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EXAMINATION OF MERCURY EXPLORATIONS' PROPERTIES IN ENDAKO AREA, B.C.

N.T.S. 93-K

ATLAS EXPLORATIONS LIMITED

By: K.M.Dawson Nov. 1969

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K. M. DAWSON

ATLAS EXPLORATIONS LIMITED

November 25th, 1969

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INTRODUCTION

On November 20th and 21st, 1969, the writer accompanied by Robert E. Chaplin of Mercury Explorations Ltd. (N.P.L.) visited several of Mercury's properties in the vicinity of Endako Mine. Rock outcroppings and overburden conditions were examined, and correlated with I.P. results. Two soil and four rock samples were taken south of the Count Claims. The objects of the examination were:

1. to determine priorities for additional work on the properties, based upon geophysical and geochemical responses, and geological environment;
2. to assess the nature and extent of additional work needed on the properties prior to diamond drilling;
3. to estimate the size and cost of a drilling program that will adequately test the properties.

SUMMARY

Priorities for additional work required on Mercury claims are:

1. Count
2. Fort
3. Tat
4. Chess
5. Bonus

4900 feet of vertical diamond drilling should be located on the basis of 45 line-miles of concurrent I.P. - magnetometer-soil sample surveys. Total cost estimate for the program is $83,550.00.

CONCLUSIONS AND RECOMMENDATIONS

1. An I.P. anomaly on Count Claims is the number one priority area. Rock outcroppings south of the claims show the area to be a contact zone between Casey alaskite and Nithi quartz monzonite, with alteration and mineralization similar to that on Nithi Mountain to the north.

   Fill-in I.P. and ground magnetometer lines should be run over the anomalous area, with N-S lines on 1000 ft. spacing and two E-W lines along the northern and southern sides of Counts Lakes. N-S lines should be extended to cover open ground to the south on which molybdenite mineralization was observed. Soil samples for Mo should be taken at 300 ft. intervals along N-S lines. About 14 line-miles each of I.P., magnetometer and soil sampling work are required. Overburden depths are estimated to be 150-200 ft. Four 400 ft. drill holes may be located on the basis of this work.

2. A coincident I.P. - geochem anomaly on the Fort claims is the second priority area. The anomalous area is underlain by Endako quartz monzonite and is adjacent to a major fault zone. The fault zone is intruded locally by andesite porphyry, rhyolite and basalt dykes. Sparse molybdenite mineralization and kaolinite alteration are intersected in drill core near MacDonald and Casy Lakes along the fault to the north.

Three N-S I.P. lines should be run to the west of the anomaly to test possible extensions and a soil Mo anomaly on the western portion of the Fort claims. Ground magnetometer should be run along I.P. lines crossing the anomaly, and soil samples for Mo should be taken at 300 ft. spacing along the same lines. About 10 line-miles each of soil sampling and magnetometer work are required, plus 3 line-miles of I.P. survey. The area is underlain by glaciolacustrine silts probably 50 to 150 ft. deep. Three 400 ft. diamond drill holes may be located on the basis of this work.

3. An I.P. anomaly on Tat claims west of Stern Lake is the third priority area. Rocks of Simon Bay diorite complex are overlain by Tertiary Endako Group lavas immediately north of the anomaly, and Casy alaskite crops out 1½ miles to the west. The area may be a contact zone between alaskite and older diorite. A weak aeromagnetic spot high borders the I.P. anomaly on the north.

   Fill-in I.P. lines on 1000 ft. spacing should be run N-S across the anomaly, and three E-W I.P. lines should bracket the anomalous area. A ground magnetometer survey should be run over these fill-in lines, and soil sampling for Mo at 300 ft. intervals should be done concurrently. About 12 line-miles each of I.P., magnetometer and soil sampling are required. The area occupies the broad drift-covered valley of Stern Creek, and overburden depths in excess of 150 ft. may be encountered. Apparent resistivities, however, indicate overburden depths may be less. Two 400 ft. diamond drill holes may be located on the basis of this follow-up work.

4. A weak I.P. anomaly on Chess claims is the fourth priority area. Carr (1965, p.118) notes a sheared

and altered outlier of Endako quartz monzonite occurs within Casey alaskite immediately north of Cheskwa Lake, at the NW end of Chess claims. Chaplin (1969 p.12) reports exposures of weakly sheared, slightly sericitized coarse-grained quartz monzonite along a pipeline right-of-way in the vicinity of the I.P. anomaly.

This locality was not visited by the writer, hence the type and significance of the hydrothermal alteration cannot be assessed. The claims cover a contact zone between Casey alaskite and Endako quartz monzonite, and may be an area of intersection between major NW and NE structural trends. These two geological factors are prime controls for molybdenite mineralization in Endako area.

The I.P. anomaly is defined by N-S lines 1 mile apart. Two or three fill-in N-S lines across the anomaly are needed, as well as one NW-SE line down the long axis of the anomaly. A ground magnetometer survey should be run concurrently. Soil sampling for Mo has not been done in the area, hence the existing soil grid to NE should be extended across the claims. About 6 line-miles each of I.P., magnetometer and soil sampling are required. Overburden depth in the area has not been estimated. Two 400 ft. diamond drill holes may be located on the basis of this work.

5. A strong I.P. anomaly on Bonus claims one mile west of Endako village constitutes the fifth priority area. Outcroppings of fresh Glenannan quartz monzonite occur to north and south of Bonus claims, a rock unit in which no molybdenite mineralization has been observed by the writer. The anomalous zone straddles Highway 16,

the C.N.R. right-of-way, a natural gas pipeline, and Endako River.

The anomalous area may be better defined by extending the present I.P. survey lines about 1 mile southward, and running a ground magnetometer survey over the area. About 3 line-miles each of I.P., and magnetometer work are required. Soil geochemistry for Mo may be misleading due to excessive depth of overburden. I.P. results indicate bedrock-overburden interface sloping upward to the north, but depths in excess of 200 ft. may be encountered beneath the anomaly. Ownership of surface rights in this area should be ascertained before additional work is started. One deep diamond drill hole, in the order of 500 ft., should adequately test the area.

6. Soil Mo anomalies on the western part of the Tat claims probably reflect mineralized glacial float transported from the vicinity of Owl Lake showings four miles to the west. No further work appears warranted in this area, nor on the North claims adjoining the K & S claims of United Buffadison on the east.

COST ESTIMATE

Cost of I.P. surveys are estimated to be $250 per line-mile, with cost of concurrent ground magnetometer surveys and soil sampling estimated at $50 per line-mile each.

Diamond drilling costs are estimated at $10 per ft. based upon recent contracts with Endako Mines.

Costs of supervision and contingencies are based upon Chaplin's estimates:

1. Count Claims:

14 line-miles of I.P.-Mag. Soil	$ 5,000.00
1600 ft. of diamond drilling	16,000.00
Supervision	1,500.00
Contingencies	5,000.00
Total	$27,500.00

2. Fort Claims:

10 line-miles of mag.-soils	$ 1,000.00
3 line miles of I.P.	750.00
1200 ft. diamond drilling	12,000.00
Supervision	1,000.00
Contingencies	4,000.00
Total	$18,750.00

3. Tat Claims:

12 line-miles of I.P.-Mag.-Soil	$ 4,200.00
800 ft. diamond drilling	8,000.00
Supervision	1,000.00
Contingencies	3,000.00
Total	$16,200.00

4. Chess Claims:

6 line-miles of I.P.-Mag.-Soil	$ 2,100.00
800 ft. diamond drilling	8,000.00
Supervision	1,000.00
Contingencies	2,000.00
Total	$13,100.00

5. Bonus Claims:

3 line-miles of I.P.-Mag.	$1,000.00
500 ft. diamond drilling	5,000.00
Supervision	500.00
Contingencies	1,500.00
Total	$8,000.00
GRANT TOTAL OF 5 PROJECTS	$83,550.00

GEOLOGY

The reader is referred to enclosed papers by E. T. Kimura and A. D. Drummond on geology and alteration of Endako Mines (1969) for an up-to-date summary of mine geology. Regional geology of Endako area is covered by J. M. Carr (1965).

The Endako area is underlain by the predominately quartz monzonitic phases of Topley batholith, ranging in age from mid-Jurassic to Early Cretaceous. Molybdenite-pyrite-magnetite mineralization in these rocks is accompanied by K.-feldspar and quartz-sericite pyrite envelopes, and pervasive kaolinization. Minor occurrences of molybdenite abound, but major concentrations are controlled by intersections of two or more regional structural features.

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Respectfully submitted,

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CERTIFICATE OF ANALYSIS

NO. 7459

INVOICE NO. 2438

DATE RECEIVED Nov. 27/69

DATE ANALYSED Dec- 1/69

TO: Atlas Explorations Ltd.,
330 - 355 Burrard St.,
Vancouver, B. C.

ATTN: Mr. Ken Dawson

SAMPLE NO.:	PPM Copper	PPM Molybdenum	
Soil #1	10	3	Count
Soil #2	10	2	Count

Certified by

Hydrothermal Alteration at Endako — A Comparison to Experimental Studies

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ABSTRACT

The significance of K-feldspar-bearing and sericite-bearing envelopes within the pervasively kaolinized rocks of the Endako molybdenite deposit may be explained in the light of experimental studies by J. J. Hemley of the system K_2O — Al_2O_3 — SiO_2 — H_2O.

The relative vein sequence of hydrothermal alteration products is illustrated more distinctly at Endako Mines than in many of the porphyry copper deposits. Cross-cutting relations indicate a relative age sequence among the various silicate stages which is in agreement with a chemical control based on the activity ratio of K^+/H^+ in a nearly isothermal environment.

A. D. DRUMMOND

E. T. KIMURA

Dr. A. D. DRUMMOND received his primary and secondary education in Vancouver and graduated in geological engineering from the University of British Columbia as a B.A.Sc. in 1959, and as an M.A.Sc. in 1961. He obtained his doctorate in 1966 from the University of California. From 1958 to 1961, he was employed by Kennco Explorations (Western) Limited on the Lime Creek molybdenum deposit, which is now in production as British Columbia Molybdenum Limited. He has been associated with the Placer Development group of companies since 1963, first with Craigmont, then with Endako, and since 1967 as research geologist of Canex Aerial Exploration Limited.

E. T. KIMURA was born in Vancouver, and graduated from the University of British Columbia with a B.A. in geology and physics in 1955. He then returned for one year of postgraduate studies in geology. Mr. Kimura joined Eldorado Mining and Refining Ltd., at Eldorado, Sask., in 1956 as a mine geologist. He joined Craigmont Mines Ltd. as open-pit geologist in 1962, and transferred to Enkado Mines Ltd. as senior geologist in 1964.

THE PAPER WAS PRESENTED: at the 70th Annual General Meeting of the Institute, Vancouver, April, 1968.

KEYWORDS: Endako Mines Ltd., Hydrothermal alteration, Molybdenum deposits, Kaolinization, Alteration mineralogy, Feldspars, Sericite, Vein mineralogy, Age relations, Chemical controls, Quartz monzonite.

INTRODUCTION

THIS PAPER IS PRESENTED to illustrate that the products of hydrothermal alteration and their interdependence can be readily explained in terms of the experimental work of J. J. Hemley in the system K_2O - Al_2O_3 - SiO_2 - H_2O. Many of the porphyry copper type of deposits (excluding Butte) do not show the relative alteration sequence as distinctly as it is seen at the Endako molybdenite deposit (Titley and Hicks, 1966).

Endako Mines is located 100 miles west of Prince George and about 350 miles north of Vancouver at the geographical center of British Columbia. The molybdenum deposit occurs in the Endako quartz monzonite, which is one of the oldest rock types of the composite Topley Intrusive and which has been dated at 140 m.y. (White *et al.*, 1967). The batholith is considered to be of Jurassic age (Armstrong, 1949, p. 92). The regional geology and structural interpretation of the Endako deposit was presented at the 1966 CIM B.C. Section convention in Victoria (Kimura and Drummond, 1966). The area was also covered by the B.C. Department of Mines (Carr, 1965).

The Endako orebody is an elongated elliptically-shaped stockwork which strikes N70°W, dips 20 to 50 degrees south, and measures about 6,000 feet long by 1,200 feet wide. Ore reserves as of March 15, 1968, at a 0.08 per cent MoS_2 cutoff, were 239,000,000 tons grading 0.15 per cent MoS_2. The mill capacity has been expanded to 22,000 tons per day. The average strip ratio for the ore reserves within the current ultimate pit outline is 0.5:1.

MINE GEOLOGY

The Endako quartz monzonite and three mineralogically distinct pre-mineral dykes form the host for the mineralized stockwork. The Endako quartz monzonite is generally equigranular (3-4 mm), with some K-feldspar crystals occasionally as large as 7 mm. This size difference imparts a suggestion of a porphyritic texture, but is not sufficiently distinctive to warrant the term "porphyritic." The rock is composed of quartz (30%), pale pink to orange-tinged K-feldspar (perthitic orthoclase, $2V_x$ large) (35%), white to greenish-tinged plagioclase (An_{20}) (30%) and partly chloritized black biotite (5%). Apatite, zircon, pyrite and magnetite comprise the accessory minerals. The K-feldspar/total feldspar ratio may vary between 2/3 and 1/2, but is predominantly 1/2. Therefore, the rock type is classified as quartz monzonite rather than granite.

Aplite is the least abundant dyke rock in the mine. It is typically fine-grained, pink, graphic-textured and composed of quartz (40%), pink orthoclase (40%), white plagioclase (An_{20}) (20%) and less than 1 per cent chloritized biotite.

Porphyritic granite is more abundant and has large Carlsbad-twinned orthoclase phenocrysts (1 cm) (3%) scattered through a finer grained, phaneritic, seriate-textured matrix (0.1-1 cm). The seriate matrix is composed of quartz (20%), K-feldspar (45%), plagioclase (25%) and biotite (5%). Zircon and apatite comprise the accessory minerals. Porphyritic granite dykes have only been observed to intrude the Endako quartz monzonite in the mine area and are, in turn, intruded by quartz-feldspar porphyry.

Quartz-feldspar porphyry is the most abundant dyke rock in the mine vicinity. Two phases have been observed: (1) a brown to pink rock composed of K-feldspar (orthoclase, $2V_x$ large) (2 mm) (1-5%) and (2) a brown rock with quartz (5-10%), K-feldspar (1-5%) and sagenitic biotite (1-3%) phenocrysts (1-2 mm) in a dense, aphanitic matrix (0.05 mm). The latter is termed the quartz-feldspar porphyry-biotite phase and, characteristically, contains scattered K-feldspar phenocrysts which may be up to 1 cm in length. The matrix is composed of quartz (50%), K-feldspar (40%), plagioclase (5%), biotite (5%), and accessory amounts of apatite and zircon. Quartz-feldspar porphyry intrudes the Endako quartz monzonite, aplite and porphyritic granite, which indicates that this dyke is the latest pre-ore dyke in the mine area.

Post-ore basalt dykes cross-cut the quartz monzonite, the pre-ore dykes and the mineralization.

MINERALOGY, ALTERATION AND RELATIVE VEIN AGE

Detailed megascopic, petrographic and X-ray diffractometer studies have been conducted on the vein mineralogy and on the attendant hydrothermal alteration. Comparisons of vein and specific types of alteration allow the formulation of a mineralization sequence.

A. Alteration Mineralogy

The presence or absence of specific mineral phases and their relationship to each other is the essence of an alteration study. It is essential that introduced or secondary features are not mistaken for primary variations within the Endako quartz monzonite hoist.

X-ray analysis of the fine-grained alteration clay minerals without the use of D.T.A. (Differential Thermal Analysis) or heat treatment facilities will allow only an approximate identification. Consequently, the terms sericite, kaolinite and montmorillonite refer, respectively, to the presence of a 10Å mica group mineral, a 7Å kaolinite group mineral and a 14Å montmorillonite-type mineral. Where present, the latter are glycolated and the shift in 14Å peak is checked. Polymorphs of sericite as outlined by Velde (1965) were not determined.

Three distinct hydrothermal alteration phases are observed within the Endako ore zone: (1) envelopes with K-feldspar; (2) envelopes with sericite; and (3) pervasive kaolinization. An envelope is defined as a band or zone of introduced silicates around a central vein or fracture. Pervasive alteration of the quartz monzonite is always present to some degree on the outward side of the envelope.

1. K-feldspar-Bearing Envelopes

Evidence of hydrothermal K-feldspar is seen in three distinct megascopic forms. Envelopes from 1/8 to 2 inches in width, which may be developed adjacent to either quartz or quartz-molybdenite veins, are composed of either K-feldspar (100%) or K-feldspar (95%) and quartz (5%). No other silicates or metallic phases are present in the envelope.

A second type of envelope is composed of K-feldspar (90%) and biotite (10%) in which quartz may locally be present in amounts of up to 5 per cent. The K-feldspar-biotite assemblage may also form lenses without the presence of a central vein. These lenses appear to have been developed along fractures and veins in widths of up to 24 inches. Envelopes are much more common than the lenses.

A third type of envelope is distinctly different in that it contains K-feldspar (60% or more), quartz (30%), biotite (up to 5%) and altered plagioclase (5% or more). This type appears to involve a relative increase in K-feldspar/total feldspar ratio over that which occurs in the adjacent pervasively altered quartz monzonite (quartz (30%), K-feldspar (35%), plagioclase (30%) and biotite (5%)).

The use of field or textural evidence appears to be the only reliable method to distinguish hydrothermal K-feldspar (envelopes) and primary K-feldspar (original constituent of quartz monzonite). Petrographic work shows that the hydrothermal K-feldspar has replaced the constituents of the original rock adjacent to the vein.

The degree of triclinicity of primary and secondary K-feldspar was compared using an X-ray diffractometer. Two modifications of K-feldspar are orthoclase (monoclinic, disordered) and microcline (triclinic, ordered). With falling temperature, disordered orthoclase will become more ordered and its structure will become progressively triclinic. X-ray analysis showed that only the disordered, monoclinic form of orthoclase is present in the samples examined.

Observations indicate that pink or salmon-coloured K-feldspar can exist either in envelopes or as a primary constituent. It is also possible to get both colours in the K-feldspar crystals without any apparent optical difference in thin section. Under high magnification, the salmon pink portion may show the presence of minute red specks which could be finely divided powdery hematite.

2. Sericite-Bearing Envelopes

A grey, megascopically sharp envelope borders on quartz-molybdenite and/or magnetite and on quartz-pyrite veins in widths of from 1/8 to 2 inches. This type of envelope is composed of quartz (55 to 60%), sericite (10Å) (30 - 35%) and finely disseminated pyrite (1 - 5%). X-ray diffractometer patterns of the envelopes show an absence of kaolinite (7Å) or montmorillonite (14Å) peaks. Within the envelope, the original K-feldspar, plagioclase and biotite in the rock have been replaced by sericite and quartz. Iron from the breakdown of the biotite has been sulphidized to form pyrite. Sericitic envelopes are less common than K-feldspar-bearing envelopes.

In only a few cases, the development of the envelope does not appear to be complete. In these, sericitized biotite, relict feldspar and a fine-grained currently unidentified mineral may be present in addition to the quartz, sericite and pyrite. The unidentified mineral is white or grey and has the following properties in thin section: colourless, untwinned, low negative relief with respect to Canada balsam, birefringence of about .007, optically positive (?) with $2V_z$ large (?), and with 'r' less than 'v' about Z. These properties agree with gypsum, but the presence of gypsum has not been confirmed.

To date, three examples of quartz-sericite-pyrite envelopes have been observed adjacent to a vein in which a pink mineral occurs in addition to the regular vein phases. Peterson, Gilbert and Quick (1946), who worked on the Castle Dome deposit in Arizona, described quartz-sericite-pyrite envelopes in which the original orthoclase is unstable and is altered to sericite while, at the same time, adularia (disordered, low-temperature modification of orthoclase) is deposited in the vein. Their description could also supply to these few cases of a pink mineral in a vein with a sericitic envelope at Endako. The significance of this assemblage is difficult to assess because of their limited occurrence.

3. Pervasive Kaolinization

Plagioclase is the most sensitive indicator of progressive pervasive alteration which occurs between the outer limit of an envelope and fresh quartz monzonite. The mineralogical change from hard grey plagioclase in fresh rock to a soft greenish mixture of kaolinite and sericite is sufficiently distinct to allow classification.

(a) Unaltered Quartz Monzonite — Fresh equigranular quartz monzonite is composed of quartz (30%), pink K-feldspar (perthitic orthoclase, $2V_x$ large) (35%), hard grey plagioclase (twinned and generally not zoned, $2\theta(131)$ - $2\theta(1\bar{3}1) = 1.50$ (AN_{20}) (30%)) and black biotite (5%). Accessory minerals are apatite, zircon, sphene and magnetite.

(b) Weak Kaolinization — Weakly kaolinized quartz monzonite contains quartz (30%), pink orthoclase (35%), greenish grey plagioclase (30%) and black or chloritized biotite (5%). Accessory minerals are apatite, zircon and magnetite or powdery hematite. The greenish-tinged plagioclase generally shows a hard grey rim and a softer greenish core. X-ray analysis of the core and rim indicate that the plagioclase is An_{20} ($2\theta(131)$ - $2\theta(1\bar{3}1) = 1.50$) and that the major alteration products are kaolinite and sericite. Minor amounts of a montmorillonite-type clay are locally present where the soft core has white 'specks' which will noticeably swell when a freshly broken rock surface is exposed to the air. Montmorillonite-type clay occurs only in the weakly kaolinized rock.

In thin section, minute amounts of a carbonate are seen along with a brownish to greenish, weakly pleochroic mineral which may possibly be a mixture of the clay minerals and chloritized biotite or chlorite. This greenish mineral is generally confined to certain more calcic zones which existed in the original plagioclase. It may also be found along minute fractures which cross-cut the zoning in the plagioclase. The carbonate and chlorite (?) are not present in sufficient quantities to be detected by X-ray.

Recognition of this alteration type is based on the presence of zoned plagioclase crystals with a hard grey rim and a soft green core which locally may show white 'specks' that swell on exposure in air, and on the presence of K-feldspar which has not been attacked.

(c) Moderate Kaolinization — Moderately kaolinized quartz monzonite has the same relative properties of minerals as the weakly kaolinized rock. Accessory minerals are also the same. K-feldspar is not attacked and the mafic component is either black or chloritized biotite. The 'plagioclase' has completely broken down and is either a soft homogeneous pale green or white mixture of clay minerals. X-ray analysis indicates only the presence of kaolinite and sericite.

In thin section, the soft white or homogeneous pale green 'plagioclase' shows sericite, kaolinite, carbonate (calcite (?)), and chloritic material in a pattern which resembles the relict core described for the weak kaolinization. As the degree of alteration is relatively more intense, the hard rim is now seen as a kaolinite-rich band which surrounds the above-described altered core. Sericite flakes have not been observed in this kaolinite replacement of the original plagioclase rim. Biotite may be sagenitic, and there are generally minute rutile grains clustered around the periphery of the biotite flakes.

Recognition of this alteration type is based on the presence of unattacked pink K-feldspar and the complete breakdown of plagioclase.

(d) Intense Kaolinization — Intensely kaolinized quartz monzonite contains quartz (30%), pale bleached 'K-feldspar' (30 - 35%), pale greenish or whitish areas (originally plagioclase) (30 - 35%) and fresh black to bleached biotite (0 - 5%). Accessory minerals are apatite, zircon and sphene (?). Either magnetite or powdery hematite and/or pyrite may be present in trace amounts. Petrographic and X-ray analysis indicate that the original plagioclase has completely broken down to kaolinite and sericite and that the residual K-feldspar has been replaced by kaolinite and a little sericite.

Some whitish (originally plagioclase) material occurs within a greenish area (also originally plagioclase) and adjacent to bleached pink orthoclase. X-ray patterns of both types of altered plagioclase are identical. Petrographic evidence indicates a greater amount of very fine grained biotite plates in the white kaolinite-rich plagioclase pseudomorphs relative to the greenish plagioclase pseudomorphs. This suggests that iron, which may impart a greenish colouration to kaolinite in one case, has been fixed in biotite in the other case and consequently the coexisting kaolinite is white. This agrees with the coexistence of secondary biotite with kaolinite in the intensely kaolinized rocks.

Recognition of this alteration type is based on the presence of completely altered plagioclase and noticeably attacked K-feldspar.

B. Vein Mineralogy

Relatively few metallic minerals are present in the orebody. Molybdenite, magnetite and pyrite are the most abundant. There are trace amounts of chacopyrite, bornite, scheelite and specularite. Bornite and specularite are less abundant than chalcopyrite.

Two types of molybdenite mineralization occur within the orebody. The most prominent mineralization is the 6-inch- to 4-foot-wide continuous quartz vein with characteristic ribbons of molybdenite. Some molybdenite occurs as very finely divided grains within the quartz veins. The second type occurs as fine fractures filled with quartz-molybdenite in the form of a stockwork adjacent to and surrounding the major quartz veins. This zone of stockwork forms a halo to economic mineralization around the major quartz veins and may range in width from 20 to 200 feet.

The appearance and magnetic susceptibility of magnetite in quartz-magnetite veins varies with depth. Near surface, 'magnetite' is termed 'powdery hematite,' as it has a red streak, is non-magnetic and gives only hematite peaks on an X-ray pattern. With depth, powdery hematite becomes weakly to strongly magnetic and the colour and streak change simultaneously from red to brownish black or black. A polished section of a black magnetite with a brownish streak showed that very fine hematite grains occur along unoriented fractures within the magnetite. Iron has been dissolved as ferrous iron and oxidized to insoluble ferric oxide or hematite. A reaction of the following type is thought to occur:

$$2Fe^{++} + \tfrac{1}{2}O_2 + 2H_2O = Fe_2O_3 + 4H^+.$$

This variation in the magnetite with depth suggests that the development of hematite is secondary and is probably related to a Tertiary erosion surface.

Table I — Showing Relative Ages of Veins and Envelopes

The following notation is used: Qu — quartz; K-spar — K-feldspar; Bio — biotite; Ser — sericite; Mo — molybdenite; Mag — magnetite; Py — pyrite; Cpy — Chalcopyrite; Bn — bornite; Spec — specularite.

Stage	Vein	Envelope
1 (oldest)	Qu, Qu-Mo Qu-Mag (± Py)	(a) K-spar (b) K-spar-Bio., (c) Qu-K-spar-Bio- (minor altered plagioclase)
2	(Qu-Mo minor K-spar) Qu-Mag Qu-Mo Qu-Mag-Mo (all ± Py, Cpy, Bn) Qu-Py (± Mo, Mag)	(Qu-Ser-Py) ((?)) Qu-Ser-Py Qu-Ser-Py Qu-Ser-Py Qu-Ser-Py ((Pyrite Zone))
3*	Qu-Mo Qu-Mag Qu-Mag-Mo (± Py, Cpy)	((No Envelopes))
4*	Qu-Py	((No Envelopes)) (Occasionally, may have 'bleached halo' around veins)
5	Spec, minor Qu Calcite Chalcedony	((No Envelopes))
6 (youngest)	Late unfilled fractures	

*Barren quartz veins may also occur with Stages 3 and 4.

Quartz-specularite veins, which are a late feature in the development of the Endako stockwork, are distinct and have an entirely different origin.

Chalcopyrite in the larger quartz-molybdenite veins generally occurs with pyrite and magnetite. Specks of bornite are rare, but when observed they occur on fractures near chalcopyrite.

C. Age Relations of Vein & Alteration Types

A sequence of relative vein ages and alteration types has been determined from numerous observations of cross-cutting relationships in logging drill core and in mapping the open pit (see Table I). The various stages outlined in Table I are superimposed on each other, with their net result being the Endako stockwork. Five to seven individual cross-cutting features may be present in a single hand specimen.

The following type of observation is the basis for Table I. A quartz-molybdenite vein with a K-feldspar envelope may be intersected by a quartz-molybdenite vein with a quartz-sericite-pyrite envelope without any offset. The relative age can be deduced because the introduced K-feldspar of the first envelope has been replaced by sericite at the intersection area of two veins. The problem of geometry of zoned alteration around central veins or fractures has been discussed by Meyer and Hemley (1967, pp. 180-183).

Three K-feldspar-bearing envelopes are shown in Stage 1. There does not appear to be any correlation between a specific type of envelope and the vein mineralogy. Similarly, there is no apparent correlation between specific vein minerals and seritic envelopes. However, within the orebody, the following generalization is true: K-feldspar-bearing envelopes are more commonly developed on quartz-molybdenite veins and sericitic envelopes are more commonly developed on quartz-magnetite veins. The presence of magnetite and molybdenite with both envelope types points out that a sulphur-oxygen fugacity ratio has played an integral role in the mineralization history.

The width of the envelopes does not appear to bear any relation to vein width and/or vein mineralogy. For example, a 1-inch K-feldspar envelope can occur on a ⅛-inch quartz-molybdenite vein as often as a ¼-inch K-feldspar envelope can occur on a 1-inch quartz-molybdenite vein. The width of the envelope is dependent on the length of time that the original fracture was open to the altering and mineralizing fluid. Maximum envelope width recorded is 8 inches.

There are a few quartz-molybdenite veins which contain pink K-feldspar and which have quartz-sericite-pyrite envelopes. Their relative position in Table I is not accurately known. They are grouped with the other examples of sericitic envelopes and are thought to be transitional between Stages 1 and 2.

A 200- to 500-foot zone rich in pyrite occurs along the south side of the orebody. Within this zone, sericitic envelopes up to ½ inch thick are developed on quartz-pyrite (± molybdenite and/or magnetite) veins, but within the orebody sericitic envelopes are developed on quartz-magnetite-molybdenite (± pyrite) veins.

The stockwork must have been under tensional stress during the formation of the large rich quartz-molybdenite veins without envelopes (Stage 3). These veins have been reopened several times to allow the precipitation of as many as twenty-one individual molybdenite ribbons over a width of approximately 8 inches. Assuming that two ribbons were formed along the walls during each fracture period, there would have been a minimum of ten fracture periods in the formation of a vein of this type.

Quartz-pyrite veins without sericitic envelopes in the orebody and pyrite zone occasionally have a 'bleached halo' with a width of up to ½ inch. There is no difference in rock texture within the halo, but the following features can be noted: (1) biotite is not present; (2) altered greenish plagioclase in the rock has turned white; (3) pink or salmon pink K-feldspar may be present; and (4) the accessory mineral is pyrite within the halo and an iron oxide outside. This suggests that within the halo Mg and Fe have been leached as biotite has been removed, altered plagioclase has been bleached white and Fe has been sulphidized and fixed as pyrite. These halos are of minor abundance and cannot be shown as a separate stage in Table I.

There is no correlation between the intensity of pervasive alteration and the vein mineralogy. However, within the stockwork, the most commonly encountered alteration type would lie between weak and moderate kaolinization. Therefore, in general, the pervasive alteration type outward from Stage 3 or 4 vein or Stage 1 or 2 envelope will range from weak to moderate kaolinization.

It is doubtful if there is any alteration effect on the quartz-monzonite due to the veins or fractures of Stages 5 or 6. A few quartz-specularite veins were observed within an intensely kaolinized shear zone, but, because, the vein was not broken, it may have followed a previously developed shear. Calcite occurs as late veins, as open space fillings (calcite rhombs up to 1 inch) and as a breccia matrix to quartz-molybdenite veined and altered quartz monzonite. Chalcedony may be found with the calcite.

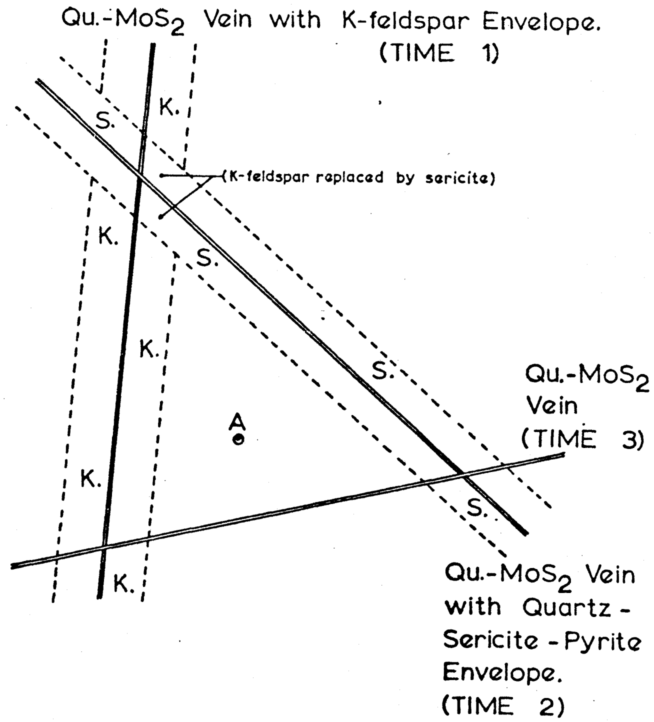


Figure 1.—Diagram illustrating time relationships of major veining events during mineralization. (Host rock is pervasively altered outward from veins with or without envelopes.)

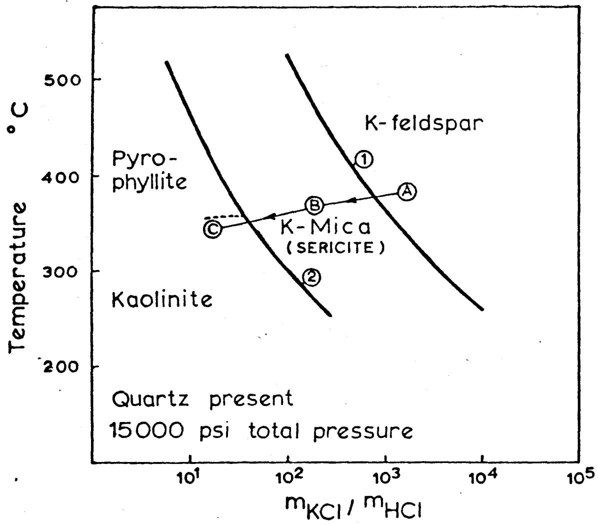
D. Chemical Controls

The question of chemical control would depend on the method that Time 1 conditions were changed to Time 2 or Time 3 conditions (see *Figure 1*). K-feldspar envelopes were developed earlier than sericite envelopes, as seen by cross-cutting relations where sericite has replaced the introduced K-feldspar. Outward from these envelopes and outward from the Stage 3 and 4 veins, the rock has been pervasively kaolinized. Textural evidence indicates that the kaolinization must have developed during the formation of the veins with and without envelopes. Late veins and fractures of Stage 5 and 6 are considered to be post-alteration and, consequently, are not part of this discussion.

The interrelationship of K-feldspar-bearing envelopes, sericite-bearing envelopes and pervasive kaolinization is discussed by Hemley (1959) and Hemley and Jones (1964). The suggested mechanism is a progressive ion leaching or migration of Ca^{++}, Na^{+}, Mg^{++}, Fe^{++}, and Fe^{+++} toward the vein with simultaneous migration of K^{+} and H^{+} outward from the vein. H^{+} and K^{+} would diffuse into the rock in response to concentration gradients from the vein. The K^{+}/H^{+} activity ratio would then vary outward from the vein in some non-linear manner which is dependent on the rate of supply of heat, K^{+} and pH and on the rate of removal of leached constituents. Iron may not be removed in the case of the K-feldspar-biotite or quartz-sericite-pyrite envelopes, where the iron is fixed in the biotite or sulphidized to pyrite respectively. Using this concept of two-way migration and fixation, the development of K-feldspar and sericite-bearing envelopes and the absence of an envelope can be explained by the same chemical control.

From the experimental work of Hemley (1959) *(Figure 2)*, the mechanism could be either temperature or the activity ratio of K^{+}/H^{+}. Temperature must have changed between Time 1 and Time 3 conditions, but it is possible that the temperature difference was not great. Consider a case, such as shown in *Figure 1*, where a quartz-molybdenite vein is imposed on a quartz-molybdenite vein with a quartz-sericite-pyrite envelope which has been imposed on a quartz-molybdenite vein with a K-feldspar envelope. Temperature variation from the vein with the K-feldspar envelope would have to be in the order of 100°C over perhaps an inch. A gradient of this magnitude is unlikely, but it is concluded that some temperature change occurred between Time 1 and Time 3. The major control is more logically assigned to variations in the activity ratio of K^{+}/H^{+}.

Using Hemley's curves, it is suggested that for Stage 1 veins with K-feldspar envelopes, the activity ratio of K^{+}/H^{+} at Time 1 must have been in the K-feldspar field. K-feldspar adjacent to these veins has completely changed the mineralogy and texture of the original rock. At some later time (Time 2), the activity ratio was within the K-mica (sericite) field as sericite replaces the earlier hydrothermal K-feldspar. The K^{+}/H^{+} ratio would further decrease with time (Time 3) and would move into the field of kaolinite. The K^{+}/H^{+} ratio will also decrease outward from veins with or without envelopes. This latter mechanism is the cause of the pervasive kaolinization.



Circled numbers relate curves to following equations:

$$3/2KAlSi_3O_8 + H^+ = 1/2KAl_3Si_3O_{10}(OH)_2 + 3SiO_2 + K^+, \quad (1)$$

(K-feldspar) (sericite)

$$KAl_3Si_3O_{10}(OH)_2 + H^+ + 3/2H_2O = 3/2Al_2Si_2O_5(OH)_4 + K^+. \quad (2)$$

(sericite) (kaolinite)

Figure 2.—Reaction curves for the system K_2O-Al_2O_3-SiO_2-H_2O. After Hemley (1959). (Line A-B-C is explained in text.)

The general trend in the change of the activity ratio with time is illustrated by line A-B-C *(Figure 2)*. Point A would represent the Stage 1 veins and the development of K-feldspar envelopes at Time 1; point B would represent Stage 2 veins and the development of sericitic envelopes at Time 2; and point C would represent the development of Stage 3 veins without envelopes. The slope of line A-B-C would necessarily be low and positive because the temperature difference would be small. Absolute location of the trend line is unknown because the temperature at point C is unknown. Point C must be below the pyrophyllite field (about 350°C), as pyrophyllite is absent. Consequently, this line indicates only the generalized trend in chemical change during mineralization.

Several other possible variables may be important in this system, but their individual role is not fully understood. The activity of silica has been reported by Fournier (1967) to be responsible for the coexistence of the K-feldspar-kaolinite pair. At Ely, Nevada, Fournier reported that plagioclase broke down to a mixture of hydrothermal K-feldspar and kaolinite at low temperature and high silica activity at 1,000 bars. At Endako, K-feldspar may replace altered plagioclase within K-feldspar-bearing envelopes, but the K-feldspar-kaolinite pair are not observed to be a breakdown product of plagioclase. This is in agreement with Meyer and Hemley (1959), who suggest that K-feldspar was metastable at the time of formation of kaolinite in the argillite zone at Butte, Montana.

The partial pressure of sulphur and oxygen are important controls in this system, because sulphides (molybdenite and pyrite) as well as an oxide (magnetite) exist in the veins. Meyer and Hemley (1967) note a strong correlation between hydrogen metasomatism and the fugacity of sulphur in ore mineral assemblages and state that "strong hydrogen metasomatism exists only when the S/O fugacity ratio is relatively high, not merely when oxygen fugacity is high" (p. 222).

SUMMARY AND CONCLUSIONS

Three characteristic alteration features of the Endako quartz monzonite within the Endako molybdenum deposit are: (1) K-feldspar-bearing envelopes, (2) quartz-sericite-pyrite envelopes and (3) pervasive kaolinization. Quartz-molybdenite (minor magnetite) veins with K-feldspar-bearing envelopes are more common within the orebody than quartz-magnetite-molybdenite veins with quartz-sericite-pyrite envelopes. Pervasive breakdown of the original plagioclase to kaolinite and some sericite occurs on the outward side of the envelopes and adjacent to quartz-molybdenite veins without envelopes. Kaolinization imparts a characteristic greenish hue to the original quartz monzonite. Cross-cutting relations indicate a relative age sequence among the various alteration stages which is in agreement with a chemical control based on the activity ratio of K^+/H^+ in a nearly isothermal environment.

The relative vein sequence of hydrothermal alteration products is illustrated more distinctly at Endako than in many of the porphyry copper deposits. The change in silicate mineralogy with time can be satisfactorily explained in terms of the chemical controls, as outlined by the experimental work of J. J. Hemley. It is hoped that more descriptions of mineral deposits will be published which stress the variation of silicate and metallic mineralogy with time during mineralization so that experimentalists may more closely approximate natural alteration assemblages in their laboratory investigations.

ACKNOWLEDGMENT

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Geology of the Endako Molybdenum Deposit

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ABSTRACT

The Endako molybdenum deposit is situated 100 miles west of Prince George, B.C., in the composite Jurassic Topley Intrusions. It occurs in older Endako quartz monzonite which is bounded on the south by François granite, and on the north by Casey alaskite and Glenannan granite.

The orebody in plan is roughly an elongated elliptical-shaped body which strikes N70°W, dips 20 degrees to 50 degrees south, and measures 6,400 feet long by 1,200 feet wide. In the vicinity of the orebody, the Endako quartz monzonite is intruded by pre-mineral aplite, porphyritic granite and quartz-feldspar porphyry, and post-mineral basalt dykes.

Mineralogy is simple and consists of quartz, molybdenite, pyrite, magnetite, calcite and, rarely, chalcopyrite occurring as veins and on fracture surfaces. Hydrothermal alteration has locally produced K-feldspar envelopes and quartz-sericite-pyrite envelopes, and has pervasively kaolinized the host rock.

The Endako orebody is visualized as a restricted stock work formed on an elongated east-west dome by uplift and intrusion, and localized at the intersection of regional east-west and northwest fault systems.

The orebody is classified as a low-grade porphyry-type deposit.

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A. D. DRUMMOND

E. T. KIMURA was born in Vancouver, and graduated from the University of British Columbia with a B.A. in geology and physics in 1955. He then returned for one year of postgraduate studies in geology. Mr. Kimura joined Eldorado Mining and Refining Ltd., at Eldorado, Sask., in 1956 as a mine geologist. He joined Craigmont Mines Ltd. as open-pit geologist in 1962, and transferred to Endako Mines Ltd. as senior geologist in 1964.

Dr. A. D. DRUMMOND received his primary and secondary education in Vancouver and graduated in geological engineering from the University of British Columbia as a B.A.Sc. in 1959, and as an M.A.Sc. in 1961. He obtained his doctorate in 1966 from the University of California. From 1958 to 1961, he was employed by Kennco Explorations (Western) Limited on the Lime Creek molybdenum deposit, which is now in production as British Columbia Molybdenum Limited. He has been associated with the Placer Development group of companies since 1963, first with Craigmont, then with Endako, and since 1967 as research geologist of Canex Aerial Exploration Limited.

MANUSCRIPT SUBMITTED: on December 19, 1968.

KEYWORDS: Endako Mines Ltd., Molybdenum deposits, Topley Intrusions, Hydrothermal alteration, Porphyry-type deposits, Mine geology, Quartz monzonite, Mineralization, Structural geology, Stockworks, Ore control.

INTRODUCTION

THE ENDAKO MOLYBDENUM DEPOSIT is located about 100 miles west of Prince George in central British Columbia. The mine property is 6 miles southwest of the village of Endako, which is on Highway 16 and a branch line of the Canadian National Railway.

The Endako area is within the Interior System of the Canadian Cordillera and, more specifically, within the physiographic subdivision referred to as the Nechako Plateau. Local terrain is flat to gently rolling. Pleistocene glaciers moved eastward across the area, and have imprinted and accentuated easterly-trending lineaments. Topographic relief ranges from an elevation of 2,200 feet at Endako village to 3,500 feet on the crest of the Endako open pit.

HISTORY AND DEVELOPMENT

The molybdenite deposit was discovered in 1927 by two local hunters who staked four mineral claims to cover an area of mineralized float. They subsequently uncovered a 2-foot-wide quartz-molybdenite vein. During 1934, a short inclined shaft was sunk on the vein structure and a short adit was driven into the hillside to intersect another vein. The property, during the period 1934 to 1959, was examined by various companies and individuals, but little exploratory work was done. It should be noted that about 95 per cent of the area is masked by overburden, and this hampered examination and exploration of the prospect. The original discoverers allowed their mineral claims to lapse in 1959.

The key claims were later re-staked and, following a program of trenching and mapping, R and P Metals Corporation Ltd. initiated a diamond drilling in 1962. Drilling results were encouraging and Endako Mines Ltd. (N.P.L.) was incorporated as a private company on June 21, 1962. It became a public company on August 10, 1962.

Personnel from Canadian Exploration Limited, a wholly-owned subsidiary of Placer Development Limited, examined the property in late August 1962. As a result of their favourable examination, Canadian Exploration Limited entered into exploration of the property in October 1962. Following the completion and evaluation of 190 diamond drill holes totalling 80,000 feet and 2,700 feet of underground work for bulk sample testing, the decision to develop the property for production was announced in March 1964.

Construction of the 10,000-tpd mine plant and development of the open pit began in June 1964. The mine was officially opened on June 8, 1965. Modifications to the plant during the first two years allowed mine production to be gradually increased to a throughput of 17,500 tons per day. A major mill expansion to increase milling capacity commenced in June 1967 and was completed by November of 1967.

Production is currently being maintained at 25,000 tons per day at an average ore grade of 0.16 per cent MoS_2. Two products, molybdenum sulphide and molybdenum oxide, are produced. Ore reserves within an ultimate pit design are calculated at a cut-off grade of 0.08 per cent MoS_2 and are estimated at 239,000,000 tons with an average grade of 0.15 per cent MoS_2. The ultimate open-pit strip ratio will be 0.5:1.

REGIONAL GEOLOGY

The Endako molybdenite orebody occurs in the Topley Intrusions, which are considered to be of late Jurassic age and are intruded into early Mesozoic sediments and volcanic rocks. Regional distribution of the Topley Intrusions extends from the center of Babine lake to Quesnel, a distance of about 180 miles along a regional northwesterly trend (*Figure 1*).

The emplacement of the Topley Intrusions was probably influenced and related to the regional structural events which occurred during Jurassic time for the Central and North-Central Belt of the Cordillera of British Columbia. It is presumed that emergent and uplifted areas, with associated northwest fault control and granitic intrusions, prevailed for this period. The continuation of regional stress conditions after intrusion is evidenced by the structural trends which surround and cross-cut the Topley rocks. The predominant trends are northwest, east-west and, to a lesser degree, northeast lineations. These may have been developed as part of the compressional components which formed the Skeena Arch during the Upper Jurassic - Lower Cretaceous period. The axis of this regional east-west- to east-northeast-trending structural uplift existed across the north tip of Babine lake (Souther and Armstrong, 1966.)

The Topley Intrusions comprise a composite batholith in which granite, quartz monzonite, granodiorite, quartz diorite and diorite have been identified. The Endako deposit is centrally situated within the batholith and occurs in one of the oldest recognized rock intrusions of this batholith.

LOCAL GEOLOGY

The distribution of rock types, the major structures and the ore deposit in the Endako mine area are shown in *Figure 2*.

Rock Types

The names of the various rock types follow the usage of Carr (1966).

Takla Group volcanic rocks of Lower Mesozoic age are a sequence of dark green to purple lavas, tuffs and flow rocks which locally contain small white quartz, feldspar and biotite phenocrysts in a hard aphanitic matrix.

Topley Intrusions consist of four distinct rock types in the mine area.

(a) *Endako Quartz Monzonite,* the ore host, is generally equigranular (3-4 mm), with some K-feldspar crystals in places as large as 7 mm. This size difference imparts a suggestion of a porphyritic texture, but is not sufficiently distinct to warrant the term "porphyritic." The rock consists of quartz (30%), pale pink to orange-tinged K-feldspar (perthitic orthoclase) (35%), white to green-tinged plagioclase (An_{20}) (30%) and partially chloritized black biotite (5-10%), with accessory magnetite, pyrite, apatite and sphene. The K-feldspar/total feldspar ratio ranges from two-thirds to one-half, but is predominantly one-half and, therefore, the rock is referred to as quartz monzonite rather than granite. Scattered dark rounded biotite-rich inclusions 2-10 cm across are common. The rock is readily recognized by

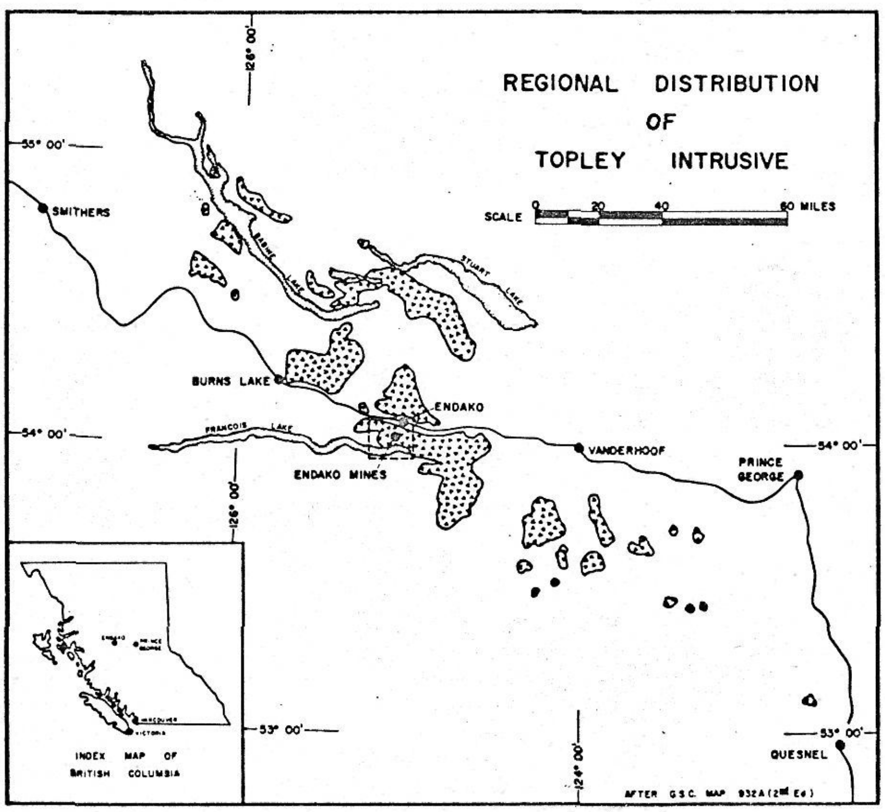


Figure 1.—Regional setting of Topley Intrusions, showing the northwest trend of the batholith.

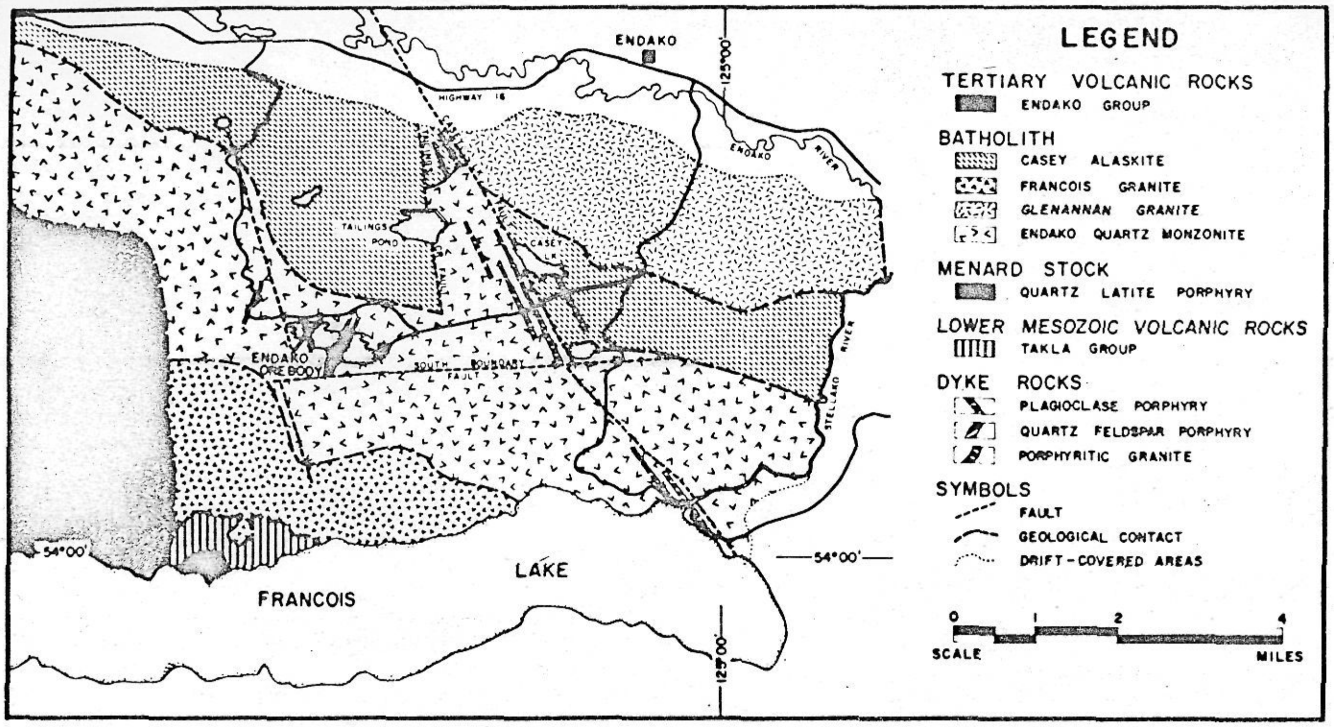


Figure 2.—Geology of the Endako area.

its characteristic pink to bright orange-pink K-feldspar.

(b) *Casey Alaskite* is normally a fine-to medium-grained (1-3 mm), sugary-textured, leucocratic rock. It is made up of quartz (40%), pale pink K-feldspar (45%), white plagioclase (5-15%), partially chloritized biotite (2-5%) and accessory pyrite and hematite (1%). The subrounded sugary quartz has a characteristic greasy grey appearance. Some coarser grained, inequigranular and subporphyritic varieties occur locally; they are mineralogically the same as normal Casey alaskite, and may be in sharp contact with it, but age relations are not known.

(c) *Francois Granite* is a distinctive red equigranular (3-4 mm) rock composed of quartz (35%), perthitic K-feldspar (45%), white plagioclase with greenish cores ($An_{13\text{-}18}$) (15%), chloritized biotite (3-5%), and accessory amounts of magnetite, pyrite and sphene (1%). Some feldspar grains exhibit a rare rapakivi textural feature in which K-feldspar grains are mantled by white plagioclase. This texture appears to be confined to this rock type, and to date has been noted only in specimens from near the contact with Endako quartz monzonite.

(d) *Glenannan Granite* is a coarse-grained granite to quartz monzonite consisting of quartz (20-25%), pink K-feldspar (40-55%), white plagioclase (15-30%) and biotite (5-10%). Texturally, the rock ranges from essentially equigranular (5-6 mm) to porphyritic, with K-feldspar and plagioclase crystals up to 2 cm. Pegmatitic phases with grains ranging from 1-2 cm across have also been locally noted, with quartz (25%), K-feldspar (70%), plagioclase (5%) and less than 1 per cent biotite.

Menard Stock is a small arcuate-shaped stock of quartz latite porphyry which intrudes Takla volcanic rocks. The rock consists of 40 per cent disoriented phenocrysts (2-5 mm) of white plagioclase, quartz and biotite in a reddish-brown to purple aphanitic groundmass. There is no evidence to suggest that this intrusion is related to the Topley Intrusions.

Endako Group volcanic rocks of Tertiary age overlie the older rocks. These rocks are predominantly dark green to grey, porphyritic, vesicular basaltic flows.

Plagioclase Porphyry Dykes ranging from 50 to 200 feet wide form a swarm about 1 mile adjacent and subparallel to the northwesterly-trending Casey Lake fault. The dykes intrude Endako quartz monzonite and Casey alaskite, and locally cut mineralization. The rock contains euhedral white plagioclase phenocrysts 4-6 mm long (10-15%) and biotite flakes (1-2%) in a dark green to grey aphanitic matrix. These rocks may be related to the Tertiary volcanism.

Basalt dykes are dark green and fine-grained to porphyritic. They are the youngest known intrusions in the area and intrude all of the Topley Intrusions and the plagioclase porphyry dykes in the mine area.

Relative Ages of Rock Types

The oldest rocks in the area are those of the Takla Group of Lower Mesozoic age. The Topley has intruded these rocks. Within the Topley, the Endako quartz monzonite is one of the older rock types and has been dated at 140 m.y. (White *et al.* 1967). The adjacent Francois granite to the south and Casey alaskite to the north are younger, as evidenced by dykes, correlated with these rocks, which are intruded into Endako quartz monzonite. The Glenannan granite is older than the Casey alaskite, as a dyke rock correlative with the latter intrudes the former. As yet, age relations cannot be determined between Glenannan granite and Endako quartz monzonite and between Francois granite and Casey alaskite.

The Menard quartz latite porphyry stock intrudes Takla volcanic rocks, but there is insufficient evidence to suggest that it is pre- or post-Topley.

Tertiary volcanic rocks of the Endako Group are the more recent rock types. Plagioclase porphyry and younger basalt dykes are probably related to late Tertiary volcanism.

Structure

Two major fault trends occur in the mine area; these are local representatives of regionally developed fault systems. The local fault trends are represented by the east-west South Boundary fault and the northwest-trending Casey Lake fault, Tailings Creek fault and another fault located near the west end of the Endako orebody. These faults form conspicuous topographic lineaments.

Relative movement and displacement along the South Boundary fault is unknown. It is considered that this fault acted as a major control for the development of the Endako stockwork.

Relative horizontal movement along the northwesterly faults is indicated by the apparent offsets of the Endako quartz monzonite and Casey alaskite (*Figure 2*).

MINE GEOLOGY

The molybdenum deposit occurs wholly within the Endako quartz monzonite. The orebody can be considered as a series of east-west ore bands oriented *en echelon* so as to form an ore zone elongated in a northwesterly direction. The zone is 6,400 feet long by 1,200 feet wide. The dip and depth of economic mineralization varies; the west end dips 55 degrees south and is over 1,000 feet deep, the central portion dips 35 degrees south and is 700 feet deep, and the east end dips 20 degrees south and is less than 100 feet deep.

The Endako quartz monzonite in the mine area is intruded by pre-mineral aplite, porphyritic granite and quartz-feldspar porphyry and post-mineral basalt dykes (*Figure 3*).

Aplite is typically a pink, fine sugary-textured rock containing graphically intergrown quartz and K-feldspar. The estimated modal composition is quartz (40%), pink K-feldspar (40%), white plagioclase (An_{20}) (20%) and less than 1 per cent chloritized biotite. Randomly oriented aplite dykes occur in all rock types of the Topley batholith in vicinity of the mine, but are especially numerous within and near the Endako ore deposit. The aplites, which are observed in association with the ore deposit as ¼-inch- to 4-ft-wide unoriented dykes, may not be of the same age as the widespread regionally distributed aplites.

"Porphyritic granite" is a pink, massive dyke rock containing about 3 per cent large Carlsbad-twinned orthoclase phenocrysts (1 cm) scattered throughout a fine-grained, phaneritic, seriate-textured matrix (0.1-1 mm). The matrix is composed of quartz (20%), K-feldspar (45%), plagioclase (25%) and biotite (5%). Zircon and apatite are accessory minerals. The dykes range from 4 to 50 feet wide and generally trend northeast. They have only been observed in the immediate mine area.

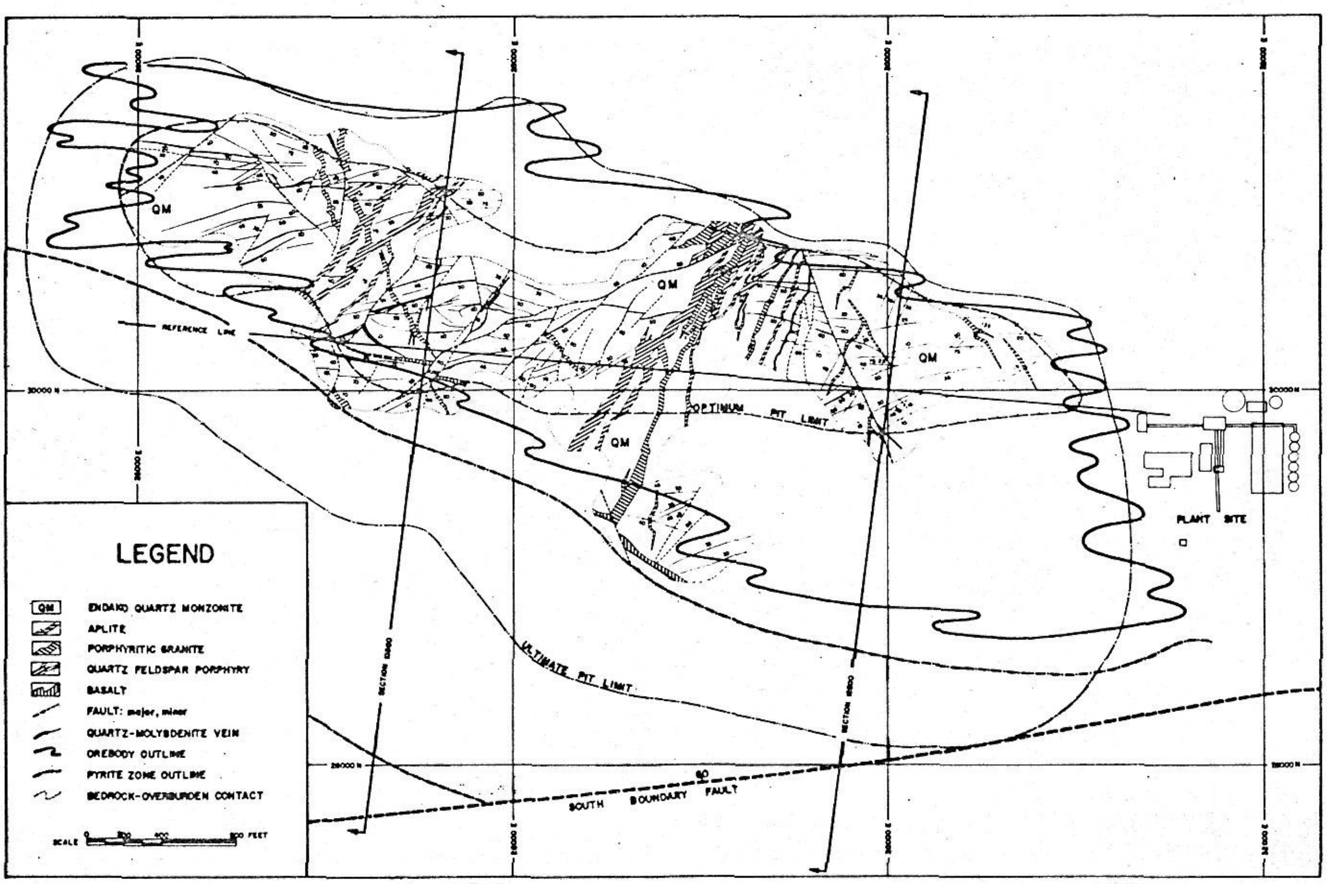


Figure 3.—Geological map of open-pit surface.

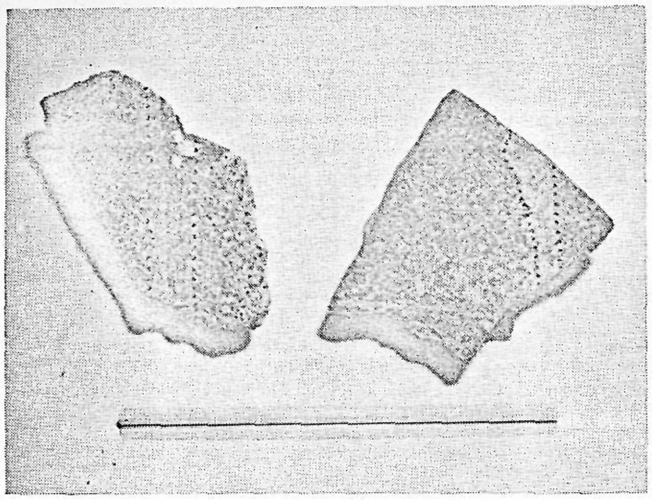


Figure 4.—Specimen on left shows a quartz-sericite-pyrite envelope developed on a quartz-magnetite vein. Specimen on right shows a K-feldspar envelope developed on a barren *quartz vein.*

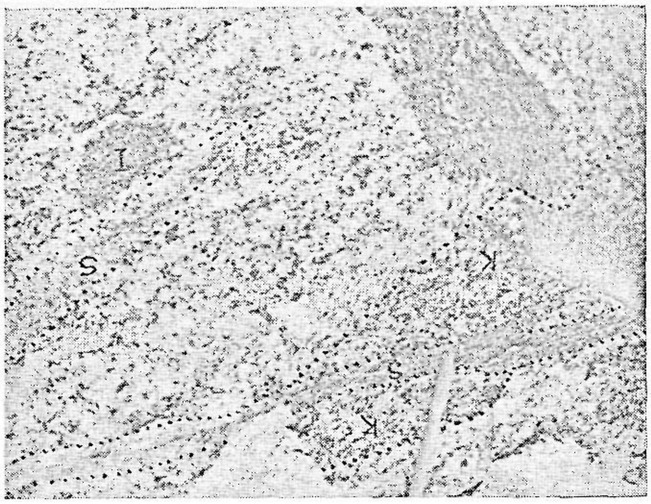


Figure 5.—Quartz-sericite-pyrite(S) envelope cross-cutting a K-feldspar-biotite(K) zone in weakly kaolinized monzonite. A second quartz-sericite-pyrite envelope is outlined *alongside a mafic-rich inclusion(I).*

Quartz-feldspar porphyry is the most abundant dyke rock in the mine area. These dykes range from several inches to 150 feet in width, and characteristically show very close jointing. Two distinct types have been observed:

(a) A brown to pink rock composed of 10 to 15 per cent phenocrysts (2 mm) of quartz and K-feldspar in an aphanitic matrix.

(b) A brown rock composed of quartz (5-10%), K-feldspar (1-5%) and sagenitic biotite phenocrysts (1-2 mm) (1-3%) in a dense, aphanitic matrix. The matrix also contains scattered euhedral K-feldspar phenocrysts up to 1 cm in length. This dyke rock is termed quartz-feldspar porphyry "biotite variety." Dyke contacts with host rocks are sharp and rarely exhibit chilled selvages. Local attitudes of individual dykes may be observed to strike at any angle from the general trend due to angular and blocky faulting within the Endako quartz monzonite. "Porphyritic granite," quartz-feldspar porhpry and several larger aplite dykes are present as swarms in two parts of the orebody. The easterly swarm trends northwest and the westerly swarm is oriented in conjugate northeast and northwest directions (*Figure 3*). All dykes are near vertical to steeply west-dipping.

Cross-cutting relationships have established the following age relationships: aplite (oldest); "porphyritic granite;" and quartz-feldspar porphyry (youngest).

Basalt and porphyritic basalt dykes have been intruded into post-mineral faults.

HYDROTHERMAL ALTERATION

Three distinct hydrothermal alteration products are recognized in the Endako ore zone. Orange-pink K-feldspar has been developed as ⅛-inch envelope to 2-foot-wide zones on veins and fractures. A quartz-sericite-pyrite phase is also developed as ⅛- to 2-in.-wide envelopes on veins. Pervasive kaolinization of the Endako quartz monzonite is widespread, and varies from a slight development of kaolinite in plagioclase in otherwise unaltered rock to complete alteration of both plagioclase and K-feldspar to a soft creamy white or green clay.

The general distribution and intensity of hydrothermal alteration across the ore zone are shown in *Figure 6*. The trends of the zone boundaries are inferred; it is presumed that the transition zones would be subparallel to the orebody.

Reference is made to a succeeding paper in this issue entitled "Hydrothermal Alteration at Endako Mines — A Comparison to Experimental Studies" (A. D. Drummond and E. T. Kimura, 1969), which details the significance of hydrothermal alteration and its relationship to vein mineralogy within the Endako ore deposit.

MINERALIZATION

The most abundant primary ore minerals in the orebody are molybdenite, pyrite and magnetite, with minor amounts of chalcopyrite and traces of bornite, bismuthinite, scheelite and specularite. All of these minerals are intimately associated with quartz veining. Calcite and chalcedony occur in late veins and fractures. Beryl is a rare vein mineral (personal communication, K. M. Dawson, University of British Columbia); it occurs as small (1-3 cm), pale green, prismatic crystals and radiating clusters in quartz-molybdenite-pyrite veins.

Ore minerals occur in two types of veins: in large quartz-molybdenite veins and in fine fracture-fillings and veinlets in the form of a stockwork.

The major quartz-molybdenite veins occur within the ore zone as a series of subparallel 6-inch- to 4-foot-wide veins. Molybdenite typically occurs as thin (1/32-1/4 inch) closely-spaced laminae and as finely divided grains in milky white quartz veins (*Figure 7*).

Brecciation of veins with subsequent quartz-molybdenite healing is common. Magnetite, pyrite and minor chalcopyrite are intimately associated with molybdenite. Large veins may swell, pinch and horsetail (*Figure 8*), but the structural continuity of vein systems has been traced for over 2,000 feet along strike. The veins influence and control the trend of stockwork development.

Quartz, molybdenite and associated ore minerals occur in randomly oriented fractures in a stockwork adjacent to and surrounding the major quartz-molybdenite veins. Veinlets range from minute wisps of molybdenite to 2-inch-wide quartz-molybdenite veins (*Figures 7* and *9*). Veins within the economic stockwork are spaced from inches to several feet apart. The economic limits of mineralized stockwork range from 20 to 200 feet wide.

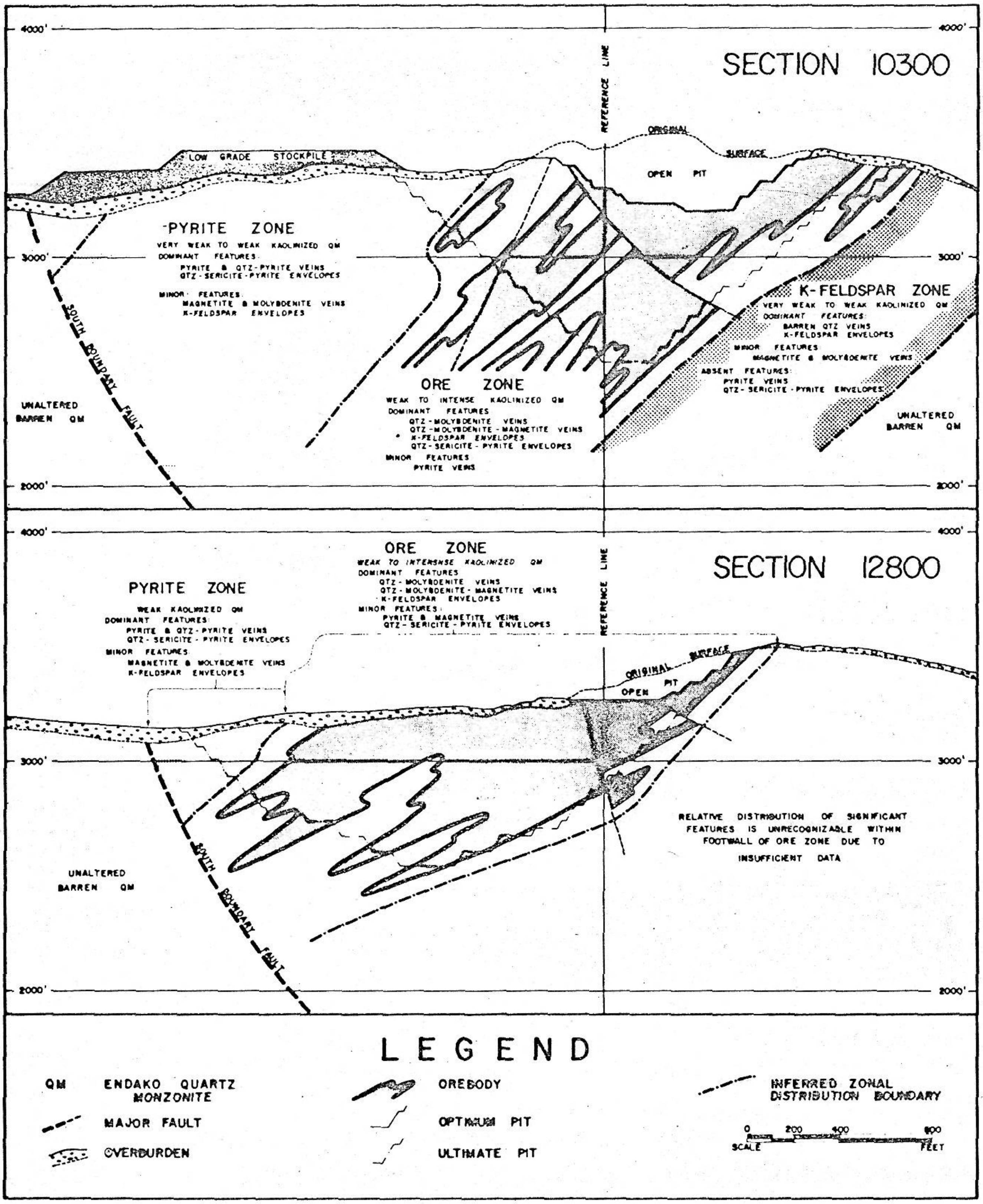


Figure 6.—Geological Cross Sections (looking west).

The distribution and orientation of veins across the present open pit are illustrated in *Figure 10*. Four subparallel sets of major vein systems occur in that part of the orebody which is west of the easterly dyke swarm. East of this dyke swarm, only one major vein has been observed within a very well developed stockwork. Variations in vein distribution and habit are reflected in the distribution of molybdenite values across the open pit (see lower half of *Figure 10*). The west half of the pit is characterized by erratically distributed high-grade assays due to large veins. Generally lower but more uniform grades, which are attributable to mineralization of a well-developed stockwork, are apparent in the east half of the open pit.

Vein development is restricted to very fine fracture-fillings in the intensely jointed pre-mineral dykes. Despite the lack of larger veins, the concentration of molybdenite and the over-all ore grade are unaffected by differences in the host rock.

A pyrite zone bounds the orebody to the south (*Figures 3* and *6*). The zone consists of fine quartz and pyrite, minor magnetite and rare molybdenite mineralization as fracture-fillings in a poorly-developed stockwork. Pyrite content is estimated to be about 1 per cent. The zone has not been recognized in other peripheral areas of the orebody.

The sequence of formation of hydrothermal alteration products and primary vein minerals is discussed in a succeeding paper (Drummond and Kimura, 1969).

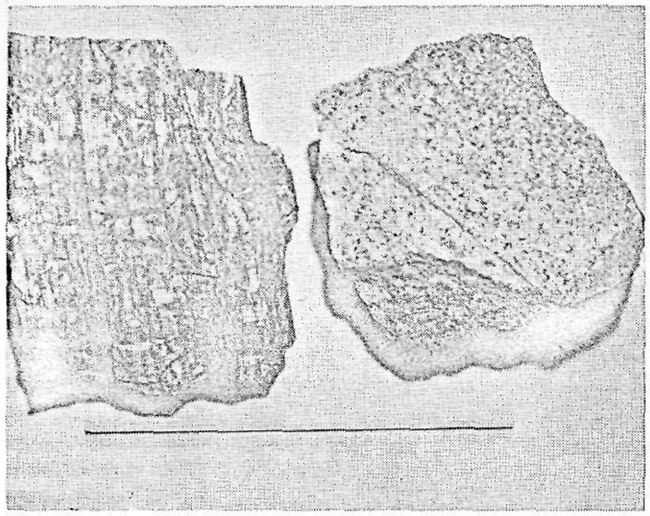


Figure 7.—Major quartz-molybdenite vein on left, showing banded molybdenite mineralization in quartz. Very fine quartz-molybdenite veinlets in weakly kaolinized quartz monzonite at right.

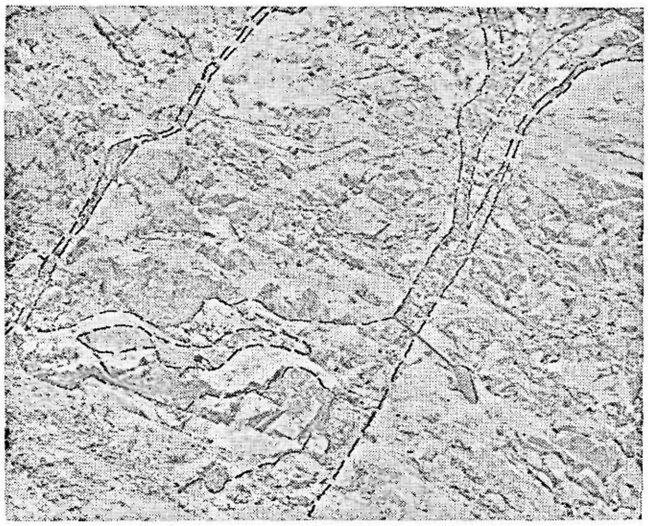


Figure 8.—Major quartz-molybdenite vein showing horsetail features. A subparallel smaller vein occurs at left.

Figure 9.—Quartz-molybdenite stockwork in moderate to intensely kaolinized quartz monzonite.

OXIDATION

A yellow- to honey-brown zone of surface oxidation ranges in depth from 5 to 60 feet over the orebody. The zone appears to have deeper penetration on south-facing slopes, along major fault zones and within the well-fractured quartz-feldspar porphyry dykes. Ferrimolybdite and limonite are the chief secondary minerals. Other oxidation products include malachite, pyrolusite, powdery hematite and powellite (oral communication, J. A. Gower and K. M. Dawson, University of British Columbia). None of the molybdenum oxide minerals are economically recovered.

Oxidation has not appreciably affected the larger and more compact quartz-molybdenite veins. However, molybdenite in the majority of the finer veinlets within the oxide zone has been converted to secondary molybdenum minerals.

STRUCTURE

Structural elements of the Endako orebody are illustrated in *Figure 10*. The available data from two open-pit benches was divided into two sub-areas, with the divisional boundary being established along the western margin of the easterly dyke swarm. Structural data are plotted on lower-hemisphere equal-area projections.

There are significant differences in structural trends between the two sub-areas. Most quartz-molybdenite veins in the westerly sub-area strike east-west and dip steeply south; a minor population of east-west striking and flat-lying veins is noted. Mineralization in the easterly sub-area occurs principally as thin

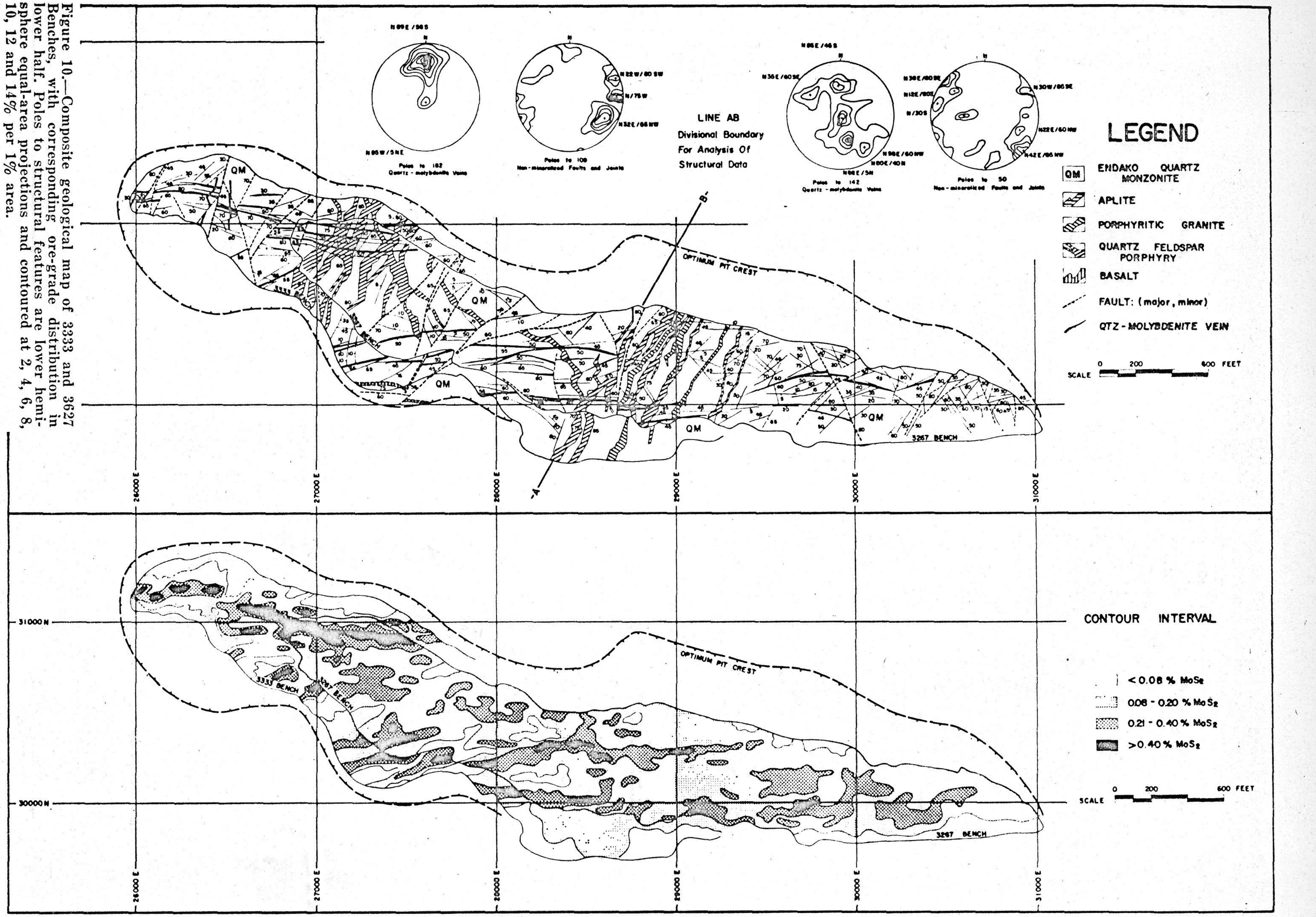
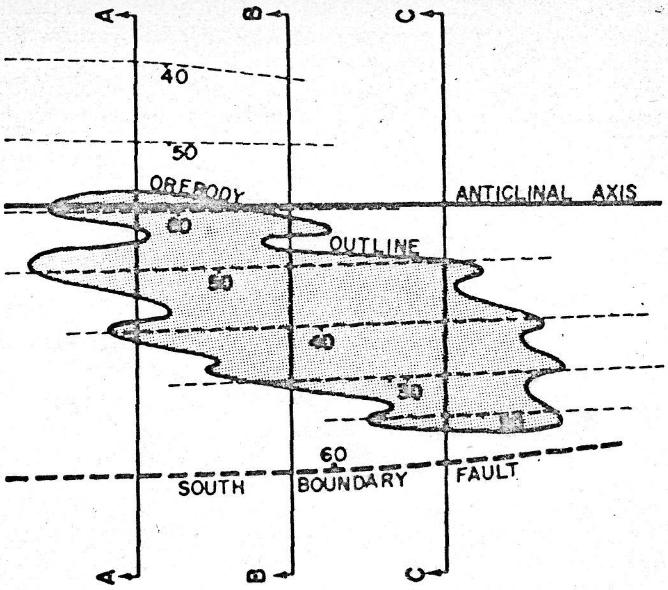
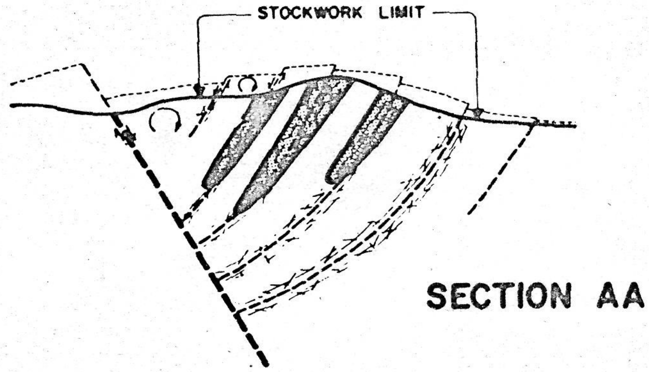


Figure 10.—Composite geological map of 3333 and 3627 Benches, with corresponding ore-grade distribution in lower half. Poles to structural features are lower hemisphere equal-area projections and contoured at 2, 4, 6, 8, 10, 12 and 14% per 1% area.

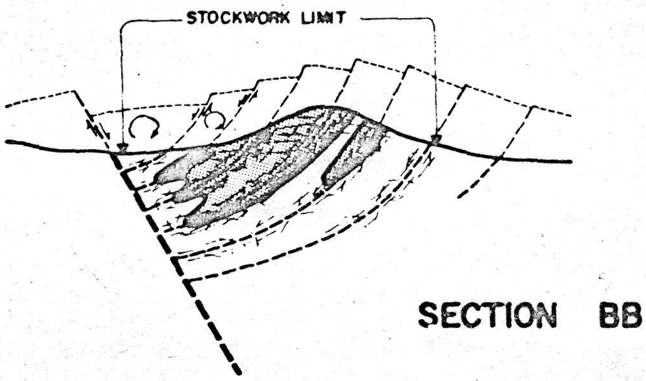
Plan shows an elongate and uplifted structural model which is represented by a major longitudinal normal fault (South Boundary fault) and conjugate-dipping curvo-planar antithetic faults (major quartz-molybdenite veins). The model is subjected to vertical westerly downward tilting and subsequent erosion. This produces structurally high and low levels from west to east within the Enkado stockwork as well as establishing the spatial location and attitude of ore bands with respect to the South Boundary fault.



Structurally high level of antithetic wedge is represented by maximum downward tilt and minimum erosion. Relative position of steep-dipping ore zone to the South Boundary fault is considerable distance. Ore zone is a series of discrete bands centered on widely spaced antithetic faults.



Intermediate structural level is represented as an area of maximum anticlinal arching. Numerous flat-lying tensional features and veins occur in a well-developed stockwork.



Structurally low level of antithetic wedge is represented by maximum upward tilt and erosion. Uniform flatter-lying ore zone occurs adjacent and abutting the South Boundary fault and within an intense stockwork developed around converging antithetic faults.

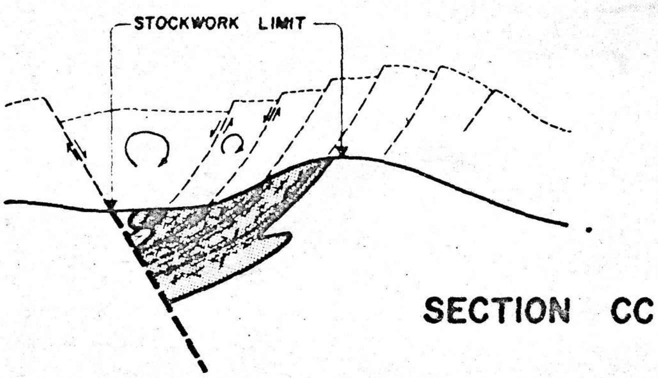


Figure 11.—Schematic illustrations of plan and sections of antithetic fault structure.

veinlets in a stockwork. The random orientation of these veins is shown on the plots as several preferred strikes but distinctly variable dips. The south-dipping veins in the eastern area are not as steep as those in the western area. Flat-lying veins are more prevalent in the east sub-area.

The dominant trends of unmineralized faults and joints are northeast, northwest and due north. East-west faults generally occur along major quartz-molybdenite veins, and are seen as gouge along contacts and brecciation within the vein. These vein contact features are not represented on the stereonet plots.

In summary, the mineralized veins strike east-west, northeast and northwest; these attitudes are subparallel to post-mineral faults. Pre-mineral dykes, which were probably intruded into major fault zones, strike northeast and northwest (see *Figures 3* and *10*). These local attitudes are concordant to the regional structural trends and can probably be defined as the resultant local representatives of regionally developed fault systems.

Structural Interpretation of Stockwork Development

The Endako stockwork is an elongated elliptical-shaped zone of intense fracturing and veining. The peripheral extent of the stockwork is restricted, and this is indicated by the virtual lack of quartz veins in areas outside of the orebody. The entire south-dipping fracture system abuts against the north-dipping South Boundary fault.

The stockwork is thought to have formed along an elongated east-west dome during repeated periods of uplift, collapse and dyke intrusion. The dome formed at the intersection of regional east-west and northwest fault systems. The repeated conditions of uplift and collapse along the elongated dome are pictured as being the main influence for the development of a longitudinal north-dipping normal fault and subsequent antithetic south-dipping curvo-planar structures (Wisser, 1960). The structural model is illustrated in *Figure 11*, in which the South Boundary fault is envisaged as the north-dipping normal fault and major sets of east-west quartz-molybdenite veins as the south-dipping antithetic faults. The concept of antithetic faulting is also applied in order to interpret the gradual change in dip along the length of the deposit and the spatial location of the stockwork in relation to the South Boundary fault. If the entire antithetic fault structure had been tilted about 10 to 20 degrees west, then the erosion of this tilted block to the present exposed datum would allow the west end to occupy a more steeply dipping and structurally high level as compared to the more flatly dipping and structurally low east end. Thus, the higher-level west end would spatially have been farther away from the South Boundary fault relative to the structurally lower east end which abuts against this major fault.

Fracture zones, which now form the stockwork developed along the curvo-planar antithetic faults. At structurally high levels antithetic faults were widely spaced, thus high-grade veins surrounded by a limited amount of stockwork fracturing were formed. At structurally lower levels, antithetic faults and associated fracture zones converged, and as a result, major vein systems grade into a single stockwork.

The schematic diagrams in *Figure 11* illustrate the structural model described above.

ORE CONTROL

Ore control for the Endako ore deposit is predominantly structural. The intersection of regional east-west and northwest fault structures was the focal point for repeated periods of uplift and collapse to produce a well-developed and restricted pattern of fracturing which was favourable for ore deposition. The concept of antithetic faulting can be used to explain the spatial orientation and distribution of veins within the stockwork.

CONCLUSION

The Endako orebody is a porphyry-type deposit. Mineralization occurs as veins and stockworks in quartz monzonite and three types of pre-mineral dykes. Several periods of uplift and collapse under localized stress conditions at the intersection of regional east-west and northwest structures formed an elongated east-west dome. An antithetic fault system and associated fracturing in this dome controlled three phases of hydrothermal alteration and molybdenite mineralization.

ACKNOWLEDGMENT

The authors are indebted to the geologists who are currently and previously associated with Endako Mines Ltd. (N.P.L.) for their part in geologic mapping and the compilation of data. Special acknowledgment is given to K. M. Dawson for his assistance in the interpretation of local geology and in undertaking selected geological studies.

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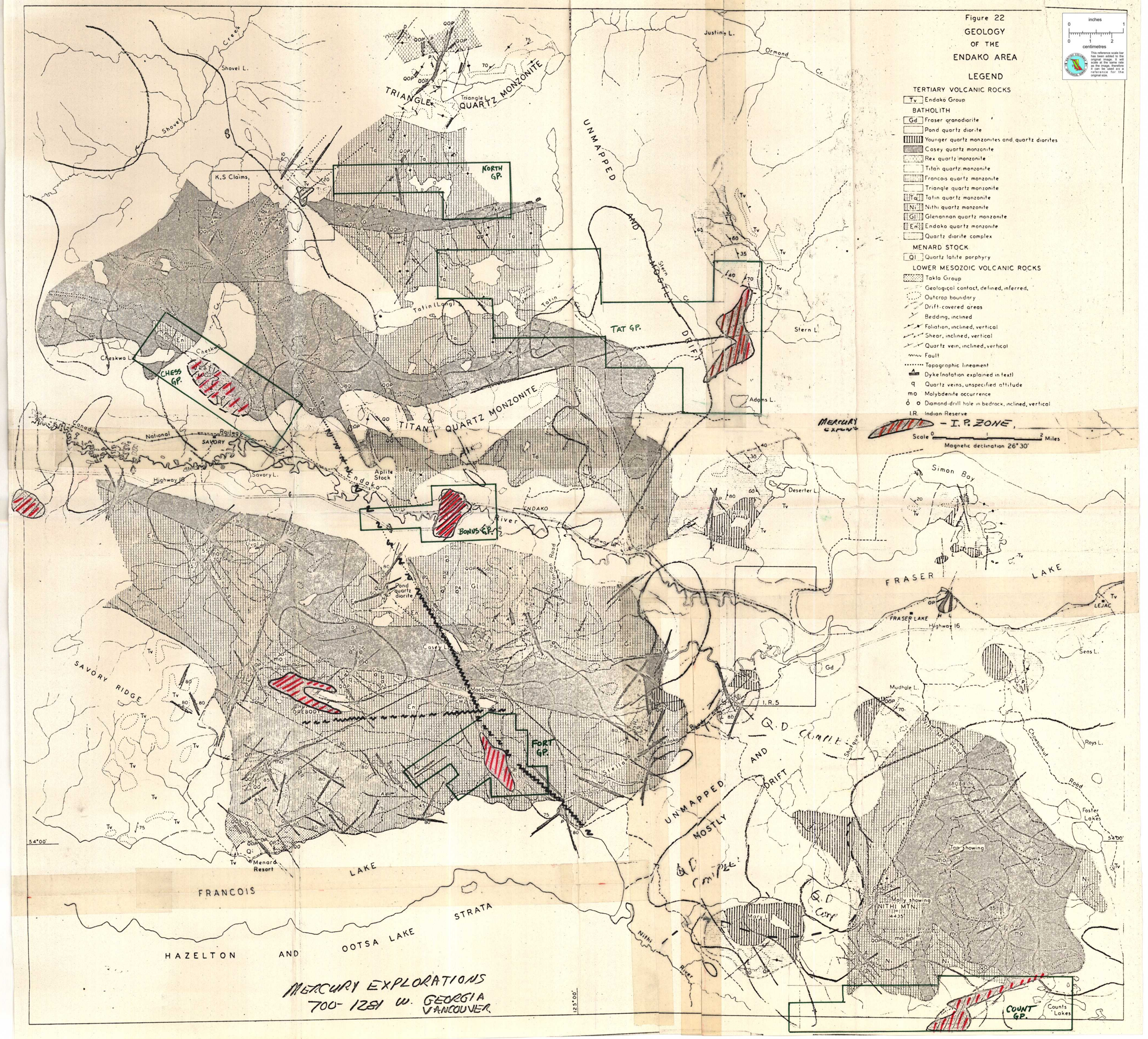
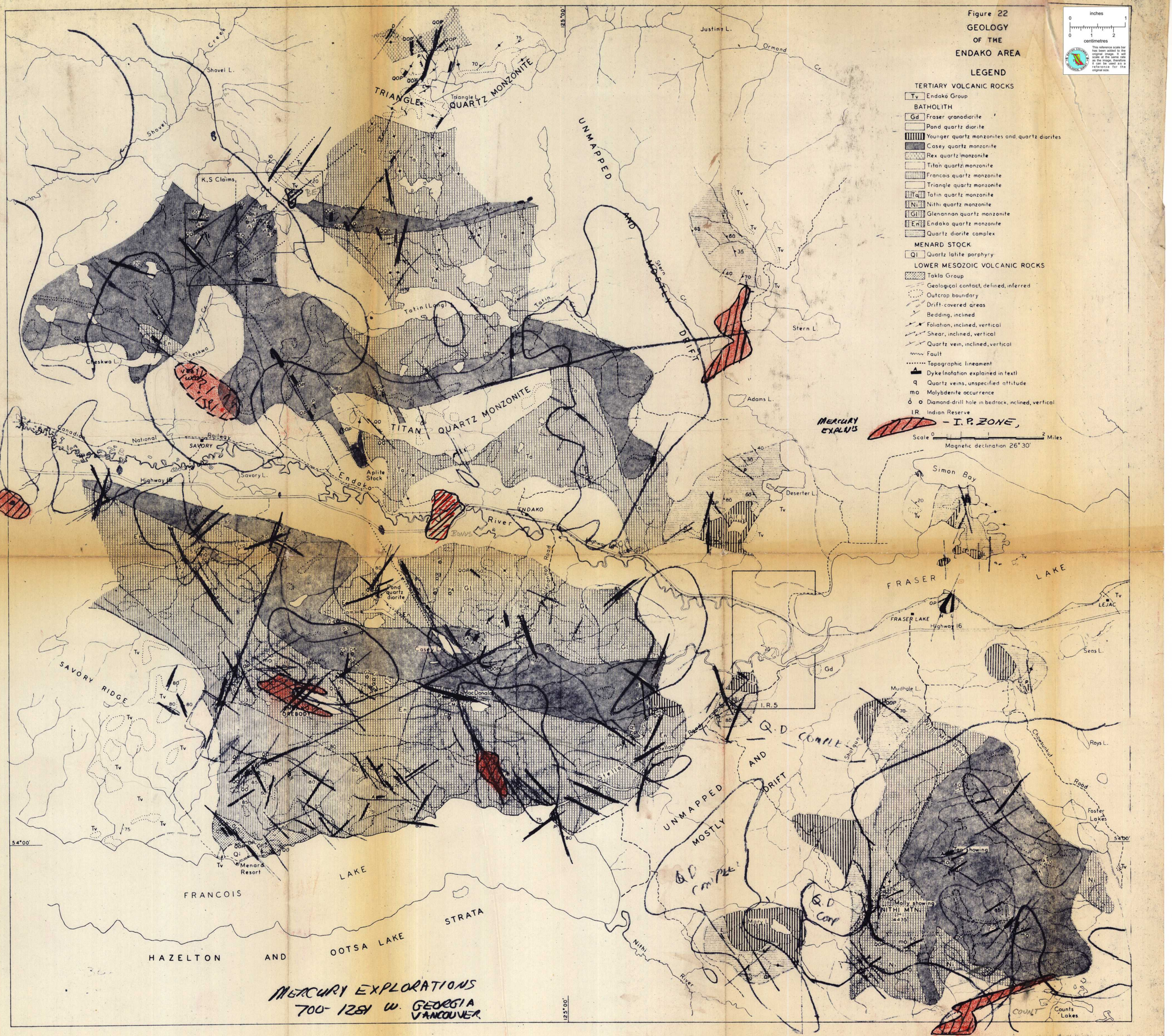


Figure 22
GEOLOGY OF THE ENDAKO AREA
LEGEND
TERTIARY VOLCANIC ROCKS
Tv Endako Group
BATHOLITH
Gd Fraser granodiorite
Pond quartz diorite
Younger quartz monzonites and quartz diorites
Casey quartz monzonite
Rex quartz monzonite
Titan quartz monzonite
Francois quartz monzonite
Triangle quartz monzonite
Ta Tatin quartz monzonite
Ni Nithi quartz monzonite
Gl Glenannan quartz monzonite
En Endako quartz monzonite
Quartz diorite complex
MENARD STOCK
Ql Quartz latite porphyry
LOWER MESOZOIC VOLCANIC ROCKS
Takla Group
Geological contact, defined, inferred
Outcrop boundary
Drift-covered areas
Bedding, inclined
Foliation, inclined, vertical
Shear, inclined, vertical
Quartz vein, inclined, vertical
Fault
Topographic lineament
Dyke (notation explained in text)
q Quartz veins, unspecified attitude
mo Molybdenite occurrence
Diamond-drill hole in bedrock, inclined, vertical
I.R. Indian Reserve
MERCURY EXPLNS - I.P. ZONE
Scale 2 Miles
Magnetic declination 26°30'
TRIANGLE QUARTZ MONZONITE
TITAN QUARTZ MONZONITE
UNMAPPED AND MOSTLY DRIFT
NORTH GP.
TAT GP.
CHESS GP.
BONUS GP.
FORT GP.
COUNT GP.
K.S Claims
Shovel L.
Triangle L.
Justine L.
Ormond Cr.
Tatin (Long) L.
Stern L.
Adams L.
Cheskwa L.
Canadian National Railway
SAVORY
Savory L.
Highway 16
Aplite Stock
Endako
ENDAKO River
Deserter L.
Simon Bay
FRASER LAKE
FRASER LAKE
LEJAC
Seas L.
Pond quartz diorite
Casey
MacDonald
OREBODY
SAVORY RIDGE
Mudhole L.
Gd
I.R. 5
Q.D. COMPLEX
Roys L.
Foster Lakes
Tan showing
Molly showing
NITHI MTN.
Mary L.
Nithi River
Counts Lakes
Menard Resort
FRANCOIS LAKE
HAZELTON AND OOTSA LAKE STRATA
54°00'
125°00'
MERCURY EXPLORATIONS
700-1281 W. GEORGIA
VANCOUVER



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- I. P. ZONE,
Scale 0 1 2 Miles
Magnetic declination 26°30'
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BRITISH COLUMBIA GEOLOGICAL SURVEY
TRIANGLE QUARTZ MONZONITE
TITAN QUARTZ MONZONITE
UNMAPPED AND MOSTLY DRIFT
Q.D. COMPLEX
Q.D. COMPLEX
Q.D. Comp
K,S Claims
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