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 (Figure 1). 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 (Pearson, 1993). Geological reserves as of 1992 are in Table 1 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 1).

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 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 3 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.
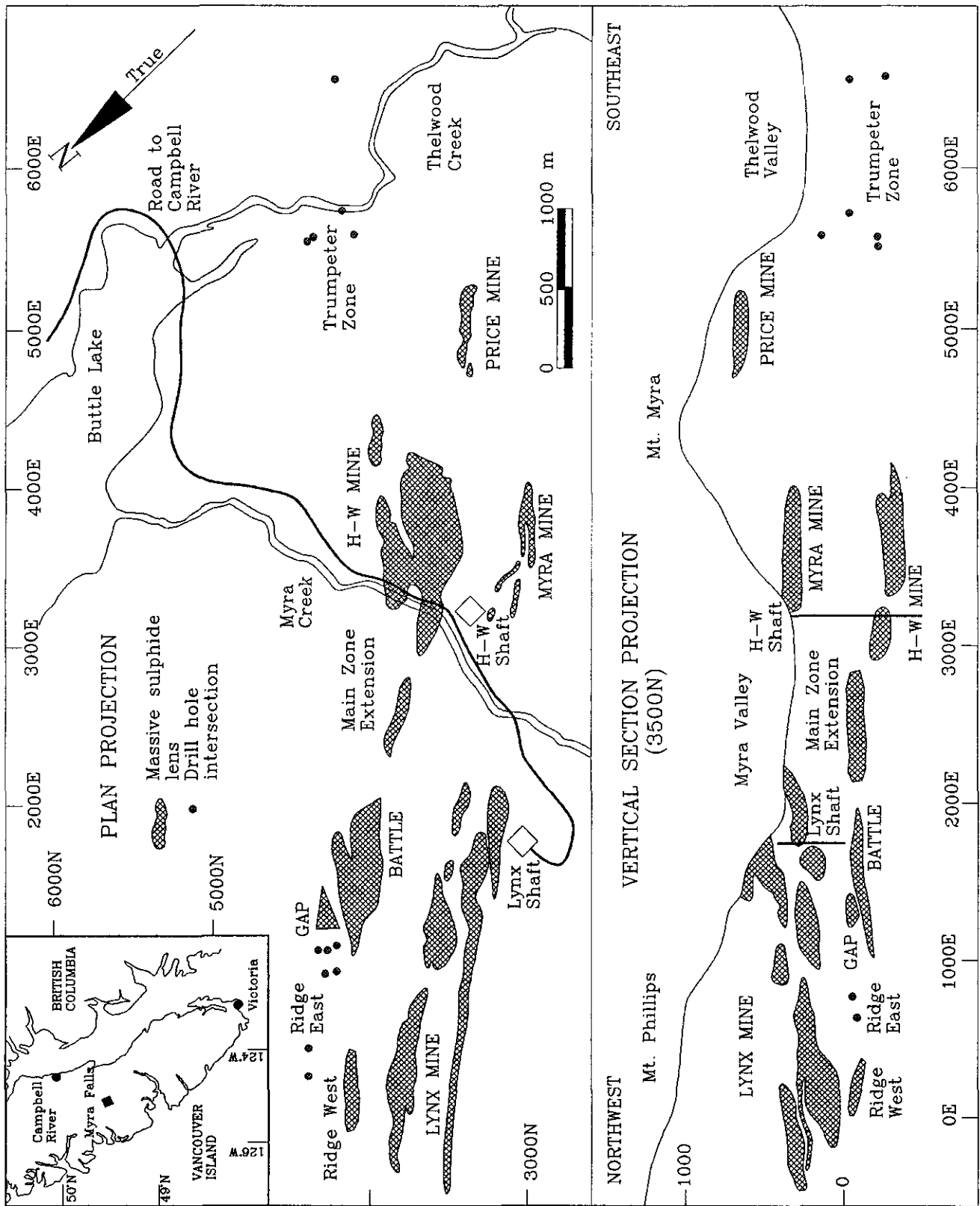
Figure 1. Buttle Lake mining camp, central Vancouver Island, southwestern British Columbia, showing the surface and vertical projections of major orebodies and prospective zones (Westmin Resources Limited Annual Report, 1992).

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

	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

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.

Table 2 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 1), 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 (Juras, 1987). Rhyolite flows and vo caniclastic 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).

		Formation	Thickness	Lithology
Paleozoic	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).

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 3. 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 (Juras, 1987).

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 textured. 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. The 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. The 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
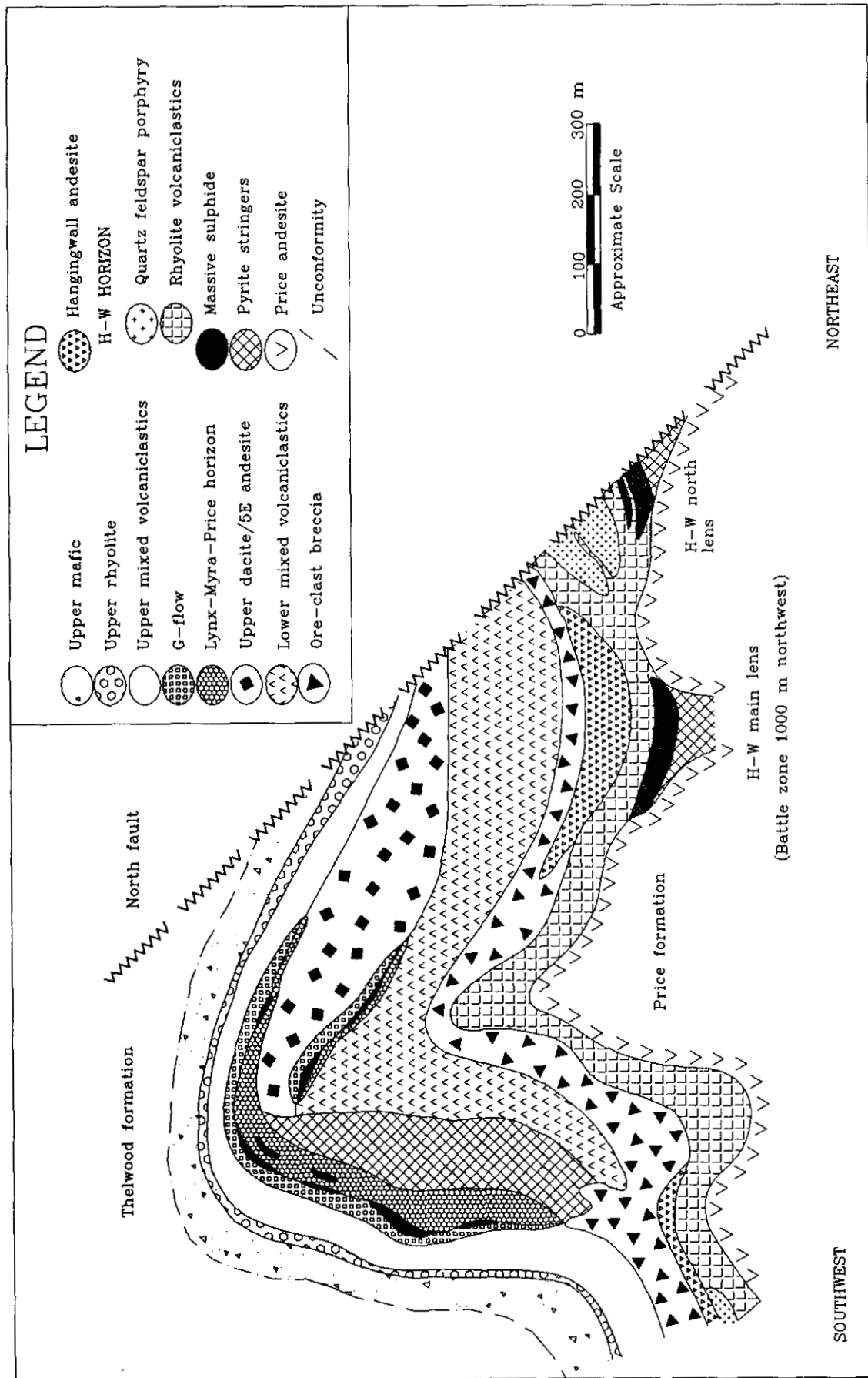
Figure 2. Schematic cross-section of the Myra formation, Buttle Lake camp, central Vancouver Island, southwestern British Columbia. The Myra formation hosts all known volcanogenic massive sulphide deposits in the camp. Figure is compiled from Juras (1987) and Pearson (1993).

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 (Walker, 1985; Figure 3). 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 (Juras, 1987; Walker, 1985). Most are high-angle normal faults with trends to the northeast, north, northwest and east-southeast; some are strike-slip. Figure 3 shows the North fault which dips around 45° 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° 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 3 and 4): 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. 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 (Plate 1a). 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 (Plate 1b). Pillow fragments are pinkish, scoriaceous and have convex edges. Inter-flow sediments (Plate 1c) are moderately well sorted to well-sorted fining-upwards turbidites.

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 is tabular and occurs at the contact between the basaltic andesite of the Price formation and the felsic volcanics of H-W horizon (Figure 4). Current reserves are about 2 million tonnes of high-grade ore (Table 1). Massive sulphides are zoned with: pyrite and chalcopyrite rich core zones close to synmineral faults (Plate 2a); banded pyrite and dark sphalerite in the central parts of most sulphide lenses (Plate 2b); and pale yellow sphalerite at the top and periphery of the ore zone (Plate 2c). Bedding was found in sulphides at the top of the main ore zone (Plate 2d). 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 (Plate 3a); and thin to medium bedded, graded, well sorted, variably silicified rhyolite tuff (Plate 3b). 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 (Plate 3a) 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.
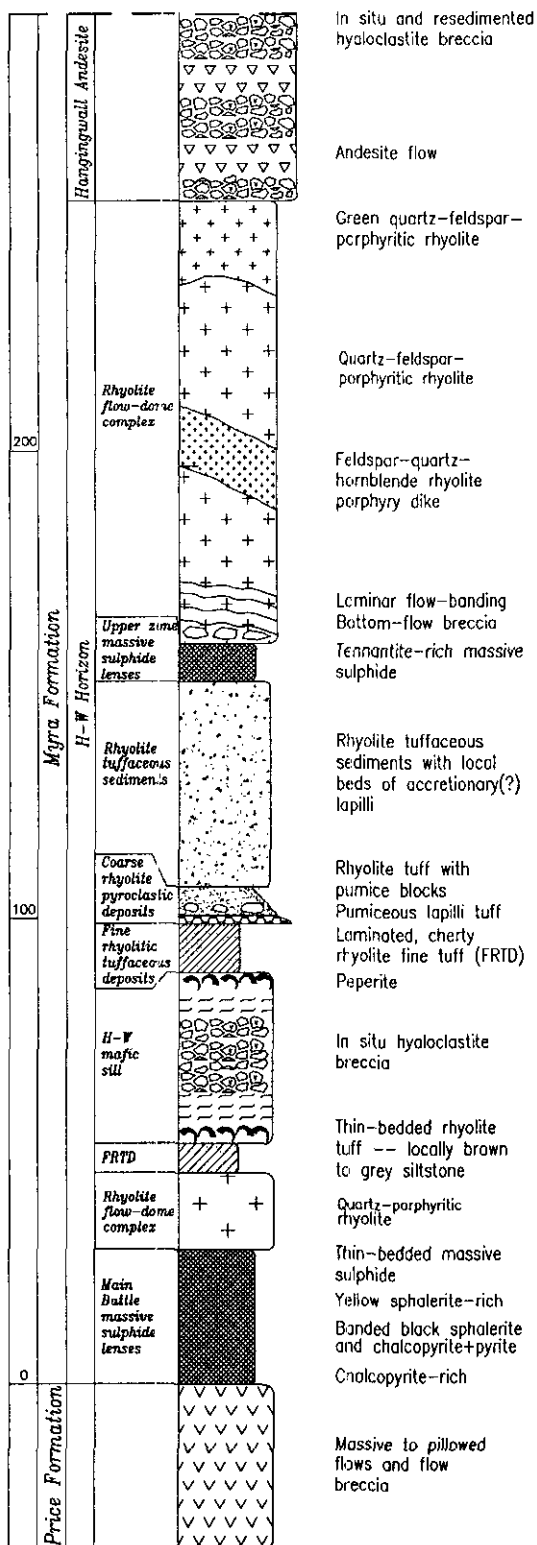
Figure 3. Stratigraphic column of H-W horizon as established mainly in the Battle zone, Buttle Lake camp. Scale on the left is in metres.

H-W 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 (Plate 4a). 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 (Plate 4b). 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 base of most sills (Plate 4c and Figure 5). 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 5 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 (Plate 5a). The pumiceous component 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 desription below) predated the pyroclastic eruption. The pumiceous component 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).
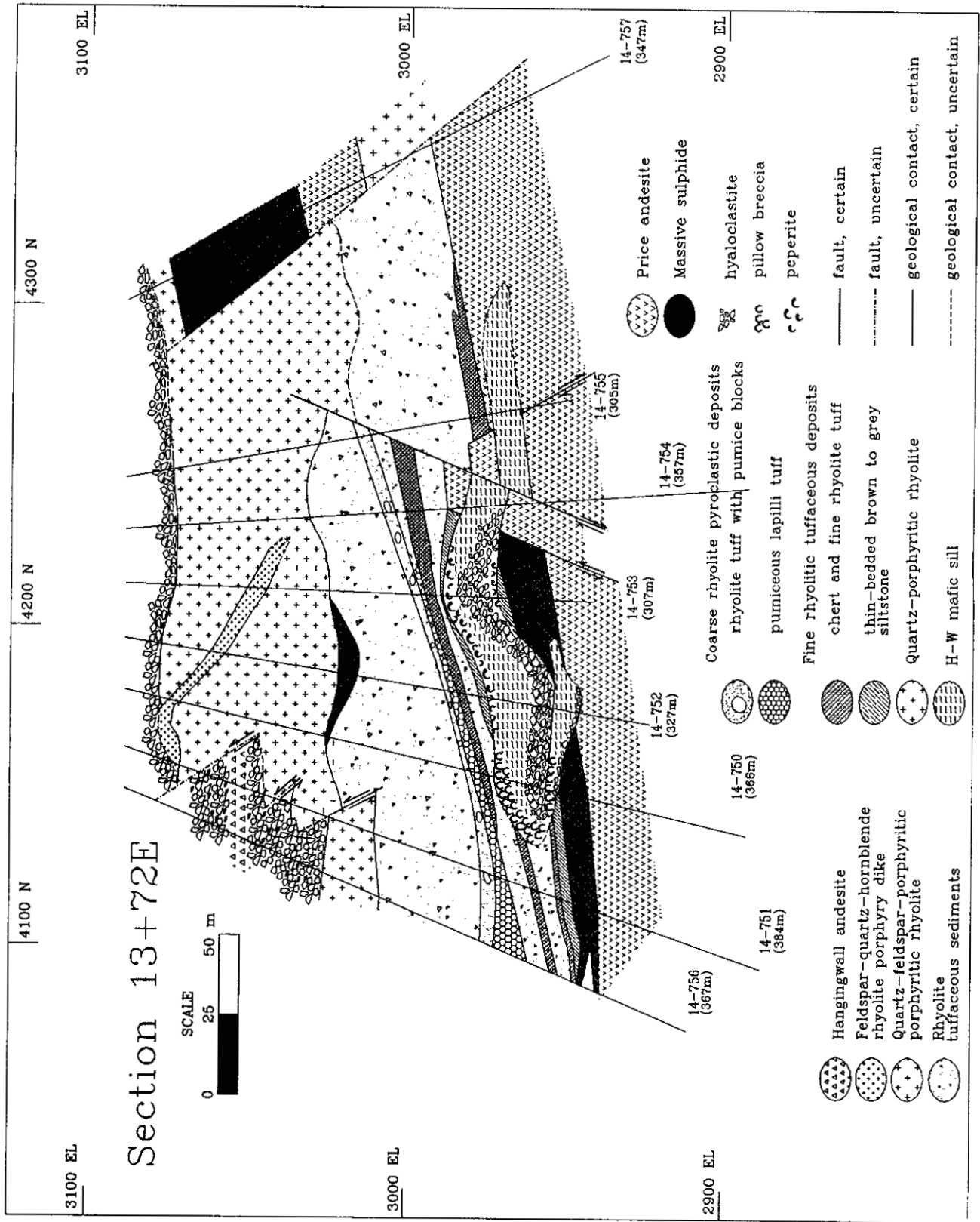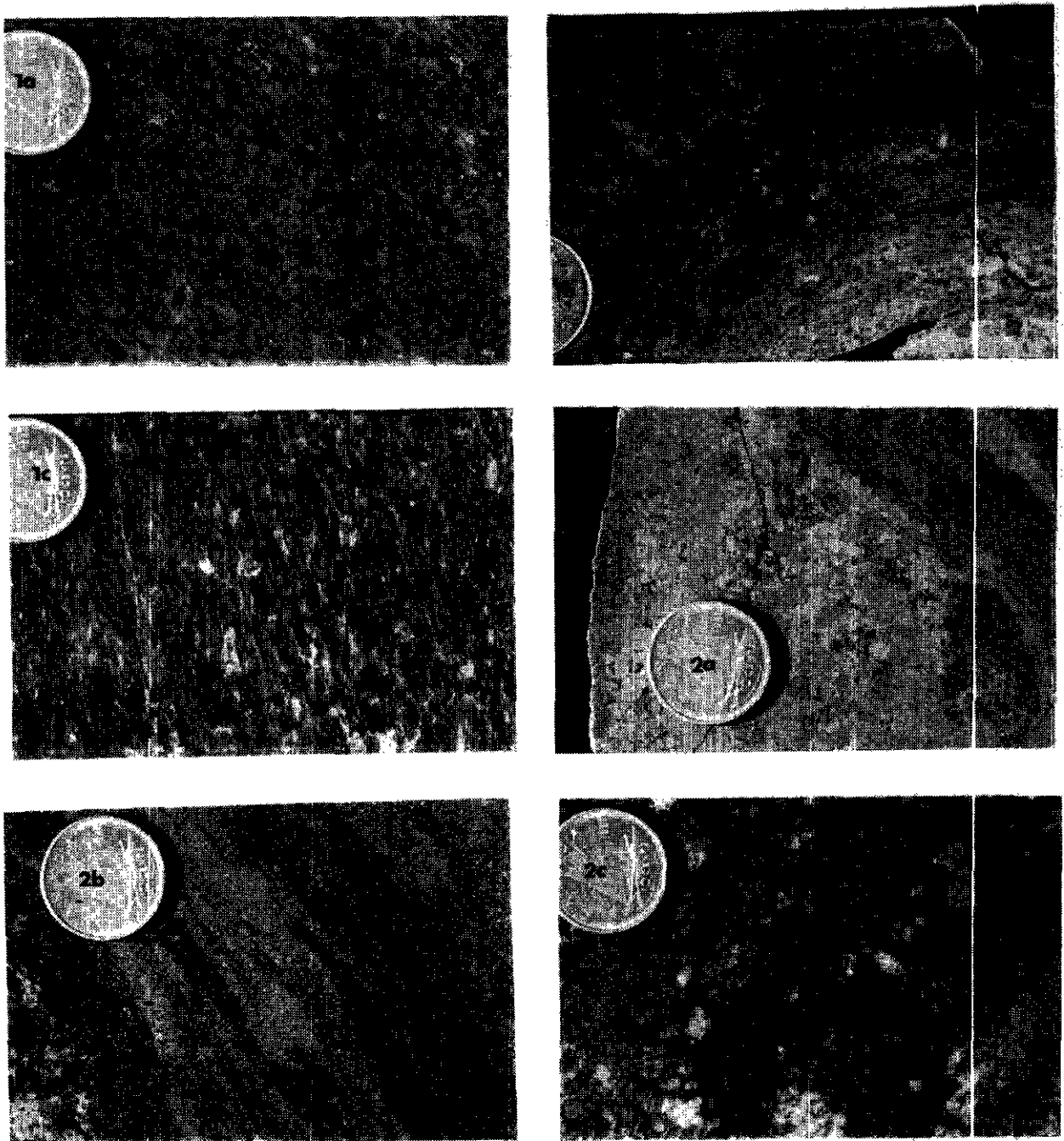
Figure 4. Cross-section of the Battle zone (13+72 E), Buttle Lake camp.

Section 13+72E

SCALE
0   25   50 m

Hangingwall andesite

Feldspar–quartz–hornblende
rhyolite porphyry dike

Quartz–feldspar–porphyritic
porphyritic rhyolite

Rhyolite
tuffaceous sediments

Coarse rhyolite pyroclastic deposits
rhyolite tuff with pumice blocks

pumiceous lapilli tuff

Fine rhyolitic tuffaceous deposits
chert and fine rhyolite tuff

thin–bedded brown to grey
siltstone

Quartz–porphyritic rhyolite

H–W mafic sill

Price andesite

Massive sulphide

hyaloclastite

pillow breccia

peperite

fault, certain

fault, uncertain

geological contact, certain

geological contact, uncertain

14–757
(347m)

14–755
(305m)

14–754
(357m)

14–753
(307m)

14–752
(327m)

14–750
(366m)

14–751
(384m)

14–756
(367m)

3100 EL

3000

2900 EL

4300 N

4200 N

4100 N

3100 EL

3000 EL

2900 EL

Plate 1. *Price formation.* (a) Massive andesite flow (DDH 14-751, 375 m or 1230 feet). Flows are the dominant volcanic facies (>90%) in the Price formation. Specimen has 25% green sausseritized feldspar, 1% pyroxene, 3% quartz-filled amygdules and 2% disseminated pyrite. (b) Andesite pillow breccia (DDH 14-757, 341.6 m or 1121 feet). Scoriaceous pillow fragmen with 2 to 10 millimetre quartz-filled amygdules. (c) Interflow sediments (DDH 14-751, 354.5 m or 1163 feet). Fragments are si brounded, moderately well sorted coarse sand to pebble-sized grains of Price andesite.

Plate 2. *Main Battle massive sulphide lenses.* (a) Chalcopyrite-rich ore from the basal part of the sulphide lens (DDH 14-751, 323.4 m or 1061 feet). Veins of coarse pyrite and chalcopyrite cross-cut and replace fine-grained dark brown sphalerite. (b) Banded pyrite and dark sphalerite from the middle part of the sulphide lens (DDH 14-751, 321.3 m or 1054 feet). Chalcopyrite-rich vein crosscuts banded sulphides. (c) Pale yellow sphalerite from the top of the sulphide lens (DDH 14-751, 318.8 m or 1046 feet) Sample, almost pure sphalerite with 5% pyrite, has 15% chert inclusions. (d) Interbedded sphalerite, pyrite and shale from top of the sulphide lens (DDH 14-753, 280 m or 920 feet). Bedding to core axis angles in the sulphide unit are the same as in the overlying ine rhyolitic tuffaceous deposits. Chalcopyrite is concentrated in dewatering pillar structures that are perpendicular to the bedding.
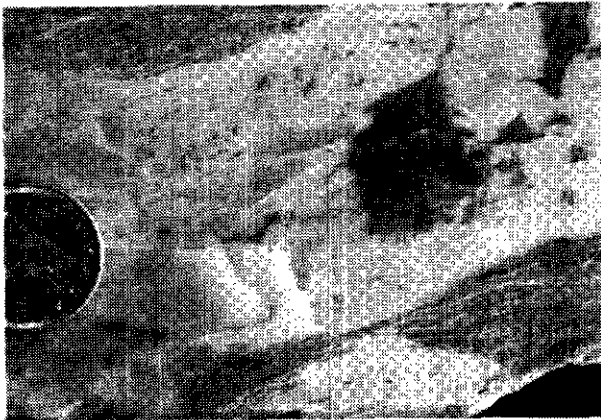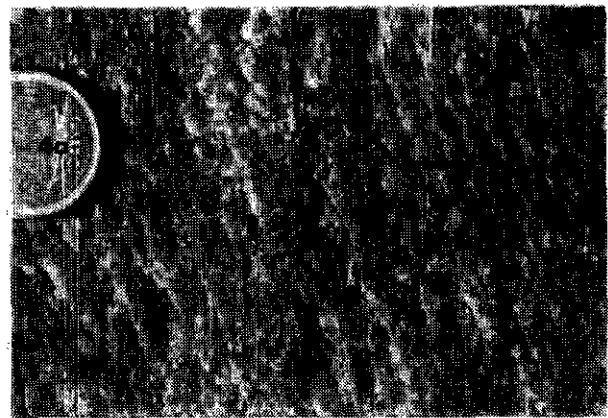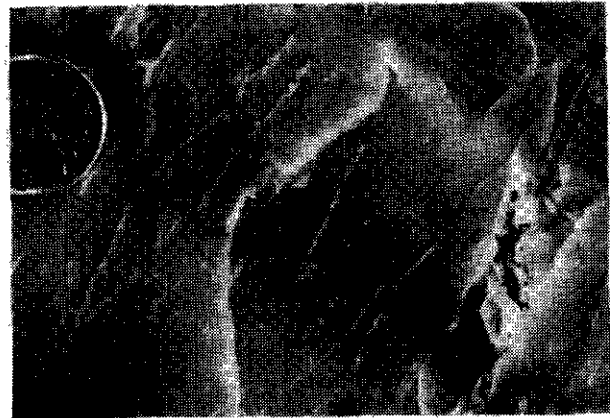
Plate 3. *Fine rhyolitic tuffaceous deposits.* (a) White, distinctively laminated chert (DDH 14-751, 306 m or 1004 feet). Locally Battle zone chert may be silicified rhyolite tuff. Quartz and sulphide veins crosscut laminations at 90°. (b) Fine-grained rhyolite tuffaceous sandstone (DDH 14-751, 290 m or 953 feet). Dark grey layer on the left (base) is mostly flattened pumice fragments with 10% 1- millimetre quartz crystals. Pale grey layer is fine-grained, silicified rhyolite tuff with quartz veins perpendicular to bedding. Layer at right (top) is coarse-grained rhyolite tuff. It contains 0.5% quartz crystals and 2% black devitrified pumice fragments.
Plate 4. *H-W mafic sill.* (a) Massive sill (DDH 14-753, 268 m or 879 feet). The sample is pink due to pervasive sericite-pyrite alteration. (b) Swirly pink and white peperite from the top of sill (DDH 14-753, 263 m or 863 feet). White material is siliceous and contains euhedral quartz crystals; it is most likely incorporated felsic tuffaceous sandstone from overlying units. (c) *In situ* hyaloclastite (DDH 14-750, 299 m or 980 feet); the matrix is pyritized.
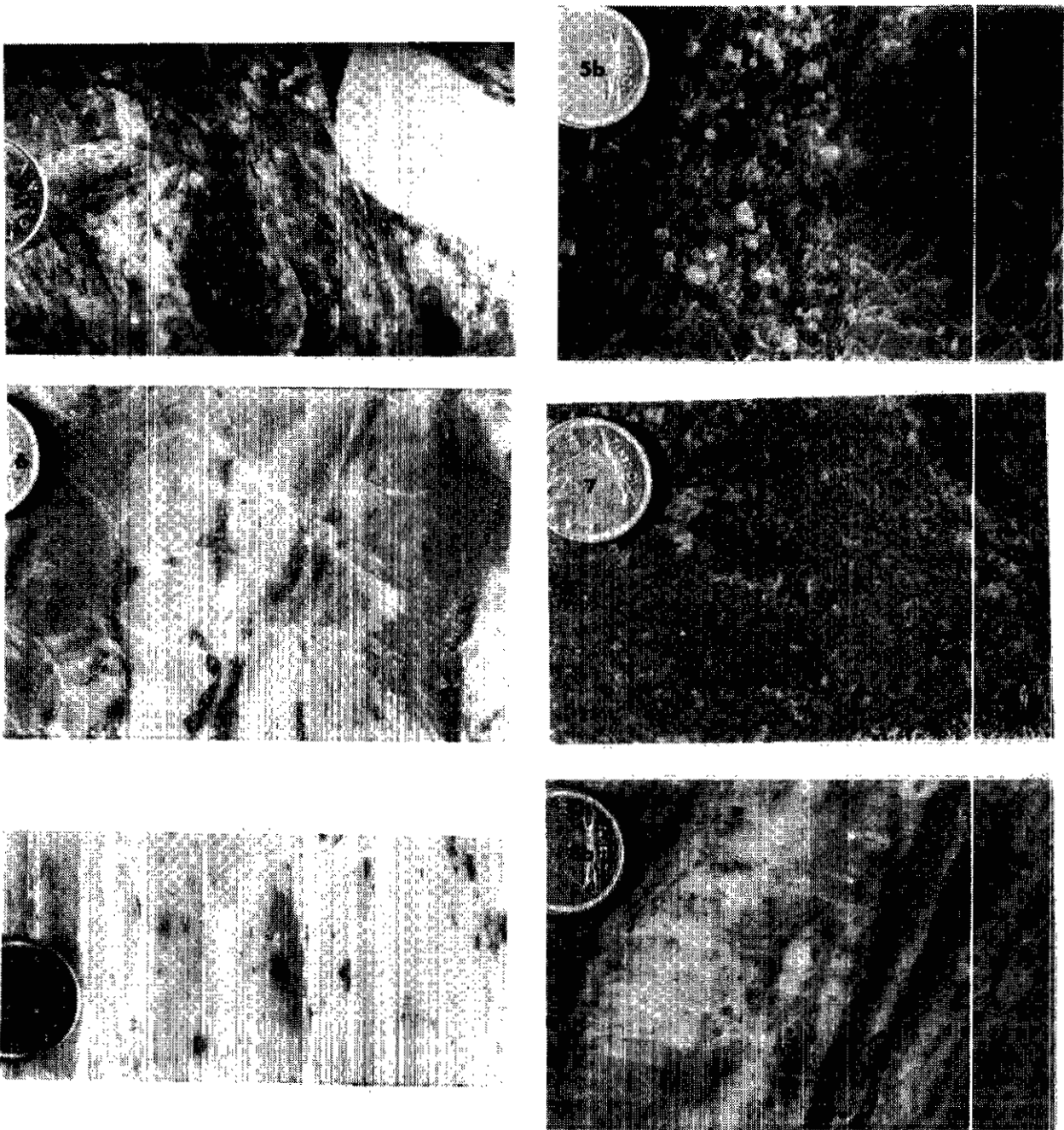
Plate 5. *Coarse rhyolite pyroclastic deposits.* (a) Pumiceous lapilli tuff (DDH 14-753, 254 m or 834 feet) contains 15% pale grey to white weakly quartz-porphyritic to aphanitic rhyolite fragments in a black, compacted, pumiceous, crystal-rich matri c with 10% 1 to 2- millimetre quartz eyes and 15% 2 millimetre feldspars. The flattened texture of the pumice fragments is restricte d to this unit, and may indicate welding. (b) Rhyolite tuff with pumice blocks (DDH 14-753, 252 m or 828 feet). Pumice blocks are in a fine-grained, medium- bedded rhyolite tuff.

Plate 6. *Rhyolite tuffaceous sediments.* Tuffaceous sandstone (DDH 14-750, 260 m or 854 feet). This specimen is in ensely altered by polymetallic quartz-sericite veins, but relict sedimentary bedding is still visible.

Plate 7. *Upper zone massive sulphide lenses* (DDH 14-723, 217.9 m or 715 feet). Specimen contains sphalerite > tetrahedrite > pyrite > galena > chalcopyrite.

Plate 8. *Rhyolite flow-dome complex.* (a) Vitric quartz-porphyritic rhyolite (QP) with 1 to 2% 1-millimetre quartz eyes (DDH 14-904, 281 m or 923 feet). There are only trace feldspar phenocrysts in this specimen. Fragments of this material are fo nd in the batwing lapilli tuff. (b) Flow-banded quartz-porphyritic rhyolite (QFP) from the base of the flow-dome complex (DDH 14-753, 221.9 m or 728 feet). QFP contains 3-5% 1 to 2-millimetre quartz eyes and 15% 1 to 2-millimetre sericitized feldspar Flow bands are marked by trails of pyrite grains.
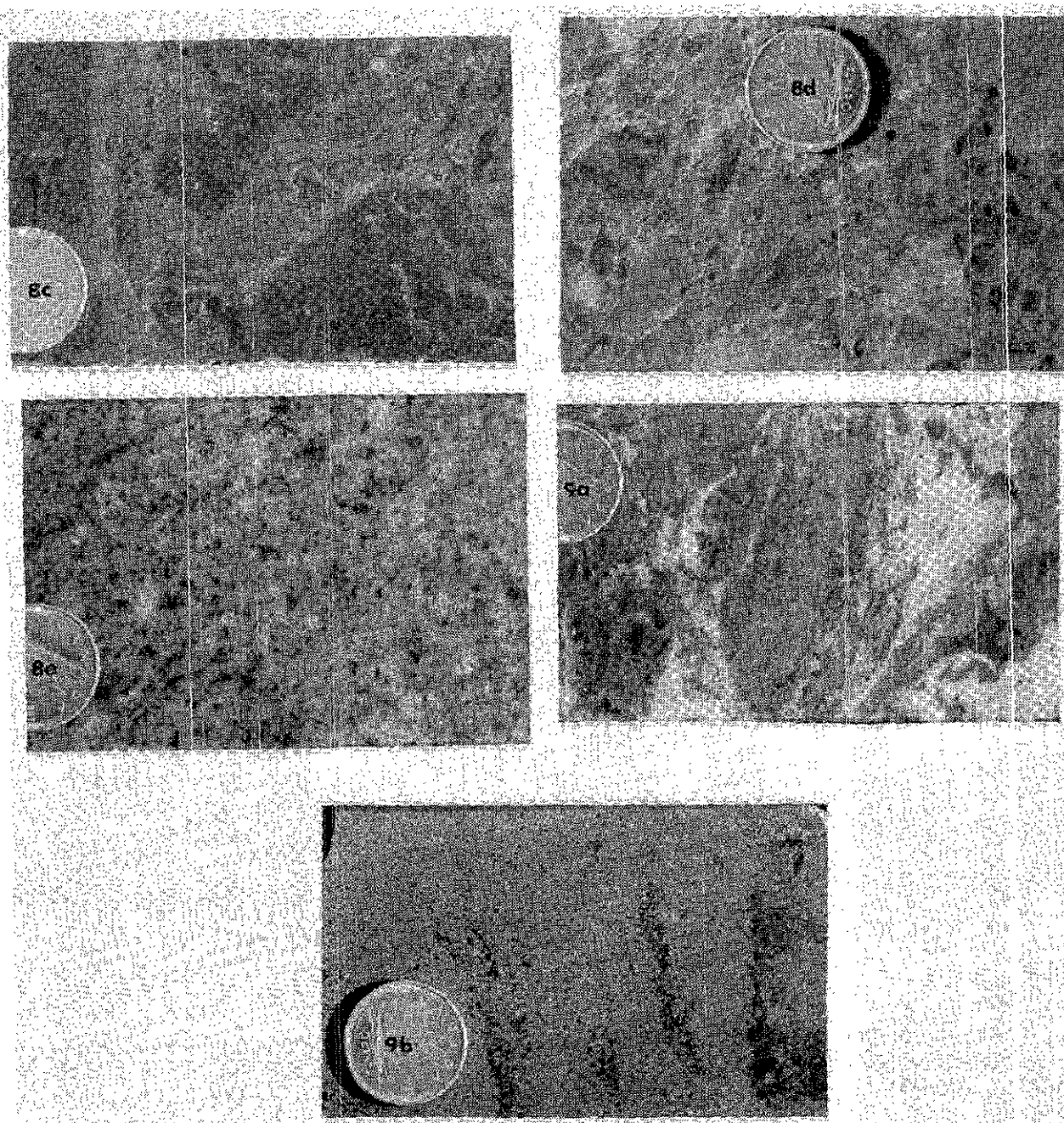
Plate 8 *continued...* (c) Massive to autobrecciated, chaotically flow-banded QFP from the top of the flow-dome complex (DDH 14-756, 242 m or 794 feet.); crystal contents are as in (b) above. (d) Monomict QFP breccia (DDH 14-751, 222 m or 729 feet) locally occurs on top of the rhyolite dome. (e) Feldspar-quartz-hornblende rhyolite porphyry dike (QFPD; DDH 14-753, 221.8 m or 728 feet). Massive, green-grey QFPD with 35% 2 to 3-millimetre feldspar crystals and 10% 1 to 3-millimetre quartz eyes. Green colour is due to chlorite alteration of hornblende. This unit crosscuts the QFP units described above.

Plate 9. *Gap massive sulphide lenses.* (a) Barite-rich massive sulphide from the upper part of the Gap lens (DDH 14-757, 200 m or 656 feet). Mineralogy is: sphalerite > barite > pyrite > quartz > galena > tetrahedrite. Barite in centre shows convex surfaces that face up-hole (to the right). (b) Copper-rich massive sulphides (DDH 14-757, 223.7 m or 734 feet). Sample is pyrite rich with black crystals of sphalerite that are characteristic of Gap-style mineralization. Mineralogy is: pyrite > sphalerite > bornite > chalcocite.
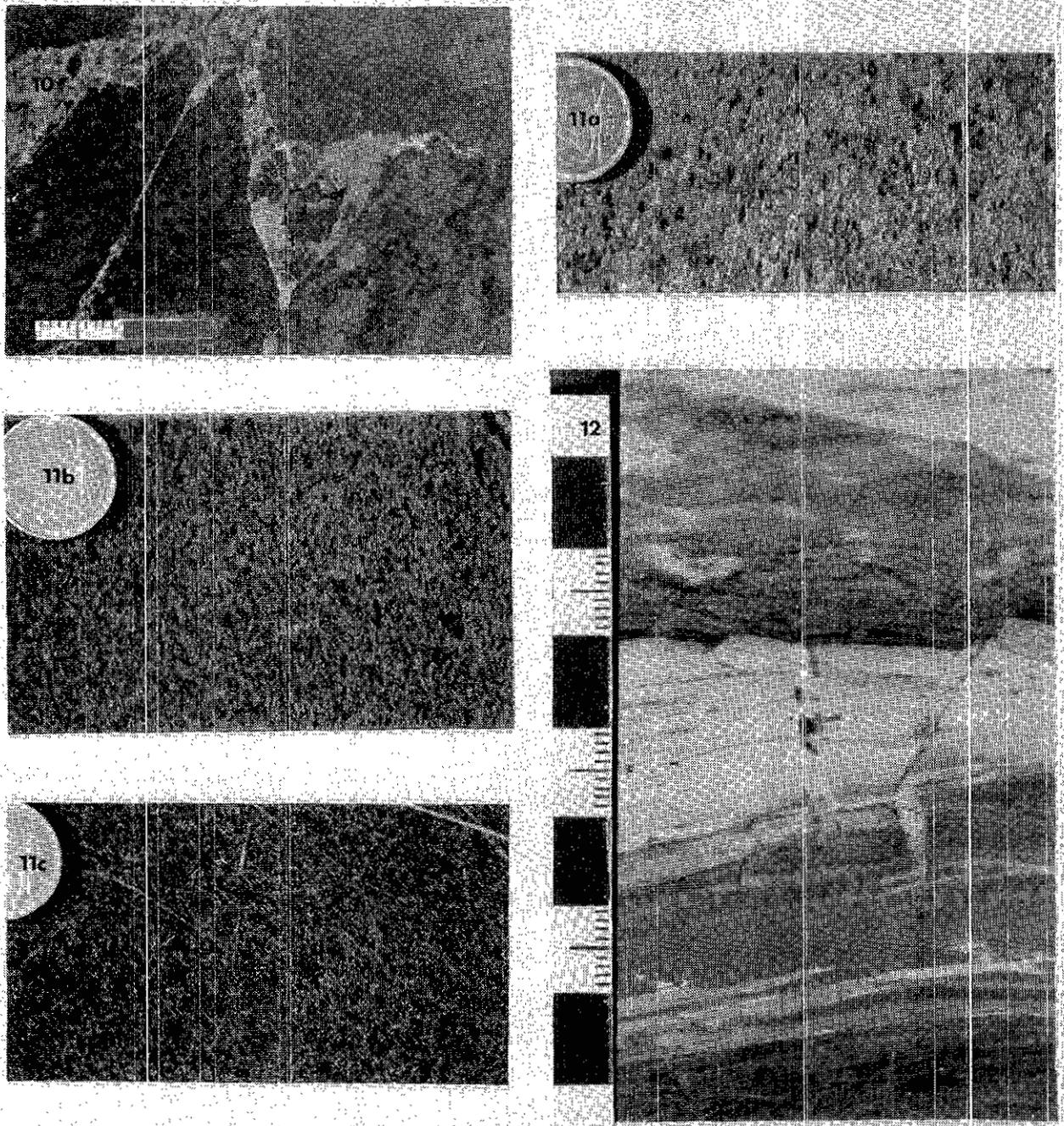
Plate 10. *Hangingwall andesite* hyaloclastite breccia (DDH 14-720, 169 m or 556 feet). Cuspate fragments of andesite that can be jigsawed together are characteristic of this unit. 1% QFP fragments are also present.

Plate 11. *Dikes.* (a) Pale green, feldspar-phyric, trachytic mafic dike (DDH 14-920, 301.7 m or 990 feet). (b) Dark green, augite and feldspar-phyric mafic dike (DDH 14-757, 282 m or 925 feet). (c) Dark blue-green, weakly feldspar-porphyritic andesite dike (DDH 14-750, 195.7 m or 642 feet); pale specks are leucoxene.

Plate 12. Miniature ore deposit (DDH 14-720, 194 m or 634 feet). Specimen contains a block-faulted layer at the base, with quartz-filled feeders along the 'faults'. Mineral zoning is normal with a pyrite-rich base and barite-sphalerite mineralization away from the feeder.

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 (Plate 5b) 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 (Plate 6) 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 3 metres thick at the top (drill hole 14-755; Figure 4).

Polymetallic sulphide stringer networks are common in the rhyolite tuffaceous sediments, probably because it was permeable. Stringer networks are characterized by sphalerite-pyrite-galena-tennantite 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 (Plate 7) occur mostly at the contact between rhyolite tuffaceous sediments and the overlying quartz-feldspar-porphyritic rhyolite. 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: 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, and will be 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 (Plate 8a) . 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 (Plate 8b). 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 (Plate 8c). 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 (Plate 8d). 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 (Plate 8e). 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 lens occurs 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-tennantite (Plate 9a). Barite is locally mammilary; convex surfaces face up-hole.Copper-rich mineralization is: pyrite-sphalerite-chalcopyrite-bornite-tennantite-chalcocite (Plate 9b). 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 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 (Plate 10). 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 (Plate 11a); dark green augite and feldspar phyric mafic dikes (Plate 11b) and andesite dikes (Plate 11c). 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 THE 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 1)). 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. Plate 12 shows the depositional style of the orebodies in miniature. 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 3 and 4) 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 (Plate 4a) 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 Gap massive sulphide lens. Pumiceous rhyolite lapilli tuff forms a pyroclastic flow up to 10 metres thick throughout the Battle zone (Figure 5). 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.

The Gap massive sulphide lens was 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.

ACKNOWLEDGMENTS

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NOTES