GEOLOGICAL INVESTIGATIONS OF THE TULSEQUAH CHIEF MASSIVE SULPHIDE DEPOSIT, NORTHWESTERN BRITISH COLUMBIA (104K/12)

By R.L. Sherlock, F. Childe, T.J. Barrett, J.K. Mortensen, P.D. Lewis
Mineral Deposit Research Unit, U.B.C.
T. Chandler
Redfern Resources Limited
P. McGuigan, G.L. Dawson
Cambria Geological Limited
R. Allen
Volcanic Resources

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INTRODUCTION

The Tulsequah Chief volcanogenic massive sulphide deposit (58° 30'N, 133° 35'W) 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). At present, access to the site is limited to small aircraft via two nearby airstrips. The Tulsequah Chief deposit is accessible by adits at several levels on the west side of Mount Eaton. The Big Bull deposit is located along strike 10 kilometres south of Tulsequah Chief on the southern flank of Mount Manville at the confluence of the Tulsequah and Taku rivers (Figure 1).

Fieldwork in 1993 involved relogging and sampling of selected drill-core through sections of the Tulsequah Chief mine stratigraphy, as well as underground sampling on the 5400 level and surface sampling around both the Tulsequah Chief and Big Bull deposits. Samples are being analyzed for lithogeochemistry, geochronology, mineralogy and fluid inclusions. This contribution describes the preliminary results and interpretations of the volcanic stratigraphy at the Tulsequah Chief deposit.

The objectives of the overall study are: to define the main stratigraphic units at Tulsequah Chief on the basis of detailed lithogeochemistry and petrography; to determine if this stratigraphy can be correlated across the 4400E and 5300E faults, which divide the property into western, central and eastern blocks; to identify the different levels and styles of mineralization and their origins; to date both the host volcanic rocks and the associated intrusive rocks; and to determine the distribution and intensity of alteration associated with mineralization.

For a detailed discussion of the regional geology the reader is referred to Kerr (1948), Souther (1971), Nelson and Payne (1984) and Mihalynuk *et al.* (1994).

EXPLORATION AND PRODUCTION HISTORY

The Tulsequah Chief deposit was discovered in 1923 by W. Kirkham of Juneau. Subsequent activity in this area led to the discovery in 1929 of both the associated Big Bull massive sulphide deposit and the Polaris-Taku gold deposit. The Tulsequah Chief and Big Bull deposits were acquired by the Consolidated Mining and Smelting Company of Canada, Limited (Cominco) in 1946 and brought into production in 1951. The mines closed in 1957 due to depressed metal prices. Total production from the two orebodies was 933 520 tonnes with an average grade of 1.59% copper, 1.54% lead, 7.0% zinc, 3.84 grams per tonne gold and 126.5 grams per tonne silver. Of this ore, 622 136 tonnes were from the Tulsequah Chief orebody and the remaining 311 384 tonnes from the Big Bull deposit (McGuigan *et al.*, 1993).

A joint venture between Cominco and Redfern Resources Limited from 1987 to 1991 led to extensive exploration including over 21 000 metres of surface and underground diamond drilling (Casselman, 1988, 1989, 1990). In June 1992, Redfern Resources purchased Cominco's interest (60%) in the property and consequently now owns 100% of the Tulsequah Chief and Big Bull orebodies and adjacent ground. In 1992 an additional 4 579 metres of underground diamond-drilling was completed; in addition, surface mapping and relogging of drill core were carried out by Cambria Geological Limited. Reserve estimates made by Cambria Geological at the end of the 1992 program for all ore horizons and classes were 8 500 592 tonnes grading 1.48% copper, 1.17% lead, 6.86% zinc, 2.56 grams per tonne gold and 103.4 grams per tonne silver (McGuigan *et al.*, 1993).

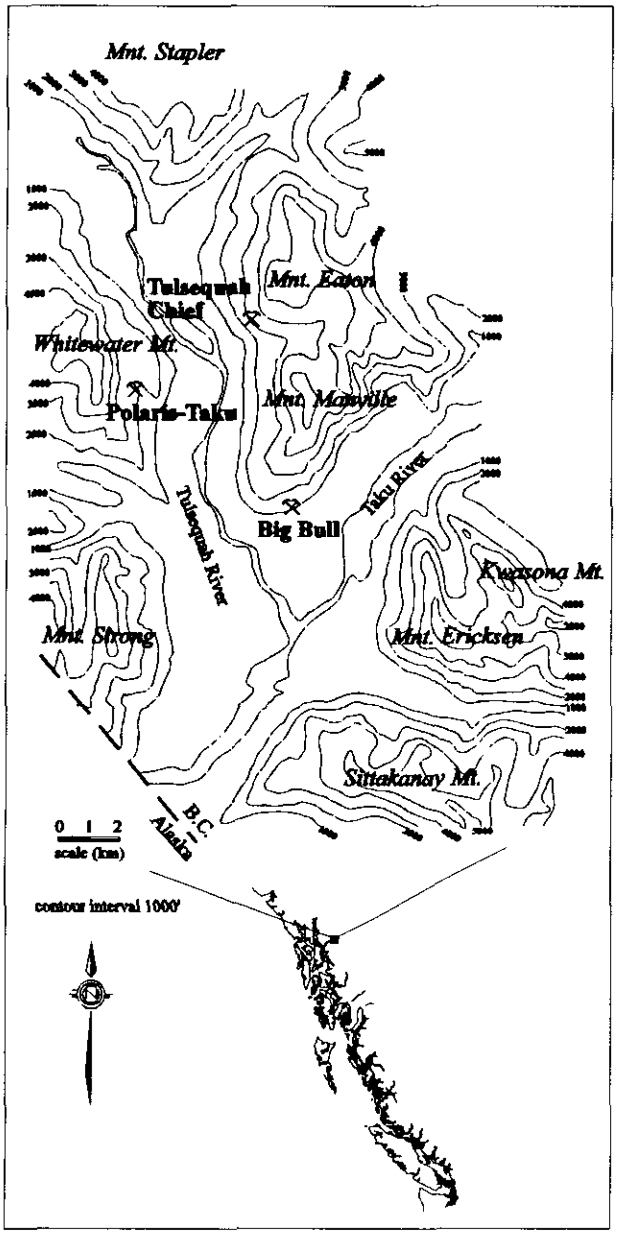

Figure 1. Location map for the Tulsequah Chief, Big Bull and Polaris-Taku deposits, from Nelson and Payne (1984).

Current exploration on the property, by Redfern Resources Limited, consists of geological mapping, geophysical surveys, underground and surface diamond-drilling at both the Tulsequah Chief and Big Bull orebodies. Diamond drilling in 1993 includes 8 060 metres from the surface and underground at Tulsequah Chief, and 3 700 metres from the surface at Big Bull.

MINE SEQUENCE STRATIGRAPHY

The stratigraphy at the Tulsequah Chief deposit is composed of a series of northward-younging mafic and felsic volcanic rocks (Figure 2). The stratigraphically lowest unit (unit 1) is composed of mafic volcanic rocks forming the footwall to mineralization. This unit is directly overlain by a series of dacitic flows, sills and volcaniclastic material (units 2 and 4). On the basis of contact relationships, units 2 and 4 are interpreted to have originally been a single felsic (dacitic) package which was subsequently intruded by a large mafic sill (unit 3). The upper felsic unit (unit 4) is overlain by a series of mafic flows or sills and volcaniclastic sediments (unit 5). All of these units are intruded by Tertiary Sloko dikes, mainly of felsic composition. The lithological units are based on field descriptions and limited petrology and may be modified as a result of future lithogeochemical results.

UNIT 1

Unit 1 forms the stratigraphic footwall to the massive sulphide deposits and comprises mainly massive to flow-brecciated mafic volcanics with minor volcanic sediment. Alteration and metamorphism have modified the primary mineralogy to an assemblage of quartz, sericite, chlorite, biotite, pyrite and hematite. The top of the unit is strongly amygdaloidal and commonly contains hyaloclastic textured material. The amygdules are typically filled by quartz, pyrite and chalcopyrite. Cordierite porphyroblasts are variably developed in areas immediately underlying the sulphide mineralization.

UNIT 2

Unit 2 is the principle host to sulphide mineralization in the lower mine stratigraphy, and comprises massive, flow-brecciated and volcaniclastic dacite. Several massive sulphide lenses, collectively termed the H-AB horizon, are hosted by dacite mass-flow material containing variable amounts of sulphide and cherty clasts. Intrusive into the mass-flow unit are dacite sills that locally dilate and split the package. This process, and subsequent fault dislocations, has separated the mineralized horizon into discrete sulphide lenses termed the F, AB_1, AB_2, H, I and G zones (Figure 2). Unit 2 thickens to the west, which may indicate a dacitic source in this direction. The dacite consists of plagioclase and quartz phenocrysts in a groundmass of quartz, sericite and epidote.

UNIT 3

A thick massive mafic sill (unit 3) with chilled margins and intercalations of dacitic material at either margin separates the upper and lower felsic packages. Unit 3 is up to 50 metres thick and is slightly discordant to stratigraphy; it probably represents a low-angle sill that has intruded the dacitic (fragmental-rich) package. The margins of unit 3 are finer-grained then the interior which has a diabasic texture. The primary mineralogy of the sill comprises augite, plagioclase and olivine phenocrysts in a fine-grained plagioclase groundmass. This assemblage is overprinted by coarse-grained randomly oriented chlorite and amphibole of possible metamorphic origin. The unit appears to be relatively unaltered compared to units 1, 2 and 4, suggesting it was emplaced after the mineralizing event. Unit 3 may be the subvolcanic equivalent of unit 5.

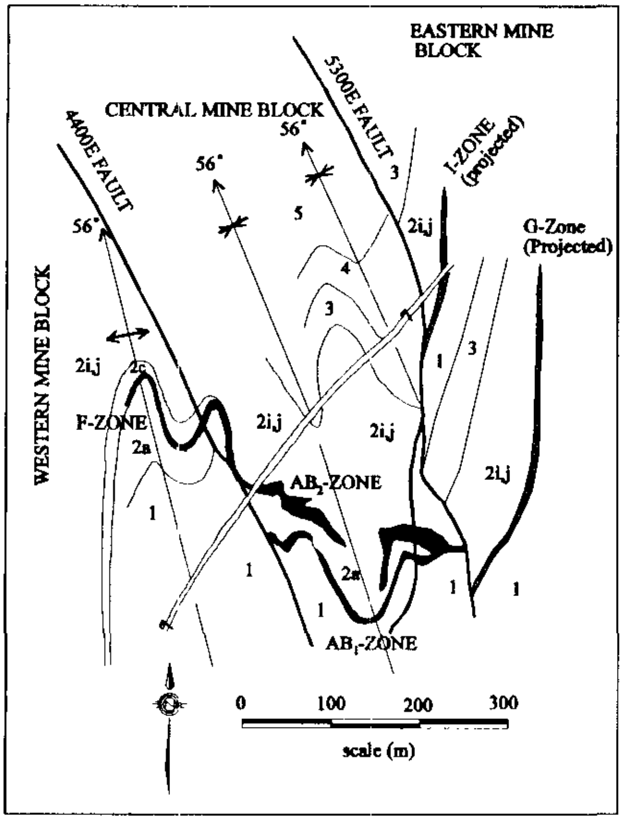

Figure 2. Tulsequah Chief 5400 level geology map: 1, undifferentiated basalt; 2a, mixed felsic fragmental rock; 2c, banded to massive chert; 2i,j, dacite flow, flow breccia and lapilli tuff; 3, undifferentiated mafic sill; 4, undifferentiated upper felsic horizon; 5, undifferentiated mafic flows and epiclastic rocks; 7, Sloko dike. Black areas are sulphide mineralization. Mapping from McGuigan *et al.*, 1993.

UNIT 4

The upper felsic package (unit 4) is very similar to unit 2 but may contain a greater proportion of volcaniclastic material. Unit 4 is composed mainly of dacitic mass-flows with pumice, lithic, chert and barite fragments. The preservation of angular pumice fragments suggests that the volcaniclastic material has not been highly reworked. East of the 5300E fault felsic rocks, previously assigned to unit 4, are host to the I zone sulphide lens which was the main focus of early mining activity. Recent mapping and drill-hole interpretation suggest that the I zone may be a structural offset of the G zone and may correlate with the lower felsic stratigraphy of unit 2.

UNIT 5

The upper mafic package (unit 5) is primarily massive mafic flows or sills, and intercalated sediments composed mainly of argillite, siltstone, ash tuff and minor chert. The unit is typically unaltered and lies above all known mineralization.

STRUCTURE

Stratigraphic units at Tulsequah Chief outline a series of north to northwest-plunging folds which are divided into three discrete structural blocks by the 5300E and 4400E faults (Figure 2). These faults are exposed in several locations in the 5400 level mine workings. The 5300E fault is the most significant and probably has the largest displacement of the faults on this level. 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.

MINERALIZATION

The sulphide deposits described here occur primarily within volcaniclastic mass-flows of unit 2. Several sulphide facies have been defined by Cambria Geological Limited and Redfern Resources. The pyrite facies consists mainly of massive pyrite with little base metal content. The zinc facies is composed primarily of semimassive pale yellow sphalerite, pyrite, galena, chalcopyrite and tetrahedrite, with barite, quartz and sericitically altered lithic fragments. The copper facies is mainly massive pyrite with up to several percent disseminated chalcopyrite. Stringer mineralization is quite common in the footwall and is composed of thin, anastomosing quartz veins with dark red sphalerite and minor chalcopyrite.

The sulphides in unit 2 felsic volcaniclastics may have formed from hydrothermal fluids that precipitated metals within the highly permeable felsic mass-flow, close to the seafloor. Also present in unit 2 are near-massive sulphide beds that may represent precipitates directly onto the seafloor, where barite and chert also accumulated episodically. Finally, the presence of detrital massive sulphide fragments and chert and barite clasts in unit 2 indicates that some reworking has occurred. The different styles of mineralization are currently under study in terms of stratigraphic level and facies variations, mineralogical and isotopic variations, and temperature and composition of mineralizing fluids.

Although the overall mine stratigraphy is relatively consistent, the composition of the sulphide mineralization and its relationships to extrusive and intrusive rocks are quite variable. This is best demonstrated by drill holes TCU 90-22 (Figure 3) and TCU 92-36 (Figure 4). Although these two holes are located less than 200 metres apart, TCU 90-22 intersects an interval of uninterrupted sulphide mineralization, in contrast to TCU 92-36 which intersects two significant intervals of mineralization separated by about 24 metres of dacite sill and 7 metres of mafic sill.

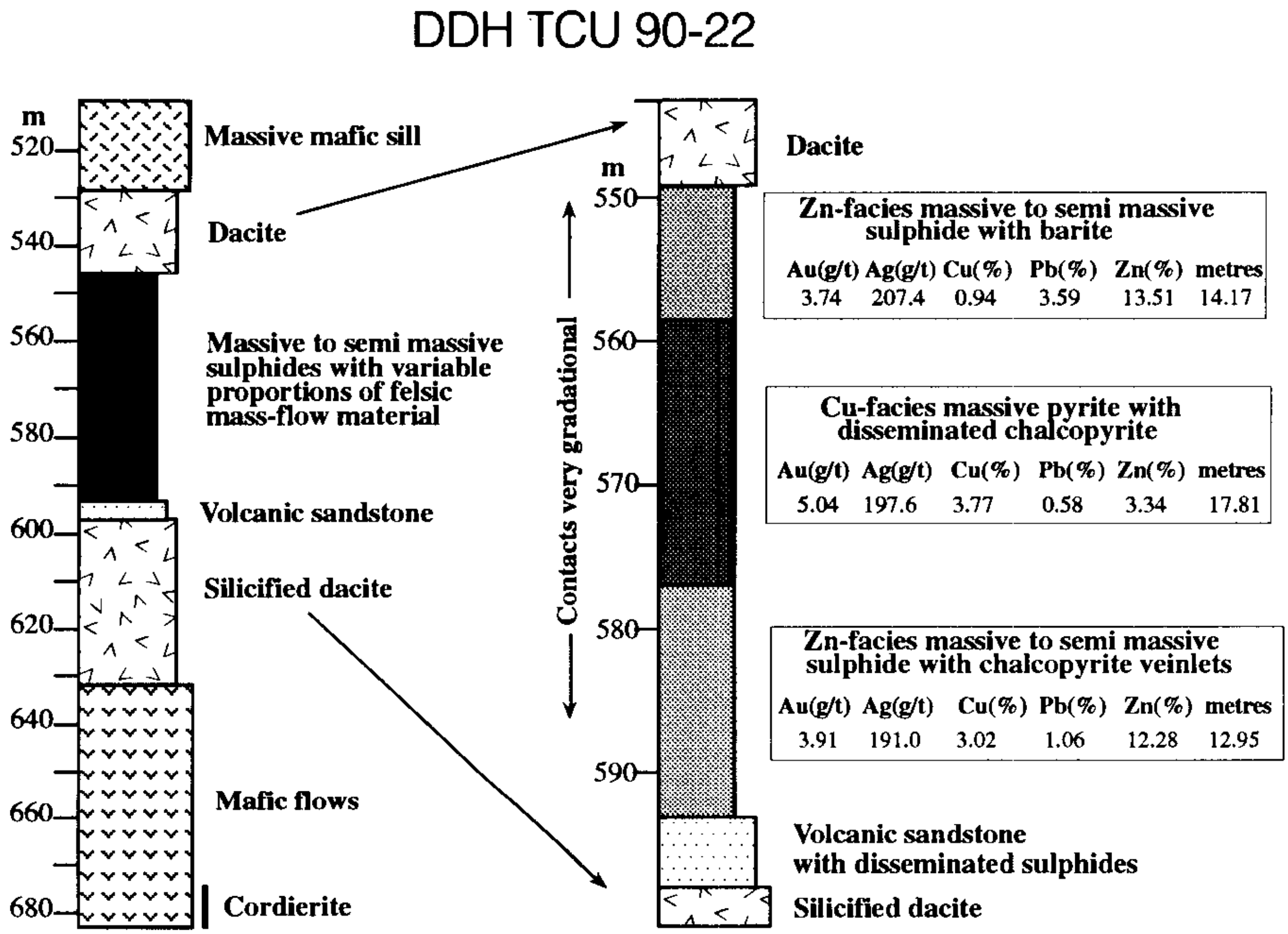

Figure 3. Stratigraphic section for diamond-drill hole TCU 90-22.

GEOCHRONOLOGY

On the basis of mapping and biochronology by Nelson and Payne (1984), the Tulsequah Chief deposit was considered to be mid-Pennsylvanian to Early Permian in age. The fossil locality described by Nelson and Payne is about 2 kilometres northeast of the Tulsequah deposit, making its stratigraphic position with respect to the ore horizon uncertain. In order to help date the volcanic stratigraphy, a coarse-grained volcaniclastic rock from unit 4, near the 6400 portal, was analyzed by J. Mortensen. Results for this sample are presented below.

ANALYTICAL TECHNIQUES

Approximately 50 kilograms of dacite from unit 4, the upper felsic volcanic unit, was collected by M. Casselman of Cominco for U-Pb dating. Zircons were separated using conventional Wilfley table and heavy liquid techniques. Most zircon fractions were abraded prior to analysis (Krogh, 1982) to minimize the effects of surface-correlated lead loss. Uranium-lead analyses were done at the geochronology laboratory at the Geological Survey of Canada (Ottawa). Criteria for selection of grains for analysis, and procedures used for dissolution, chemical extraction and purification of uranium and lead, and mass spectrometry are described in detail by Parrish *et al.* (1987). Procedural blanks were 20 to 7 picograms for lead and less than 1 picogram for uranium. Uranium-lead analytical data are given in Table 1. Errors assigned to individual analyses were calculated using the numerical error propagation method of Roddick (1987). Age calculations employed the decay constants recommended by Steiger and Jäger (1975), and initial common lead compositions from the model of Stacey and Kramers (1975). Concordia intercept ages were calculated using a modified York-II regression model as described by Parrish *et al.* (1987), and the algorithm of Ludwig (1980). All errors in ages are given at the 2σ level.

ANALYTICAL RESULTS

About one-half of the original dacite sample was processed initially. Only a small amount of zircon was recovered. The zircons form a relatively homogeneous population of mainly fine, very pale pink, clear grains with rare to abundant clear, bubble- and rod-shaped inclusions. Igneous zoning was faint to absent, and no cores were observed. The grains range from equant to

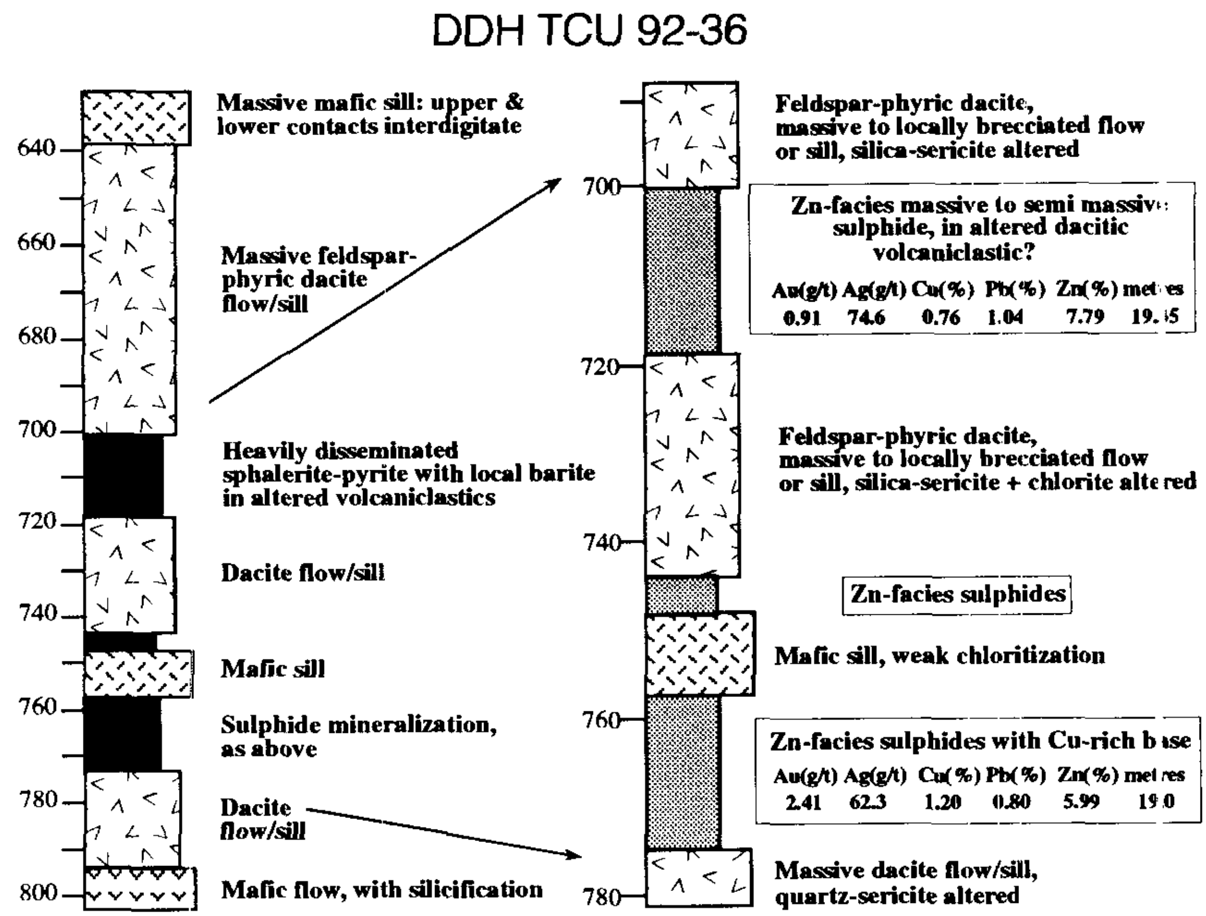

Figure 4. Stratigraphic section for diamond-drill hole TCU 92-36

TABLE 1
URANIUM-LEAD ANALYTICAL DATA FOR TULSEQUAH CHIEF UNIT 4 DACITE

Sample Description	Wt. (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$ (meas.)[3]	% ^{208}Pb[2]	$^{206}Pb/^{238}U$[4] (± % 1s)	$^{207}Pb/^{235}U$[4] (± % 1s)	$^{207}Pb/^{206}Pb$[4] (± % 1s)	$^{207}Pb/^{206}Pb$[4] (Ma, ± % 2s)
A: N,+74,a	0.039	198	61.6	4291	20.0	0.26286(0.09)	3.6394(0.10)	0.10042(0.04)	1631.8(1.4)
B: N,+74,a	0.057	269	84.9	6950	12.4	0.28528(0.09)	4.9473(0.10)	0.12577(0.03)	2039.7(1.1)
C: N,-44	0.079	275	55.5	5519	8.8	0.19475(0.08)	2.6157(0.10)	0.09741(0.03)	1575.1(1.3)
D: N,-44	0.063	390	64.8	2876	8.3	0.16325(0.09)	1.9072(0.11)	0.08473(0.05)	1309.4(1.8)
EA: bulk,a	0.011	193	11.3	737	12.6	0.05633(0.14)	0.4162(0.40)	0.05358(0.35)	353.4(15.8)
EB: bulk,single,a	0.003	292	15.1	318	15.8	0.04805(0.21)	0.3566(0.89)	0.05383(0.79)	363.9(35.4)
F: bulk,best prisms,a	0.015	213	12.0	1237	11.6	0.05478(0.10)	0.4042(0.23)	0.05352(0.19)	350.7(3.7)

[1] +74, -74 refers to grain size in diameter (μ); N, nonmagnetic on Frantz magnetic separator; a, abraded

[2] radiogenic Pb; corrected for blank, spike and initial common Pb

[3] corrected for spike and fractionation

[4] corrected for blank Pb and U, and common Pb. Errors are 1 standard error of mean for isotopic ratios and 1σ for derived ages

stubby prismatic (l:w = 2-3) subhedral forms to irregular, anhedral, commonly broken grains showing smoothly corroded surfaces suggestive of magmatic corrosion. Four fractions were selected for analysis. Two of these were relatively coarse (>74μ diameter) equant to prismatic grains, and were strongly abraded prior to dissolution. Two other fractions of finer unabraded grains were also analyzed. The four analyses are all moderately to highly discordant (Figure 5) and yield surprisingly old $^{207}Pb/^{206}Pb$ ages (up to 2040 Ma). In view of the probable mid-Paleozoic crystallization age inferred for the volcanic rocks in the Tulsequah region, the data were taken to indicate the presence of a major component of older zircon in the sample, either as inherited cores or, more likely, as xenocrysts that did not differ greatly in appearance from the igneous grains. Zircon was subsequently separated from the remaining sample of dacite, and three fractions were selected and abraded. One fraction (F) was of the clearest, most euhedral prismatic grains in the sample, a second fraction (EA) consisted of very clear fragments with at least one well-preserved euhedral facet, and the third fraction was a single, faintly zoned, subhedral, stubby prismatic grain with a slightly more inclusion-rich core. These three fractions yield much younger $^{207}Pb/^{206}Pb$ ages, and define a linear array (Figure 5) with calculated upper and lower intercept ages of 350.6 +14.7/-6.2 and -72 ± 267 Ma, respectively. One of the fractions (EA) is concordant with a $^{207}Pb/^{206}Pb$ age of 353.8 ● 15.8 Ma. The similarity of the $^{207}Pb/^{206}Pb$ ages of the three fractions suggests that they were all free of inheritance (despite the slightly cloudy core visible in single grain EB). We consider the best estimate of the crystallization age of the dacite sample to be given by the $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$ ages of fraction EA, and therefore assign a latest Devonian to earliest Mississippian age of 353.4 +15.8/-0.9 Ma to the sample.

DISCUSSION

A preliminary interpretation of the early geological history of the mine area is:

1) accumulation of a widespread mafic volcanic basement composed of basaltic flows and sills and minor tuffaceous sediments;
2) accumulation of massive dacitic volcanic flows and flow breccias;
3) mass flows of dacitic to heterolithic volcaniclastic debris with local baritic to cherty intervals;
4) emplacement of sulphide mineralization at a number of stratigraphic levels associated with the dacitic volcaniclastic package; sulphides infilled porous unconsolidated debris flows and accumulated as exhalative units together with barite and chert between debris flows;
5) intrusion of the dacitic volcaniclastic package by one or more dacite sills which acted to dilate the original mineralized intervals;
6) intrusion of the unit 3 mafic sill, further dilating the felsic package to produce felsic units 2 and 4;

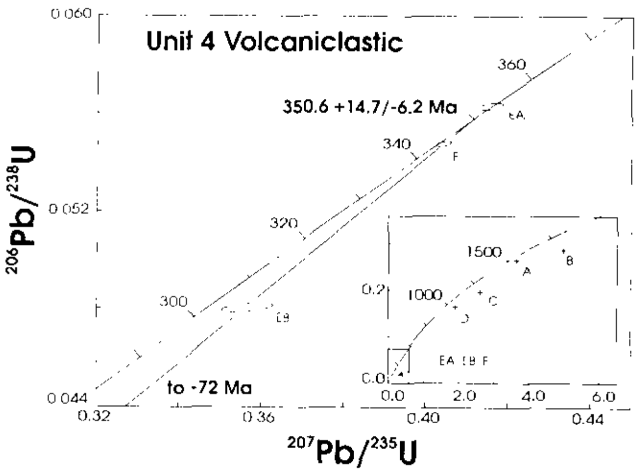

Figure 5. $^{206}Pb/^{238}U$ vs. $^{207}Pb/^{235}U$ concordia diagram for unit 4 (upper felsic horizon)

7) accumulation of the unit 5 mafic volcanic rocks. It is possible that unit 5 is coeval with, and genetically related to the unit 3 sill.

FURTHER WORK

Further work will involve: examination of primary volcanic textures and facies relationships to determine the physical environment of ore formation; lithogeochemical and petrographic analysis of all units to determine the stratigraphic relationships and the effect of alteration throughout the camp; uranium-lead geochronology on newly collected samples from, the upper and lower felsic volcanic packages within the central mine block, unit 3 mafic intrusion, a felsic volcanic sample from the Big Bull deposit and two regional felsic units.

Galena samples were collected from all mineralized horizons for lead isotope analysis. On a regional scale a detailed analysis of the lead isotopic signature may yield information on the tectonic setting and evolution of the Tulsequah Chief and Big Bull deposits. Locally, minor variations in the lead isotopic composition of the different ore lenses may assist in correlating mineralized horizons between the major fault blocks.

Mineralized intervals have been sampled for fluid inclusion and stable isotope analysis to determine the physical and chemical conditions of the ore-forming fluids and how they may have varied both temporally and spatially.

ACKNOWLEDGMENTS

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