surface. It would appear that the orebodies in this mile-long zone parallel the trace of the present surface and lie within a few hundred feet of it. They may have been emplaced at a rather uniform distance below the former surface, from which erosion has since removed several hundred feet.

Relation to Bedding

The ore shoots lie in an 800-foot stratigraphic horizon which contains more tuff and less argillite and greywacke than the beds above and below. This horizon roughly parallels the surface in the mine area. The tuffs are apparently more suited to alteration and ore deposition than the other rocks. In the centre of the ore shoots all the rocks are altered and ore-bearing, but on the margins alteration is more selective, and ore follows tuffaceous beds. Black (3) found that some stopes showed higher and lower grade sections raking parallel to the trace of the bedding, a fact that would indicate a minor control by bedding even within the central portions of the ore shoots.

Relation to Porphyry

In the principal producing veins (Nos. 4, 6, 7, and 8) the southwest ends of the ore shoots lie about 500 feet from the porphyry margin or its projection, and their centres of gravity are 600 to 800 feet from it. In Nos. 1 and 2 the shoots lie closer to the porphyry, and their higher gold-silver ratios may indicate a higher-temperature type of mineralization. Nos. 4, 6, and 7 have been traced on surface across the porphyry; the grades are low.

Relation to Folding

The centres of gravity of the ore shoots in Nos. 4, 6, 7, and 8 veins are close to the structural terrace of the minor southwest fold. The maximum concentration of ore within this zone occurs at its intersection with the larger northeast anticline. Approximate normal distances between the productive veins are as follows:

Vein No.	1		4		6	Anticlinal axis	7		8		9
Distance, feet		880		210		130		300		460	

Relation to Altered Zones

The bleached zones contiguous to the veins extend northeast from the porphyry, and apex about 900 feet from the contact, or just northeast of the principal ore shoots; the shoots lie near the apexes rather than near the centres of gravity of the zones. The pitch of the ore shoots and of the bleached zones is easterly, parallel to the strike of the porphyry contact. The zones vary rapidly in thickness, and show no relationship to the size of the enclosed veins.

Relation to Major North-South Fault

The ore shoots on Nos. 4, 7, and 8 veins bottom about 300 feet above the fault plane. No. 6 narrows about 150 feet above the fault, but continues down to it. The present surface of the ore shoots of these veins is 600 to 800 feet above the fault plane. Below the fault, the ore in No. 11 vein continues up to the fault plane.

CONCLUSIONS

The folding and porphyry intrusives in the area show two main trends. The ore zone is parallel to one of these trends and influenced by the other. The ore shoots may have been controlled by a steep geothermal gradient related to both the surface and the porphyry.

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Vol #2 Structural Geology of Canadian Ore deposits

PACIFIC NICKEL PROPERTY

*by A. E. Aho**

The Pacific Nickel property lies 7 miles northwest of Hope and 100 miles east of Vancouver, in the Coast Mountains of southwestern British Columbia. Nickel-copper sulphides were discovered in ultrabasic rocks on this property in 1923 and the deposits were explored by Pacific Nickel Mines until 1937, then again between 1951 and 1954 by Pacific Nickel Mines and by Newmont Mining Corporation through its subsidiary,

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Western Nickel. The property was studied by C. E. Cairnes (1) in 1924, by W. E. Cockfield and J. F. Walker (2) in 1933, by H. C. Horwood (3), (4) in 1936 and 1937, and by the writer in 1951 and 1952. Except for a few thousand tons for trial shipments, the property has never been mined. Indicated ore reserves now total somewhat over one million tons averaging about 1.4 per cent nickel and 0.5 per cent copper, with lesser values in precious metals and cobalt.

GEOLOGIC SETTING

The nickeliferous ultrabasic rocks form part of the core of a 15-mile-wide block of Late Palæozoic metamorphic rocks and Mesozoic intrusives which extend north-south between the coast batholith of British Columbia and the Chelan batholith of Washington. Margins of this block are faulted in part against less metamorphosed volcanic and sedimentary rocks largely of Jurassic and Lower Cretaceous age (*Geol. Surv., Canada,* Map 737A, 1942). Serpentinites, suggestive of deep transgressive structure, occur within the block, and also at its east margin along faults which are southern extensions of the regional Yalakom-Fraser River fault zone. Some of the other mineral deposits in the Hope area appear to be spatially related to these major faults.

The mineralization at Pacific Nickel occurs almost exclusively within a stock-like mass of ultrabasic rocks which mingle with, and partly cut, a larger batholithic mass of genetically related diorites and norites of late Mesozoic age (Figure 1). The ultrabasic mass consists essentially of fresh, medium-grained hornblendic pyroxenite with peridotitic cores and with a remarkable margin of pegmatitic hornblendite. The most hornblendic rocks appear to be chiefly products of reaction and replacement of the pyroxene and olivine rocks. The mineralization consists of disseminated and massive pyrrhotite, with subordinate pentlandite and chalcopyrite, amongst fresh olivine, bronzite, and, less commonly, augite and hornblende. Both the ultrabasics and mineralization are cut by small hornblenditic and dioritic dykes, and by veins and alteration zones.

STRUCTURE

General Trends

The Pacific Nickel property contains two general structural trends, a north-south trend and a less well defined east-west trend, which lie nearly at right angles to one another. The north-south trend consists of foliation in the metamorphic rocks, which in general strikes north and dips steeply west, with a strong lineation pitching northward in the plane of foliation. Some of the intrusive contacts are concordant with this foliation, which

conforms with regional trends in the area. The east-west structural trend, which appears to control the mineralization, is expressed by the fabric and shape of the diorites and ultrabasics. In the diorites on the west side of the property most internal structures trend westerly and plunge or dip steeply north. In the ultrabasics (Figure 1) some hornblendite and peridotite bodies tend to be elongated east-west; the south contact, although irregular, trends generally north 75 degrees west; and most of the mineralization lies along a north 75 degrees west zone in the southwestern part of the ultrabasics.

Main Mineralized Zone and Plunging Structure Within It

Nearly all of the known ore and the well mineralized localities, much of the disseminated mineralization, and four of five main geophysical anomalies form a broadly linear N75°W-trending zone (Figure 1), which extends for at least a mile and a half and is of the order of a thousand feet wide. The mineralized localities tend to fall into groups within areas of ultrabasic rock which are at least partly separated from each other by diorite or schist, so that this main mineralized zone crosses many contacts. The rest of the mineralization and related anomalies could be imagined with less certainty to lie on two other N75°W zones, one on either side of the main zone.

The ultrabasic mass along the main mineralized zone plunges about 70 degrees northward and apparently widens at depth. Within these ultrabasics small bodies of diorite, although irregular in plan, often appear to be downwardly elongated, steeply plunging northward, and broadly accordant with the ultrabasics (Figure 2). As determined from drill-hole data, geophysics, and mapping, the ore forms similar elongate bodies, plunging steeply in a general northerly direction in concordance with the plunge of surrounding pyroxenite, peridotite, and diorite, and in places following or paralleling contacts between these rocks.

Orebodies

The ore forms two types of steeply plunging bodies within the ultrabasics, namely zoned and "massive". (The term "massive" is used here to imply massive structure. Most of the ore actually carries 50 per cent or more silicates in a sulphide matrix.)

The zoned types of orebodies are pipe- or parsnip-shaped, sulphide-rich ultrabasic assemblages, commonly with olivine-rich cores and bronzitic borders which may extend beyond the limit of the sulphides. The concentric zoning varies in complexity; the sulphides occur in rings as well as in cores; and some zones may contain little or no sulphides. The

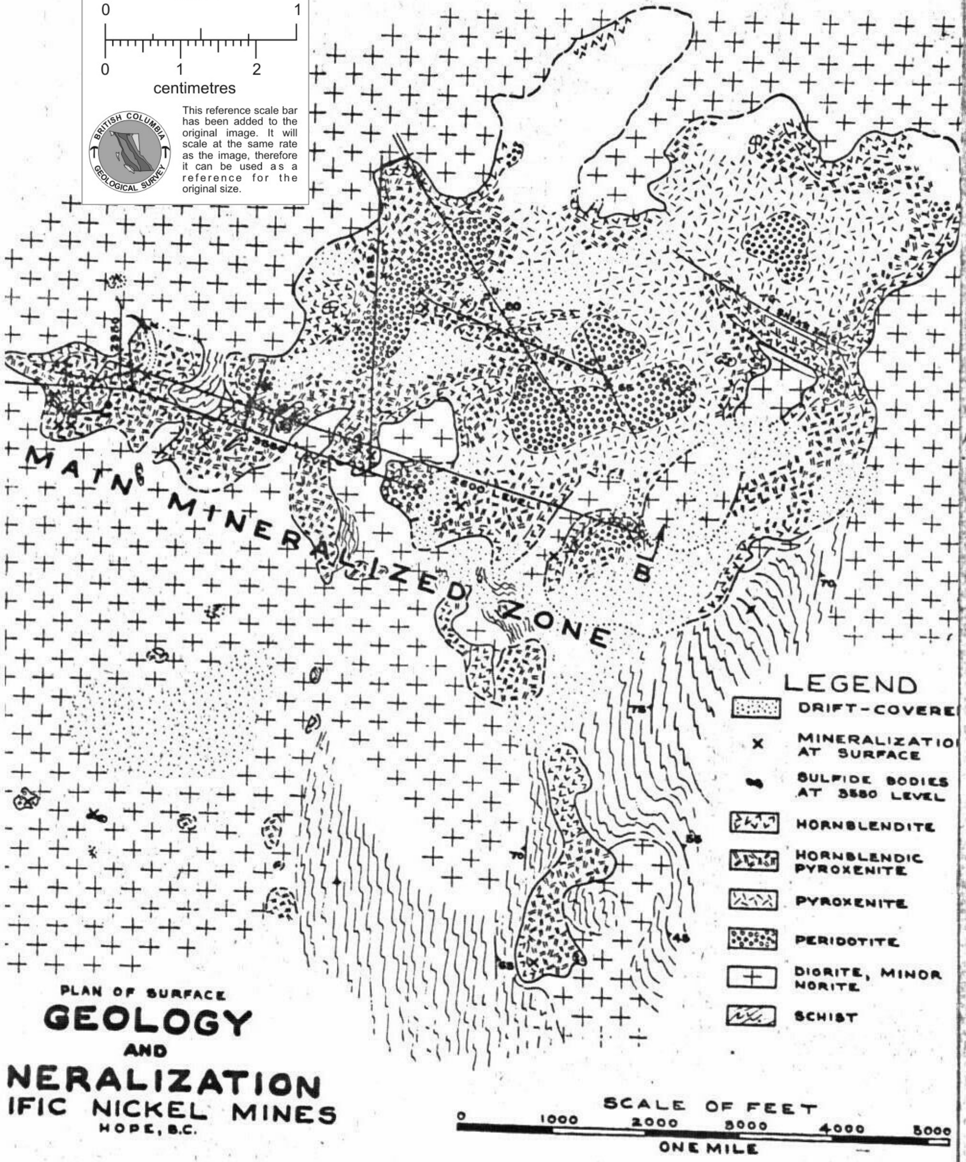


Figure 1. *Plan of surface geology and mineralization, Pacific Nickel property.*

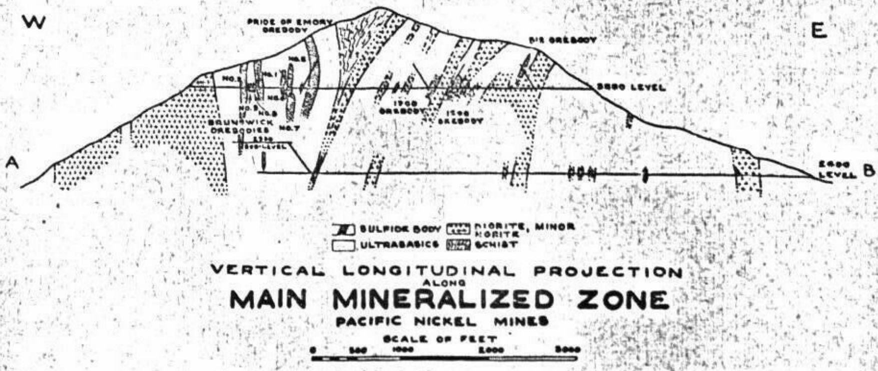


Figure 2. *Vertical longitudinal projection along line AB of Figure 1, within the main mineralized zone, Pacific Nickel property.*

diameters of most of the zoned orebodies range from about 50 to 150 feet, and the plunge lengths of some reach 5 to 10 times their diameter. Although the sulphide zones show local pyroxenitic inclusions and patches or schlieren of sulphides, much of the zoning is gradational; this and other features suggest replacement origin. These ore-bearing ultrabasic assemblages are generally more magnesian, locally richer in sulphides, and poorer in augite and hornblende than the surrounding ultrabasics.

The "massive" types of orebodies are similar in size and in general shape to the zoned ones but are more irregular in cross-section and show flow lines, banding, drag-folds, sharp contacts, inclusions, and hornblendic reaction rims, all of which suggest injection origin as opposed to replacement. No zonal arrangement of rocks was observed around most of the "massive" orebodies.

Of less common occurence are dykelike or veinlike sulphide bodies up to a foot or two wide, which grade into dykes of pyroxenite and hornblendite, and which show features suggestive of injection as well as replacement.

For genesis of the sulphide deposits at Pacific Nickel a good case could be presented for magmatic segregation followed by injection and minor replacement. However, the writer has found considerable evidence to support an alternative replacement and conversion theory (5), in which he suggests that ascending water vapour above 650°C. could deposit the sulphides and, by removal or addition of silica, convert bronzite to olivine and vice versa to produce the zoning. Under these high-temperature conditions, which approach those of sulphide melts, it would not seem unreasonable to expect some movement of the more massive sulphides, giving rise to injection phenomena.

Fracture and Fault Patterns

Most of the visible fractures at Pacific Nickel are post-ore and have doubtful significance as ore controls. However, application of statistical methods to analysis of the fracture and fault patterns gave definite enough results to aid in structural interpretation. The full analysis is presented here, since similar applications may be useful in dealing with other structural problems. The fractures were mapped in detail, plotted on work-sheets, and then their poles were plotted on lower-hemisphere equal-area projections (Figure 3). All the plotted measurements were made in horizontal workings on the 3,550 level, in which north-south crosscuts are equivalent in total length to east-west drifts, so that the strikes are statistically represented. Unplotted measurements made in raises and at cliffs on the surface show that most dips are steep enough to be statistically represented also, but a few widely spaced, flat-dipping faults were noted.

Most of the fractures fall into three well defined sets: (x), (y), and (z) (Figure 3F). Sets (x) and (y) are best developed, and many of the fractures are co-zonal with them, so that the poles of these two sets lie on a well defined girdle. Set (x) strikes N10°W and dips 40°E, set (y) strikes N35°E and dips 80°NW, and set (z) strikes N42°W and dips 55°W. Sets (x) and (y) thus lie at 70 degrees to one another and set (z) makes an angle of 90 degrees with set (x) and 70 degrees with set (y). In any one locality one of the three sets of fractures is generally best developed and one is weak or absent. Fine-grained dioritic dykes (Figure 3A) occur mostly in the western part of the 3,550 level and largely follow fractures of set (x), which are best developed there, while the more numerous hornblendite dykes (Figure 3B) largely follow fractures of set (y), which are best developed in the eastern part of the 3,550 level and in the 512 crosscut. Faulting (Figure 3C) has occurred chiefly on fractures of set (x). Slickensided fractures or minor faults (Figure 3D) are well developed only along sets (x) and (z). Set (z) fractures are tight and many are walled with slip-fibre anthophyllite. Joints (Figure 3E) fall largely into sets (x) and (z). Plotting of poles of 340 fractures mapped in the 2,600 level and 2,950 sublevel by R. F. Sheldon in 1953 and 1954 shows a pattern similar to that in the upper workings but with set (x) much more prominent, probably as a result of (a) actual difference in fracture pattern, (b) lack of north-south crosscuts, or (c) difference of choice in mapping.

All of the known faults within the property appear to have a relatively small displacement, probably of the order of a few tens to a hundred feet or more. Faulting in the brittle diorites follows clearly defined zones dominated by a master fault, whereas in the tougher ultrabasic rocks it tends to be more diffuse. Where possible, the probable main direction of

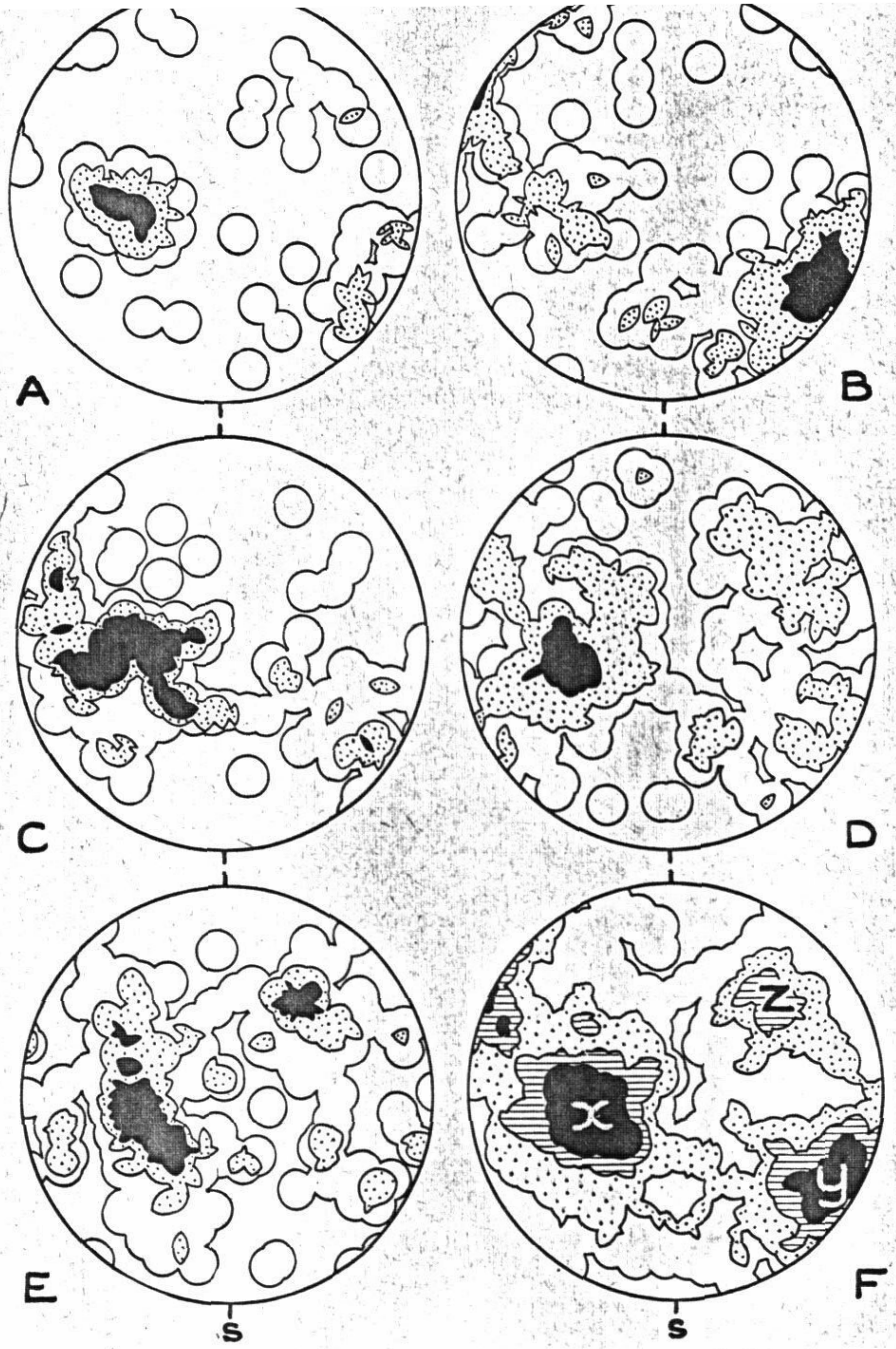


Figure 3. Lower hemisphere equal-area projections of poles of fractures, Pacific Nickel property.
(A) *75 dioritic dykes. Contours 1, 3, 6 poles per 1% area.*
(B) *184 hornblendite dykes. Contours 1, 3, 12 poles per 1% area.*
(C) *139 faults. Contours 1, 3, 6 poles per 1% area.*
(D) *258 slickensided fractures. Contours 1, 3, 8 poles per 1% area.*
(E) *184 joints. Contours 1, 3, 6 poles per 1% area.*
(F) *Composite of A, B, C, D, and E (840 fractures). Contours 1, 6, 12, 20 poles per 1% area.*

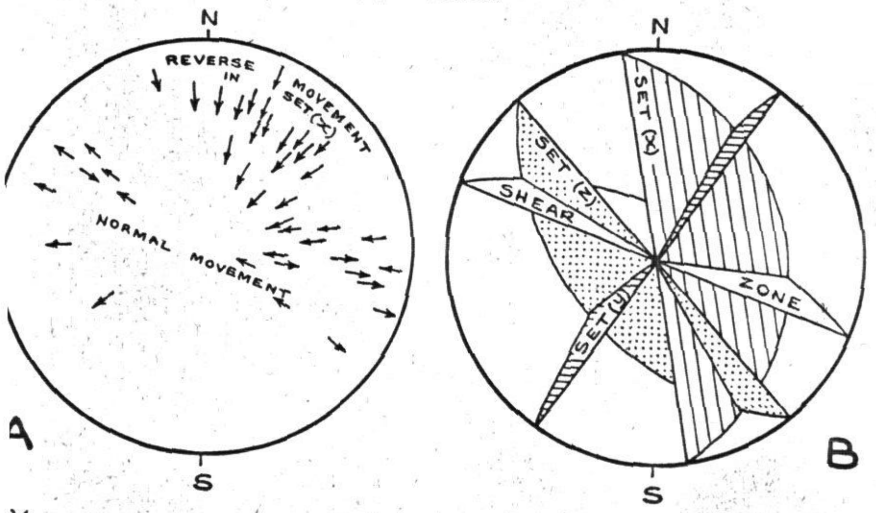
latest movement was determined from slickensides and grooves (good), from shear fractures and foliation (good), from offset of dykes, ore, and contacts (best, but uncommon), from drag on dykes (rare), from tension joints (rarely good), and from drag-folds and gouge (often doubtful). Widths of gouge and sheared rock were used as a qualitative expression of the strength of a fault. Of the faults whose direction of movement was determined, reverse faults along set (x) are the strongest and most common (Figure 4A), while normal faults along the girdle fractures are weak and less common. Pitch of direction of the latest movement on the fault surface of many of the reverse faults averages about 50 degrees northward. This knowledge may be helpful in finding ore which has been displaced by such a fault, as in Brunswick No. 9 orebody.

Since they form such a definite pattern, the three sets of fractures (x), (y), and (z) are very probably genetically related. Horwood (3) attributed east-west fractures (set (z)) to tear fractures developed in blocks of rock as a result of unequal movement along the east- and west-dipping faults (sets (x) and (y)). Alternatively, the fractures may have originated as tension joints during initial cooling of the igneous complex, and sets (x) and (y) may have opened, favouring dyke emplacement. Set (z), meanwhile, may have been kept closed by compressive stresses which later resulted chiefly in reverse faulting along the most favourably oriented fractures, set (x).

Figure 4. *Fault movements and fracture relations.*

(A) *Fault movements. Each arrow represents independently determined movement in a fault surface and along a line which cuts the lower hemisphere of the equal-area projection at the tail of each arrow. Inwardly directed arrows represent reverse movement and outwardly directed arrows represent normal movement.*

(B) *Fracture relations. Lower-hemisphere equal-area projection of the planes of fracture sets and shears, showing spatial relations.*



STRUCTURAL CONTROL OF MINERALIZATION

Known Localization

No reason is yet apparent for localization of the bulk of the ore within the main N75°W mineralized zone. Some of the orebodies tend to favour contacts between different phases of the ultrabasic-diorite complex, but the localization of most of them is not apparent. Similarly, in a number of localities disseminated mineralization is localized along margins or contacts of bodies of bronzitite, hornblendite, peridotite, or norite within the general pyroxenitic mass, but in a greater number of cases the reason for its distribution again is not apparent. In a few localities replacement patches and disseminations of sulphides do appear to be localized along or near zones of fracturing or faulting.

Fracturing has clearly localized much of the small-scale mineralization, most of which appears to be a dying phase which cuts the ore or mingles with it. This mineralization consists of (a) a few discontinuous pyroxenite-hornblendite-sulphide veins or dykes, and bands of sulphides; and (b) veinlets and replacement patches or beaded stringers of sulphides, with accompanying alteration.

Possible Reasons for Localization

Cockfield and Walker (2) thought that the linear distribution of mineralization suggested control by fracturing, shearing, or jointing. Such control could apply with either injection or replacement origin of the ore. If the ore were injected as molten sulphides, such injections could have been localized by weak contacts, by incompletely crystallized rocks, by strained localities, by fractures, or by other dissimilarities of the rock. Similarly, if the ore were formed by high-temperature replacement and conversion, the individual orebodies may have been localized by steeply-dipping lineation, by permeable zones, or by intersections of steep fractures with shears, contacts, or other planar structures.

The high-temperature ore-forming process, especially if it were replacement-conversion, would have been intense enough to obliterate any obvious sign of most types of controlling structures in and near any strong mineralization. Nevertheless, even if ore-controlling structures were obliterated, the observable fracture patterns might provide some clue to possible control by earlier fracturing, provided that the same tectonic environment persisted. For example, a strong northwest-trending shear zone (Figure 4B) in the eastern part of the ultrabasic mass strikes parallel to the main mineralized zone and dips parallel to the probable plunge of ore within it. The general N75°W structural trend of the main mineralized zone therefore may reflect a similar underlying, northward-dipping shear which served as a feeder for the mineralization. Intersections of set (y) fractures with such a shear zone or with east-west contacts or other planar structures may have localized some of the ore.

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CANAM DEPOSIT*

by W. R. Bacon†

THE CANAM property is in southern British Columbia, 24 miles southeast of Hope. It is reached by 5 miles of road from Mile 26 on the Hope-Princeton Highway.

Between the years 1930, when the property was discovered, and 1938 development work by The Consolidated Mining and Smelting Company of Canada, Limited included some open-cuts and six adits totalling 2,700 feet in length. Canam Copper Company Ltd. explored the property intermittently from 1947 to 1955 by diamond drilling and underground work, including driving No. 10 adit. From surface down to the level of No. 10 adit, about 1,250,000 tons of ore has been outlined with an approximate grade of 1.25 per cent copper, 0.8 ounce silver per ton, and 0.01 ounce gold per ton. The ore in the upper part of the deposit also contains a little molybdenum and a little uranium.

In June, 1955 Canam Copper Company Ltd. made arrangements to have the property brought into production under the direction of Mogul Mining Corporation Ltd. of Toronto, and a new low level adit has been started.

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†Geologist, British Columbia Department of Mines.

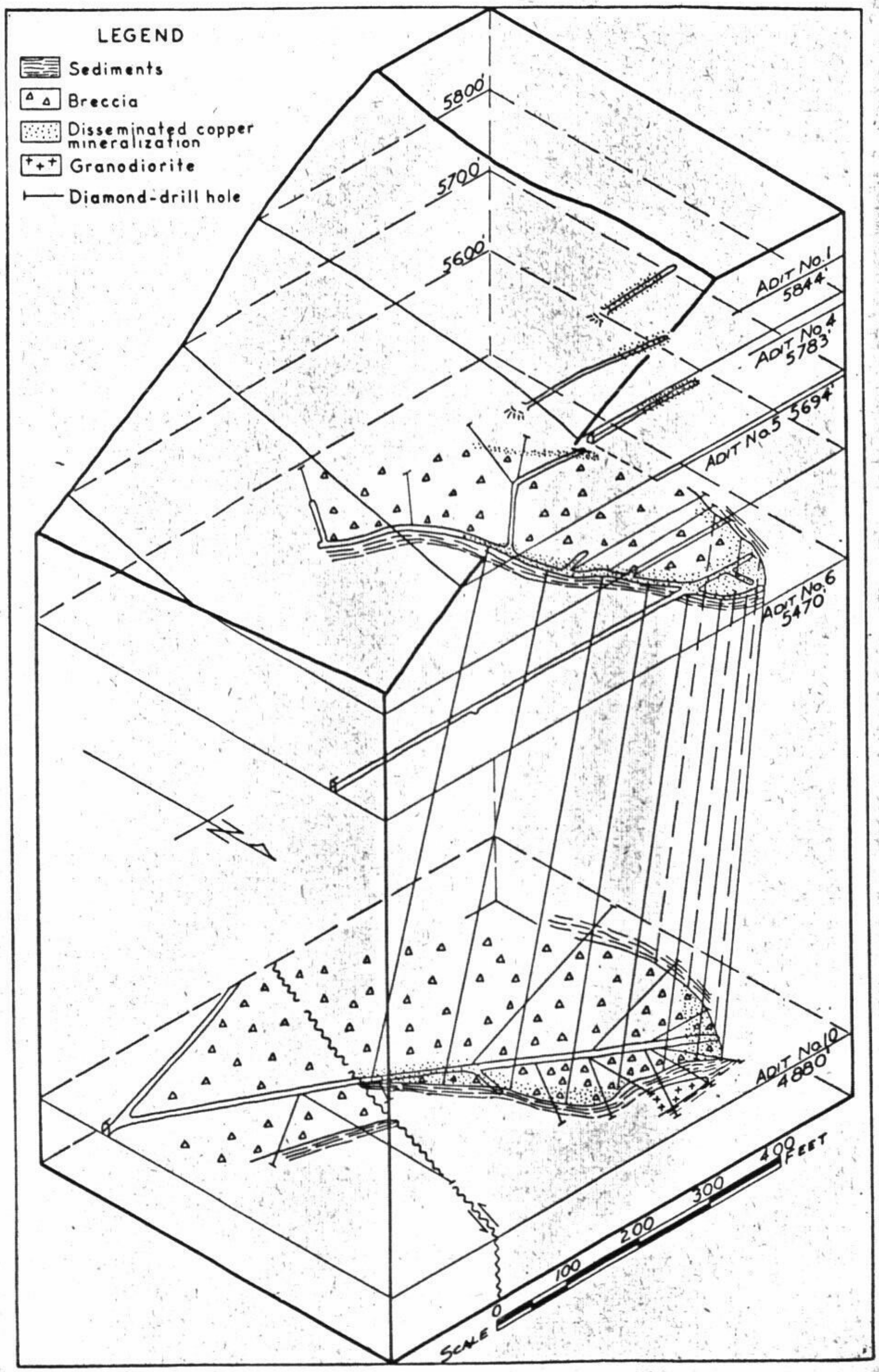

Figure 1. Isometric diagram of Canam deposit.

GENERAL GEOLOGY

The principal rocks on the Canam property are chert, cherty argillite, and argillite. They are considered to be Jurassic or Lower Cretaceous in age. Although massive bands to 150 feet in thickness occur, these rocks are in general thinly bedded. Conformable bands of pyrrhotite, a fraction of an inch in thickness, are not uncommon in the well-bedded rocks, and fine tourmaline can be observed in various places.

The sediments strike slightly west of north and dip quite steeply, generally eastward; however, sharp divergences from this general attitude are fairly common.

Dark grey dioritic sills, in which slender prismatic crystals are conspicuous, are fairly common in the sediments. In general the sills are less than 25 feet in thickness, but a few are as much as 100 feet thick. Under the microscope the sills are seen to consist largely of amphibole (pargasite) and plagioclase (near An50).

The Invermay quartz diorite stock outcrops 2,000 feet north of the workings. It intrudes the sediments. Tourmaline occurs in joints and fractures in the quartz diorite and is particularly conspicuous where the intrusive is brecciated.

A steeply dipping mass of granodiorite is exposed in the No. 10 adit, between 1,640 feet and 2,215 feet from the portal. Between 1,640 feet and 1,800 feet this rock is strongly sheared. Tourmaline occurs in some of the fractures.

Breccia outcrops of reddish brown to brown colour are a prominent surface feature. The area of breccia outcrops is roughly elliptical; the longitudinal axis trends northwestward and is about 1,100 feet long. The lesser axis is about 450 feet. Exploration has been carried to a point where it seems reasonably safe to assume that this area is largely, if not entirely, underlain by breccia.

The breccia consists of angular to subrounded fragments of sedimentary rock in a matrix of secondary minerals. The fragments are of sedimentary material identical with the rocks that surround the breccia outcrop area. Approximately 90 per cent of the fragments are less than a foot in length, and many measure less than 6 inches. Of the remainder, few are more than 3 feet in length, but several larger blocks of unbrecciated rock within the brecciated zone have been partly exposed by the underground workings.

The subrounded outline of certain of the fragments is clearly the result of replacement. Light grey to greenish alteration rims are fairly common around darker cores. Some of the smaller fragments are fractured and veined by minerals of the matrix. Tourmaline occurs sporadically in matrix and fragments.

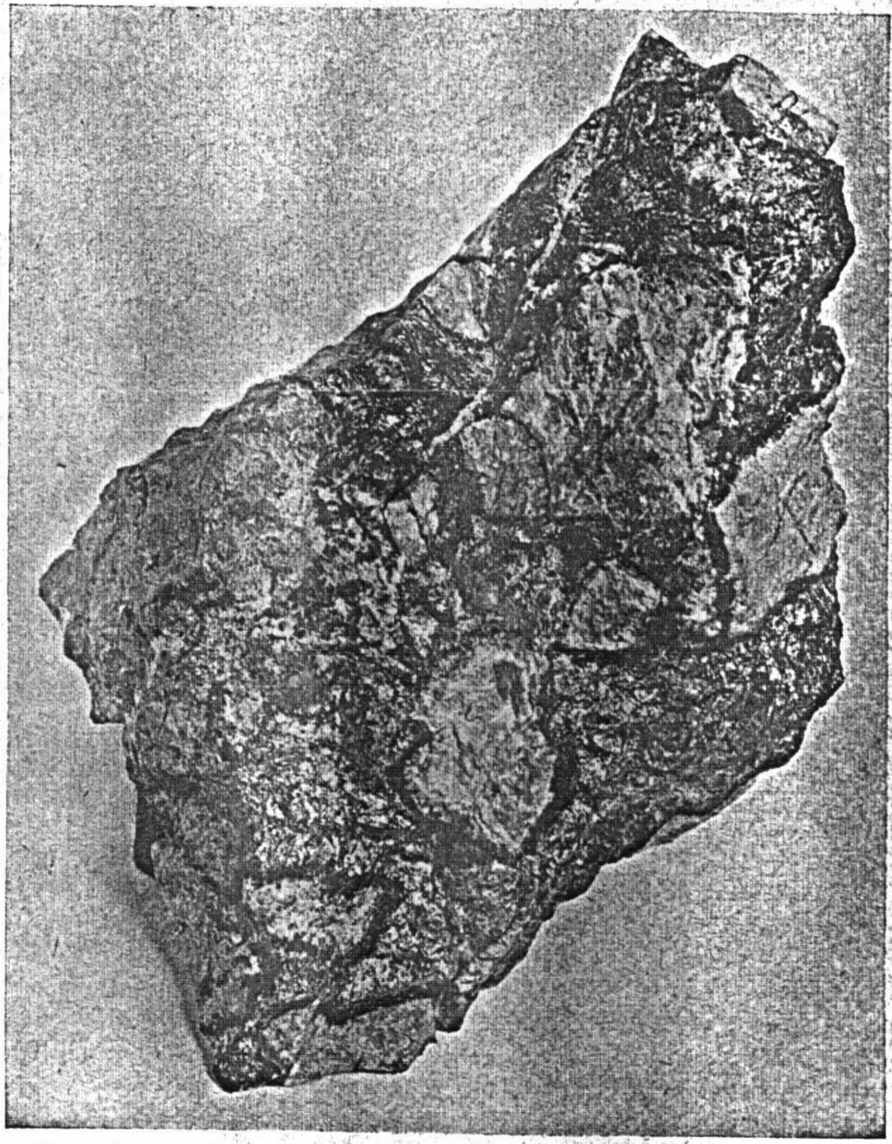

Figure 2. Canam ore. Sedimentary fragments are rimmed by tourmaline (dark). Shiny interstitial material is largely chalcopyrite. (B.C. Govt. photo.)

The matrix presents a variable appearance. In the upper adits (Nos. 1 to 7) it is commonly light grey in colour and appears to consist largely of quartz, chlorite, carbonate, alkali feldspar, white mica, and kaolin. In the

No. 10 adit, however, the matrix is generally dark green, due to a predominance of chlorite.

THE DEPOSIT

The breccia is the host rock for the Canam deposit. Chalcopyrite, pyrrhotite, and pyrite are the most abundant minerals. Smaller amounts of magnetite, molybdenite, uraninite, dark brown sphalerite, and arsenopyrite, and minute amounts of galena and scheelite occur sporadically. With the exception of arsenopyrite, these minerals are confined to the matrix of the breccia. Arsenopyrite occurs mainly in the matrix, but at the northern extremity of No. 10 adit it was found within fragments. Although clearly an introduced mineral, the magnetite is not closely associated with the sulphides.

The molybdenite and uraninite are closely associated spatially.

Some of the better grade ore has a striking appearance. Black tourmaline may be found rimming the barren fragments, accentuating the brecciated nature of the host rock, and the interstitial material consists largely of chalcopyrite and pyrrhotite. These sulphides are intimately associated, the chalcopyrite veining and replacing pyrrhotite.

Although mineralization has been found elsewhere in the breccia, the main Canam deposit occurs in the northwestern part of the breccia mass, around its periphery (*see* Figure 1). The mineralization gradually weakens toward the centre of the breccia, much of which is essentially barren. The deposit is roughly U-shaped in plan; the outer margin is sharply defined, being the abrupt contact between barren unbrecciated sediments and mineralized breccia, whereas the inner boundary of the deposit is an "assay wall".

STRUCTURAL CONSIDERATIONS

Because economic mineralization has been found only in the breccia, it is important, particularly with respect to possibilities at depth, to consider the probable origin of the breccia. The following facts should be taken into account:

1. The apparent outline of the breccia strongly indicates a pipelike form.
2. The breccia fragments are of sedimentary material identical with the sediments that enclose the breccia mass in plan.
3. Where exposed, the contact between breccia and surrounding sediments is sharply defined.
4. There is no diminution in brecciation toward the periphery of the breccia mass; on the contrary, abundant fragments can be noted in several places within inches of the periphery.

5. Where it can be observed, the bedding in the sediments adjacent to the deposit parallels the periphery of the breccia.
6. Brecciation in the Invermay stock, crushing of the granodiorite tongue in No. 10 adit, and the presence of innumerable faults in the workings all testify that great stresses have been operative, not only in the vicinity of the deposit but in the area as a whole.

Although the form of the breccia mass might suggest a mode of origin related to explosive igneous activity, the evidence is inadequate to substantiate this theory, and facts 3, 4 and 5 are hardly compatible with such an origin.

Fact 2 does not suggest that a distinct horizon in a layered sequence alone yielded by brecciation during folding. It is obvious, however, that the shape of the breccia mass has been modified by deformation.

Because of the occurrence of slickensides along parts of the breccia-sediment contact and of a great many faults in the workings, a theory of origin related to faulting merits consideration. It would be difficult, however, to reconcile such a theory with the rather smooth horizontal outline of the breccia as it is known, or with the conformability of breccia and adjacent sediments.

The theory of origin that would seem to be consistent with most of the evidence involves an originally fragmental horizon, i.e., a sharpstone conglomerate or intraformational breccia. Possibly the breccia mass is a fanglomerate or fossil talus slide. Such a theory is entirely acceptable, however, only if the conformability of breccia and sediments is either overlooked or considered accidental in the few places where it is possible to observe this feature.

Deformation in the area has been intense and, although the breccia as a whole is not considered to be a product of deformation, there is evidence that a minor amount of fragmentation was caused by stresses. Innumerable faults, in addition to fractures in the matrix of the breccia, are evidence of considerable adjustment to stresses.

Whatever the precise origin of the host rock, the Canam is an example of a widely recognized type — the breccia-filling deposit. The locus of the mineralization indicates that parts of the contact between breccia and sediments formed an important channelway for the mineralizing solutions. There is no obvious concentration of mineralization along any of the known faults.

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