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GEOLOGY OF THE KUTCHO CREEK VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS, NORTHERN BRITISH COLUMBIA

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ABSTRACT

The Kutcho Creek volcanogenic massive sulphide deposits occur within the Upper Triassic Kutcho Formation in northwestern British Columbia. The Kutcho Formation consists of a bimodal, spilitic assemblage with an interpreted calc-alkaline composition. These volcanic rocks are overlain by Upper Triassic to Lower Jurassic sedimentary rocks. This volcanic-sedimentary succession of isoclinally folded greenschist facies rocks forms a fault-bounded allochthon.

Three massive sulphide zones occur on one horizon in the highest volcanic cycle in the thickest and most felsic section of the Kutcho Formation. These zones, comprising numerous sulphide and gangue sections, form a linear trend for 3.5 km near the top of a felsic lapilli tuff unit and are interpreted to overly a hydrothermally altered fissure. They are overlain by a section of felsic quartz-feldspar crystal tuff, lapilli crystal tuff and minor mafic rocks. Sulphide zones are ellipsoidal, elongate and commonly wedge-shaped in section. They consist of sphalerite, chalcopyrite and bornite in a gangue of minor to massive pyrite with dolomite, quartz and sericite. Vertical copper-zinc zonation in the deposits is not apparent but lateral zoning occurs in the plane of the deposits with distal exhalite facies being zinc-enriched. The sulphide zones are underlain by barren, disseminated pyrite along their 3.5 km trend; the abundance of disseminated pyrite decreases with depth.

INTRODUCTION

Prior to the discovery of the Kutcho Creek deposits no mineralization or volcanic rocks were known in the area. The discovery of pyritic sericite schist in 1967 and volcanogenic massive sulphide deposits in 1973 indicated a previously unknown mineralized volcanic sequence. Subsequent work by the B.C. Ministry of Mines and the Geological Survey of Canada recognized volcanic and conformably overlying sedimentary formations of Upper Triassic to Lower Jurassic age within an allochthon called the King Salmon assemblage. Exploration to date by Esso Minerals Canada and Sumac Mines Limited has defined two potentially economic massive sulphide lenses and one low-grade lens that together comprise the Kutcho Creek deposit.

LOCATION

The Kutcho Creek deposit is located in northwestern British Columbia about 100 km east of Dease Lake and 210 km south of Watson Lake, Yukon (Fig. 1). The nearest road, the Stewart-Cassiar highway, passes through Dease Lake. An air-strip is located 10 km west of the deposit and a tote road connects the deposit with the air-strip.

HISTORY AND OWNERSHIP

The Kutcho Creek deposit was first detected in 1967 by a single Cu and Zn stream sediment geochemical anomaly during a regional survey in which Imperial Oil Limited was a participant. Brief field checks from 1967 to 1970 located sericite schists, iron-stained patches in a creek bed, and minor barren pyrite float. In 1972, Sumac Mines Ltd., controlled by Sumitomo Metal Mining Co., Ltd., located disseminated pyrite with minor chalcopyrite during stream sediment anomaly follow-up in a creek west of the Esso geochemical anomaly. Esso located a high-grade massive sulphide boulder in 1973 near the source area of the 1967 stream sediment anomaly.

Staking and subsequent exploration resulted in Esso owning the east end of the outcropping Kutcho zone and the deep Esso West zone (Fig 5). Sumac owns the down-plunge, westerly portion of the Kutcho zone and the Sumac West zone.

REGIONAL GEOLOGY

Regional geology of the Cry Lake (NTS 104 I) area has been described and interpreted by Gabrielse (1962, 1978, 1979), Monger and Thorstad (1978), Thorstad (1983) and Tipper (1978). The Kutcho Creek deposit occurs within the Kutcho Formation, the lowest stratigraphic unit in a sequence of rocks called the

King Salmon assemblage. These rocks form part of the King Salmon allochthon, a southwesterly transported thrust slice bounded to the south by the King Salmon thrust fault and to the north by the Nahlin thrust fault (Fig 2). The Nahlin Fault brings Permo-Triassic Cache Creek Group rocks into contact with the Upper Triassic to Lower Jurassic King Salmon assemblage. The King Salmon assemblage is, in turn, thrust on to Jurassic and Triassic volcano-sedimentary rocks.

The King Salmon allochthon and Cache Creek structural belt are truncated to the north and east by the major northwesterly trending, dextral, strike-slip Kutcho Fault. The terrane north of the Kutcho Fault is predominantly underlain by the Middle Cretaceous Cassiar Batholith, Omineca Crystalline Belt rocks, as well as Proterozoic and Paleozoic miogeosynclinical rocks. South of the King Salmon allochthon, the composite Hotailuh Batholith of Lower Triassic to Middle Jurassic age intrudes Mesozoic rocks.

The King Salmon assemblage consists of the Upper Triassic Kutcho and Sinwa formations and the overlying Lower Jurassic Inklin Formation. The Kutcho Formation is composed predominantly of pyroclastic and volcaniclastic rocks with intercalated sedimentary and flow or intrusive rocks. Kutcho volcanic rocks have a Rb-Sr age of 210 $\pm$ 10 Ma, with a Sr87/Sr86 initial ratio of 0.7042 (Thorstad, 1983) and are overlain by Sinwa Formation crystalline limestone and intercalated minor conglomerate and argillite. The overlying Inklin Formation is composed of intercalated greywacke, dark grey to black shale and siltstone, and black phyllite. A basal conglomerate is generally present and conglomerate layers and lenses are common throughout. Sedimentary bedding in greywacke-shale and/or phyllite sequences are usually obscured by well-developed foliation.

Regional Structure and Metamorphism

Rocks of the King Salmon assemblage are isoclinally folded and have a single, penetrative foliation. The foliation is axial planar and is subparallel to the leading edge of the sole of the King Salmon thrust fault. Development of folds, penetrative cleavage and metamorphism are considered to be contemporaneous with thrusting that occurred between Early Toarcian and Middle Bajocian time (Thorstad, 1983). Kutcho Formation rocks have mineral assemblages indicating metamorphism within the quartz-albite-epidote-biotite sub-facies. A K-Ar date of 120 $\pm$ 5 Ma for hydrothermal sericite in the footwall of a massive sulphide zone (Bridge et al, 1978) likely indicates up-dating by the Cretaceous intrusive events of the Cassiar Batholith.

KUTCHO FORMATION

The Kutcho Formation is composed of pyroclastic, flow and epiclastic rocks with intercalated shales, subordinate synvolcanic intrusive rocks and possible sills. The volcanic succession is interpreted to be calc-alkaline (Thorstad, 1983; Panteleyev, 1974). However, the apparent calc-alkaline nature of Kutcho Formation volcanic rocks may not reflect the original parentage because all the rocks are spilitized. The suite is bimodal with basalt and basaltic-andesite and rhyodacite to rhyolite predominating.

The Kutcho Formation is relatively thin in most areas west of Kutcho Creek where it consists of mafic rocks, interpreted to be mainly flows and tuffs, with minor felsic tuffs. The formation appears thickest in the vicinity of the Kutcho deposit (Fig. 2) where it is estimated to be at least 2 km with its base not exposed. Thickness, however, cannot be accurately determined due to isoclinal folds, facies changes and probable axial planar faults.

GEOLOGY OF THE DEPOSIT

The geology of the Kutcho property has been described by Bridge et al (1977), Bridge (1978, 1979), Thorstad (1983), Panteleyev (1974, 1976) Pearson and Panteleyev (1975), and Weber (1977). The Kutcho massive sulphide zones occur in the uppermost felsic pyroclastic cycle in the Kutcho Formation (Fig. 4). They occur at the sharp transition between footwall rhyolitic lapilli tuff with minor ash tuff, and hanging wall rhyolitic crystal- and lapilli-crystal tuffs with porphyritic mafic rocks. The sulphide zones are at or near the top of the felsic lapilli tuff (LT). Numerous, thin, massive sulphide sections above the main sulphide section occur in lapilli-crystal tuff (LCT) and near the base of the quartz-feldspar crystal tuff (QFCT) (Fig. 4). Above the hanging wall felsic pyroclastic rocks, the stratigraphy changes abruptly to a highly variable sequence comprising thin-bedded ash, lapilli and crystal tuffs with epiclastic rocks, argillite and mafic rocks of the Tuff-Argillite unit.

The volcanic section with the massive sulphide zones occurs on the north-dipping limb of an anticlinal fold (Fig. 3). The following sections describe the Kutcho volcanic and sedimentary rock units, and sulphide zones in their stratigraphic sequence (Fig. 4). Geology has been interpreted from outcrop and 292 drill holes. Most drill holes are in or near the massive sulphide zones.

Lower Footwall Rocks

The section below the immediate footwall rocks of the massive sulphide deposits, interpreted to be about 2 km thick and with its base unexposed, consists of mafic flows and tuffs, plus dacitic to rhyolitic tuffs. Mafic flows are massive, fine-grained, non-porphyritic and commonly contain spheroidal masses of epidote with minor calcite up to 25 cm in diameter. Felsic tuffs are commonly quartz- or plagioclase-bearing crystal tuffs that locally occur in successive, graded cycles. Possible synvolcanic intrusive rocks include an elongate body of rock interpreted as trondhjemite (Panteleyev, 1974) in the lower part of the sequence (Fig. 3) and minor, massive, aphanitic rhyolites. Minor, thin argillite bands occur commonly intercalated with felsic tuff.

There is no evidence of hydrothermal alteration in this lower volcanic sequence. Epidote is ubiquitous; carbonate, sericite and chlorite occur in minor amounts; mafic minerals are replaced by chlorite and/or biotite.

Footwall Lapilli Tuff (LT)

The immediate footwall of the sulphide zones consists of a homogeneous, 300 m thick lapilli tuff with closely packed 1-20 mm thick fragments in a fine-grained micaceous-siliceous matrix. It contains minor 1 mm quartz phenocrysts, and minor ash tuff layers. This tuff unit is altered to quartz-sericite-dolomite-chlorite schist, referred to as "pale green schist" by Sumac geologists. Fragments and matrix have a micromosaic texture and are difficult to distinguish except in drill core (Fig. 6a and 6b). Quartz phenocrysts 1-2 mm in diameter occur

in trace amounts and become more common 100-300 m away from the footwall disseminated pyrite zone (Fig. 6c). Immediately below the massive sulphide zones, the LT is silvery white to pale green. It ranges between light to medium green at depth and across strike from the sulphide lenses but color changes do not correlate with microscopically detectable proportions of sericite and chlorite nor with K_2O content.
Below the Kutcho zone the base of the LT can only be distinguished by the transition from schistose rocks to hard, felsic lapilli tuff without hydrothermal sericite. Beyond the Kutcho zone the base of the LT is sharp in outcrop with the lower footwall rocks being massive, fine-grained crystal tuffs.

A 5-40 m thick mafic ash tuff bed with dolomite porphyroblasts and disseminated pyrite extends over a strike length of at least 4 km below the massive sulphide zones in the footwall LT (Fig. 4 and 7). Minor disseminated sphalerite, pyrite and chalcopyrite occur locally in LT immediately below the mafic ash tuff bed.

Massive Sulphide Zones

Three elongate, *en echelon*, massive sulphide zones with up to 300 m gaps between them occur along a 3.5 km strike length (Fig. 5 and 11). From east to west, they are called the Kutcho, Sumac West and Esso West zones. Each zone is an elongate, ellipsoidal body consisting of multiple sulphide and low-sulphide gangue sections. They commonly pinch out up dip to the south but are thick and interdigitate with LT and LCT on their down dip, north edges. The zones have different volumes but all have maximum thicknesses through their central portions or north edges of about 30 m. The base of each zone is transitional into footwall disseminated pyrite but top contacts are commonly sharp.

The three zones appear to occur at a constant stratigraphic position but the central Sumac West zone is interpreted to be in a slight depression relative to the plane of the others (Fig. 8 and 9). The zones have a general strike of 280° and dip 45°-50° north which is conformable with bedding attitudes in overlying sedimentary rocks. The overall trend of the three zones is 285° with a 5°-10° plunge approximately parallel to lineations and fold axes.

The sulphide zones rake gently across the north-dipping limb of an isoclinal fold. Fold geometry in the vicinity of sulphide zones is poorly known because of thickness and facies changes. Also, faults probably parallel to the axial plane of the fold further complicate spatial relations.

Kutcho Zone

The Kutcho zone contains 17,000,000 tonnes of open pit mineable reserves of 1.62% Cu, 2.32% Zn, 29.2 g/t Ag and 0.3 g/t Au. The eastern edge of the zone reaches the bedrock surface and is covered by a layer of till up to 3 m thick. Indications of the eroded edge of the sulphide zone include rare fragments of fresh to weathered massive sulphides, a 1 m thick section of limonitic indigenous gossan, minor patches 1 to 2 m thick of ferricrete downslope from the zone, and a strong color anomaly in a creek draining the eroded portion.

The Kutcho zone is internally variable. It has a lower massive pyrite section transitional from footwall disseminated pyrite. Significant base metal values occur from the upper portion of this section to the top of the zone. A low-sulphide LT section is common within the lower massive pyrite section. Up to six sections of massive sulphides, mineralized dolomite-quartz- sericite rock or mineralized LT overlie the lower massive pyrite section.

Non-sulphide gangue minerals are, in order of abundance, dolomite, quartz and sericite. The sulphide minerals are, in order of abundance, pyrite, sphalerite, chalcopyrite, bornite, minor chalcocite, trace tennantite, galena, digenite (Cu_9S_5) and djurleite ($Cu_{1.96}S$). Idaite (Cu_5FeS_6) has been identified in the Sumac adit in the central part of the Kutcho zone (Deane, 1983). Both copper and zinc are concentrated in the middle to upper portions of the sulphide zone. The lower massive pyrite section commonly is barren at its base; its contact is transitional from barren disseminated pyrite in the footwall. Silver content correlates closely with copper and occurs mainly within chalcocite, digenite and djurleite (Gasparrini, 1979). Pyrite varies from fine-grained to coarsely granular. It typically is recrystallized and texturally homogenous with a grain size of less than 1 to 2 mm. Sphalerite occurs as disseminations and thin crude bands within massive pyrite. Chalcopyrite and bornite occur as fine disseminations or remobilized coarse patches and veinlets. About half the copper in the Kutcho zone is contained in bornite.

Sumac West Zone

The central Sumac West zone has been incompletely defined and sampled by drilling due to its low grade. It is estimated to contain about 10,000,000 tonnes grading 1.0% Cu and 1.2% Zn. It is a very homogenous body of fine-grained massive pyrite with minor quartz, dolomite and sericite gangue. The massive pyrite contains disseminated or minor bands of sphalerite, disseminated chalcopyrite and rare disseminated bornite. Development of footwall disseminated pyrite below the massive pyrite is weaker than under the Kutcho and Esso West zones.

Esso West Zone

The most westerly and deepest of the three massive sulphide zones, the Esso West zone, contains approximately 1,000,000 to

1,500,000 tonnes with about twice the metal grade of the Kutcho zone. It appears to consist of a main body and a smaller, slightly discordant southerly body. However, both bodies occur at the same stratigraphic position and may be connected.(Fig. 5). Intense footwall disseminated pyrite occurs below both bodies and below the gap between them. This zone is similar mineralogically to the Kutcho zone but is slightly coarser-grained and lacks low-grade massive pyrite sections.

Additional small massive sulphide bodies have been intersected in drill holes up to 450 m northwest of the Esso West zone roughly along the linear trend of the three main sulphide zones (Fig. 5).

Metal Zonation

Lateral zonation of Cu and Zn occurs between the massive sulphide zones, the ore horizon peripheral to them and the distal ore horizon. The three massive sulphide zones have average Cu:Zn ratios of 0.5 to 0.8:1. Intersections in the ore horizon of dolomite-pyrite-lapilli tuff and pyritic lapilli tuff 100 to 300 m beyond edges of the ore zones are commonly zinc-rich, contain no bornite, and have average Cu:Zn ratios of 0.1:1. Drill hole intersections in the ore horizon 1.3 to 4.0 km beyond the three sulphide zones are not as zinc-rich and have variable Cu:Zn ratios from 0.1:1 to 0.9:1 but commonly greater than 0.3:1. One minor disseminated sulphide zone 4 km beyond the Kutcho zone which may be related to a small hydrothermal vent has a Cu:Zn ratio of 3.7:1.

No vertical Cu and Zn zonation comparable to the common Cu-rich base and Zn-rich top in volcanogenic massive sulphide deposits is recognized at Kutcho. The Kutcho zone has a barren massive pyrite basal section and variable Cu:Zn ratios in the overlying sections with an increase in relative Cu content along its perimeter where Cu:Zn ratios are commonly greater than 1:1. The Sumac zone has a relatively uniform Cu and Zn distribution. Cu:Zn ratios in the Esso West zone are extremely variable. Bornite is common in both the shallow Kutcho zone and the Esso West zone which is about 450 m below surface. There is an apparent correlation between bornite in massive sulphide zones and the occurrence of a strong footwall disseminated pyrite zone.

Hangingwall Quartz-Feldspar Crystal Tuff (QFCT)

The QFCT is now a quartz-feldspar-sericite-chlorite-dolomite schist (quartz-eye schist in Sumac's nomenclature) of variable thickness . It contains 10-45% quartz phenocrysts 1-10 mm in diameter and 0-20% 1-4 mm, sericitic plagioclase phenocrysts. They are commonly brecciated and show undulatory extinction (Fig. 6d); less commonly, they are embayed (Fig. 6e) and rarely, they are bipyramidal. A coarse breccia phase occurs erratically in the middle to upper portion of the unit

(Fig. 6f). The breccia is usually matrix-supported and contains 5-20%, but locally over 50%, fragments. Fragments range from 1 cm to 1 m in diameter and are commonly of dark green chloritic QFCT with 5-30% quartz phenocrysts and 0-5% plagioclase phenocrysts. Breccia fragments are texturally identical to the matrix with the exception of rare fragments of felsic ash tuff. Fragments are commonly rounded and partially to totally altered to clinozoisite- epidote. Hematite occurs in both matrix and fragments of this unit. Some sections with disseminated hematite in the matrix enclose fragments containing up to 50% hematite.

Numerous minor textural and compositional variations occur throughout the QFCT section but all are transitional and can not be related to tuff or flow contacts. Where no mafic flows or sills occur at the contact of the QFCT and the overlying Tuff- Argillite Unit, the top of the QFCT is commonly graded. Up to four graded beds less than 1 m thick, in which 5-10 mm quartz phenocrysts grade upwards to 1-2 mm phenocrysts, have been observed at the top of the unit in drill holes over the Esso West zone.

Hanging Wall Lapilli Crystal Tuff (LCT)

The LCT is texturally and compositionally similar to the footwall LT but contains minor to 15% quartz phenocrysts 1-10 mm in diameter and thin beds of QFCT. Referred to as sericite-quartz schist by Sumac, it occurs directly above the LT as well as both above and within sulphide zones. It is a thin transitional unit between footwall LT and hanging wall QFCT near sulphide zones but thickens north, down dip, of these sulphide zones where it appears to be facies-equivalent with QFCT and interdigitates with it (Fig. 4). Across or along strike from the sulphide zones, the ore horizon occurs approximately at the contact between footwall LT and hangingwall LCT (Fig. 13).

Hanging Wall Facies Variations

Location of the sulphide zones correlates with a change in hanging wall felsic pyroclastic rocks from QFCT on the south to LCT on the north. The QFCT is about 200 m thick from about the south edge of the sulphide zones to 100 m south of the zones (Fig. 11). It thickens to about 250 m west and south of the Esso West zone. The QFCT continues to thicken southwards but it is not known how much of this is primary as opposed to structural thickening. The QFCT is about 50 to 100 m thick over the axis of the three sulphide zones but commonly thins out completely over the north edge or up to 100 m beyond the north, down dip, edge of the sulphide zones (Fig. 11).

The LCT therefore occupies the stratigraphic position of the QFCT over the north, down dip, edge of the sulphide zones. It is commonly only up to 10 m thick over the main portions and southerly portions of these sulphide zones (Fig. 12) but thickens to 150 m or more north of them. The combined thickness of the interdigitating QFCT and LCT is relatively uniform except south of the sulphide zones where the section thickens rapidly (Fig. 8-10).

The reason for correlation of sulphide zones along a 3.5 km strike-length with a facies change in hanging wall rocks is uncertain. However, the relationship has provided a useful exploration guide. Interpretations of this include a dome-related, hydrothermal-vent-proximal interpretation by Bridge (1979 and 1981) and a basin-related, vent-distal interpretation by Tucker and Terriff (1980). Bridge interpreted the Kutcho and Esso West zones as lying on an elongate ridge of footwall LT with hanging wall rocks representing submarine pyroclastic flows originating from vent sources parallel to the ridge and sulphide zone axes. Tucker and Terriff postulated that sulphide zones were deposited in basins on the LT paleosurface and that hanging wall QFCT and LCT units unconformably overlie them.

Mafic Rocks

Mafic sills and some tuffs or flows occur in clusters within the hanging wall QFCT-LCT and commonly occupy a major portion of the overlying Tuff-Argillite unit (Fig. 4). In the Tuff-Argillite unit they appear to be mainly sills. The proportion, textures and stratigraphic position of mafic rocks varies greatly between drill holes and they occupy most of the QFCT-LCT and Tuff-Argillite section east of the Kutcho zone. They are called amphibolitic schist by Sumac and basic schist by Thorstad (1983). Mafic rocks in the QFCT-LCT section over sulphide zones usually form clusters or piles at the facies change between QFCT and LCT (Fig. 7) and are concentrated over the area between the axes and the north edge of the sulphide zones. These mafic rocks appear to be mainly flows with a pyroclastic component.

Mafic rocks range from an originally augite-rich rock to more common, foliated, crowded plagioclase porphyries called meta-gabbro in the field. Augite has commonly been replaced by hornblende, chlorite, tremolite- actinolite, biotite and epidote. Plagioclase phenocrysts up to 2 cm in diameter are partially to totally altered to epidote (Fig. 6g) with minor sericite, chlorite and carbonate. Chlorite and epidote are abundant in the groundmass and fine-grained potassium-feldspar is rare. These mafic rocks are interpreted to be alkaline (Thorstad, 1983), and possibly Takla Formation equivalents based on similar chemistry and petrology (Monger, 1977). However, this alkaline designation of the mafic rock suite is deduced mainly from alkali and silica contents; a questionable deduction considering the high mobility of alkalis during spilitization and metamorphism.

Tuffaceous mafic sections with an altered, dolomite and sericite-bearing, schistose groundmass and rare, 1-2 mm quartz phenocrysts, occur locally directly above the massive sulphide zones or ore horizon and are restricted to this stratigraphic interval. Locally, dolomitic gangue in the upper portions of massive sulphide zones contains sericitic plagioclase phenocrysts which may be indicative of dolomitized mafic rocks altered by the sulphide-related hydrothermal event.

Minor pyrite, pyrrhotite and rare chalcopyrite are disseminated through the mafic rocks. Disseminated hematite is commonly present up to 2%.

Tuff-Argillite Unit

The heterogenous Tuff-Argillite Unit directly overlies the QFCT or LCT and represents a sharp change from felsic pyroclastic volcanism to a mixed and highly variable succession of felsic tuffs and epiclastic rocks with interbedded argillite and locally minor to abundant mafic rocks. The tuffs are mainly fine-grained and grade into epiclastic rocks with argillite fragments and into tuffs with a variable argillaceous component to black, graphitic, calcareous argillite. Minor disseminated pyrite and pyrrhotite is common.

Conglomerate

The Kutcho Formation is capped by conglomerate which consists of clasts derived from the underlying volcanic rocks.

Boudinaged lenses of limestone and argillite occur within the conglomerate. It does not appear to mark a significant hiatus between predominantly volcanic and predominantly sedimentary rocks.

DEPOSITIONAL ENVIRONMENT

The volcanic and sedimentary rocks containing the sulphide deposits were definitely deposited in a submarine environment. Thin argillite beds are common throughout the volcanic section and the hanging wall QFCT and LCT are overlain by a section with abundant argillite and argillaceous tuffs (Fig. 7 to 10). Graded cycles are locally common in the felsic pyroclastic rocks. The footwall LT is very uniform but 4 to 5 km east of the Kutcho zone it consists mainly of graded cycles. The cycles have sharp contacts and consist of lower sections with 1 cm quartz phenocrysts grading upwards to a top section with 1 to 2 mm quartz phenocrysts. The hanging wall QFCT is generally homogenous but locally has graded cycles at its top.

The LT, QFCT and LCT are interpreted to be subaqueous pyroclastic flow deposits. They have the homogeneity, general lack of stratification, poor size sorting, grading and wide areal extent characterizing subaqueous flows (Fiske, 1963; Fiske and Matsuda, 1964; Niem, 1977). The monolithic breccia phase in the QFCT (Fig. 6f) probably formed by autobrecciation in partly consolidated subaqueous pyroclastic flows.

The volcanic rocks in the Kutcho Creek area likely formed from one calc-alkaline magma source. The three massive sulphide zones may have formed in a linear fumarole field within a fissure zone with several centres of exhalation. The hanging wall QFCT and LCT may have originated from fissures parallel to one which gave rise to the sulphide zones. Whether these zones formed in basins or on topographic highs can not be positively determined. However, they do correlate with a hanging wall facies change and they appear to have formed over a hydrothermal source and consequently are proximal in the sense of Franklin et. al. (1981).

WALL ROCK ALTERATION

General Statement

This section describes alteration mineralogy which is interpreted to have evolved within the hydrothermal system from which the sulphide lenses developed. Mineralogy has been determined by megascopic and microscopic observations and by XRD in two drill holes in the Kutcho zone (Wyslouzil and Deane, 1979). Sericitic and dolomitic alteration envelop the massive sulphide lenses and are readily distinguishable in outcrop and core. Quartz veins and evidence of silicification are very minor. Chlorite is only a minor component of the footwall rocks. Clinozoisite-epidote of spilitic or metamorphic origin is commonly abundant in plagioclase-bearing hanging wall rocks but is absent near mineralization. Hematite is only abundant in the hanging wall and is absent within about 10 m of the ore horizon and in hydrothermally altered footwall rocks.

Sericite

Sericite is a common metamorphic mineral in the felsic volcanic rocks in the Kutcho area where it is always present in at least trace amounts. The footwall LT is the most sericitic unit in the Kutcho Formation (Fig. 6b). Hydrothermal sericite is ubiquitous in footwall LT for at least 200-300 m stratigraphically below the sulphide zones and occurs along the ore horizon for at least 4 km from known sulphide zones. White to pale green lustrous schists associated with footwall disseminated pyrite and the immediate hanging wall schists are the most sericitic.

Sericite alteration without chlorite in the hanging wall forms a sharply defined zone of limited extent. The QFCT commonly contains both chlorite and sericite but is exclusively sericitic to a maximum of 24 m above the sulphide zones. A zone of total alteration to apple-green colored sericite with relict quartz phenocrysts commonly occurs for about 3 m above the massive sulphides especially in the Esso West zone.

Sericite and/or dolomite has destroyed all feldspar in the footwall of the sulphide zones. Plagioclase phenocrysts in the sulphide zone hanging wall rocks have been converted to about

20% sericite (Fig. 6h). After being partly sericitized, it appears that plagioclase near the sulphide zones was replaced by dolomite (Fig. 6i).

Dolomite

The greatest concentration of dolomite occurs as lenses in hanging wall rocks directly above the massive sulphides and as lenses up to 320 m north of these sulphide zones along the ore horizon. Disseminated dolomite is also ubiquitous in footwall rocks.

Massive, granular, dolomite-quartz aggregates form lenses up to 10 m thick. They occur mainly from the top of the massive sulphide zones to 30 m above the zones. Lenses of gray dolomite 1 to 2 m thick containing disseminated sulphides occur within them. They are usually ore-grade and are part of the sulphide zones.

Augen-shaped porphyroblasts, irregular patches and minor veins of dolomite occur throughout the hanging wall and footwall rocks. Coarse, patchy dolomite, commonly with enclosed grains of quartz, has replaced plagioclase phenocrysts (Fig. 6i), quartz phenocrysts (Fig. 6j), rock fragments (Fig. 6k) and groundmass (Fig. 6d). The hanging wall of the Kutcho zone commonly contains 10-25% disseminated dolomite in an area from 14-66 m above the top of the massive sulphide body. Disseminated dolomite in the footwall of the three sulphide zones generally corresponds with the zone of footwall disseminated pyrite (Fig. 4) but lesser amounts of dolomite occur throughout the entire footwall LT.

Quartz

Quartz is the most abundant mineral in host rocks of the Kutcho deposit. It is mainly a primary constituent and constitutes most of the groundmass, fragments and phenocrysts. Thin quartz veins are rare in footwall rocks. Thin section examination indicates that some quartz is introduced or redistributed. Elongate, curved crystalline quartz is common surrounding pyrite grains or in strain shadows around pyrite grains within the footwall pyritic feeder zone (Fig. 61). Some bull-quartz veins up to 1-3 m thick occur at the top of or within the upper portion of the massive sulphide zones and may be due to regional metamorphism and deformation.

Chlorite

Chlorite occurs in both hanging wall and footwall rocks but is a minor component compared to sericite. Alteration studies (Price, 1975-1979) indicate that chlorite distribution does not correlate with the footwall pyritic feeder zone. Rather, it is a common regional metamorphic mineral in volcanic rocks of the Kutcho Formation.

Epidote-Clinozoisite

Epidote is a common regional metamorphic mineral in both mafic and felsic rocks in the Kutcho Formation and may also have formed during spilitization (Faila, 1974; Vallance, 1974; Reed, 1983). It is absent in the hydrothermally altered footwall and immediate hanging wall rocks of the sulphide zones. It appears that epidote did not form in the hydrothermal system which formed the sulphide zones.

Minor to abundant epidote-clinozoisite occurs in hanging wall rocks, especially in the breccia phase of the QFCT. The epidote-clinozoisite zone overlies the zone of hanging wall dolomitic alteration. The stratigraphically lowest observations of epidote-clinozoisite are 37 to 77 m above the top of the Kutcho zone. Epidote is a common accessory mineral in the mafic rocks and has been observed within 4 m of massive sulphides. Epidote-clinozoisite is absent in footwall LT and its equivalents except in areas at least 1 km beyond known sulphide zones.

Hematite

Hematite occurs as fine-grained disseminations distributed erratically throughout the hanging wall QFCT, LCT and mafic rocks. It is generally in the matrix but also occurs in plagioclase phenocrysts in QFCT. It occurs mainly as irregular, diffuse reddish grains and, less abundantly, as sub-rounded black grains. Hematite commonly occurs from about 10 m above the sulphide lenses to near the base of the Tuff-Argillite unit. It is absent in footwall rocks except in locations at least 1 km from known sulphide zones.

Hematite in hanging wall rocks may reflect a change from reducing environments of massive sulphide deposition to oxidizing environments resulting from dilution of the hydrothermal system by normal sea water. The presence of hematite in both felsic pyroclastic rocks and mafic rocks may indicate that both were deposited under similar redox conditions or modified under similar conditions.

Alteration Halos

The extent of alteration in felsic wall rocks of massive sulphide zones is best indicated by Na_2O-depletion accompanying destruction of sodic plagioclase and by K_2O-enrichment at least partly due to development of sericite. The ratio $Na_2O/Na_2O + K_2O$ is useful in quantifying the extent of hydrothermal wall rock alteration since it usually defines a much smaller area than the region of sericitic alteration.

The interval within which sulphide zones occur, referred to as the ore horizon (Fig. 7 and 13), is commonly altered over a thickness of at least 20 m and for at least 4 km beyond the three known massive sulphide zones. Alteration, as measured by Na_2O-depletion and K_2O-enrichment, occurs to about 300 m stratigraphically below, and to about 500 m beyond margins of the massive sulphide zones. Hanging wall alteration is less intense. It extends about 200 m above the sulphide zones and about 100 m beyond them (Fig. 13).

Loss-on-ignition indicating hydration and carbonation is high in the footwall of the sulphide zones but data is available for only four holes. MgO and CaO are enriched in both the hanging and footwall rocks around the sulphide zones and probably occur mainly as dolomite. However, chemical analyses for these oxides are limited.

Footwall Alteration Halos

The ratio $Na_2O/Na_2O + K_2O$ indicates that intense alteration occurs at least 190 m stratigraphically below the sulphide zones, and moderate alteration extends an additional 100 m below this (Fig. 13). This overlaps and extends beyond the area marked by minor disseminated footwall pyrite. This ratio averages 0.3 for footwall rocks stratigraphically below the massive sulphide zones, and 0.2 for rocks up to 270 m beyond the margins of these lenses. Rocks below the north margin of the Kutcho zone are the most intensely altered because the inferred footwall pyritic feeder is apparently centered near the north margin (Fig. 4). The vertical limit of alteration in the footwall decreases to about 40 m in the area 270 to 500 m beyond sulphide zones which coincides with an increase in the $Na_2O/Na_2O + K_2O$ ratio to 0.4. Drill core samples of unaltered footwall rocks more than 500 m beyond known sulphide zones and below a thin zone of alteration coincident with the ore horizon have average $Na_2O/Na_2O + K_2O$ values of 0.7 or greater.

Alteration is associated with the ore horizon and immediate hanging wall and footwall rocks for at least 4.0 km eastward beyond the Kutcho zone. Footwall rocks from drill holes more than 500 m beyond known sulphide zones have average $Na_2O/Na_2O + K_2O$ ratios of 0.4 usually to between 10 to 25 m below the ore horizon. No megascopic or microscopic features have been observed to precisely account for the sharp change from Na_2O-depleted and K_2O-enriched rocks immediately below the ore horizon to less altered rocks at depths of 10 to 25 m below the ore horizon. Plagioclase is destroyed below the ore horizon and is partly altered in the less altered rocks greater than 10 to 25 m below the ore horizon. However, abundant groundmass sericite persists below the sharp change in alkali ratios at 10 to 25 m below the ore horizon.

Hanging Wall Alteration

Alteration causing Na_2O-depletion and K_2O-enrichment in hanging wall QFCT and LCT units is weaker than in footwall rocks but occurs in a distinct halo above and around the massive sulphide zones. It extends to the top of the felsic pyroclastic section up to 180 m stratigraphically above the sulphide zones and to 100 m beyond the edges of the zones. $Na_2O/Na_2O + K_2O$ ratios are lowest in LCT for several metres above tops of sulphide zones. Alteration persists through the stratigraphic section such that average ratios for rocks up to 50 m above sulphide zones and for rocks from 50 m above sulphide zones to the top of the QFCT-LCT section are almost constant for varying positions across or along strike from sulphide zones . The average alkali ratio of 0.6 for hanging wall rocks over sulphide zones to 100 m across strike beyond sulphide zones indicates moderate alteration. Rocks 100 to 4000 m along strike have average ratios of 0.7. Unaltered QFCT lithologies above and below the ore horizon have average $Na_2O/Na_2O + K_2O$ ratios of 0.9.

Plagioclase is commonly totally destroyed immediately above sulphide zones and is altered to about 10-20% sericite (Fig. 6h) in the QFCT-LCT section for up to 180 m above sulphide zones. Groundmass sericite is similarily most abundant immediately over sulphide zones and also persists through the whole QFCT-LCT section.

EXPLORATION ASPECTS OF MASSIVE SULPHIDE ZONES

Geochemistry

Analysis of soil samples over the Kutcho zone indicates the presence of the sulphide body only over its eroded east end even though the boulder-clay till cover is only 2 to 3 m thick in this area and soil development is poor. Total, hot extractable Cu, Zn, Pb, Mo, Ag, As and Hg produce isolated anomalous values but there is no significant soil geochemical anomaly.

Silt sampling in creeks draining the Kutcho zone shows anomalous metal values directly below it. However, silts collected from these creeks where they flow into an east tributary of Kutcho Creek about 2 km north of, and parallel to, the Kutcho zone may or may not produce anomalous values. Although the Kutcho zone was originally detected in silt samples, repeatability of metal content in silts is poor at locations more than 1.5 km downstreams from it.

Heavy mineral concentrates are anomalous in Cu, Zn, Pb, Ag, Au, As, Mo, Sb and Hg over a distance of 1.3 to 2 km only in the creek draining the eroded east edge of the Kutcho zone. The creek traversing the ore horizon between the Kutcho and Sumac West zones, which cuts through LT with disseminated to semi-massive pyrite, and creeks east of the Kutcho zone, only have above background contents of Pb and Mo in heavy mineral concentrates.

An indigenous gossan and a minor patch of ferricrete near the east end of the Kutcho zone are anomalous in some of the metals enriched in this sulphide zone. The indigenous gossan is anomalous in Cu, Zn, Pb, As, Mo, Ag, Au and Hg but gossan and ferricrete associated with chalcopyrite-bearing footwall mineralization about 5.6 km east of the Kutcho zone is only anomalous in Cu, As and Mo (Table 1).

Metal	Kutcho Zone massive sulphides	Kutcho Zone indigenous gossan	Kutcho Zone ferricrete	East footwall mineralization indigenous gossan and ferricrete
Cu	1.70%	830-881	456	119-1750
Zn	2.40%	1220	4540	45-96
Pb	400-800	536-710	332	80-106
Cd	90-120	3	--	--
As	100-1200	280-305	315	254-373
Bi	30-200	13	--	--
Sb	10-300	11-26	26	37-50
Se	100-200	30	--	--
Sn	10-20	3	--	--
Co	100	2	--	--
Mo	50-100	292-520	53	38-48
Ag	27-41	5.8-28.0	0.0	0.1-1.3
Au	0.2-0.9	0.28-0.31	0.03	0.03-0.14
Hg	4.1-7.0	1.8	--	0.06-0.14

TABLE 1 : Contents of 14 metals in ppm unless otherwise indicated in Kutcho zone massive sulphides and gossans, and of gossans associated with distal footwall mineralization 5.6 km east of the Kutcho zone. The Kutcho zone indigenous gossan is a 1 m by 4 m porous mass of limonite which was probably a low-grade lens of footwall massive pyrite. The Kutcho zone ferricrete is a small patch of 1 to 2 m thick slabs of glacial till and minor plant stems cemented by limonite that occurs downslope from the eroded sulphide zone.

Geophysics

The up-dip edge of the Kutcho zone is close to ground surface while the east end is eroded at the bedrock surface. Sulphide lenses and zones are all electrically conductive. The Kutcho zone and east end of the Sumac West zone are readily detected by ground and airborne electromagnetic systems except for airborne VLF-EM. Induced polarization anomalies associated with low resistivity in the Kutcho zone were initially drilled by Sumac and confirmed the existence of massive sulphides. All sulphide zones are non-magnetic. Weak ground and airborne magnetic anomalies that occur along the north edge of the Kutcho zone reflect mafic rocks in the hanging wall section.

Charged potential surveys, both on surface and in drill holes, have proven successful at Kutcho Creek (Suzuki et al, 1977). Although the three massive sulphide zones are separated by 50 to 300 m, there is enough disseminated pyrite on the ore horizon or in the footwall pyritic zones to provide electrical continuity between massive sulphide zones. Equipotential patterns around the Kutcho and Sumac West zones are elongated westwards indicating the next en echelon massive sulphide body, the Esso West zone.

CONCLUSIONS

The Kutcho volcanogenic massive sulphide deposit occurs in the thickest part of the volcanic-dominated Kutcho Formation. Felsic rocks in this formation are much more abundant near deposits than elsewhere. Rocks are spilitized on a regional scale and hydrothermally altered in the vicinity of the deposits. The common spilite-keratophyre volcanic rock assemblage associated with volcanogenic massive sulphide deposits (Andrews and Fyfe, 1976; Hutchinson et. al., 1980; Stephens, 1982; Tatsumi et. al., 1970; Zachrisson, 1982) results from sub-sea interaction of circulating brines with the various rock types prior to sulphide formation on the sea floor (Munha and Kerrich, 1980). The Na-enrichment in spilitized rock can occur at very low water/rock ratios (Reed, 1983). The hydration, carbonatization and oxidation of the rocks by CO_2-rich and oxygenated fluids results in leaching of Ca, Mg, K, Al, Fe, Mn plus transition metals and deposition of Na by albitization of plagioclase.

Hydrothermal alteration around the sulphide zones and along the ore horizon is characterized by Na_2O-depletion and K_2O and CaO-enrichment. Alteration occurs in both hanging wall and footwall rocks but is strongest within and around a disseminated pyrite zone that extends over a 3.5 km strike under the three known massive sulphide lenses. The lenses overlie interpreted pyritic feeder zones and formed when a reduced, slightly acidic, hydrothermal fluid reacted with sea water to precipitate iron and base metal sulphides.

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TABLE 1 : Contents of 14 metals in ppm unless otherwise indicated in Kutcho zone massive sulphides and gossans, and of gossans associated with distal footwall mineralization 5.6 km east of the Kutcho zone. The Kutcho zone indigenous gossan is a 1 m by 4 m porous mass of limonite which was probably a low-grade lens of footwall massive pyrite. The Kutcho zone ferricrete is a small patch of 1 to 2 m thick slabs of glacial till and minor plant stems cemented by limonite that occurs downslope from the eroded sulphide zone. The location of the Kutcho zone gossan and ferricrete is shown on Fig. 14.

Fig. 1: Location map of Cry Lake map area, 104I, with indexed locations of regional geology map (Fig. 2) and property geology map (Fig. 3).

Fig. 2: Geology of King Salmon allochton, Cry Lake map area, B.C. Geology after Gabrielse (1979) and Thorstad (1983), modified by Esso Minerals Canada staff. Numerous small areas of Sinwa and Kutcho Formation rock surrounded by Inklin Formation rocks are omitted from the map in the area of Turnagain Lake.

Fig. 3: Geology of the Kutcho Creek property. See Fig. 4 for legend. The three massive sulphide zones are shown projected vertically to surface.

Fig. 4: Stratigraphic column for the Kutcho Formation in the vicinity of the Kutcho deposit with an idealized cross section of a massive sulphide zone.

Fig. 5: Plan and vertical longitudinal section of the three massive sulphide zones at Kutcho Creek.

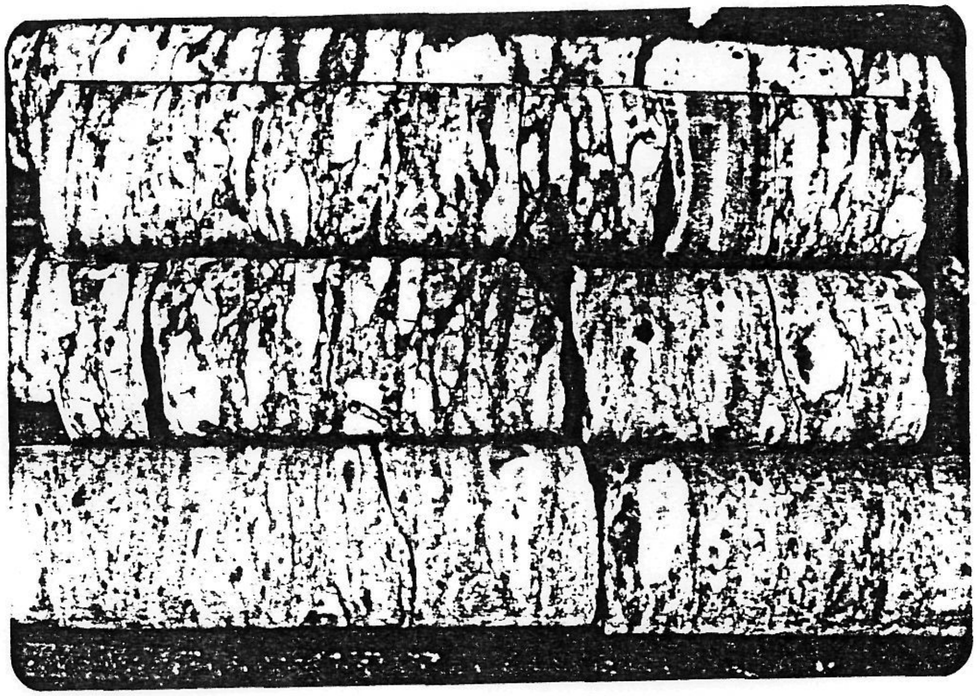

Fig. 6(a): Footwall lapilli tuff, DDH 10, 237 m. Core diameter 34 mm.

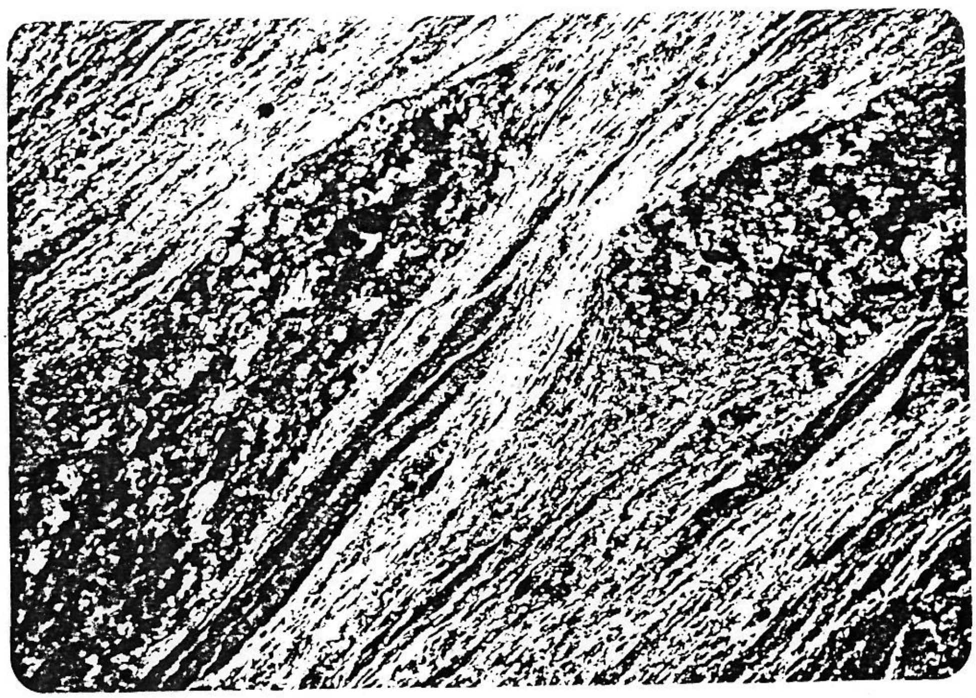

Fig. 6(b): 1-2 mm thick fragments in footwall lapilli tuff, DDH 62, 316 m. All photomicrographs with crossed nicols. Sericite white, dolomite bands gray. Field of view 8 mm.

Fig. 6(c): 1 mm brecciated quartz phenocrysts in footwall lapilli tuff, DDH 10, 270 m. Field of view 8 mm.

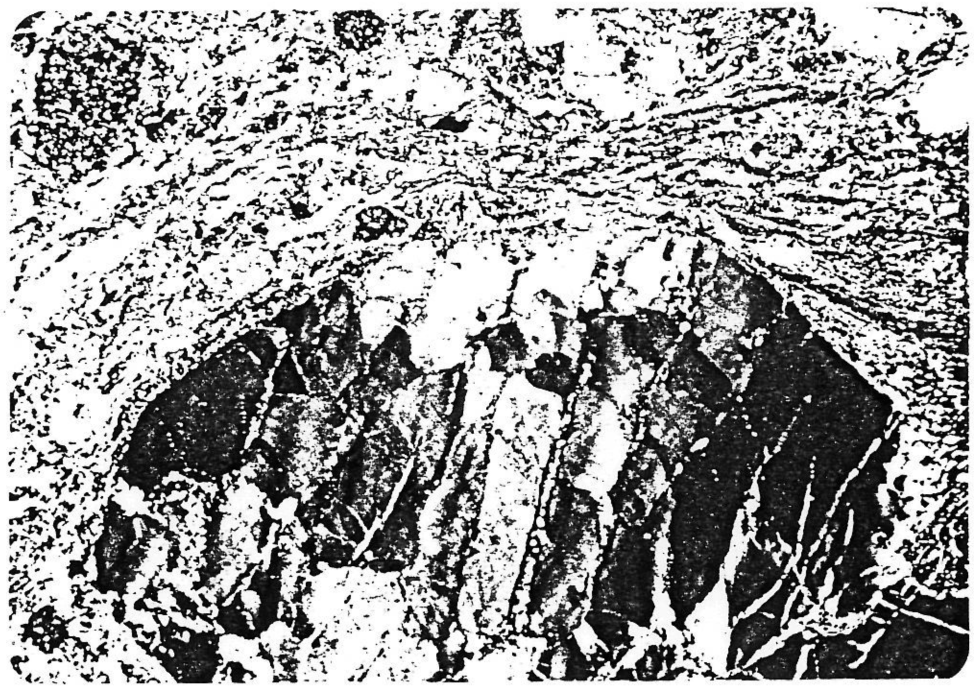

Fig. 6(d): 7 mm brecciated quartz phenocryst with undulatory extinction in QFCT, DDH 71, 449 m. Abundant sericite and dolomite in matrix. Field of view 8 mm.

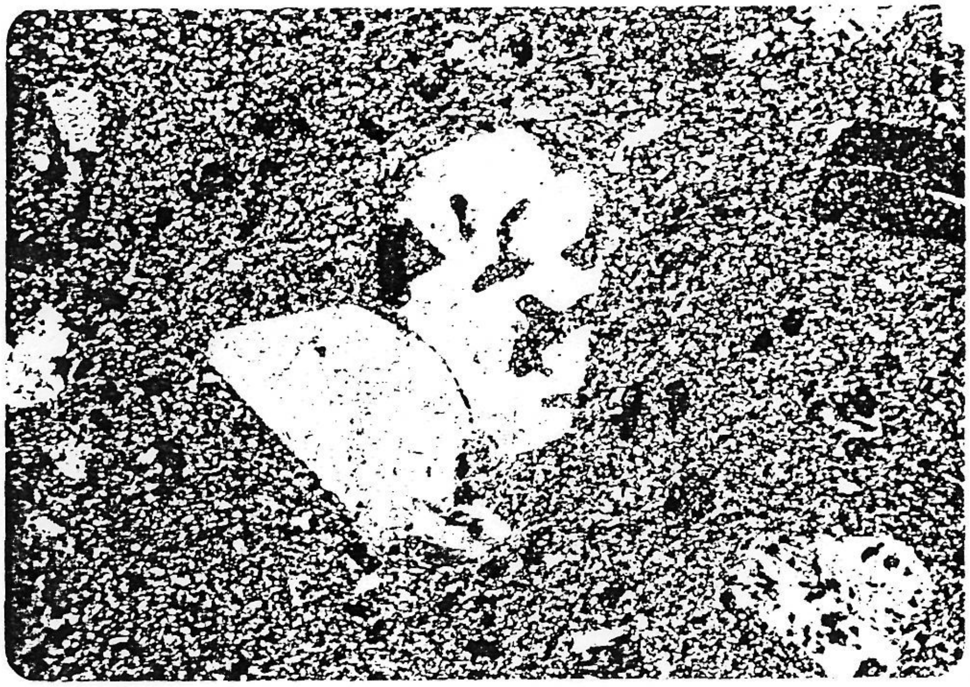

Fig. 6(e): Embayed and unembayed quartz phenocrysts in QFCT, DDH 8, 6 m. Weakly sericitic matrix with epidote-clinozoisite crystals (dark). Field of view 8 mm.

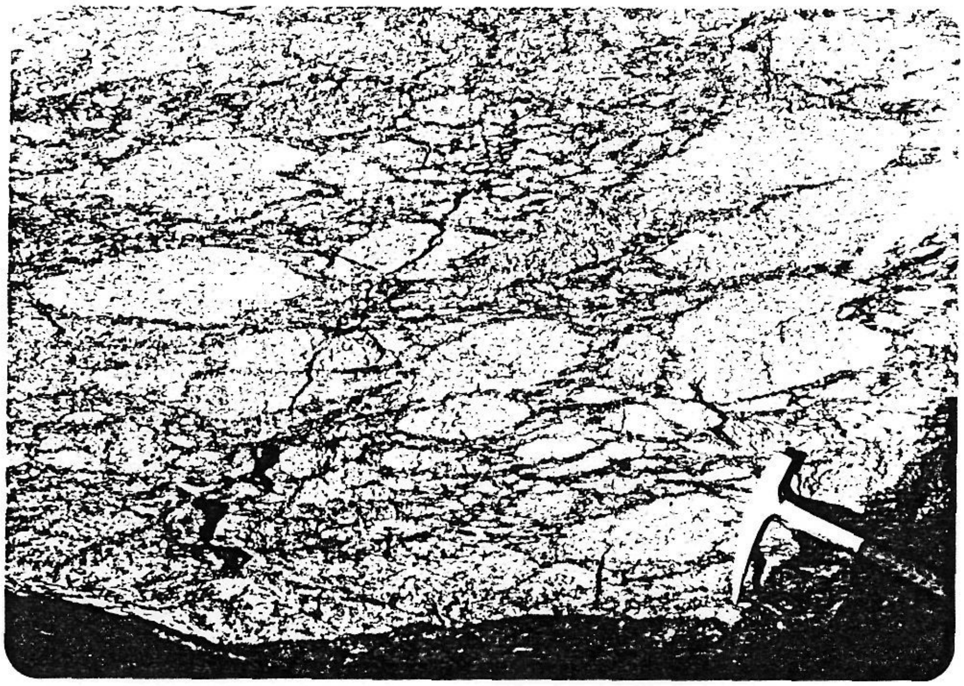

Fig. 6(f): Breccia phase in QFCT.

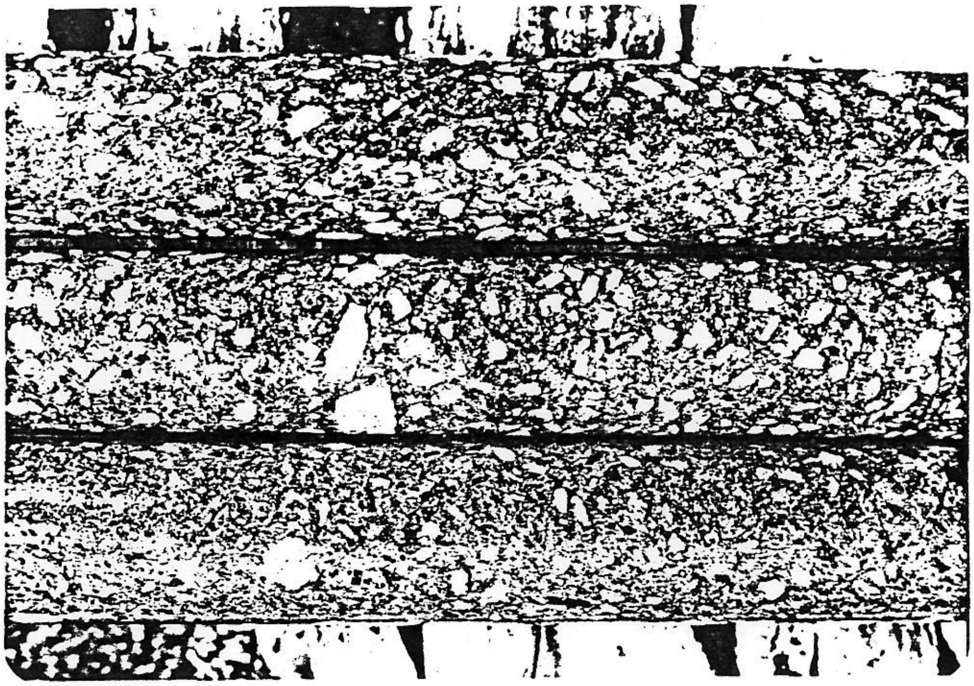

Fig. 6(g): Hanging wall mafic rocks with intensely epidote altered plagioclase phenocrysts (light) and chloritized augite (dark), DDH 79, 296 m. Core diameter 34 mm.

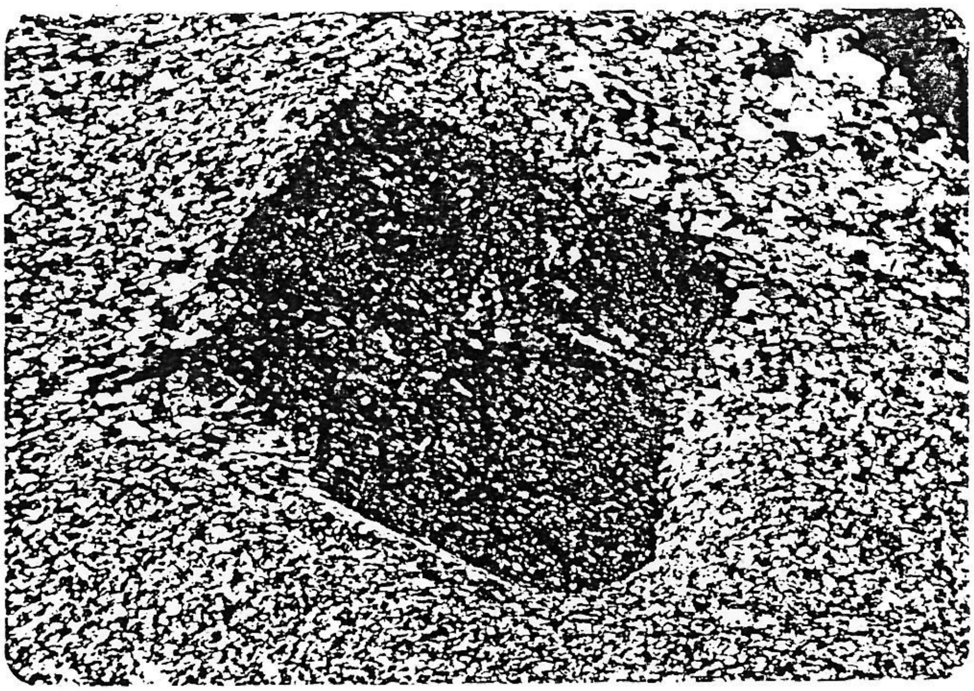

Fig. 6(h): Plagioclase phenocryst in QFCT partly replaced by sericite, DDH 4, 26 m. Field of view 3.3 mm.

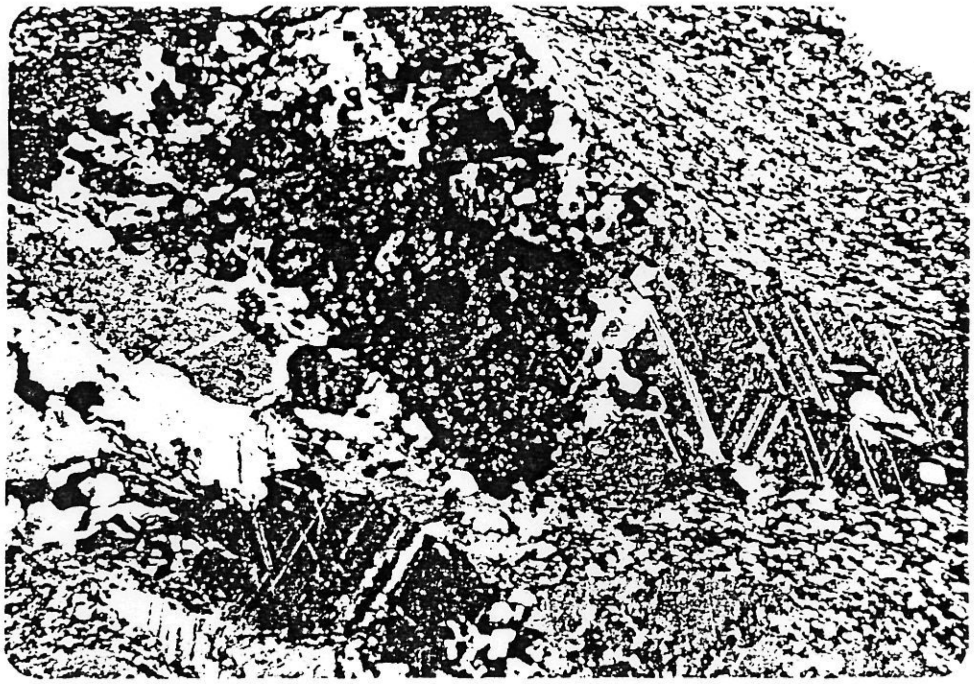

Fig. 6(i): Partly sericitized plagioclase phenocryst (black with white sericite) in QFCT replaced by dolomite (mainly showing twin lamellae), DDH 4, 26 m. Field of view 3.3 mm.

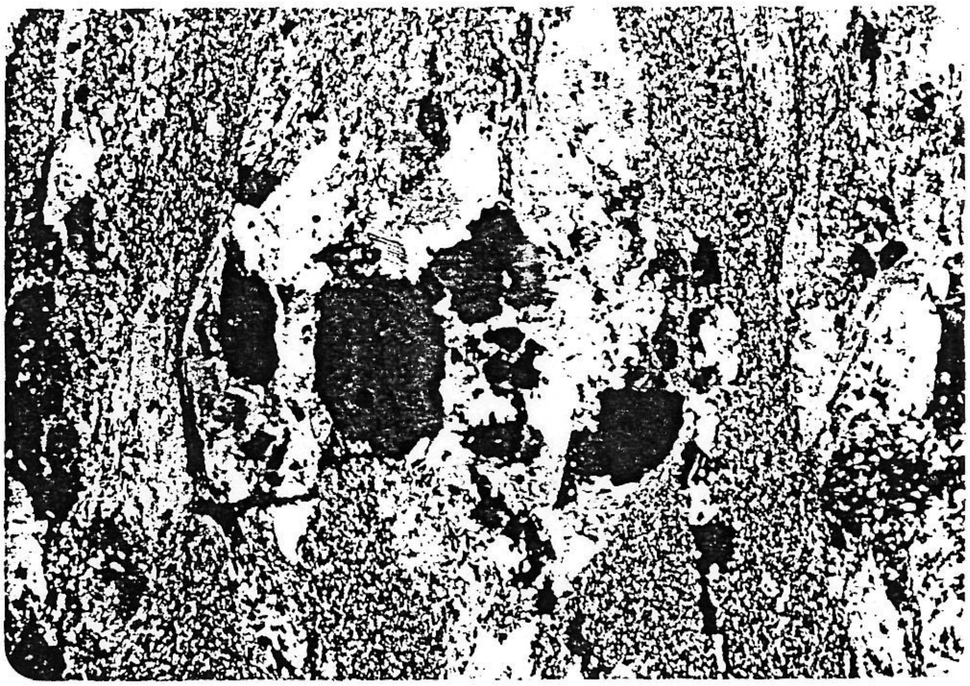

Fig. 6(j): Quartz phenocryst (gray to black) in QFCT mainly replaced by dolomite (light), DDH 1, 54 m. Field of view 8 mm.

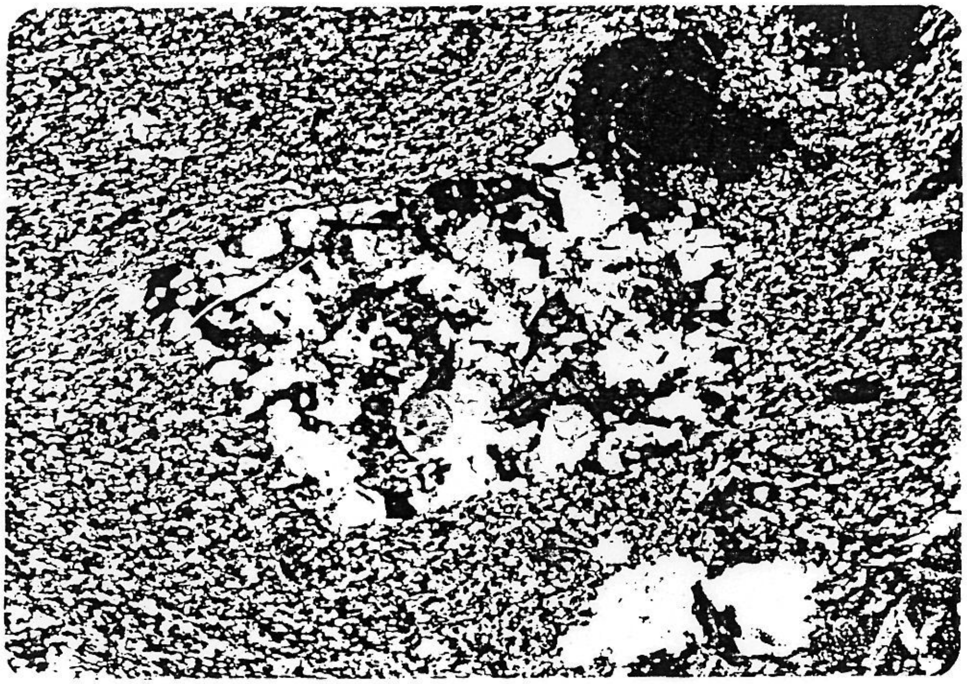

Fig. 6(k): Fragment in QFCT mainly replaced by dolomite and minor sericite-chlorite, DDH 4, 26 m. Field of view 3.3 mm.

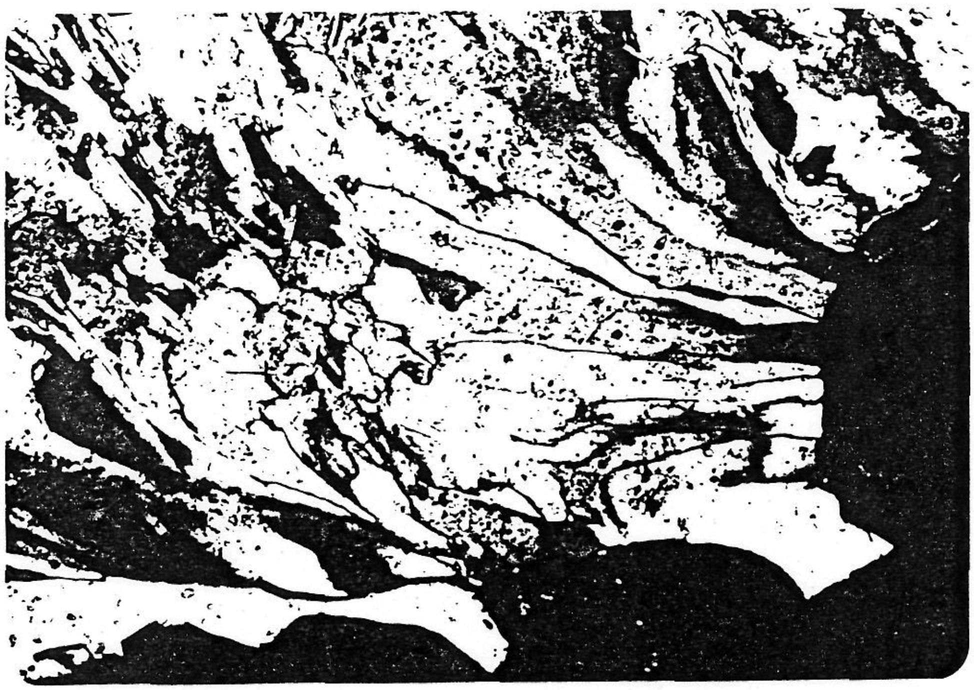

Fig. 6(l): Elongate and curved crystalline quartz growths around pyrite (black) in footwall lapilli tuff, DDH 6, 81 m. Field of view 0.9 mm.

Fig. 7: Section 38640E through the east end of the Kutcho zone. The sections in Fig. 7-10 are all rotated 45^o so that the 45^o north dip of the units is brought to the horizontal. The section locations are shown on Fig. 5. Unaltered footwall rocks refers to rocks apparently not affected by the hydrothermal system that formed the sulphide zones.

Fig. 8: Section 36380E through the west end of the Sumac West zone. Legend on Fig. 7.

Fig. 9: Section 36140E through the east end of the Esso West zone with the west end of the Sumac West zone projected to section. Legend on Fig. 7.

Fig. 10: Section 35780E through the main body and south body of the Esso West zone. Legend on Fig. 7.

Fig. 11: Isopach map of hanging wall quartz-feldspar crystal tuff (QFCT). Figures 11 and 12 are east-west planes dipping 45^o north which correspond closely to the plane of the three massive sulphide lenses.

Fig. 12: Isopach map of hanging wall lapilli crystal tuff (LCT).

Fig. 13: Schematic cross and longitudinal section of the ratio $Na_2O/Na_2O + K_2O$ in footwall and hanging wall rocks around massive sulphide zones. Ratios are the averages for the indicated positions relative to sulphide zones and the ore horizon. Vertical intervals are measured stratigraphically above the top of, or below the bottom of, the sulphide zones or ore horizon. Column A is for samples from drill core in holes through, or up to 100 m beyond the margins of the sulphide zones. Columns A to D are based on samples from DDH 1, 3, 6, 8, 14, 40, 44, 58, 70, 71, 79, 109, KT-28 and KT-33; DDH 10, 62, and KT-20, DDH 65, 94B1, 94B3, 95, 95B1, 95B2, 97, 97B1 and 97B2; DDH 16, 20, 41, 78, 90, 103, 106, 120, 121 and WKC-2 respectively. ICP, XRF and whole rock wet chemical analyses on 686 samples are incorporated in the diagram. Locally the ore horizon has high $Na_2O/Na_2O + K_2O$ ratios because it consists of dolomite and quartz. Ratios from these lithologies have been excluded from the diagram. Unaltered equivalents on the right side of the figure refers to rocks not affected by the hydrothermal system that formed the sulphide zones.