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Catface

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Abstract

The Catface copper-molybdenum porphyry deposit is one of the westernmost porphyry deposits with respect to the northwest-trending tectonic belts of British Columbia. The well-exposed host pluton is one of a group emplaced along a linear zone parallel to the west coast of Vancouver Island. The mineral deposit is believed by the author to be associated with the top of a magma chamber or cupola. The complex history of the deposit involves intrusion of Tertiary and probable Jurassic plutons into Permian and Triassic country rock.

The emplacement of intrusions and the formation of related mineralized zones have been controlled largely by fault and fracture systems. Breccias are common, including intrusion breccias, but a well-defined 'pipe' system is not evident. Metamorphism associated with the intrusions is readily evident, but hydrothermal alteration is not as intense as it is at many other Canadian Cordilleran porphyry deposits. Assymetrically arranged mineralization diminishes with depth in apparent relation to decreasing fracturing and alteration.

Sulphide mineralization, although sparse, is zoned and a sulphur-iron deficiency is believed to be responsible for an annular core containing bornite as well as the more widely distributed chalcopyrite. Pyrrhotite accompanies pyrite and is a distinguishing characteristic of a western 'belt' of porphyries of Vancouver Island and Washington State.

Study of the fine-grained primary and secondary copper minerals has revealed many complexities. Bornite occurs on the cleavage planes of biotite and copper is contained within the biotite lattice. Silicate grains, particularly feldspars, contain minute disseminated copper sulphides in their cores and fractures. Uncommon copper minerals, such as idaite and valleriite, are present.

Oxidation of the deposit under a wet temperate climate and marked relief has been erratic, controlled chiefly by fault zones with resulting irregular and limited secondary enrichment. The deposit is detectable by geochemical and some geophysical methods, particularly self potential.

Location and Physical Description

THE CATFACE RANGE is a heavily treed peninsula, 4 to 8 kms wide, jutting into the Pacific Ocean 13 kms northwest of Tofino on the west coast of Vancouver Island. The Range contains two subdued mountain tops, the South Peak (elevation 880 meters) and the North Peak (960 meters). Access is by boat or float plane from Tofino to Hecate Bay, from where a logging road, 6 kms long, leads to the deposit.

The Catface deposit consists of several mineralized zones — the Cliff or main zone, the Irishman's Creek zone and the Hecate Bay zone. The main zone crops out on South Peak between 460 and 880 m (Lat. 49°15′20″N, Long. 125°59′00″W, NTS 92/F5W) (Fig. 1). The Irishman's Creek zone is located immediately north of the main zone. The Hecate Bay zone is about 2 kms to the southeast of the peak. Deposits related to the latter extend to sea level. Only the main zone is covered in any detail in this paper and, unless specified otherwise, most data refer to it.

The main deposit occupies a mountain top with about 50 per cent rock outcrop. The major mineralized exposure is on the west side of the mountain and referred to as "Catface Cliffs". Anomalous amounts of copper occur within a north-south-trending zone 1000 meters long and up to 920 meters wide. Mineralization extends intermittently from the 880-m elevation to below the deepest drilling at 280 meters.

History

The name Catface is derived from the resemblance of a partly treed cliff face to the head of a Canada lynx when viewed from the sea to the northwest. A large patch of malachite near the base of this cliff is visible from the water, and is portrayed on paintings in Ahousat native village across the inlet to the northwest. Although intermittent work was recorded on an undescribed claim near Catface as late as 1918, the only record of serious prospecting appears in the 1898 Annual Report of the B.C. Minister of Mines, which reported a 20-foot adit driven on Catface Mountain. There is some suggestion that this or a similar adit had been started many years earlier.

Current interest started in 1960 when a Ventures Limited pilot-prospector, Gerald Davis, and a Herbert Inlet mine operator, John A. Jackson, climbed to the base of the cliffs and found oxidized material in a fault zone that indicated at least one important mineralized area. Fresher samples were later 'plucked' from the cliffs using the company helicopter. These samples displayed weak disseminated copper and molybdenum sulphides in granitic rock. The property was then staked on the possibility that these samples were representative of the whole cliff face.

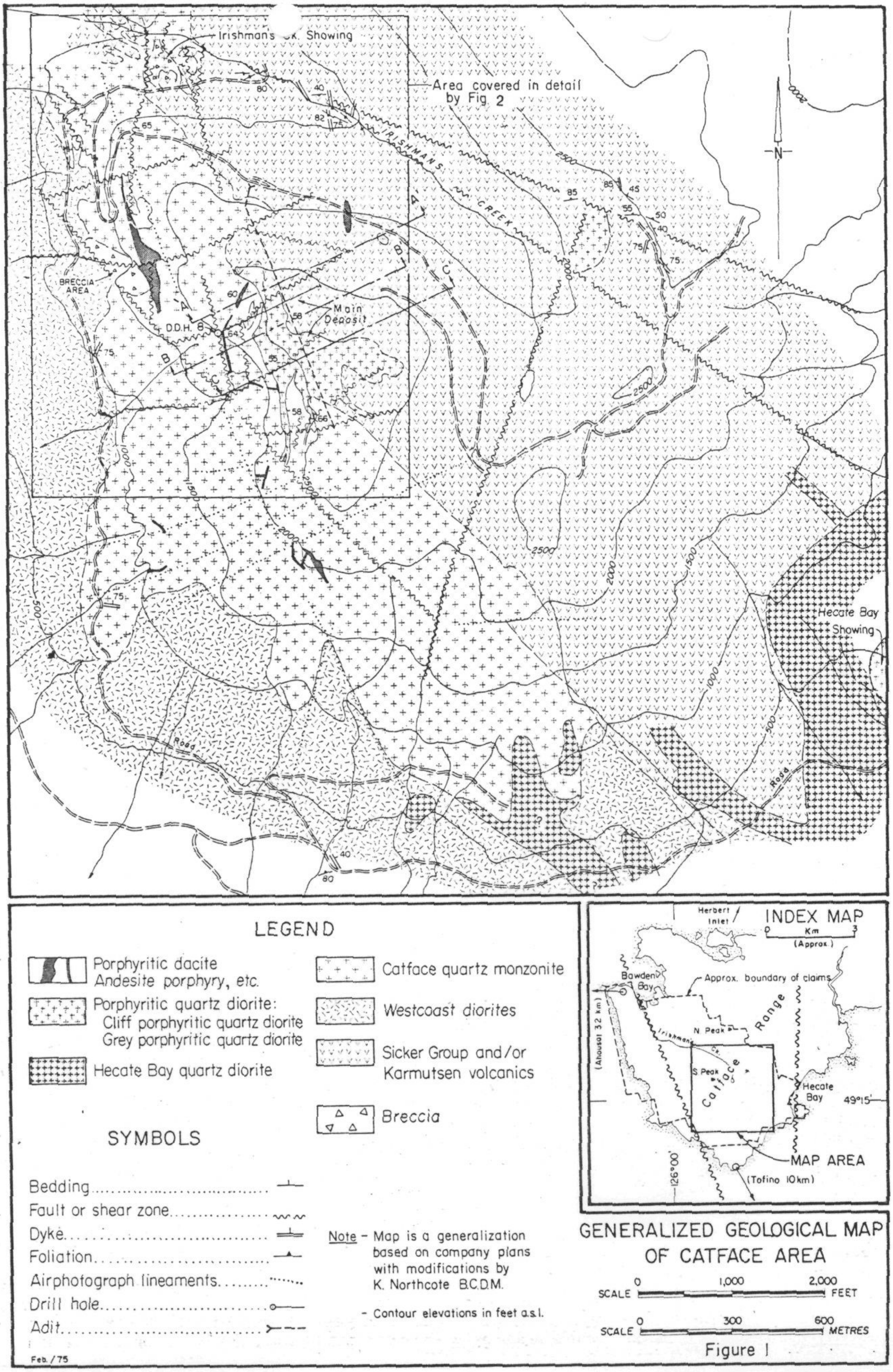
Activity in 1961 and 1962 included 3,715 m of drilling in low-angle EX holes collared at accessible locations along a major fault scarp at the base of the cliffs. A program of surface drilling (BQ) from the top and back of the mountain was undertaken later, supported by helicopter (see Plate 3). An 825-m adit was driven in 1970, from which 2,213 m of underground AQ and NX drilling was completed in 1971. Drilling then totalled 19,698 m in 127 holes on the property. All core was assayed and that from underground was colour-photographed, with the record stored on microfilm.

In 1963, Catface Copper Mines Limited (a wholly owned subsidiary of Falconbridge Nickel Mines Limited) was incorporated to hold the property.

Geology

REGIONAL

Mapping by Muller and Carson (1969) shows volcanic flow and clastic rocks of the Upper Permian Sicker Group in fault contact with diorite of the Westcoast Crystalline Complex. The age of the volcanic rocks, however, is open to question because of the similarity of some of them to rocks of the younger and more widespread Karmutsen Group (Triassic), which are well displayed a few kilometers to the north of the peninsula. Both the Westcoast Diorite and the Sicker Group have been intruded by younger quartz



GENERALIZED GEOLOGICAL MAP OF CATFACE AREA

Figure 1

monzonite of possible Jurassic age, and still later the entire assemblage was intruded Tertiary quartz diorite with which most of the mineralization appears related.

According to Carson *et al.* (1975), Tertiary intrusions appear to be arranged along three lines radiating outward from the Tofino area. Catface and a number of less well exposed quartz diorite stocks and related porphyries fall along a belt that extends 50 to 60 kms northwesterly. In the writer's view, the upward migration of these intrusions appears to have terminated in a cover of volcanic rocks at elevations little greater than the present surface. The Catface deposit appears to be related to a cupola of a high-level quartz diorite intrusion.

Catface Peninsula lies a few kilometers east of the projection of a major regional fault system that trends about N 40°W and which approximately delineates the eastward limit of Tertiary sediments (see Figs. A and B, in pocket). Two dominant north- and northwest-trending lineaments on the peninsula appear to be faults and so are called the Hecate and Bowden faults respectively (Fig. 1). Apparent horizontal displacement of the Hecate fault, indicated by offset contacts, is dextral and amounts to about 100 meters. Geological mapping and air-photo studies indicate numerous lineaments and faults between the two main fault zones. Most of these trend at large angles to the two major faults. A few of the more important faults and lineaments are shown in Figure 1.

LOCAL

Most rock units near the deposit have been well described and illustrated by Northcote (1972) and only minimal description is presented here. The intrusive rocks and a hood or capping of volcanic rocks in the vicinity of South Peak host the main mineral deposit.

1. Volcanic and Sedimentary Rocks

Sicker and/or Karmutsen Group

The oldest rocks on the property include a sequence at least a thousand meters thick of basalt and andesite flows, tuff breccias and agglomerates. These are thought by Muller and Carson (1969) to be a northern extension of the mid-Pennsylvanian - Lower Permian division of the Sicker Group, which also includes minor limestone and other sedimentary rocks. Southerly dipping limestone beds only a few kilometers to the north of the Catface deposit are presumed to be near the top of this unit, as are smaller outcrops on the beaches both east and west on Catface Peninsula. The uppermost volcanics involved at Catface, however, appear to overlie the limestone and also to resemble closely the Upper Triassic Karmutsen Group, except for some minor foliation. Correct identification of these volcanic rocks could be of importance in considering a source rock for copper, but this cannot be resolved until local structure is better known. In the South Peak area, the volcanic rocks have indistinct bedding, but are believed to form a steep-limbed northwest-trending anticline with an axis just east of the peak. A lip-like remnant occurs above the intrusive rocks on the peak and thickens toward the North Peak, which is composed entirely of volcanic rocks. Deep drilling collared in intrusive rocks in the adit has indicated that volcanic rocks are abundant (Figs. 4, 5). It is not clear whether these intersections represent roof pendants or parts of jagged projecting walls of the conduit system occupied in large part by the intrusive rocks.

FIGURE 1 — (left) — Generalized geological map of the Catface area.

TABLE 1 — Chemical A ses of Catface Rocks

	1.	2.	3.
SiO_2	ND*	ND	ND
Al_2O_3	14.8	14.0	15.4
Fe_2O_3	11.5	2.4	3.5
MgO	5.7	0.6	1.3
CaO	13.8	1.7	3.3
Na_2O	3.3	5.0	2.8
K_2O	1.0	2.6	1.9
TiO_2	1.4	0.2	0.4

ND not determined
1. typical altered andesite
2. quartz monzonite
3. gray porphyritic quartz diorite

The volcanic rocks contain approximately 40 per cent plagioclase laths (andesine), 35 per cent hornblende and a few quartz phenocrysts in a very fine grained groundmass of quartz, feldspar, fibrous tremolite/actinolite and diopside. The plagioclase laths are poikilitic, partly saussuritized, sericitized and silicified where fractured. Forsteritic olivine has been identified. Chlorite, biotite and sericite (often having preferred orientation) are alteration products of hornblende and diopside. Minor (< 1%) carbonate is present. Opaque minerals include hematite, magnetite and rutile. A chemical analysis is presented in Table 1.

2. Intrusive Rocks

The most abundant intrusive rocks within the main mineralized area (Fig. 2) are quartz monzonite and younger quartz diorite. Included with the latter are numerous porphyritic dykes and plugs. Diorite occurs near the outer limits of this area.

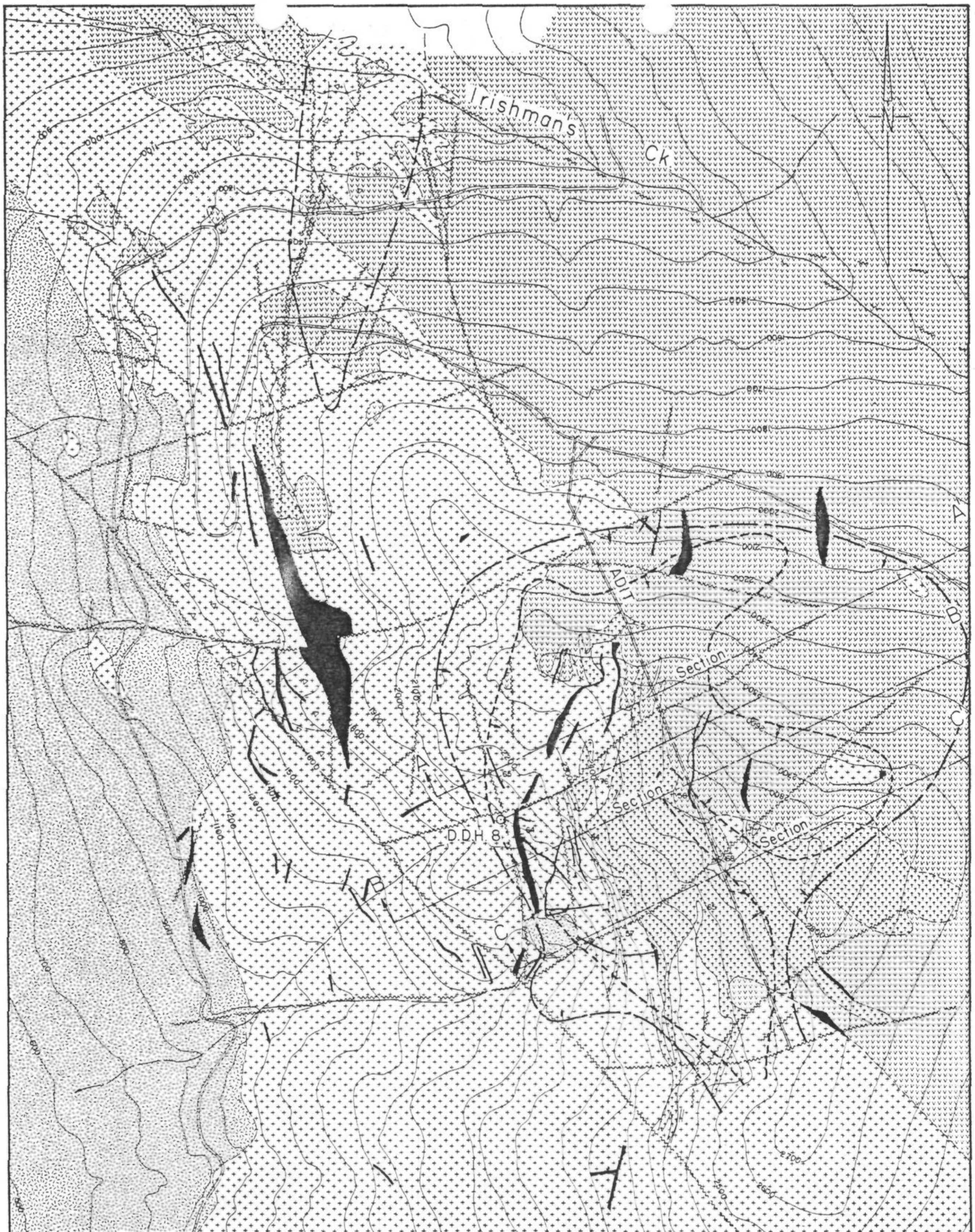
(a) *Westcoast Diorite*

Westcoast Diorite is well exposed along the south and west coast of the peninsula, but its continuation inland to the western base of Catface Mountain is largely obscured by overburden. It intrudes the volcanic sequence and contains partly assimilated subangular volcanic fragments.

The diorite consists of unzoned subhedral plagioclase (An_{40-30}), sub-poikilitic hornblende, quartz (0-20%) and accessory sphene, apatite, zircon and magnetite. Zircons from gneissic varieties elsewhere in the Alberni map area have yielded radiometric dates of 263 ± 7 m y and a dyke cutting these gneisses has a K-Ar age of 192 ± 9 m y, so that Muller (1974) suggested that the diorite, at least in part, may be dioritized Sicker Group. Small exposures of gabbroic rock that are correlated with mafic phases of the Westcoast Crystalline Complex occur on the southeast side of the peninsula.

(b) *Quartz Monzonite*

Quartz monzonite is the coarsest rock in the area. Its greatest exposure is on the central west-sloping part of the mountain, where it outcrops northwesterly for about 3,000 meters. A maximum width of 1,200



Dip (See Figure 1 for Legend)

Contact
- observed
- inferred

Contour elevations in feet a.s.l.

Outer limit of 0.20% Cu (projected to surface)

Py, Po / Bn — Bornite / pyrite-pyrrhotite boundary

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GEOLOGICAL MAP

SOUTH PEAK - CATFACE MOUNTAIN

Figure 2

Scale 0 — 500 — 1,000 Feet

Scale 0 — 300 Metres

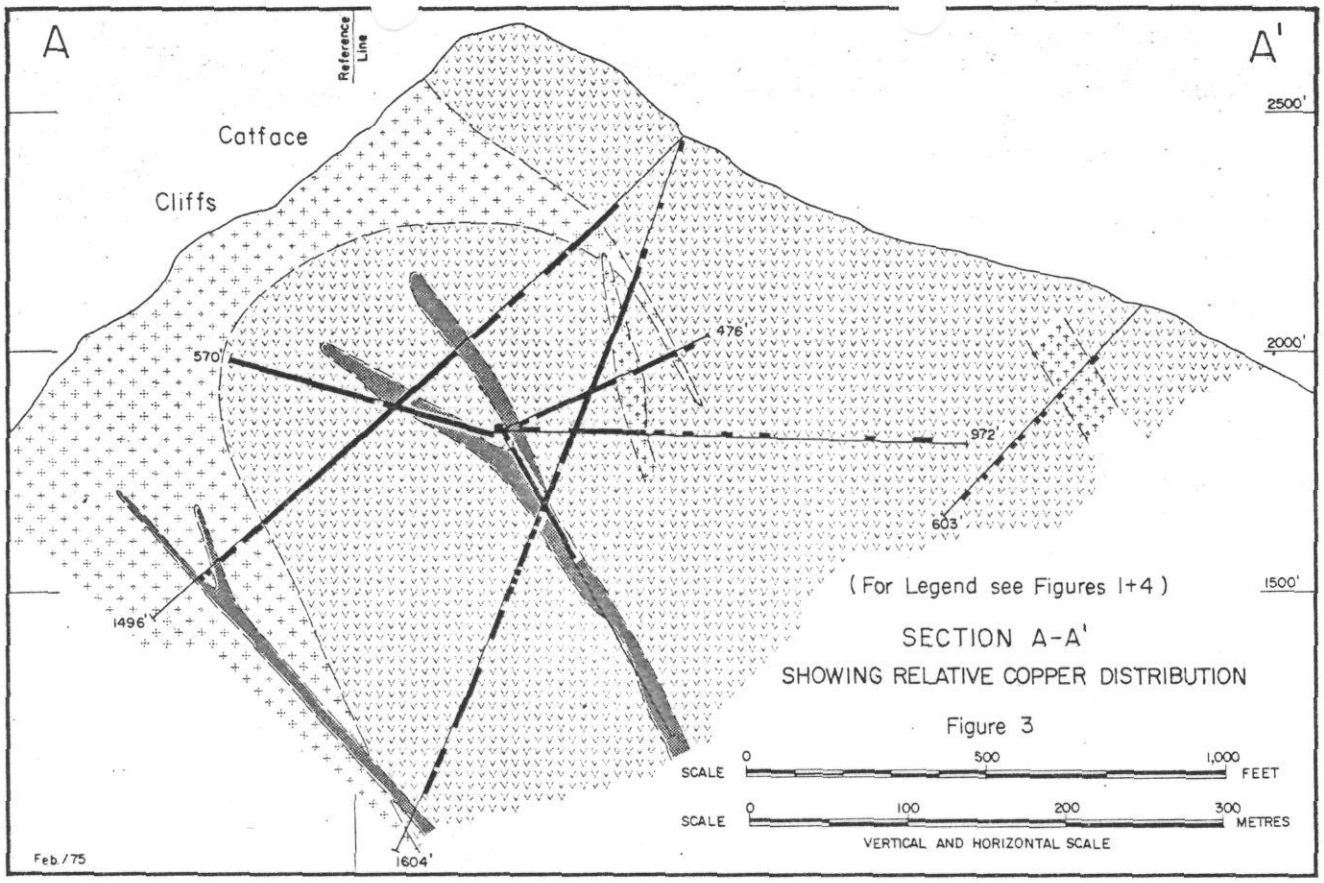

FIGURE 3 — Section A-A', showing relative copper distribution.

meters is attained south of the cliffs, from where it tapers sharply horizontally and vertically. The creamy-white-weathering rock is easily recognized by its high quartz content. Some phases approach granodiorite in composition. Basic and volcanic xenoliths of all shapes, size and degree of assimilation are numerous throughout the quartz monzonite, especially near the volcanic contacts, where stoping in all stages is displayed.

The age of the quartz monzonite is unknown, but the large grain size and relatively intense metamorphism indicate a closer relationship to the Jurassic Island intrusions than to younger intrusions. Muller (1974) reports a date of 59 m y on quartz monzonite collected south of Tofino. This date at present appears slightly discordant with others in the Tofino area, but, if substantiated, an Early Tertiary or Late Cretaceous age for the Catface quartz monzonite is also a possibility.

The rock is medium to coarse grained, leucocratic to holofelsic, and rarely porphyritic. It is composed of about 48 per cent subhedral oscillatory zoned plagioclase (An_{22}, mean grain size 1 mm), 30 per cent anhedral quartz as interstitial grains and 15 per cent white orthoclase (mean grain size 0.5 mm). Orthoclase and rare microcline are commonly replaced by albite. The mafic content ranges from trace to 15 per cent, and includes amphibole (hornblende/tremolite/actinolite) and pyroxene (augite, diopside). Scapolite and apatite have been identified.

Mortar textures, cataclastic fracturing and crushed zones are unusually common, particularly in the feldspars. Altered, pale blue-green feldspar containing up to 320 ppm copper, as finely divided oxide, carbonate or silicate, is also common.

Moderate alteration (hydrothermal and deuteric) of the quartz monzonite has transformed most of the biotite to chlorite, and plagioclase and some of the orthoclase are saussuritized in varying degrees. The K-feldspar is partly altered to sericite and kaolinite. Quartz veinlets (which appear to have originated in part from derived silica) are common. The amphibole is generally partly altered either to chlorite or to zoisite, biotite and magnetite. The pyroxenes are generally chloritized, and show signs of uralite and epidote alteration. Carbonate is rare, but locally constitutes as much as 3 per cent of the rock. A representative chemical analysis is shown in Table 1.

(c) *Early Dykes*

A number of small, northwest-trending, fine-grained highly altered dykes or dyke remnants of diorite composition cut the older rocks. The most common of these is pyroxene-rich diorite lamprophyre.

(d) *Hecate Bay Quartz Diorite*

The Hecate Bay Quartz Diorite is a fresh, medium-grained, equigranular, leucocratic rock occupying much of the area east and southeast of South Peak. It has been dated by K-Ar analysis of biotite as Tertiary (48 ± 12 m y, Muller & Carson, 1969). It intrudes the volcanic sequence, Westcoast Diorite and quartz monzonite. Dykes of quartz diorite cut volcanic rocks in the North Peak area.

The quartz diorite, except for sparse quartz (as little

FIGURE 2 — (left) — Geological map of South Peak, Catface Mountain.

as 5 per cent in dioritic phase and the absence of phenocrysts, is similar in composition to the porphyritic subdivisions described later, but it is generally less intensely altered.

(e) *Porphyritic Quartz Diorite and Granodiorite*

These rocks are believed to form porphyritic cupolas to the Hecate Bay Quartz Diorite, with which they are similar in texture, structure and composition. Intervening volcanic remnants prevent the observation of direct correlation.

The porphyritic quartz diorite and granodiorite, which have a bulbous dyke-like form, crop out in a northwest direction in the cliff area over a length of 770 meters and a maximum width of 700 m and extend to a depth of at least 600 meters. The trend is more northerly in the quartz monzonite. Emplacement appears to have been strongly controlled by pre-existing structures or contacts, particularly those of the quartz monzonite.

Several poorly exposed plugs, up to 240 m in diameter, penetrate the volcanic sequence east of South Peak. The widespread quartz diorite dykes in the volcanic rocks to the north may be weakly porphyritic.

At least two subdivisions, based on form and texture, are described below.

(i) *Cliff Porphyritic Intrusions* — These intrusions constitute about half the exposures on the cliffs and form weakly lenticular or dyke-like bodies. They are fine to medium grained, leucocratic and weakly porphyritic. These rocks also contain the Hecate Bay mineralized occurrence.

(ii) *Gray (Halo) Porphyritic Intrusions* — These intrusions, chiefly found on top of South Peak, are less elongate than the cliff intrusions. The term 'Halo' has been applied to them because of limonitic stains around erratically distributed, altered mafic clots containing chalcopyrite. The limonite stains are most pronounced on surface, but continue to at least several hundred meters in depth. Plagioclase phenocrysts similar to those of the Cliff phase produce the porphyritic texture.

The porphyritic rocks contain approximately 55 per cent rhythmically zoned plagioclase (An_{28} to An_{44}), 1 to 25 per cent orthoclase (in the granodiorite phase), 15 to 40 per cent quartz, 2 per cent pyroxene, 4 per cent amphibole (tremolite/richterite/hornblende), and an average of 4 per cent biotite, epidote and chlorite.

Some of the biotite and epidote and most of the chlorite (with minor magnetite) are alteration products of the amphiboles. Cataclastic fracturing of the feldspar is common. The plagioclase is partly altered to zoisite, and K-feldspar is commonly sericitized. Minor scapolite and carbonates are present. A representative chemical analysis is given in Table 1.

(f) *Porphyry Dykes*

Pre-ore porphyry dykes compose up to 5 per cent of the rocks in the map area, and are of particular interest because they enhance dominant structures. The dykes trend northerly to northwesterly for 1500 m in the quartz monzonite, and occur as continuous bodies as much as 370 m long that may exceed 50 m in width. Dips are generally 50 to 70 degrees eastward, parallel to the Footwall fault (Fig. 7). Minor easterly trending offshoots of the larger dykes appear to cut some of the quartz diorite bodies, but not others, indicating less well developed east-trending structures or overlapping ages. Chilled contacts are not clearly evident.

Three dyke types, andesite, dacite and quartz feldspar porphyry, have been distinguished in mapping, although mineralogically and genetically all are closely related. Gradations of all three types can occur along the length of one dyke and they have been collectively referred to by Northcote (1972) as 'porphyritic dacite'. The phenocrysts consist of plagioclase (An_{31-42}) that exhibits poorly developed normal zoning, and quartz. The highly altered fine-grained matrix consists of quartz, plagioclase and some orthoclase, with chloritized mafic minerals, acicular tremolite, calcite and occasional patches of epidote. These dykes contain approximately 25 per cent quartz, 50 per cent plagioclase and up to 15 per cent tremolite.

(g) *Breccias*

Outcrops and drill intersections of both intrusive and tectonic breccias are common, but the origin and pattern of distribution are not clear. Most breccias, including a barren irregularly defined intrusive 215 m long, occur within the quartz monzonite intrusion (Fig. 2). The Irishman's Creek prospect contains (tectonically?) brecciated quartz monzonite in which the chloritic groundmass is mineralized.

Some outcrops of breccia contain fragments of quartz monzonite, basic diorite and porphyry set in a dark green, fine-grained, seemingly volcanic matrix; however, others consist of volcanic and basic diorite fragments in a quartz monzonite matrix. Some breccias contain fragments of earlier breccias (as observed on other porphyry deposits on Vancouver Island east of Catface).

The more clearly defined intrusion (or explosion?) breccias apparently were formed during or prior to emplacement of the porphyritic intrusions, as clasts of porphyritic quartz diorite have not been found in them.

Narrow dykes of porphyritic quartz diorite occasionally contain singular fragments of volcanic rock nearly as wide as the dyke itself. As the fragments are hundreds of meters from any possible source, the fluidity of the intrusions must have been great.

Structure

The dominant structures at Catface are a series of northerly and easterly trending faults and related fracture systems. The most prominent structures seen on surface are the northerly trending Footwall fault near the base of the cliffs and a well-developed sheeting within the intrusions on the cliffs (Fig. 7).

Faults shown on Figure 1 are well defined, whereas "air-photo lineaments", which often parallel faults, lack evidence such as offsets. Ten steeply dipping faults have been recognized within the main map area (Fig. 2), dividing it into a number of blocks. Some faults within the main ore zone contain intensely sheared rocks and all faults are believed to pre-date mineralization, although some may have been subject to later movements. Mapping shows a northwest-trending fault west of the cliffs that transects, terminates or deflects oblique faults. The Footwall fault (Figs. 2, 7), which dips 50 to 70°E, contains highly sheared rock across widths of up to 6 meters. Easterly faults exposed on the cliffs contain up to 3 meters of sheared rock. Northwesterly trending faults, although only

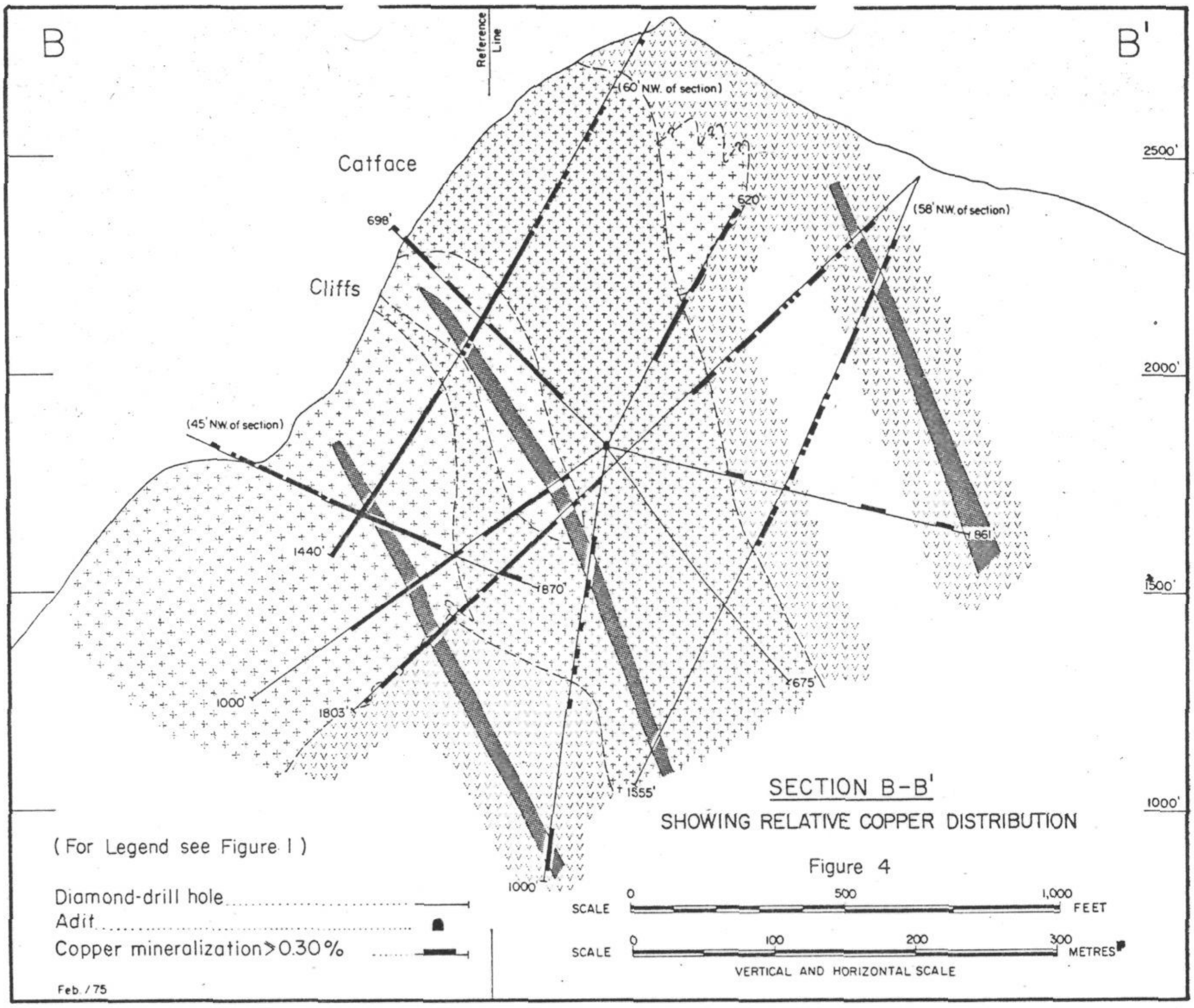

FIGURE 4 — Section B-B′, showing relative copper distribution.

intermittently exposed, are believed to be responsible, for example, for a portion of the steep overburden-covered Irishman's Creek valley which, as partially shown on Figure 2, marks the north limit of both important mineralization (at least near-surface) and intrusions other than narrow dykes.

Joint fracture systems are complex and have variable attitudes, depending on their position with respect to faults and rock type. The most persistent fracture system within the intrusive rocks strikes north to northeast parallel to the Footwall fault and dips 50 to 70°E. Up to 130 fractures per meter have been measured. This system, which is particularly well developed in the cliff-area quartz monzonite, produces a marked 'sheeting'. The second most intense system strikes east to southeastward and dips steeply north. A conjugate (?) system with the same strike dips steeply south. The normal fracture density within the intrusive rocks of this second system is only about 10 fractures per meter. A third poorly developed system strikes northeasterly, dips moderately to steeply north and normally has a low fracture density, although local readings of 100 per meter have been recorded.

Within volcanic rocks, several fracture orientations are present, including those seen within the intrusion. In the 860-m-long adit, about half of which is in volcanic rocks, 5,500 joints, with an average attitude of N 24°W and a 51°E dip, were mapped.

The porphyry dykes within the intrusions generally parallel the northerly trending fracture system, but may diverge along a secondary system, thus forming a step-like pattern. The northerly trending fracture system appears weakly arcuate in outline on the upper cliffs, which is suggestive of domal fracturing.

Fault breccias occur within the intrusions of quartz monzonite, but structural implications are not clear. Breccia fragments less than 10 centimeters in diameter are enclosed by a groundmass of highly chloritized and crushed material which, in some instances, prevented a clear distinction between fault and intrusion breccias.

Metamorphism

Limestones near the Westcoast Diorite (and/or Hecate Bay Quartz Diorite) have been metamorphosed to marble and calc-silicates. Volcanic rocks, early dykes and sedimentary rocks have been noticeably hornfelsed near the intrusions. The hornfels consists in large part of extremely fine grained, brown-weathering biotite and is commonly accompanied near the diorite by a coarse amphibole. Partially assimilated volcanic and dioritic xenoliths occur within the quartz monzonite, with the former displaying recognizable original features such as amygdules.

Granitic rocks at Catface have unusual cataclastic textures. An examination of over 100 thin sections has led petrographers to conclude that "commonly undulatory extinction in the quartz and persistent cataclastic fracturing and mortaring in the feldspars of both quartz diorites and monzonites are believed to be the result of regional or local metamorphism closely followed by hydrothermal alteration".

Hydrothermal Alteration

Alteration, which is only weakly to moderately developed at Catface, has not been mapped in detail, but a broad annular zoning is recognized. A central zone in which alteration is visually evident contains a core several hundred meters in diameter approximately corresponding to the cliff area. It is characterized by quartz monzonite within which feldspars have been substantially altered to sericite and kaolinite, mafic minerals have been chloritized, quartz occurs on most fractures and silicification is present. Petrographic examination reveals further details of alteration within the central core, such as plagioclase that has been partly saussuritized as well as sericitized, and orthoclase that has been albitized or kaolinitized as well as weakly sericitized. The alteration decreases gradually in intensity outward from the core to a point about 2 kilometers away, where the mafic minerals are fresh enough for K-Ar dating. Beyond this, alteration is insignificant.

Secondary biotite occurs generally as clusters within the intrusive rocks and more locally in zones bordering sulphide veinlets. Its occurrence and distribution have not been studied in detail. Silica is present in anomalous amounts, both as quartz, which has filled fractures in the rocks and has partially replaced feldspar grains, and as opaline silica restricted to interstitial areas around crushed feldspars. Silicification appears to have overlapped and accompaned the sulphide mineralization, whereas other alteration preceded mineralization.

The development of clay minerals, which impart a creamy colour to the rock, is more pronounced near surface from weathering of the kaolinized feldspars.

Epidote and iron oxide, derived from the alteration of the more iron-rich silicates, form an elongate halo around the more siliceous central core. As volcanic rocks closer to the cliffs are more epidotized than the intrusions, the inner epidote-zone boundary is poorly defined, but approximates the outer bornite-zone boundary, as shown on Figure 2. Anomalous concentrations of epidote and iron oxides are recognized at least for hundreds of meters beyond this indistinct boundary. Epidote and zoisite occur most commonly as alteration patches in amphiboles. Most chlorite and some magnetite have formed through the alteration of biotite, amphibole and pyroxenite.

Carbonate (generally calcite) is sparse and most common in the volcanic rocks.

Chlorite near the central zone appears darker than that removed from it. This appears to result from both a higher iron or iron oxide content and included very fine grained secondary biotite.

The paucity of K-feldspar in the Catface area is notable.

Mineral Deposits

MINERALOGY

Opaque and some nonmetallic minerals present, identified either by X-ray or optical microscopy, include chalcopyrite, bornite, pyrite, pyrrhotite, molybdenite, chalcocite, covellite, idaite, digenite, native copper, cuprite, valleriite, tenorite, limonite (± geothite), magnetite and hematite, plus azurite, malachite and minor chrysocolla accompanied by cupriferous amorphous silica (chalcedony-opal).

Chalcopyrite is the most common sulphide and is most abundant within the main zone of the Catface deposit as veinlets or fracture coatings and disseminations, although it is widespread interstitially in all rocks of the peninsula. It is the main constituent of several well-defined veins in the cliff area which pinch and swell to widths of as much as 15 centimeters and are traceable for lengths of up to 220 meters. Discrete disseminated grains average 60 to 75 microns in diameter, but a grouping also occurs in the 45-55-micron range. A smaller number of grains measuring 3 to 5 microns form cores and fracture fillings (in part silica healed) in altered plagioclase crystals. Fine-grained chalcopyrite also occurs in biotite, amphibole and chlorite. Occasionally, chalcopyrite may be completely enclosed by geothite that formed from the oxidation of pyrite.

Bornite is similar to chalcopyrite in grain size and association, but is more restricted. It replaces siliceous amygdules in the volcanic rocks, but it is most common in breccias and altered volcanic rocks and quartz monzonite. Bornite forms interstitial grains and occurs with chalcopyrite on fractures in these rocks. It is most common in a centrally located bornite zone (Fig. 2) in which bornite may be more abundant locally than chalcopyrite, and pyrite and pyrrhotite are essentially absent. This zone is approximately coincidental with the central siliceous zone described under "Alteration".

Bornite has a strong affinity for biotite or its related alteration products. Minute grains of bornite are found in the biotite cleavage planes, and some copper is contained in the biotite lattice. Idaite resembles, is related to and is distinguishable from bornite only with difficulty. Investigation indicates that it is never as abundant as bornite, although it may be present in important amounts.

Minor chalcocite is believed to be secondary after chalcopyrite and bornite. Chalcocite, which along with all other secondary minerals has a grain size of less than 30 microns, commonly forms a rim on primary sulphides. Minute blebs have been noted in fault zones close to surface, but generally it appears as a black sooty coating on surface rocks. Traces of digenite occur with chalcocite. Covellite appears as coatings on copper minerals exposed to the atmosphere, and a mineral identified tentatively as valleriite occurs in trace amounts in oxidized zones. Cuprite-tenorite-limonite assemblages have widespread distribution as minute dendrites on bleached and weathered surfaces and are an important prospecting guide. Dispersed fine grains of secondary native copper have been recognized, chiefly within limonite.

Molybdenite occurs throughout most of the deposit associated with copper minerals as finely disseminated flakes or as coatings in or near quartz-filled fractures in granitic and volcanic rocks. Quartz veinlets up to a centimeter wide may contain molybdenite rosettes

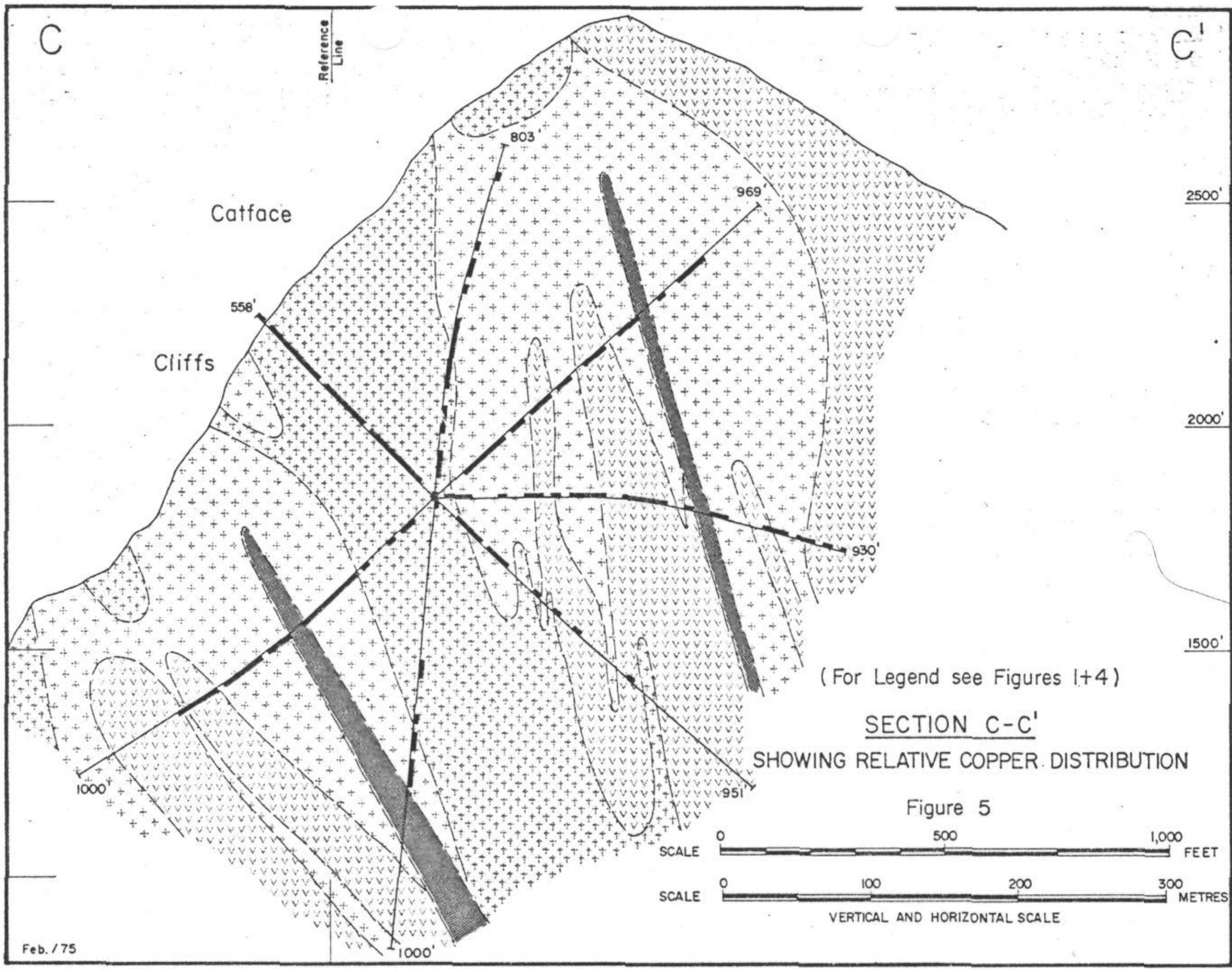

FIGURE 5 — Section C-C', showing relative copper distribution.

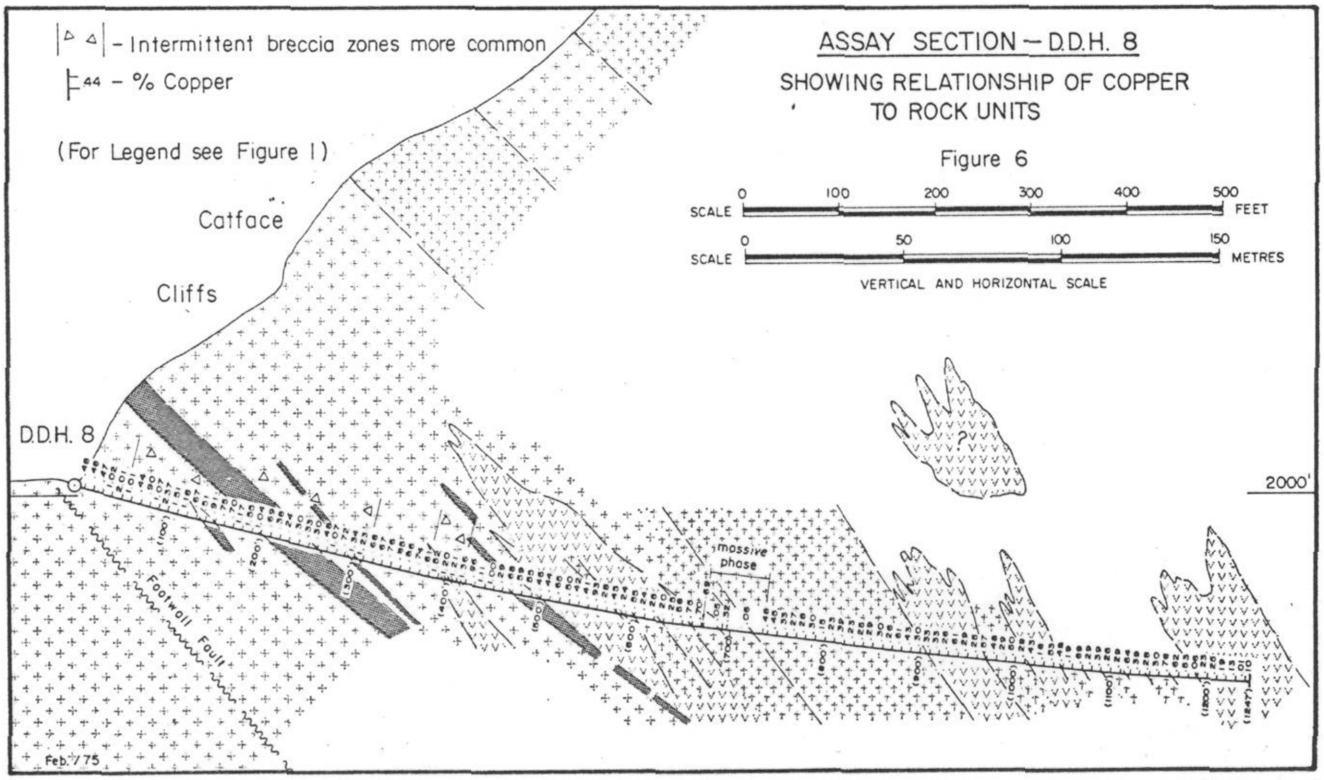

FIGURE 6 — Assay Section — D.D.H. 8, showing relationship of copper to rock units.

formed later than the accompanying chalcopyrite. Some of the best concentrations of molybdenite occur west of the Footwall fault, but the over-all distribution in the copper zone is variable. The molybdenite content is relatively more persistent than that of copper in the weakly fractured parts of the porphyritic quartz diorite intrusion. The amount of rhenium present in the only molybdenite sample analyzed was 300 ppm.

Pyrite, although less abundant than chalcopyrite, occurs as disseminated grains in all rocks of the peninsula and is particularly evident in most dykes. The amount of pyrite increases from traces in the central part of the main deposit to 5 or 10 per cent in the Irishman's Creek prospect, where chalcopyrite, pyrrhotite and magnetite are also abundant. It is a minor constituent accompanying chalcopyrite in the Hecate Bay prospect.

Pyrrhotite, which is unusually common in porphyry deposits on Vancouver Island (and in northwest Washington State), is most abundant in the volcanic rocks, particularly north of the main deposit, and also occurs in minor amounts associated with dykes. Like pyrite, it is absent in the central part of the main deposit, except for minor amounts near the north end. Small pyrrhotite veins, one of which is auriferous, occur to the west of the Figure 2 map area and pyrrhotite-sphalerite deposits occur on Vargas Island to the southwest. Minor minerals present include magnetite, one exposure of which occurs on the southern slopes of Irishman's Creek, and hematite, which along with magnetite is limited to finely dispersed grains in altered mafic minerals. A few grains of graphite, galena and sphalerite have been recognized. At least one occurrence of a bitumen-like substance has been recorded in drill core.

A concentrate representative of the main deposit indicates that the major minerals are present in the following amounts: chalcopyrite 60 per cent, bornite 17 per cent, chalcocite 2 per cent, pyrite (including marcasite) 1.5 per cent and pyrrhotite 0.5 per cent. The concentrate also contains minerals derived from country rock, such as ilmenite and zircon, as well as about 16 per cent 'gangue' minerals such as azurite, malachite and chrysocolla. Minor elements present in anomalous amounts in the concentrate include silver, chromium, titanium and manganese.

PARAGENESIS

The main paragenetic stages, based largely on megascopic evidence, are indicated below:

Stage (1) — Pyrite — pyrrhotite — magnetite (contemporaneous)

Stage (2) — Quartz, chalcopyrite, bornite, molybdenite

Stage (3) — Secondary minerals

Some molybdenite, particularly that present in rosette form, appears to have overlapped and crystallized later than chalcopyrite, but other occurrences appear to be earlier. Its relationship to bornite is indefinite. Minute pyrite-calcite veins cut chalcopyrite-bearing veins.

DISTRIBUTION AND GRADE

The main mineralized rocks are the quartz monzonite and volcanic hosts, each of which contain about one-third of the total sulphides present. Dykes contain about 5 per cent and bodies of porphyritic quartz diorite contain the remainder.

Brecciated and fragmental volcanic rocks, well fractured or brecciated quartz monzonite, and intrusion breccias are the most favourable host rocks and parts of the porphyritic quartz diorites the least favourable. All rocks within the zones outlined in Figure 2 are mineralized. The over-all grade of the area tested is low due to the inclusion of central core material. All shear zones, most of which are associated with the faults shown, contain better than average grades. Normally, copper grade changes gradually across distances of a hundred meters or more.

The main mineralized zone, arbitrarily defined by rocks containing at least 0.2 per cent copper, is shown as a composite of surface and projected values in Figure 2. It is bulbous in outline and measures approximately 900 meters along a northerly axis and averages about 600 meters in width. A plunge to the south is indicated by the position of the mineralized zone in the adit. Mineralization within the main zone is largely controlled by faulting and fracture density, as well as proximity to hydrothermally altered rocks within the upper portion of the inferred cupola and the adjacent volcanic rocks. Cross sections (Figs. 3-5) indicate that sizeable zones of more than 0.3 per cent copper occur only in the upper part of the deposit. A low-grade central core of uncertain shape and size is found in less fractured and less altered porphyritic quartz diorite and minor amounts of other rocks. This core is partially encircled by the bornite zone, measuring 700 meters north and 450 meters east. The bornite zone, which contains chalcopyrite, but only trace amounts of pyrite or pyrrhotite, coincides approximately with more siliceous rocks in the cliff area. A gradation occurs outward from the bornite-chalcopyrite zone to an encircling chalcopyrite-pyrite zone which may contain pyrrhotite. The mineralized zones transgress all rock contacts (Fig. 2).

A central drill-hole section at about the 660-meter level (D.D.H. 8) shows copper content in all types of host rocks (Fig. 6). Ore grade increases with fracture density, which is greatest in the quartz monzonite near the surface and decreases gradually toward the central and deeper core of less-fractured quartz diorite. The low copper content of the porphyry dykes relative to that of the quartz monzonite is also a result of decreased fracture density. However, near the south boundaries of the main deposit, as well as at depth (Fig. 4), the dykes can retain a low but significant copper content while the grade of the intruded rock decreases appreciably. Most of the scant mineralization in volcanic rocks of the North Peak is adjacent to dykes.

The Irishman's Creek prospect (Fig. 1) marks the northernmost exposure of the quartz monzonite, quartz diorite, volcanic rock assemblage. Disseminated chalcopyrite, pyrite and some pyrrhotite occur in all rock types, but a brecciated zone in the quartz monzonite is the most favourable host. Fracturing is less widespread than in the main deposit. Sulphide-rich masses containing magnetite, as well as chalcopyrite, pyrite and pyrrhotite, occur across a width of a meter in or near a poorly exposed pyroxenite (?) dyke in the creek bed. Easterly trending subsidiary faults and the dyke which parallels the creek in part may indicate a major structural feature not evident otherwise because of extensive overburden. Limited preliminary drilling and trenching have partially outlined a zone of anomalous copper mineralization (greater than 0.2 per cent copper) measuring about 350 meters long in a northerly direction, and about 100 meters wide. Total

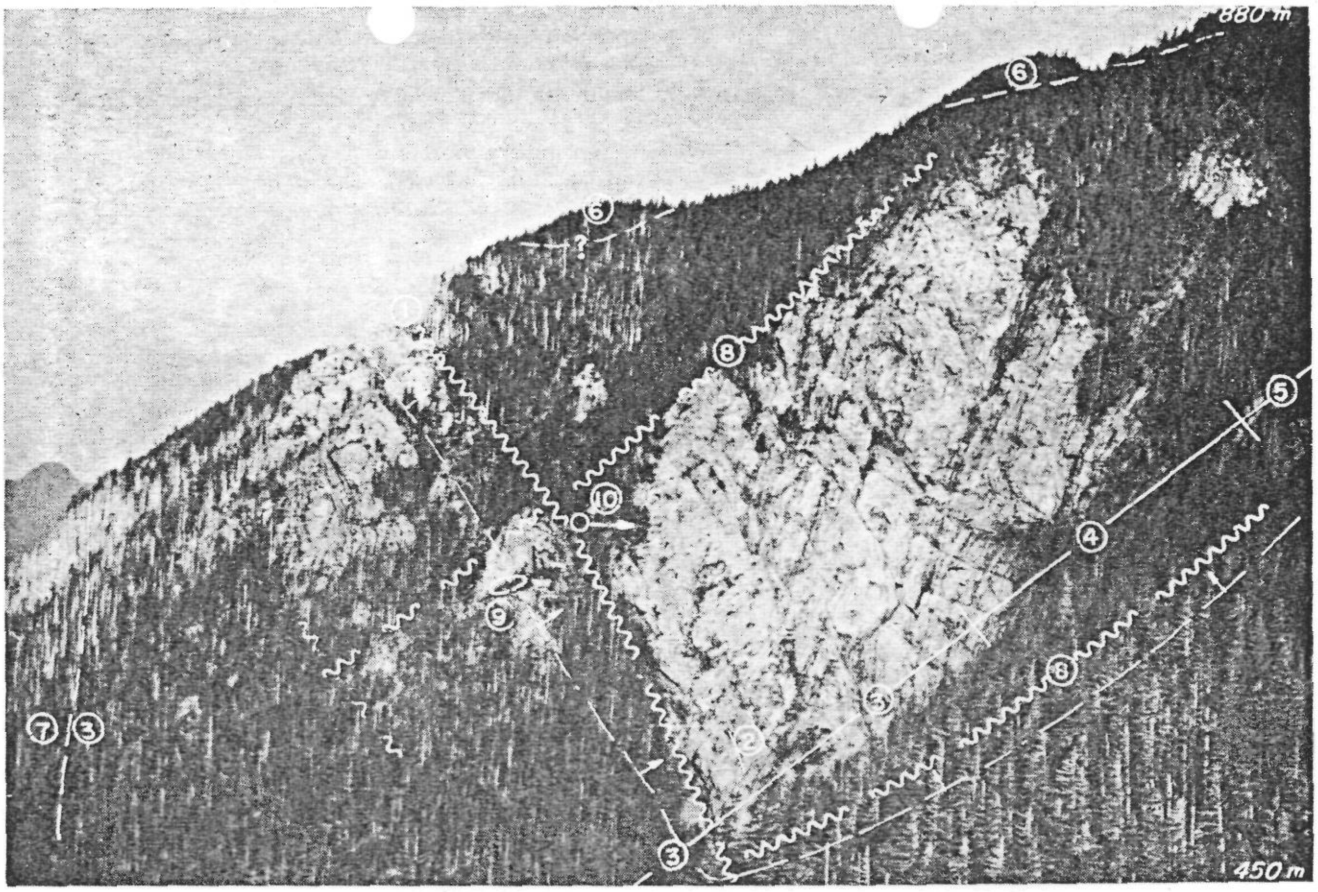

FIGURE 7 — Catface Cliffs, looking north. Note prominent east-dipping fracture system. Lines down cliff are water stains. 1. Footwall fault. 2. Center of porphyry dyke. 3. Quartz monzonite. 4. Cliff porphyritic quartz diorite. 5. Grey (Halo) porphyritic quartz diorite. 6. Volcanic rocks. 7. Diorite (off photo). 8. Cross faults. 9. Prominent copper stain. 10. D.D.H. 8. Dashed line with inward-facing arrows shows limit of 0.2% surface copper mineralization.

sulphides present may be up to 10 per cent in some of the brecciated zones, but the average grade is similar to that of the main deposit because of abundant pyrite and pyrrhotite.

The Hecate Bay deposit (Fig. 1) appears to be circular and about 300 meters in diameter, although copper-bearing shear zones on its periphery extend for an additional few hundred meters. Limited investigation has shown it to consist of a body of moderately fractured porphyritic quartz diorite similar in appearance to the Cliff sub-type, but enclosed by Hecate Bay quartz diorite. Chalcopyrite and pyrite occur both as fracture fillings and disseminations. Copper grade within the shear zones approaches 1 per cent locally, but that of the main plug-like body, as currently exposed, is probably only one quarter of this. Mineralized occurrences believed related to other smaller bodies of this type occur at intervals to the shores of Hecate Bay about 1 kilometer to the east.

SUPERGENE ALTERATION AND ENRICHMENT

Malachite and minor azurite are common on freshly broken surface rock, and in or near fault structures to considerable depth. Limonite-tenorite-cuprite assemblages averaging about 60 per cent copper (termed "cupriferous limonite") are important, but are normally detected only by microscopic examination. Their distribution as coatings on some mineral grains near fault zones at depths of up to 600 meters is notable, because the least fractured of the surface rocks appear leached or oxidized for a depth of only about a meter. Chalcopyrite mineralization affected by this cupriferous limonite has been enriched.

Geochemistry

The first soil and silt geochemical surveys on Catface Peninsula used rubeanic methods. Results from these surveys were later substantiated by atomic absorption techniques. Copper concentration in soils over and around mineralized outcrops ranges from 10 to 1000 ppm, with a modal range of 150 to 250 ppm. The average pH of the soils, which are subject to an average of 380 cms of rainfall per year, ranges from 4.0 to 4.5. Copper in stream-sediment samples ranges from 10 to 5000 ppm. The sample population is bimodal, with peaks averaging in the 100-200-ppm and 500-600-ppm class intervals. Molybdenum content ranges from less than 2 to 60 ppm.

Two features are evident:

(i) Estuarine sampling would indicate the presence of mineralization only if samples were taken from creeks running directly into the sea rather than through the swampy platform area. Anomalous (twice background) copper dispersion trains are in the order of 2500 meters long.

(ii) Molybdenum dispersion in the drainage is erratic and restricted. Anomalous dispersion trains greater than three times background are 300 meters long.

"Copper-moss", a distinctive red algae identified as *trentopohlia-iolithus* and used as a prospecting guide because of its association with copper (content up to 200 ppb) or sulphur, is present on some rock surfaces.

Geophysics

Geophysical ground tests have been limited because of steep topography and the lack of suitable ground contacts directly over the main deposit. IP tests gave discernable but weak response, because of variable but considerable thicknesses of near-barren cap rock, but were more positive at Irishman's Creek, where more concentrated sulphides are present near surface.

Self-potential surveys showed unusual, but persistent, highs (300-400 millivolts with a 100-millivolt background) over large but low-sulphide-bearing areas both on the cliffs and near their base. The high readings may not be due to sulphide content alone.

EM tests and magnetic surveys were not diagnostic. Air-detected radioactivity associated with intrusions near the South Peak is double local background.

Discussion

The Catface regional setting is that of a cupola of quartz diorite emplaced in and capped by volcanic rocks. The cupola is genetically related to a large elongate Tertiary intrusion that is sparingly exposed. The emplacement of this pluton was guided by intersections of regional and local faults and by contacts which guided earlier and smaller quartz monzonite intrusions. Mineralization affects both the upper portion of the cupola, which consists largely of dyke-like porphyritic bodies and porphyry dykes, and the invaded host rocks, which consist of Paleozoic and possibly Triassic volcanic sequences intruded by quartz monzonite of undetermined age. Some blocks of volcanic host rock were assimilated, both by the quartz monzonite and the quartz diorite, but most were stoped from the roof and the walls which formed the original magma chamber and settled into highly fluid magmas. Intrusion and collapse breccias formed at different times within the enclosing rock. Fracturing of the host rocks occurred, particularly at higher levels, related to intrusive-induced doming as well as local faulting. Micro-shattering of rock-forming minerals was extensive. Hydrothermal alteration, although not intense, was widespread, with processes such as silicification influencing rock competency. The mineralizing process, which occurred after all rocks were emplaced and major structures developed, was controlled by fault and fracture systems. Dykes may have provided part of a feeder system. In and around the more shattered upper section of the cupola, fracture filling and replacement envelopes were intensely developed. Roof pendants and breccia zones were most susceptible to mineralization. Mineral zoning, probably caused by sulphur and iron availability, resulted in the central annular pyrite-free bornite-chalcopyrite zone, which appr[illegible]ately coincides with a siliceous one, and an outer [illegible]rite-pyrrhotite-chalcopyrite zone. Minor oxidation occurred along fault zones and some secondary enrichment caused by descending copper-iron solutions developed.

The quartz diorite appears to have been the direct source and the basic copper-bearing volcanic rocks the indirect source of the copper.

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