



**The Geology of the Big Bull Polymetallic Volcanogenic Massive Sulphide Deposit,
Northwestern British Columbia
(104K/12)**

**Robert G. Carmichael
Redfern Resources Ltd.**

**Ross L. Sherlock and Timothy J. Barrett
Mineral Deposit Research Unit, U.B.C.**

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INTRODUCTION

The Big Bull mine is one of two historic base and precious metal producers on Redfern Resources Ltd.'s Tulsequah Chief property, located in northwestern British Columbia, 110 kilometres southwest of Atlin (Figure 1). The Big Bull deposit is situated on the northeast bank of the Taku River, about 8.5 kilometres south of the Tulsequah Chief deposit.

The Big Bull deposit is a polymetallic volcanogenic massive sulphide body hosted by a variably altered sequence of mafic and felsic volcanic flows, sills and volcanoclastic rocks, which together form part of the upper Paleozoic Stikine assemblage (Mihalynuk *et al.*, 1994). Quartz-sericite-pyrite alteration of the felsic rocks is intimately associated with, but laterally more extensive than the mineralization. The geometry of the deposit and associated alteration package is complicated by two generations of folds and several faults.

EXPLORATION AND MINING HISTORY

The Big Bull deposit was staked by V. Manville of Juneau in 1929. Massive sulphide ore outcropped in a small creek bed over a width of 2 to 8 metres, and a strike length of about 140 metres. Sporadic drilling and underground work were carried out by various parties until 1946, when Cominco Ltd. acquired the property. Big Bull went into production in August, 1951, and continued until December, 1955, with a total production of 326 658 tonnes grading 1.2% Cu, 1.9% Pb, 7.3% Zn, 5.14 g/t Au and 154 g/t Ag. The ore was milled at the nearby Polaris-Taku minesite.

The Big Bull mine was developed on three underground levels, with access to the two lower levels provided by a 90-metre shaft. Approximately 100 000 tonnes of ore was mined from the glory hole, using

both surface and underground methods. In December, 1955, low metal prices combined with more favorable economics at the Tulsequah Chief mine forced the closure of the Big Bull mine. Reserves remaining at closure totalled 57 540 tonnes grading 1.1% Cu, 1.5% Pb, 5.6% Zn, 3.43 g/t Au and 154 g/t Ag.

Interest in the Tulsequah Chief property was rekindled in the early 1970s with the recognition that the deposits are volcanogenic rather than structurally controlled sulphide replacements. Cominco resumed exploration in 1987, mainly at Tulsequah Chief with only limited work at the Big Bull deposit. In 1992, Cambria Geological Limited, undertook a detailed surface mapping program at Big Bull and, in 1993, Redfern Resources Limited initiated a detailed compilation and exploration program. During 1993 to 1994, Redfern drilled 9 084 metres in 27 holes, successfully demonstrating that massive sulphide mineralization continued below the old workings with several holes intersecting ore grade material over widths up to 6 metres.

REGIONAL GEOLOGY

The regional geology of the Big Bull area is only summarized here; readers are referred to Mihalynuk *et al.* (1994) for a more complete discussion. The Tulsequah area is underlain by a geologically complex sequence of Mesozoic to Paleozoic rocks that are crosscut by Cretaceous to Tertiary intrusions (Figure 1). Hostrocks for massive sulphide mineralization have been assigned to the middle to upper Paleozoic Stikine assemblage. Mihalynuk *et al.* (1994) divide the Stikine assemblage in the Tulsequah area into three structural-stratigraphic blocks: the Mount Eaton block, the Sittakanay block and the Mount Strong block. The Big Bull and Tulsequah Chief deposits occur within the Mount Eaton block, an arc-related bimodal mafic-felsic volcanic package which is divided into lower, middle and upper stratigraphic divisions.

The lower division rocks are dominated by a gitephyric, chlorite-quartz amygdaloidal mafic flows and breccias with minor interbedded limestone. The mafic

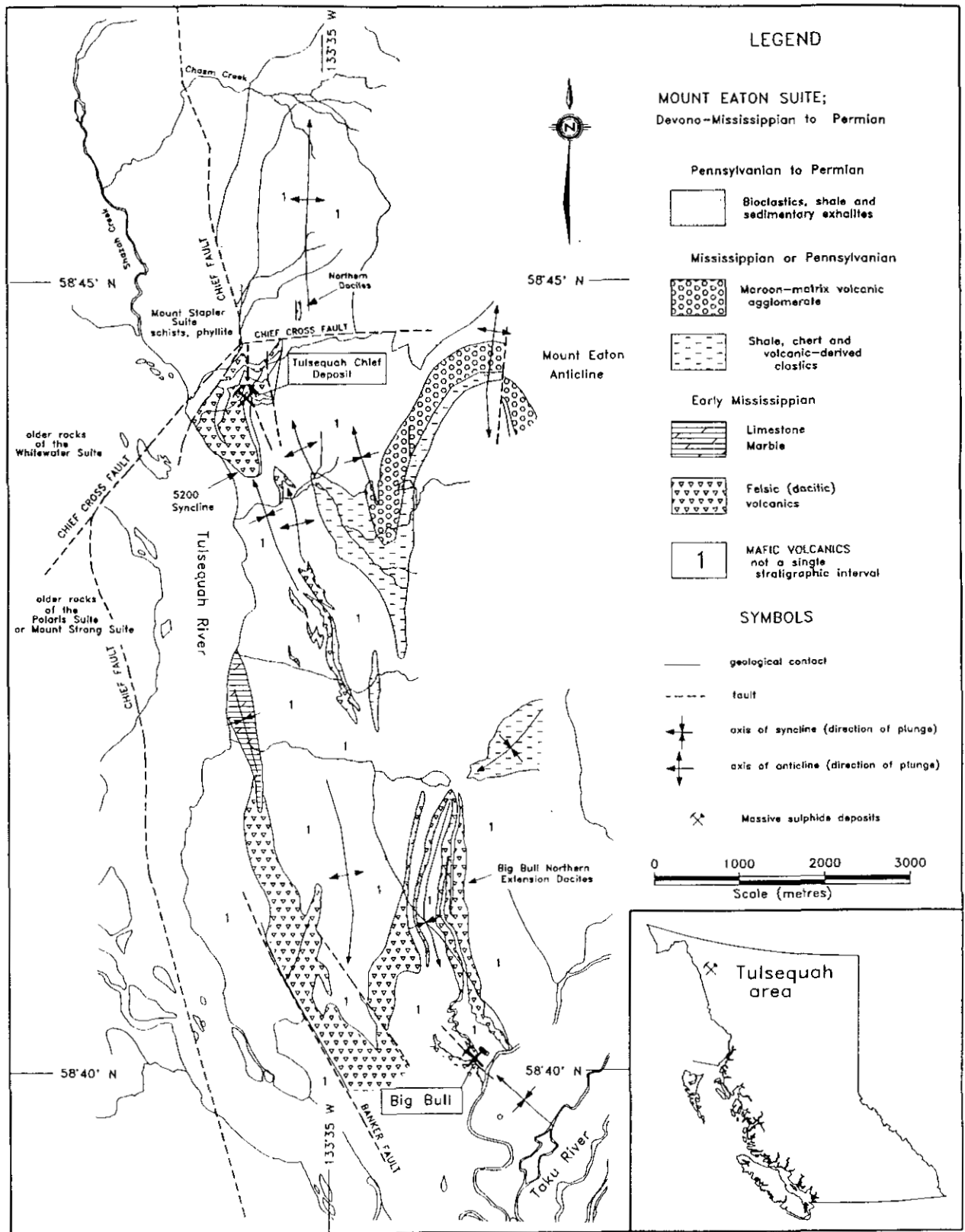


Figure 1. Simplified geology of the Tulsequah area, modified from Mihalynuk *et al.* (1994) and Nelson and Payne (1984).

rocks are typically massive and homogeneous, although pillows are preserved locally. Overlying this mafic package is a sequence of felsic tuffs and feldspar and quartz-phyric felsic flows, brecciated flows and volcanoclastic rocks. The Big Bull and Tulsequah Chief deposits are associated mainly with felsic tuffaceous rocks of this division (Figure 1). A U-Pb date of $353.4 \pm 15.8 - 0.9$ Ma (Sherlock *et al.* 1994) was obtained from zircons in the dacitic volcanoclastic and flow rocks at the Tulsequah Chief mine.

Middle division rocks are dominated by green pyroxene and occasionally feldspar-phyric mafic breccias and agglomerates. Lesser amounts of basalt flows, mafic ash tuff, pyroxene-feldspar crystal tuff, tuffite and turbidites are also present. The upper division rocks are sediment dominated and consist of polymictic volcanic conglomerate at the base, succeeded by coarse-grained limestone and volcanic-rich debris flows, lapilli ash tuffs, volcanogenic turbidites and basalt breccias. A middle Pennsylvanian age has been assigned to fossil debris in a sequence of bioclastic rudites, micrites and calcareous turbidites at the top of this section (Nelson and Payne 1984).

The Mount Eaton block is characterized by at least two phases of folding: a prominent post-Early Jurassic phase which trends north-northwest, and a later east-trending phase of gentle warping. Metamorphism is sub-greenschist to middle greenschist facies. The regionally significant Llewellyn fault is the largest of a series of north to northwest-trending faults in the area, and can be traced as far north as the southern Yukon. In the Tulsequah area, the Llewellyn fault has been traced to the Tulsequah Chief mine, where it is offset to the west by the Chief cross fault, and then continues south, under gravels of the Tulsequah River valley.

The Sittakanay block is separated from the Mount Eaton block by the Taku River. It is lithologically similar to the Mount Eaton block, although more deformed, and has been correlated with Mount Eaton stratigraphy by Mihalynuk *et al.* (1994). The Mount Strong block is a sediment-dominated package that is separated from the Mount Eaton block by the Tulsequah River. Correlations between the Mount Strong and other blocks are uncertain. The Mount Strong block hosts the mesothermal gold mineralization at the Polaris-Taku deposit.

DEPOSIT STRATIGRAPHY

The Big Bull stratigraphy has been divided into five main lithologic units: unit 1 mafic volcanic rocks, unit 2 dacite tuffs and minor flows, unit 3 maroon andesite tuffs, unit 4 basalt tuffs, and unit 5 mafic intrusives (Figure 2). These subdivisions represent a modification of previous work by Dawson and

Harrison (1993) and Carmichael and Curtis (1994). Feldspar-phyric mafic dikes and a distinctive quartz feldspar porphyry dike postdate all other lithologies, and are thought to be related to the Eocene Soko Group.

UNIT 1: MAFIC VOLCANIC ROCKS

The oldest unit in the Big Bull mine stratigraphy is only exposed to the east of the deposit, and has not been intersected in drill core. It is characterized by mixed mafic lapilli and ash tuffs, with occasional fine-grained, massive, homogeneous, feldspar-phyric sections which are interpreted as flows. Lapilli tuffs typically contain quartz-amygdaloidal basalt fragments, and tend to be massive. Ash tuffs are thinly (1-2 cm) bedded to massive.

UNIT 2: FELSIC TUFFS AND FLOWS

Felsic crystal, crystal lithic, and lapilli tuffs host the ore at the Big Bull deposit (Photo 1). This unit is primarily a grey to greenish grey, laminated to chaotically banded dacite, which Payne (1993) has petrographically identified as metamorphosed and deformed dacite tuff and crystal tuff. The tuffs are commonly weakly porphyritic, with plagioclase phenocrysts in a compositionally layered plagioclase-sericite-rich groundmass. Magnetite and/or hematite occur as disseminations and disrupted bands forming up to 15% of the unit locally. Unit 2 typically shows chaotic banding on a 2 to 5-millimetre scale, although fragmental textures are rare. Locally well preserved bed forms show grain-size grading which helps to establish local structural relationships. Occasional massive, feldspar-phyric flows have been identified within this unit.

UNIT 2a: QUARTZ-SERICITE-PYRITE

Unit 2a represents parts of unit 2 that were hydrothermally altered during the formation of the Big Bull deposit. The rock comprises a strongly foliated sericite-quartz-pyrite assemblage, containing 5 to 20% disseminated and stringer pyrite, with local base metal sulphides and tetrahedrite. The quartz-sericite-pyrite alteration appears to form a stratiform layer near the top of the felsic tuffs, but may in places be discordant to stratigraphy.

UNIT 2b: MASSIVE SULPHIDE

Unit 2b includes mineralization that ranges from massive, banded sulphides, to 30 to 40% disseminated and stringer sulphides in a matrix of barite, sericite

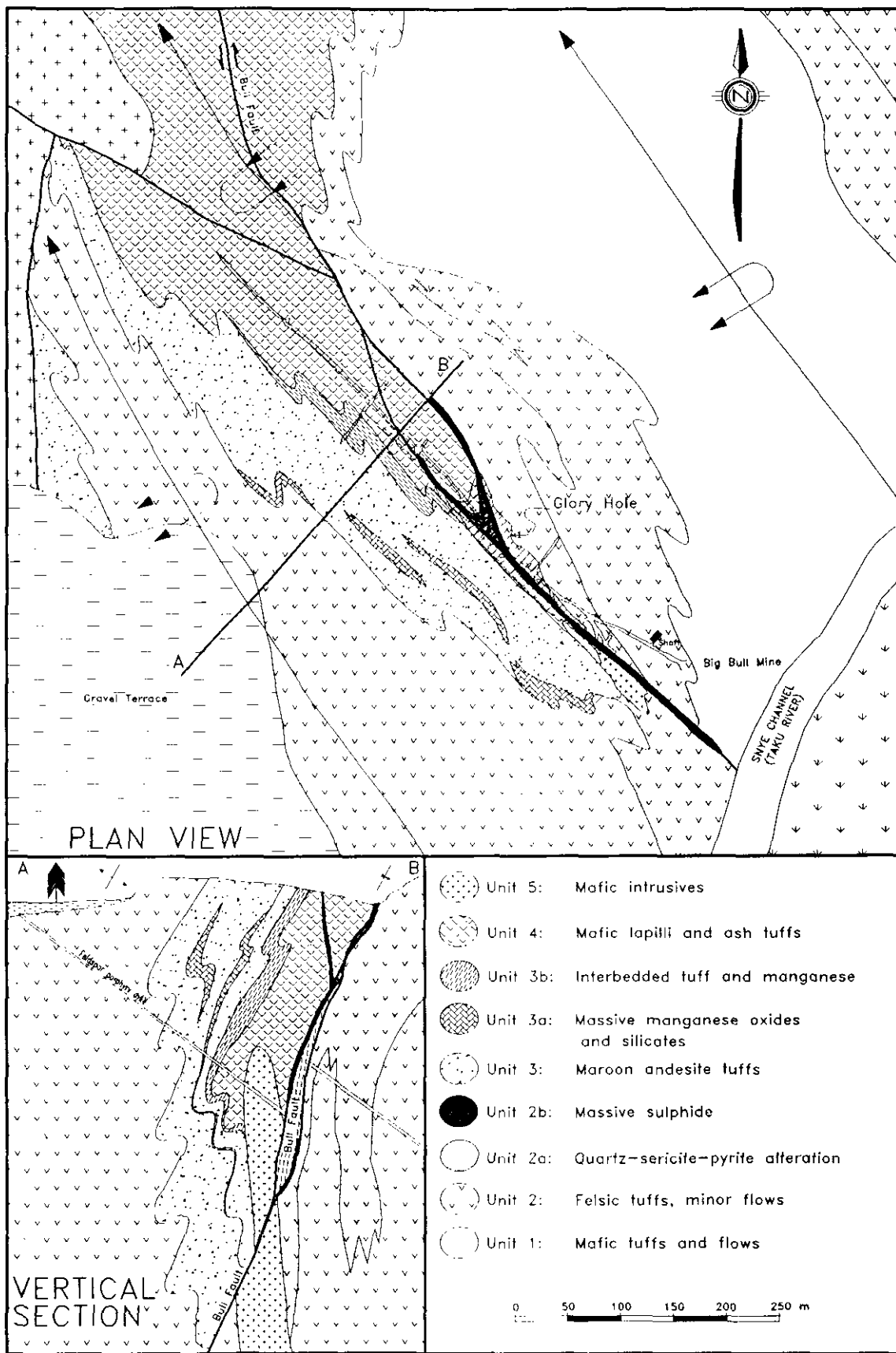


Figure 2. Big Bull Deposit, plan view and vertical section showing simplified geology.



Photo 1. Well bedded dacite tuff (unit 2), host to the massive sulphide mineralization.

and silica. The mineralogy comprises pyrite, galena, sphalerite, chalcopyrite and tetrahedrite, in a matrix of barite and sericitized lithic fragments. The sulphides are recrystallized, with well developed annealed textures that have obliterated any primary features. The sericitic fragments within the mineralized lenses may represent altered lithic fragments that were incorporated in the mineralized interval. Base metal grades can be visually estimated within this unit, but gold and silver values are difficult to predict.

UNIT 3: ANDESITE TUFF

Grey to maroon, fine to coarse-grained, locally phyllitic andesitic fragmental rocks conformably overlie unit 2 felsic tuffs. The maroon colour is typically due to fine-grained disseminated red hematite, and hematite-discoloured fragments that range in size from 0.5 to 50 millimetres. This unit is variably calcareous, with some sections containing up to 30% disseminated white calcite. The tuffs range from massive to very well bedded, with graded bedding and scour marks commonly, but not exclusively, indicating an overturned section. Fine-grained hematite gives the rock a distinctive maroon colour in places.

UNIT 3a: MANGANESE CHEMICAL SEDIMENT

Massive, black, fine-grained manganese oxides and silicates typically occur near the stratigraphic base of unit 3. They reach a maximum known thickness of 31 metres in drillhole BB94020. Interbeds of red mudstone occur locally within the manganese unit, as do breccia and replacement textures. Geochemistry and x-ray diffraction suggests that the manganese minerals present are braunite and piemontite.

UNIT 3b: INTERBEDDED TUFF AND MANGANESE

This distinctive unit often occurs at the stratigraphic top of unit 3. Its bedded nature and unique appearance make it useful as a marker interval. Maroon to pink crystal and ash tuff are interbedded with black, massive manganese silicates on a 1 to 10-centimetre scale. Manganese beds are contorted and disrupted, and appear to represent thinly bedded equivalents of unit 3a.

UNIT 4: BASALT TUFF

Unit 4 comprises dark green, chlorite-epidote-rich, mafic lapilli, ash and crystal tuffs. Patches and streaks of black hematite (1 to 20 mm) characterize this unit. Saussuritized feldspar crystals and crystal fragments are common, locally forming up to 30% of the rock. This unit is conformable, and often gradational contact with unit 3.

UNIT 5: MAFIC INTRUSIVES

Mafic intrusives occur as both dark green, fine-grained diabase sills, and as larger diorite bodies. They are included as one unit here, although the relationship between the intrusives is unknown. Sills are typically massive to moderately well foliated, contain abundant chlorite and biotite, and are devoid of primary textures. Their interpretation as intrusive is based largely on contact relations and stratigraphic position. However, they can be difficult to differentiate from massive intervals of unit 4, particularly when they are intrusive into that unit. A large body of blocky weathering diorite outcrops northwest of the glory hole area; the diorite is massive, equigranular to weakly feldspar phyrlic, and medium to fine grained.

LITHOGEOCHEMISTRY

Lithogeochemical data suggest that the volcanic rocks at the Big Bull deposit are chemically similar to those at Tulsequah Chief. As the rocks from both deposits are variably altered, whole-rock geochemistry is best compared in terms of immobile element ratios, as described by Barrett and MacLean (1994). In a plot of Al_2O_3 versus TiO_2 , felsic rocks at Big Bull outline a narrow fan of alteration lines (Figure 3). This indicates that they were derived from a narrow range of felsic precursor compositions through mass loss and mass gain effects during hydrothermal alteration. Some of the largest net mass loss effects occur in proximity to the mined-out massive orebodies.

Mafic rocks at Big Bull show a range in TiO_2/Al_2O_3 ratios that are interpreted as resulting

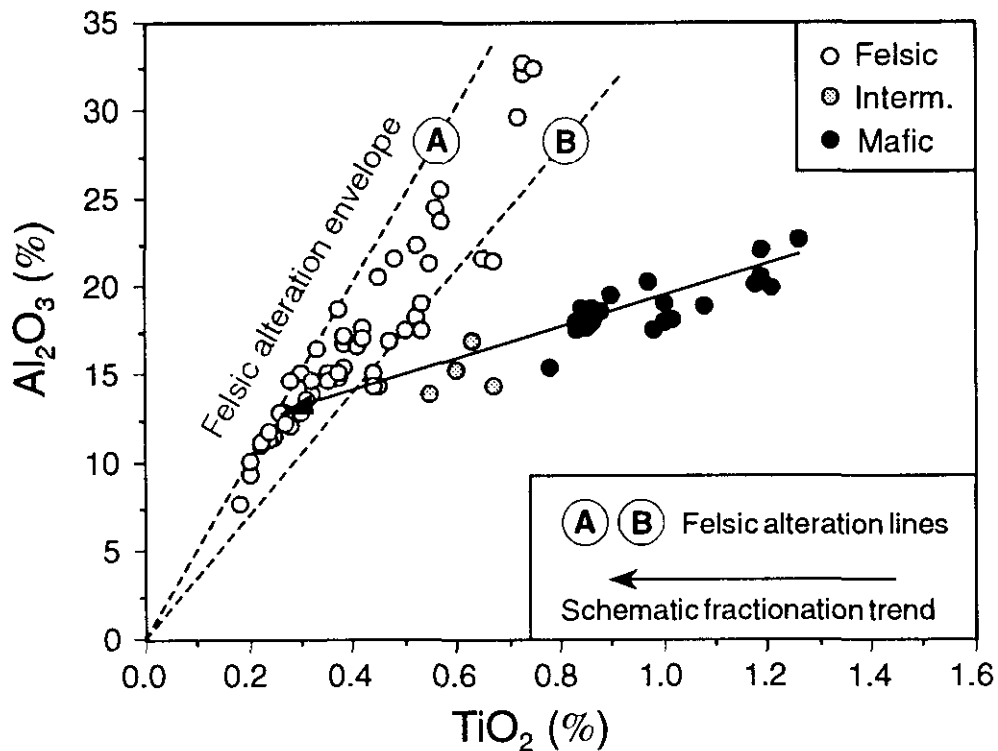


Figure 3. Lithochemical Al_2O_3 versus TiO_2 plot for host volcanic rocks at the Big Bull deposit. Samples are from both drillholes and outcrop within several hundred metres of the old mine workings. The dashed lines represent bounding compositions for the altered felsic rocks. A schematic fractionation trend is shown linking least altered rock types, although confirmation of this relationship requires further work.

largely from fractionation effects. Although not plotted here, the mafic rocks can be effectively subdivided using trace element plots such as nickel versus chromium. Mafic intrusives are typically characterized by higher nickel, chromium and magnesium abundances relative to the mafic volcanics, indicating that the former were derived from a more primitive mafic magma. The mafic intrusives are relatively unaltered, and probably represent a second phase of mafic magmatism that occurred after the main phase of sulphide-forming hydrothermal activity.

STRUCTURE

Rocks in the Big Bull area have been affected by two phases of folding and several episodes of faulting, creating an area of structural complexity (Figure 2; Barclay, 1993; Dawson and Harrison, 1993; Lewis, 1993; Carmichael and Curtis, 1993). The lithologic contacts (S_0) trend north-northwest, with steep dips to the southwest.

The first and most important phase of folding (S_1) consists of tight, approximately cylindrical, moderately overturned, folds with axial planar cleavage oriented at about $140/84^\circ$ southwest, and fold axes trending 321° and plunging at 30 to 50° (Photo 2). A stereonet plot of measured bedding orientations (Figure 4) defines a great circle, the pole of which has an

orientation of $321/54^\circ$, approximately parallel to the measured fold axis, suggesting that only one major phase of deformation has occurred. Parasitic folds on the east side of the glory hole are consistent with a synclinal closure to the west. The first phase of folding is represented by the Big Bull syncline, which repeats unit 2 dacites west of the glory hole (Figure 2).

A second, very weak phase of folding is indicated by a spaced, planar crenulation fabric which does not appear to have significantly reoriented either S_0 or S_1 fabrics. Axial planes are oriented roughly east-west, and dip steeply to the north.

Brittle faulting is an important element in the structural history of the Big Bull deposit. The Bull fault is a northwest-striking, steeply west-dipping structure which is approximately axial planar to the Big Bull syncline. In many instances the Bull fault has disrupted the massive sulphide lenses, with brecciated and rotated mineralized blocks present in the fault gouge. The fault has had a complex history involving several periods and directions of movement, the latest of which offsets a quartz feldspar porphyry dike of probable Eocene age. Although the amount and direction of displacement across the fault is unknown, apparent offsets of lithologic units suggest sinistral strike-slip movement. Detailed structural mapping in the collapsed stope area indicates that faults occurring

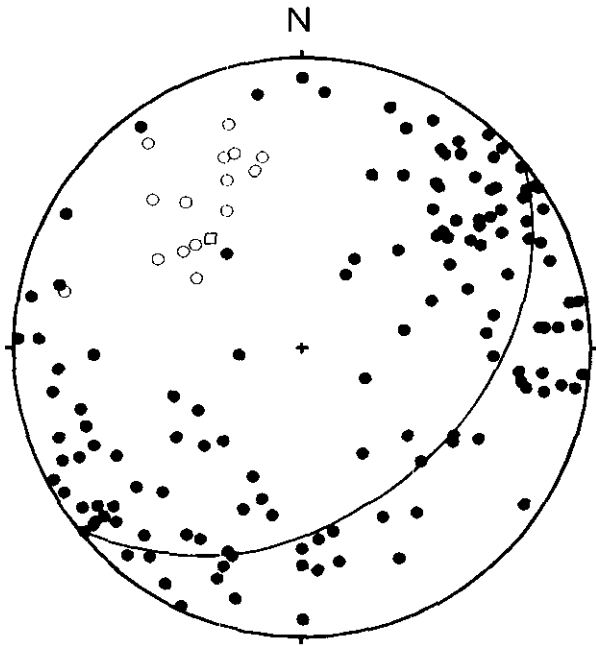


Figure 4. Stereonet plot of poles to bedding surfaces, and measured fold axes. Also shown is the pole to the great circle defined by the poles to the bedding.
 ● Bedding orientations; □ pole to the great circle;
 ○ fold axes.

within unit 2a, subparallel to S_0 and S_1 , generally show a dextral offset along southeast-plunging axes or sinistral offset along shallow northwest-plunging axes (Barclay, 1993).

DISCUSSION

The Big Bull deposit is associated with the same suite of felsic-mafic volcanic rocks that hosts the Tulsequah Chief massive sulphide deposit (Figure 1). The stratigraphy at Big Bull includes a mafic footwall (unit 1) that is overlain by an altered felsic package (unit 2) which is in turn overlain by a second package of mafic rocks (units 3, 4). The altered felsic package is the host to the massive sulphide mineralization. This sequence of rocks has been intruded by a diabase-textured mafic sill (unit 5), that has dilated the altered felsic interval, but is relatively unaltered itself, suggesting it was intruded after hydrothermal activity but prior to structural deformation. This overall sequence of lithologies is similar to the stratigraphy at the Tulsequah Chief deposit (Sherlock *et al.* 1994; Sebert *et al.* 1995).

Litho-geochemistry suggests that the volcanic rocks (and mafic intrusives) at Big Bull are closely comparable to those at Tulsequah Chief (Figure 5). At both deposits, the felsic rocks form alteration trends that largely overlap, suggesting that they were derived from similar precursor compositions. Mafic rocks in the stratigraphic footwall at Tulsequah Chief have lower values of nickel, chromium and commonly MgO than mafic rocks that are interpreted as synvolcanic intrusives within the felsic hangingwall stratigraphy.

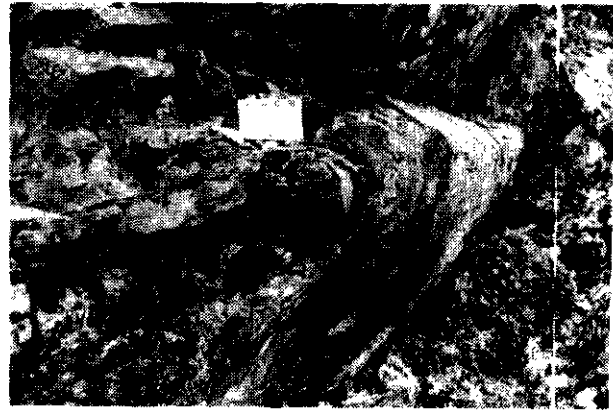


Photo 2. Outcrop-scale folding.

The mafic intrusive rocks at Tulsequah Chief are weakly altered relative to footwall mafic volcanics and are also closer to basalt in composition. At Big Bull, a group of mafic rocks with high Ni-Cr values is similarly interpreted as representing more primitive intrusives into felsic stratigraphy.

The main difference between the hostrocks at Big Bull and Tulsequah Chief is the nature of the volcanoclastic rocks. Felsic volcanic rocks at Tulsequah Chief are primarily coarse grained, poorly bedded, unsorted debris-flow units which are interbedded with felsic flows and intruded by felsic sills. The felsic rocks are altered, variably mineralized, and are interpreted to have been emplaced contemporaneously with the hydrothermal activity that formed the ores. At Tulsequah Chief, the coarse-grained and poorly sorted nature of the felsic volcanoclastic rocks, and the prevalence of flows and sills suggests that they were deposited close to a felsic volcanic centre.

The volcanoclastic rocks at the Big Bull deposit contrast sharply with those at Tulsequah Chief in that they are finely laminated and very fine grained, with well preserved bed forms, although these have been contorted and locally disrupted by subsequent deformation. At Big Bull, massive felsic lavas, either as flows or sills, are rare. These features support a distal setting for the volcanoclastic rocks at the Big Bull deposit.

In addition to the massive sulphide mineralization at Big Bull, there is a second phase of hydrothermal activity represented by massive manganese oxide and silicates (unit 3a). This unit appears to occur stratigraphically above the massive sulphides, in the andesite tuffs (unit 3). The manganese mineralization may represent a low temperature hydrothermal system that existed after the higher temperature system that formed the sulphides, or it may be a lateral facies equivalent of the massive sulphides. The structural

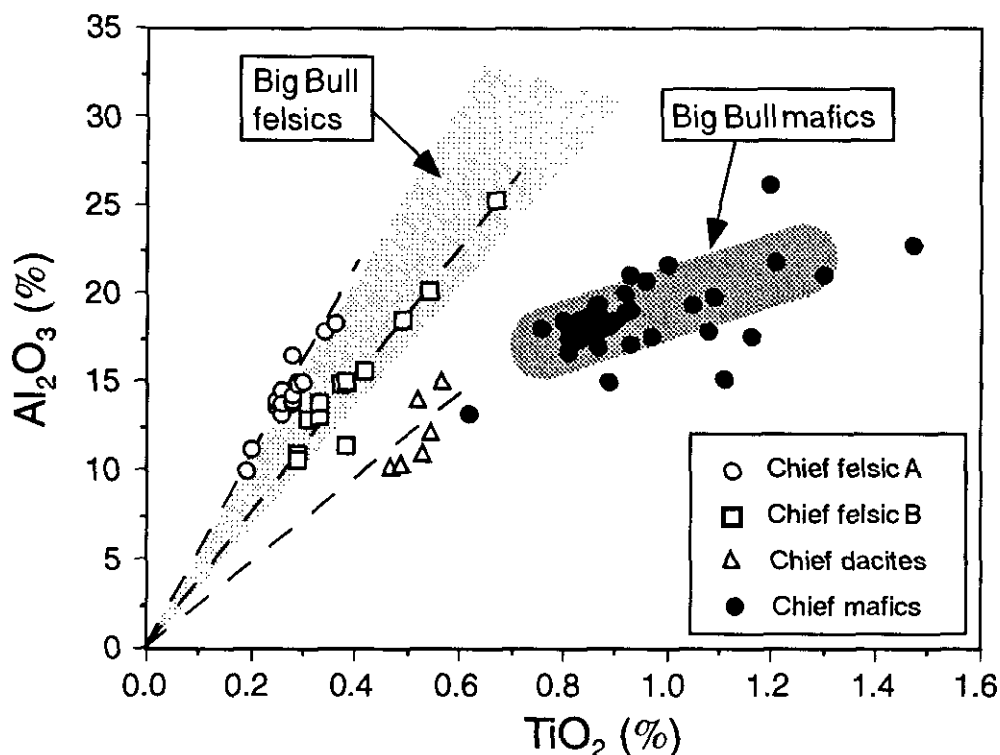


Figure 5. Al_2O_3 versus TiO_2 plot comparing host volcanic rocks at the Big Bull and Tulsequah Chief deposits. Samples from Tulsequah Chief are mainly from drillholes within several hundred metres of the old mine workings. At Tulsequah Chief, two fairly distinct felsic alteration trends (A and B) are evident, and also a smaller group of dacitic samples that may represent mixtures of felsic and mafic debris. The mafic rocks at Tulsequah Chief can be divided into two groups based on Ni-Cr data; the mafic intrusives lie within the $\text{TiO}_2 = 0.8\text{-}1.0\%$ interval.

complexity at the Big Bull deposit presently precludes the establishment of the sulphide-manganese relationships.

SUMMARY

The Big Bull deposit is a polymetallic volcanogenic massive sulphide deposit which occurs in a bimodal, largely tuffaceous sequence within the Paleozoic Stikine assemblage. The host rocks are chemically similar and roughly stratigraphically equivalent to those at the nearby Tulsequah Chief deposit. The sequence of events that formed the Big Bull deposit is outlined below, and shown schematically in Figure 6.

1. Deposition of widespread mafic footwall rocks.
2. Deposition of finely bedded felsic tuffs, with contemporaneous hydrothermal activity, alteration of the felsic package, and deposition of massive sulphides.
3. Deposition of finely bedded mafic tuffs, with coeval low-temperature hydrothermal discharge and the formation of massive manganeseiferous chemical sediments. These chemical sediments may represent cooling of the first, sulphide-

depositing hydrothermal system or, alternatively, the lateral margin of a second hydrothermal system.

4. Intrusion of mafic sills \pm flows after the main phase of hydrothermal activity had ended.
5. Folding of the stratigraphy into a syncline in the Big Bull area.
6. Offset of the stratigraphy along the Bull fault, forming the present deposit configuration.

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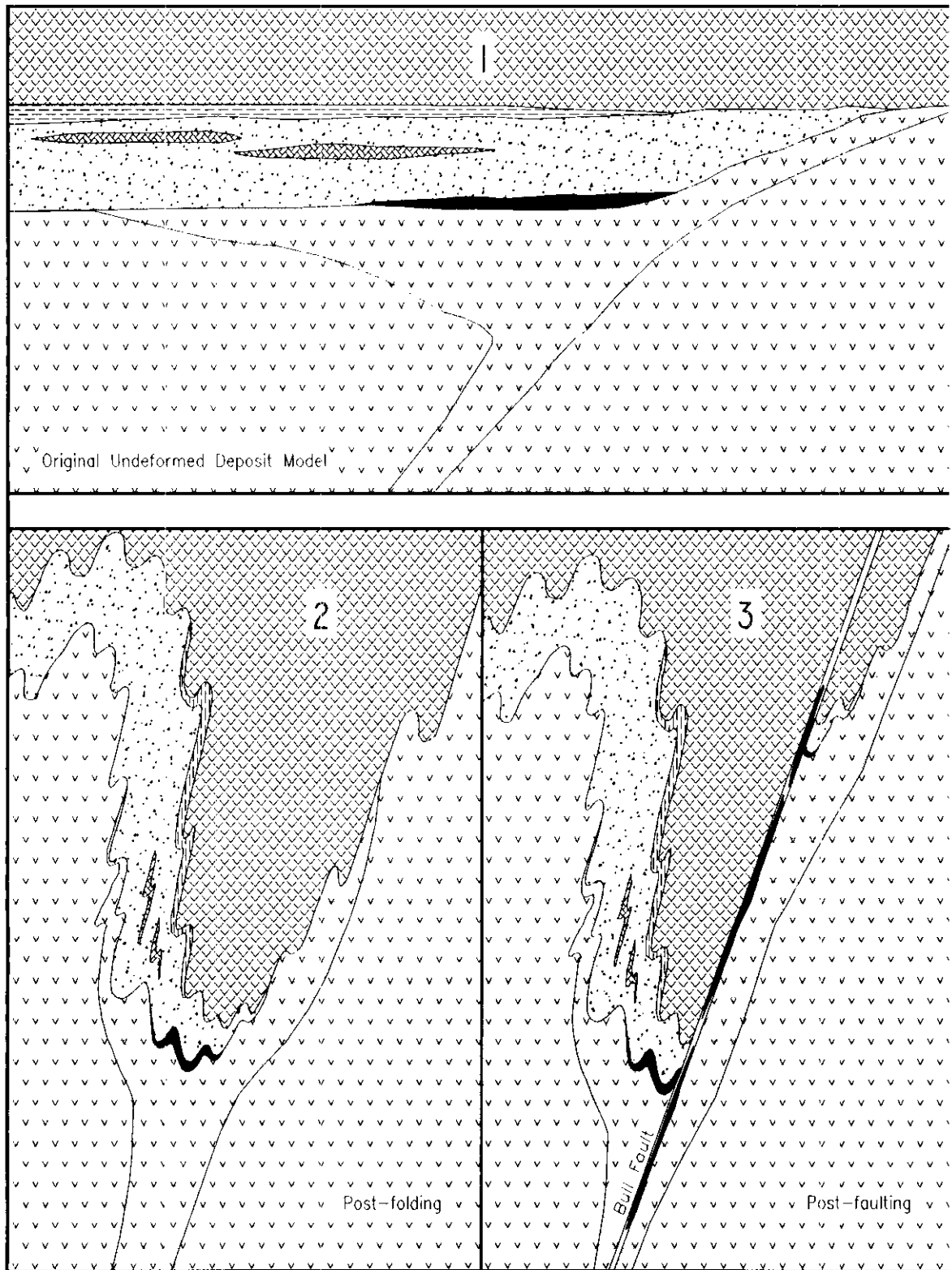


Figure 6. Schematic diagrams through the Big Bull deposit, showing its structural evolution. 1: deposition of the volcanic strata; 2: folding of the strata into a syncline; and 3: offset of the strata along the Bull fault (see Figure 2 for legend).

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