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GEOLOGY OF ENDAKO MINE

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(A SUMMARY)

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ENDAKO MINE

INTRODUCTION

Endako mine is the largest molybdenum producer in Canada and second largest in the world after Climax, Colorado. The deposit is an elongate stockwork of quartz-molybdenite veins developed within the Endako quartz monzonite phase of Topley Intrusions. In comparison with other Cordilleran porphyry-type copper and molybdenum deposits, Endako is notable for the paramagmatic affiliations of hydrothermal alteration and mineralization, the well-defined sequence of potassic, sericitic and argillic alteration stages, and the lack of ore-controlling breccias and minor intrusions.

Endako mine is located 100 miles west of Prince George, British Columbia, within the glaciated uplands of the Nechako Plateau.

HISTORY AND DEVELOPMENT

The original Stella vein was discovered in 1927, but the large-tonnage potential of the deposit was not recognized until 1962, when a small but encouraging drilling program was initiated by R and P Metals Corp.Ltd. Canadian Exploration Ltd. examined, optioned and commenced drilling the property in late 1962. The decision to develop the deposit for production was announced in March 1964, and the mine was officially opened on June 8, 1965.

Production is currently being maintained at 27,500 tons per day at an average ore grade of 0.16% MoS_2. Reserves are estimated at 209 million tons of ore averaging 0.15% MoS_2, calculated at a cut-off grade of 0.08% MoS_2 (1971 figures).

REGIONAL GEOLOGY

Geologic knowledge of Endako area is based primarily upon mapping by Armstrong (1949), Tipper (1963), Carr (1966) and the writer (Dawson, 1971).

The Topley batholith, of Jurassic age, extends west-northwestward from Quesnel to Babine Lake, a distance of some 180 miles. The batholith flanks and intrudes the southwestern margin of a flexure in the Stuart Lake High, an elongate, fault-bounded belt of Cache Creek metamorphic rocks in central British Columbia. This belt of Carboniferous-Permian rocks was uplifted in Late Triassic time along steeply-dipping peripheral faults which subsequently provided conduits for rising Topley magma. South and west of Stuart Lake High, Topley batholith intrudes volcanic and sedimentary rocks of the Takla-Hazelton Assemblage that were laid down intermittently in Late Triassic to Middle Jurassic time.

The oldest and most extensive Topley unit, the Middle Jurassic Simon Bay diorite complex, is a concordant mesozonal pluton whose prominent foliation parallels the northwest batholithic trend and probably reflects pre-existing structural controls upon its emplacement. In Endako area, Simon Bay rocks are intruded by Late Jurassic Topley phases (Endako, Nithi, Glenannan, Casey and Francois plutons) of discordant, epizonal type and west-northwest elongation. The predominantly quartz monzonitic plutons are closely grouped in radiometric age (137-141 m.y.) and represent a relatively short period of differentiation of the parental Topley magma, with enrichment in silica and alkalies in youngest phases.

Youngest Late Jurassic to Early Cretaceous Topley units in Endako area (Stellako and Fraser plutons) are more granodioritic in composition and divergent from the regional northwest trend.

Topley Intrusions are overlain by extensive, flat-lying andesitic and basaltic Endako Group flows of Eocene age. Related dykes intrude post-ore fractures in Endako area.

MINE GEOLOGY

Geology of the Endako deposit is drawn, in part, from the more comprehensive description by Kimura and Drummond (1969). Potassium-argon ages of Endako area rocks are drawn from White, et al (1970).

1. Rock Types

Ages and descriptions of rock units in Endako area are summarized in Table 1. Endako quartz monzonite and three types of acidic pre-ore dykes form the host for the mineralized stockwork. Endako quartz monzonite is a subporphyritic to equigranular rock with average mode: microperthitic pink orthoclase 44.5%; quartz 22.6%; gray zoned oligoclase (An_{19}) 26.3%; brown biotite 4.6%; hornblende 0.6%; accessory minerals 2.0%. Aplite, porphyritic granite and quartz-feldspar porphyry dykes occur in two swarms in the central pit area. Post-ore basalt and andesite dykes cross-cut thr quartz monzonite, pre-ore dykes and mineralized stockwork.

2. Structure

Endako orebody is an elongated elliptically-shaped zone of stockwork that occurs wholly within Endako quartz monzonite. The orebody may be considered as a series of major east-west veins oriented en echelon to form a zone elongated in a northwesterly direction. The orebody, including the Denak zone, is 11,000 feet long by 1,200 feet wide. The average dip of mineralized stockwork is a consistent 50^{o} south over the orebody length, but depth of economic mineralization varies from a minimum of 100 feet at the east end to over 1,000 feet at the west end.

The development of Endako orebody was influenced by three related igneous events: emplacement and crystallization of Endako quartz monzonite; intrusion of residual granitic magma as pre-ore dykes; and ascent of hydrothermal fluids through the localized zone of intense fracturing.

Early compressional stresses, active during emplacement and cooling of Endako pluton, apparently generated localized doming and fracturing in the vicinity of the mine, an area occupying the intersection of regional east-west, northwest and northeast fracture systems. Intrusion of pre-ore dykes accompanied the principal structural adjustment of the pluton: wrench faulting along principal orebody faults and secondary shears; doming of the orebody area; and antithetic faulting along conjugate southward and northwestward-dipping fractures. Many large veins and smaller stockwork veinlets follow the predominant east-west and northeast fracture directions.

Localization and development of Endako stockwork is summarized in Figure 1, and schematic plan and sections of the orebody are given in Figure 2.

3. Alteration and Vein Mineralogy

A. Alteration Mineralogy

Three distinct alteration phases are recognized by Drummond and Kimura (1969) within the Endako ore zone: (1) envelopes with K-feldspar; (2) envelopes with sericite; and (3) pervasive kaolinization.

Envelopes 1/8-inch to 2 feet wide containing principally salmon-pink orthoclase are developed around Stage 1 (oldest) quartz, quartz-molybdenite and quartz-magnetite (all $\pm$ pyrite) veins. K-feldspar envelopes may be of three types: 100% orthoclase; 90% orthoclase and 10% biotite; and 60% orthoclase, 30% quartz, 5% biotite, 5% altered plagioclase. Grey envelopes 1/8-inch to 2 inches wide containing 55-60% quartz, 30-35% sericite, and 1-5% finely disseminated pyrite are developed around Stage 2 quartz-molybdenite

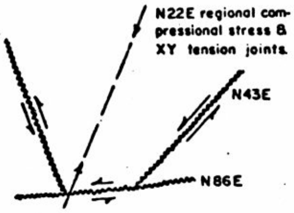


FIGURE 1 a.

Pre-doming stress and early fractures.

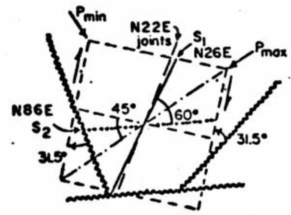


FIGURE 1 b.

Shear stress orientation in the fault-bounded orebody block. Shear S_1 augments existing N22E fractures. Shear S_2 develops after S_1 is intruded by pre-ore dykes.

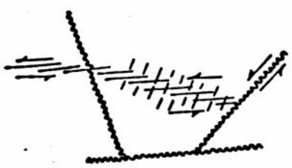


FIGURE 1 c.

Doming occurs over the weakened zone of intersecting S_2 shears and NNE dykes and fractures. S_2 shears first become YZ tension fractures under release of lateral NNE stress then become normal faults during domal uplift and subsidence.

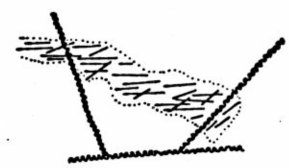
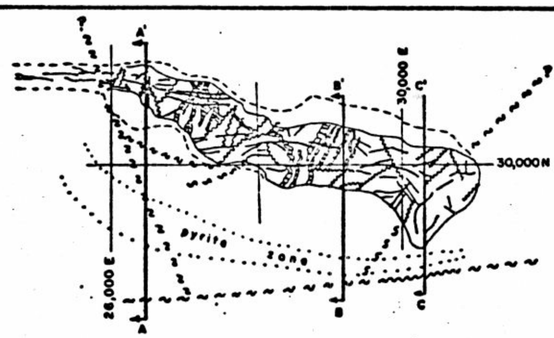


FIGURE 1 d.

Schematic plan of orebody showing en echelon array of E-W veins, with antithetic NE veins.

FIGURE 1. Localization and development of Endako stockwork.

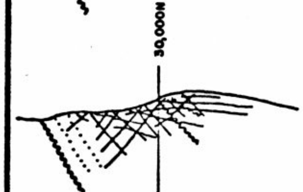


SECTION AA' : West Pit

The orebody is a narrow zone of large, mainly south-dipping veins. A few flat and shallow northerly-dipping veins occur. The stockwork is very limited in extent. Post-ore NE fractures are abundant. Orebody is at the maximum distance from S. Boundary fault.

SECTION BB': Central Pit

A combination of vein trends occur. Large EW/45S veins are predominant. Flat to moderate northerly-dipping veins occur. Stockwork is well-developed. A large NNE zone of dykes occupies the central orebody.



SECTION CC': Southeast Pit

Strongest vein trend is NE/0-30°NW. Flat veins are the largest. EW/50S veins are of secondary importance. Stockwork is most intensely developed here. Apparent shallow south dip of orebody is due to flat veins. South Boundary fault passes close by.

FIGURE 2. Schematic sections showing veins and stockwork.

and/or magnetite, and quartz-pyrite veins. Sericitic envelopes are less abundant than K-feldspar-bearing envelopes. Within the sericitic envelope original K-feldspar, plagioclase and biotite have been replaced by sericite and quartz, and iron from the breakdown of biotite has been sulphidized to form pyrite.

Quartz monzonite may be contemporaneously kaolinized outward from potassic and sericitic-enveloped veins, and is pervasively kaolinized within the stockwork of Stage 3 quartz-molybdenite veins. Degrees of pervasive alteration are arbitrarily defined by the progressive mineralogical change of hard grey plagioclase in fresh rock to a soft greenish mixture of kaolinite and sericite, and the kaolinization of primary K-feldspar under intense argillization. Weak kaolinization is typified by plagioclase grains showing a hard unaltered rim and a soft greenish core of kaolinite, lesser sericite, and locally montmorillonite. Moderately kaolinized rock is characterized by complete replacement of plagioclase by a greenish or white mixture of kaolinite and sericite. K-feldspar is not attacked in either weak or moderate stages of kaolinization and biotite may be either chloritized (primary) or fresh (secondary). Intensely kaolinized quartz monzonite is typified by partial or complete replacement of primary K-feldspar by kaolinite plus a little sericite, and complete breakdown of plagioclase to kaolinite and sericite. Intensely kaolinized rock contains both greenish and white mixtures of clay minerals, but only the white material contains very fine-grained secondary biotite. Ferrous iron that imparts a green colour to kaolinite in one case is fixed in biotite in the other case and consequently the coexisting kaolinite is white.

B. Vein Mineralogy

The most abundant primary metallic minerals are molybdenite, pyrite and magnetite, with minor amounts of chalcopyrite and traces of sphalerite, bornite, specularite and scheelite. A single occurrence of beryl and bismuthinite was found.

Molybdenite occurs in two types of veins: large, 6-inch to 4-feet wide quartz veins containing laminae and fine disseminations of molybdenite; and fine fracture-fillings and veinlets of quartz-molybdenite as stockworks adjacent to major veins. Brecciation of major veins with subsequent quartz-molybdenite healing is common.

Magnetite, pyrite and minor amount of chalcopyrite commonly are associated with molybdenite, but may also form distinct veins. Magnetite in quartz veins has undergone supergene martitization (oxidation to hematite) that progressively decreases in intensity with increasing depth. A pyrite zone that bounds the orebody on the south is a poorly-developed stockwork of veinlets containing quartz, pyrite, minor magnetite and rare molybdenite. Pyrite content of the zone is an estimated 1 percent.

Post-molybdenite veins including relatively abundant calcite, and relatively rare quartz-specularite and chalcedony occur throughout the orebody, and may be either a terminal stage of deposition from ore-bearing fluids, or younger epithermal deposits related to Eocene volcanism.

Secondary minerals include limonite, hematite, ferrimolydite, powellite, pyrolusite and malachite. Depth of oxidation varies from 1 to 5 feet in general, and development of secondary minerals is not extensive.

TABLE 1

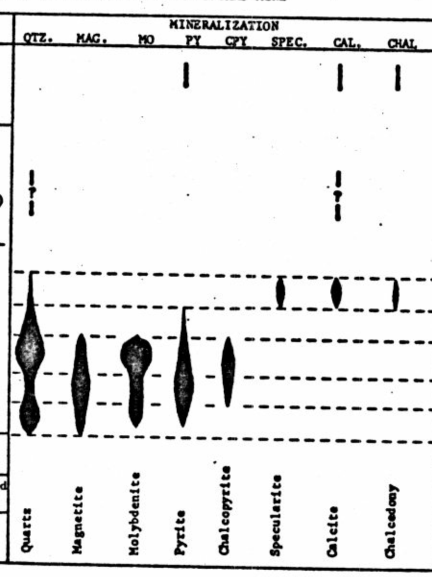
TABLE OF FORMATIONS - ENDAKO AREA

ROCK UNIT	AGE	DESCRIPTION
Endako Group	Eoc.(50±2 m.y.)	Porph.andesite and basalt flows, agglomerate and related dykes.
Fraser qtz.monz.	L.Cret.(112±4 m.y.)	Pink biot.hb qtz.monz. Small circular stock.
Stellako intrusions	U.Jur.(136±5 m.y.)	Pink biot.qtz.monz.,pink-grey hb-biot.granodiorite, Discordant, NNE trend.
Francois granite	U.Jur.(137±5 m.y.)	Red porph.biot.granite.Miarolytic,chilled margins. No Mo deposits.
Casey alaskite	U.Jur.(138±5 m.y.)	Leuco granite and qtz.monz.Discordant stocks and satellitic dykes. Mo deposits at OWL L.,TATIN L.,NITHI MT.,ENDAKO.
Glenannan complex	U.Jur. (134-140±5 m.y.)	Zoned pluton north of Endako.Pink proph.granite,qtz. monz.,granod. No Mo deposits.
Nithi qtz.monz.	U.Jur. (138-141±5 m.y.)	Pink-grey subporph.biot.-hb.qtz.monz.Resembles Endako qtz. monz.and may be equivalent.Mo deposit at NITHI MT.
Qtz.felds porph. Porph. granite aplite	Endako pre-ore dykes (140±5 m.y.)	Brown-pink porphyry dykes up to 150' wide,abundant at mine Porph.pink Kspar granite dykes up to 50' wide. Pink sugary aplite up to 4" wide.
Endako qtz.monz.	U.Jur.(141±5 m.y.)	Pink subporph.biot.-hb.qtz.monz.Host rock at Endako mine.
Simon Bay diorite complex	M.Jur. (155±6 m.y.)	Coarse g'd.,foliated hb.diorite, qtz.diorite,granodiorite, gabbro. Mesozonal,concordant pluton. Oldest Topley unit. No Mo deposits.
Takla Group	U.Trias.	Rhyodacite and andesite stocks,flows and pyroclastics.

TABLE 2

SUMMARY OF GEOLOGICAL EVENTS AT ENDAKO MINE

IGNEOUS EVENT AND AGE	STRUCTURAL EVENT	ALTERATION
Tertiary volcanism; emplacement of plagioclase porphyry and basalt dykes (50 ± 5 m.y.).	Minor movements parallel to dykes.	Deuteric chlorite-calcite-epidote propylitization.
Emplacement of Stellako pluton (136 ± 5 m.y.).	Movement on EW and NE faults.	
Emplacement of younger Stage II plutons: Glenannan, Casey, Francois (140-137 ± 5 m.y.).	Post ore fracturing and faulting (Stage 6)	
Termination of cooling of Endako pluton.		
	Stage 5 veins	None
	Stage 4 veins	Minor bleaching
Hydrothermal alteration and mineralization (140 ± 5 m.y.)	Stage 3 veins	Weak to intense pervasive kaolinization.
	Stage 2 veins	Quartz-sericite-pyrite envelopes.
	Stage 1 veins	Kspar,Kspar-biot.,qtz-Kspar-biot.envelopes.
Emplacement of acidic mine dykes (140 ± 5 m.y.)	Doming, antithetic stockwork fracturing	
Onset of cooling and crystallization of pluton	NNE compression,NNE and EW secondary shearing	
Emplacement of Endako quartz monzonite (141 ± 5 m.y.).	NE,NW and EW regional fracturing.	



4. Age Relations of Vein and Alteration Minerals

Age relations of vein and alteration minerals plus corresponding structural and igneous events are given in Table 2.

A sequence of relative ages of vein and alteration assemblages has been determined from observations of cross-cutting relationships. There is no significant correlation between vein mineralogy and a specific type of alteration envelope or intensity of pervasive kaolinization. However, within the orebody, K-feldspar envelopes are more commonly developed around quartz-molybdenite veins, sericitic envelopes commonly enclose quartz-magnetite veins, and weak to moderate kaolinization is the commonest intensity of pervasive alteration.

Five stages of alteration and mineralization have been defined. Stage 1 and 2 veins and envelopes were described previously. The greatest volume of molybdenite was deposited in Stage 3 veins, which may contain quartz-molybdenite, quartz-magnetite,and/or quartz-magnetite-molybdenite (all $\pm$ pyrite, chalcopyrite). Pervasive argillic alteration accompanies Stage 3 mineralization. Stage 4 veins contain quartz and pyrite, and lack associated alteration other than occasional bleaching around the veins. Stage 5 veins contain quartz-specularite, calcite and chalcedony, and lack associated alteration. Post-ore unfilled fractures define Stage 6.

ORE CONTROLS

Three interrelated factors; structural, chemical and thermal effects, combine to control the nature and distribution of vein and alteration minerals at Endako mine.

1. The structure of the orebody has been described previously. Configuration of stockwork is the principal ore-localization factor. From east to west along the length of the orebody, relatively homogeneous stockwork generated by intense domal movement gives way to poorly-developed stockwork adjacent to large shear veins. Homogeneity of ore values varies accordingly. Stockwork fracturing and ore values terminate abruptly along the north side of the orebody, but diminish gradually southward towards the pyrite zone that marks the southern limits of stockwork mineralization.

2. Chemical control of hydrothermal mineralization and alteration is evident from the spatial and temporal relationships between alteration assemblages of Stages 1, 2 and 3. K-feldspar envelopes are intersected by sericitic envelopes, and the rock outward from these envelopes and Stage 3 veins is pervasively kaolinized. The mechanism relating potassic, sericitic and argillic alteration is a progressive ion leaching or migration of Ca^{++}, Na^{+}, Mg^{++}, Fe^{++} and Fe^{+++} toward the vein, with simultaneous outward migration of K+ and H+.

The K+/H+ activity ratio controls outward diffusion of K+ and H+ and varies outward from the vein mainly in response to variations in temperature, K+ and H+ concentration gradients, rate of removal of leached constituents, and pressure. Reaction curves for the system K_2O-Al_2O_3-S_1O_2-H_2O developed by Hemley (1959) show that temperature and K+/H+ activity ratio are the most significant variables in determining stability of phases in the system. Drummond (1969) notes the relative age sequence of K-feldspar-sericite-kaolinite is in agreement with a chemical control based on the activity ratio of K+/H+ in a nearly isothermal environment.

3. Thermal controls are evident in zonation of alteration assemblages from north to south across the orebody. A relative abundance of K-feldspar-bearing envelopes defines a "K-feldspar zone" about 800 feet wide parallel to

the orebody and flanking it on the north. The transition to the orebody proper is marked by a sharp increase in the abundance of molybdenite, sericitic envelopes and intensity of pervasive kaolinization. The transition to the "pyrite zone" is marked by a sharp decrease in abundance of K-feldspar alteration, a gradual diminishment in intensities of molybdenite mineralization, kaolinization and sericitic alteration, and an increase in relative abundance of pyrite.

Alteration zonation suggests decreasing temperature from the ore zone towards the south, implying similar temperature variations for sulphide deposition. Fluid inclusion studies support this trend. Minimum filling temperatures for fluid inclusions in quartz from K-feldspar-enveloped veins are slightly higher than 500°C; those for inclusions in quartz from sericite-enveloped veins center around 480°C; whereas those for quartz veins without envelopes but within pervasively argillized rock range from 380°C to 460°C (Dawson, 1971). These temperatures are in agreement with Hemley's (1959) experimental data for stability fields of the alteration phases.

Minor element content of pyrite shows a similar temperature-dependent trend across the orebody. In Q-Mode factor analysis of 12-element spectrochemical data from 67 orebody pyrites, Mn, Ni and Sn define Factor I which coincides with the ore zone, whereas Factor II (Co and Cu) coincides with the pyrite zone (Dawson,1971). Correlation of Factors I and II to ore and pyrite zone respectively implies that the factors are related to mineralizing processes that gave rise to the two mineralogically distinct zones.

Within a single vein or vein system, thermal gradients may have been less significant than chemical controls in affecting the stability of an alteration or sulphide phase, but on a megascopic scale temperature gradients have controlled the relative abundance of mineral assemblages in the orebody area.

CONCLUSIONS

The Endako stockwork was localized within an early quartz monzonitic phase of Topley batholith by wrench faulting and doming generated by cooling of the batholith and intrusion of pre-ore dykes. Hydrothermal fluids effecting alteration and mineralization of the stockwork were generated contemporaneously with the cooling of the Endako pluton. Abundant early potassic alteration and relatively high fluid inclusion temperatures attest to the paramagmatic affiliation of vein and alteration mineral assemblages. Cross-cutting relations indicate a relative age sequence among the alteration stages which is in agreement with a chemical control based primarily on the activity ratio of K^{+}/H^{+}. Concurrent north-south zonation of stockwork mineralization, principal alteration types, fluid inclusion temperatures, and minor element content of pyrite indicates thermal gradients diminished southward across the orebody from a "high" centered over the K-feldspar zone.

January, 1971.

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