



## GEOLOGY OF THE TULSEQUAH CHIEF VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT, NORTHWESTERN BRITISH COLUMBIA (104K/12)

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### INTRODUCTION

The Tulsequah Chief massive sulphide deposit is located along the east bank of the Tulsequah River, 100 kilometres south of Atlin, British Columbia and 70 kilometres northeast of Juneau, Alaska (Figure 1, inset). The Tulsequah Chief mine produced 622 136 tonnes of ore between 1954 and 1957. Exploration was resumed in the Tulsequah area in 1987 by Cominco Ltd. and Redfern Resources Ltd. In 1992 Redfern Resources purchased Cominco's interest in the mine. At the end of 1994 reserves for all ore intervals and classes were 8 500 000 tonnes at 1.41% copper, 1.23% lead, 6.65% zinc, 2.52 g/t gold and 105.66 g/t silver.

Fieldwork in the summer of 1994 consisted of detailed logging of drill core and underground mapping of the 5400 level main haulage. The main objective of this work was to further define the mine stratigraphy and the distribution of mineralization and alteration facies. Particular attention was given to the depositional style and character of the sulphides, the felsic volcanic host rocks and the mafic footwall of the deposit.

### REGIONAL GEOLOGY

A brief overview of regional geology follows, summarized from Mihalyuk *et al.* (1994).

The Tulsequah Chief deposit is hosted within an arc-related bimodal mafic-felsic volcanic suite of latest Devonian to earliest Mississippian age (Sherlock *et al.*, 1994) in the Stikine Terrane. The host volcanics comprise the Mount Eaton structural block which has

been divided into lower, middle and upper divisions (Mihalyuk *et al.*, 1994).

The lower division is dominated by felsic tuffs and includes lesser volumes of felsic feldspar and quartzphyric flows, brecciated flows and volcanoclastics. The latter two lithologies are the main ore host at Tulsequah Chief (Figure 1). The felsic flows and volcanoclastics overlie chlorite-quartz-amygdaloidal basaltic andesite breccias in the mine area. A U-Pb date of  $353.7 \pm 15.8 - 0.9$  Ma (Late Devonian to early Mississippian) was obtained from zircons contained in the felsic rocks in the mine area (Sherlock *et al.*, 1994).

Middle division rocks are represented by green pyroxene and locally feldspar-phyric 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, basalt breccias, and notably, an upper sequence of bioclastic rudites, micrites and calcareous turbidites. A middle Pennsylvanian age has been assigned to the fossil debris in this upper unit (Nelson and Payne, 1984).

### MINE SEQUENCE STRATIGRAPHY

The mine stratigraphy at the Tulsequah Chief deposit comprises a northward-younging, folded succession of mafic and felsic volcanic rocks (Figure 2). The stratigraphically lowest unit (unit 1) is composed of mafic volcanics of basaltic andesite composition (Sherlock *et al.*, 1994). This unit is directly overlain by a

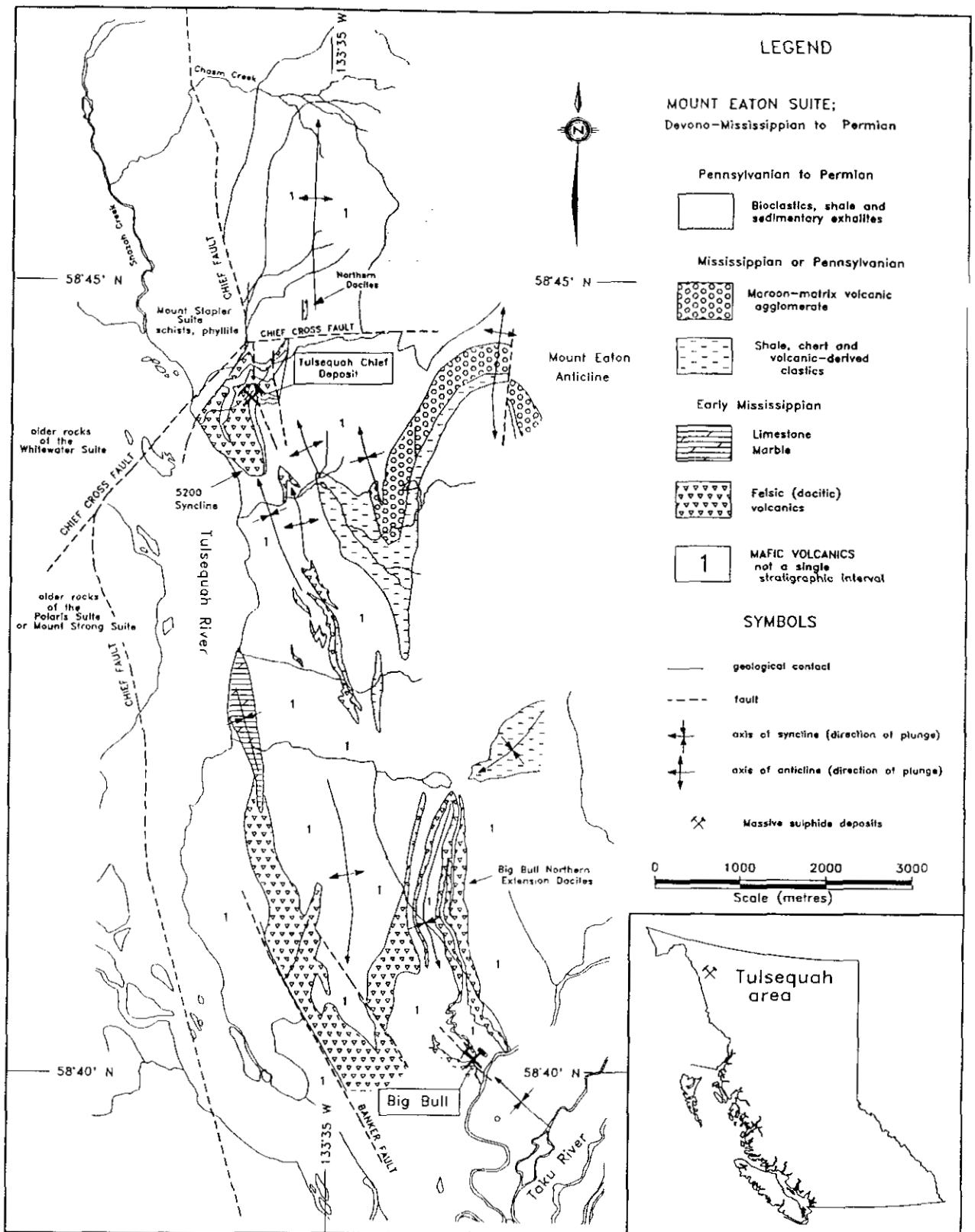


Figure 1. Simplified geology of the Tulsequah area, modified from Mihalynuk *et al.* (1994) and Nelson and Payne (1984).

series of felsic volcanics and reworked felsic-rich volcanoclastic debris (unit 2). The felsic sequence is intruded by a large gabbro sill (unit 4). A sequence of basaltic flows, sills and mafic-rich volcanoclastic sediments (unit 3) caps the felsic volcanics (Sherlock *et al.*, 1994). This second mafic sequence may represent the lowermost part of the middle division of the Mount Eaton block. All of these units are cut by felsic Sloko dikes of Tertiary age which tend to parallel or occupy major fault zones running north or northeast. Holes TCU92-36 and TCU92-37 (Figure 3 and 4) provide representative examples of the mine stratigraphy.

### Unit 1

Unit 1 forms the stratigraphic footwall to the massive sulphide deposits and comprises mainly massive to vesicular brecciated mafic volcanics of basaltic andesite composition. Minor intervals of fine-grained mafic sandstones are also present. The flows at the top of this unit are commonly strongly amygdaloidal and the amygdules are typically filled by quartz and pyrite. Locally the unit is composed of angular to subrounded, strongly vesicular, scoria-like fragments hosted in an angular clast-rich (possibly hyaloclastic) matrix with plagioclase feldspar. The vesicular fragments range from 0.5 to 30 centimetres across and locally contain zoned quartz-filled vesicles. The sandstones display normal grading in some laminations which fine upwards from feldspar crystal rich bases.

### Unit 2

Unit 2 comprises the felsic package. Lithochemical results indicate that these rocks vary from dacitic to rhyolitic composition (Carmichael *et al.*, 1995, this volume). The upper portion, between the 4400E and 5300E faults, is composed of a sequence of flow breccias and massive to banded flows ranging from 3 to 15 metres thick. Individual units may be separated by unhealed quench brecciated to autoclastic fragmentals. The top of the felsic sequence is locally capped by a layer of granular to blocky, partially reworked quench brecciated debris up to 15 metres thick. The lower part of the sequence in the main mine block tends to have thinner layers of flows and flow breccias 1 to 6 metres thick, and a slightly higher proportion of unhealed autoclastics to partially reworked felsic-rich volcanoclastic debris.

Porphyritic textures are common in the flows and flow breccias, which typically host a combined volume of about 5 to 8% subhedral to euhedral feldspar and subordinate quartz crystals, 1 to 3 millimetres in diameter. Two groups of porphyritic felsic units are recognized by the presence or absence of visible quartz phenocrysts. Quartz grains are most prevalent in the upper part of the pile. This contrasts with flows and flow breccias at the base of the sequence, beneath the main sulphide lenses, that are purely feldspar porphyritic.

The feldspar quartz porphyries in the upper part of the felsic sequence are typically massive with local fracturing. Only rare examples of well developed flow banding were observed. Some of these units may be shallow sills that have intruded into a brecciated pile (Sherlock *et al.*, 1994).

The healed flow breccias are typically weakly banded and feature porphyritic to bleached-aphanitic, rounded to subangular blocks in a relatively darker, chlorite-altered, feldspar-quartz-porphyritic matrix. Banded sheared autoclastics, jigsaw-textured quench breccias and other flow-derived fragmentals also occur as intercalations throughout the sequence.

The volcanoclastic debris contains rounded to angular dacite blocks (up to 30 cm across) with pumice, lithic, chert and barite fragments. It varies from chaotic unstratified mass-flow units to well sorted, graded volcanoclastic sandstones. The preservation of angular pumice fragments in some portions suggests that the volcanoclastic material has not been highly reworked. The debris also locally includes rounded vesicular fragments of altered mafic footwall (unit 1), up to 5 centimetres in diameter.

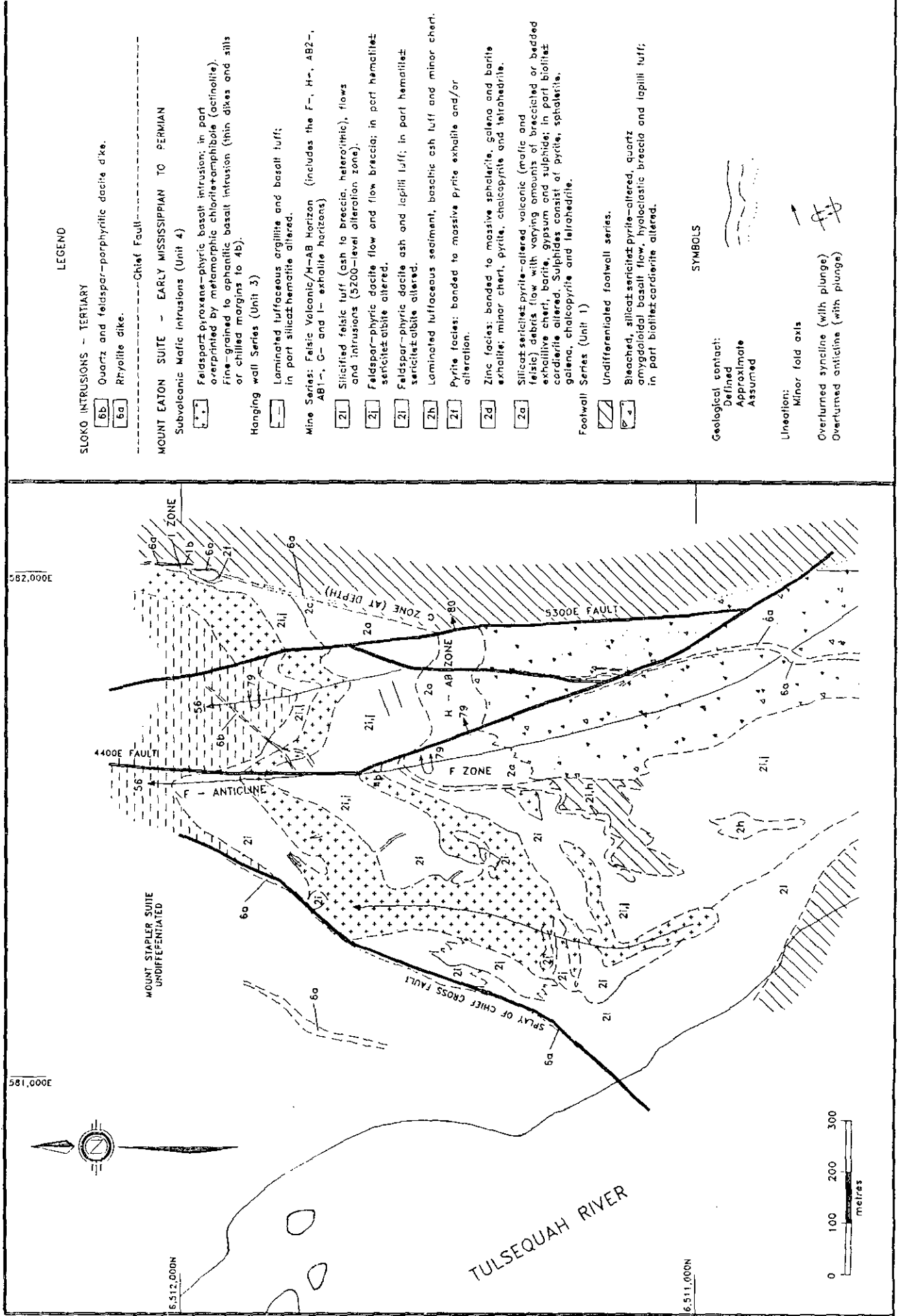
The upper part of the felsic package, east of the 5300E fault, contains a greater proportion of volcanoclastic material, mainly dacite-rich mass flows with pumice, lithic, chert and barite fragments. These felsic rocks are host to the I zone sulphide lens, which was the main focus of early mining activity. Similar dacite-rich mass flows are dominant to the west of the 4400 E fault in the western limb of the F anticline. Hole TC93-09 (Figure 5) intersected a part of the stratigraphy in this area.

### Unit 3

The upper mafic sequence consists primarily of massive basalt flows and equivalent sills, with intercalated sediments including: variably muddy basaltic siltstones (possibly reworked ash tuffs), basaltic lapillistones, and feldspar and mafic crystal-rich tuffaceous sandstones. A few chlorite and quartz-filled vesicles occur in the flows and sills. Normally graded beds with feldspar crystal rich bottoms and flame structures were noted in some of the siltstones. This unit is typically unaltered and lies above all known mineralization. A series of mudstones, vitric (pumiceous) lapilli tuffs, and felsic ash layers occurs at the base of the sequence and marks the transition to the felsic volcanics (unit 2) below.

### Unit 4

A massive mafic sill, up to about 100 metres thick, intrudes and dilates the felsic package. The margins of the sill are chilled and locally host intercalations of dacitic material at both the upper and lower contacts. The primary mineralogy of the sill comprises augite, plagioclase and sparse, altered olivine phenocrysts in a



LEGEND

SLOKO INTRUSIONS - TERTIARY  
 6b Quartz and feldspar-porphyrific dacite d'ke.  
 6a Rhyolite dike.

----- Chief Fault -----

MOUNT EATON SUITE - EARLY MISSISSIPPIAN TO PERMIAN  
 Subvolcanic Mafic Intrusions (Unit 4)

2\* Feldspar-pyroxene-pyritic basalt intrusion; in part overprinted by metamorphic chlorite-epidote (actinolite).  
 Fine-grained to ophanitic basalt intrusion (thin dikes and sills or chilled margins to 4b).  
 Hanging wall Series (Unit 3)

2 Laminated tuffaceous argillite and basalt tuff; in part siliceous hematite altered.

Mine Series: Felicit Volcanic/H-AB Horizon (includes the F-, H-, AB2-, AB1-, G- and I- exhalite horizons)

2i Silicified felsic tuff (ash to breccia, heterolithic), flows and intrusions (S200-level alteration zone).

2j Feldspar-pyritic dacite flow and flow breccia; in part hematite sericitic albite altered.

2k Feldspar-pyritic dacite ash and lapilli tuff; in part hematite sericitic albite altered.

2h Laminated tuffaceous sediment, basaltic ash tuff and minor chert.

2f Pyrite facies: banded to massive pyrite exhalite and/or alteration.

2d Zinc facies: banded to massive sphalerite, galena and barite exhalite; minor chert, pyrite, chalcocopyrite and tetrahedrite.

2a Siliceous sericitic pyrite-altered volcanic (mafic and felsic) debris flow with varying amounts of brecciated or bedded exhalite chert, barite, gypsum and sulphide; in part biotite cordierite altered. Sulphides consist of pyrite, sphalerite, galena, chalcocopyrite and tetrahedrite.

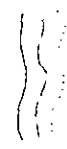
Footwall Series (Unit 1)

Undifferentiated footwall series.

Bleached, siliceous sericitic pyrite-altered, quartz amygdaloidal basalt flow, hyaloclastic breccia and lapilli tuff; in part biotite cordierite altered.

SYMBOLS

Geological contact:  
 Defined  
 Approximate  
 Assumed



Unconformity:  
 Minor fold axis



Overturned syncline (with plunge)  
 Overturned anticline (with plunge)

Figure 2. Tulsequah Chief surface geology.

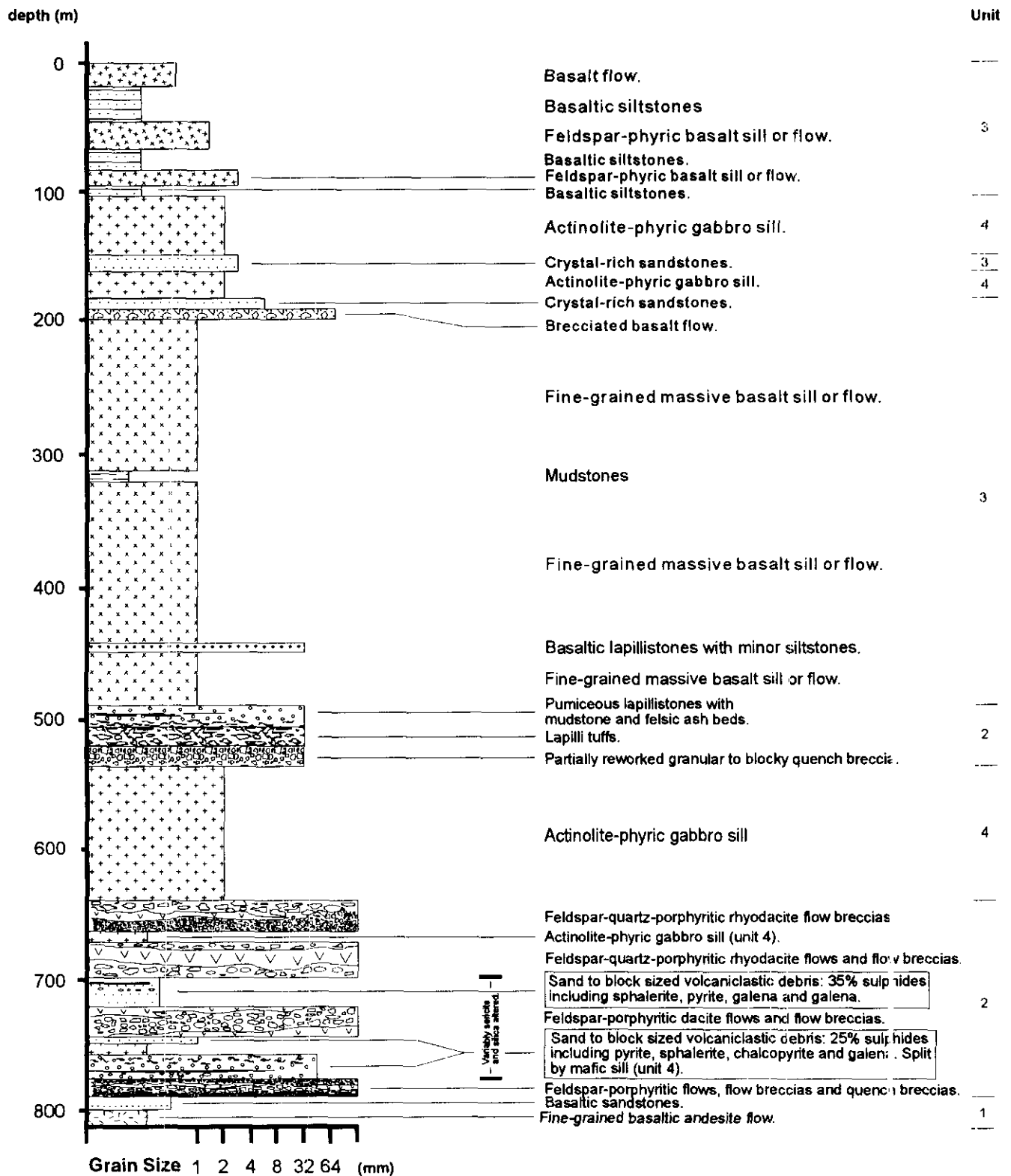


Figure 3: Simplified stratigraphy for diamond-drill hole TCU92-36.

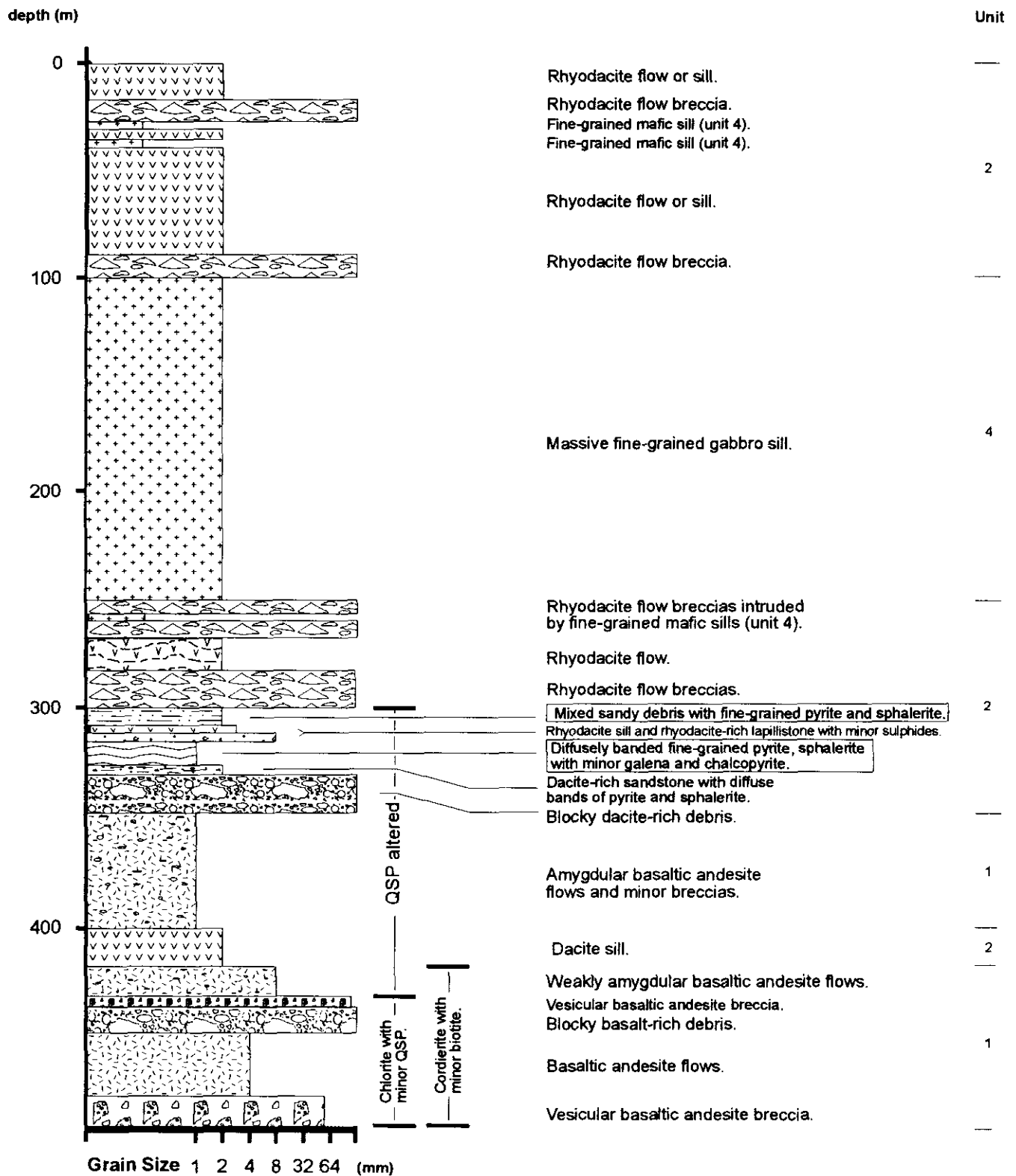


Figure 4: Simplified stratigraphy for diamond-drill hole TCU92-37.

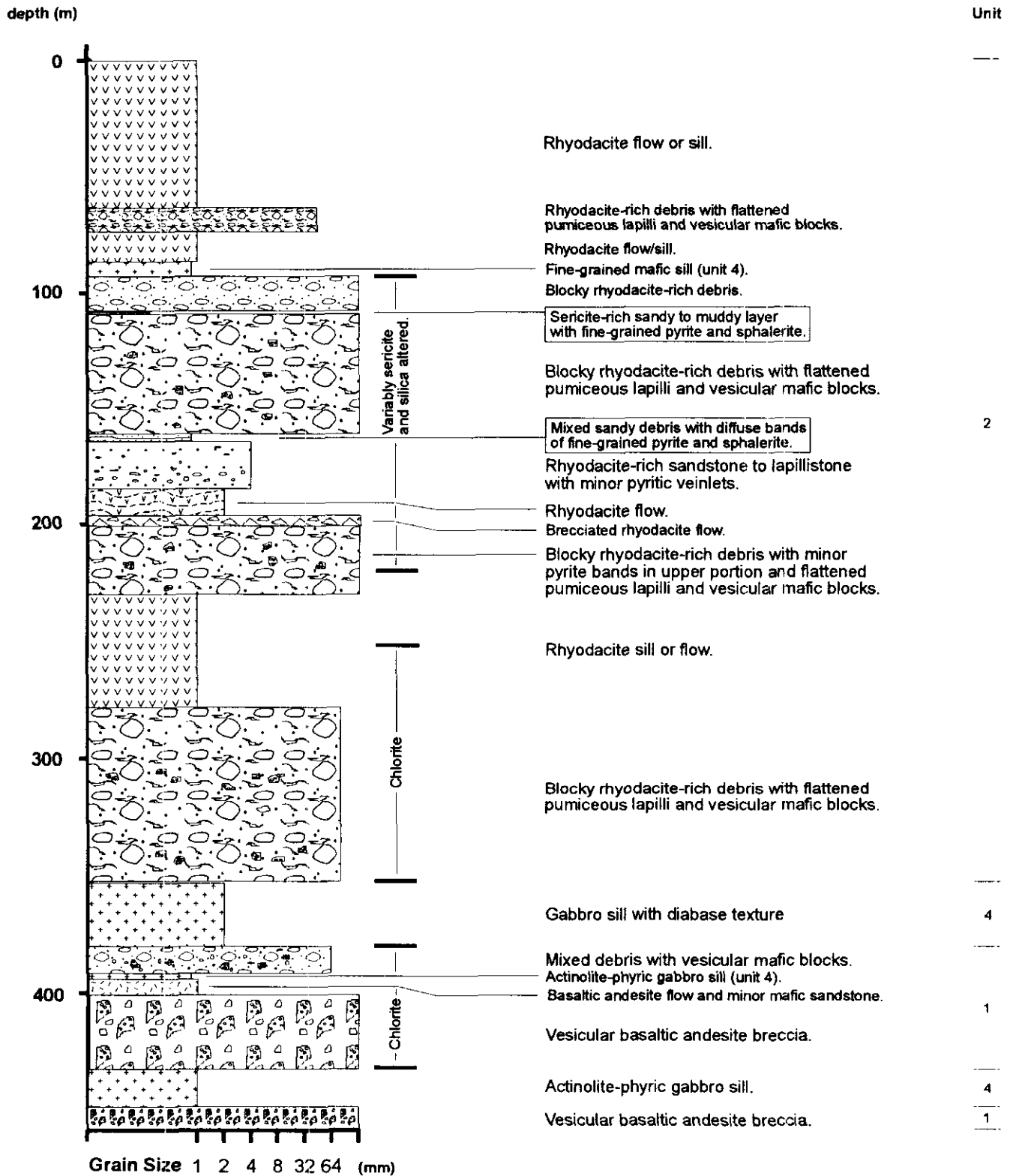


Figure 5: Simplified stratigraphy for diamond-drill hole TC93-09.

fine-grained, matted plagioclase dominated groundmass. Diabasic texture is common. In some areas, an overprint of coarse-grained chlorite and actinolite, probably of metamorphic origin, imparts a pseudocumulate texture to the rock.

This unit appears to be relatively unaltered when compared to units 1 and 2, which suggests that it was emplaced after the hydrothermal activity. The sill appears to be slightly discordant to stratigraphy on the basis of its contact relationships. It intrudes the felsic volcanic package in holes TCU92-36 and TCU92-37 but occurs much lower in the stratigraphy in hole TC93-09 where it intrudes mixed volcanoclastic debris immediately above the mafic footwall. Similar discontinuous actinolite-phyric sills have been noted in the hangingwall mafics; comparisons of adjacent drill hole intersections indicate that they may grade into flows along strike. Dark fine-grained mafic dikes and sills on the order of several metres thickness frequently cut footwall mafic rocks and the felsic pile (Figures 4 and 5). These mafic intrusives are also relatively unaltered and may be smaller apophyses of the gabbroic intrusive.

## LOCAL STRUCTURE

Stratigraphic units at Tulsequah Chief outline a series of east-verging, moderately north to northwest-plunging folds (the F-anticline, the A-syncline and the H-syncline, Figure 2). These folds are interpreted to be parasitic structures on the western limb of the Mount Eaton anticline. This folded succession is subdivided into three discrete structural blocks by the north trending 5300E and 4400E faults (Figure 2).

The 5300E fault is the most significant and probably has the largest displacement. Kinematic indicators record an early period of dextral motion with a gently northward-plunging slip vector, followed by movement along a southerly plunging slip vector of unknown sense. The dextral motion is probably the most important in terms of displacement, but determination of absolute displacements requires a detailed analysis of stratigraphy in the central and eastern mine blocks. The 4400E and minor unnamed faults of variable orientation cause no large-scale displacement of stratigraphic contacts (Sherlock *et al.*, 1994).

The Chief cross fault dextrally offsets the mine stratigraphy and the Mount Eaton block immediately north of the mine workings. The displacement on this structure may be on the order of 2 kilometres (Mihalynuk *et al.*, 1994).

## MINERALIZATION

Several massive sulphide lenses, termed the F, AB<sub>1</sub>, AB<sub>2</sub>, H, I and G zones, are hosted in unit 2 felsic autoclastics, coarse-grained felsic-rich mass flows and other finer grained mixed volcanoclastics. The ore lenses are composed of variable proportions of banded to

disseminated, semimassive sulphides intercalated or intermixed with barite fragments, cherty clasts, variably altered fine to coarse-grained felsic-dominated lithic and vitric detritus.

Sulphide deposition occurred during the felsic volcanic cycle and was interrupted by a resurgence of felsic volcanism consisting of the extrusion of flows and the intrusion of shallow sills. The presence of felsic-rich mass-flow layers and of occasional sulphide rip-up clasts in some brecciated flow units indicates an active environment that locally reshaped and reworked the sulphide deposits.

Several sulphide facies have been defined by Cambria Geological Limited (McGuigan *et al.*, 1993). The pyrite facies consists mainly of fine-grained banded to massive pyrite with little base metal content. The zinc facies is composed primarily of semimassive, pale yellow, fine-grained sphalerite, pyrite and galena with subordinate chalcopyrite and tetrahedrite. The copper facies is mainly massive pyrite with up to 10% intergrown chalcopyrite. Stringer mineralization is common in the immediate footwall and is composed of thin, anastomosing quartz veins with dark red sphalerite and minor chalcopyrite. Chalcopyrite and tetrahedrite also frequently occur in crosscutting veinlets within the sulphide lenses. Barite and chert tend to be clastic and are generally minor constituents in sulphide-rich volcanoclastic debris; together they constitute less than 10% of the ore, volumetrically.

The sulphide-rich lenses in the felsic volcanoclastics may have been partially formed as infillings from hydrothermal fluids that precipitated metals within the highly permeable felsic mass-flows, close to the seafloor (Sherlock *et al.*, 1994). However, some sections of the zinc facies display finely laminated to diffusely banded textures and may be of exhalative origin. The presence of detrital massive sulphide fragments, altered to unaltered lithic and minor vitric fragments, the clastic habit of chert and barite, and the composite bedded succession of mixed sulphide and volcanoclastic layers indicates that reworking has occurred.

A detailed example of the mineralization in hole TCU92-36 is given in Figure 6. The sulphides occur in two distinct lenses separated by feldspar-porphyrific flows and flow breccias. They are mainly fine-grained banded to disseminated sphalerite, pyrite and minor galena, accompanied by clastic chert and barite, hosted in sericitized and silicified volcanoclastic debris. Total sulphide content is between 25% and 40% (by volume). The banding is often contorted or discontinuous. The lower sulphide-rich interval contains clastic sections with some pyritic lapilli. Occasional beds and laminations of massive pyrite and massive, mixed fine-grained sphalerite and pyrite also occur. The associated debris consists of rounded to subangular felsic blocks and lapilli, some strongly sericitized, and pervasively sericitized to chloritized flattened lapilli which have been interpreted as pumice. The same type of lapilli is also a common constituent in the blocky felsic-rich debris in hole TC93-09 (Figure 5).



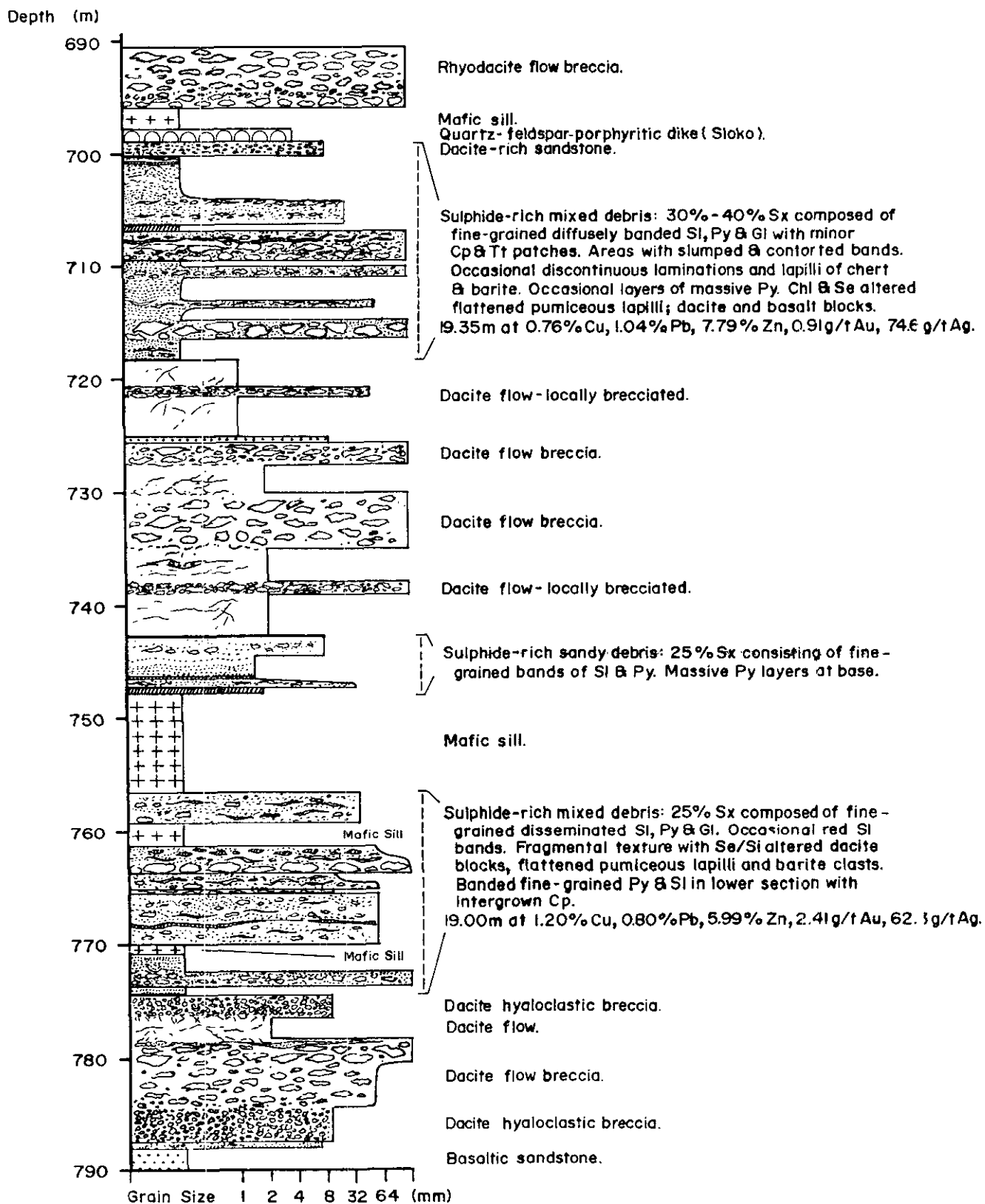


Figure 6: Detail of mineralization in diamond-drill hole TCU92-36.

## ALTERATION

Alteration attributed to hydrothermal activity has affected parts of the footwall mafic suite, the heterolithic mass-flow debris found beneath the massive sulphides lenses, and in some cases the felsic volcanics and equivalent fragmentals between sulphide lenses. Two significant mineral assemblages are noted: quartz-sericite-pyrite (QSP), and chlorite with or without quartz and pyrite.

Most of the QSP alteration is confined to the footwall immediately beneath the sulphides in the main mine block between the 4400E and 5300E faults, where it is often so intense that it obscures primary textures. Both alteration types are often observed as repetitive, alternating zones subparallel to bedding. This was seen in the lower part of hole TCU92-37 where QSP alteration occurs with chlorite in the footwall mafics and in the mixed debris and dacite flows below the sulphide intersections. Variable amounts (up to 10% by volume) of disseminated fine to coarse-grained pyrite and crosscutting quartz-pyrite patches and veinlets are associated with both the QSP and chlorite assemblages and may constitute stockwork mineralization. The QSP alteration of the mafic footwall is notably less intense in the western limb of the F anticline (hole TC93-09) where it has mainly affected the upper section of blocky volcanoclastic debris.

Cordierite porphyroblasts and fine-grained biotite are variably developed, generally in areas immediately underlying the sulphide mineralization, often with chlorite. Cordierite also occasionally occurs with sericite and pyrite, and has been noted in the sericitized and silicified altered volcanoclastic debris surrounding the sulphide mineralization. These occurrences of cordierite may be the result of a metamorphic overprint of an original clay-rich hydrothermal alteration. A similar origin is possible for the biotite. Both biotite and cordierite occur in the mudstone beds capping the felsic volcanics.

A strongly bleached, sericitic alteration zone, up to 1 metre, wide locally penetrates into the felsic flows and fragmentals capping the sulphide lenses. Quartz-sericite alteration, not necessarily with pyrite, is also common in the felsic-rich to mixed volcanoclastic gangue within sulphide-bearing beds. The degree of alteration in these units is variable, however. Some of the coarser debris units contain both bleached quartz-sericite altered and unaltered dacite blocks. Both chloritized and sericitized pumiceous lapilli occur in the same-sulphide rich lenses. This variation in the degree of alteration of fragments may be a reflection of reworking.

Significant chlorite occurs in some of the dacite-rich clastic rocks and fragmental flows above and below the sulphide-rich lenses. It is succeeded by sericite-rich assemblages close to the lenses.

Silicification is highly variable in intensity and is not necessarily associated with sericite. This is notable in large portions of the chlorite-altered mafic footwall, where the silicification is usually accompanied by pyrite

in patches and veinlets. Silicification is also found as local alteration in fractured mafic and dacite flow units with chlorite, epidote and, in places, hematite.

Crosscutting chlorite veinlets hosting various combinations of magnetite, quartz, epidote and locally pink garnet are found throughout the mine stratigraphy. These veinlets frequently display selvages of white to pearly quartz and possibly albite. They may represent a later hydrothermal event, possibly related to the gabbro intrusion.

## DISCUSSION AND SUMMARY

Detailed logging of the drill core indicates that the sulphide mineralization at Tulsequah Chief is hosted in a felsic-dominated sequence. This felsic package was emplaced on a pre-existing basement of basaltic andesite breccias, flows and minor fine-grained mafic-derived sediments. The style and chemistry of felsic volcanism varies from a preponderance of quenched to autobreccia-rich feldspar-porphyrific intervals and dacite-rich debris flows in the lower part, to an upper section dominated by massive feldspar-quartz-porphyrific flows or sills. The proportion of blocky felsic-rich debris *versus* brecciated dacite flows varies from hole to hole and increases significantly to the west and to the east of the main mine block. The lower part hosts the sulphide lenses, which are sometimes accompanied by finer grained, reworked volcanic sandstones or lapillistones.

Sulphide deposition took place in a volcanically active and gravitationally unstable environment. The frequent clastic to discontinuous to disturbed textures observed in the sulphide lenses, together with their composite nature and significant content of volcanic debris, suggest that reworking possibly by mass flows and slumpage, was an important process. The presence of finely banded layers of sphalerite and pyrite with rare intact barite laminations implies that exhalation was also an important depositional mechanism. Some of the stratiform sulphides may be of replacement-infilling origin but further evidence is required to substantiate this hypothesis. Some of the copper mineralization consists of crosscutting veinlets and patchy intergrowths with banded sphalerite and pyrite-rich sulphides, and therefore is a late-stage mineralizing event.

The most intense sericite-silica alteration occurs immediately beneath the sulphide lenses in the main mine block (in the hinge of the A syncline). It alternates with chloritic alteration and extends outward laterally, subparallel to stratigraphy. Crosscutting siliceous and pyritic veinlets may represent stockwork mineralization.

Banded to laminated mudstone beds and chert laminations occur at the contact between the felsic volcanics (unit 2) and the overlying basaltic flows and sediments (unit 3). The gabbro sill (unit 4) is relatively unaffected by alteration and similar sills are present within the upper basaltic package. These observations suggest that unit 3 and unit 4 are coeval.

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## NOTES