po	E		0.01-0.25	E-A	eq-l															
Py	A		<0.1	E,S	cubes															
																		Po,Ccp,Gn,QF Ccp,Gn,Sp,QF Po,Ccp,Gn,Sp,QF		

General Comments: Base of sample consists of planar parallel laminated pyrrhotite (with sphalerite and galena) intercalated with semi-pelite/pelite. Top part of sample consist of soft-sediment folded pyrrhotite-silicate intercalations that are cross-cut by a pyrite vein

93-C022	6839	121.3/37	Qtz/Kfs	A		0.025-0.25	S,A	eq			X						
			Rt/Zn(?)	T		<0.02	A	ind									
			Ser	E		<0.025	E,S	ac				X					- undulatory extinction
			Ms	T		<0.5	E,S	l									- highly fractured
			Chl	T		0.1-0.5	E	l									- aligned parallel to laminations and to Qtz/fields contacts
			Trm	T		<0.2	S	eq				X					
			Bt	T		0.1-0.2	S,A	l									- anomalous white-grey birefringence
			Grt	A		0.1-0.5	S,A	eq-el									- associated with Sulph
			Amp	A		0.05-0.6	E,S	pr				X					- restricted to Po laminae
			Ccp	T		<0.1	A	blebs									- restricted to Po laminae
			Gn	T		-	A	patches									- intergrown w/ Po
			Sp	A		<0.1	S,A	pr-el									- remobilized along laminae and grain contacts
			Po	E		0.01-0.25	E,A	eq-l									- lath-shape grains tend to be coarser-grain than equant grains

General Comments: Samples consists of planar parallel intercalated sulphides (primarily pyrrhotite with minor sphalerite) and sericitized semi-pelite

Table A3.2 -continued-

Sample	DDH Interval F/m	Mineralogy		Grain Habit			Grain Textures			Inclusions	Comments																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
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93-C062d	4495 -70 5/21.5	Qtz/Kfs	A	<0.05	S,A	eq																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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Po	X	0.01-0.8	F-A	eq-l				X																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													

General Comments: Sample consists of planar parallel interlamated sulphide and chloritized semi-pelite

93-C092	3952 66 2/20.2	Qtz/Kfs	A	0.02-0.1	F.S	eq			X							
		Ser	A	<0.005	E.S	ac				X						
		Ms	A	<0.2	F	l					X					
		Chl	A	<0.4	F.S	l				X						
		Carb	I	<0.2	F	pr					X					
		Bt	I	<0.1	S.A	eq-el				X						
		Grt	A	<0.1	S.A	eq-el										
		Gn	A	<0.01(?)	A	-			X							
		Sp	X	0.1-1.0	S.A	eq-el			X							
		Po	A	0.05-0.5	S.A	eq-l			X							

General Comments: Sample consists of thickly laminated spikelite with subordinated laminated pyrrhotite with rare interlayered sericitized semi-pelite

93-C095a	3952 75 5/23	Qtz/Kfs	A	<0.1	S.A	eq-pr			X							
		Ms	A	<0.1	F	l				X						
		Chl	A	<0.2	F	l-ac				X						
		Carb	I	<0.1	E.S	pr					X					
		Grt	I	<0.25	S.A	eq-el				X						
		Gn	A	-	A	-			X							
		Sp	X	<0.25	S.A	eq-el										
		Po	A	0.01-0.5	S	eq-l			X							
		Adv	I	0.02-0.4	E	pr-rhomb*			X							

General Comments: Sample consists of alternating bands of sphalerite and pyrrhotite with the occasional chloritized semi-pelite interlayer

- undulatory extinction
- anomalous white-grey birefringence
- intergrown with Bt

- undulatory extinction
- restricted to silicate laminae
- anomalous white-grey birefringence
- infills fractures within Sulph laminae
- restricted to Sulph laminations
- extensively remobilized

- undulatory extinction
- infills secondary porosity
- remobilized along Sulph grain contacts

Table A3.2 - continued -

Sample	1) ITH Interval F/m	Mineralogy	Grain Habit	Primary Dtl Col	Grain Textures Rst Rpl Fsl Bx Pok Fab	Inclusions	Comments
93-C101a	3971 26 5/8 1	Qtz/Kfs	E	X			- undulatory extinction - restricted to silicate layers
		Zr	T		X		
		Ser	A		X		
		Ms	A		X		
		Chl	A		X		
		Trm	A		X		
		Bt	A		X		
		Grt	T		X		
		Amp	T		X		
		Ccp	T		X		
		Gn	A		X		
		Sp	A		X		
93-C113c	3994 12 2/3 7	Qtz/Kfs	A		X		- undulatory extinction
		Ser	A		X		- intergrown with Sulph
		Ms	A		X		- anomalous white-grey birefringence
		Chl	A		X		- intergrown with Bt, associated with silicate laminae
		Trm	A		X		- intergrown with Trm
		Bt	A		X		- intergrown with Po
		Amp	T		X		- occurs primarily as disseminated grains in silicate laminae
		Ccp	T		X		
		Gn	A		X		
		Sp	A		X		
		Po	A		X		
		Apv(?)	T		X		
93-C123f	1866 8/2 4	Qtz/felds	E		X		- undulatory extinction
		Ser	E		X		- replaces Bt, white-grey and green-grey birefringence
		Chl	A		X		- intergrown with Bt, restricted to silicate interlayers
		Trm	T		X		- intergrown with Trm, restricted to silicate interlayers
		Bt	A		X		
		Ms	A		X		
		Trm	A		X		
		Chl	A		X		
		Sp	A		X		
		Po	A		X		
		Apv(?)	T		X		
		Trm	A		X		

General Comments: Sample consists of planar parallel laminated pyrrhotite and sphalerite with intercalated semi-pelite/pelite. Sulphide laminae have sharp basal contacts and gradational upper contacts (weak grading?).

General Comments: Sample consists of planar parallel laminated pyrrhotite (subordinate sphalerite) with intercalated semi-pelite/pelite layers. Sulphide laminae have sharp basal contacts and slightly gradational upper contacts.

Table A12 -continued-

Sample	DDH Interval l/m	Mineralogy		Grain Habit		Primary		Grain Textures					Inclusions	Comments	
		Min	DS %	Grain Size	Xlin	Shape	Dbl	Col	Rst	Rpl	Ext	Brs			Pok
93-C123f -continued-		Ccp	A	-	A	-			X						- intergrown with Po and Sp - remobilized along lamination planes and grain contacts
		Gn	A	-	A	-			X						
		Sp	X	A	0.1-0.2	S/A	eq-el			X	X	X		Po, Ccp, Gn, Qtz	
		Po	A	A	0.1-0.5	F/A	eq-l			X			X	Ccp, Gn, Sp, Qtz	
General Comments: Sample consists of slightly deformed interlaminate sphalerite, pyrrhotite and semi-pelite															
93-C133b	804 42/12.8	Qtz/Kfs	T	0.01	A	inter				X					- undulatory extinction - white/faint green-grey birefringence - intergrown with Bt. associated with silicate laminations - intergrown with Trm - rims Po - disseminated along Sulph. laminae
		Set	T	0.005	F/S	ac				X					
		Chl	A	0.01	F/S	ac-l				X					
		Trm	A	0.01-0.25	A	el, s-mid									
		Bt	A	0.05-0.1	F/S	l				X			X	Sp, Qtz	
		Grt	T	0.2-0.3	F/S	pr				X					
		Ccp	T	-	A	-				X					
		Sp	A	0.1	A	eq-el			X				Qtz		
		Po	X	A	0.2	S/A	eq-l			X			Qtz		
		Apv	T	0.1-0.3	S	pr-rhomb*				X					
		General Comments: Sample consists of planar parallel interlaminate pyrrhotite and semi-pelite													
93-C152b	5063 178.6/54.4	Qtz/Kfs	A	0.1	A	eq			X						- undulatory extinction - grains are highly fractured - anomalous white-grey birefringence
		Trm	T	0.005	A	s-mid	X								
		Chl	T	0.3	F/A	l			X				X		
		Ab	A	0.5	F/S	pr-hl			X						
		Grt	A	-	A	-			X						
		Sp	A	0.01-0.25	S	eq-el			X			X	Po, Gn		
		Po	T	0.15	A	mid			X					Gn, Sp, Qtz	
		Py	X	A	0.01-0.1	F/S	cubes			X	X				
General Comments: Sample consists of laminated sphalerite and galena that are subsequently replaced by pyrite															
93-C160b	4483 211/64.3	Qtz/Kfs	T	0.3	A	eq			X						- undulatory extinction - anomalous white-grey birefringence - intergrown with Sulph
		Ms	A	0.3	F/S	l-t				X			X	Po, Qtz	
		Chl	T	0.3	F/S	ac-l				X			X		
		Ccp	T	-	A	-			X						
		Grt	A	-	A	-			X						
		Sp	X	A	0.2	S/A	eq-el			X				Po, Gn, Qtz	
		Po	T	0.01-0.3	F/S	eq-l			X				Gn, Sp, Qtz		
		Py	T	1.0	F	cubes			X	X					

General Comments: See comments for sample 93-C161b

Table A3.2-continued.

Sample	ID#1 Interval F/m	Mineralogy		Grain Habit			Grain Textures					Inclusions	Comments					
		Min	DS	%	Grain Size	Xln	Shape	Primary		Secondary								
								Dnl	Col	Rxt	Rpl	Fxt	Btx	Pok	Fab			
03-C161b	4483-224 3/68-4	Qtz/Kfs	A		<0.1	A	eq				X						- undulatory extinction - grains are highly fractured - anomalous white-grey birefringence - infills secondary porosity - overgrown with Fe - extensively remobilized	
		Zir	T		<<0.01	A	cl, s-md	X										
		Ms	A		<0.4	F	l								X			
		Chl	A		<0.1	F-S	ac-l				X							
		Caab	A		0.01-0.1	F-S	pr				X							
		Ccp	T		.	A	.				X							
		Gm			.	A	.				X							
		Sp	X	E	0.01-0.5	S, A	eq				X							Po, Sp, Qf
		Pr	E		0.02-0.2	F-A	eq				X							Po, Sp, Qf Ccp, Gm, Qf Ccp, Gm, Sp, Qf

General Comments Sample consist of massive to weakly banded schistose and mylonite

[illegible]

General Comments: Sample consists of weakly laminated to banded splinteritic and pyrotholite with minor amount of intercalated semi-pelite

Qz/Kfs	A	-0.05	A	ureg	X	Sp Cin Po Py,Ccp	- undulatory extinction - replaces Kfs, patchy distribution - associated with sulphides
Ser	T	-0.005	E	ac	X		
Carb	A	-0.5	F,S	uk	?	X	
Msc?	F	-0.1	F	ac			
	F	-0.5		I		X	
Chl	F	-0.0025	S			X	
Grt	A	-	A	-			
Sp	E	0.1	F,S	ureg	X		
Po	F	-0.3	S,A	en-ureg	X		
					X		- extensively remobilized

General Comments Sample consists of interlaminate sphalerite, pyrrhotite, semi-pelite

Table A3.4. Petrography summary table for the Hu sulphide zone (Hu ore).

Sample	DDH Interval F/m	Mineralogy		Grain Habit		Grain Textures						Inclusions	Comments																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
		Min	IDS %	Grain Size	Xln	Shape	Primary DH	Col	Rst	Rpl	Ext			Brx	Pok	Fab																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
93-C0276	2442 99/30.2	Qtz/Kfs	A	0.05-0.5	S,A	eq-pr			X																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																

General Comments. Sample consists of interlayered Po and Sp + Gn

Table A14 - continued -

Sample	ID#1 Interval Fm	Mineralogy		Grain Habit		Primary		Grain Textures						Inclusions	Comments				
		Min	DS %	Grain Size	Xln Shape	Dil	Col	Rst	Rpl	Est	Bx	Pok	Fab						
93-C120d -continued-		Gn		T		A				X									
		Sp		A	0.1-0.25	S,A	eq-el			X	X					Po,Gn,QF	- infills intragranular fractures in Grt		
		Po	X	E	<0.25	S,A	eq-t			X	X					Gn,Sp,QF	- well developed polygonal texture		
General Comments: Samples consists of contorted bands to near massive Po and Sp. Silicates are disseminated throughout the rock and due not form discrete layers																			
93-C120e	3994 91 8/28	Qtz/Kfs		E	0.05-0.5	S,A	eq			X									
		Ser	A		<0.005	E,S	ac				X								
		Ms	A		0.05-0.5	E	bl				X								
		Chl	A		<0.1	E,S	ac-l				X								
		Carb	A		0.05	E,S	bk-mb												
		Grt	A		0.5-2.0	A	el, s-mid				X								
		Amph	T		<0.2	E,S	pr-ac				X								
		Gn		T		A				X									
		Sp		A	0.1-0.25	S,A	eq-el			X	X	X							
		Po	X	E	<0.25	S,A	eq-t			X	X	X					Po,Gn,Sp,QF	- aligned parallel to lamination plane	
General Comments: Sample consists of alternating bands to laminations of sulphide-rich rock and sericitized/semi-pelite																			
93-C120f	3994 92/28 1	Qtz/Kfs		A	<0.05-0.1	A	eq			X									
		Ms	A		<0.1	E,S	l				X								
		Chl	E		<0.2	E,S	ac-bl				X								
		Carb	A		<0.1-0.75	S	bk					X							
		Amph	A		<0.25	E,S	pr, ac-bl				X								
		Gn		A		A				X	X	X							
		Sp		A	0.01-0.25	A	eq-el, irreg			X	X	X							
		Po	X	A	<0.5	E:A	eq-t			X	X	X					Po,Gn,Sp	- associated with Sulph - forms Chl-rich bands - forms Carb-rich bands - associated with Sulph - remobilized along bands - forms fine colloform bands with Po	
		General Comments: Samples consists of colloform banded sulphides and carbonate. Banding is not vague in hand sample																	
		93-C120g	3994 92 2/28 1	Qtz/Kfs		F	<0.05	A	eq			X							
Ser	A				<0.005	E,S	ac				X								
Chl	A				<0.2	E,S	l-bl				X								
Carb	A				0.1-0.5	S	bk					X							
Grt	T				1.0-2.0	A	el				X								
Amph	A				0.2-1.0	E,S	pr-bl				X								
Ccp	T					A				X									
Gn		A		A				X	X							Po,Gn,Sp,QF	- alteration of silicate laminae - associated with Sulph laminae - infills lamination plane fractures - highly fractured - associated with Sulph laminae - associated with Sulph grain contacts - remobilized along grain contacts and fractures		

Table A3.4 - continued -

Sample	DDH Interval 11/m	Mineralogy		Grain Habit			Grain Textures						Inclusions	Comments		
		Min	DS %	Grain Size	Xln	Shape	Primary Dil	Col	Rst	Rpl	Ext	Brx			Pok	Jab
93.C120g -continued-		Sp	A	0.05-0.3	S,A	cl. irreg.			X	X				X	Ccp,Gn,QF	
		Prp	X	0.5	E-A(?)	eq-t			X	X				X	Ccp,Gn,Sp,Qf	
		Apy	I	0.1	E	imb.*								X		

General Comments: Sample consists of finely laminated Po + Sp and sericitized semi-pelite. Sulphide abundance increases up-section

93-C126a	1866 76 8/23.4	Qtz/Kfs	E	-0.2	A	eq			X						- undulatory extinction
		Ser	A	-0.005	E	ac									- associated with Qtz/Kfs laminae
		Ms	A	-0.3	E-S	l									- associated with Qtz/Kfs laminae
		Chl	A	-0.0025	E	ac									- forms radial aggregates
		Carb	A	0.1-0.5	F-S	bk-rmb									- associated with Sulph laminae, aligned parallel to lamination plane
		Trm	A	0.05-0.25	S-A	eq, r-trd(?)									- restricted to Qtz/Kfs laminae, associated with Bt
		Bt	A	0.1-0.2	F	l									- restricted to Qtz/Kfs laminae
		Grt	A	0.1-1.0	S-A	el-eq									- replaces Carb
		Anp	I	-0.3	F-S	pr, ac-bl									- associated with Grt and Sulph
		Ccp	I	-	A	-									- millis fractures within Grt
93-C126c	1866 77 8/23.7	Qtz/Kfs	A	0.05-0.25	S-A	eq-pr			X						- associated with Sulph
		Chl	A	-0.1	F	ac									
		Carb	I	0.1-0.5	F-S	bl-rmb									
		Trm	A	-0.1	S-A	eq-pr									
93-C138f	804 112 5/34.3	Qtz/Kfs	I	-0.25	A	eq			X						- undulatory extinction
		Ser	A	-0.005	F	ac									- alters Qtz/Kfs laminae
		Ms	A	-0.25	F-S	l-bl									- intergrown in Ser
		Carb	I	0.025-0.1	F-S	bk-rmb									- millis vugs within Sulph laminae
		Trm	A	-0.1	S-A	eq-pr									
		Grt	A	0.1-0.5	S-A	eq-el									
93-C138g	804 112 5/34.3	Qtz/Kfs	I	-0.25	A	eq			X						- undulatory extinction
		Ser	A	-0.005	F	ac									- alters Qtz/Kfs laminae
		Ms	A	-0.25	F-S	l-bl									- intergrown in Ser
		Carb	I	0.025-0.1	F-S	bk-rmb									- millis vugs within Sulph laminae

General Comments: Sample represents base of Hs sulphide zone, marked by a gradual increase (up-section) in disseminated sulphide abundance with sulphides becoming laminated at the top of the sample

93-C126a	1866 76 8/23.4	Qtz/Kfs	E	-0.2	A	eq			X						- undulatory extinction
		Ser	A	-0.005	E	ac									- associated with Qtz/Kfs laminae
		Ms	A	-0.3	E-S	l									- associated with Qtz/Kfs laminae
		Chl	A	-0.0025	E	ac									- forms radial aggregates
		Carb	A	0.1-0.5	F-S	bk-rmb									- associated with Sulph laminae, aligned parallel to lamination plane
		Trm	A	0.05-0.25	S-A	eq, r-trd(?)									- restricted to Qtz/Kfs laminae, associated with Bt
		Bt	A	0.1-0.2	F	l									- restricted to Qtz/Kfs laminae
		Grt	A	0.1-1.0	S-A	el-eq									- replaces Carb
		Anp	I	-0.3	F-S	pr, ac-bl									- associated with Grt and Sulph
		Ccp	I	-	A	-									- millis fractures within Grt
93-C126c	1866 77 8/23.7	Qtz/Kfs	A	0.05-0.25	S-A	eq-pr			X						- associated with Sulph
		Chl	A	-0.1	F	ac									
		Carb	I	0.1-0.5	F-S	bl-rmb									
		Trm	A	-0.1	S-A	eq-pr									
93-C138f	804 112 5/34.3	Qtz/Kfs	I	-0.25	A	eq			X						- undulatory extinction
		Ser	A	-0.005	F	ac									- alters Qtz/Kfs laminae
		Ms	A	-0.25	F-S	l-bl									- intergrown in Ser
		Carb	I	0.025-0.1	F-S	bk-rmb									- millis vugs within Sulph laminae
		Trm	A	-0.1	S-A	eq-pr									
		Grt	A	0.1-0.5	S-A	eq-el									
93-C138g	804 112 5/34.3	Qtz/Kfs	I	-0.25	A	eq			X						- undulatory extinction
		Ser	A	-0.005	F	ac									- alters Qtz/Kfs laminae
		Ms	A	-0.25	F-S	l-bl									- intergrown in Ser
		Carb	I	0.025-0.1	F-S	bk-rmb									- millis vugs within Sulph laminae

General Comments: Sample consists of interlaminated Sp + Po and chloritized psammite/semi-pelite

93-C126a	1866 76 8/23.4	Qtz/Kfs	E	-0.2	A	eq			X						- undulatory extinction
		Ser	A	-0.005	E	ac									- associated with Qtz/Kfs laminae
		Ms	A	-0.3	E-S	l									- associated with Qtz/Kfs laminae
		Chl	A	-0.0025	E	ac									- forms radial aggregates
		Carb	A	0.1-0.5	F-S	bk-rmb									- associated with Sulph laminae, aligned parallel to lamination plane
		Trm	A	0.05-0.25	S-A	eq, r-trd(?)									- restricted to Qtz/Kfs laminae, associated with Bt
		Bt	A	0.1-0.2	F	l									- restricted to Qtz/Kfs laminae
		Grt	A	0.1-1.0	S-A	el-eq									- replaces Carb
		Anp	I	-0.3	F-S	pr, ac-bl									- associated with Grt and Sulph
		Ccp	I	-	A	-									- millis fractures within Grt
93-C126c	1866 77 8/23.7	Qtz/Kfs	A	0.05-0.25	S-A	eq-pr			X						- associated with Sulph
		Chl	A	-0.1	F	ac									
		Carb	I	0.1-0.5	F-S	bl-rmb									
		Trm	A	-0.1	S-A	eq-pr									
93-C138f	804 112 5/34.3	Qtz/Kfs	I	-0.25	A	eq			X						- undulatory extinction
		Ser	A	-0.005	F	ac									- alters Qtz/Kfs laminae
		Ms	A	-0.25	F-S	l-bl									- intergrown in Ser
		Carb	I	0.025-0.1	F-S	bk-rmb									- millis vugs within Sulph laminae
		Trm	A	-0.1	S-A	eq-pr									
		Grt	A	0.1-0.5	S-A	eq-el									
93-C138g	804 112 5/34.3	Qtz/Kfs	I	-0.25	A	eq			X						- undulatory extinction
		Ser	A	-0.005	F	ac									- alters Qtz/Kfs laminae
		Ms	A	-0.25	F-S	l-bl									- intergrown in Ser
		Carb	I	0.025-0.1	F-S	bk-rmb									- millis vugs within Sulph laminae

Table A3.4 - continued.

Sample	D/H Interval F/m	Mineralogy		Grain Habit		Primary		Grain Textures					Inclusions	Comments	
		Min	DS %	Grain Size	X/H	Shape	D/I	Col	Rst	Rpl	Fst	Brx			Pok
93-C138f		Trm	I	<0.2	A	eq, s-rnd								Po, Gn, Sp	- restricted to Qtz/Kfs laminae, associated with Bt
-continued-		Bt	I	0.05-0.25	S	l-bl			X					Po, Gn, Sp	- restricted to Qtz/Kfs laminae - highly fractured, replaces Carb, associated with Sulph laminae
		Grt	I	<1.0	A	s-rnd, el			X			X	X	Po, Gn, Sp, QF	- remobilized
		Gn	A	-	A	-			X					Po, Gn	- well developed polygonal texture
		Sp	X	0.05-0.5	S, A	eq-el, s-rnd			X					Po, Gn	
		Po	X	<0.1	E, A	eq-t			X				X	Gn, Sp	

General Comments: Sample consists of contorted Sp and Po laminae with intercalated sericitized semi-pelite

93-C138g	804 114/34.7	Qtz/Kfs	A	<0.25	A	eq			X						
		Ser	A	<0.005	E	ac			X						
		Ms	A	<0.1	E, S	l-bl			X						
		Carb	I	0.1-0.5	E, S	bk-nmb			X						
		Trm	I	<0.2	A	eq, s-rnd			X						
		Bt	I	0.05-0.25	E, S	l-bl			X						
		Grt	I	<1.0	A	s-rnd, el			X						
		Ccp	I	-	A	-			X						
		Gn	A	-	A	-			X						
		Sp	A	0.05-0.5	S, A	eq-el, s-rnd			X						
		Po	E	<0.1	E, A	eq-t			X						

General Comments: Similar to 93-C138f

93-C138h	804 115.8/35.3	Qtz/Kfs	I	<0.25	A	eq			X						
		Ser	A	<0.005	E	ac			X						
		Ms	A	<0.25	E, S	l-bl			X						
		Carb	I	0.025-0.1	E, S	bk-nmb			X						
		Trm	I	<0.2	A	eq, s-rnd			X						
		Bt	I	0.05-0.25	S	l-bl			X						
		Grt	I	<1.0	A	s-rnd, el			X						
		Gn	A	-	A	-			X						
		Sp	X	0.05-0.5	S, A	eq-el, s-rnd			X						
		Po	E	<0.1	E, A	eq-t			X						

General Comments: Sample represents upper transition from the sulphide rock to overlying meta-sedimentary rock. Sample consists of interlaminate Sp-Po and semi-pelite, with a gradual decrease up-section in the frequency of sulphid- laminae

93-C149b	5232 276.5/84.3	Qtz/Kfs	I	<0.1	A	irreg			X						
		Ser	A	<0.005	E	ac			X						
		Ms	A	<0.25	E, S	I			X						
		Chl	E	0.0025	E	ac			X						

- overprinted by Chl alteration ?
- associated with Sulph
- pervasively alters samples

Appendix 4

Summary of whole-geochemistry for non-sulphide and sulphide samples

Table A4.1. Summary of analytical techniques, validity of results and detection limits for major and trace element whole-rock geochemistry.

Element	Method		Validity of Results			Detection Limit
			Absolute	+	Relative	
SiO ₂	XRF/ICP	+/-	0.50%	+	1% of CONC.	0.50%
TiO ₂	XRF/ICP	+/-	0.02%	+	1% of CONC.	0.02%
Al ₂ O ₃	XRF/ICP	+/-	0.20%	+	1% of CONC.	0.20%
Fe ₂ O ₃ (t)	XRF/ICP	+/-	0.06%	+	1% of CONC.	
Fe ₂ O ₃	CALC	+/-		+		
FeO	CHEM	+/-	0.20%	+	5% of CONC.	
MnO	XRF/ICP	+/-	0.01%	+	2% of CONC.	0.03%
MgO	XRF/ICP	+/-	0.04%	+	1% of CONC.	0.03%
CaO	XRF/ICP	+/-	0.01%	+	1% of CONC.	0.03%
Na ₂ O	XRF/ICP	+/-	0.03%	+	1% of CONC.	0.03%
K ₂ O	XRF/ICP	+/-	0.05%	+	1% of CONC.	0.05%
P ₂ O ₅	XRF/ICP	+/-	0.01%	+	1% of CONC.	0.01%
H ₂ O (t)	CHEM	+/-	0.20%	+	5% of CONC.	0.10%
CO ₂ (t)	CHEM	+/-	0.10%	+	5% of CONC.	0.10%
CO ₂	CHEM	+/-	0.10%	+	5% of CONC.	0.20%
C	CHEM	+/-	0.20%	+	5% of CONC.	0.10%
S (t)	CHEM	+/-	0.02%	+	5% of CONC.	0.10%
S (t)	DIONEX	+/-	5 PPM	+	(included in absolute)	50 PPM
Cl	DIONEX	+/-	5 PPM	+	(included in absolute)	100 PPM
F	DIONEX	+/-	5 PPM	+	(included in absolute)	50 PPM
Ag	ICP-ES	+/-	2 PPM	+	10% of CONC.	0.1 PPM
Au	FADCP	+/-		+		1 PPB
B	ICP	+/-		+		10 PPM
Ba	ICP-ES	+/-	30 PPM	+	10% of CONC.	30 PPM
Be	ICP-ES	+/-	0.5 PPM	+	5% of CONC.	0.5 PPM
Cd	ICP-ES	+/-		+		0.02 PPM
Co	ICP-ES	+/-	5 PPM	+	5% of CONC.	5 PPM
Cr	ICP-ES	+/-	10 PPM	+	5% of CONC.	10 PPM
Cs	ICP-ES	+/-	10 PPM	+	5% of CONC.	0.02 PPM
Cu	ICP-ES	+/-	10 PPM	+	5% of CONC.	10 PPM
Ga	ICP-ES	+/-		+		
Hf	ICP-ES	+/-		+		
Hg	WET	+/-		+		5 PPB
Hg	WET	+/-		+		0.01 PPM
In	ICP-ES	+/-		+		
La	ICP-ES	+/-	10 PPM	+	5% of CONC.	10 PPM
Mo	ICP-ES	+/-		+		
Nb	ICP-ES	+/-	10 PPM	+	10% of CONC.	100 PPM
Nb	ICP-MS	+/-	10 PPM	+	10% of CONC.	100 PPM

Table A6.1. -continued-

Element	Method		Validity of Results			Detection Limit
			Absolute	+	Relative	
Ni	ICP-ES	+/-	10 PPM	+	5% of CONC.	10 PPM
Pb	ICP-ES	+/-	20 PPM	+	10% of CONC.	100 PPM
Pb	ICP-MS	+/-	20 PPM	+	10% of CONC.	100 PPM
Rb	ICP-ES	+/-	10 PPM	+	2% of CONC.	100 PPM
Rb	ICP-MS	+/-	10 PPM	+	2% of CONC.	100 PPM
Sc	ICP-ES	+/-	0.5 PPM	+	5% of CONC.	
Sn	ICP-ES	+/-		+		
Sr	ICP-ES	+/-	20 PPM	+	5% of CONC.	20 PPM
Ta	ICP-ES	+/-		+		0.2 PPM
Th	ICP-ES	+/-		+		
Tl	ICP-ES	+/-		-		
U	ICP-ES	+/-		+		
V	ICP-ES	+/-	5 PPM	+	5% of CONC.	5 PPM
Y	ICP-ES	+/-	5 PPM	+	5% of CONC.	5 PPM
Yb	ICP-ES	+/-	0.5 PPM	+	5% of CONC.	0.5 PPM
Zn	ICP-ES	+/-	5 PPM	-	5% of CONC.	
Zr	ICP-ES	+/-	10 PPM	+	10% of CONC.	100 PPM
Zr	ICP-MS	+/-	10 PPM	+	10% of CONC.	100 PPM
LOI	CHEM ₁	+/-		+		

- All analyses were conducted at the Geological Survey of Canada, Mineral Resources Division - Analytical Chemistry Section.

- Au, B, and Hg were analysed at XRAL Laboratories, Don Mills, Ontario, Canada.

Abbreviations:

ICP- Induce-coupled plasma spectroscopy

XRF - X-ray fluorence

ICP-ES - Induced-coupled plasma

CHEM - Chemical methods

ICP-MS - Induced-coupled mass-spectroscopy

WET - Wet leaching and cold vapour

DIONEX - DIONEX ion chromatography

CALC - Calculated

FADCP - Fire assay d coupled plasma spectroscopy

Analytical Techniques:

- ICP data of major elements were obtained on a 0.5 g sample fused with lithium metaborate, dissolved in 5% HNO₃ and diluted to 250 ml.

- ICP data of trace elements were obtained on a 1.0 g sample (acid + fusion of residue) dissolved in 10% HCl and diluted to 100 ml.

- Fe₂O₃ is calculated using: $Fe_2O_3 = Fe_2O_3(t) (ICP) \cdot 1.11134 \times \frac{t}{c} \cdot O$ (volumetric)

Table A4.2. Whole-rock geochemistry of hanging wall meta-sedimentary and albitic rocks.

Sample		93-C001	93-C004	93-C015	93-C021	93-C037	93-C078a-b	93-C123c	93-C142b	93-C160c
DDH		7027	7027	6839	6839	2370	4501	1866	5232	4483
Lithology		s-pelite (l)	s-pelite (l)	qtzite (l)	pelite (l)	pelite (l)	s-pelite (l)	s-pelite (l)	pelite (l)	pelite (l)
SiO ₂	%	50.70	28.40	68.80	65.80	69.30	59.80	70.70	27.20	23.00
TiO ₂	%	0.36	0.79	0.31	0.75	0.55	0.26	0.32	0.97	0.57
Al ₂ O ₃	%	12.60	19.00	9.00	19.70	15.50	9.31	10.30	21.20	15.20
Fe ₂ O ₃ (t)	%	19.60	26.90	12.70	2.10	5.60	15.80	9.40	16.40	28.00
Fe ₂ O ₃	%				0.90				2.60	
FeO	%				1.10				12.40	
MnO	%	0.29	0.56	0.19	0.04	0.07	0.12	0.09	0.98	0.55
MgO	%	6.51	14.50	2.12	1.47	3.24	3.74	3.07	22.10	13.20
CaO	%	1.16	0.65	0.29	0.35	0.51	2.11	0.11	0.83	0.72
Na ₂ O	%	0.12		0.10	0.20	0.50	0.32	0.10		0.13
K ₂ O	%	1.78	2.41	2.80	6.42	1.57	0.10	3.56		0.49
P ₂ O ₅	%	0.07	0.14	0.09	0.06	0.09	0.04	0.07	0.13	0.05
H ₂ O (t)	%				2.7				11.0	
CO ₂ (t)	%		0.2		0.2	0.2			0.2	
CO ₂	%						0.9			
C	%									
S (t)	%	5.64	4.25	4.96		1.12	5.59	3.01		10.60
S (t) D-EX	PPM				3085.0				3383.0	
Cl	PPM	254.0	116.0			217.0	232.0		198.0	
F	PPM	1229.0	3366.0	1364.0	1696.0	1922.0	1663.0	2179.0	1985.0	3030.0
Ag	PPM	31.00	0.70	1.40	1.70		2.60	7.70	1.30	5.50
Au (FADCP)	PPB	3							3	4
B (ICP)	PPM	76	23	170	62	9620	7230	104		
Ba	PPM	190.0	230.0	360.0	1000.0	200.0	40.0	290.0	30.0	150.0
Be	PPM	0.7	0.7	1.2	3.0	2.7		1.0	0.8	0.7
Cd	PPM	20.00	23.00	9.70	0.35	0.18	26.00	2.50	5.70	110.00
Co	PPM		5.0							7.0
Cr	PPM	32.0	55.0	27.0	59.0	33.0	22.0	20.0	46.0	34.0
Cs	PPM	1.50	6.10	5.90	6.50	1.80	0.28	7.30	1.20	0.81
Cu	PPM	100.0	74.0	110.0	30.0	34.0	97.0	49.0		59.0
Ga	PPM	15.00	29.00	11.00	25.00	18.00	11.00	13.00	26.00	20.00
Hf	PPM	7.30	8.50	6.30	5.90	8.40	6.60	4.50	11.00	5.00
Hg (Wet)	PPB	202	158	110	12	13	180	87	35	835
Hg (Wet)	PPM									
In	PPM	2.20	1.80	1.50	0.31	0.53	1.80	1.00	0.67	8.40
La	PPM	63.0	71.0	25.0		11.0		27.0	38.0	40.0
Mo	PPM	0.49	2.40	3.20	1.60	1.80	0.69	1.20	4.40	3.80
Nb	PPM									
Nb (MS)	PPM	10.00	19.00	6.50	16.00	13.00	3.10	8.20	22.00	12.00
Ni	PPM									
Pb	PPM	30000.0	490.0	1100.0	1500.0		1100.0	4700.0	510.0	4100.0
Pb (MS)	PPM					68.00				
Rb	PPM		120.0	110.0	210.0			110.0		
Rb (MS)	PPM	88.00	100.00			70.00	4.90		1.10	19.00
Sc	PPM	7.5	18.0	6.1	19.0	10.0	5.9	6.7	17.0	14.0
Sn	PPM	120.00	110.00	53.00	110.00	210.00	37.00	6.80	3.10	50.00
Sr	PPM					57.0	74.0			
Ta	PPM	0.46	1.00	0.47	1.00	0.88	0.42	0.41	1.40	0.66
Th	PPM	11.00	15.00	6.80	18.00	12.00	8.10	8.70	18.00	9.90
Tl	PPM	2.10	3.40	3.90	5.10	1.80	0.19	9.50	0.06	0.98
U	PPM	3.30	5.30	2.50	3.70	3.80	1.90	2.30	9.90	4.20
V	PPM	16.0	91.0	24.0	91.0	34.0	19.0	19.0	95.0	61.0
Y	PPM	54.0	48.0	24.0	33.0	35.0	12.0	21.0	25.0	42.0
Yb	PPM	3.9	3.8	2.5	3.4	4.2	1.5	2.0	3.3	4.3
Zn	PPM	4100.0	4300.0	2500.0	170.0	160.0	8200.0	360.0	1100.0	35000.0
Zr	PPM	220.0	240.0	220.0	210.0	320.0	190.0	180.0	350.0	160.0
Zr (MS)	PPM									
Total		102.5	98.7	102.0	100.5	99.6	100.0	101.6	100.4	96.8
LOI	PI M	5.1	7.5	3.1		2.2	2.4	2.5		11.6

Table A4.2. -continued-

Sample		93-C168d	93-C170d	93-C030-32	93-C070	93-C081	93-C095b	93-C114a	93-C124c	93-C125e
DDH		1972	1972	2442	3385	4501	3952	3994	1866	1866
Lithology		s-pelite (l)	s-pelite (l)	s-pelite (H)	s-pelite (H)	pelite (H)	qtzite (H)	qtzite (H)	qtzite (H)	s-pelite (H)
SiO ₂	%	69.10	66.10	63.90	56.80	68.10	48.70	71.70	63.20	77.00
TiO ₂	%	0.40	0.71	0.53	0.70	0.37	1.06	0.37	0.42	0.48
Al ₂ O ₃	%	12.70	18.70	13.20	13.60	11.00	26.10	10.50	11.40	13.20
Fe ₂ O ₃ (t)	%	3.10	1.60	6.80	14.60	9.90	4.20	5.90	9.60	2.20
Fe ₂ O ₃	%	1.10	0.40				1.50			1.20
FeO	%	1.80	1.10				2.40			0.90
MnO	%	0.15	0.05	0.44	0.17	0.08	0.17	0.55	0.71	0.16
MgO	%	2.38	1.70	2.99	6.74	3.03	2.65	2.62	3.06	0.74
CaO	%	3.54	0.67	4.19	0.36	0.69	2.06	2.08	3.60	3.56
Na ₂ O	%	1.00	0.10	0.20	0.50	0.40	0.20	0.10	0.30	0.10
K ₂ O	%	3.49	6.25	3.52	2.45		8.14	2.49	1.77	3.98
P ₂ O ₅	%	0.10	0.08	0.11	0.08	0.05	0.29	0.11	0.10	0.07
H ₂ O (t)	%	1.8	3.0				4.2			1.9
CO ₂ (t)	%				0.2	0.2			0.2	0.2
CO ₂	%	1.7	0.6	1.5			0.9	0.1		
C	%									
S (t)	%			2.15	1.70	3.66		2.06	3.03	
S (t) D-EX	PPM	4724.0	1501.0				6999.0			3716.0
Cl	PPM	314.0	541.0	163.0	259.0		229.0			211.0
F	PPM	1150.0	1186.0	1269.0	1543.0	1183.0	2341.0	1458.0	1733.0	1105.0
Ag	PPM	2.60	0.28	2.10	0.16	13.00	3.40	7.40	7.90	0.11
Au (FADCP)	PPB			3			1	1		8
B (ICP)	PPM	53	93	34	2280	8710	252	28	10	47
Ba	PPM	440.0	720.0	970.0	280.0		1200.0	310.0	170.0	500.0
Be	PPM	1.9	1.9	2.2	2.9		4.0	1.7	1.7	1.9
Cd	PPM	0.58	4.00	3.10	0.76	50.00	15.00	23.00	30.00	0.12
Co	PPM	5.0		15.0	33.0			5.0	10.0	
Cr	PPM	24.0	51.0	37.0	33.0	26.0	68.0	26.0	26.0	29.0
Cs	PPM	13.00	9.70	4.40	6.30	0.13	5.80	3.80	6.40	4.20
Cu	PPM			38.0	53.0	48.0	26.0	30.0	40.0	
Ga	PPM	16.00	26.00	17.00	24.00	11.00	35.00	13.00	14.00	16.00
Hf	PPM	5.10	5.10	5.90	7.10	4.00	22.00	8.20	5.10	6.60
Hg (Wet)	PPB	141	179	110	6	343	75	611	960	9
Hg (Wet)	PPM									
In	PPM	0.19	0.35	0.11	0.43	4.00	1.60	1.00	0.36	0.29
La	PPM	36.0	44.0	50.0	47.0	15.0	62.0	37.0	24.0	42.0
Mo	PPM	0.72	0.84	1.90	1.50	1.20	4.50	1.00	3.80	1.00
Nb	PPM									
Nb (MS)	PPM	12.00	16.00	12.00	19.00	5.80	30.00	10.00	11.00	13.00
Ni	PPM			18.0	13.0				13.0	
Pb	PPM	130.0	900.0	2000.0	120.0	2700.0	7800.0	7400.0	4700.0	
Pb (MS)	PPM									96.00
Rb	PPM	180.0	270.0	140.0	120.0		270.0			160.0
Rb (MS)	PPM				100.00	0.99				
Sc	PPM	7.8	18.0	12.0	8.2	7.2	18.0	6.4	8.6	9.0
Sn	PPM	2.00	21.00	13.00	44.00	45.00	400.00	37.00	3.90	20.00
Sr	PPM	62.0		29.0		64.0		23.0	29.0	
Ta	PPM	0.52	0.59	0.71	0.91	0.67	1.00	0.35	0.58	0.77
Th	PPM	9.40	16.00	11.00	12.00	8.30	26.00	9.00	9.30	13.00
Tl	PPM	11.00	8.60	5.10	1.50	0.20	6.10	6.40	5.40	4.30
U	PPM	2.80	3.20	3.70	3.30	2.10	7.60	2.90	3.40	3.50
V	PPM	22.0	81.0	49.0	29.0	22.0	68.0	17.0	35.0	28.0
Y	PPM	37.0	37.0	39.0	58.0	15.0	68.0	36.0	34.0	38.0
Yb	PPM	3.8	4.0	3.7	4.6	2.1	6.8	3.6	3.8	3.4
Zn	PPM	290.0	710.0	930.0	390.0	15000.0	2400.0	7800.0	10000.0	74.0
Zr	PPM	220.0	200.0	230.0	250.0	140.0	1000.0	350.0	180.0	240.0
Zr (MS)	PPM									
Total		100.0	100.1	100.1	98.5	100.3	100.7	100.3	101.1	101.1
LOI	PPM			27	36	30		22	26	

Table A4.2. -continued-

Sample		93-C135d	93-C142d	93-C150b	93-C156f	93-C158a	93-C159b	93-C163b	93-C164b	93-C165a
DDH		804	5232	5063	5063	5063	5063	4483	4483	4483
Lithology		qtzite (H)	qtzite (H)	albitite (H)	pelite (H)	albitite (H)	s-pelite (H)	albitite (H)	pelite (H)	albitite (H)
SiO ₂	%	69.00	34.40	64.50	23.10	70.40	62.60	57.90	29.10	60.50
TiO ₂	%	0.47	0.68	0.26	0.47	0.34	0.71	0.47	0.80	0.40
Al ₂ O ₃	%	12.80	15.10	6.90	12.10	14.50	20.00	18.50	21.00	18.80
Fe ₂ O ₃ (t)	%	7.80	17.70	12.20	30.40	3.10	2.40	6.80	18.80	4.30
Fe ₂ O ₃	%	1.70						0.80	2.70	
FeO	%	5.50					2.20	5.40	14.50	
MnO	%	0.39	1.23	0.17	0.09	0.03	0.03	0.14	0.46	0.08
MgO	%	3.50	15.10	5.14	15.30	1.60	2.59	5.01	20.60	2.68
CaO	%	0.74	0.69	1.90	0.52	0.56	0.47	0.67	0.59	0.98
Na ₂ O	%	0.10	0.10	1.12	0.08	7.60	1.80	6.90	0.10	9.20
K ₂ O	%	2.55	4.54		0.57		5.60	0.51		0.17
P ₂ O ₅	%	0.11	0.15	0.06	0.08	0.10	0.10	0.11	0.08	0.04
H ₂ O (t)	%	2.7					2.8	3.1	10.4	
CO ₂ (t)	%						0.2		0.2	
CO ₂	%			1.1						0.5
C	%									
S (t)	%		3.99	5.64	15.50	1.28				1.00
S (t) D-EX	PPM	2178.0					5492.0	2119.0	393.0	
Cl	PPM	366.0	188.0			287.0		380.0	226.0	572.0
F	PPM	1208.0	7412.0	826.0	4872.0	512.0	1067.0	1357.0	3538.0	562.0
Ag	PPM	2.50	62.00	1.80	3.40	0.94	0.96	0.70	0.26	0.33
Au (FADCP)	PPB		1	10	14	1		4		
B (ICP)	PPM	1730					73	715	1840	25
Ba	PPM	320.0	350.0	30.0	70.0	60.0	930.0	160.0	50.0	100.0
Be	PPM	1.4	1.4		0.7	20.0	21.0	1.2	0.7	1.0
Cd	PPM	0.51	42.00	3.80	1.00	0.10		2.30	0.11	0.16
Co	PPM	7.0	8.0	11.0	15.0				5.0	
Cr	PPM	33.0	40.0	17.0	28.0	25.0	25.0	29.0	44.0	22.0
Cs	PPM	5.80	17.00	0.23	5.50	0.28	0.26	0.50	0.63	0.29
Cu	PPM		54.0	39.0	150.0	11.0	11.0			
Ga	PPM	16.00	20.00	8.70	15.00	8.00	8.20	19.00	29.00	17.00
Hf	PPM	7.90	10.00	4.70	5.40	7.10	7.00	5.80	8.90	5.90
Hg (Wet)	PPB	21	550	54	25	12	6	13		6
Hg (Wet)	PPM									
In	PPM	0.32	1.40	1.40	1.60	0.11	0.16	0.22	0.14	0.03
La	PPM	21.0	66.0	15.0	17.0			11.0	44.0	35.0
Mo	PPM	2.50	4.40	0.78	2.90	2.30	2.60	3.20	1.90	0.87
Nb	PPM									
Nb (MS)	PPM	13.00	13.00	8.50	11.00	9.10	9.40	13.00	21.00	11.00
Ni	PPM	12.0								
Pb	PPM		45000.0	2700.0	1500.0	1100.0	1100.0	300.0	180.0	
Pb (MS)	PPM	100.00								43.00
Rb	PPM	130.0					210.0			
Rb (MS)	PPM			1.50	42.00	0.80	0.58	14.00	2.90	5.30
Sc	PPM	9.4	17.0	4.3	10.0	4.6	4.6	8.5	11.0	6.7
Sn	PPM	21.00	2.40	13.00	28.00	59.00	88.00	27.00	68.00	34.00
Sr	PPM							20.0		20.0
Ta	PPM	0.83	0.96	0.45	0.47	0.60	0.48	0.44	1.40	0.54
Th	PPM	11.00	17.00	5.80	9.60	7.80	7.90	7.60	17.00	8.40
Ti	PPM	4.10	9.60	0.13	2.80	0.17	0.13	0.40	0.14	0.13
U	PPM	3.70	7.10	1.80	3.50	2.70	2.80	3.10	4.00	2.30
V	PPM	35.0	76.0	12.0	36.0			35.0	60.0	19.0
Y	PPM	38.0	36.0	28.0	19.0	150.0	150.0	32.0	72.0	35.0
Yb	PPM	4.1	3.3	3.1	2.5	13.0	13.0	3.3	6.7	3.2
Zn	PPM	270.0	12000.0	1200.0	410.0	80.0	81.0	580.0	390.0	110.0
Zr	PPM	270.0	390.0	160.0	170.0	290.0	270.0	200.0	310.0	220.0
Zr (MS)	PPM									
Total		100.2	100.3	99.5	99.0	99.8	100.1	100.1	101.3	98.8
LOI	PPM		5.4	5.1	15.9	1.6				2.1

Table A4.2. -continued

Sample		93-C011	93-C042	93-C056	93-C058-59	93-C107e	93-C117b	93-C136b-c	93-C014	93-C026
DDH		7027	2370	4495	4495	3976	3994	804	7027	2442
Lithology		pelite (hu)	s-pelite (hu)	pelite (hu)	s-pelite (hu)	qtzite (hu)	s-pelite (hu)	s-pelite (hu)	s-pelite (Hu)	s-pelite (Hu)
SiO ₂	%	18.50	66.80	26.60	46.80	54.10	62.30	71.80	44.50	75.10
TiO ₂	%	0.52	0.56	0.29	0.96	0.42	0.47	0.50	0.97	0.50
Al ₂ O ₃	%	12.50	14.20	12.30	15.00	10.60	13.10	13.90	22.50	13.50
Fe ₂ O ₃ (t)	%	45.10	7.60	31.30	18.10	16.90	9.80	4.30	11.90	3.00
Fe ₂ O ₃	%							1.10		1.10
FeO	%							2.90		1.70
MnO	%	0.15	0.31	0.08	0.17	0.76	0.66	0.49	0.08	0.28
MgO	%	3.59	3.37	9.49	11.80	6.16	4.01	1.60	4.86	1.05
CaO	%	3.22	0.50	0.13	0.57	1.82	1.63	2.10	1.98	0.64
Na ₂ O	%	0.15	0.30	1.92	1.00	0.10	0.10	0.20	4.70	0.20
K ₂ O	%	2.74	2.62	0.10	0.09	2.14	3.12	3.39	0.41	4.08
P ₂ O ₅	%	0.10	0.10	0.01	0.16	0.09	0.08	0.08	0.03	0.07
H ₂ O (t)	%				6.9			2.2		1.8
CO ₂ (t)	%		0.2	0.2						0.2
CO ₂	%	1.8			0.1		0.6	0.3	1.2	
C	%	0.2								
S (t)	%	19.80	2.39	17.00		4.87	2.64		3.86	
S (t) D-EX	PPM				428.0			1178.0		3802.0
Cl	PPM		146.0		177.0	353.0	138.0	192.0		167.0
F	PPM	1612.0	2072.0	1931.0	1620.0	3654.0	1279.0	1003.0	1229.0	701.0
Ag	PPM	4.80				31.00	0.83	1.30	5.60	
Au (FADCP)	PPB	6		7	5				14	80
B (ICP)	PPM	596	5370	12	18	14	21	275	10109	24
Ba	PPM	360.0	340.0	70.0	50.0	100.0	380.0	460.0	110.0	630.0
Bc	PPM	1.0	1.9	5.8	2.4	0.8	1.8	1.7	2.7	1.7
Cd	PPM	8.10	0.31	1.10		35.00	29.00		0.38	0.19
Co	PPM	10.0	5.0	100.0		19.0	17.0		9.0	
Cr	PPM	27.0	39.0	23.0	69.0	26.0	28.0	31.0	49.0	30.0
Cs	PPM	1.30	3.40	1.80	0.78	12.00	5.8	4.80	0.51	4.50
Cu	PPM	420.0	80.0			63.0	46.1		54.0	
Ga	PPM	16.00	17.00	23.00	38.00	16.00	16.00	18.00	24.00	16.00
Hf	PPM	9.50	5.90	9.80	13.00	4.30	5.20	7.70	11.00	7.00
Hg (Wet)	PPB	56	13	24		992	796	19	11	12
Hg (Wet)	PPM									
In	PPM	1.10	0.53	0.31	0.42	0.94	0.64	0.30	0.99	0.19
La	PPM	64.0	32.0	27.0	34.0	41.0	39.0	68.0		46.0
Mo	PPM	21.00	2.10	0.91	4.70	2.60	1.30	1.20	0.85	1.10
Nb	PPM									
Nb (MS)	PPM	18.00	13.00	5.30	23.00	12.00	13.00	13.00	15.00	13.00
Ni	PPM			27.0		28.0	11.0			
Pb	PPM	970.0				17000.0	530.0	420.0	660.0	
Pb (MS)	PPM		44.00	20.00	53.00					32.00
Rb	PPM		130.0				160.0	140.0		160.0
Rb (MS)	PPM			6.80	5.50				16.00	
Sc	PPM	6.8	12.0	18.0	35.0	8.9	9.5	10.0	16.0	9.5
Sn	PPM	85.00	260.00	380.00	140.00	87.00	26.00	100.00	190.00	95.00
Sr	PPM		43.0			21.0		31.0	100.0	
Ta	PPM	0.88	0.89	0.40	1.00	0.34	0.33	0.53	1.10	0.82
Th	PPM	15.00	12.00	10.00	22.00	9.10	11.00	13.00	15.00	13.00
Ti	PPM	1.10	3.20	0.10	0.11	12.00	7.40	4.30	0.21	3.60
U	PPM	5.70	3.50	4.80	6.80	4.20	2.80	4.00	7.00	3.20
V	PPM	10.0	53.0	68.0	220.0	38.0	32.0	36.0	48.0	30.0
Y	PPM	53.0	31.0	55.0	69.0	93.0	37.0	43.0	35.0	41.0
Yb	PPM	5.4	3.3	5.0	7.6	8.9	3.5	3.8	5.3	3.9
Zn	PPM	2100.0	87.0	90.0	260.0	12000.0	9900.0	180.0	180.0	150.0
Zr	PPM	270.0	230.0	320.0	430.0	200.0	200.0	270.0	370.0	260.0
Zr (MS)	PPM									
Total		109.0	99.9	99.7	102.0	101.3	99.8	101.0	98.3	100.8
LOI	PPM	8.5	2.7	15.3		4.1	3.4		5.9	

Table A4.2. -continued-

Sample		93-C050	93-C054	93-C073b	93-C074a	93-C088	93-C097e	93-C102c	93-C105b	93-C108e
DDH		4495	4495	3385	3385	4501	3952	3971	3971	3976
Lithology		s-pelite (Hu)	albitite (Hu)	albitite (Hu)	pelite (Hu)	s-pelite (Hu)	qtzite (Hu)	qtzite (Hu)	Hu ore	pelite (Hu)
SiO ₂	%	66.80	58.40	55.00	35.00	58.50	62.00	77.80	64.70	80.40
TiO ₂	%	0.56	0.54	1.06	0.79	0.65	0.47	0.36	0.40	0.37
Al ₂ O ₃	%	15.30	17.50	16.70	20.30	17.80	12.40	9.10	11.00	8.70
Fe ₂ O ₃ (t)	%	6.30	7.50	13.20	24.10	10.20	3.50	4.70	4.60	3.70
Fe ₂ O ₃	%				3.00	2.40	1.10			2.60
FeO	%				19.00	7.00	2.20			1.00
MnO	%	0.07	0.05	0.03	0.18	0.13	0.38	0.15	0.36	0.22
MgO	%	2.83	5.46	1.80	11.40	4.33	2.90	0.82	2.97	0.94
CaO	%	0.50	0.56	0.47	0.63	0.48	8.75	1.14	7.84	2.09
Na ₂ O	%	0.20	6.70	8.30	1.90	0.50	0.30	0.20	0.30	0.20
K ₂ O	%	3.76	0.16	0.11	0.26	3.03	2.35	2.67	2.08	0.82
P ₂ O ₅	%	0.09	0.08	0.20	0.13	0.10	0.03	0.05	0.10	0.04
H ₂ O (t)	%	2.6	3.2		7.9	4.0	2.4			1.2
CO ₂ (t)	%									
CO ₂	%	0.3				0.1	4.2	0.3	3.5	0.3
C	%									
S (t)	%			4.44				2.28	1.21	
S (t) D-EX	PPM	4735.0	3564.0		1258.0	834.0	3202.0			5985.0
Cl	PPM	357.0	234.0	100.0	224.0	116.0	261.0	121.0	234.0	401.0
F	PPM	1590.0	972.0	462.0	1826.0	1383.0	860.0	505.0	907.0	867.0
Ag	PPM	2.10				0.58	0.98	5.40	2.80	0.81
Au (FADCP)	PPB	3	14					3	16	
B (ICP)	PPM	3470	31	22	1620	4100	11	13	34	3670
Ba	PPM	970.0	70.0	40.0	90.0	930.0	280.0	340.0	410.0	130.0
Be	PPM	2.5	2.4	1.1	0.7	1.1	1.9	1.7	1.5	1.8
Cd	PPM	3.70	1.80			0.94	2.90	16.00	10.00	0.81
Co	PPM		6.0	17.0	7.0	7.0		9.0	7.0	
Cr	PPM	34.0	30.0	98.0	58.0	52.0	36.0	23.0	27.0	25.0
Cs	PPM	2.30	0.37	0.31	1.70	2.30	2.60	3.30	2.70	1.20
Cu	PPM	16.0		120.0			10.0	33.0	19.0	16.0
Ga	PPM	20.00	19.00	17.00	51.00	23.00	13.00	10.00	14.00	10.00
Hf	PPM	6.10	11.00	15.00	7.80	5.80	4.00	7.80	5.20	9.30
Hg (Wet)	PPB	103	9			15	77	674	517	55
Hg (Wet)	PPM									
In	PPM	0.18	0.37	0.04	0.24	0.71	0.33	0.49	0.13	0.23
La	PPM	100.0	150.0	39.0	62.0	54.0	16.0	39.0	31.0	21.0
Mo	PPM	1.90	0.78	2.00	28.00	1.90	1.40	0.80	0.98	0.44
Nb	PPM									
Nb (MS)	PPM	14.00	11.00	39.00	18.00	14.00	15.00	9.00	10.00	8.40
Ni	PPM	10.0		18.0	17.0	20.0	10.0	10.0	13.0	
Pb	PPM	610.0				140.0	460.0	3200.0	1300.0	340.0
Pb (MS)	PPM		22.00	22.00	18.00					
Rb	PPM	120.0				100.0	140.0			
Rb (MS)	PPM	100.00	4.00	2.30	10.00	84.00			96.00	37.00
Sc	PPM	12.0	12.0	22.0	28.0	17.0	8.2	6.4	8.2	6.3
Sn	PPM	21.00	450.00	190.00	77.00	58.00	54.00	42.00	3.10	120.00
Sr	PPM	24.0				40.0	76.0		73.0	50.0
Ta	PPM	0.83	0.26	1.80	1.10	1.00	1.20	0.40	0.50	0.57
Th	PPM	13.00	15.00	23.00	17.00	15.00	12.00	10.00	10.00	11.00
Ti	PPM	1.00	0.04	0.03	0.06	1.10	3.60	4.60	3.30	1.30
U	PPM	3.60	3.00	6.90	3.40	3.90	2.60	2.50	2.90	2.40
V	PPM	44.0	30.0	60.0	120.0	77.0	29.0	20.0	28.0	19.0
Y	PPM	29.0	63.0	86.0	41.0	32.0	31.0	28.0	34.0	22.0
Yb	PPM	3.0	6.4	8.2	4.3	3.8	3.4	2.9	3.8	2.8
Zn	PPM	1200.0	76.0	78.0	260.0	590.0	720.0	4800.0	3500.0	450.0
Zr	PPM	220.0	460.0	550.0	250.0	200.0	140.0	310.0	210.0	350.0
Zr (MS)	PPM									
Total		100.7	100.8	101.5	101.1	99.9	100.1	100.5	99.8	100.1
LOI	PPM			2.8				2.5	3.8	

Table A4.2. -continued-

Sample		93-C111d	93-C111e	93-C111b	93-C137a-c	93-C137e	93-C143a	93-C148	93-C166g	93-C033
DDH		3976	3994	3994	804	804	5232	5232	4483	2442
Lithology		s-pelite (Hu)	s-pelite (Hu)	s-pelite (Hu)	qtzite (Hu)	s-pelite (Hu)	qtzite (Hu)	qtzite (Hu)	pelite (Hu)	qtzite (U)
SiO ₂	%	64.80	71.30	62.40	79.50	66.80	73.20	16.10	15.40	79.50
TiO ₂	%	0.55	0.46	0.46	0.38	0.49	0.43	0.18	0.44	0.42
Al ₂ O ₃	%	15.20	12.80	11.80	8.80	14.00	10.50	5.32	9.90	11.50
Fe ₂ O ₃ (t)	%	4.40	2.90	5.60	5.50	9.20	5.50	19.40	51.50	1.50
Fe ₂ O ₃	%	1.60	1.20							0.30
FeO	%	2.50	1.50							1.10
MnO	%	0.41	0.45	0.56	0.64	0.53	1.11	0.99	0.24	0.03
MgO	%	1.57	1.53	3.91	0.93	1.80	2.31	8.70	6.15	0.51
CaO	%	5.09	2.96	8.10	1.02	1.10	1.28	23.40	0.17	0.59
Na ₂ O	%	0.30	0.10	0.20	0.10	0.10		0.13	0.62	0.10
K ₂ O	%	3.49	3.88	1.57	1.87	3.96	3.28	0.18	0.43	3.74
P ₂ O ₅	%	0.10	0.06	0.11	0.04	0.08	0.09	0.01	0.01	0.04
H ₂ O (t)	%	2.4	1.9							1.5
CO ₂ (t)	%				0.2					
CO ₂	%	1.4	1.5	3.4				18.5		0.1
C	%									
S (t)	%			1.00	1.21	2.06	1.25	8.07	22.40	0.08
S (t) D-EX	PPM	6072.0	3975.0							830.0
Cl	PPM	255.0	312.0	280.0	293.0	148.0	218.0			197.0
F	PPM	1139.0	789.0	929.0	652.0	1160.0	1223.0	1332.0	809.0	575.0
Ag	PPM	1.80	1.00	0.77	0.18		0.85	6.90	1.80	
Au (FADCP)	PPB				7	6		3		
B (ICP)	PPM	19	17	14	1000	43	49		869	31
Ba	PPM	810.0	510.0	320.0	250.0	560.0	520.0	50.0	290.0	540.0
Be	PPM	2.7	1.8	1.5	1.1	1.9	2.6		1.1	1.1
Cd	PPM	12.00	1.20	2.40		0.25	6.00	18.00	47.00	0.24
Co	PPM	8.0	5.0	7.0	8.0	15.0		8.0	10.0	5.0
Cr	PPM	39.0	26.0	31.0	26.0	30.0	34.0	12.0	23.0	26.0
Cs	PPM	3.50	4.50	2.10	3.00	6.50	3.30	1.60	0.82	4.10
Cu	PPM	19.0	10.0	17.0	32.0	35.0	18.0	140.0	290.0	
Ga	PPM	19.00	14.00	16.00	10.00	17.00	13.00	6.80	17.00	12.00
Hf	PPM	5.00	6.10	5.90	9.70	5.90	8.00	5.90	5.00	9.00
Hg (Wet)	PPB	536	43	122	11	19	94	235	289	18
Hg (Wet)	PPM									
In	PPM	0.22	0.09	0.07	0.17	0.24	0.27	1.20	1.80	0.19
La	PPM	38.0	37.0	29.0	33.0	40.0	34.0	15.0	38.0	40.0
Mo	PPM	2.70	0.77	2.40	0.66	1.80	7.90	2.70	2.20	0.65
Nb	PPM									
Nb (MS)	PPM	14.00	13.00	11.00	9.00	13.00	12.00	4.90	12.00	11.00
Ni	PPM	18.0		12.0		14.0	22.0	11.0	85.0	
Pb	PPM	1000.0	790.0	570.0			1500.0	4800.0	890.0	
Pb (MS)	PPM				38.00	28.00				42.00
Rb	PPM	160.0	160.0		100.0	180.0	150.0			170.0
Rb (MS)	PPM			73.00	80.00			14.00	17.00	
Sc	PPM	13.0	8.5	9.5	6.6	10.0	8.1	5.7	7.1	8.1
Sn	PPM	7.10	19.00	5.30	20.00	2.00	6.40	1.00	51.00	1.80
Sr	PPM	79.0	23.0	41.0	21.0		28.0	51.0		
Ta	PPM	0.39	0.23	0.39	0.56	0.66	0.80	0.42	0.67	0.77
Th	PPM	13.00	12.00	10.00	11.00	12.00	10.00	5.60	8.10	13.00
Tl	PPM	3.80	5.30	3.10	2.80	5.40	2.80	0.67	0.50	2.10
U	PPM	3.80	3.10	3.40	3.00	3.30	3.60	1.50	9.70	2.90
V	PPM	59.0	26.0	42.0	19.0	36.0	35.0	8.0	34.0	25.0
Y	PPM	44.0	35.0	29.0	29.0	35.0	29.0	21.0	24.0	24.0
Yb	PPM	3.9	3.2	3.0	3.2	3.8	2.9	2.6	3.1	2.6
Zn	PPM	2200.0	420.0	840.0	92.0	200.0	1900.0	5200.0	17000.0	74.0
Zr	PPM	230.0	240.0	220.0	340.0	190.0	290.0	180.0	170.0	380.0
Zr (MS)	PPM									
Total		100.6	100.4	99.5	100.5	100.4	99.6	102.2	109.3	99.8
LOI	PPM				1.4	2.6	1.8		10.7	

Table A4.2. -continued-

Sample		93-C076b	93-C097d	93-C121d	93-C128e
DDH		3385	3952	3994	1866
Lithology		albite (U)	qtzite (U)	s-pelite (U)	s-pelite (U)
SiO ₂	%	54.10	66.50	66.70	69.60
TiO ₂	%	1.12	0.51	0.51	0.41
Al ₂ O ₃	%	19.00	14.10	13.20	11.40
Fe ₂ O ₃ (t)	%	9.00	6.60	4.50	6.70
Fe ₂ O ₃	%	1.60		1.70	1.50
FeO	%	6.70		2.50	4.70
MnO	%	0.04	1.25	0.26	0.22
MgO	%	5.42	2.19	3.12	1.53
CaO	%	0.50	2.31	4.13	4.60
Na ₂ O	%	7.40	0.10	0.50	1.50
K ₂ O	%	0.17	3.52	3.11	1.80
P ₂ O ₅	%	0.36	0.08	0.11	0.06
H ₂ O (t)	%	3.5		2.3	1.5
CO ₂ (t)	%	0.2			
CO ₂	%		0.4	1.5	1.5
C	%				
S (t)	%		1.74		
S (t) D-EX	PPM	6219.0		8192.0	3425.0
Cl	PPM	279.0	182.0	218.0	416.0
F	PPM	1181.0	1069.0	1195.0	750.0
Ag	PPM		1.30	0.69	0.26
Au (FADCP)	PPB			1	
B (ICP)	PPM	46	26	55	14
Ba	PPM	30.0	530.0	660.0	240.0
Be	PPM	0.9	1.8	1.7	2.8
Cd	PPM		11.00	2.50	1.40
Co	PPM	5.0	12.0	8.0	13.0
Cr	PPM	92.0	33.0	33.0	29.0
Cs	PPM	1.10	3.80	5.20	8.80
Cu	PPM		33.0	19.0	19.0
Ga	PPM	27.00	18.00	16.00	13.00
Hf	PPM	20.00	4.30	7.20	5.60
Hg (Wet)	PPB		200	154	65
Hg (Wet)	PPM				
In	PPM	0.09	0.50	0.12	0.08
La	PPM	16.0	31.0	40.0	36.0
Mo	PPM	0.99	2.00	1.40	1.80
Nb	PPM				
Nb (MS)	PPM	25.00	11.00	14.00	11.00
Ni	PPM	11.0	17.0	18.0	20.0
Pb	PPM		950.0	280.0	120.0
Pb (MS)	PPM	16.00			
Rb	PPM		150.0	150.0	130.0
Rb (MS)	PPM	6.70			
Sc	PPM	22.0	11.0	9.5	9.0
Sn	PPM	42.00	47.00	9.60	0.56
Sr	PPM		21.0	62.0	68.0
Ta	PPM	1.40	0.93	0.74	0.38
Th	PPM	32.00	11.00	12.00	11.00
Ti	PPM	0.06	3.30	5.60	3.30
U	PPM	5.50	2.90	3.60	2.40
V	PPM	150.0	46.0	37.0	31.0
Y	PPM	25.0	31.0	37.0	40.0
Yb	PPM	3.2	3.1	3.9	4.1
Zn	PPM	65.0	3300.0	950.0	330.0
Zr	PPM	900.0	170.0	270.0	200.0
Zr (MS)	PPM				
Total		101.0	100.0	100.9	100.9
LOI	PPM		2.7		

Table A4.3. Whole-rock geochemistry of sulphide rocks from the hanging wall and main ore zone.

Sample		93-C099b	93-C122b	93-C139a-e	93-C167e	93-C019	93-C022	93-C038
DDH		3971	1866	5232	1972	6839	6839	2370
Lithology	Unit	Main Band	Main Band	Main Band	Main Band	1 Lam	1 Lam	1 Lam
SiO ₂	%	1.72	2.77	5.54	23.30	59.80	48.50	37.00
TiO ₂	%	0.05	0.09	0.15	0.21	0.57	0.42	0.51
Al ₂ O ₃	%	1.17	2.05	4.46	5.32	14.40	13.80	12.40
Fe ₂ O ₃ (t)	%	37.50	38.20	20.10	38.60	8.35	21.70	34.50
Fe ₂ O ₃	%							
FeO	%							
MnO	%	0.60	0.03	0.53	0.12	0.10	0.11	0.53
MgO	%	0.99	0.33	4.53	1.00	1.99	1.48	1.84
CaO	%	1.20	0.13	0.59	0.71	0.93	0.66	0.50
Na ₂ O	%	0.09	0.16	0.11	0.78	0.29	0.33	0.25
K ₂ O	%	0.17	0.57		1.36	4.41	4.34	3.34
P ₂ O ₅	%	0.01	0.02	0.04	0.04	0.07	0.04	0.04
H ₂ O (t)	%							
CO ₂ (t)	%					0.2	0.1	
CO ₂	%	1.7		0.1				
C	%			0.2	0.3			
S (t)	%	37.70	27.90	21.80	12.00	5.32	10.70	16.50
S (t) D-EX	PPM							
Cl	PPM					147.0		
F	PPM	210.0	180.0	315.0	344.0	1355.0	1535.0	1534.0
Ag	PPM	28.00	340.00	300.00	3.10	19.00	5.30	0.11
Au (FADCP)	PPB	13	38	61	31		4	
B (ICP)	PPM	17			47	72	65	1380
Ba	PPM	120.0	120.0	50.0	250.0	690.0	740.0	540.0
Be	PPM				1.1	2.2	2.3	1.5
Cd	PPM	52.00	13.00	930.00	120.00	120.00	80.00	1.80
Co	PPM	82.0	18.0	7.0	19.0		11.0	29.0
Cr	PPM		14.0	11.0	21.0	39.0	29.0	39.0
Cs	PPM	0.31	0.39	0.07	2.80	6.80	5.00	3.50
Cu	PPM	470.0	490.0	210.0	64.0	59.0	240.0	270.0
Ga	PPM	4.90	2.90	6.70	6.60	18.00	17.00	17.00
Hf	PPM	0.55	0.32	0.75	2.10	5.50	5.30	6.20
Hg (Wet)	PPB	1250	484	6790	33300	1700	1260	48
Hg (Wet)	PPM							
In	PPM	16.00	3.70	90.00	5.60	4.30	2.70	0.87
La	PPM	17.0	51.0	15.0	14.0	50.0	12.0	
Mo	PPM	2.10	7.40	4.40	18.00	8.30	7.10	2.00
Nb	PPM							
Nb (MS)	PPM	1.10	0.48	3.40	4.80	12.00	11.00	11.00
Ni	PPM	30.0	33.0		34.0			
Pb	PPM	13000.0	183000.0	199000.0	17000.0	13000.0	4000.0	
Pb (MS)	PPM							42.00
Rb	PPM							
Rb (MS)	PPM	7.50	19.00	0.38	74.00			
Sc	PPM	15.0	10.0	7.3	11.0	12.0	9.4	11.0
Sn	PPM	230.00	59.00	1.50	8.00	82.00	73.00	290.00
Sr	PPM				24.0			
Ta	PPM	0.29	0.35	0.41	0.30	0.67	0.90	0.49
Th	PPM	1.00	1.60	3.70	4.20	11.00	9.40	8.80
Tl	PPM	1.20	3.20	3.90	11.00	5.00	4.10	2.70
U	PPM	1.20	0.99	2.40	3.90	4.10	3.40	3.40
V	PPM			12.0	18.0	66.0	44.0	43.0
Y	PPM		8.0	10.0	14.0	30.0	30.0	29.0
Yb	PPM	0.7	1.0	1.1	1.6	3.2	4.4	1.8
Zn	PPM	15000.0	2200.0	188000.0	47000.0	40000.0	28000.0	500.0
Zr	PPM					160.0	140.0	180.0
Zr (MS)	PPM	24.00	13.00	32.00	90.00			
Total		85.8	90.9	97.1	90.3	102.0	105.7	107.8
LOI	PPM	20.4	6.8	3.1	17.7	3.3	3.5	9.0

Table A4.3. -continued-

Sample		93-C062b	93-C062e	93-C066b-67b	93-C092-93	93-C113c	93-C160b	93-C161b
DDH		4495	4495	3385	3952	3994	4483	4483
Lithology	Unit	I Lam	I Lam	I Lam	I Lam	I Lam	I Lam	I Lam
SiO ₂	%	10.80	53.80	22.80	14.00	63.70	9.48	0.64
TiO ₂	%	0.07	0.50	0.70	0.11	0.60	0.20	
Al ₂ O ₃	%	1.81	13.20	18.10	2.70	15.60	5.52	
Fe ₂ O ₃ (t)	%	14.80	16.90	23.60	20.80	8.20	22.90	33.10
Fe ₂ O ₃	%							
FeO	%							
MnO	%	0.16	0.12	0.32	0.67	0.11	0.33	0.21
MgO	%	0.61	1.75	10.60	0.62	2.06	5.12	1.13
CaO	%	0.20	0.55	1.29	0.71	0.75	1.36	2.10
Na ₂ O	%	0.14	0.19	0.45	0.15	0.10	0.11	0.09
K ₂ O	%	0.24	4.10	0.18	0.50	4.82	0.30	
P ₂ O ₅	%	0.03	0.08	0.08	0.03	0.11	0.03	
H ₂ O (t)	%							
CO ₂ (t)	%		0.2			0.2		
CO ₂	%				0.2		0.6	2.7
C	%						0.3	
S (t)	%	23.20	8.40	9.60	21.80	3.72	22.60	28.90
S (t) D-EX	PPM							
Cl	PPM							
F	PPM	200.0	2043.0	2831.0	182.0	1807.0	2390.0	
Ag	PPM	350.00	1.40	18.00	150.00	3.80	120.00	180.00
Au (FADCP)	PPB	10		8	68	1	20	13
B (ICP)	PPM	651	647	8680	40	25		
Ba	PPM	60.0	450.0	100.0	110.0	780.0	80.0	60.0
Be	PPM		1.4	0.5		2.5		
Cd	PPM	1200.00	140.00	290.00	1000.00	27.00	890.00	640.00
Co	PPM			12.0	19.0	7.0		20.0
Cr	PPM		33.0	46.0	12.0	41.0	15.0	
Cs	PPM	0.33	2.10	0.56	0.56	6.50	0.67	
Cu	PPM	140.0	120.0	110.0	270.0	71.0	150.0	200.0
Ga	PPM	2.50	18.00	25.00	3.70	20.00	7.90	0.42
Hf	PPM	0.43	4.90	8.40	1.10	4.50	2.00	0.04
Hg (Wet)	PPB	4270	799	957	5270	687	6150	4700
Hg (Wet)	PPM							
In	PPM	23.00	6.70	24.00	83.00	3.60	59.00	28.00
La	PPM		18.0	32.0		31.0	13.0	
Mo	PPM	2.40	4.20	7.10	2.50	3.30	3.70	1.00
Nb	PPM							
Nb (MS)	PPM	1.40	10.00	16.00	2.00	12.00	4.20	0.13
Ni	PPM			13.0				12.0
Pb	PPM	174000.0	620.0	12000.0	228000.0	2600.0	78000.0	134000.0
Pb (MS)	PPM							
Rb	PPM					150.0		
Rb (MS)	PPM	11.00		9.40	25.00		14.00	0.29
Sc	PPM	7.7	10.0	12.0	7.3	13.0	6.5	10.0
Sn	PPM	30.00	120.00	92.00	75.00	53.00	55.00	38.00
Sr	PPM			71.0				
Ta	PPM		0.47	1.10	0.24	0.50	0.30	
Th	PPM	1.50	9.50	14.00	2.50	11.00	3.70	0.11
Tl	PPM	4.50	3.50	0.42	7.90	7.20	3.70	3.00
U	PPM	1.50	4.00	4.60	1.70	3.70	1.80	0.35
V	PPM		52.0	64.0		67.0	22.0	
Y	PPM	7.0	20.0	33.0	8.0	31.0	14.0	
Yb	PPM	0.6	2.5	4.0	0.8	3.5	1.8	
Zn	PPM	254000.0	40000.0	68000.0	160000.0	8200.0	246000.0	194000.0
Zr	PPM		140.0	240.0		200.0		
Zr (MS)	PPM	15.00			48.00		90.00	1.40
Total		95.1	104.2	97.0	101.3	101.4	101.6	101.8
LOI	PPM	3.3	4.7	7.8	3.9	3.5	8.6	8.4

Table A4.3. -continued-

Sample	93-C161f	93-C169a-d	93-C154b	93-C154d	93-C155c	93-C156b	93-C156e
DDH	4483	1972	5063	5063	5063	5063	5063
Lithology	Unit	I Lam	I Lam	H "ore"	H "ore"	H "ore"	H "ore"
SiO ₂	%	2.87	12.30	2.55	14.60	5.36	5.30
TiO ₂	%	0.05	0.11	0.03	0.19	0.15	0.12
Al ₂ O ₃	%	1.66	2.80	1.02	5.17	3.79	2.87
Fe ₂ O ₃ (t)	%	63.70	23.20	15.60	22.20	15.50	19.70
Fe ₂ O ₃	%						49.40
FeO	%						
MnO	%	0.07	0.44	0.24	0.13	0.25	0.12
MgO	%	2.57	1.85	0.32	0.67	0.30	0.78
CaO	%	0.15	3.13	0.16	0.21	0.31	0.20
Na ₂ O	%	0.08	0.53	0.15	2.11	0.16	0.47
K ₂ O	%	0.14	0.29	0.16	0.31	1.08	0.48
P ₂ O ₅	%	0.02	0.05	0.04	0.05	0.16	0.03
H ₂ O (t)	%						
CO ₂ (t)	%						
CO ₂	%		2.5				
C	%						
S (t)	%	31.00	23.30	25.10	24.80	23.50	24.70
S (t) D-EX	PPM						36.90
Cl	PPM						
F	PPM	1331.0	154.0	157.0	210.0	242.0	286.0
Ag	PPM	88.00	15.00	340.00	130.00	260.00	280.00
Au (FADCP)	PPB	2	20	36	40	17	30
B (ICP)	PPM					27	
Ba	PPM	140.0	70.0	80.0	70.0	200.0	390.0
Be	PPM						100.0
Cd	PPM	200.00	870.00	1200.00	830.00	910.00	800.00
Co	PPM	36.0	17.0	8.0	9.0	6.0	12.0
Cr	PPM				17.0	13.0	11.0
Cs	PPM	0.45	1.00	0.05	0.27	0.50	0.34
Cu	PPM	350.0	96.0	170.0	240.0	380.0	230.0
Ga	PPM	3.90	4.20	1.90	5.50	6.60	4.10
Hf	PPM	0.37	0.50	0.12	0.98	0.65	0.54
Hg (Wet)	PPB	1280		8870	8520		8260
Hg (Wet)	PPM		106			21.7	
In	PPM	18.00	29.00	140.00	74.00	59.00	57.00
La	PPM				17.0		11.0
Mo	PPM	1.20	2.40	2.70	2.90	1.80	2.20
Nb	PPM						
Nb (MS)	PPM	0.89	1.90	0.35	1.90	2.20	1.40
Ni	PPM	22.0	27.0	11.0	12.0		
Pb	PPM	39000.0	127000.0	299000.0	129000.0	262000.0	280000.0
Pb (MS)	PPM						21000.0
Rb	PPM						
Rb (MS)	PPM	8.40	17.00	4.10	13.00	41.00	18.00
Sc	PPM	11.0	6.9	8.8	10.0	7.7	9.2
Sn	PPM	23.00	2.00	0.72	69.00	73.00	63.00
Sr	PPM		38.0				
Ta	PPM				0.29	0.23	0.23
Th	PPM	0.97	1.90	0.59	3.90	2.80	2.10
Tl	PPM	2.10	14.00	7.00	5.10	8.00	6.70
U	PPM	0.57	4.10	1.40	2.10	1.90	1.90
V	PPM				10.0	12.0	7.0
Y	PPM		7.0		8.0	5.0	7.0
Yb	PPM	0.8	0.7		0.9	0.5	0.8
Zn	PPM	64000.0	203000.0	240000.0	182000.0	239000.0	190000.0
Zr	PPM						
Zr (MS)	PPM	17.00	22.00	4.90	44.00	32.00	24.00
Total		112.8	103.7	99.5	101.7	100.9	102.0
LOI	PPM	12.5	6.4	1.9	12.2	2.5	4.3
							27.0

Table A43. -continued-

Sample	93-C037b		93-C044a	93-C047	93-C0724-e	93-C098	93-C104c-e	93-C110a-d
DDH	2442	2370	2370	3385	3952	3971	3976	
Lithology	Unit	Hu ore	Hu ore	Hu ore	Hu ore	Hu ore	Hu ore	Hu ore
SiO ₂	%	15.60	8.55		49.60	5.28	23.60	10.40
TiO ₂	%	0.11	0.08		1.08	0.05	0.17	0.09
Al ₂ O ₃	%	2.66	1.76		16.30	1.11	4.11	2.21
Fe ₂ O ₃ (t)	%	44.50	60.40	33.00	14.10	42.30	23.10	24.10
Fe ₂ O ₃	%							
FeO	%							
MnO	%	0.29	0.14	0.53	0.03	0.32	0.42	1.62
MgO	%	0.70	0.43		2.59	0.34	1.74	0.53
CaO	%	1.01	0.19	0.09	0.05	0.20	4.00	0.80
Na ₂ O	%	0.11	0.11	0.08	7.30	0.10	0.14	0.09
K ₂ O	%	0.70	0.51		0.32	0.32	1.07	0.41
P ₂ O ₅	%	0.02	0.01		0.03	0.01	0.07	0.05
H ₂ O (t)	%							
CO ₂ (t)	%				0.2	0.2		
CO ₂	%	0.4	0.3				2.3	0.8
C	%							
S (t)	%	26.20	30.50	31.60	4.51	29.30	20.70	25.40
S (t) D-EX	PPM							
Cl	PPM							
F	PPM	131.0	179.0		436.0	80.0	366.0	850.0
Ag	PPM	76.00	100.00	130.00	0.18	180.00	57.00	81.00
Au (FADCP)	PPB	7	28	238	70	80	49	21
B (ICP)	PPM	10	39	12	625	23	22	
Ba	PPM	270.0	510.0	90.0	70.0	110.0	260.0	7400.0
Be	PPM				1.0		0.5	
Cd	PPM	320.00	200.00	390.00		620.00	520.00	1400.00
Co	PPM	20.0	26.0	18.0	380.0	25.0	13.0	9.0
Cr	PPM	12.0	10.0		59.0	12.0	13.0	
Cs	PPM	0.76	0.89	0.15	0.48	0.59	0.99	2.90
Cu	PPM	290.0	710.0	460.0	18.0	440.0	160.0	110.0
Ga	PPM	3.90	2.70	2.00	18.00	2.00	6.40	4.40
Hf	PPM	1.20	0.84	0.03	15.00	0.69	2.10	1.10
Hg (Wet)	PPB		9880		8			
Hg (Wet)	PPM	14.6		54.6		26.3	19.7	64.2
In	PPM	1.60	4.30	0.12	0.07	1.90	2.90	6.20
La	PPM				20.0		21.0	
Mo	PPM	4.80	2.50	0.72	2.70	3.60	4.10	2.60
Nb	PPM							
Nb (MS)	PPM	2.60	1.80	0.09	32.00	1.20	4.10	2.10
Ni	PPM	30.0	19.0		23.0	26.0	11.0	
Pb	PPM	55000.0	35000.0	86000.0		86000.0	35000.0	64000.0
Pb (MS)	PPM				93.00			
Rb	PPM							
Rb (MS)	PPM	33.00	25.00	0.82	9.50	16.00	45.00	23.00
Sc	PPM	9.1	11.0	10.0	16.0	11.0	6.1	8.1
Sn	PPM	15.00	76.00	59.00	93.00	58.00	6.50	10.00
Sr	PPM				20.0			22.0
Ta	PPM	0.20			1.90		0.28	0.31
Th	PPM	2.30	1.70	0.05	19.00	1.10	3.80	1.40
Tl	PPM	3.40	2.20	2.30	0.14	3.50	3.00	4.00
U	PPM	1.00	0.73	0.05	9.70	1.30	1.80	1.30
V	PPM				65.0		8.0	
Y	PPM	9.0	5.0		48.0		13.0	8.0
Yb	PPM	1.1	0.9		6.2	0.6	1.5	0.7
Zn	PPM	124000.0	72000.0	204000.0	110.0	188000.0	186000.0	277000.0
Zr	PPM				520.0			
Zr (MS)	PPM	54.00	37.00	1.10		26.00	90.00	46.00
Total		110.3	113.9	94.4	96.4	107.1	103.7	101.6
LOI	PPM	8.5	10.4	11.3	6.9	9.3	7.0	9.5

Table A4.3. -continued-

Sample	93-C120e	93-C126e/g	93-C166b	93-C069	93-C074b	93-C079b	93-C109a
DDH	3994	1866	4483	3385	3385	4501	3976
Lithology	Unit	Hu ore	Hu ore	Hu ore	vein	vein	vein
SiO ₂	%	18.30	14.50	14.90	48.60	47.30	64.80
TiO ₂	%	0.16	0.12	0.36	0.26	0.61	0.72
Al ₂ O ₃	%	4.04	3.03	8.63	8.31	16.00	18.90
Fe ₂ O ₃ (t)	%	40.00	47.70	32.90	25.70	9.80	5.50
Fe ₂ O ₃	%						
FeO	%						
MnO	%	0.35	0.75	2.72	0.03	0.26	0.22
MgO	%	1.21	0.62	1.70	2.20	2.74	0.92
CaO	%	2.90	0.95	2.07	0.52	7.39	0.63
Na ₂ O	%	0.16	0.11	0.60	0.42	6.30	0.10
K ₂ O	%	1.04	0.75	1.26		0.58	5.88
P ₂ O ₅	%	0.03	0.04	0.01	0.04	0.10	0.08
H ₂ O (t)	%						
CO ₂ (t)	%						0.1
CO ₂	%	2.1	0.5	1.3		5.6	1.6
C	%		0.2				
S (t)	%	25.30	27.30	23.30	18.20	3.14	21.10
S (t) D-EX	PPM						1.84
Cl	PPM						196.0
F	PPM	674.0	208.0	905.0	558.0	483.0	1813.0
Ag	PPM	29.00	33.00	31.00	1.20	0.19	41.00
Au (FADCP)	PPB	49	23	10	20	3	5
B (ICP)	PPM	18	13	339	6800	632	75
Ba	PPM	270.0	590.0	520.0	60.0	140.0	50.0
Be	PPM	0.5		1.3	2.8	1.0	
Cd	PPM	310.00	330.00	340.00	3.20		240.00
Co	PPM	20.0	18.0	110.0	280.0	24.0	9.0
Cr	PPM	14.0	12.0	24.0	25.0	43.0	56.0
Cs	PPM	0.96	1.20	0.53	0.09	0.53	0.04
Cu	PPM	270.0	330.0	160.0	96.0	41.0	110.0
Ga	PPM	5.30	4.00	10.00	14.00	19.00	0.26
Hf	PPM	2.00	1.50	4.00	3.00	5.30	0.11
Hg (Wet)	PPB		16900	2030	21	29	1340
Hg (Wet)	PPM	16.5					108
In	PPM	1.80	2.10	2.50	0.46	0.12	19.00
La	PPM			16.0	140.0	42.0	41.0
Mo	PPM	4.00	2.90	2.40	2.30	1.70	0.51
Nb	PPM						2.10
Nb (MS)	PPM	3.80	3.00	7.70	4.70	14.00	0.11
Ni	PPM	27.0	18.0	53.0	28.0	79.0	11.0
Pb	PPM	19000.0	30000.0	35000.0	460.0		17000.0
Pb (MS)	PPM					96.00	1100.0
Rb	PPM						210.0
Rb (MS)	PPM	44.00	33.00	49.00	0.37	14.00	0.38
Sc	PPM	7.9	10.0	11.0	7.2	14.0	8.5
Sn	PPM	5.80	3.60	75.00	29.00	67.00	11.00
Sr	PPM				42.0	250.0	34.00
Ta	PPM	0.29	0.30	0.53	0.40	0.73	0.45
Th	PPM	3.50	2.70	7.10	4.90	13.00	0.14
Tl	PPM	2.70	2.80	2.00	0.15	0.19	0.96
U	PPM	2.10	1.50	7.80	1.20	2.80	0.05
V	PPM			28.0	23.0	68.0	
Y	PPM	12.0	7.0	30.0	38.0	46.0	20.0
Yb	PPM	1.4	1.1	5.9	2.8	4.3	3.1
Zn	PPM	120000.0	112000.0	121000.0	980.0	130.0	82000.0
Zr	PPM			130.0		180.0	200.0
Zr (MS)	PPM	81.00	63.00				4.80
total		109.7	110.9	105.7	105.2	100.1	104.8
LOI	PPM	9.4	10.5	12.7	11.5	7.1	11.0
							3.1

Table A4.3. -continued-

Sample		93-C149b	93-C089a	93-C090b-c	93-C112a	93-C167b	93-C170f
DDH		5232	3952	3952	3994	1972	1972
Lithology	Unit	vein	trmtc	brec	brec	brec	fault
SiO ₂	%	12.30	78.30	4.36	8.81	45.80	52.50
TiO ₂	%	0.43	0.37	0.10	0.08	0.40	0.17
Al ₂ O ₃	%	10.00	8.00	2.69	2.20	11.70	5.20
Fe ₂ O ₃ (t)	%	37.40	7.60	33.80	17.90	23.30	8.70
Fe ₂ O ₃	%						
FeO	%						
MnO	%	0.37	0.03	0.22	0.39	0.21	0.24
MgO	%	10.30	1.28	0.77	0.33	2.47	3.25
CaO	%	0.61	0.31	0.32	1.22	1.59	10.80
Na ₂ O	%	0.09	0.30	0.12	0.15	1.56	
K ₂ O	%		0.20	0.43	0.64	2.67	1.43
P ₂ O ₅	%	0.07	0.08	0.05	0.03	0.06	0.04
H ₂ O (t)	%						
CO ₂ (t)	%		0.2			0.2	
CO ₂	%	0.1		0.3	0.6		15.5
C	%						
S (t)	%	20.40	2.72	26.30	24.10	12.90	2.07
S (t) D-EX	PPM						
Cl	PPM		121.0				456.0
F	PPM	1189.0	412.0	306.0	316.0	726.0	442.0
Ag	PPM	8.10	13.00	200.00	330.00	1.10	0.69
Au (FADCP)	PPB	24		33	46	50	
B (ICP)	PPM		6280	168		83	55
Ba	PPM	80.0	50.0	130.0	130.0	370.0	160.0
Be	PPM		1.1			1.4	0.6
Cd	PPM	290.00	3.60	80.00	960.00	60.00	23.00
Co	PPM	13.0		46.0	8.0	9.0	9.0
Cr	PPM	23.0	30.0	14.0		32.0	15.0
Cs	PPM	0.18	0.15	0.38	0.91	7.80	4.60
Cu	PPM	330.0	53.0	710.0	360.0	79.0	38.0
Ga	PPM	14.00	10.00	4.50	3.40	16.00	7.10
Hf	PPM	4.50	4.10	0.57	0.37	3.50	1.80
Hg (Wet)	PPB	2960	25	651		16300	1090
Hg (Wet)	PPM				17.8		
In	PPM	32.00	0.72	16.00	320.00	2.90	0.57
La	PPM	79.0		15.0		30.0	
Mo	PPM	2.70	1.30	2.60	1.80	8.10	0.99
Nb	PPM						
Nb (MS)	PPM	9.80	8.00	0.47	1.70	7.50	4.30
Ni	PPM					18.0	
Pb	PPM	5600.0	3200.0	274000.0	193000.0	5500.0	280.0
Pb (MS)	PPM						
Rb	PPM						
Rb (MS)	PPM	0.73	7.30	16.00	30.00		74.00
Sc	PPM	8.2	4.0	9.4	8.0	9.0	4.2
Sn	PPM	5.80	280.00	277.00	190.00	20.00	3.90
Sr	PPM		30.0			55.0	130.0
Ta	PPM	0.58	0.31		0.34	0.42	0.35
Th	PPM	8.70	7.40	2.10	1.40	7.20	3.70
Tl	PPM	0.31	0.25	2.10	10.00	12.00	2.20
U	PPM	3.70	2.20	2.50	1.40	3.40	1.50
V	PPM	30.0	16.0	5.0		46.0	19.0
Y	PPM	33.0	54.0		5.0	16.0	17.0
Yb	PPM	3.4	3.7	0.7	0.5	2.0	1.8
Zn	PPM	96000.0	420.0	16000.0	254000.0	24000.0	6500.0
Zr	PPM	140.0	140.0			110.0	
Zr (MS)	PPM			21.00	14.00		72.00
Total		102.5	100.5	98.7	101.4	106.0	100.7
LOI	PPM	12.3	1.7	4.7	3.3	6.3	14.5

Appendix 5
Cominco data
for meta-sedimentary sequences
and sulphide zones

Table A5.1. Thicknesses of hanging wall meta-sedimentary sequences (data from Cominco mine records).

DD#	Latitude	Departure	Stratigraphic Sequence Thickness													
			I Sequence		II Sequence		hu Sequence		I-hu (inclusive)		Hu Sequence		U		Total Hanging Wall	
	(N)	(E)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
244	11414.00	4977.00	48.0	14.6					48.0	14.6	81.0	24.7			129.0	39.3
296	10017.00	4738.00	25.0	7.6	25.0	7.6	8.0	2.4	58.0	17.7	23.0	7.0			81.0	24.7
302	9396.50	4069.00	9.0	2.7	39.0	11.9			48.0	14.6	17.0	5.2			65.0	19.8
397	9419.00	3770.00	22.0	6.7	15.0	4.6			37.0	11.3	45.0	13.7			82.0	25.0
511	12651.42	3488.65	31.0	9.4	44.0	13.4			75.0	22.9	5.0	1.5			80.0	24.4
722	10589.26	5131.73	34.0	10.4	0.0	0.0			34.0	10.4					34.0	10.4
761	9811.64	4427.29	33.0	10.1	8.0	2.4			41.0	12.5					41.0	12.5
804	11200.20	5053.94	21.0	6.4	12.5	3.8	5.0	1.5	38.5	11.7	48.5	14.8			87.0	26.5
863	9422.09	4463.55	21.0	6.4	21.0	6.4			42.0	12.8					42.0	12.8
945	9577.95	4880.56	30.0	9.1	66.0	20.1	10.0	3.0	106.0	32.3	74.5	22.7	X		180.5	55.0
1105	10209.07	4480.29	54.5	16.6	0.0	0.0			54.5	16.6	92.0	28.0	X		146.5	44.7
1113	9210.45	4464.74	42.5	13.0	34.0	10.4			76.5	23.3					76.5	23.3
1141	9997.39	4486.04	30.0	9.1	14.0	4.3	3.0	0.9	47.0	14.3	1.0	0.3			48.0	14.6
1515	10001.35	4491.13	18.0	5.5	25.0	7.6	5.0	1.5	48.0	14.6	8.0	2.4			56.0	17.1
1584	9998.20	4736.26			15.0	4.6			15.0	4.6	65.0	19.8			80.0	24.4
1787	11589.67	4944.73	9.0	2.7	59.0	18.0			68.0	20.7	35.0	10.7			103.0	31.4
1817	11390.26	4979.79	16.0	4.9	5.5	1.7			21.5	6.6	87.0	26.5	X		108.5	33.1
1827	10214.20	5223.28	14.0	4.3	77.0	23.5			91.0	27.7	41.0	12.5	X		132.0	40.2
1866	11404.72	5075.36	17.0	5.2	13.0	4.0	7.8	2.4	37.8	11.5	32.2	9.8	X		70.0	21.3
1972	9100.00	4766.32	35.0	10.7					35.0	10.7					35.0	10.7
2163	9595.61	4537.21	28.0	8.5	29.0	8.8	6.0	1.8	63.0	19.2	4.5	1.4			67.5	20.6
2192	12493.85	3925.36	27.0	8.2	35.0	10.7			62.0	18.9	6.0	1.8			68.0	20.7
2203	9609.44	4424.74	25.0	7.6	57.5	17.5			82.5	25.1	40.0	12.2			122.5	37.3
2283	11223.93	4262.54	18.0	5.5	24.0	7.3			42.0	12.8	67.0	20.4			109.0	33.2
2285	11196.68	4259.02									77.0	23.5			77.0	23.5
2289	12402.22	3819.59	32.0	9.8	27.5	8.4			59.5	18.1	68.5	20.9	X		128.0	39.0
2370	10400.40	4984.07	8.0	2.4	7.5	2.3	4.5	1.4	20.0	6.1	65.0	19.8			85.0	25.9
2442	11004.62	4982.43	30.0	9.1	6.0	1.8			36.0	11.0	123.0	37.5	X		159.0	48.5
2490	11549.22	4903.65	53.0	16.2					53.0	16.2	17.0	5.2	X		70.0	21.3
2531	10611.41	5005.79	17.0	5.2	13.0	4.0			30.0	9.1	67.5	20.6			97.5	29.7
2585	13009.00	3736.00	25.0	7.6	26.0	7.9			51.0	15.5	8.0	2.4			59.0	18.0
2725	12825.31	3877.59	21.0	6.4	28.5	8.7			49.5	15.1	1.0	0.3			50.5	15.4
2872	11597.50	5075.12	21.0	6.4	18.0	5.5			39.0	11.9	102.0	31.1	X		141.0	43.0
3202	11817.89	4936.20	29.0	8.8	40.0	12.2			69.0	21.0	67.5	20.6	X		136.5	41.6

Table A5.1. -continued-

DDII	Latitude	Departure	Stratigraphic Sequence Thickness													
			I Sequence		H Sequence		hu Sequence		I-hu (inclusive)		Hu Sequence		U		Total Hanging Wall	
	(N)	(E)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
3215	11786 03	4967 93			37.5	11.4	37.5	11.4	65.5	20.0	103.0	31.4				
3231	10232 68	5294 62	38.0	11.6	20.0	6.1	58.0	17.7	79.0	24.1	X	41.8				
3377	10372 24	4499 22	51.5	15.7	0.0	0.0	51.5	15.7	57.0	17.4		108.5				
3383	10410 36	4500 11	37.0	11.3	24.0	7.3	61.0	18.6	5.0	1.5		66.0				
3384	12221 61	4140 13			72.5	22.1	72.5	22.1				72.5				
3385	12254 98	3973 08	13.5	4.1	16.0	4.9	29.5	9.0	46.0	14.1	X	75.5				
3393	10596 61	4503 67							80.0	24.4		80.0				
3634	12580 48	3450 09	19.0	5.8	29.0	8.8	48.0	14.6	86.0	26.2		134.0				
3690	12582 10	3452 06	35.5	10.8	46.5	14.2	82.0	25.0	10.5	3.2		92.5				
3803	11868 52	4924 83	31.5	9.6			31.5	9.6	96.0	29.3	X	127.5				
3918	9964 58	5264 91	25.0	7.6	26.0	7.9	51.0	15.5	66.5	20.3		117.5				
3950	10390 17	4903 65	8.0	2.4	0.0	0.0	13.0	4.0	51.0	15.5	X	64.0				
3952	10578 13	4892 16	27.0	8.2	16.0	4.9	49.0	14.9	23.0	7.0	X	72.0				
3954	10577 67	4892 76	25.0	7.6	17.0	5.2	42.0	12.8	65.0	19.8		107.0				
3971	10949 95	5117 43	19.5	5.9	6.0	1.8	29.0	8.8	79.5	24.2		108.5				
3976	11434 73	5073 96			9.0	2.7	18.5	5.6	72.0	21.9		90.5				
3994	11081 49	5133 50	7.0	2.1	13.5	4.1	37.5	11.4	54.0	16.5		91.5				
4360	10199 58	4563 80			15.5	4.7	19.5	5.9	64.5	19.7		84.0				
4483	11647 65	3708 57	30.0	9.1	46.0	14.0	76.0	23.2	12.5	3.8		88.5				
4495	11012 61	4032 58	22.0	6.7	23.5	7.2	59.0	18.0	25.0	7.6		84.0				
4561	12185 19	3437 78	18.5	5.6	9.5	2.9	28.0	8.5	67.0	20.4		95.0				
4537	12284 47	3401 14	16.0	4.9	13.0	4.0	29.0	8.8	18.0	5.5		47.0				
5001	10762 02	4548 04	24.5	7.5	29.0	8.8	53.5	16.3				53.5				
5023	9796 49	4220 37							76.5	23.3		76.5				
5063	10002 93	4240 18	13.5	4.1	7.0	2.1	20.5	6.2	45.5	13.9		66.0				
5091	9377 75	4275 13	25.0	7.6	28.5	8.7	53.5	16.3	5.0	1.5		58.5				
5232	11020 74	4696 74	20.5	6.2	2.0	0.6	22.5	6.9	59.0	18.0		81.5				
5237	1105 77	4765 14	17.5	5.3	0.0	0.0	17.5	5.3	120.5	36.7		138.0				
5247	10790 44	4742 49	47.0	14.3	0.0	0.0	47.0	14.3	30.0	9.1		77.0				
5260	11206 49	4875 25	22.5	6.9	7.5	2.3	30.0	9.1	45.5	13.9		75.5				
5261	11206 77	4878 46							62.0	18.9		62.0				
5269	10817 27	4791 73							60.0	18.3		60.0				
5271	10804 70	4679 91	18.0	5.5	10.0	3.0	28.0	8.5	48.5	14.8		76.5				
5282	12005 90	4655 42	26.0	7.9	8.0	2.4	46.0	14.0	71.0	21.6		117.0				
5359	10977 56	4347 10	9.0	2.7			9.0	2.7				9.0				

Table A5.1 -continued-

DDH	Latitude	Departure	Stratigraphic Sequence Thickness											
			I Sequence		H Sequence		hu Sequence		I-hu (inclusive)		Hu Sequence		U Total Hanging Wall	
	(N)	(E)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
5733	11996.08	3550.58	16.5	5.0	10.0	3.0			26.5	8.1			26.5	8.1
5788	12552.02	3430.35	44.1	13.4	22.0	6.7			66.1	20.1			66.1	20.1
6824	10348.22	4988.18	24.0	7.3	60.0	18.3			84.0	25.6			84.0	25.6
6836	10806.08	4983.44	26.0	7.9	57.0	17.4			83.0	25.3			83.0	25.3
6839	10999.33	4913.96	28.5	8.7					28.5	8.7			28.5	8.7
6840	10194.42	4930.03	16.0	4.9	12.0	3.7			28.0	8.5	16.0	4.9	44.0	13.4
7027	11899.76	4799.37	36.5	11.1	47.5	14.5			84.0	25.6	15.5	4.7	99.5	30.3
Statistical Summary														
			n		66		71		71		15		15	
			ave		25.7		7.8		21.5		6.6		2.4	
			max		54.5		16.6		77.0		23.5		52.5	
			min		7.0		2.1		0.0		0.0		0.0	
			stdev		11.1		3.4		19.3		5.9		7.0	

4

PM-1 3 1/2" x 4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

A

DDH 2370

DDH 1866

DDH 397

DDH 1866

DDH 3976

**Vertical Scale
(feet)**

D

A'

DDH 3385

**Vertical Scale
(feet)**

140

130

120

110

100

90

80

70

60

50

Depth from surface (in feet)

3000

4000

5000

6000

7000

8000

9000

Middle Aldridge Formation

Moyie sill

Moyie sill

Moyie sill

DDH 1972

Hu

DDH 5063

H "ore"

DDH 2370

DDH

3952

Fault ?

U

DDH 3971

DDH 804

DDH 1866

DDH 7027

Extent of Massive Albite Alteration

U

hu

Hu

H"

10

5

0

U

Extent of Massive Albite Alteration

Hu ore

hu

Hu

Hu ore

Explanation for core sections

Alteration/metamorphism:

	Biotite
	Biotite + chlorite +/- garnet
	Chlorite +/- pyrite
	Albite +/- pyrite
	Albite + chlorite +/- pyrite
	Muscovite +/- sulphide
	Tourmaline
	Carbonate

Lithology:

	Quartzite/quartzitic psammite
	Semi-pelite
	Pelite
	Semi-pelite to pelite
	Graded/interbedded meta-sedimentary rock
	Meta-conglomerate
	Veins/veinlets
	Laminated/banded sulphide
	Interlaminated meta-sedimentary rock and sulphide
	Massive sulphide

Hanging Wall
Footwall

70
60
50
40
30
20
10
0
-10

Datum

9000

DDH 1972

Hu

DDH 6063

H "ore"

H

laminations

Extent of Fo

Alteration/metamorphism:

Biotite

Biotite + chlorite +/- garnet

Chlorite +/- pyrite

Albite +/- pyrite

Albite + chlorite +/- pyrite

Muscovite +/- sulphide

Tourmaline

Carbonate

Lithology:

Quartzite/quartzitic psammite

Semi-pelite

Pelite

Semi-pelite to pelite

**Graded/interbedded
meta-sedimentary rock**

Meta-conglomerate

Veins/veinlets

Laminated/banded sulphide

**Interlaminated meta-sedimentary
rock and sulphide**

Massive sulphide

**Deformed sulphide
(i.e. convolute folding)**

Breccia

Missing/broken core

Symbols:

- Fault zone

• - Sample

I, H, etc. - Stratigraphic Sequences

**- Sequence Contact
(known/approximated)**

**- Sequence Contact
(assumed)**

Chlorite content:

>20 vol%

10-20 vol%

1-10 vol%

<1 vol%

Hanging Wall

Footwall

Datum

20

10

0

-10

-20

-30

-40

-50

-60

9000 N

9200 N

9400 N

9600 N

I la

aminations

Extent of Foot

Burchett Fault

Burchett Fault

9800 N

10000 N

10200 N

I laminations

Main ore zones

Alpha Fault

10800 N

11000 N

11200 N

11400 N

Datum

12400 N

Main Water Course

No. 2 Fault

000 N

12200 N

- Sequence Contact
(known/approximated)

- Sequence Contact
(assumed)

>20 vol%

10-20 vol%

1-10 vol%

<1 vol%

Ottawa-Careton Geoscience Centre
and
Department of Earth Sciences, Carleton University

Figure 4.3. South to northwest (A-A') geological cross section through the hanging wall of the Sullivan Zn-Pb-Ag deposit, showing the stratigraphic relationship between the altered and unaltered meta-sedimentary and sulphide "ore" facies. Mine grid and core measurements are in feet. Datum = base of I quartzite marker unit.

by
Andrew G. Conly *B.Sc. (Hon.)*

This figure is part of the following M.Sc. Thesis:

Geological setting and genesis of the hanging wall sulphide zones, Sullivan Zn-Pb deposit, southeastern British Columbia. M.Sc. Thesis, Carleton University, Ottawa, ON, 254 p.

5

OF/DE

5

PM-1 3 1/2" x 4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

U

DDH 5232

Hu ore

H 5232

B'

Reference Drill Hole
(=least altered)
(courtesy of W.D. Goodfellow)

DDH 4501

Reference Drill Hole
(=least altered)
(courtesy of W.D. Goodfellow)

Hu

H

8839

laminations

[illegible]

495

Hu ore

Hu

hu

Extent of Massive Albitite

H

I laminations

I

DDH 4483

Albitite

**Vertical Scale
(feet)**

Dep

6000

7000

8000

9000

Moyie sill

Alteration/met

Biot

Biot

Chl

Alb

Alb

Mu

Tou

Ca

Vertical Scale
(feet)

35

25

Symbols:

• - Sample

I, H, etc. -

Explanation for core sections

Amorphism:

te
te + chlorite +/- garnet
orite +/- pyrite
te +/- pyrite
te + chlorite +/- pyrite
scovite +/- sulphide

maline

bonate

Fault zone

Lithology:

	Quartzite/quatztic psammite
	Semi-pelite
	Pelite
	Semi-pelite to pelite
	Graded/interbedded meta-sedimentary rock
	Meta-conglomerate
	Veins/veinlets
	Laminated/banded sulphide
	Interlaminated meta-sedimentary rock and sulphide
	Massive sulphide
	Deformed sulphide (i.e. convolute folding)
	Breccia
	Missing/broken core

Stratigraphic Sequences

Chlorite content:

>20 vol%

Hanging Wall

Footwall

40

30

20

10

Datum

0

-10

-20

-30

-40

-50

hu

Extent of
Footwall
Breccia

Alpha F2

I laminations

Main ore zone

Main Water Cou

Main ore zones

Extent of Massive Albitite

H

I laminations

I

**Vertical Scale
(feet)**

Datum

Albit

Albit

Musc

Tour

Carb

Symbols:

- F

• - Sample

I, H, etc. - S

- S

- S

(

**Vertical Scale
(feet)**

ite +/- pyrite

Semi-pelite to pelite

ite + chlorite +/- pyrite

Graded/interbedded
meta-sedimentary rock

covite +/- sulphide

Meta-conglomerate

maline

Veins/veinlets

bonate

Laminated/banded sulphide

Interlaminated meta-sedimentary
rock and sulphide

Massive sulphide

Deformed sulphide
(i.e. convolute folding)

fault zone

Breccia

Missing/broken core

Stratigraphic Sequences

Chlorite content:

- >20 vol%
- ◐ 10-20 vol%
- ◑ 1-10 vol%
- <1 vol%

Sequence Contact
(known/approximated)

Sequence Contact
(assumed)

Footwall

-10
-20
-30
-40
-50
-60
-70
-80

**Extent of
Footwall
Breccia**

Alpha Fault

5100 E

5000 E

Main ore zones

Main Water Course

Scale Variation →

4800 E

4700 E

4600 E

4500 E

4400 E

4300 E

Main ore zones

Burchett Fault

Scale Variation →

Scale Variation →

4600 E 4500 E 4400 E 4300 E 4200 E 4100 E 4000 E 3900 E

|
3800 E

|
3700 E

|
3600 E

|
3500 E

|
3600 E

|
3500 E

|
3400 E

|
3300 E

5
0

De

**Figure 4.4. East
hanging wall of t
relationship betwe
"ore" facies. Mine
quartzite marker u**

This figure is part of
Conly, A.G., 199
zones Sullivan Zn-
Carleton University

10
5
0

De

**Figure 4.4. East
hanging wall of t
relationship betwe
"ore" facies. Mine
quartzite marker u**

This figure is part of
Conly, A.G., 199
zones Sullivan Zn-
Carleton University

Ottawa-Carleton Geoscience Centre
and
Department of Earth Sciences, Carleton University

to northwest (B-B') geological cross section through the
Sullivan Zn-Pb-Ag deposit, showing the stratigraphic
altered and unaltered meta-sedimentary and sulphide
grid and core measurements are in feet. Datum = base of I
t.

by
Andrew G. Conly *B.Sc. (Hon.)*

the following M.Sc. Thesis:

*Geological setting and genesis of the hanging wall sulphide
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END

1 1-0 6-9/6

FIN