DAY 4: BUTTLE LAKE VMS CAMP

STOP 4-1: UNDERGROUND TOUR OF H-W AND/OR BATTLE ZONE (FIGURE 17)

In the very early morning we drive from Campbell River to the south end of Buttle Lake in Strathcona Provincial Park. The tour starts at the Myra Falls operation site, approximately 80 km from Campbell River (Figure 1). Basic underground gear will be provided (hard hats, belts and steel-toed boots with a limited size range, *etc.*).

We will view ore-hosting lithologies of the Myra formation and examples of the main ore types. See the following papers in this field guide: (i) Pearson, (ii) Barrett *et al.*, and (iii) Robinson *et al.*

STOP 4-2: ROAD LOG (FIGURE 17)

In the afternoon we retun to Campbell River and make four stops to view examples of the stratigraphic sequence overlying the Myra formation in the Sicker Group. The following notes refer to Figure17 (refer also to the stratigraphic columns in Figure 3 [inside back cover] and Table 2):

1. 0.0 km. H-W headframe.

2. 2.5 km (southwest end of Buttle Lake). Thelwood formation (sharp banded tuff). Turbiditic, thin to medium bedded tuffaceous mudstone to sandstone with chert interbeds. Intercalated with synsedimentary mafic sills. This unit probably unconformably overlies the Myra formation that hosts the ore zones.

3. 4.0 km (southeast end of Buttle Lake). Flower Ridge formation (scoria clast unit). Bedded mafic tuffs, lapilli tuffs and pyroclastic breccias with prevalent and distinctive scoriaceous (amygdular) clasts. This unit has a lower contact that is gradational with the Thelwood formation. Its upper contact is abrupt against Buttle Lake Limestone. From this stop point a clear view of Price hillside is available; its geology is detailed in Juras (1987, unpublished PhD thesis, The University of Brisish Columbia). The original VMS discovery in the Buttle Lake camp was in the creek immediately to the left of the Price adit near the middle of the hillside.

4. 16.1 km (Karst Creek day area and boat ramp, east side of Buttle Lake). Buttle Lake Formation is characterized by crinoidal limestone with abundant chert nodules and beds.

5. 31.4 km (central-eastern side of Buttle Lake). Karmutsen Formation in this area is characterized by pillowed and hyaloclastite basalt. Exposures near Campbell Lakes (Figure 17) are columnarly jointed, indicating subaerial deposition. Native copper is common in the Karmutsen basalt. For example there are native copper showings on Quadra Island, immediately east of Campbell River.

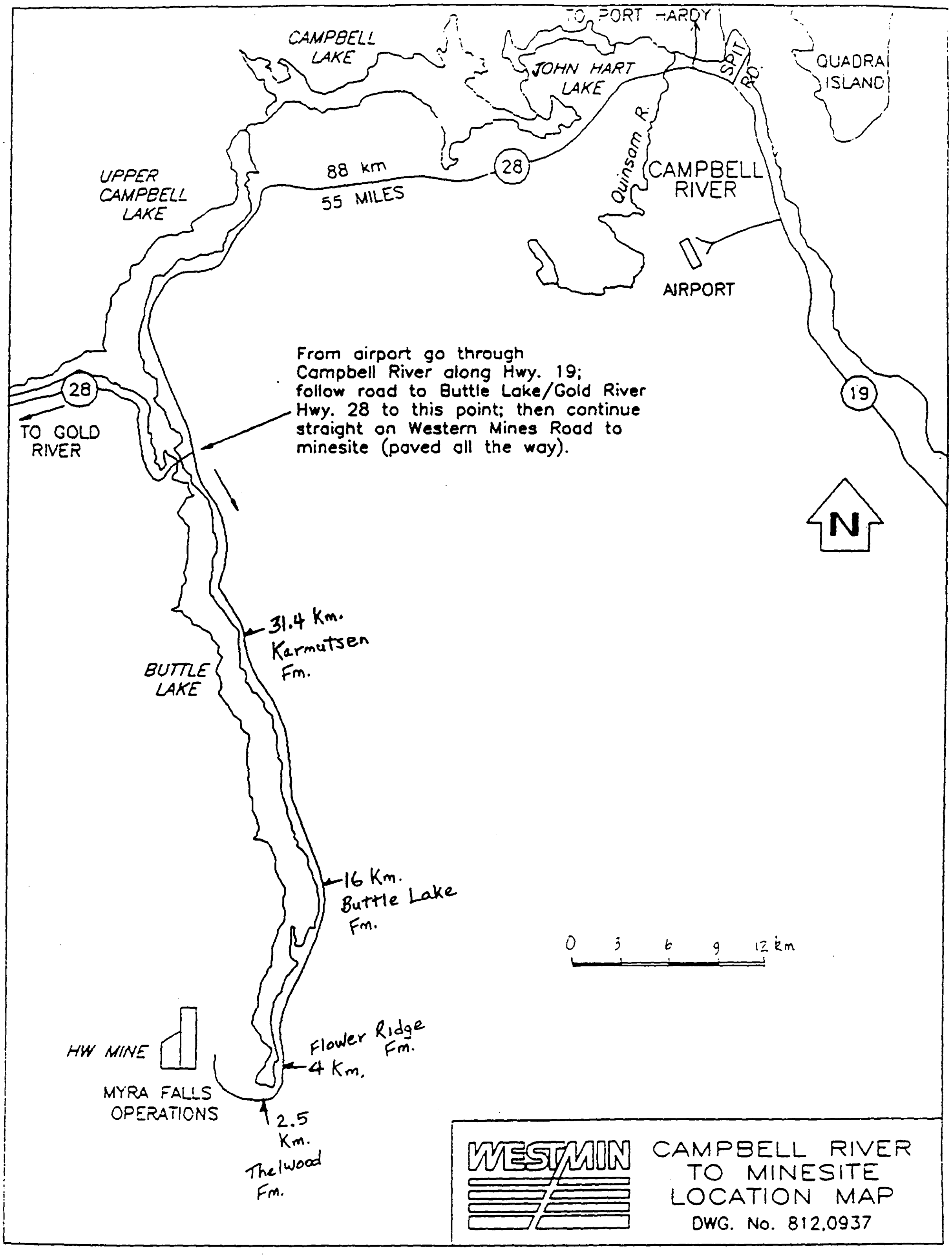

Figure 17. Fourth day travel route Campbell River to Myra Falls. Locations of field stops are shown.

MINING ZINC-RICH MASSIVE SULPHIDE DEPOSITS ON VANCOUVER ISLAND, BRITISH COLUMBIA

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Abstract

The Myra Falls Minesite, of Westmin Resources Limited, is located at the geographic center of Vancouver Island, within the confines of Strathcona Provincial Park (Figures 1 and 17). The Operation includes two active underground mines, H-W and Lynx, together with a modern 3,650 tpd milling facility. Recent exploration successes will lead to the commissioning of a third mining area in late 1993 - The Battle/Gap Mine.

These ore deposits are complexly metal-zoned volcanogenic massive sulphides of Devonian Age, hosted in the Myra Formation of the Sicker Group volcanic assemblage. Three distinct felsic volcanic units are defined within the 450 metre thick Myra Formation. They are, from oldest to youngest, the H-W Horizon, the LMP Horizon and the Upper Rhyolite Unit. Massive sulphide mineralization occurs throughout the property in the H-W and LMP Horizons. There are a number of orebody types, including polymetallic massive sulphides, polymetallic disseminated sulphides, zoned pyritic massive sulphides, clastic sulphide zones and stringer sulphide zones. Individual orebodies range in size from 10,000 tonne zinc-rich polymetallic lenses to the 10 million tonne, zoned massive sulphide H-W main lens.

The property has been in continuous operation for 26 years, producing over 13 million tonnes of ore averaging 2.2 g/t Au, 64.0 g/t Ag, 1.9% Cu, 0.6% Pb, and 5.6% Zn. Current Geological reserves stand at 12.5 million tonnes at a comparable grade, including 4 million tonnes of recently discovered high grade ore in the Battle and Gap Zones.

Mining and milling methods have evolved over time to enable successful extraction and milling of these complex ores. Change is ongoing with the recent conversion of the H-W Mine to large-scale bulk mining methods, and the development of effective computerized ore reserve calculation and mine planning tools. These changes, in concert with successful exploration techniques that led to recent high grade ore discoveries, have breathed new life into the Operation and should assure its' present and future viability.

Several other noteworthy aspects of the operation will be briefly addressed, including the challenges inherent in operating a mine within a Provincial Park setting.

Introduction

The Myra Falls Operations of Westmin Resources Limited are located in steep, mountainous terrain near the south end of Buttle Lake on Vancouver Island (Figures 1 and 17). Westmin's claim block, seven km long by two to three km wide, is situated in Strathcona Provincial Park, one of British Columbia's oldest and largest parks. The first claims in the area were staked in 1917, when Strathcona Park was opened for prospecting. Three massive sulphide showings were located then; two in Myra Creek Valley and the third in adjacent Thelwood Creek Valley. These showings became, in time, the Lynx, Myra and Price Mines (Figure 18).

Sporadic exploration work continued through to 1961, when Western Mines Limited (the precursor to Westmin Resources Limited) acquired the claims and concentrated its efforts on the Lynx claim group. Ore definition drilling quickly indicated a mining reserve of 1.9 million tonnes, part of which could be mined by open pit. Mining started in the pit in 1966, proceeded rapidly underground and has continued to the present day.

The open pit phase was completed in 1975 with 1.6 million tonnes mined. The Lynx Mine operated at production rates of 600 to 900 tonnes per day until 1985, at which time

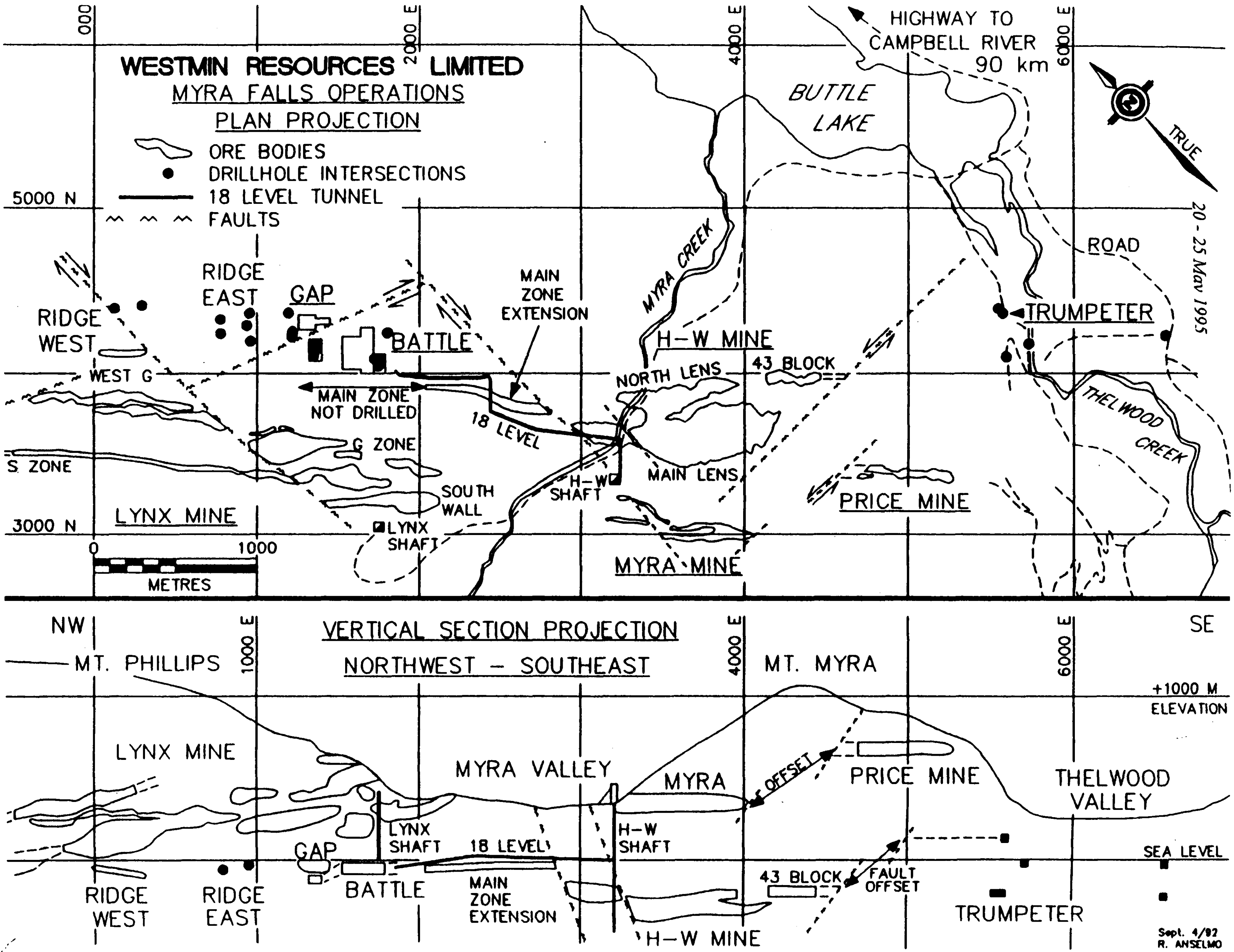

Figure 18. Plan and vertical projections of ore bodies, Buttle Lake camp, central Vancouver Island.

production gradually decreased to the current 300 tonnes per day. Production to date at Lynx has been 5.3 million tonnes grading 2.5 g/t Au, 90 g/t Ag, 1.6% Cu, 1.0% Pb, and 7.5% Zn. There is excellent potential for additional reserves and mine exploration continues unabated.

In 1969, with production and reserves comfortably established at the Lynx Mine, exploratory drilling turned to the Myra claims directly across Myra valley. A series of high grade, precious-metal-rich ore intersections led quickly to a production decision and the Myra Mine came on-stream in 1972. This mine operated for 13 years, at production rates ranging from 200 to 400 tonnes per day, until reserve depletion in 1985. Total production was 1.0 million tonnes grading 3.0 g/t Au, 160 g/t Ag, 1.0% Cu, 1.5% Pb, and 9.5% Zn.

The Price claims, in Thelwood valley, received serious attention in 1979, resulting in the discovery of the Upper Price Zone. Underground development and drilling subsequently has defined a geological reserve of 185,000 tonnes grading 1.5 g/t Au, 66 g/t Ag, 1.4% Cu, 1.3 % Pb, and 10.4% Zn. The location of this zone in Thelwood valley, as well as its distance from existing workings, has precluded any early development but its day will come.

Concurrent surface drilling in 1979 resulted in the discovery of the H-W orebodies, at a depth of 400 m below the floor of Myra valley (see Fig. 18). Accelerated exploration drilling on this zone in 1980 indicated the potential for a major massive sulphide deposit, of unprecedented size for the camp, and a favourable production decision was soon forthcoming. The H-W Mine was commissioned in 1985 and has operated since then at production rates of 2,700 to 4,000 tonnes per day. Total production to January 1st, 1993 was 7.5 million tonnes grading 1.9 g/t Au, 30 g/t Ag, 2.1% Cu, 0.3% Pb and 4.2 % Zn. Remaining mining reserves at that date were calculated at 6.2 million tonnes grading 1.9 g/t Au, 32 g/t Ag, 1.6% Cu, 0.4% Pb, and 3.8% Zn.

Mine exploration is ongoing, with expenditures of (Cdn) $3 to $4 million per annum. This commitment has resulted in several recent high-grade ore discoveries, revitalizing the operations. These new zones now total 3.6 million tonnes proven and probable geological reserves, grading 1.8 g/t Au, 55 g/t Ag, 2.2% Cu, 0.6% Pb, and 11.2% Zn. In addition, there are 2.7 million tonnes of possible reserves at a similar grade. The first of the new ore zones to reach production will be the Battle Zone, in July 1993 - opening a new chapter in the history of the Myra Falls mining operations.

Property-wide production to January 1st, 1993, has been 13.8 million tonnes grading 2.2 g/t Au, 64 g/t Ag, 1.9% Cu, 0.6% Pb, and 5.6% Zn, mined over 26 years of continuous production. Current geological reserves in all categories are 15.2 million tonnes, at 2.0 g/t Au, 48 g/t Ag, 2.0% Cu, 0.5% Pb, and 7.1% Zn. These figures certainly reflect a major zinc resource.

During its life to date Myra Falls Operations has continually evolved by embracing new mining and milling methods. Hence, successful application of innovative geological thinking to the search for new orebodies has resulted in discovery of ore to be extracted and processed by methods that are continuously under review and improvement.

Minesite facilities now comprise: two operating underground mines, the Lynx and H-W; a modern 3,650 tpd concentrator, assay lab, mine offices and shops, surface tailings disposal system, and two hydroelectric power plants totalling 11 mW. A 180 person camp is in operation, but the majority of the 450 employees commute daily 90 km from Campbell River via bus transportation provided by Westmin.

Geological setting

Regional geology

The Insular belt of the Canadian Cordillera underlies most of Vancouver Island. The lower members of this belt, including the Palaeozoic Sicker and Buttle Lake Groups, the Triassic Vancouver Group, and the Jurassic Bonanza Group (Figure 2, inside front cover) are postulated to be part of an allocthonous terrane. This terrane has been named Wrangellia by Jones, Silberling, and Hillhouse (1977), and is thought to have been accreted onto North America some 150 million years ago.

Volcanic hosted massive sulphide (VHMS) mineralization is present in the oldest member, the Palaeozoic Sicker Group. Sicker Group rocks are exposed on Vancouver Island in fault-bounded structural uplifts and the Buttle Lake uplift hosts the Myra Falls massive sulphide orebodies. Massive sulphide ore was also mined intermittently by others in a smaller uplift area, near Duncan, British Columbia, 160 km to the south. Four formations are identified (Juras, 1987) in the Sicker Group at Myra Falls: the late Devonian Price and Myra Formations, the early Mississippian Thelwood Formation and the Mississippian Flower Ridge Formation.

The Price Formation (Footwall H-W Andesite in Mine terminology) is greater than 400 m thick (base unexposed) and consists of a sequence of massive basaltic andesite flows and volcaniclastics. These rocks are poorly exposed on the mine property and are recognized mainly in drillcore.

The Myra Formation (Mine Sequence), which hosts all known ore occurrences at Myra Falls, conformably overlies the Price Formation. This Formation is up to 450 m thick and is subdivided into ten stratigraphic units that are described later under Mine Geology. These units show remarkable continuity along their NW-SE trend but exhibit abrupt facies changes, across strike in a NE-SW direction, reflecting their depositional environment. The environment of deposition is interpreted to be related to rifting within an oceanic island arc system.

Conformably overlying the Myra Formation is the Thelwood Formation, a 270 to 500 m thick thin-to-medium-bedded sequence of siliceous volcaniclastic rocks and subaqueous pyroclastic flows intruded by mafic sills.

The uppermost formation in the Sicker Group is the Flower Ridge Formation. It is also the youngest Palaeozoic stratigraphy exposed in the mine area. This Formation is up to 1,000 m thick, is basaltic in composition and consists mainly of fine to coarse submarine volcaniclastic deposits.

The Sicker Group, within the Buttle Lake uplift, has undergone regional greenschist facies metamorphism. This resultant metamorphic veil appears to have overprinted most evidence of submarine hydrothermal alteration.

Mine geology

Stratigraphy within the Mine Sequence has been used as perhaps the most critical exploration tool, and will therefore be discussed in considerable detail. Other areas of Mine Geology described include the sulphide deposits, alteration and structural geology.

THE MINE SEQUENCE (MYRA FORMATION)

The Mine Sequence (Myra Formation) is subdivided into ten informal litho-stratigraphic units (Juras and Pearson, 1990; Figures 19 and 20). These units are described below in order of decreasing relative age:

1. The H-W Horizon is the lowermost unit (up to 200 m thick), and consists mainly of felsic tuffs and flows, with subordinate argillites, mafic flows, volcaniclastics and massive sulphides. These rocks are widespread throughout the mine area and represent the thickest and most extensive rhyolite sequence seen. In general, argillites and felsic tuffs predominate in the SW part of the property; above the H-W Main Lens for example, whereas felsic flows are more common in the NE, above the H-W North Lens position. The mafic flow component typically is present in the central region, associated with argillite. These mafic flows consist of aphyric to pyroxene-phyric komatiitic basalt and hyaloclastite (Juras 1987). Massive sulphides are present as clasts, stringers, laminae and lenses (see Figures 19 and 20).

   The bulk of the massive sulphide mineralization was deposited at the base of the H-W Horizon. This position is represented by the H-W Main Lens, H-W North Lenses, and the Battle Zone, which together total some 25 to 30 million tonnes of pyritic massive sulphides. Stratigraphically higher in the H-W Horizon are the Upper Zone massive sulphides, consisting of small baritic, precious-metal-rich polymetallic ore zones represented by the H-W Mine Upper Lenses and the Gap Zone. Higher again, Hanging Wall Zone sulphide deposits occur at the top of the H-W Horizon; in the Ridge Zone

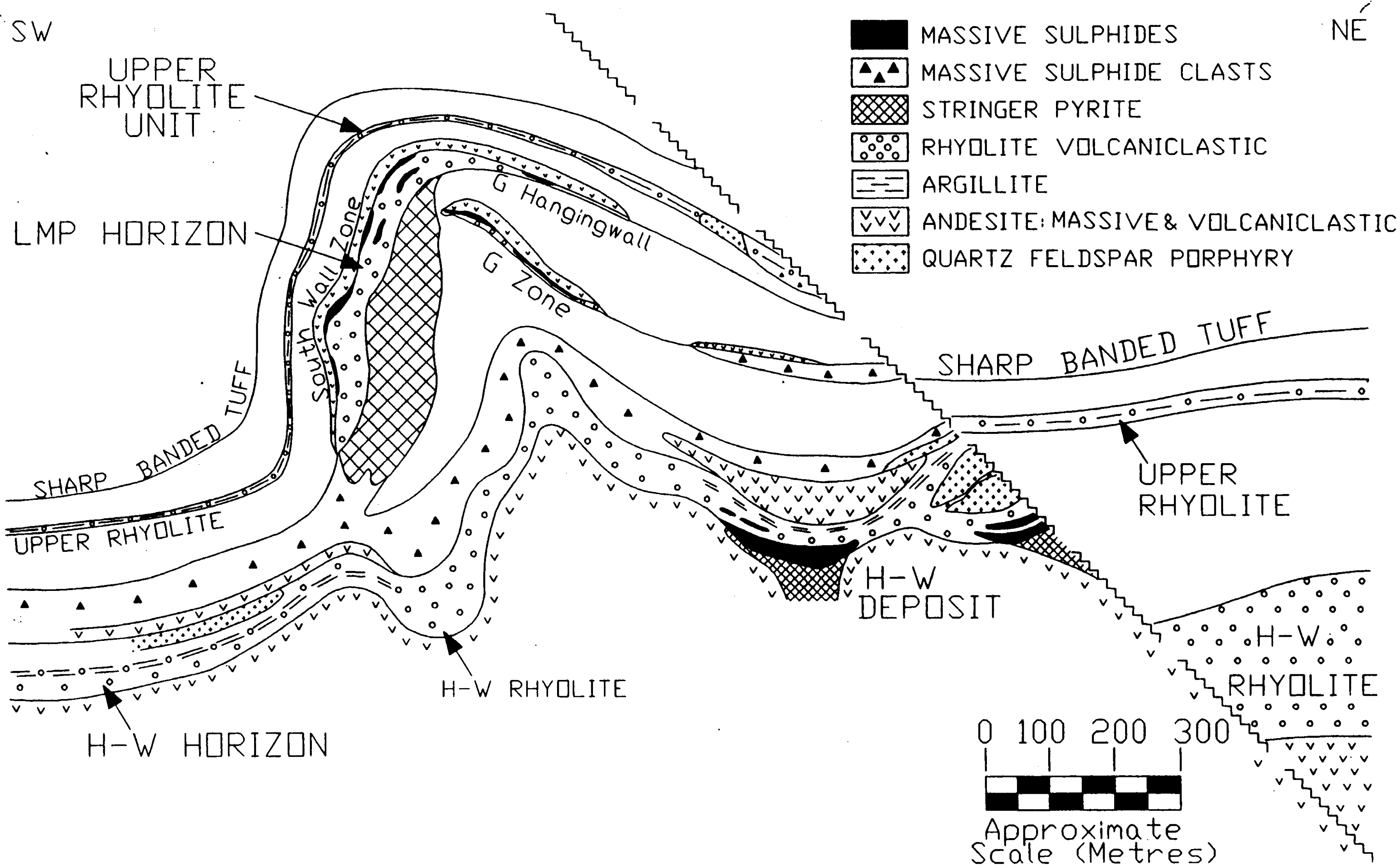

Figure 19. Composite cross-section of the mine sequence, Myra formation, Buttle Lake camp.

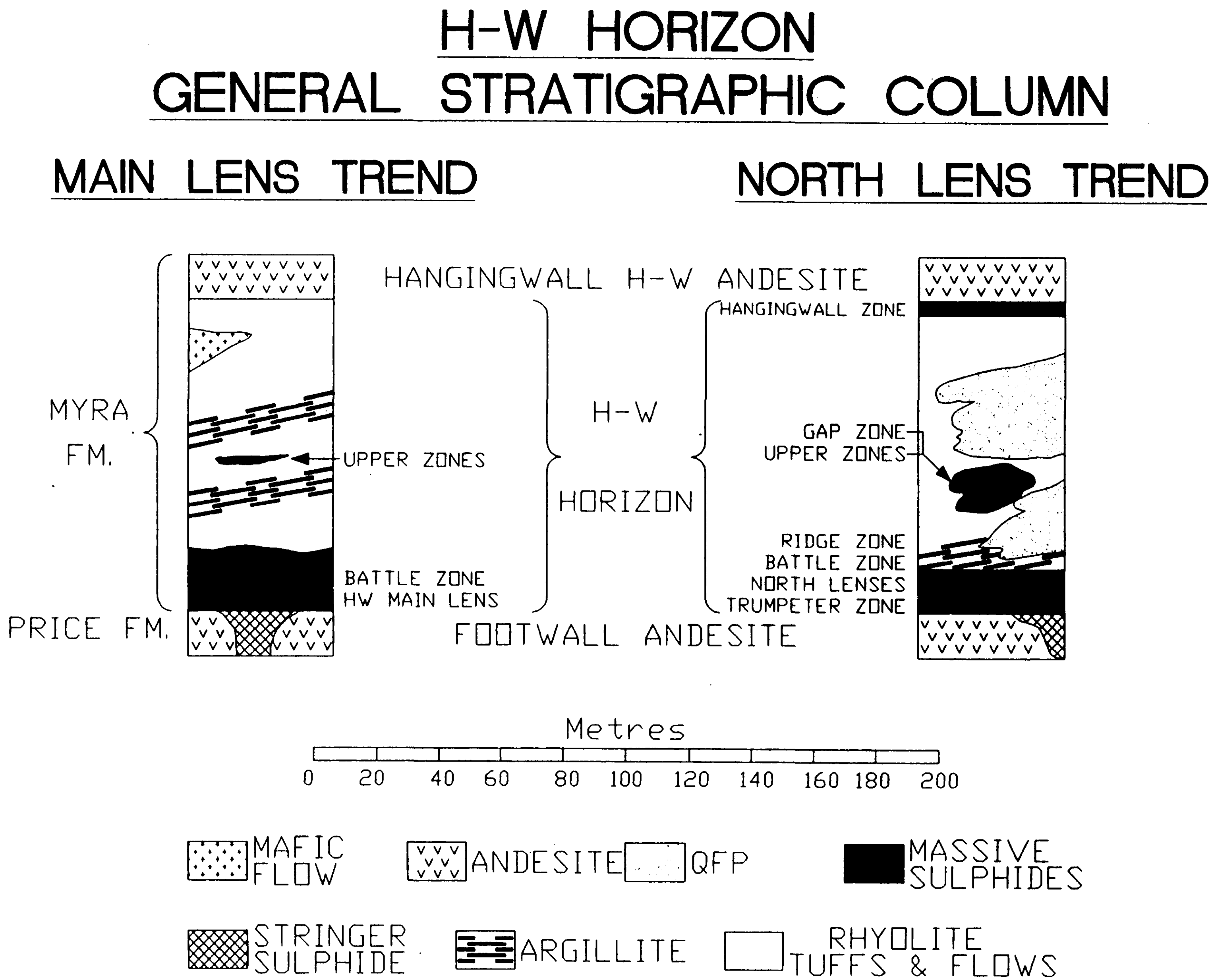

Figure 20. General stratigraphic column for the H-W horizon, Buttle Lake camp, central Vancouver Island, southwestern British Columbia.

area. Massive sulphide clasts are observed throughout the Horizon, but are rarely of economic significance.

2. Overlying the H-W Horizon is the Hangingwall H-W Andesite. This unit is up to 100 m thick and consists of basaltic andesite to andesite flows and pyroclastics. These rocks are thickest over the H-W Main Lens, perhaps because that lens was deposited in a restricted palaeotopographic low.
3. The Ore Clast Breccia Unit contains a series of volcaniclastic submarine debris flows and subordinate subaqueous pyroclastic deposits, up to 90 m thick. This unit is characterized by subangular massive sulphide clasts, ranging from 1 cm to 1.5 m in diameter, but these clasts are never abundant enough to make ore grade.
4. The Lower Mixed Volcaniclastic Unit is also up to 90 m thick and is composed of andesitic volcaniclastic deposits, ranging from breccias to fine tuffs. These rocks are thickest to the southeast (Price Zone) and thin to the northwest (Lynx Mine area).
5. The Upper Dacite/5E Andesite/North Dacite Units represent three approximately contemporaneous, yet different, eruptive events exposed throughout the mine property in this stratigraphic position. These units are discontinuous and non-overlapping and consist mainly of andesitic and dacitic flows and pyroclastic deposits.
6. The Lynx-Myra-Price (LMP) Horizon, occupying the middle of the Mine Sequence, contains the G-Zone and G- Hangingwall Zone massive sulphide mineralized rhyolite members. Both members consist mainly of massive to thick-bedded vitric rhyolite tuff to lapilli tuff, capped by massive sulphide ore lenses; the G-Zone, S-Zone and G Hanging Wall Zone orebodies. The LMP Horizon ranges in thickness from ten to 150 m.
7. Hangingwall to most Lynx ore bodies is the G flow unit. It consists of several two to 15 m thick basalt flows and flow breccias, thickest in the Lynx Mine area above the Lynx G Zone ores. Jasper fragments and lenses are noted in this unit, as are amygdules filled with epidote or calcite. Total thickness of this unit ranges from five to 50 m.
8. The Upper Mixed Volcaniclastics Unit, which is up to 50 m thick, consists of volcaniclastic rocks of mafic to intermediate composition, ranging from fine tuff to tuff-breccia deposits. Mafic clasts predominate and are most abundant to the SW. Intermediate clasts, although everywhere subordinate, are most common toward the NE, especially in the Lynx Mine area.
9. The Upper Rhyolite Unit, the stratigraphically uppermost felsic unit in the Mine Sequence, is up to 50 m thick and is characterized by an association of Quartz Feldspar Porphyritic (QFP) rhyolite, argillite, chert and jasper. These units consist of intercalated rhyolite coarse tuff to tuff breccia and laminated beds of grey to black siliceous argillite, white to pale green chert and minor jasper.
10. The uppermost litho-stratigraphic unit in the Mine Sequence, the Upper Mafic Unit, is up to 200 m thick. The main rock types present are basaltic in composition and occur mainly as hydroclastic and pyroclastic deposits. Subordinate sedimentary deposits are present in the lower part of this unit, range from two to seven m thick, and are composed of thin-bedded to massive cherty tuff, chert and mudstone.

Sulphide deposits and alteration

Massive sulphide deposits (here defined as deposits of 50% or greater sulphide by volume) are known to occur within two of the three felsic volcanic units described above, namely the H-W Horizon and the LMP Horizon. These deposits are generally conformable, fine-grained, massive-to-layered lenticular beds of massive sulphides, commonly disrupted by folding and faulting. Stringer and disseminated sulphide zones are present but rarely are of mineable grade. Sulphide clasts are widely distributed throughout the Mine Sequence, and several ore grade clastic sulphide zones are developed in the H-W Horizon.

Metal distribution is complex, both laterally and vertically, and results in a large range of base and precious metal grades. In decreasing order of abundance, the main sulphide minerals present are: pyrite, sphalerite, chalcopyrite, galena, tennantite, and bornite. Minor amounts of electrum, stromeyerite, chalcocite, and argentite are are also present. Non-sulphide gangue minerals are barite, quartz and sericite. The typical metal zonation pattern consists of a copper-rich core, flanked by increasingly zinc-rich zones and culminating in a baritic zinc-lead-precious metal rich fringe. (Figure 21). The massive sulphide bodies range widely in size, from 10,000 tonne high grade polymetallic lenses to the strongly metal zoned, heavily pyritic H-W main lens of 10 million tonnes.

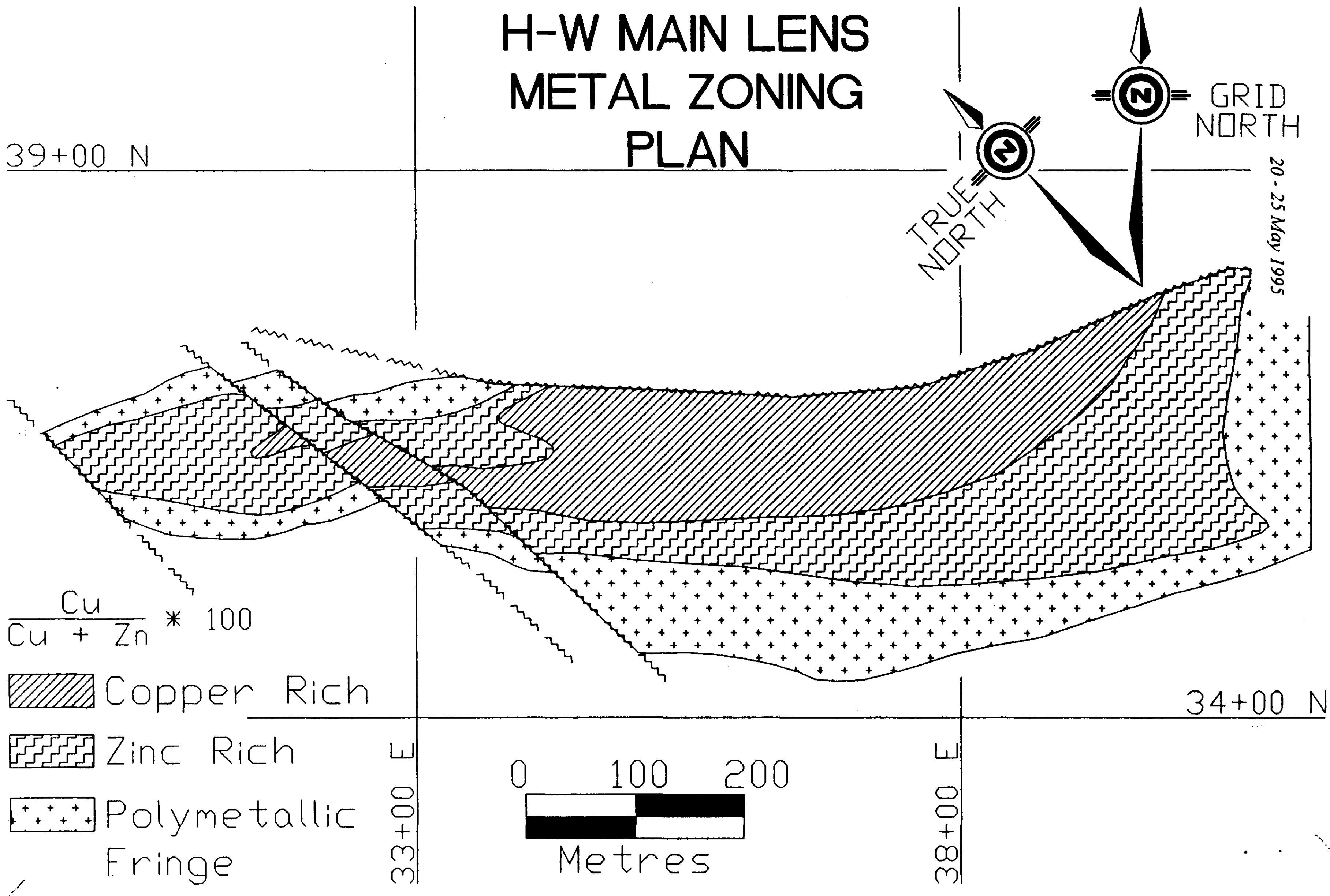

Figure 21. H-W main lens metal zoning plan, Buttle Lake camp, central Vancouver Island.

These sulphide bodies are generally massive to weakly layered. Layering, where present, is characterized by millimetre to metre thick layers of recrystallized coarse grained sphalerite, chalcopyrite-pyrite and pyrite. Individual layers can be traced up to tens of metres, particularly along strike.

Grain size in the massive sulphides is variable, ranging from fine grained to very fine grained in the massive pyritic sections and medium to fine grained within the polymetallic zones. Pyrite grain size is much coarser in the stringer zones, and coarse grained sphalerite and barite occurs in the polymetallic ores. Remobilized chalcopyrite is common in both the massive sulphides and the wallrock.

Non-sulphide clasts, ranging from several millimetres to approximately one metre in their longest dimension, are common in the massive sulphides, especially in the fringing polymetallic zones. Rhyolite, barite, chert, jasper and argillite clasts are present in varying abundance and relative proportions.

Barite is generally restricted to the fringe areas of the H-W Main and North Lenses, but is a common constituent of the Upper Zone and the Lynx-Myra-Price Horizon (LMP) polymetallic orebodies. Massive barite beds are rare but are present in both the H-W and LMP Horizons.

Syn-depositional, diagenetic and post-depositional structures and resulting textures are seen in or adjacent to massive sulphides at a scale of millimetres to metres. Development of layering, soft sediment slumping or folding, and extensional growth faulting took place during deposition. Growth faults and asymmetrical slump folds are observed in ore. Piercements (or diapirs) of dense, ductile massive sulphides, which are found in the overlying brittle hangingwall, may have developed during compaction, or more likely, during later folding. These piercements resemble sedimentary flame structures in their morphology, and range up to ten metres in height and a few metres in width.

Hydrothermal alteration, synchronous with massive sulphide mineralization, occurs as both discrete crosscutting zones in the footwall and as haloes around the orebodies. Two main pyritic feeder systems are known, one below the H-W Main Lens and the other associated with the Lynx and Myra deposits. Both systems exhibit NW-SE linear trends, parallel to the direction of least facies variation. Several smaller feeder zones are recognized, associated with the H-W North Lenses, the Price Mine and the Battle and Gap Zones. These feeder zones typically are developed in footwall andesitic volcanic rocks and have completely replaced them by assemblages of quartz, sericite and pyrite. Pyrite content ranges from one to 30%. Chalcopyrite and sphalerite are also present, in generally sub-economic amounts. The large H-W feeder system also has a zone of moderate to strong albitization and silicification. This zone flanks the quartz-sericite-pyrite assemblage and is composed of albite and quartz and/or sericite.

Structural geology

A period of NE-SW compression, during the Mesozoic, resulted in both ductile and brittle deformation. Cylindrical, closed, symmetrical folds, with NW-SE trending axial traces, developed in conjunction with mineral lineation and a subparallel cleavage. Groups of NE, N and E striking, intermediate to high angle, faults are ubiquitous and display both normal and lateral movement. These appear to cut-off the lesser developed NW striking NE dipping thrust faults and minor extensional faults. Fault zones may be from several millimetres to tens of metres thick, and their composition varies from sericite-chlorite-quartz schist to sericite with or without clay gouge and breccia. Measured displacements range from centimetres up to 350 m.

Mine exploration and ore reserves

As in most successful mining operations, mine exploration has played a vital role in the survival and profitability of the Myra Falls Operations. Exploration history, tools and techniques, and recent discoveries are examined below.

History

Mine exploration has been a constant at Myra Falls over the 26 years of its mining life. The minimum expectation has been to annually replace mined-out ore reserves in existing working areas, and in most years that objective has been met. Beyond that, exploration over the years has been successful in periodically enlarging the ore reserves base by finding new mining areas and "widening the playing field".

Four periods of significant new ore discovery are described below:

1. From 1964 to 1966, surface mapping and diamond drilling, along with subordinate underground work, resulted in the definition of a mining reserve base of 1.9 million tonnes of good grade ore. This reserve was sufficient to initiate mining at the Lynx Mine in 1966, starting with the open pit and moving quickly into underground operations.
2. From 1969 to 1971, exploration efforts spread to the Myra Claims, across Myra valley from the Lynx Mine. Underground development and diamond drilling resulted in the discovery of the Myra high grade lenses in late 1969 and the remainder of the Myra Mine deposits in 1970-1971. These reserves proved to be invaluable in the mid-1970's as their high grade nature carried the operations through a period of low metal prices and high taxation.
3. By 1978, Myra Mine reserves were completely defined and exploratory work in the immediate mine area had proved negative. In addition, at the Lynx Mine, the productive G ore horizon had been traced up to, but not across, the major right-lateral Lynx-Phillips Fault and new discoveries in the rest of the mine had for several years been insufficient to replace reserves. To address this situation, a complete review and revitalization of the exploration program was undertaken and new target areas established. This effort was soon rewarded in 1979-1980, with the discovery of: (a) the Upper Price Zone - a small (185,000 tonne) extension of the Myra Mine. It was discovered in Thelwood valley, across the major left-lateral Myra-Price fault; (b) the West G orebodies at Lynx - the fault offset of the Lynx Mine G Zone; and (c) the H-W Mine, a comparatively very large deposit in the H-W Horizon, located some 400 m below Myra valley.
4. By 1987 the H-W Mine was in full production; the Myra Mine was exhausted; and the Lynx Mine was in decline and operating at only 300 tonnes/day. Exploration strategy was again reviewed and an aggressive program was re-established to assure replacement of the property ore reserve base, which was being depleted at rates of up to 4,000 tonnes/day. This program has been very successful, with a string of new ore discoveries starting in 1989 and continuing to the present day.

Recent ore discoveries

The exploration program review in 1987 developed a number of scenarios which would lead to complete, broad-scale, minesite coverage in specific time frames. The chosen scenario aimed at property coverage in six years, i.e. by 1993. This plan was duly initiated, with expenditures in the range of (Cdn) $3-4 million per year, and has resulted in a series of remarkable new ore discoveries (see Figure 18). These new ore zones have revitalized the operations and more than replaced losses to the reserve base through mining and declining metal prices.

The new discoveries are predominately within the H-W Horizon, and in order of discovery, are:

1. H-W Mine 42 and 43 Blocks (H-W Horizon). These are the continuation of the H-W North Lens trend eastward towards the Myra-Price fault. 43 Block is a new type of ore zone, consisting of mineable grade fragmental sulphides interbedded with thin massive sulphide beds. This zone is equidimensional in cross-section, being some 35 to 45 m wide by 30 to 40 m thick, and has a strike length of 320 m. Current geological reserves on the zone are 750,000 tonnes grading 2.7 g/t Au, 55 g/t Ag, 1.9% Cu, 0.5% Pb, and 5.8% Zn. 42 Block occurs as a two to four metre thick massive sulphide bed about 60 m northeast of 43 Block. Drilling positions to test this occurrence are poor and reserves have been not calculated to date, but it remains a prime exploration target.
2. Ridge Zone (H-W Horizon). Exploration in 1988 focused on the trend of the H-W Horizon, northwest from the H-W Mine. This target lay 300 m below and 200 to 300 m

to the northeast of the existing Lynx Mine workings. Crosscuts were driven on the Lynx Mine lower levels to provide drill positions on 150 m spacing, along the H-W Horizon trend. Subsequent drill programs in 1989-1990 resulted in over 50 ore grade massive sulphide intersections, ranging from 0.2 to 22.5 m thick. Three mineralized stratigraphic positions were recognized here in the H-W Horizon - Hangingwall Zone, Upper Zone and Contact Zone, and ore intersections were obtained in all three. This effort did not lead to a production decision due to distance from existing workings, structural complexities and questionable ore continuity. A geological reserve has been calculated and is 668,000 tonnes grading 2.3 g/t Au, 91 g/t Ag, 1.2% Cu, 1.2% Pb, and 9.6% Zn.

3. Lynx Mine Targets (LMP Horizon). Concurrent with exploratory efforts in the new areas, exploration in the Lynx Mine was refocused in 1989 to examine parts of the mine that had been missed in the first pass of ore definition and mining. Two general targets were chosen: areas in close proximity to major faults, and untested stratigraphy up-dip and down-dip from known G and S zone lenses. This work was successful and has reversed the declining ore reserve picture. The new lenses are generally small in size (10,000 to 50,000 tonnes each), and are structurally complex, but commonly are high grade. Because they occur within the framework of mine development, access costs are comparatively low and these orebodies can have real economic impact. An example is 10-G-54 ore lens, defined in the fall of 1992 as 27,000 tonnes grading 4.1 g/t Au, 95 g/t Ag, 1.8% Cu, 1.2% Pb, 10.8% Zn, and already in production.
4. Gap Zone (H-W Horizon). Mine exploration in 1991 concentrated on tracing the H-W Horizon from the Ridge Zone discoveries back toward the H-W Mine workings - an area heretofore inaccessible from either surface or underground. In May of 1991, the Gap Zone discovery hole on this program intersected 33.1 m grading 3.6 g/t Au, 365.0 g/t Ag, 4.5% Cu, 0.5% Pb and 18.5% Zn. Exploratory stage drilling has recently been completed and delineates the Gap Zone as a high grade polymetallic ore lens, with dimensions of 20 to 30 m high by 40 to 50 m wide, and 250 m strike length. Geological reserves are now 1.0 million tonnes grading 3.0 g/t Au, 149 g/t Ag, 1.7% Cu, 1.1% Pb, and 12.8 % Zn. This lens is within the Upper Zone stratigraphic position, which is also represented by high grade polymetallic ore lenses above the H-W Main Lens and in the Ridge Zone area. Mineralogically, the Gap Zone is distinct, containing significant bornite, chalcocite and electrum, in addition to the more common sphalerite, chalcopyrite, tennantite, and pyrite.
5. Extension Zone (H-W Horizon). Development from the H-W mine started toward the Gap Zone in late 1991. Exploration diamond drilling from this access soon intersected and traced the Extension Zone, the faulted off and structurally complex westward extension of the H-W Main Lens. Grades are marginal to moderate and it is thus not an immediate mining target. Drilling to date is on 100 to 120 m spacing along strike and much definition drilling remains to be done. A geological reserve has been calculated, and totals 414,000 tonnes grading 1.2 g/t Au, 51 g/t Ag, 1.8% Cu, 0.3% Pb, and 3.7% Zn.
6. Battle Zone (H-W Horizon). Attempts to trace the Gap Zone east were generally unsuccessful but the drilling did intersect mineralization on the Contact Zone position of the H-W Horizon, some 30 to 50 m stratigraphically below the Gap Zone. This stratigraphic position is represented elsewhere on the property by the H-W Main Lens and H-W North Lenses, which are large tonnage and show excellent strike continuity. With this in mind, the Battle Zone became our prime target and remains so today. Drilling to date indicates a number of high grade, metal-zoned massive sulphide lenses ranging up to 35 m thick. The zone has been tested over 700 m of strike length on 100 to 110 m spaced exploration sections. Ore definition drilling started in late 1992 and has added significant ore tonnage to the south of the expected limits of the Battle Zone ore. Geological reserves have been calculated, and at January 1st, 1993, they were 3.4 million tonnes grading 1.1 g/t Au, 24.5 g/t Ag, 2.7% Cu, 0.5% Pb, and 12.9% Zn.
7. Trumpeter Zone (H-W Horizon). This new ore zone was discovered in early 1992, through surface drilling in Thelwood valley. The drill program leading to discovery was conceived as a test of the postulated fault offset position of 42 and 43 Blocks, across the Myra-Price fault. Surface drilling is an economical exploration technique for the mine property only in the deeply incised valleys - Myra and Thelwood. Drilling in Thelwood valley had been suspended for some 10 years and it took an extensive public information

and government approval process to re-establish the program. This program encompassed a number of initiatives to ensure protection of the environment. These initiatives included the use of vegetable oil for hydraulics, extra mufflers and mast "socks" to ensure that a nearby herd of elk would not be disturbed by the noise, and the capture and removal of all drill cuttings to the tailings disposal area. This program was quickly rewarded with the discovery of the Trumpeter Zone, a copper-rich pyritic massive sulphide lens that is believed to be the faulted off continuation of H-W 42 Block. Geological reserves for this Zone are calculated at 122,000 tonnes grading 3.2 g/t Au, 69 g/t Ag, 6.3% Cu, 0.3% Pb, and 4.6% Zn. The Trumpeter Zone lies at the same elevation as the H-W Mine workings, but approximately 1,500 m towards the southeast. Underground development is not expected to reach this zone for a number of years, but it remains an active and exciting exploration target.

Ore reserves

Ore Reserves are calculated annually, at year end, by an ore reserve team of geologists and engineers. Reserves are calculated initially as geological reserves in the Proven, Probable, and Possible categories. Engineering and geological constraints are combined with economic factors to define Mining Reserves - the basis for mine planning. In addition, the Geology team calculates a Resource category of marginal grade material (where economics are the decisive factor), and a Potential Reserve (where information is insufficient to allow reportable reserves to be calculated). The geological categories, including resources and potential, can be combined as a Mineral Inventory to help direct long-term planning. Tonnes and grades are reported for the Geological Proven/Probable Reserve and Mining Reserve categories and tonnes only for the Geological Possible Reserves category. Geological Resources and Geological Potential numbers are not published.

The reserves are calculated by classical sectional methods, using Net Smelter Return (NSR) values to define cut-off grades. Increasingly, calculations are computer-assisted using "Medsystem" software, developed by Mintec, Inc.

Future exploration

The Myra Falls Operations claim block, seven km long by two to three km wide, is a challenge to explore and well over half of the property remains to be tested. Much of it is accessible only through underground development. Surface drilling, for over 90% of the property, would require 2,000 to 3,000 m deep drillholes to reach the H-W Horizon targets. However, surface drilling is economically feasible in the lower levels of Myra and Thelwood valleys and is continuing in those areas.

As described previously, mineralization is present over a 450 m thick stratigraphic interval, in two mainly felsic volcanic horizons - the LMP Horizon, and the H-W Horizon (Figures 19 and 20). In addition, there is sketchy evidence of another felsic horizon in the Footwall H-W Andesite Formation - a possibility that warrants evaluation.

Exploration targets are defined by favourable stratigraphy, as noted above. Within the right stratigraphic unit, paleotopography (as indicated by facies and thickness distribution), mineralization, alteration and structure further define favourable areas.

The main exploration tools in use to date have been our experience base and knowledge of mine stratigraphy, supplemented by intensive diamond drilling programs. Westmin does most of its own underground drilling, using ten company-owned drills that range from 150 m depth capacity Gopher drills to a 1,000 m depth capacity Longyear 38. Drilling rates per year have ranged from 20,000 m to 60,000 m, depending on the need for ore definition and exploration work. Surface drilling is sporadic and is therefore contracted. Diamond drilling in areas of high potential is based on a pattern that fully tests the linear nature of the orebodies. Drill sections are spaced at 120 to 150 m intervals along the NW-SE trend, and drillholes on section are spaced only 30 to 50 m apart to ensure the narrow, linear ore trends are adequately tested.

This property has a vast exploration potential. To test this potential is a time consuming and expensive business and continuous exploration is essential. The new ore discoveries are the tangible results of Westmin's consistent exploration effort and expenditure, augmented by on-site expertise and commitment.

Westmin is an integral part of a Mineral Deposits Research Unit (MDRU) at the University of British Columbia in Vancouver. MDRU is a joint Industry-Government-University initiative, and is sponsoring graduate research to help ensure that our future exploration programs make the best possible use of the data recovered, so that we continue to find new orebodies.

Mining and milling

Mining and milling of these widely distributed, metal zoned and mineralogically complex orebodies is both challenging and rewarding. Methodologies have evolved over time in response to changing conditions and continue to do so today to ensure that the operations remain viable.

MINING

Myra Falls Operations provides a good example of the evolution of mining methodology to meet changing conditions. The orebodies in all three Mines have been, and continue to be, challenging to extract. In the Myra and Lynx Mines, challenge lay in orebody size, shape and structural disruption. The H-W Mine is characterized by much larger massive sulphide bodies, hence orebody size is rarely a concern; but the complex distribution of metal grades presents its own problems. The currently producing Lynx and H-W Mines will be discussed separately.

Lynx mine

The Lynx Mine has been in continuous operation for 26 years, at production rates ranging from 900 to the current 300 tonnes per day. Mineable reserves have rarely exceeded five years planned production so exploration for, definition of, and development to new orebodies has always been aggressive. Lynx ore lenses are developed on both limbs of the NW-trending asymmetrical anticline within the Lynx-Myra-Price Horizon. S Zone and South Wall Zone ore is developed on the SW limb as steeply dipping lenses, with typical dimensions of three to ten m thickness, 30 to 60 m in height and 60 to 120 m strike length. G Zone orebodies are found along the more gently dipping NE limb, are of similar dimension, and have provided the bulk of the Lynx Mine production.

These ore bodies are developed along a known 2,750 m strike length and unfolded dip length of 750 m. An estimated 120 individual ore lenses have been mined to date, with total production from the Lynx of 5.3 million tonnes. Detailed definition drilling, with 15 m drillhole spacing, and sound geological interpretation are essential for stope planning and grade control. Ore grade is reasonably constant within individual lenses and throughout the Mine as a whole, but structural complexity and small scale faulting makes interpretation and mining a challenge. Ground conditions vary widely, from poor to excellent, with the SW limb ore zones exhibiting poorer conditions in general.

Lynx Mine has been developed from a 335 m deep internal shaft, situated just south of the south limb orebodies. To date, total underground development comprises 56 km of drifting, on 12 levels. Seven of these levels are accessed by the internal shaft and are spaced 45 m apart. The remaining levels are developed from adits on the steep mountainside. The various development levels are connected, for ventilation and access, by 18 km of raises.

In the initial 10-12 years of mine life, the bulk of production came from classical cut and fill mining, with subordinate room and pillar mining in the flatter G Zone ore lenses. As mining moved further and further away from the Lynx shaft, the cost of backfill became prohibitive and non-fill mining methods came to the fore. Room and pillar mining proved to be a very productive alternative, with mining recoveries averaging 85% or more. Most of the G and West G Zone orebodies were mined that way. The steep dipping SW limb ore zones are more difficult to mine, with poorer ground conditions a big factor. They are now mined by longhole retreat or "Avoca" methods, with mixed results. Ongoing experimentation is improving productivities but engineering profitable extraction of these lenses will always be a challenge.

Over the past two years, the Lynx Mine staff have had great success in cutting costs and improving productivity. That effort, in conjunction with the discovery and development of new orebodies, has enabled the mine to stay competitive despite its small size.

H-W mine

The H-W Mine was commissioned in September 1985. Access to it is from a 715 m deep, six compartment, vertical shaft. Five main levels are developed, at 45 m and 90 m spacing. The uppermost level, 18 Level, is actively advancing toward the new Battle and Gap Zones. 20 and 21 Levels were driven to provide definition drilling platforms to test the H-W Main and North Lenses. 23 Level is the main stope access level and is interconnected to 21 Level above and 24 Level below through internal ramps. These ramps provide access to the various stopes and the 21 Level maintenance shop. 24 Level is a track haulage level, and connects with all main ore and waste passes. It is also being advanced westward to the Battle and Gap area, in concert with 18 Level above. Ore haulage on 24 Level is accomplished with 15 tonne ore cars, pulled by electric locomotives on 914 mm gauge track. All ore is crushed underground in a 1.2 m Kenco jaw crusher, and is transported to surface in 11 tonne skips. A two km long covered conveyor belt transports ore from the H-W headframe to the concentrator for processing.

The H-W Main Lens and North Lenses are generally flat lying, thick, strongly metal zoned pyritic massive sulphide beds. H-W Main Lens dimensions are 300 m wide by 1,200 m long, with massive sulphide thicknesses ranging from 3 m along the fringes to 60 m in the core areas. Metal grades range widely, from $200 Net Smelter Return (NSR) fringe polymetallic ore to less than $20 NSR massive pyrite zones in the core areas. Detailed diamond drilling is necessary to define ore grades, both for economics and for blending to achieve consistent mill feed. The North Lenses comprise many types, from small, high-grade polymetallic lenses to large variable grade pyritic bodies. This set of ore zones has been traced over a strike length of 1,200 m and is still being explored both NW and SE along trend.

Initial mining in the H-W Mine emphasized room and pillar methods, favoured because of quick access to the ore and good productivity. Other mining methods used were cut and fill, on the more steeply dipping polymetallic fringes to the Main Lens, and longhole stoping in thick sections of the core area.

A major change to predominantly longhole mining was initiated in 1991, in response to the declining productivities and increasing costs of room and pillar mining. That change was completed during 1992 and 85% of production tonnes now come from longhole mining. In 1992, 25 longhole panels were mined, ranging in size from 8,000 to 114,000 tonnes, with an average of 34,000 tonnes. Computerized scheduling techniques were developed to ensure continuous production and backfilling. Five yard and seven yard scooptrams are used to move blasted ore to the ore passes. Backfill is classified mill tailings, cemented if necessary.

In concert with the change in mining methods, increased attention is paid to ore block grades and NSR's, using the Mintec Medsystem mine planning software. This computer modeled estimate of ore block value is compared against estimated block mining costs to ensure a positive cash flow.

MILLING

Myra Falls Operations produces copper and zinc concentrates for shipment throughout the world. Mill feed from mining operations averages 3,650 tonnes per day at mill head grades that range from 1.5 to 3.0 g/t Au, 20 to 30 g/t Ag, 1.2 to 4.5% Cu, and 2.5 to 6.5% Zn. Blending in the production system generally results in relatively constant or smoothly varying mill head grades, but pronounced spikes and troughs can occur for each metal.

The Myra Falls Concentrator has a name plate capacity of 4400 dry metric tonnes per day (dmtpd) and is capable of producing roughly 400 dmtpd each of copper and zinc concentrates and roughly 15 kg/d of gold concentrate. The copper concentrate grades roughly 26% Cu, 1.5% Pb, 3.5% Zn, 0.5% As, 10 g/t Au, and 250 g/t Ag. The zinc concentrate grades roughly 54% Zn, 1% Cu, 7% Fe, and 3 g/t Au. The gold concentrate grades roughly 2.5% Au and 1% Ag, from two Knelson Concentrators.

Lynx mine ore is crushed on surface with a primary jaw crusher and moved by conveyor belt 100 m to the mill coarse ore bin where it is combined with ore from the H-W Mine. The mixed ores are crushed in the secondary crushing plant, which is a conventional circuit employing one standard cone and one short head cone in closed circuit with a vibrating screen. The Lynx crusher is operated remotely from the secondary crusher. Two fine-ore bins feed two conventional rod mill/ball mill circuits. The flotation circuit is a non-conventional design (Mular and Veloo, 1991). Cyclone overflow is conditioned and feeds the copper roughers, and the copper rougher concentrate feeds the copper regrind circuit. The copper regrind overflow feeds the first cleaners, and the first cleaner tail feeds the cleaner scavengers. First cleaner concentrate feeds the copper column. Copper column tail combines with copper rougher concentrate and copper cleaner scavenger concentrate and reports to the copper regrind. Copper cleaner scavenger tail is conditioned with copper rougher tail and reports to the zinc roughers. Copper column concentrate reports to de-watering as final concentrate.

The zinc circuit is identical to the copper circuit (the zinc rougher tail combines with zinc cleaner scavenger tail and reports to mill final tail). Mill final tail is cycloned to produce backfill sand and the fines are thickened and distributed by spray bar in the tailing pond. All the water from the mill process, mine drainage, and surface runoff is treated with lime. The resultant sludge is removed in settling and clarifying ponds. Water is recycled to the mill and the excess is discharged to Buttle Lake. Both concentrates are thickened and filtered with pressure filters and the concentrates are trucked 90 km to an ocean port in Campbell River where they are shipped to various Japanese and North American smelters.

The Westmin flotation circuit is unique in that conventional counter current flotation is not used. The only recycle stream is through the regrind. This circuit is easy to operate, has low cleaner circulating loads, and responds quickly to operator action.

Environmental controls

Our location is in the center of a Provincial Park, on a drinking water reservoir and at the headwaters of a river system important to the recreational, native and commercial salmon fisheries.

This has given environmental operations at the mine an important public profile and an opportunity to demonstrate that mining and nature can co-exist. An innovative tailings disposal and water treatment system is combined with on-going reclamation efforts and public information displays, tours and forums to document Westmin's commitment to that goal.

Tailings disposal

Tailings disposal in the 1967 to 1984 period was sub-aqueous deposition in Buttle Lake, some 3 km downstream from the mill. Tailings flowed by gravity through a 25 cm diameter high density polyethelene pipe to a raft on the north shore of the Lake and deposited on the lake floor beneath 30 metres of water. An emergency tailings pond near the mill was an alternate site which was used whenever tailings flow to the Lake was interrupted. This system operated essentially trouble-free during its life. However, the discovery of the large, pyritic H-W deposit and the gradual increase of metal concentrations in Buttle Lake in the late 1970's resulted in a partly politically mandated decision to develop an on-land facility to replace the sub-aqueous system. Subsequent study of the rising metal concentrations in Buttle Lake has shown that this was not due to sub-aqueous tailings deposition but was caused by ground water leaching metals from the extensive waste dumps. This acid drainage was reaching Myra Creek, which transported it to Buttle Lake.

The new tailings disposal had, then, to serve two purposes: intercept the acid drainage from waste dumps and, secondly, provide a storage area for decades of tailings production. An area below the waste dump was chosen and cleared; Myra Creek was diverted and an extensive outer embankment built to contain the tailings. Finally, collection drains were placed at the toe of the waste dump to capture the acid drainage for treatment.

The tailings are deposited using a subaerial technique. In this method, a thickened slimes slurry, approximately 50% solids, is distributed through spray bars along the outer embankment. Under the spraybars rapid settlement takes place, while finer particles travel some distance further, thus forming a sloping beach. Water "rolls" off the beach and is collected in a pond beyond the beach, to be drawn off through decant pipes to the pumphouse. After a three to six cm layer of tailings has been deposited, another set of spray bars is used and the initial deposit is allowed to drain and air dry. This causes thin, virtually impervious layers to deposit, resulting in the formation of an unsaturated, stable deposit.

Water treatment facilities are extensive and effective, collecting and treating contaminated groundwater, mine water, concentrator effluent, yard drainage and discharge from two sewage plants. Normal effluent quality from the system is less than 0.01 mg/L dissolved Zn, up to 0.20 mg/L total Zn, less than 0.01 mg/L Cu; and Pb and Cd levels below detection limits.

Reclamation

Since the H-W Mine start-up, reclamation efforts have emphasized removal of obsolete facilities and installations, such as the tailings line and road to Buttle Lake. Hydroseeding and landscaping work has been extensive to enhance the appearance of the site and work has started on reclaiming the old Lynx open pit. Surface diamond drilling set-ups are quickly cleaned up and re-seeded. Drillholes are plugged and casings are cut off below ground level so no trace remains of drilling activity. A sizeable and increasing, ($4.0 million and expected to rise to $22.0 million by 1995), reclamation bond is posted with the Provincial Government to address post-closure reclamation and remediation.

Public involvement

In recent years there has been growing public concern regarding the environment and a decline in support for extractive industries, in general, and mining in particular. Westmin's case is even more sensitive because the Myra Falls Operations is the only mining operation in a British Columbia Provincial Park and it is of outmost importance that the Company maintain strong public support for its continued activities.

Westmin's approach to public involvement is to be open and proactive. The Company tries to maintain a positive public image and a high community profile through advertising, community events, school contacts, open houses, tours and public meetings. Westmin and its employees take an active role in charities, community events, team or event sponsorships, displays, etc. In terms of the mining operations the Company regularly hosts community open houses and site tours where the operations are reviewed, changes are discussed and questions are answered.

In the case of operational initiatives which would be perceived to have an impact on the community or the public, Westmin sponsors community meetings to explain the initiative (concept or problem), the reason for it and possible outcomes. The Company seeks community feedback in terms of ideas, suggestions, concerns, etc. which it can bring to the problem before finalizing a solution. In this manner a solution to a problem is generally well thought out, with plenty of public input and usually no surprises or public apprehensions when a new program is finally announced.

Westmin's experience with this approach to public involvement has been positive. While it can be time-consuming and more expensive to work through the public process, there are many benefits. The public process forces the Company to carefully consider each initiative from various perspectives, which helps to avoid mistakes caused by hasty decisions. Secondly there is a high level of public awareness and understanding of the Company and its Myra Falls Operations and a good deal of community support for Westmin's position. This is a benefit which can not be bought, only earned over a number of years, but it is of immense value when Westmin or the mining industry in general is under attack. Mining companies have very little intrinsic political support, particularly in large urban centres distant from mining operations and the approval of local communities encourages urban politicians to be responsible.

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NOTES

GEOLOGICAL INVESTIGATIONS OF THE H-W DEPOSIT, BUTTLE LAKE CAMP, CENTRAL VANCOUVER ISLAND (092F/12E)

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EXCERPT FROM: B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1993, Paper 1994-1, pages 339-344.

Introduction

The Myra Falls deposits of the Buttle Lake mining camp (49° 34'N, 125° 36'W) occur in Paleozoic Sicker Group rocks of Vancouver Island, within the Wrangellia allochthonous terrane of the Insular Belt of the western Cordillera (Figure 2, inside front cover). The deposits are located at the south end of Buttle Lake, 90 kilometres by highway from Campbell River (Figures 1 and 17). The deposits include the past-producing Lynx and Myra orebodies, which were brought into production in 1967, and the producing H-W orebody and adjacent North Lens, discovered in 1979. In 1991 the Battle and Gap zones were discovered along strike and to the west of the H-W orebody; they are scheduled to begin production in 1993. Proven and probable geological reserves as of January 1, 1993, are 12 516 300 tonnes grading 1.9 % copper, 0.5 % lead, 6.3 % zinc, 2.1 grams per tonne gold and 45.6 grams per tonne silver (Westmin Resources Limited Annual Report, 1992).

This paper is based on 1993 fieldwork involving relogging and sampling of selected drill-cores through the stratigraphic sequence hosting the H-W orebody, as well as preliminary lithogeochemistry and ore petrology. Robinson *et al.* (1994 and this field guide) describe stratigraphic relations in the Battle zone, which occurs at the same level in the camp stratigraphy as the H-W deposits. In order to avoid repetition of the general geology and mine stratigraphy the reader is referred to Robinson *et al.* (1994 and this field guide) for a detailed discussion. Earlier work on the geology and geochemistry of the volcanic hostrocks is summarized and discussed by Juras (1987); preliminary fluid inclusion results are reported by Hannington and Scott (1989).

H-W stratigraphy

The stratigraphy at the H-W deposit comprises a series of relatively flat lying mafic and felsic volcanic units (Figures 19 and 22). Stratigraphic columns for two exploration holes that penetrated thick sections of the H-W orebody are given in Figure 23. The stratigraphically lowest unit, the Price andesite (DCp, Figure 22), forms the footwall to the sulphide mineralization and comprises at least 300 metres of massive to pillowed andesite flows and flow breccias, with minor volcaniclastic andesitic rocks. This unit is directly overlain by the Myra formation, the lowest part of which is the H-W horizon (unit 1, Figure 22). The H-W horizon comprises 50 to 100 metres of felsic subaqueous volcaniclastic and pyroclastic beds, lesser interbedded black mudstones, and a lens of quartz-feldspar-porphyritic rhyolite up to 50 metres thick.

Much of the footwall beneath the Main and North lenses is intensely altered to a sericite-pyrite-quartz assemblage, locally with significant chlorite. Lateral to this, the alteration is dominated by an albite-sericite-quartz assemblage. Least-altered samples are massive, feldspar±pyroxene-phyric andesite (Juras, 1987).

The massive sulphide lenses occur at the contact between the Price andesite and the H-W horizon (Figures 19 and 22). They are underlain by a strongly altered and pyritized feeder zone that extends at least 25 to 50 metres down into the andesitic footwall. Mineralization directly above the footwall andesite is typically massive pyrite with only tracedisseminated chalcopyrite. This style grades vertically into massive pyrite with several percent disseminated chalcopyrite, that constitutes the bulk of the ore body. This massive sulphide is typically overlain by an upper interval of semimassive to disseminated polymetallic mineralization alternating with felsic mass-flow units. This upper interval of mineralization tends to be dominated by sphalerite, galena, tennantite and barite.

The felsic mass-flow units of the H-W horizon are composed of a monomict assemblage of rhyolite clasts. Beds range ranging from 0.1 to 1 metre thick and are generally graded, with younging directions up-hole. Clasts range from rounded to subangular and appear to have been reworked.

A large body of quartz-feldspar-porphyritic rhyolite (QFP) wedges into the H-W horizon about 50 to 100 metres to the north of the H-W deposit, and thickens progressively northwards. It can be traced for more than 2 kilometres westwards to the Battle zone. The H-W horizon also contains distinctive black mudstone intervals with interbedded felsic volcaniclastic rocks. Black mudstones that occur just above the H-W orebody continue northwards above the QFP wedge, but not below it.

The H-W andesite is a sill-flow complex that is partially intrusive into the H-W horizon. It comprises flows and breccias of basaltic andesitic and andesite that form a lens of several hundred metres in diameter above the area of the H-W deposit. To the southwest, in the area of 33+50N, the H-W andesite is overlain by a lens of siliceous dacite up to 75 metres thick (Figure 22). Above the H-W deposit, in the area of 39+50N, a smaller dacite lens intervenes between the H-W horizon and the H-W andesite.

Stratigraphically above the H-W andesite is the ore-clast breccia, which consists of mainly andesite volcaniclastic debris-flows, locally with some rhyolite and minor sulphide clasts. This is followed by green tuff breccias and bedded coarse to fine tuffs, which mark the end of the first volcanic cycle. An overlying thick sequence of mafic-rich volcaniclastics with lesser rhyolite forms the second volcanic cycle, and is host to the Myra-Lynx-Price orebodies.

Lithogeochemistry

A suite of 27 whole-rock samples from exploration holes W-111 and W-123 was analyzed by X-ray fluorescence using glass beads for major elements, and pressed pellets for trace elements. The locations of the samples are shown next to the stratigraphic logs in Figures 22 and 23. The purpose of the lithogeochemical study was to identify the main volcanic units, particularly where core and petrographic identification is difficult due to severe alteration.

The lithogeochemical data for the H-W volcanic rocks have been examined using immobile element relationships (*e.g.* Ti-Al-Zr) to identify rock types and characterize alteration, as described by MacLean and Kranidiotis (1987), MacLean (1990), and Barrett and MacLean (1991). The results (Figure 5) define two main alteration trends in plots of both Al_2O_3 *versus* TiO_2 (a) and Al_2O_3 *versus* Zr (b). These trends result from alteration of rhyolite and andesite precursors. Ideally, a single alteration line results from alteration of a homogeneous precursor, with the spread of points along a given alteration line reflecting the overall mass change in the mobile elements. Net mass gain in mobile elements moves a sample point from its precursor location along a line towards the origin, whereas net mass loss moves a point in the opposite direction.

The altered footwall andesites show a small compositional range in terms of their immobile element ratios. This primary range leads to a fan-like distribution for the altered samples (Figure 24). Of particular interest is the fact that the footwall andesite (DCp, Figure 21), which in places is altered beyond recognition and contains up to 50% sulphides, yields a perfectly straight alteration line in the Al_2O_3 *versus* TiO_2 plot (Figure 24a). This indicates that the drilled interval from at least 636 to 682 metres was derived from an andesitic precursor with uniform immobile element ratios. A later study will present calculated elemental mass changes in the alteration zone of the H-W deposit.

Five samples of H-W andesite from the hangingwall (unit 2, Figure 22) have a tight Al_2O_3 *versus* Zr composition (Figure 24b). Their major element composition, and lack of alkali exchange in particular, indicates that the H-W andesite is much less altered than the

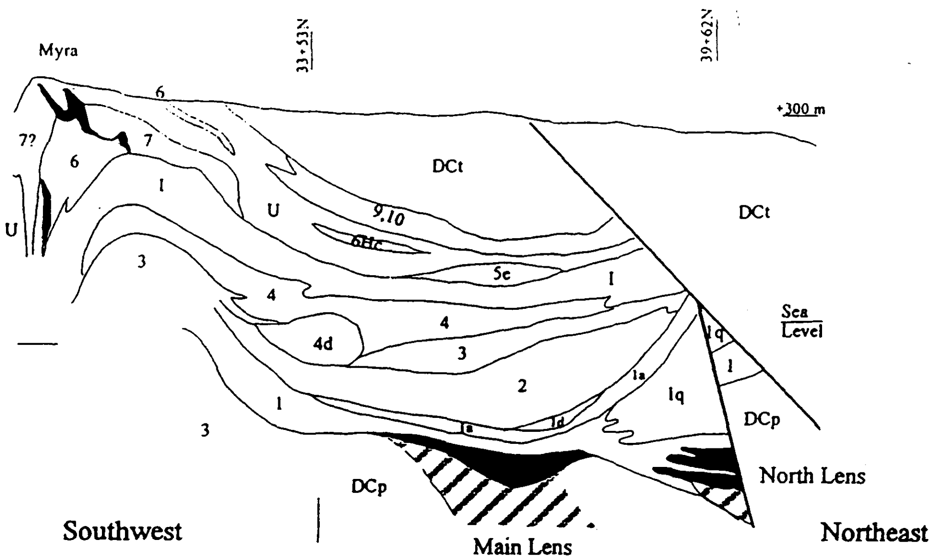

Figure 22. Stratigraphic section through the H-W area at 34+75E. DCp, Price Formation; 1, H-W horizon; 1a, argillite; 1d, dacite; 1q, quartz-feldspar-porphyritic rhyolite; 2, H-W andesite; 3, ore-clast breccia; 4; lower mixed volcanics; 4d, lower mixed volcanics, dacite; I, undifferentiated Myra formation, interzone units; 5e, andesite; 6, Lynx-Myra-Price horizon; 6Hc, Lynx-Myra-Price chert horizon; U, undifferentiated Myra formation, upper units; 7, G-flow unit; 9, upper rhyolite unit; 10, upper mafic unit; DCt, Thelwood formation. Solid black areas represent massive sulphide lenses, striped areas represent zones of massive pyrite alteration. After Juras (1987).

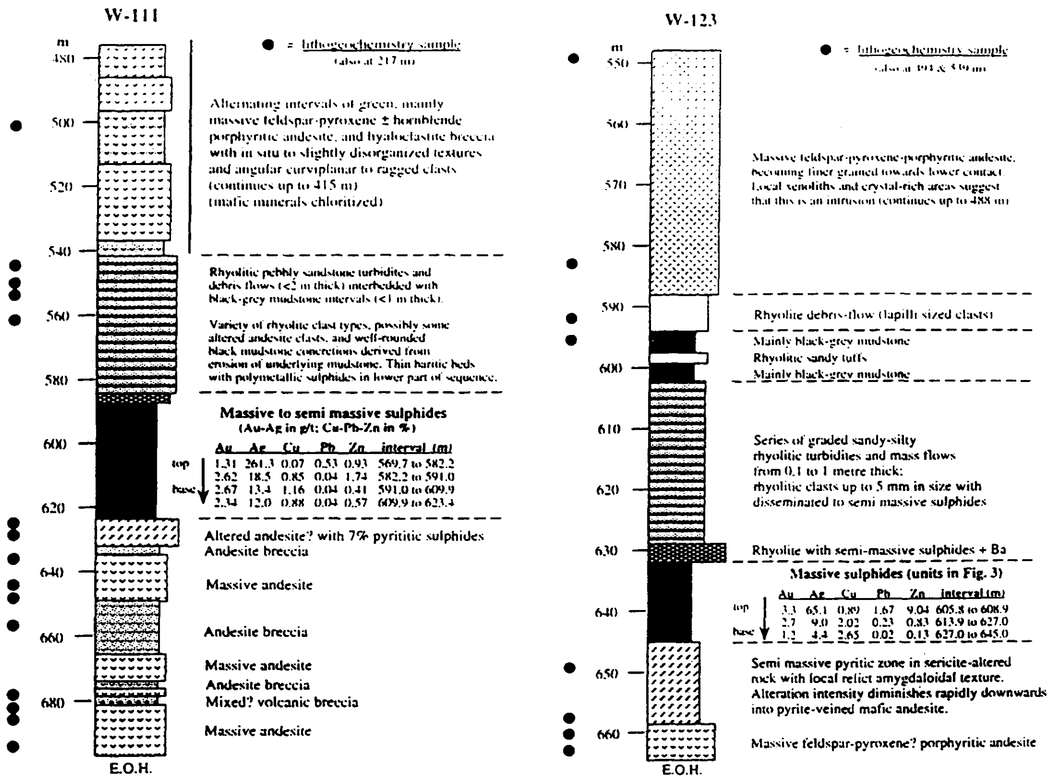

Figure 23. Stratigraphic column for drill hole W-111 and W-123, H-W orebody. The black dots are lithogeochemical sample locations.

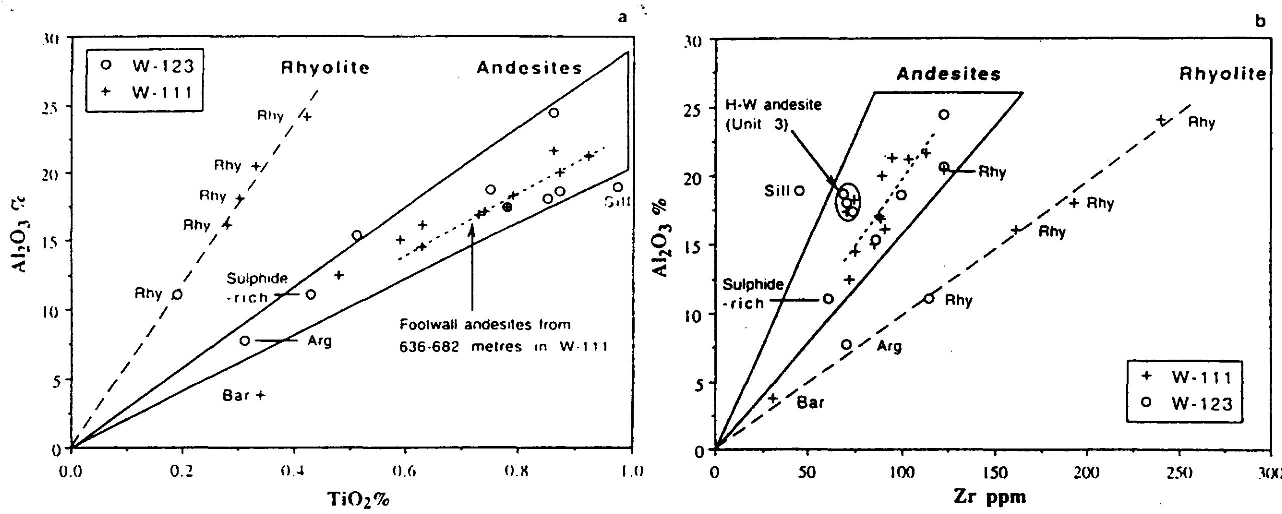

Figure 24. Plot of Al_2O_3 versus TiO_2 *(a) and* versus *Zr (b) for volcanic rocks from the H-W lens, drill holes W-111 and W-123. Most of the samples fall along andesite or rhyolite alteration lines, making this technique a useful tool for discriminating between extremely altered rhyolites and andesites.*

footwall andesite. Although the H-W andesite has slightly higher Al_2O_3 *versus* Zr ratios than the footwall andesite, their Al_2O_3 *versus* TiO_2 ratios are similar, as are other trace element ratios. This suggests that the H-W and footwall andesites are compositionally closely related.

The single rhyolite alteration line (Figure 24) is rather unexpected, given the fact that the samples were taken from several felsic mass-flow or turbidite beds. These clastic rocks in fact had a heterolithic appearance due to the different textures and colours of the clasts. However, the slope of the felsic alteration line closely corresponds to a pure end-member rhyolite composition (based on Westmin Resources unpublished data for least-altered rhyolites). Thus, essentially all of the fragments must be of rhyolite composition. The monolithic nature of these beds suggests that they were rapidly emplaced (into a muddy basin at this particular locality).

It is of interest that the immobile element plots clearly indicate that several altered units logged by previous workers as rhyolites are actually andesite and *vice versa*. Thus, these plots can usefully serve to establish original rock types and improve stratigraphic correlation.

Samples in the H-W data set plot consistently in both Al_2O_3 *versus* TiO_2 and Al_2O_3 *versus* Zr space, except for one rhyolite sample that has shifted onto the andesite alteration line, probably due to zirconium loss. This effect can occur in some felsic rocks if zirconium becomes incompatible during magmatic fractionation or is lost by crystal sorting (MacLean and Barrett, 1993). For this reason, Al_2O_3-TiO_2 plots show the most consistent immobile element relations.

Sulphide mineralization

The H-W deposit consists of the Main, North and Upper sulphide lenses, of which the first two occur at the base of the H-W horizon (unit 1). The lenses consist of fine-grained massive to thinly banded pyrite, sphalerite and chalcopyrite with minor bornite, galena and tennantite; gangue minerals are quartz, barite and sericite. The Main lens is some 1200 m long, 500 m wide and up to 80 m thick (Juras, 1987). There is a general zoning from a pyrite core with sphalerite and chalcopyrite-rich areas, to a pyrite-poor barite-rich margin with notable sphalerite, chalcopyrite, galena and bornite (Walker, 1985). The Upper lens mineralization is near the top of the H-W horizon (unit 1). It comprises disseminated to locally massive polymetallic sulphides. Much of the intervening sequence of unit 1 felsic volcaniclastics is strongly altered, probably as a result of continued hydrothermal activity after formation of the Main and North lenses.

Mineral compositions

Polished mounts (total area ≈92 cm^2) were prepared from six samples of disseminated, brecciated, banded and massive sulphide ores. These were characterized in terms of mineralogy, textures and mineral chemistry. The modal proportions of each ore and gangue phase were estimated visually: four stope samples from the H-W deposit contain 40 to 90 volume percent sulphides, averaging about 60%. Two drill-core samples from the Upper zone contain 8 to 15% sulphides. The five key ore minerals, in terms of average volume percent across the sample set, are: pyrite (28%), sphalerite (9%), chalcopyrite (7%), galena (1%) and tennantite (0.4%), averaging a total of 45% for all samples.

Four complementary techniques were used for mineral analysis. On scales ranging from about 0.01 to 1 millimetre, polished samples were analyzed for major, minor and trace elements. Elements expected at levels of 0.1 weight percent (1000 ppm) or more were analyzed by electron microprobe (EPM). A survey of minor and trace elements in the 5 to 5000 ppm range was conducted by proton microprobe (PIXE). A limited study of gold distributions (<10 ppm) was carried out using accelerator mass spectrometry (AMS) and ion microprobe (SIMS) methods.

The EPM and PIXE data indicate that common sulphides, particularly pyrite, almost always contain much less than 500 ppm (0.05 wt.%) arsenic. Silver occurs at significant levels in only two minerals, namely tennantite (0.1-1.2 wt.%) and galena (60-250 ppm, based on three PIXE analyses). Over 30 elements were analyzed by microprobe methods; the PIXE survey also yielded some minor element data. Cadmium is present in sphalerite and tennantite at concentrations of 0.33 and 0.1 weight percent, respectively. Chalcopyrite contains a few tens of parts per million selenium and indium; tennantite contains up to 500 parts per million tellurium. Pyrite and chalcopyrite may each host tens of parts per million of molybdenum.

Good agreement in reconnaissance surveys of gold by SIMS, and its ultrasensitive variant AMS, indicates that gold contents in pyrite and chalcopyrite are in the 25 to 1000 parts per billion range, with the higher values occurring in pyrite. This is inadequate to account for the 1.9 to 3.9 grams per tonne gold reported in the bulk assays. Contributions from submicroscopic inclusions at grain boundaries and scattered grains of gold or electrum (not seen in this study) may account for the balance. A third possibility not yet evaluated is a contribution from 'invisible gold' in tennantite (PIXE lacks the sensitivity required for a definitive check on gold).

Conclusions

A preliminary interpretation of the lithological sequence in the H-W area is:

1. Accumulation of a widespread mafic volcanic footwall of andesitic flows and sills.
2. Deposition of some massive sulphides on the mafic volcanic footwall.
3. Accumulation of felsic volcaniclastic debris-flows in the area of the H-W deposit but in felsic flows (or shallow sills) in the area of the north lens.
4. Continued sulphide deposition as infillings within porous unconsolidated felsic debris-flows, and local precipitation of barite and chert.
5. Accumulation of pelagic black mud, with continued episodic deposition of felsic debris-flows in the black muds.
6. Emplacement of an andesite sill/flow complex (H-W andesite) into and onto the felsic debris-flow unit.
7. Accumulation above the H-W andesite of mafic-rich and lesser felsic volcaniclastics that form the second volcanic cycle and host the Myra-Lynx-Price orebodies.

Immobile element plots have been used to effectively identify heavily altered (and locally mineralized) rocks near the H-W orebody. These identifications allow the hangingwall-footwall contact to be established, and permit correlation of individual volcanic (and even volcaniclastic) units within the mine stratigraphy.

Furthur work

Our continued work at Myra Falls will include: definition of the H-W stratigraphy and extent of hydrothermal alteration using detailed lithogeochemistry and petrography; comparison of H-W stratigraphy with that of the Battle zone 1 to 2 kilometres to the west (Robinson *et al.*, 1994, this field guide); identification of the mineral assemblages in the H-W orebody and the trace metal composition of sulphides and sulphosalts; and characterization of the temperatures and compositions of the mineralizing fluids. Once these volcanic units are identified using immobile element relations, mass changes will be calculated for each mobile element in order to reveal the intensity and distribution of hydrothermal alteration around the H-W orebody.

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MAJOR LITHOLOGIES OF THE BATTLE ZONE, BUTTLE LAKE CAMP, CENTRAL VANCOUVER ISLAND (92F/12E)

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Introduction

The Buttle Lake mining camp (49°34' north, 125°36' west) is located in Strathcona Park near the south end of Buttle Lake, 90 kilometres southwest of Campbell River, British Columbia (Figures 1 and 17). It is a major volcanogenic massive sulphide district hosted by the Myra formation of the Paleozoic Sicker Group. Past production has come from several mines: Lynx open pit, Lynx underground mine, Myra open pit and H-W underground mine. The Price deposit, discovered early in the history of the camp, has received sporadic work but has not been mined. Current production is from H-W mine, however, ore from the recently discovered Battle and Gap zones will be mined in late 1993. Between 1966 and 1992, 13.8 million tonnes of ore grading 1.9% copper, 5.6% zinc, 0.6% lead, 2.2 grams per tonne gold and 64.0 grams per tonne silver had been mined from the camp (Westmin Annual Report, 1992). Of this, 7.5 million tonnes are from H-W, 5.3 million tonnes are from Lynx and 1.0 million tonnes are from Myra mine. Geological reserves as of 1992 are in Table 2 and total more than 12 million tonnes. Exploration within the camp has also defined several new prospective zones. These are: Trumpeter, Ridge and the Main Zone Extension (Figure 18).

Massive sulphides occur mainly at two stratigraphic levels within the Myra formation. The lowest member of the Myra formation, H-W horizon, hosts the H-W main lens and the Battle and Gap zones. The upper Lynx-Myra-Price horizon hosts several small sulphide lenses.

This paper focuses on the lithologies in the Battle zone, and establishes a detailed stratigraphy for the H-W horizon in this area.

History

James Cross and associates from Victoria staked the claims covering the H-W, Lynx, Price and Myra mines in 1918 when Strathcona Park was first opened for prospecting. The Paramount Mining Co. of Toronto started developing the property, but depressed metal prices and inconclusive findings halted the operations in 1925. The property remained dormant until 1959, when the Reynolds Syndicate acquired the claims. An option to purchase agreement was negotiated with Western Mines Limited in 1961. Exploration initially focused on the Lynx showings. By mid-1964, 1.5 million tonnes of ore were defined on five levels. To service the new mine, Western Mines built the present 40-kilometre road along the east side of Buttle Lake. Previous access to the property had been by boat and barge. In 1966 the Lynx pit started production at 775 tonnes per day. Continued drilling established underground reserves and the pit was phased out in favour of underground production by 1975.

In 1970, the Myra deposit was evaluated. Open-pit production began in 1972 and continued until 1986 when the mine closed due to depletion of reserves. In 1976, Brascan

TABLE 2. PROVEN AND PROBABLE GEOLOGICAL RESERVES IN BUTTLE LAKE CAMP, CENTRAL VANCOUVER ISLAND, AS OF 1 JANUARY 1993 (WESTMIN RESOURCES LIMITED ANNUAL REPORT, 1992)

Lense/zone	Reserves (tonnes)	Gold (g/t)	Silver (g/t)	Copper (%)	Lead (%)	Zinc (%)
H-W	8 955 100	2.2	39.6	1.7	0.4	4.3
Lynx	315 300	3.0	94.0	1.7	1.1	10.0
Price	185 000	1.5	66.4	1.4	1.3	10.4
Gap	634 400	3.2	151.5	1.8	1.1	13.3
Battle	2 013 700	1.1	24.2	2.6	0.5	12.7
Extension	231 100	1.2	60.4	1.7	0.4	3.8
Trumpeter	61 200	3.2	68.9	6.3	6.3	4.6
6 Level	120 500	1.3	91.4	0.4	0.9	6.0
TOTAL	12 516 300	2.1	45.6	1.9	0.5	6.3

Ltd. acquired control of Western Mines Limited and formed Westmin Resources Limited. The Price showings were evaluated between 1979 and 1981, but development has been put on hold indefinitely.

Exploration for new orebodies in 1976 resulted in the discovery of H-W deposit three years later at about 1000 metres below the Myra valley floor. Production from H-W main lens began in 1985. Exploration continued into the 1990' s, and in May of 1991, the high-grade Gap lens was discovered. Five months later the Battle zone was found. Current drilling on the property is focused on definition of the Battle and Gap zones.

Regional geology

The Buttle Lake massive sulphide deposits occur within the Myra formation of the Paleozoic Sicker Group. The Sicker Group is the oldest stratigraphic unit recognized on Vancouver Island, and represents the base of Wrangellia, an allochthonous terrane that underlies most of the Island (Jones *et al.*, 1977). The Sicker Group is exposed by three major uplifts: Buttle Lake, Cowichan - Horne Lake and Nanoose (Figure 2, inside front cover).

Table 3 presents an informal revised stratigraphy for the Buttle Lake uplift established by Juras (1987). This table of formations incorporates earlier work by Yole (1969), Jeffery (1970) and Muller (1980). In order of decreasing age the formations recognized are: Price, Myra, Thelwood, Flower Ridge, Buttle Lake and Henshaw.

The Price formation consists of feldspar-pyroxene- porphyritic basaltic andesite flows, flow breccias, hyaloclastites, pillowed flows and minor volcaniclastic sediments. Most flows contain 1 to 8% quartz and chlorite-filled ovoid amygdules less than 1 millimetre long. The freshest rocks are moderately altered to chlorite-epidote-plagioclase-actinolite assemblages. Rocks below massive sulphide lenses are totally altered to sericite and pyrite with or without chlorite. This unit is known to be over 300 metres thick from diamond drilling; the base is not exposed in the Buttle Lake uplift. It is Late Devonian or older based on an isotopic Late Devonian age for the overlying Myra formation. The basaltic andesite probably represents a major period of early arc volcanism (Juras, 1987).

The Myra formation is 310 to 440 metres thick and is composed of rhyolitic to basaltic rocks with lesser sedimentary units. Most volcanic rocks are clastic, with lesser flows and intrusions. Sedimentary rocks are primarily volcanic greywacke with interbedded argillite and chert. Lithologic units are continuous along the northwest trend of the ore zones (Figure 18), but have abrupt lateral northeast to southwest facies changes. Deposition of the Myra formation was complex, because material was deposited from three separate volcanic centres

TABLE 3. TABLE OF FORMATIONS FOR THE PALEOZOIC SICKER GROUP IN THE BUTTLE LAKE UPLIFT, CENTRAL VANCOUVER ISLAND, SOUTHWESTERN BRITISH COLUMBIA. MODIFIED FROM JURAS (1987).

Paleozoic age	Formation	Thickness	Lithology
Early Permian(?)	Henshaw formation	5-100 m	Conglomerate, epiclastic deposits, vitric tuff
Early Permian to Pennsylvanian	Buttle Lake formation	300 m	Crinoidal limestone[3], minor chert
Pennsylvanian or Mississippian	Flower Ridge formation	650+ m	Moderately to strongly amygdaloidal mafic lapilli tuff (scoria clast), tuff breccia, minor tuff and flows, and syndepositional(?) sills[2]
Early Mississippian(?)	Thelwood formation	270-500 m	Subaqueous pyroclastic deposits, siliceous tuffaceous sediments, mafic sills
Late Devonian	Myra formation	310-440 m	Intermediate to felsic[1] volcanics, volcaniclastics, minor sediments, massive sulphide mineralization
Late Devonian or older	Price formation	300+ m	Feldspar-pyroxene porphyritic basaltic andesite flows, flow breccias, minor sediments

[1] 370 ± 6 Ma, U-Pb zircon (Juras 1987).
[2] 276 ± 8 Ma, K-Ar hornblende: Early Permian (unpublished data; C. Godwin, J. Harakal and D. Runkle, The University of British Columbia).
[3] Pennsylvanian to Early Permian based on brachiopods (Fyles, 1955), fusulinids (Sada and Danner, 1974), foraminifera (Muller *et al.*, 1974) and conodants (Brandon *et al.*, 1986).

(Juras, 1987). Rhyolite flows and volcaniclastic rocks were formed within an ancient volcanic arc to the northeast, towards Buttle Lake. Massive sulphides, pelagic deposits, volcanogenic sediments and andesite flows fill an intra-arc basin. Mafic flows and volcaniclastic deposits mark an intra-arc or back-arc provenance to the northwest, towards Mount Myra. Uranium-lead zircon dating of rhyolite by Juras (1987) established a Late Devonian age of 370 Ma for the Myra formation. Details of the formation are outlined in the following section on mine geology.

The Thelwood formation unconformably overlies the Myra formation. It is 270 to 500 metres thick and consists of fine-grained siliceous tuffaceous sediments, volcaniclastic debris-flows and penecontemporaneous mafic sills. Tuffaceous sedimentary units may be 5 to 30 metres thick. They are generally massive, fine to coarse crystal-lithic tuff at the base and are capped by pale green to grey, locally cherty, thin-bedded tuffaceous mudstone and siltstone. Most units represent an A, E turbidite sequence. Volcaniclastic debris-flows are 4 to 25 metres thick, moderately well sorted, crudely stratified, and consist of vitric-lithic, fine lapilli-tuff and coarse tuff. Scoured bases and boulder sized rip-up clasts of tuffaceous sediment units are common. Mafic sills are 1 to 90 metres thick and consist of basaltic andesite. Contacts with the sediments are locally peperitic, indicating that the Thelwood formation was unlithified at the time of sill intrusion (Juras, 1987). Thus, this unit represents a sediment-sill complex of the Guyamas Basin type. The Thelwood formation has not been dated in the Buttle Lake uplift. However, the sediment-sill unit of Muller *et al.* (1974) in the Cowichan - Horne Lake uplift probably correlates with the Thelwood formation. The sediment-sill unit contains radiolaria of Mississippian age (Muller, 1980).

The Flower Ridge formation is dominantly basaltic volcaniclastic rocks in conformable contact with the Thelwood formation. It is over 650 metres thick and is characterized by strongly amygdaloidal feldspar and pyroxene porphyritic basaltic lapilli-tuff and pyroclastic breccia. Amygdules are filled with quartz, albite, clinozoisite and/or epidote and pumpellyite. Other rock units include tuffaceous siltstone and wacke, basalt flows and flow breccias, bedded tuffaceous mudstone and argillaceous sediments. The section is expanded by a large number of hornblende-phyric basaltic sills. The Flower Ridge formation marks the resumption of shallow marine mafic volcanism. A K-Ar date of 276±8 Ma on hornblende (unpublished data, C. Godwin, J. Harakal and D. Runkle, 1991) from the sills indicates that this unit may be Early Permian if the sills are penecontemporaneous.

The Buttle Lake formation is primarily massive to bedded crinoidal limestone with associated chert lenses and nodules, greywacke and argillite. This unit is 100 to 500 metres thick and conformably overlies the Flower Ridge formation. The age of this unit is Pennsylvanian to Early Permian based on brachiopods (Fyles, 1955), fusulinids (Sada and Danner, 1974), foramanifera (Muller *et al.*, 1974) and conodants (Brandon *et al.*, 1986).

The Henshaw formation both overlies and locally scours out the Buttle Lake formation. It is 5 to 100 metres thick and is composed of conglomerate, distinctive purple epiclastic deposits and purple to grey vitric tuff beds. Crinoidal limestone boulders are characteristic. The Henshaw formation marks the unconformity between the Buttle Lake limestone and basalt of the overlying Triassic Karmutsen Group.

Mine geology: the Myra formation

The Myra formation is a complex sequence of mafic to rhyolitic volcaniclastic rocks and lesser flow units that fill a basin that trends northwest. The formation is characterized by relatively continuous units in a northwest-southeast direction but by rapid northeast-southwest facies variations (Walker, 1985). Juras (1987) recognized ten lithostratigraphic units in the Myra formation, displayed on the schematic cross-section of Figure 19 (*cf.* Figure 22). They are: H-W horizon, hangingwall andesite, ore clast breccia, lower mixed volcaniclastics, upper dacite/5E andesite, Lynx-Myra-Price horizon, G-flow, upper mixed volcaniclastics, upper rhyolite and upper mafic.

Lithology

H-W HORIZON

The H-W horizon is predominantly felsic flows and volcaniclastics. It is 15 to 200 metres thick and occurs throughout the mine area. There are five general members within H-W horizon (Juras, 1987): massive sulphide lenses; argillite; H-W mafic; pyroclastic and epiclastic deposits; and felsic flows and domes. H-W horizon is discussed in detail in the section on the geology of the Battle zone.

Massive sulphides are pyrite-rich, zoned lenses with chalcopyrite-rich core zones and zinc-rich margins. The H-W main lens is the largest on the property, and contained a total of 12 million tonnes of massive sulphide. The argillite member is 1.5 to 45 metres thick and consists of black siliceous argillite, fine to coarse rhyolitic tuff and minor chert. It is massive to thin bedded, and represents A, E and A, B, E turbidite sequences. The H-W mafic unit intrudes and flows over the argillite member. It is a pale green pyroxene-phyric basalt with peperitic, pillowed and quench brecciated (hyaloclastite) margins. Pyroclastic and epiclastic deposits make up most of H-W horizon in the central region. Pyroclastic deposits are quartz-feldspar crystal- lithic-vitric lapilli tuff and coarse to fine tuff. Epiclastic deposits consist of debris flows, some of which contain up to 25% fragments of Price formation andesite. Felsic flows and domes are of three types: quartz-feldspar porphyritic; aphyric to feldspar porphyritic; and feldspar- porphyritic dacite.

HANGINGWALL ANDESITE

Hangingwall andesite is mostly basaltic andesite flows and hyaloclastite flow breccias. This unit is up to 100 metres thick; individual flow members may be over 3 metres thick. Well-sorted greywackes are also present. The hangingwall andesite is thickest over the H-W main lens, probably because that lens was deposited in a topographic low (Pearson, 1993). The hangingwall andesite is discussed in detail in the next section.

ORE-CLAST BRECCIA

The ore-clast breccia is characterized by massive sulphide clasts (Walker, 1985) and olistoliths of pyrite-mineralized rhyolite up to 50 metres long by 15 metres wide (Juras, 1987). The unit is up to 90 metres thick and consists of a series of submarine debris-flows and lesser pyroclastic deposits. There are three distinct members within the ore-clast breccia (Juras, 1987): rhyolite-rich volcaniclastic breccia with about 25% non-andesite or mafic constituents; rhyolite-poor volcaniclastic breccia with less than 10% non-andesite or mafic constituents; and interzone pyroclastic rhyolite. Clast types within the volcaniclastic breccia members are highly variable. In decreasing order of abundance they are: feldspar-phyric andesite, amygdaloidal mafic, dacite, quartz-feldspar-porphyritic rhyolite, massive sulphide, fine rhyolite tuff, chert and argillite. Clast sizes range from 1 centimetre to 150 centimetres across. The interzone rhyolite member is up to 20 metres thick and consists of bedded felsic tuff, lapilli tuff and tuff-breccia. It represents a period of felsic phreatomagmatic activity (Juras, 1987) that interrupts slide and debris-flow sedimentation.

LOWER MIXED VOLCANICLASTICS

Lower mixed volcaniclastics are dominated by andesite with lesser dacite fragments. The unit also includes rare thin flows of andesite. This unit is up to 90 metres thick and contains bedded clastic sequences and coarse clastic deposits. Bedded clastic sequences contain mostly aphyric to plagioclase-phyric subrounded andesite fragments with lesser broken to euhedral plagioclase crystals. Coarse deposits contain two types of andesite and lesser dacite clasts. Most andesite fragments contain 15% feldspar crystals and are perlitic. Other andesite fragments are feldspar glomeroporphyritic. Lower mixed volcaniclastics are distinguished from the ore-clast breccia by the absence of rhyolite and massive sulphide fragments (Juras, 1987).

UPPER DACITE/5E ANDESITE

Upper dacite/5E andesite occurs at the southeast and northwest ends of the mine property respectively. The upper dacite is divided into upper and a lower members. The lower member is up to 60 metres thick and contains resedimented hyaloclastite and pillow breccia and subaqueous pyroclastic deposits. The upper member is mostly intermediate flows with yellow-green to dark grey to purple feldspar-porphyritic flow clasts. Flows are medium to dark green with 25% feldspar crystals. The 5E andesite sequence of massive to pillowed basaltic andesite flows and flow breccias is up to 250 metres thick. Upper dacite and the 5E andesite represent two contemporaneous, but different, eruptive events (Juras, 1987).

LYNX-MYRA-PRICE HORIZON

Lynx-Myra-Price horizon is massive to bedded, fine to coarse quartz-feldspar crystal-vitric rhyolitic tuff, lapilli tuff and lesser chert (Juras 1987, Walker 1985). Massive sulphides occur at two levels within the Lynx-Myra-Price horizon. Some lenses are located at the base of the horizon where they are underlain by schistose sericite-quartz-pyrite feeder zones within the 5E andesite. Other lenses occur at the upper contact with G-Flow. Upper sulphide lenses have no underlying feeder zones. The variably altered rhyolite tuffs and lapilli tuffs probably served as a conduit for mineralizing fluids, which channelled them laterally to hydrothermal discharge sites. Massive sulphide lenses are composed of banded sphalerite, barite, pyrite, chalcopyrite, galena and tennantite.

G-FLOW

G-flow is a widespread but thin (2 to 15 m thick) package of komatiitic basalt flows and hyaloclastite breccias immediately above the Lynx-Myra-Price horizon (Juras, 1987). Least altered flow rocks consist of 5% augite glomerocrysts, trace chromite microphenocrysts and trace olivine phenocrysts. The groundmass is fine-grained actinolite, chlorite, plagioclase and relict clinopyroxene. Hyaloclastite breccias are locally hematite altered to a distinctive purple. Spherulitic textured jasper fills interstices between breccia fragments.

UPPER MIXED VOLCANICLASTICS

The upper mixed volcaniclastics are mafic to intermediate fine to coarse deposits up to 50 metres thick (Juras, 1987). Fine deposits are thin to medium-bedded, well-sorted, normally graded feldspar-crystal intermediate to mafic tuff. Locally, these deposits are capped by maroon fine tuff. Coarse deposits are characterized by a wide textural variety of mafic to intermediate clasts in a matrix composed of 5 to 15% feldspar crystals in an epidote-albite-chlorite groundmass. Lesser clast types include massive to flow-banded rhyolite, rip-up clasts of tuffaceous siltstone and white to black chert.

UPPER RHYOLITE

The upper rhyolite is 50 to 65 metres thick and contains two members: a pyroclastic-rich and a siliceous argillite and chert dominant member (Juras 1987, Walker 1985). The pyroclastic member is up to 50 metres thick and generally coarsens upward, although individual beds are normally graded. The deposits are thin to medium-bedded crystal-lithic-vitric coarse tuff to lapilli tuff, and lesser fine tuff and tuff-breccia deposits. The siliceous argillite and chert member is 1 to 15 metres thick and consists of grey to black siliceous argillite, white to pale green chert, green to grey fine rhyolite tuff and minor jasper. Round radiolarian "ghosts" occur in the argillaceous material.

UPPER MAFIC

The upper mafic unit is pyroxene-feldspar- porphyritic basalt. It is 5 metres to over 200 metres thick and is the uppermost unit within the Myra formation. Because the Myra formation is unconformably overlain by the Thelwood formation, the upper mafic unit is absent in some areas (Juras, 1987). Most of the unit is comprised of pyroclastic and hydroclastic deposits. Flows are present in the middle to upper parts of the upper mafic unit, and are 3 to 15 metres thick.

Structure

The main structural feature of the Buttle Lake camp is a megascopic subhorizontal, northwest-trending asymmetric anticline with a steeply dipping southwestern limb and a gently dipping northeast limb (Figures 19 and 22). Related mesoscopic fold structures are most common in massive sulphides and associated sericitic alteration zones. Axial planar foliation trends northwest with nearly vertical to steeply northeast dipping surfaces. Most fragmental rocks have stretched clasts that may reach length to width ratios of greater than 10:1. In general, the long axes of stretched clasts parallel the hinge (b-axis) of the anticline. Prominent a-c joints, locally quartz-carbonate veined, are present throughout the mine area.

Faults of various ages and orientations cut the mine stratigraphy. Most are high-angle normal faults with trends to the northeast, north, northwest and east-southeast; some are strike-slip. Figure 19 shows the North fault which dips around 45^{o} and downdrops the northeastern part of the mine stratigraphy by about 800 metres. It is one of the youngest faults as it cuts the overlying Thelwood formation. Some of the oldest normal faults are synvolcanic faults within the Price andesite. These important structures commonly localize synmineral feeder zones to massive sulphide mineralization. Later thrust faults dip 30^{o} and displace both the orebodies and the overlying rocks. Many of these are filled with gouge, quartz veins and late mafic dikes.

Lithology of the Battle zone

Battle zone massive sulphide lenses occur at three stratigraphic levels within the H-W horizon (Figures 19 and 25): main Battle; upper zone and Gap zone. Main Battle massive sulphides occur at the Price formation contact. Upper zone massive sulphides form thin lenses at the contact between rhyolitic volcaniclastics and an overlying rhyolite flow-dome complex. Gap massive sulphides occur as high-grade lenses proximal to the rhyolite flow-dome complex.

The geology in the Battle zone is complex due to synmineral and postmineral faulting, rapid facies changes and obliterating alteration. For these reasons, a detailed stratigraphy of the upper Price formation and the H-W horizon was established to unravel structural offsets and to help target ore zones (Figures 25 and 26). As most of the large orebodies occur in paleo-depressions within the Price formation, identification of synmineral normal faults is critical.

Price formation

The Price formation is a sequence of massive to pillowed basaltic andesite flows, volcanic breccias and inter-flow clastic sediments that include turbidites. It is over 300 metres thick, and is the lowermost unit in the mine area and the Buttle Lake uplift (Juras, 1987). The base has not been identified. Only the upper 75 metres of the formation have been intersected in Battle zone exploration drilling. All of the intersections are intensely altered; primary textures are only sporadically preserved. Individual flows are 5 to 30 metres thick and are the dominant volcanic facies (>80%) in the Price formation. Juras (1987) defined two types of andesite flows elsewhere on the property based on phenocryst assemblages. They are: pyroxene-feldspar-phyric flows with 5% euhedral clinopyroxene crystals 1 to 10 millimetres long and 3% plagioclase crystals 0.8 to 2.5 millimetres long; and feldspar-phyric flows with 15% plagioclase crystals 0.6 to 5 millimetres long and trace to 0.5% clinopyroxene phenocrysts 0.5 to 2.5 millimetres long. Feldspar-phyric flows are prevalent in the Battle zone. Contacts to individual flow units may be massive, devitrified tachylite or quench brecciated (hyaloclastite). Devitrified tachylite is dark green-black, and altered to sericite and chlorite. Hyaloclastite breccias are 1 to 6 metres thick and poorly sorted with individual fragments up to 30 centimetres in diameter in a finely shattered matrix. Most show *in situ* jigsaw-fit breccia textures, indicating minimal resedimentation of the breccia fragments. Pillow breccia is also common. Pillow fragments are pinkish, scoriaceous and have convex edges. Inter-flow sediments are moderately well sorted to well-sorted fining-upwards turbidites.

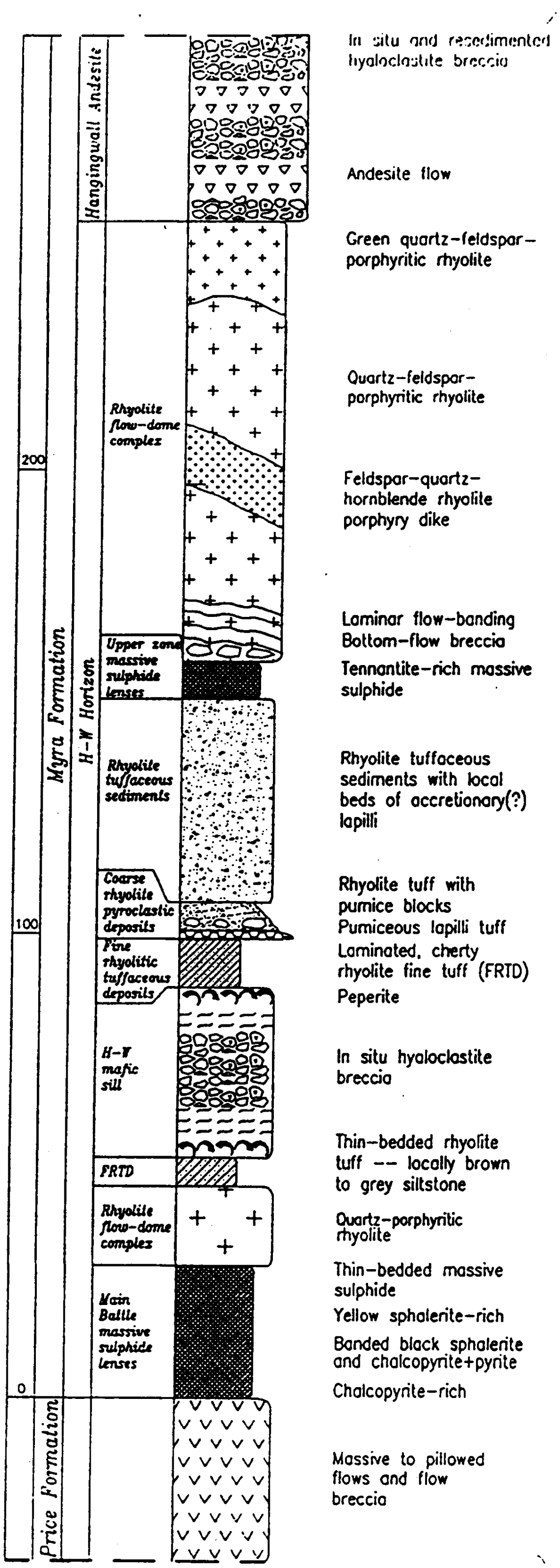

Figure 25. Stratigraphic column of H-W horizon as established mainly in the Battle zone, Buttle Lake camp. Scale on the left is in metres.

H-W horizon

H-W horizon consists of the following eight members in the Battle zone: main Battle massive sulphide lenses, fine rhyolitic tuffaceous deposits, H-W mafic sills, coarse rhyolite pyroclastic deposits, rhyolite tuffaceous sediments, upper zone massive sulphides, rhyolite flow-dome complex and Gap massive sulphide lenses. These members are described below.

MAIN BATTLE MASSIVE SULPHIDE LENSES

The main Battle massive sulphide lens occurs at the contact between the basaltic andesite of the Price formation and the felsic volcanics of H-W horizon (Figures 19, 25 and 26). The main lens is tabular, and is 140 metres wide, 600 metres long and 12 metres thick. Current reserves are about 2 million tonnes of high-grade ore (Table 2). Massive sulphides are zoned with: pyrite and chalcopyrite rich core zones close to synmineral faults; banded pyrite and dark sphalerite in the central parts of most sulphide lenses; and pale yellow sphalerite at the top and periphery of the ore zone. Bedding was found in sulphides at the top of the main ore zone. Bedding to core axis angles in the sulphide unit are the same as in the overlying fine rhyolite tuffaceous deposits. Feeder zones to the main Battle lenses are in the Price andesite, and comprise widespread networks of pyrite-quartz-chalcopyrite veins. The number of veins increases towards synmineral normal faults.

FINE RHYOLITIC TUFFACEOUS DEPOSITS

Fine rhyolitic tuffaceous deposits are mostly tuffaceous chert, thin-bedded fine tuff and tuffaceous sandstone. A typical sequence overlying the ore zone consists of: fine rhyolite tuff with compacted, devitrified, sericitized, pumice fragments; massive grey to purple tuffaceous chert; and thin to medium bedded, graded, well sorted, variably silicified rhyolite tuff. In some areas, fine rhyolite tuff is underlain by brown to grey, thin-bedded mudstone and shaly sandstone. These are not rhyolitic in composition, but are included in this unit because they are fine-grained, thin-bedded sediments above the ore zone. Tuffaceous chert forms a distinctive marker, and is described in detail below.

Tuffaceous chert occurs slightly above and peripheral to massive sulphides. Thin (<50 cm) chert beds locally occur at other levels within the H-W horizon. However, chert associated with the ore zone may attain thicknesses of up to 3 metres. This chert is massive to thin bedded, white-grey to purple or green and has a conchoidal fracture. Pure chert is rare; usually it contains a tuffaceous component and a minor sulphide component. The sulphide component is usually pyrite, although some sphalerite is locally present. Sulphides may occur as thin beds or laminae that form up to 2% of the rock, but epigenetic sulphide stringers are more common. These usually consist of chalcopyrite, sphalerite and pyrite.

H-W MAFIC SILLS

Mafic sills from 5 to 30 metres thick cross-cut the lower strata within H-W horizon. They are pink-brown due to pervasive sericite-pyrite-quartz alteration and contain 20% sericite-filled amygdules 1 to 2 millimetres in diameter. Unaltered examples of this unit were not observed in the Battle zone. Fresh samples from close to the H-W mine are medium olive-green with 5% clinopyroxene phenocrysts and glomerocrysts in a very fine grained groundmass containing feldspar, actinolite, calcite and epidote (Juras, 1987). Both upper and lower contacts of the sills are chaotic, with swirls of white material incorporated into the mafic rock. The white material is siliceous, contains trace quartz eyes, and is most likely silicified felsic sediment that has been incorporated from the fine rhyolite tuffaceous deposits. The chaotic boundary is peperite, which implies intrusion into unconsolidated and felsic rocks. Peperite margins change laterally to pillow breccia. Hyaloclastite occurs at the

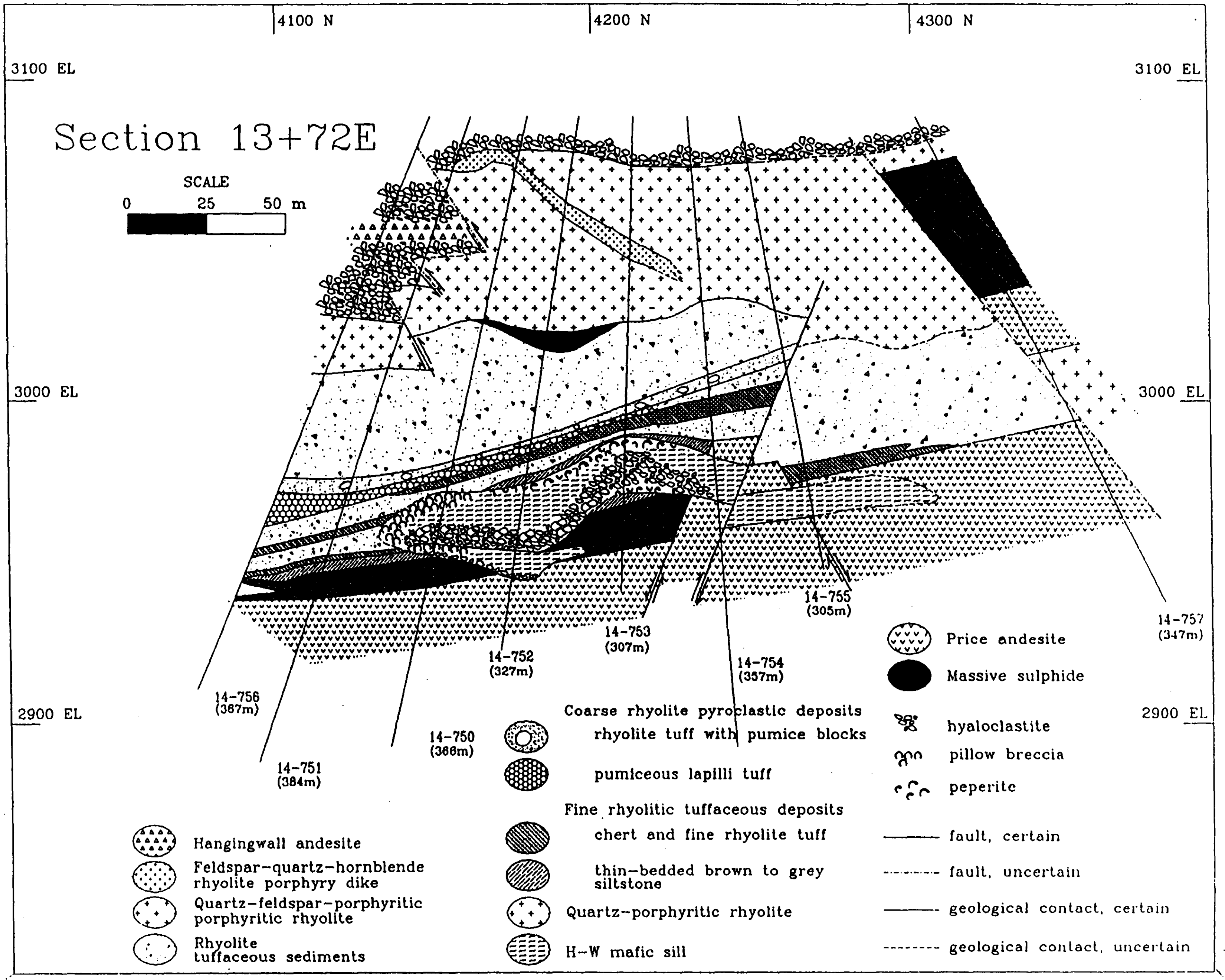

Figure 26. Cross-section of the Battle zone (13+72 E), Buttle Lake camp.

base of most sills. Fragments in the hyaloclastite are arcuate, generally less than 5 centimetres across, and occur in a finely shattered matrix. They retain *in situ* breccia textures, therefore they are not resedimented. The H-W mafic unit probably comprises number of shallow level sills that locally extruded past the sediment-water interface to form pillowed flows. It locally scours the main Battle zone massive sulphide and consequently contains sulphide fragments.

COARSE RHYOLITE PYROCLASTIC DEPOSITS

Coarse rhyolite pyroclastic deposits are composed of two related members: pumiceous lapilli tuff and rhyolite tuff with pumice blocks. Pumiceous lapilli tuff is about 3 metres thick, but locally reaches thicknesses greater than 10 metres. It contains 15% quartz-porphyritic rhyolite cognate lithic fragments in a compacted, pumiceous, crystal-rich matrix with 10% quartz phenocrysts 1 to 2 millimetres across and lesser feldspar crystals. The pumiceous matrix is dark grey to black, and devitrified to sericite. The lithic fragments are subrounded, normally graded, and fine from over 5 centimetres across at the base of the unit to 0.5 centimetres across at the top. They were probably incorporated at the vent, and indicate that the quartz-porphyritic rhyolite (see description below) predated the pyroclastic eruption. The pumiceous matrix shows intense flattening which is restricted to this unit. It is definitely a compaction texture, and may be a result of subaqueous welding (Juras, 1987).

Well-sorted, laminated tuffaceous deposits between 20 centimetres and 2 metres thick cap the lapilli tuff in some areas of the Battle zone. Conspicuously large fragments of black, sericitized, flattened, crystal-rich pumice up to 30 centimetres across occur in these units. This type of deposit is characteristic of water-settled suspension deposition of ash and pumice.

RHYOLITE TUFFACEOUS SEDIMENTS

Rhyolite tuffaceous sediments form a unit about 40 metres thick of fine to coarse, intensely silicified and sericitized tuff, tuffaceous sandstone and lapilli tuff. There are no distinct marker horizons within this unit, however, fine-grained, thin-bedded sediments are more common in the south part of the Battle zone; coarse tuff, lapilli tuff and rare breccias occur mostly to the north. Devitrified, pale green to black pumice fragments occur throughout the entire package. Spherical, concentrically zoned grains up to 10 millimetres in diameter may be accretionary lapilli. They occur in a bed three metres thick at the top (drill hole 14-755).

Polymetallic sulphide stringer networks are common in the rhyolite tuffaceous sediments, probably because it was permeable. Stringer networks are characterized by sphalerite-pyrite-galena-tetrahedrite veins with sericitic alteration envelopes in a pervasively silicified groundmass. Alteration obliterates most of the original textures and makes this rock type difficult to characterize.

UPPER ZONE MASSIVE SULPHIDE LENSES

Upper zone massive sulphide lenses occur mostly at the contact between rhyolite tuffaceous sediments and the overlying quartz-feldspar-porphyritic rhyolite (Figures 25 and 26). They are both exhalative (synsedimentary) and replacement (postsedimentary) in origin. Exhalative upper zone massive sulphides form lenses up to 5 metres thick. They are polymetallic with sphalerite > barite > tennantite > pyrite > galena > chalcopyrite. High tennantite contents make these lenses extremely silver rich (usually 150 g/t but locally up to 1000 g/t), although gold contents are not particularly high (1 to 3 g/t). Replacement upper zone lenses are thin (1 to 2 m thick) but they can be laterally extensive (over 40 m long). They are characterized by a coarse grained pyrite-quartz- sphalerite mineral assemblage.

Feeder zones to upper zone massive sulphide lenses are diffuse polymetallic stockwork zones in the aphanitic rhyolite sediments described above.

RHYOLITE FLOW-DOME COMPLEX

Rhyolite forms long linear bodies that are over 100 metres thick, 100 metres wide and 1000 metres long in the north Battle zone. There are four visually distinct members within the rhyolite flow-dome complex. They are (Figures 25 and 26): quartz-porphyritic rhyolite; quartz-feldspar-porphyritic rhyolite; green quartz-feldspar porphyritic rhyolite and feldspar-quartz-hornblende rhyolite porphyry dikes. The type of phenocrysts and their morphology is unique within each member; they are described in detail below.

Quartz porphyritic rhyolite (QP) occurs in the northernmost part of the Battle zone. It is up to 30 metres thick and forms the basal unit of the flow-dome complex. It overlies and locally intrudes the Price andesite. QP rhyolite is white to pale grey-green with high proportions of sericitized, devitrified volcanic glass. It contains 1 to 2% euhedral hexagonal and square quartz phenocrysts about 1 millimetre in diameter and trace amounts of feldspar phenocrysts. This unit is intensely silicified and sericitized due to its proximity to the ore-forming hydrothermal systems. Silicified flows are often mistaken for cherty units but are distinguishable from chert by the presence of quartz eyes and a sericitic sheen on broken surfaces.

Quartz-feldspar porphyritic rhyolite (QFP) is the most common type of rhyolite within the flow-dome complex. The upper contact with overlying andesite flows and volcaniclastics is sharp or rubbly, and may be unconformable. The lower contact overlies the tuffaceous rhyolite sediments, and may be obscured by hydrothermal alteration. The QFP is characterized by 8% sericitized feldspar phenocrysts, about 3 millimetres long, and 4% euhedral to rounded quartz phenocrysts, 1 to 5 millimetres in diameter, in an aphanitic, weakly flow-banded matrix. There are several distinct morphological units preserved within the QFP. Most of the unit is massive, white-grey to pale green with variable degrees of quartz-sericite alteration. Flow- banding is present throughout, but is concentrated at the base and margins. Flow bands are laminar in the central and basal parts of the flow, and contain aligned phenocrysts and pyrite grains. Upper and marginal parts of the QFP are strongly flow banded and more sericitic, indicating that they were once glassier. Two types of flow banding have been identified in the upper QFP: pumice-shard and chaotic flow bands. Pumice-shard flow bands are characterized by flattened black, devitrified, pumice fragments in a massive QFP matrix. The pumice fragments are stretched out in the direction of flow and define the flow banding. Chaotic flow-banded rhyolite is the most marginal facies. It is characterized by wormy textured flow bands in autobrecciated and quench-brecciated rhyolite. Flow- banded fragments are rotated with respect to each other, making this a very chaotic looking unit. Coarse deposits of rounded QFP fragments occur locally at the top of the flow-dome complex. This unit may be a reworked flow-top breccia.

Green quartz-feldspar-porphyritic rhyolite (GQFP) contains 6% round quartz phenocrysts, 0.5 to 6 millimetres in diameter, and 10% feldspar phenocrysts, 1 to 4 millimetres long, in a green, aphanitic matrix. The green colour is due to tiny crystals of hornblende within the matrix that have altered to chlorite. Locally, this unit is purple tinged where trace amounts of magnetite have altered to hematite.

Feldspar-quartz-hornblende rhyolite porphyry dikes (QFPD) have sharp, quenched contacts with the QFP. This unit is crystal rich with 35% 2 to 3- millimetre feldspar crystals, 7% quartz eyes up to 7 millimetres in diameter, and 2% hornblende crystals. The quartz eyes are partially resorbed and have quartz-feldspar coronas around them. It is mossy green due to chlorite alteration of hornblende.

GAP MASSIVE SULPHIDE LENSES

The Gap massive sulphide lenses (Figure 26) occur close to the contact between the rhyolite flow-dome complex and hangingwall andesite. Many appear to be located in depressions on the flow dome. The largest lenses are associated with quartz-porphyritic rhyolite, the lowest member within the flow-dome complex. Most lenses are zoned from lower copper and pyrite-rich mineral assemblages to upper and peripheral barite and sphalerite-rich zones. Barite-rich massive sulphide from the upper part of the Gap lens is: sphalerite-barite-pyrite-quartz-galena- tetrahedrite. Barite is locally mammilary; convex surfaces face up-hole. Copper-rich mineralization is: pyrite-sphalerite-chalcopyrite-bornite-tetrahedrite-chalcocite. Big black crystals of sphalerite up to 1 centimetre across are common in copper-rich zones and are characteristic. Feeder zones to the Gap are characterized by stockworks of coarse pyrite and quartz veins in the underlying rocks.

Hangingwall andesite

Hangingwall andesite (Figures 25 and 26) is dark green, slightly amygdaloidal, and contains about 25% feldspar and 1% pyroxene phenocrysts. It is weakly altered to a chlorite-epidote assemblage; trace magnetite grains are altered to purple hematite. Amygdules are elongate to lenticular, 1 to 2 millimetres long, and are filled with quartz, epidote and chlorite. Most of the andesite is brecciated; about 30% forms coherent flows. Approximately 10% of the hangingwall andesite consists of inter-flow sedimentary units.

Andesite breccias are composed of poorly sorted, angular fragments with arcuate clast boundaries; many of the fragments also have *in situ* (jigsaw-fit) breccia texture. Exotic fragments of QFP, massive sulphides and pale green rhyodacite comprise no more than 5% of the rock. The shape and arrangement of andesite fragments, as well as the largely monomict rock composition are characteristic of hyaloclastite breccias that form by *in situ*, subaqueous quench fragmentation. Appropriately, the andesite breccias form marginal facies to coherent andesite flows in the Battle zone. A typical andesite flow consists of 2 metres of coherent andesite, with 3 metres of hyaloclastite breccia on both the top and bottom.

The contact between the underlying H-W horizon and hangingwall andesite is generally sharp, although fragments of QFP and QFPD are commonly scoured from the flow-dome complex and incorporated into the overlying andesites. Sericitic alteration that affects the Price formation and the H-W horizon does not extend into the hangingwall andesites. This suggests that there is a time gap between alteration associated with the ore deposits and deposition of the overlying andesites.

Dikes

Most dikes in the Battle zone are mafic. Three distinct types of mafic dikes have been recognized: light green, feldspar-phyric, trachytic mafic dikes; dark green augite and feldspar phyric mafic dikes and andesite dikes. Most of the pale green dikes are intensely altered to an epidote-fuchsite-chlorite-carbonate assemblage and have irregular, quartz-carbonate veined contacts with the country rock. They may have pink quartz-carbonate filled amygdules. Dark green augite-phyric dikes may be fresh or altered to epidote, fuchsite and chlorite; they tend to have sharp contacts. Andesite dikes are dark blue-green, weakly feldspar porphyritic and unaltered. All of the dikes crosscut H-W horizon and the hangingwall andesite.

Some felsic rocks, locally intersected by drill holes in the Price andesite, may be dikes. Their full significance is not known.

Discussion and interpretation of Battle zone geology

Main Battle zone sulphides occur at the base of the felsic H-W horizon, which overlies Price formation. Price formation is a sequence of massive to pillowed flows and associated breccias that was deposited during a series of non-explosive, effusive events. Subsequent rifting formed the Buttle Lake camp basin with **minimum** dimensions of 3 by 10 kilometres (Juras, 1987). The base of the H-W horizon probably marks the initial development of a rift basin, and the first cycle of sulphide deposition (main Battle zone, which is correlative with most mineralization in the H-W mine (Figure 19)). Rifting was probably contemporaneous with the onset of felsic volcanism in the volcanic arc. Massive sulphides of the main Battle zone were deposited in small fault-bounded basins away from the locus of felsic volcanism. The faults provided conduits for metal-rich hydrothermal fluids, which upon reaction with cold sea water at and below the sea floor, deposited sulphide mud. Continued reaction of the mud with circulating fluids zoned most of these mounds to pyrite and chalcopyrite-rich cores with sphalerite-dominant upper and peripheral zones. The dominantly felsic volcanic package of the H-W horizon represents an intra-arc environment within an oceanic island-arc system (Juras, 1987).

Battle zone chert commonly, but not exclusively, occurs just above sulphide lenses (Figures 25 and 26) in the fine rhyolite tuffaceous deposits. A key question is whether or not the cherts are exhalites and therefore closely related to massive sulphides.

Exhalites are distal and proximal, contemporaneous and late-stage products of the hydrothermal systems responsible for forming massive sulphide deposits (Kalogeropoulos and Scott, 1983). They have two components, clastic and chemical. The clastic component may be volcaniclastic, epiclastic or pelagic. The chemical component is dominantly quartz, associated with either iron oxides or iron sulphides. Manganese oxides, iron-rich smectites, sericite, base metal mineralization and anomalous amounts of gold, silver, cobalt and nickel may also be present (Kalogeropoulos and Scott, 1983).

Battle zone cherts are probably not exhalites because: they do not contain significant amounts of iron sulphides or oxides; they are not enriched in gold, silver, mangenese, cobalt or nickel (M. Robinson, unpublished inductively coupled plasma data from Chemex Labs Ltd., Vancouver, British Columbia, 1993); and they have the same immobile element chemistry as the overlying rhyolites (M. Robinson, unpublished data, X-Ray Laboratories Ltd, Toronto, Ontario, 1993). In addition, contact relationships between the massive sulphides and the associated cherts suggest a "competitive" (not a cogenetic) relationship between the two rock types. For example, two closely spaced drill holes with no intervening structures contain an equal thickness (about 4 m) of chert in one hole, and sulphide in the other. A most likely scenario is that the chert was originally deposited as a layer of fine rhyolite ash against which massive sulphides were deposited. Continued hydrothermal activity silicified the ash. The presence of chert layers that are not demonstrably related to sulphide lenses indicates that a hydrothermal source related to sulphide mineralization may not be necessary to their formation.

Emplacement of rhyolite is intimately associated with ore-forming processes in the Battle zone. Fine rhyolite tuffaceous deposits probably represent the first eruption associated with emplacement of the quartz porphyritic rhyolite (QP). These deposits competed with the main Battle sulphide lenses for space during the waning stages of their deposition (see above). Massive to weakly flow-banded quartz-porphyritic rhyolite (QP) intrudes both the andesite basement and its own ejecta. This unit occurs in the footwall below the largest of the Gap massive sulphide lenses. Pumiceous rhyolite lapilli tuff forms a pyroclastic flow up to 10 metres thick throughout the Battle zone (Figure 26). It contains fragments of QP and therefore postdates eruption of the QP.

The thick section of rhyolite tuffaceous sediments may represent a period of pyroclastic activity preceeding the emplacement of the flow-banded quartz-porphyritic rhyolite. Alternatively, it may represent a period of epiclastic sedimentation. The high degree of alteration in this unit makes it difficult to determine the exact nature of this deposit. Local beds of accretionary lapilli(?) and devitrified pumice blocks occur throughout, supporting a pyroclastic origin for the sediments. However, the presence of locally preserved well-sorted fine turbidite units, especially distal to the dome, favours an epiclastic origin. Sericitized areas, which might be mistaken for pumice fragments, are commonly alteration envelopes surrounding sulphide veins. This unit was probably permeable and may have channeled hydrothermal fluids towards upper zone lenses of both exhalative and replacement type. The thicker lenses are exhalative, contain sphalerite > barite > tennantite and appear to mark a short hiatus between sedimentation and emplacement of the QFP, which intrudes and overlies the rhyolite tuffaceous sediments. The hydrothermal system continued to circulate, but fluids then became focused along the boundary between the QFP and the underlying sediments. Replacement-style upper zone massive sulphides were deposited against this boundary. These lenses are usually no more than 2 metres thick and are characterized by the presence of coarse-grained pyrite.

Gap massive sulphide lenses were deposited in depressions at the top and peripheral to the QP unit of the rhyolite flow-dome complex. They are overlain by thin flows of the QFP rhyolite. The QFP appears to have formed a cap over the Gap massive sulphide lenses which prevented their erosion. Green quartz-feldspar-porphyry flows (GQFP) overlie the QFP in central regions of the Battle zone. The last felsic event in H-W horizon was the intrusion feldspar-quartz-hornblende rhyolite porphyry dikes (QFPD). Locally, these dikes may extrude on top of the QFP and feed crystal-rich flows. Rhyolite units within the flow-dome complex progressively increase in mafic mineral content and become more coarsely crystalline as they decrease in age. This suggests progressive, episodic emplacement from deeper regions of a crystallizing source magma chamber. Crystallization of the QFP could have driven off metal-rich magmatic waters which may be related to the unique character of Gap-style mineralization.

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NOTES