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Discovery, Geologic Setting and Style of Mineralization, Sam Goosly Deposit, B. C.

CHARLES S. NEY, Chief Geologist, and
JOHN M. ANDERSON, Project Manager,
Kennco Explorations, (Western) Limited,
Vancouver, B.C.
ANDRE PANTELEYEV, Dept. of Geology,
University of British Columbia,
Vancouver, B.C.

ABSTRACT

Sam Goosly prospect, 22 miles southeast of Houston, B.C., was discovered in 1967 through geochemical reconnaissance. Soil sampling interpreted with respect to an east-to-west ice movement led to drilling targets.

Mineralization is in a window of rocks thought to be Hazelton Group surrounded by Tertiary volcanic rocks and intruded by two stocks separated by about one mile. A westerly quartz monzonite stock is dated 61.1 m.y. and an easterly gabbro-monzonite complex is dated 52.5 m.y. The Tertiary volcanics are trachyandesites shown by the B.C. Department of Mines and Petroleum Resources to be in part extrusive equivalents of the gabbro, and they overlie Hazelton rocks unconformably.

Copper-molybdenum mineralization is sparsely developed in the westerly stock. Silver-copper mineralization forms an elongate west-dipping slab between the stocks in Hazelton rocks, which are continuously pyritized. The gabbro stock is not mineralized, but some dikes related to it are slightly so. Tertiary rocks are pyritized, but are not known to carry copper-silver mineralization.

Hazelton rocks are divided into a lower conglomerate, an intermediate pyroclastic unit and an upper mainly sedimentary unit. They form a west-facing homocline. Copper-silver mineralization resides in the pyroclastic unit, mainly in a massive dust tuff through which are lenticular units of lapilli tuff. Well-mineralized rock is typically a breccia of light fragments in a dark chlorite-sulphide matrix. Sulphides are pyrite, chalcopyrite and locally pyrrhotite, with very minor tetrahedrite, sphalerite and other sulphosalts. Rock alteration is predominantly a pervasive pyrite-sericite type, with widespread tourmaline, scorzalite, gypsum, ankerite and traces of fluorite.

The most evident control of the copper-silver mineralization is the gross parallelism, over a strike length of 1.5 miles, to Hazelton strata, particularly a massive dust tuff unit. In detail, mineralization crosscuts bedding and there is no appreciable banding within sulphides. A strictly syngenetic origin is untenable, but some initial concentration in a volcanogenic environment with subsequent modification by thermal processes seems likely.


C. S. NEY


J. M. ANDERSON


A. PANTELEYEV

C. S. NEY was born at Britannia, B.C. and graduated in geology from the University of British Columbia. He spent several years at the Monarch mine at Field, B.C. in Yoho National Park. He has been employed for some years by Kennco Explorations, (Western) Limited, and is currently chief geologist.

J. M. ANDERSON was born in Powell River and graduated in geology from the University of British Columbia. He has worked for Kennecott Copper Corporation in mineral exploration in Puerto Rico, Arizona and Nevada, as well as British Columbia. He is now exploration project manager for Kennco Explorations, (Western) Limited.

A. PANTELEYEV, born in Latvia, graduated in geology from the University of British Columbia, and is now studying for his Ph.D. degree at U.B.C. He worked as a geologist for several seasons with Kennco Explorations, (Western) Limited and recently accepted a post with the British Columbia Department of Mines. His interests are in mineral deposit geology.

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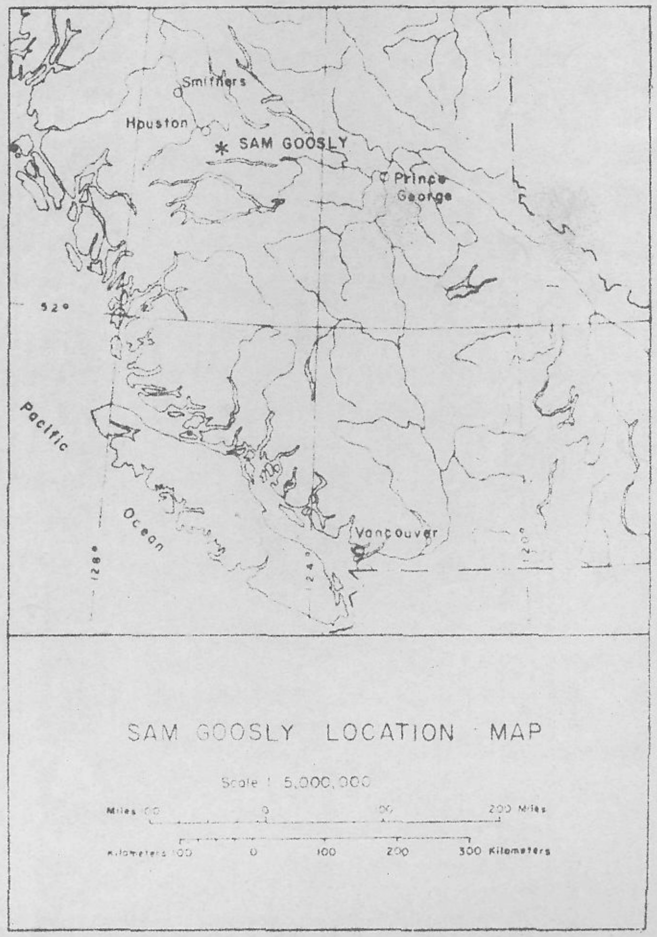

FIGURE 1 — Location Map.

INTRODUCTION

SAM GOOSLY is the name given to a recently discovered copper-silver deposit 22 miles (35 km) south of Houston, B.C., currently being investigated by Kennco Explorations. [illegible] is situated on a timber-covered upland of gentle relief at an elevation of 4300 feet (1300 m and is accessible by motor road from Houston.

This paper will discuss the mode of discovery, the geologic setting and the style of mineralization, and

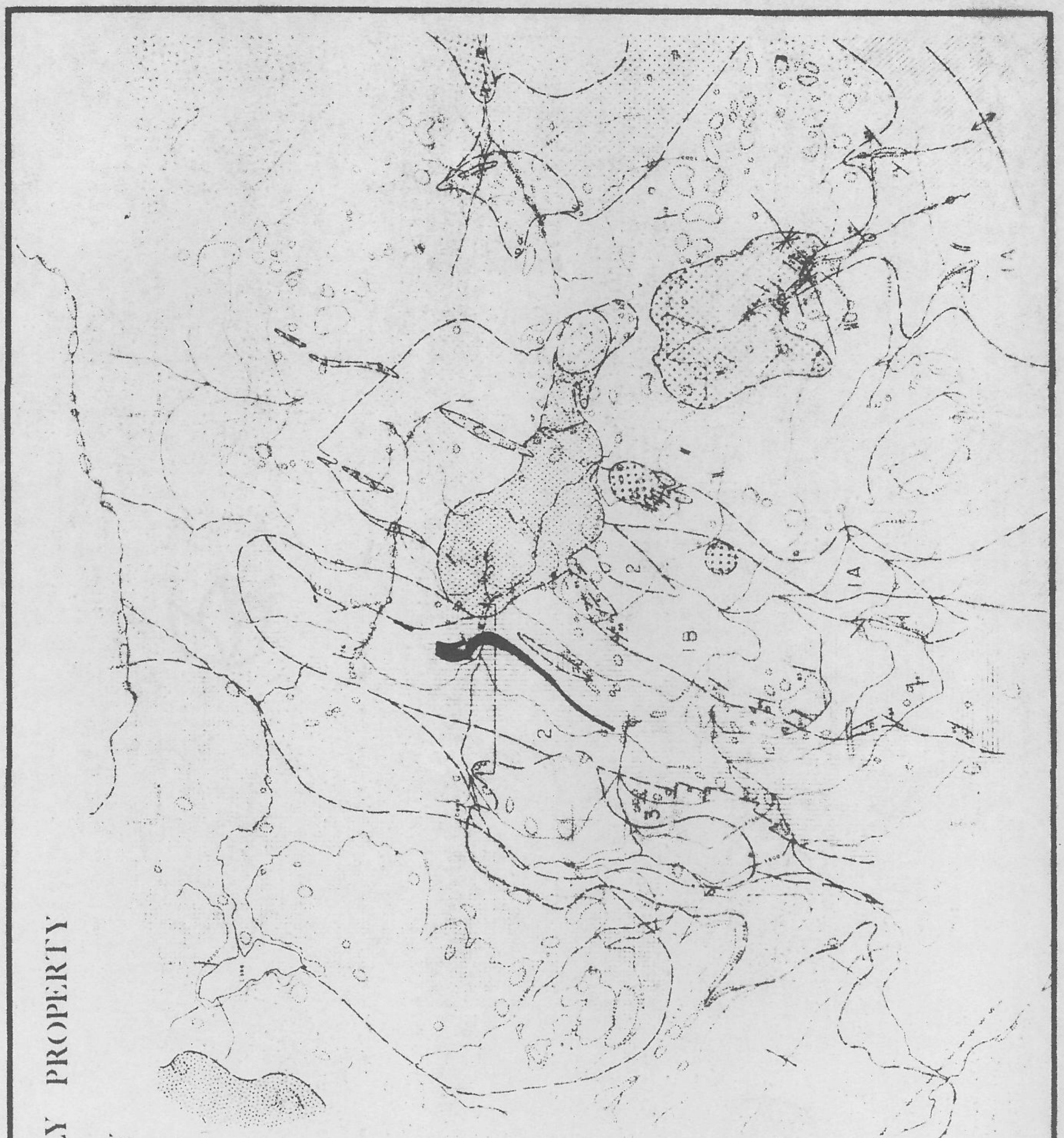

FIGURE 2 — Geology.

will present an opinion on the genesis of the deposit. Contributions of the three authors intermingle: Anderson, as project manager on the property, was largely responsible for drill-hole geology; Panteleyev mapped surface geology, and in preparation for this paper produced photographs of slabs and sections of rock and ore; Ney provided advice and acted as collator of information.

Many others, formerly or currently associated with Kennco, contributed ideas and assistance. At an early stage of development, Richard Nielsen of Kennecott's Geologic Research Division made a highly perceptive geologic study. A. Mariano of Kennecott's Ledgemont Laboratory performed mineralogical studies of rocks and ores, and J. A. Gower's petrographic guidance was extremely valuable. H. W. Fleming's interpretations of induced polarization surveys provided valuable geologic data. In the logging of drill core, U. [illegible]achowski showed the importance of sedimentary detail in interpreting this type of deposit. Maps were drafted by J. Lum.

Several others outside Kennco provided impetus to geologic studies. A. Sutherland-Brown and N. B. Church of the B.C. Department of Mines and Petroleum Resources were prompt in deciphering and appraising the district geology in its relation to Sam Goosly and other deposits. H. W. Tipper of the Geological Survey discussed geological problems that brought the district into perspective with regional geology.

Kennecott Copper Corporation at all times backed this study with encouragement and the best of research facilities. Their support and permission to publish this paper are gratefully acknowledged.

HISTORY OF DISCOVERY

The discovery of copper-silver mineralization at Sam Goosly was a team effort in which the ideas and actions of many people were involved. Conventional prospecting, geochemistry and Pleistocene geology all played a part. There is no indication that this deposit was previously known and it is sobering to reflect on how easily mineralization may be obscured in nature.

In 1961, Kennco undertook regional geochemical surveys in the Central Interior of B.C. In the Houston area, particular note was taken of a window of Hazelton rocks surrounded by Tertiary volcanic rocks, shown on Geological Survey of Canada Map 671A (scale 1: 253,440), issued in 1942. The sediments of a stream east of Goosly Lake were found to be slightly anomalous in zinc and copper. With other priorities, nothing was done with the information at that time. Sometime later Kennco's geochemist, J. Barakso, suggested that the use of fluorine in prospecting should be investigated. He set up a method for the routine analysis of fluorine, and tried it on a number of geochemical samples, including some from the Houston area. Sediments from the same creek that was slightly anomalous in zinc and copper, also proved anomalous in fluorine, with a value of 635 ppm in comparison with a local background of 400 ppm.

On the basis of these few geochemical facts, a definite program to investigate the area east of Goosly Lake was launched in 1967. Prospecting disclosed evidence of quartz monzonite containing chalcopyrite in the drainage of the anomalous creek and claims were located. Pyritized volcanic rocks, and at one point an occurrence of tetrahedrite, were recorded by a geologist-prospector. Much of the upland country away from stream valleys appeared to be continuously soil-covered, so a reconnaissance grid of soil samples spaced at 500-foot (152-m) intervals on lines 2000 feet (610 m) apart was immediately run. This survey yielded broad areas of copper and molybdenum anomalies and the sampling grid was tightened to 100 x 400 feet and eventually to 100 x 200 feet in particular areas.

Testing of the samples for silver revealed a large anomaly, partly coincident with the copper and molybdenum but also extending broadly to the northeast. The high silver values were first regarded with suspicion, and were closely checked by re-analysis. It was even suggested that the soil might have been contaminated by silver iodide from rain-making activities, but a quick calculation convinced us that this was unreasonable in view of the amount of silver in the soil.

The principal copper-molybdenum anomalies were investigated by trenching and a weak porphyry-type mineralization was found in the quartz monzonite, much as had been anticipated from initial prospecting indications. The trenches also showed that the quartz monzonite was cut by many basic porphyry dykes and was traversed axially by a zone of faulting. In this zone there are sheared dykes and at one point a small lens of silver-bearing material. A few fragments of float containing massive pyrrhotite, chalcopyrite, sphalerite and silver values were found in the course of trenching the area underlain by quartz monzonite.

Meanwhile, small pits were put down on the tetrahedrite occurrence a mile to the northeast of the quartz monzonite. They showed that some very unobtrusive pyritic tuff contained appreciable silver values over widths of several feet.

Examination of the trench walls in the quartz monzonite showed that much of the silver soil anomaly was clearly not related to the underlying bedrock but was in glacially transported material. Some resistant dykes exposed in the trenches showed glacial smoothing in a direction from ENE to WSW. A check of local air photos confirmed that such movement could have occurred, but it was contrary to expectations. Most other evidence in the district indicated that ice transport had been toward the northeast, away from the Coast Mountains.

It was then concluded that the silver anomalies were for the most part ice-transported from a source area lying to the northeast of the quartz monzonite, probably where tetrahedrite had first been observed. Drilling based on this hypothesis was successful in outlining a mineralized zone. Eventually, as details were filled in (Fig. 3), a very close correspondence was obtained between the up-ice cutoff in soil sample values and the projected surface trace of mineralization. Several holes to the west of the mineralized zone, drilled on apparently good geochemical soil anomalies, failed to locate mineralization.

Together with geochemical exploration of the property, an extensive geophysical program was conducted, including airborne magnetic and EM surveys, ground magnetic and I.P. surveys. Magnetic patterns show a 'high' over intrusive rocks east of the mineralized zone, having no direct obvious correlation with mineralization. I.P. surveys were valuable in outlining broad areas of sulphide dissemination, and they provided data useful to the interpretation of general geology, but they did not specifically indicate valuable mineralization.

GEOLOGIC SETTING

Copper-silver mineralization occurs as a tabular composite zone within and grossly conformable with a steeply dipping sequence of volcanic and sedimentary rocks. These rocks are presumed to belong to the Hazelton Group of Jurassic age. They outcrop within a window a few square miles in extent, somewhat as had been indicated by the Geological Survey (Lang *et al.*, 1942), with a separate area to the southeast. The southern boundary is suspected to be a fault, but elsewhere the window is flanked by gently outward-dipping feldspar porphyry volcanics of Ootsa Lake Group age, described and named Goosly Lake Volcanics by Church (Church, 1969). They are succeeded by younger Endako Group volcanics in the west.

There are two principal intrusive masses in the 'window'. The one in the west is a quartz monzonite stock initially investigated for disseminated copper-molybdenum mineralization. The one to the east is a complex body that varies from gabbro to monzonite, and is thought to have a close genetic relationship to the Goosly Lake Volcanics. Initially, it was suspected to be closely related to mineralization.

Figure 2 shows the general geologic setting.

HAZELTON G UP

Within the panel between the two intrusive stocks, the Hazelton strata strike fairly consistently N25°E and dip steep westerly to vertical. The section is believed to be a simple homocline with tops facing west, although unequivocal evidence of tops, even in drill cores, is hard to obtain. The southeasterly area of Hazelton shows northeast-plunging syncline-anticline structure.

Three stratigraphic divisions are distinguished. Going up section from east to west across the property they are: (1) Coarse Clastic Division, (2) Pyroclastic Division and (3) Sedimentary-Volcanic Division. They are illustrated diagrammatically in Figure 4. Thicknesses of the divisions vary greatly through the map area, and those shown in the column are approximate *maximum* values. The approximate range is also shown, over which mineralization was observed within the Pyroclastic Division.

Coarse Clastic Division (1)

The Coarse Clastic Division is predominantly a moderately sorted conglomerate composed of sub-

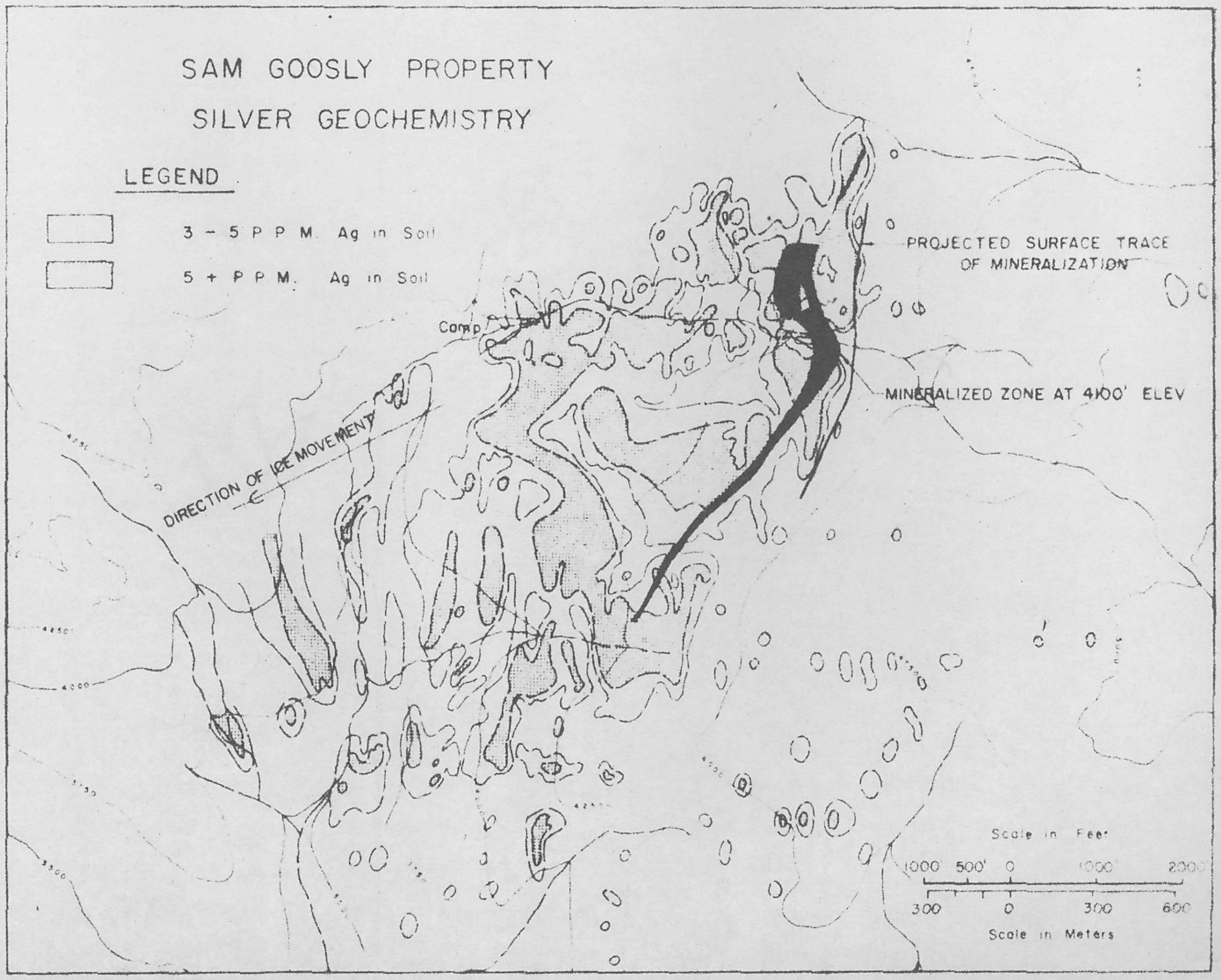

FIGURE 3 — Silver Geochemistry.

rounded clasts 5-30 cm in diameter of a variety of rock types. Feldspathic volcanic rocks are most common, sandstones and cherty quartz are present, but no plutonic rocks have been identified. Some beds in the division are composed entirely of epiclastic volcanic fragments and there are some beds of finely banded tuff. Low down in the section there is a marker sequence of distinctly reddish colored beds with dacite fragments. Some typical specimens are shown in Figure 6.

In field mapping a separation was made into a lower unit 'A', which is typically polymictic with diverse clasts in a greywacke matrix, and an upper unit 'B' which is a more mature rock composed predominantly of chert pebbles.

Rocks of this division are exposed widely on the east side of the main window and in the southeasterly window, separated from the main area by a belt of Goosly Lake Volcanics. The red bed marker occurs just east of this belt.

The division is clearly variable in thickness and interfingers with the succeeding Pyroclastic Division. From the known distribution and sparse understanding of structure it is apparent that the thickness may be as much as 8000 feet. The source direction is thought to be from the south; that of the overlying volcanic units appears to be from the North.

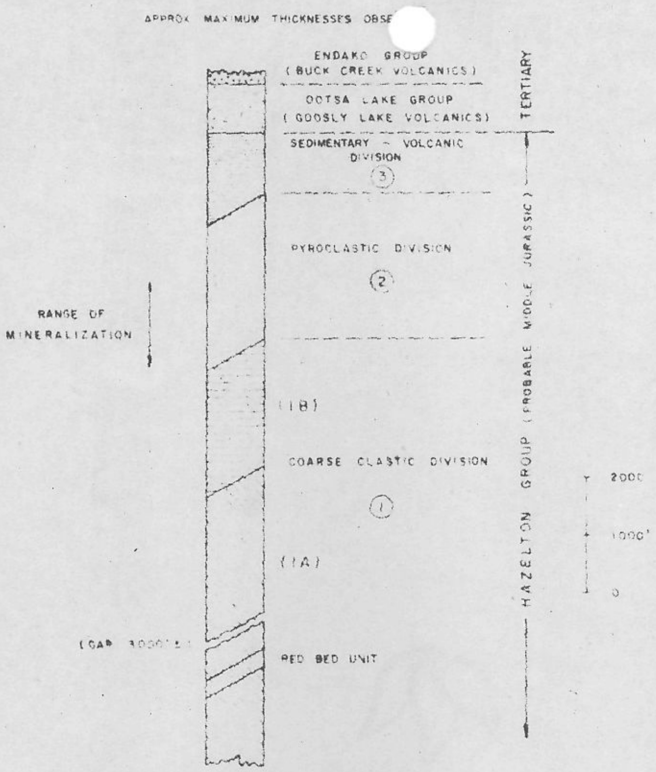

FIGURE 4 — *Stratigraphic Column.*

Pyroclastic Division (2)

The boundary between Divisions 1 and 2 is arbitrarily placed where tuffaceous or volcaniclastic material becomes predominant in fragmental rocks. The change is accompanied by a noticeable increase in the proportion of chert fragments and the assumption of a deep green chlorite colour by the matrix. At this point in the stratigraphy, the sulphides pyrite, pyrrhotite and chalcopyrite become noticeable as weakly disseminated accessory minerals in the tuffs. Typical pyroclastic material, as shown in Figure 7, contains pyrite and chlorite in the coarser laminae, and in Figure 8 a dust tuff with ash and lapilli fragments is seen to contain angular particles of pyrrhotite and chalcopyrite.

The Pyroclastic Division contains most of the known mineralization and as a consequence has been studied extensively in drill core. In logging core an early distinction was made between dust, ash, and lapilli tuff and volcanic breccia, according to size boundaries of 0.5 mm, 5 mm and 50 mm. It is not always certain that all such material is truly pyroclastic in origin. Mate-

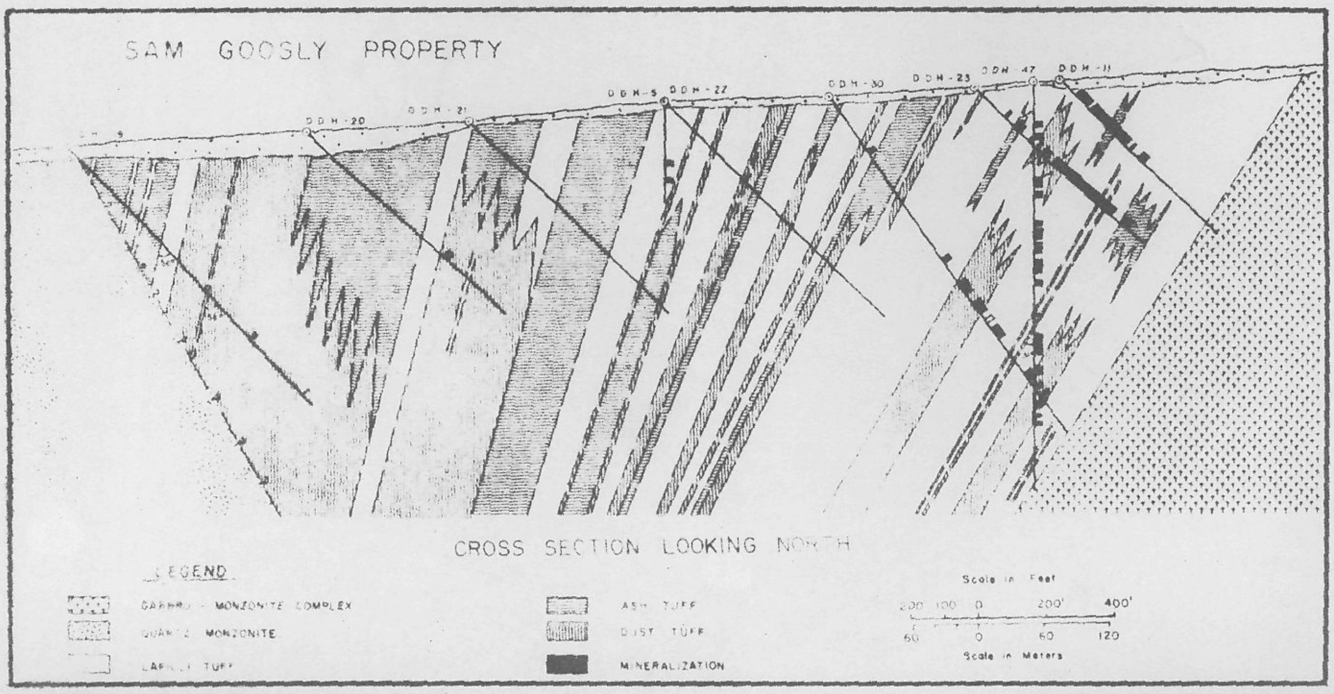

FIGURE 5 — Cross Section.

rial logged as lapilli tuff can be in bands only a few cm wide, accompanied by alteration, and suggesting a mode of origin similar to that of a pebble dyke. Much lapilli tuff is a mosaic breccia of lithified dust tuff fragments, which may have originated by slumping. Much of the Division is dust tuff, and it occurs in sections which are peculiarly massive for many tens of feet without change of grain size or recognizable bedding. Much of it has a reticulate fracturing, with dark hairlines containing hematite and fine sulphides, which may progress into breccia. Material of ash size is a relatively minor component of the Division. Units with fragments of breccia size are likewise common.

Lapilli tuff units are most important as specific host rock for copper-silver mineralization. An early recognized and dependable guide to mineralization is tuff or breccia with light felsitic fragments in a dark sulphide matrix (Fig. 15).

Some units within the Division are epiclastic with subrounded fragments — sometimes of clean chert, sometimes in considerable variety with a muddy matrix (Fig. 9, left). In some cases all the fragments are rhyolitic (Fig. 9, right). The latter rock may be derived by collapse or brecciation of rhyolite structures rather than by accumulation from fragment showers. Muddy epiclastics resemble the subaqueous flows described by Fiske in the Ohanapecosh formation of the Mt. Rainier area in Washington (Fiske, 1963).

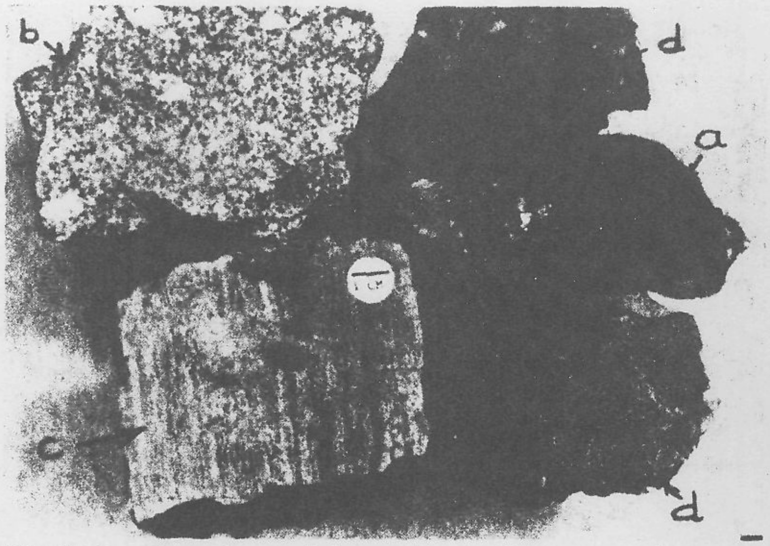

FIGURE 6 — Rock Types of Coarse Clastic Division.
(a) Typical conglomerate with clast of sandstone
(b) Epiclastic with felsic volcanic fragments
(c) Finely bedded tuff
(d) Red bed marker unit with dacite fragments.

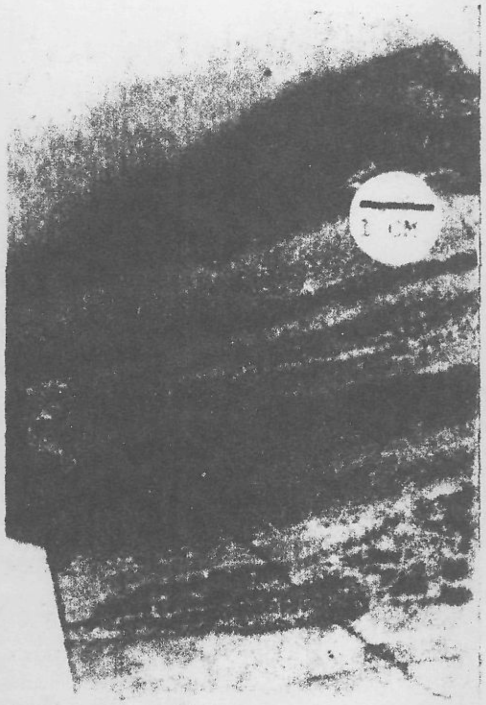

FIGURE 7 — Pyroclastic Division. Typical bedded pyroclastic with pyrite and chlorite in dark colored coarser laminae.

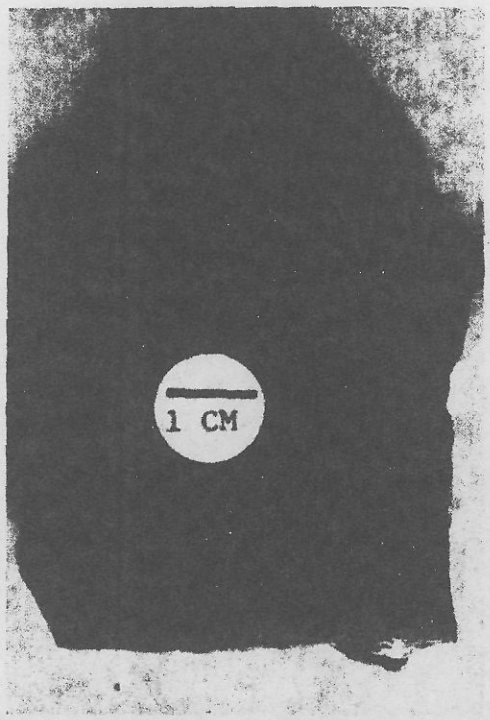

FIGURE 8 — Pyroclastic Division. Dust tuff, some ash, angular particles of pyrrhotite, clots of chlorite, and chalcopyrite.

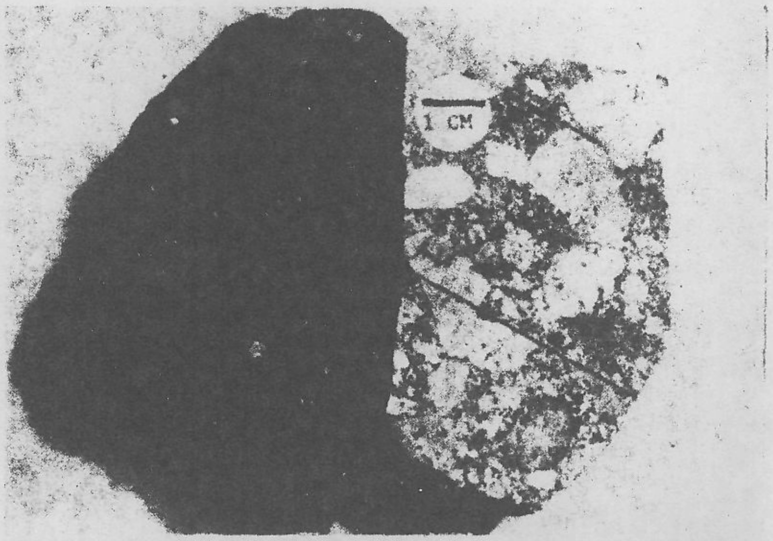

FIGURE 9 — Pyroclastic Division. Left — epiclastic with a variety of fragments in muddy matrix. Right — epiclastic with rhyolite fragments containing dark quartz phenocrysts.

Volcanic-Sedimentary Division (3)

The boundary between the Pyroclastic Division and the Sedimentary-Volcanic Division is arbitrarily taken where good bedding becomes prevalent. The materials are largely tuffaceous in origin, but include argillite, cherty argillite, quartzite and pebble conglomerate intercalated with varying amounts of tuff, all of which, in contrast to the underlying massive dust tuffs, are abundantly bedded, often graded and clearly deposited in an aqueous environment. The rocks of the Division have been seen mostly in drill cores.

An east-west cross section from drill holes (Fig. 5) shows the complexity of the Pyroclastic and the Sedimentary-Volcanic divisions. Little correlation of lapilli tuff units has been possible. Rapid changes of thickness and facies of pyroclastic units must be assumed. There is a general tendency for lapilli tuff and breccia units to wedge out downward in this section. Attemps made to interpret core-bedding intersections as flat, rather than steep dips, did not give convincing results.

In plan (Fig. 1), units also wedge rapidly and a tendeney is seen for volcanic clastics to wedge out toward the south, whereas sedimentary clastic units increase in this direction.

INTRUSIVE ROCKS

Seven principal phases of intrusive rock are recognized in the map area, one a separate stock, the other six being part of a complex stock. The distribution of these types is diagrammatically illustrated in Figure 10.

Quartz Monzonite

The stock exposed in the western part of the 'window' area has a fairly consistent composition of quartz monzonite, with phaneritic texture and medium grain size. The polished slab illustrated in Figure 11 is typical. It was stained to show potash feldspar not distinguishable in black and white but amounting to 20 per cent of the rock in smaller grains between the large subhedral plagioclase and the dark areas of quartz and biotite.

External contacts of the stock were seen only at the north end and in the westerly drill hole of the section illustrated in Figure 5 where members of the sedimentary-volcanic division are altered to hornfels for a few tens of feet.

The western contact is covered and the stock may be extensively overlapped by Goosly Lake volcanics.

Evidence of mineralization in the stock is widespread but weak. At the north end there is extensive fracturing, sericitization and copper-molybdenum mineralization that initially attracted attention. At another locality toward the south end there are veinlets containing tetrahedrite. Along the axis there is a north-trending zone of faulting in which sheared dyke rocks are involved and at one point a small lens of silver-bearing sulphide was found.

Gabbro-Monzonite Complex

This irregular composite stock on the eastern side of the 'window' initially presented an aspect of deceptive uniformity due to coarse, bladed plagioclase feldspars nearly always in trachytoid alignment. It soon acquired an array of names — monzonite, syenomonzonite, diorite and gabbro, and mapping combined with feldspar staining showed that all these phases are present so that the term 'complex' was designated.

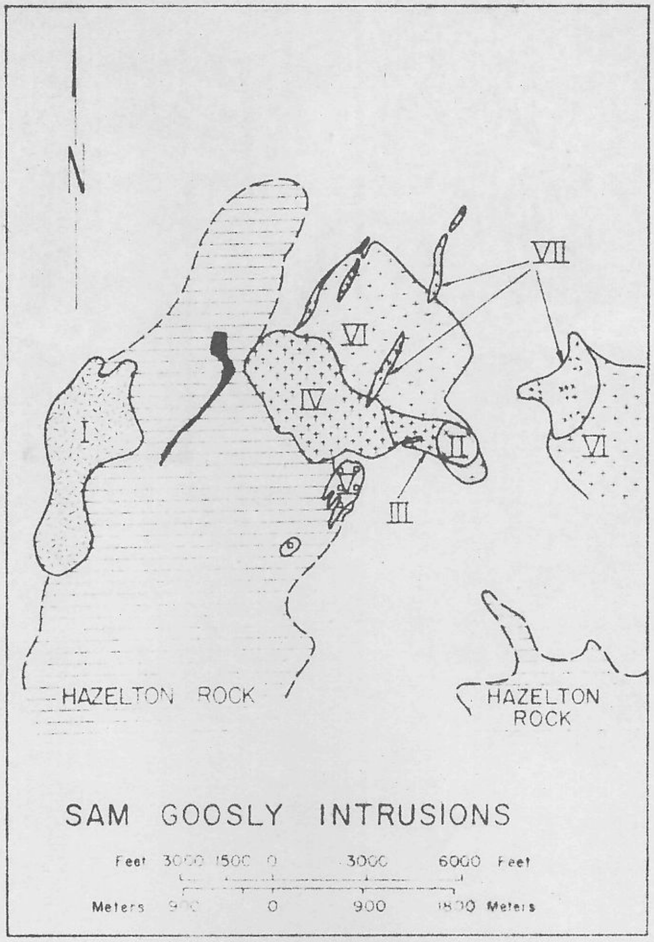

FIGURE 10 — Sam Goosly Intrusions.

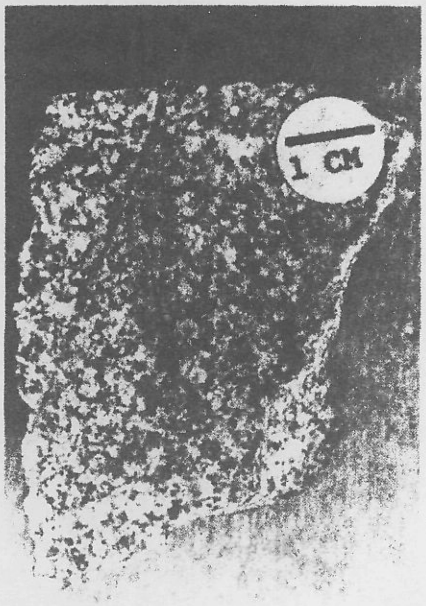

FIGURE 11 — Quartz Monzonite. Stained K-feldspar amounts to 20 per cent in smaller grains between large subhedral plagioclase and dark areas of quartz and biotite.

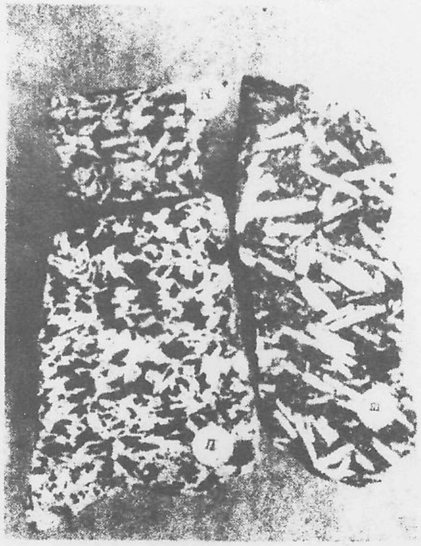

FIGURE 12 — Phases of Gabbro-Monzonite Complex, etched and stained.
II Pyroxene-labradorite gabbro
III Intermediate Phase, between monzonite and gabbro
IV Main phase, monzonite.

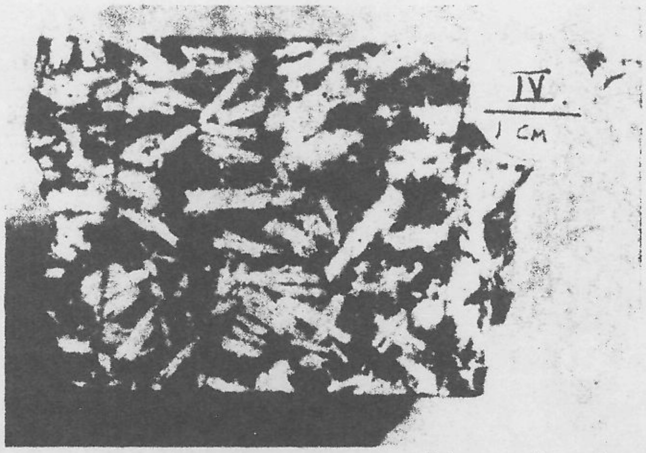

FIGURE 13 — Main Phase Monzonite, IV, stained to show gray K-feldspar clustered between lighter colored andesine laths and darker pyroxene-biotite matrix.

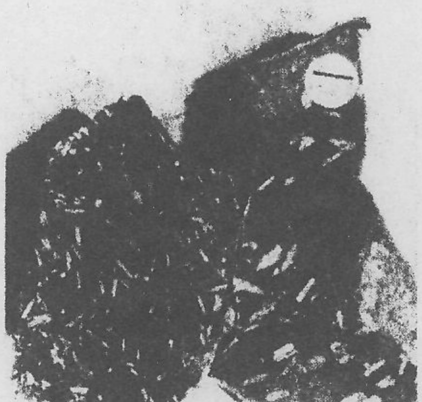

FIGURE 14 — Goosly Lake Volcanics — trachyandesite dyke on right and pyroxene trachyandesite flow on the left.

In two other aspects the Complex is distinctive: the presence of biotite as a mafic mineral even in basic phases, and an anomalously high apatite content of 5 to 8 per cent. Magnetite may amount to 10 per cent of the rock in some cases, and the response of the Complex to aeromagnetic surveys was considerable.

A small part of the Complex has the composition of true gabbro (II) in being a pyroxene-labradorite rock, illustrated in Figure 12. All other portions contain potash feldspar in varying amounts. The main mass, composed of monzonite (IV) lying immediately east of the mineralized zone, is also shown in Figure 12 and in a closer view of stained drill core in Figure 13. It is composed of 45 per cent andesine in coarse blades with 20 per cent interstitial potash feldspar with both hornblende and biotite but no pyroxene. An intermediate phase (III) is also shown in Figure 12.

Hypabyssal Rocks

Dykes and sills in great variety and size abound in the map area, being most common in the panel of Hazelton rocks and occupying about 15 per cent of the section between the two stocks. The dykes have been omitted from Figure 5 for simplicity. They are less common in the gabbro-monzonite complex and rare in the Goosly Lake Volcanics. Many of these dykes are bladed feldspar porphyry, and are almost certainly early hypabyssal equivalents of the gabbro-monzonite. Other prominent dykes and masses, seen mostly in drill core from the north-central part of the area, are monzonite. Angling through the mineralized zone and into the gabbro-monzonite is a distinctive dyke of quartz porphyry about 60 feet (18 m) wide.

Phase VI occupies an area several thousand feet square north and east of the gabbro-monzonite. Its mode of origin is not known, but it may be a combination of hypabyssal intrusive phases and altered pyritic members of the Goosly Lake Volcanics. Phase VII is biotite-monzonite from a large dyke-like mass and a separate area lies to the east.

Intrusive Ages

We have no stratigraphic data on the ages of the intrusions other than that the two main stocks cut

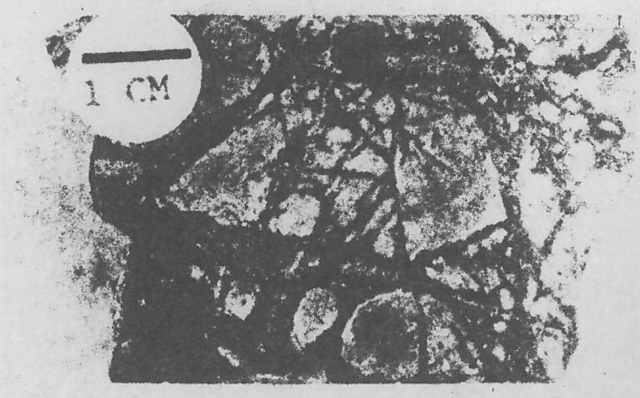

FIGURE 15 — Mineralized breccia in oblique light. Fragments of light-colored 'felsite' and dark matrix containing fine sulphides, mainly pyrite and chalcopyrite.

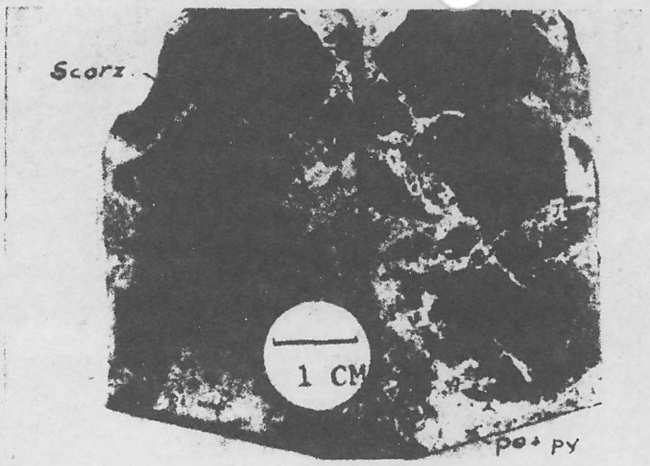

FIGURE 16 — High sulphide mineralization. Mostly pyrrhotite, pyrite and chalcopyrite infilling and veining fragments of quartz-sericite rock. The minute penetrating veinlets are mainly chalcopyrite. The very dark angular grain is scorzalite.

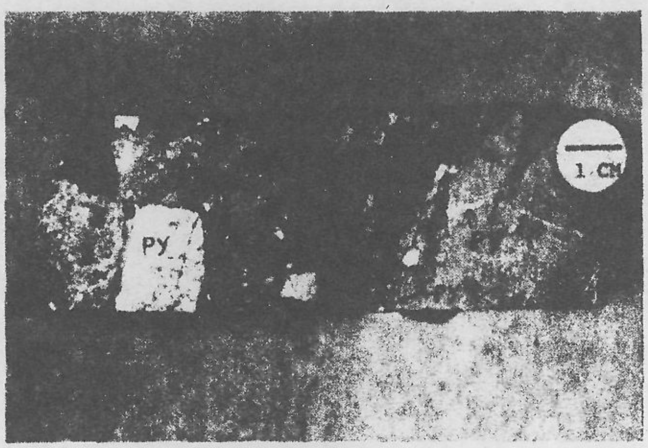

FIGURE 17 — Band of breccia ore with pyrite clasts. The large pyrite grain is suspected to be clastic. The fragment on the left is chert; most of the others are lithified dust tuff.

strata believed to be of Hazelton Group age, and the gabbro-monzonite complex is apparently directly related to effusives of Ootsa Lake Group age. Dykes related to the gabbro-monzonite are intrusive into the quartz monzonite.

Two potassium-argon determinations give ages which appear logical. For the quartz monzonite, biotite separated from a sample taken by N. Church gave a value of 61.1 m.y. when tested by Geochron Laboratories. On a separately cleaned mineral concentrate from the same rock, N. Carter at the University of British Columbia obtained a value of 56.2 m.y. Biotite from a sample of the main phase of the gabbro-monzonite complex taken a few hundred feet east of the mineralized zone gave 52.5 m.y. by Geochron, and 48.8 m.y. by Carter at U.B.C. (see Church, 1969).

There remains a question about the age of certain quartz-rich hypabyssal phases, superficially similar to the quartz monzonite, which are intrusive into the gabbro-monzonite complex.

GOOSLY LAKE VOLCANICS

Low-dipping volcanic rocks unconformably overlap the Hazelton rocks and appear to merge with the gabbro-monzonite in the north and west. They were considered to be of Lower Ootsa Lake Group age and were given the local name of Goosly Lake Volcanics by Church. The presence of large, conspicuous bladed plagioclase crystals in these rocks immediately suggests a kinship among flows, hypabyssal rocks and the gabbro-monzonite complex. Church developed this relation and showed that flows were cogenetic with intrusive phases of the complex, so that in effect the gabbro-monzonite complex is the core of a volcano surrounded by its own products of effusion. Three units are recognized: a basal flow breccia or agglomerate in the southeast part of the map area, a most extensively developed bladed feldspar porphyry of trachyandesite composition, and a biotite trachyte unit. Figure 14 shows specimens of a trachyandesite dyke and a pyroxene trachyandesite flow.

The rocks of this group can be extensively altered and pyritized, but they are not known to carry valuable mineralization in our map area.

BUCK CREEK VOLCANICS

The Goosly Lake Volcanics are overlain in the northwest corner of our map area by basaltic flows and breccias. They appear to lie with more regularity than the Goosly Lake Volcanics and may be separated from them by an unconformity. They were correlated with the Endako Group originally and were assigned the local name of Buck Creek Volcanics by Church.

MINERALIZATION

The principal metallic minerals recognized in the deposit are pyrite, chalcopyrite and tetrahedrite. Pyrrhotite is locally abundant, sphalerite is widespread but localized erratically in vein-like masses, and the over-all amount of zinc is too low to be of economic interest. Galena is relatively rare. Marcasite is locally present in association with pyrrhotite and is probably of secondary origin. Traces of arsenopyrite, ruby silver, argentite and several lead-antimony-bismuth sulphosalts have also been reported. Specular hematite is conspicuous in strata of the mineralized zone, generally outside the limits of copper-silver mineralization.

The texture of ore minerals is uniformly crystalline, but there is extreme variation in grain size. Colloform structure has been seen only on a minute scale in marcasite. Pyrite, pyrrhotite and chalcopyrite sometimes become quite massive for a few feet, but for mineralized rock in general the sulphide content is only 3 or 4 per cent. Mineralogical banding of sulphides is rare.

The grain size of pyrite can exceed 2 centimeters, and other sulphides may be in particles several millimeters in diameter, but in average mineralization the sulphides are 0.1 mm or less, comprising the dark matrix of a breccia.

Microprobe work by E. Gasparrini at University of Toronto (Gasparrini, 1971) has shown that silver is present in tetrahedrite or friebergite in amounts from zero to 18 per cent. Silver was also found in a silver-lead-bismuth sulphosalt and in one occurrence of argentite. No silver content was detectable in chalcopyrite, sphalerite, galena or lead-antimony sulphosalts.

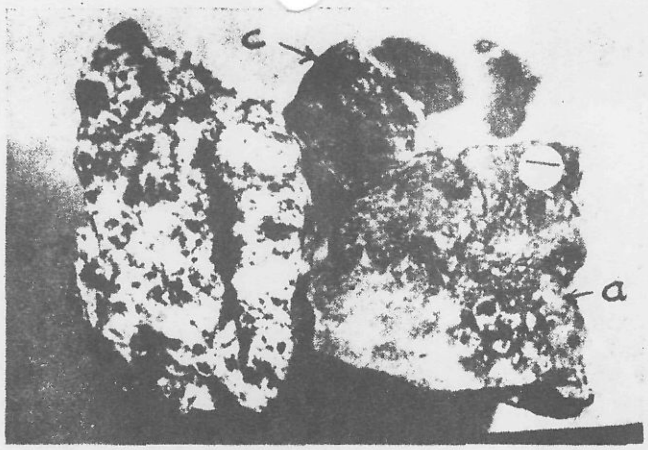

FIGURE 18 — Tourmaline-pyrite alteration in Goosly Lake Volcanics.
(a) silicified, clay-altered and tourmalinized
(b) intense clay-tourmaline alteration
(c) pyrite and tourmaline.

In arsenical tetrahedrite (tennantite) the silver content is relatively low.

As a rule in visual estimation, coarse obvious tetrahedrite did not associate with high silver values, but when the mineral was in fine crystalline, scarcely visible films, the silver content was high.

Some of the more typical ore textures and structures are illustrated. Figure 15 shows fragments of typical light-colored felsite with a dark matrix containing fine sulphide particles, mainly pyrite and chalcopyrite. Although it would appear that sulphidic material is invading rock material, there is little convincing evidence that sulphides are replacing rock. Figure 16 shows material of high sulphide content, mostly pyrrhotite with pyrite and chalcopyrite. In this section the sulphides appear to be actively penetrating rock fragments, which in this case are 90 per cent quartz and 10 per cent sericite and may be altered dust tuff or felsite of direct igneous origin. Notably the small penetrating sulphide veinlets contain a higher proportion of chalcopyrite and may be regarded as minute segregation veinlets (Tatsumi, ed., 1970, p. 69). In Figure 17 there is a large grain of pyrite that appears to be clastic. The angular lithic fragments are mostly identifiable as dust tuff, but they are somewhat diverse, and include a chert pebble on the upper left. In the lower left is a fragment bearing disseminated mineralization. Chalcopyrite and pyrite finger out into massive dust tuff on the right. This particular band of mineralization is only about 10 cm wide, but it is believed to be a bed rather than a cataclastic unit.

Sections of dust tuff which are otherwise massive may contain, for many tens of feet, lenticular pods of sulphide a few mm by a few cm, neither visibly interconnected nor associated with veinlets or fractures. The sulphides may be pyrite, chalcopyrite or tetrahedrite, alone or in combination. In other cases distinct veinlets and systems of parallel fractures containing any of the three common sulphides can be recognized. The latter type of material is more apt to have economically interesting grades.

Patterns of metal ratios within the mineralized zone have yet to be studied in detail. So far it is apparent that more massive sections of sulphide with lower Ag/Cu ratios lie on the west or hanging wall of the zone, while higher Ag/Cu ratios with lower over-all sulphide content are in the east or the footwall side.

ROCK ALTERATION

Alteration in and around the deposit presents a complex problem that has only been studied in a very general way. Specific relations of alteration to mineralization remain obscure.

Sericite, clay, chlorite and silica are the predominant alteration minerals found in the mineralized zone. The first three, along with pyrite are found very generally throughout the host rocks and in an indefinitely bounded zone around them. Silicification is more specific to mineralization, and there is a progressive hardening of the rock as mineralized sections are approached. In certain mineralized sections of lapilli tuff, fragments are seen to be progressively silicified until they are gray ghosts in a silica-sulphide rock. In part this may result from a leaching of bases, rather than any net addition of silica. In any case, it is not a prerequisite for mineralization in lapilli tuff.

Tourmaline is present in two distinct forms: masses of black schorlite and aggregates of fine needles of pale green dravite. The latter is found in host rocks close to mineralization, but again it is not a case of *sine qua non*. The black schorlite also occurs widely through the mineralized formation, but it is most conspicuously developed along with intense clay alteration and pyritization in trachyandesites of the Goosly Lake Volcanics. This impressively altered material (see Fig. 18) has not been found to contain economic amounts of either copper, silver or gold.

A conspicuously blue phosphate mineral of the lazulite series, identified as *scorzalite* (Gower, 1970), is widely dispersed through mineralized host rocks. Although no obvious relationship with copper-silver grade can be established, this mineral does appear to have some broad genetic relation to mineralization. In detail it has been noted to have a reciprocal relation to dravite. A euhedral grain may be seen in Figure 16.

Gypsum is present as veinlet networks in several local areas of the explored host rocks, but its relation to intensity of mineralization is, if anything, inverse.

Although anomalous fluorine contents in stream sediments helped direct our attention to the Sam Goosly area, the presence of fluorine-bearing minerals is poorly documented. Fluorite was noted in drill core in two doubtful cases. Analyses of typical materials show that gabbro-monzonite, an andesite porphyry dyke and some of the Ootsa Lake Volcanics are relatively high in fluorine, 1000-1400 ppm, while values in mineralized rock are in the range of 300-2000 ppm with no apparent direct correlation with copper and silver values.

The most perceptive studies of alteration to date were made by Richard Nielsen of Kennecott's Geologic Research Division (Nielsen, R. L., 1969) at an early stage of exploratory drilling in the section of mineralized ground closest to the gabbro-monzonite complex. He found evidence for three stages of alteration. First was a pervasive alteration regarded as of solfataric origin, characterized by pyrite, chalcedonic silica and muscovite or illite. Next was a contact metamorphism, characterized by andalusite and recrystallized silica, attributed to the gabbro-monzonite complex. The third alteration, specific to mineralized zones, affects brecciated and veined rocks with quartz, sericite, chlorite, tourmaline, a second stage of andalusite, and siderite.

Later observations concur with the over-all development of the first stage and the local development of the second and third. The degree of association of this third stage with mineralization remains in doubt. Nielsen, with some caution, considered that part of the mineralization was related to the first solfataric stage of alteration.

MODE OF ORIGIN AND CLASSIFICATION

Four general modes of origin have been considered for the Sam Goosly deposit, viz:

1. Epigenetic replacement from fluids associated with the quartz monzonite stock.
2. Epigenetic replacement from fluids associated with the gabbro-monzonite complex.
3. Epigenetic replacement by aggressive or thermally active fluids which derived metals from the enclosing rocks. These fluids may have been magmatic products or heated circulating vadose or connate waters.
4. The deposits are volcanogenic in the sense that mineralization is related to volcanic processes that formed the host rocks.

[1] The first mode was suggested very early in exploration by C. J. Sullivan, who visualized the mineralized breccias as zones of fluid-streaming, dipping conically toward the quartz monzonite (Sullivan, 1968-70). The quartz monzonite stock was a favoured source because it had some evidence of mineralization within it and was apparently connected to the copper-silver zones by a broad field of rock alteration and pyritization. The idea guided exploration, but lost influence as the breccias generally appeared through further work to be specific stratigraphic units rather than cone-sheets.

[2] The second mode seems most logical simply because mineralization is best developed close to the gabbro-monzonite. However, the entire gabbro-monzonite complex is physically and geochemically unconvincing as the progenitor of copper-silver mineralization. It is neither veined nor otherwise mineralized and contains only background values in metals. The associated porphyritic formations clearly show, through studies of Church and Panteleyev, that it represents a volcanic centre. The associated effusive rocks may be well altered by pyritization, sericite and tourmaline, but even in this apparently well-prepared situation no valuable mineralization has been found. Both Nielsen and Church favoured the gabbro as a concentrating agent and probable source of metal, but Nielsen suspected that there may have been an early solfataric stage of alteration and mineralization.

[3] The third mode requires no allegiance to any particular intrusion, either as a source of metals or a concentrating agent, but it does imply that the metals were brought into their present sites by replacement of country rock and open space filling. In this case the original structure and character of the rocks are less important than younger structures in localizing mineralization.

In detail within the mineralized zone, ample evidence can be construed to indicate that minerals have been emplaced hydrothermally and epigenetically. In general, ore mineral veinlets are known in a variety of rock units of varying ages and invasion of sulphides into rock is common. It seems, however, that the use of the term 'replacement' is much too free and is used merely where an ore mineral occupies space in a rock. In much of our mineralization we can see little conclusive evidence that rock minerals have been chemically removed at the behest of ore minerals. There is, on the other hand, considerable evidence that sulphide minerals are an original component of the rock, as suggested by the small particles of chalcopyrite shown in Figure 8. The occurrence of pyrite in apparently clastic fragments, as shown in Figure 17, also suggests that it is an original component.

[4] The most significant characteristic of the mineralized zone as explored to date, entirely critical to the fourth mode proposed, is that it is associated with an acid pyroclastic division of the Hazelton rocks, and is grossly parallel to the strike of these rocks for many thousand feet. Specifically the maximum development of mineralization is clearly associated with a maximum development of a particular unit of lapilli tuff and breccia.

We consider, therefore, that the main concentration of metals was effected by volcanic processes directly related to the formation of the host rocks. It was accomplished mostly during deposition and diagenesis possibly over a few thousand years, while tuffs and sediments were being laid down in a subaqueous environment. In this respect the deposit would be classed as volcanogenic, and in environment, mineralogy and geometry it compares with volcanogenic copper-iron deposits classed under the broad heading of 'Kuroko Type'. The time of this concentration is essentially that of the formation of the host rocks and, as far as we are able to determine, they are of the Hazelton Group. In this case, we do not imply that the deposit is a massive black ore or 'Kuroko' deposit but simply that in geologic setting and style of mineralization, the deposit is akin to the volcanogenic deposits so lucidly described by Japanese geologists (see Tatsumi, ed., 1970, p. 154).

Some modification of the mineralization by intrusions is natural to expect, but the nature and amount of modification are debatable points, still little understood. The quartz monzonite is flanked by zones of strong pyritization that extend in north-south belts, giving rise to pronounced I.P. anomalies. It is difficult to show whether or not this field of pyritization is independent of copper-silver mineralization. The intrusion may well have effected changes in the solfataric alteration and remobilized the dispersed sulphides in the Hazelton volcanics. Continuing pyrite-clay-tourmaline alteration and pyritic mineralization that affected Tertiary volcanic rocks may have brought about further mobilization, although any so-altered material which has been sampled to date is quite barren. The gabbro-monzonite complex probably had a low water content, but it could have generated a broad convection of ground water that effected some reorganization and concentration of metals from the nearby source in Hazelton rocks. The presence of pyrrhotite and of magnetite is particularly noticeable in mineralization nearest the complex, but there is no indication that it was a source for either silver or copper.

There are three main objections to the idea of direct volcanogenic mineralization: (1) the maximum development of lapilli tuff and of mineralization, as we know it, is closest to the prominent westward-facing lobe of the gabbro-monzonite complex; (2) it is something of a coincidence that an Early Tertiary volcanic centre would be superimposed on one of Jurassic age; and (3) there has as yet been no recognition of the alteration pipe that usually characterizes volcanogenic massive sulphide deposits. If (2) is accepted as a reasonable probability, then objection (1) be-

81164

comes tolerable, particularly if some thermal modification of mineralization by the gabbro-monzonite complex is acknowledged. Objection (3) may well disappear as investigation of the property proceeds.

One hypothesis, suggested early in exploration, was that the quartz monzonite stock occupied the subvolcanic core, and the gabbro-monzonite was a younger post-mineral phase of the same volcano. This idea is completely crushed by the data that the intrusions are Tertiary while the intervening rock is Jurassic, and that the succession faces west, not east. There is still, however, some doubt about which way the succession faces, and some slight doubt about its age.

Much critical evidence could be revealed by artificial openings. It would be highly important to prove, for example, that the thin band of mineralized breccia shown in Figure 17 is actually a bedded unit, and not a zone of fluid streaming.

The problem of mode of origin would be simplified if the age of host rocks and of mineralization could be independently determined. There must remain an element of doubt about the host rocks, now thought to be Hazelton by a consensus of geological opinion rather than direct evidence. Nielsen attempted to place limits on the age of mineralization by dating alteration sericite from mineralized breccia. A potassium-argon age of 54.8 m.y. was obtained by Geochron, and this is very close to that obtained for the gabbro-monzonite (52.5 m.y.). However, we would consider it very hazardous to accept this as the age of mineralization because of the many thermal effects in the region of the sample that could have post-dated mineralization.

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Infacon 74 to be Held in South Africa

AN INTERNATIONAL FERRO-ALLOYS CONGRESS, arranged by the Ferro-Alloy Producers' Association of South Africa, the South African Institute of Mining and Metallurgy and the National Institute for Metallurgy, will be held in Johannesburg, South Africa, in April 1974. The technical program, occupying five days, will cover the following topics in relation to all ferro-alloys:

(1) burden preparation, blending, pelletizing, handling, reducing agents;
(2) electric smelting furnaces — design, operation, management, smelting optimization, shop practice, refractories;
(3) mineralogy, reduction behaviour, smelting reactions, slags;
(4) automation, pollution control;
(5) applications, trends in consumption, trends in composition specifications.

Papers in the above topics are invited; review papers will also be welcome. Proposed titles and abstracts (not more than 200 words) should be submitted before the 30th of November, 1972, to the Chairman, Programme Committee, INFACON 74, Private Bag 7, Auckland Park, South Africa.

The abstracts will be considered during January 1973, and papers accepted for the Congress must be submitted in final form before the 31st of July, 1973. The proceedings of the Congress will be published as a special volume.

There will be a series of post-Congress tours to ferro-alloy plants and other places of both technical and scenic interest. A full ladies' program will be arranged.

The First Circular, giving further details, can be obtained from the Secretary of the Organizing Committee, INFACON 74, Private Bag 7, Auckland Park, South Africa.

Inco Scholarships Awarded for 1972-73

SEVENTY PARTICIPATING SCHOLARSHIPS in engineering and the physical sciences have been awarded to students at twenty-one Canadian universities for the 1972-73 academic year by The International Nickel Company of Canada, Limited. Twenty-two awards went to the western provinces, twenty-two to Ontario, eighteen to Quebec, and eight to the Atlantic provinces. Of the successful candidates, fourteen are in geology and geophysics, two in chemistry, one in engineering science, eleven in mining and mineral engineering, ten in metallurgical engineering and four in geological engineering. Also, seven are in chemical, seven in civil, six in electrical and eight in mechanical engineering.