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RESUMÉ ON THE NATURE OF BATHOLITHS AND GEOLOGY OF ENDAKO, BETHLEHM AND LORNEX MINES, BRITISH COLUMBIA

by

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NATURE OF BATHOLITHS

INTRODUCTION:

Batholiths are composite masses of granitic rocks exceeding 40 sq. miles. The formation of stocks (less than 40 sq. miles) is probably similar to that of batholiths and thus both may host potential orebodies. Batholiths and stocks are a major source of copper and/or molybdenum in North America, especially in the south-western United States and in British Columbia. The formation of ore and host rock are related in both time and space (age dating from porphyry bodies in B.C.)

ORIGIN:

1. Fractional melting (partial fusion) of basic rocks in the lower crust due to increase in heat flow from the mantle during an orogenic phase of geosynclinal development. Pockets of acid magma formed by fractional melting coalesce and accumulate to form a widespread magma chamber in the lower crust, doming the crust above. Relaxation of compressional forces accompanying the waning phase of the orogenic cycle, and the doming effect of magma generated may place a semi-stable block in a state of tension. Major basement faults may extend into the lower crust and tap the magma chamber. The magma then rises along faults and is extruded as viscous flows. This would cause a drop in pressure in the magma chamber and allow volatiles to concentrate near the top of the chamber. The volatile-rich magma would then erupt as huge ash flows. Cauldron subsidence may or may not be

initiated above areas where magma was depleted the most.

The absence of basaltic magma at the surface is explained by the suggestion that a basaltic magma "freezes" on the way upwards or undergoes lateral migration.

2. Anatexis, mainly of geosynclinal sediments, due to a rise of isogeotherms in the area because of downwarping of the crust.

3. Primary magma in the upper mantle.

MAGMATIC PROCESSES:

Differentiation of the magma begins with the crystallization of the more basic minerals (pyroxene and hornblende). As the process continues while successive pulses of the magma are being emplaced the magma becomes enriched in silica and potash feldspar. Magmatic pulses which we see in zoned batholiths may be the result of the cyclic diffusion of volatile constituents until the pressure is high enough to overcome the confining pressure. The rate of diffusion of water in the magma would have a significant control on emplacement.

As erosion of the land surface continues downward, the outer crystalline phases of the batholith cool more rapidly in the shallower environment, whereas the youngest phase continues to crystallize under pressure. Mineral deposits form at this time in the youngest phase. The last differentiated magma to crystallize forms aplite dykes and small irregular masses.

EMPLACEMENT:

Batholiths have been commonly pictured as enormous masses extending to great depths. Field studies, especially in recent years, on batholiths in North America, however, are showing that many of these "bottomless" batholiths rest in places on visible floors of older rocks. There is evidence of much lateral movement of magma which has formed sheetlike, tack-shaped or tonguelike masses of much less volume than commonly supposed.

Granitic melts are much lighter than metamorphic rocks - even solid granitic rocks are lighter than most high-grade metamorphic rocks and must rise through them whenever the buoyancy of the plutons exceeds the strength of the metamorpic rocks (c.f. diapirs). Pluton magmas rise in detached ballonlike forms through the crust, frequently reaching the earth's surface, and coalesce into shallow and fairly thin complexes. The plutons of magma rise until crystallization, forced by loss of heat and volatiles, prohibits further flow, or until they reach the surface. As the plutons "stiffen", the wallrocks cool down, metasomatism virtually ceases, and thin aureoles of thermal metamorphism result.

The larger and more numerous the plutons, the higher they should rise. Any pluton that reaches the surface over a wide area is roofed only by its own volcanic ejecta, and granitic textures develop as the magma crystallized beneath its insulating volcanic cover.

Experimental work has shown that liquids forced upward through artificial strata do not progress straight upward but follow inclined pathways and if conditions permit, the liquid spreads out laterally.

Gneissic terranes form in the zones, beneath the final batholiths, through which plutons rise, as wallrocks flow beneath the rising magmas and are heated and metasomatized by them.

ENVIRONMENT:

Batholiths develop characteristically in hearts of strongly folded belts during later stages of folding.

a) eugeosynclines - "Tectogene" hypothesis

b) miogeosynclines - eg. Boulder Batholith

c) unstable platforms - eg. San Juan, Mountains, Colorado

d) oceanic island arcs - eg. Aleutian Islands.

The common association of batholiths with eugeosynclines has been interpreted to indicate that the batholiths and the geosynclinal volcanic rocks have related origins. A geosynclinal environment is not essential for the generation of granitic magmas: the controlling events occur in the lower crust or upper mantle, not in the upper crust.

The depth of emplacement of batholiths has been divided into three zones, each with varying characteristics. They are with increasing depth: epizone (0 - 4 miles), mesozone (5 - 9 miles), and catazone (7 - 12 miles). Continuity appears to exist through the epizone to mesozone but the transition from mesozone to catazone is more vague. The following plutons are typically mesozonal (eg. Sierra Nevada Coast Range, Endako, Guichon); those of Late Cretaceous age (about 75 m.y.) are transitional epizonal-mesozonal (eg. Boulder Batholith) and plutons of Tertiary age as now exposed were exclusively emplaced in the epizone (eg. Granisle, Berg).

PREFERENCE FOR ROCK TYPE:

Porphyry copper orebodies are most commonly localized in siliceous rock where the structural "plumbing" has occurred. Three hypotheses might explain this observation.

1. There may be a preference for the ore-bearing solutions to deposit in the phase which has undergone the greatest degree of differentiation and thus the one with the highest percentage of silica (or alkalies). In zoned batholiths, the youngest phase is the most attractive to ore-bearing solutions. It may be that during a multiple-phase intrusion, the ore-bearing solutions tend to remain "active" until differentiation virtually ceases and the intrusion becomes prone to structural "plumbing" upon cooling etc. Emanations extend outwards into older phases through fractures and faults.

2. The structural yeilding which produces the intricate "plumbing" system is more likely to develop into granitoid and porphyritic rocks.

3. The tectonic processes accompanying intrusion may have effected more easily the youngest, more siliceous intrusive phase than other rock types.

Characteristic fractures might be explained by the volume changes that accompany rapid heating of meteoric waters by magma and/or hot igneous rock. The constant replenishment of the meteoric water resevoir would provide a very long time interval (probably tens of thousands of years), during which hydrothermal alteration (which is so characteristic in porphyry deposits) could occur, thus allowing for a complex superposition of a variety of alteration types.

ECONOMIC CONSIDERATIONS:

1. Batholiths of similar age to known mineralized batholiths of the same age hold promise in that they may have become detached from a much larger magma at depth. Eg. in southern B.C. ages of approximately 200 m.y. and 100 m.y. are important. Molybdenum prospects are mainly restricted within or near the 100 m.y. - 141 m.y. granitic rocks. Copper prospects are prominent in the 200 m.y. rocks and also spatially related younger rocks.

2. The larger the batholith, the better. It has been estimated that about 3% H_2O may exist in granitic magmas. Most analyses of granitic rocks show between 0.5 - 0.75% H_2O. Therefore, approximately 2.5% is left for hydrothermal ore solutions. Experiments on chloride mixtures (K,Na,Zn,Mg) indicate that 2.5% is sufficient. The ore depositing fluids are apparently cooled by mxining with cool ground water.

Eg. in B.C. the Guichon batholith, which hosts the major Highland Valley porphyry ores, has a surface area of approximately 400 sq. miles, and the Topley batholith, which hosts the Endako orebody, has a surface area of approximately 250 sq. miles.

3. Batholiths in a particular tectonic zone or belt indicative of a particular crustal rupturing at some time in its development.

4. The youngest, most highly differentiated porphyritic intrusive phase in a complex zoned batholith is most favourable for economic mineralization.

EXAMPLES OF THICKNESSES OF BATHOLITHS:

1. Sierra Nevada batholith: 55 to 110 km, wide and 650 km. long.

- Gravity data and seismic models suggest the batholith is tabular with a thickness of approximately 8 km. Heat flow data also suggests a thin batholith.

2. Boulder batholith: 50 km. wide and 100 km. long.

- Gravity surveys indicate the batholith is greater than 15 km thick. In general, plutons appear to be less than 10 km. thick.

GENERALIZATIONS ABOUT PORPHYRY COPPER DEPOSITS IN BRITISH COLUMBIA:

Definition:

A typical "porphyry copper" deposit in British Columbia is one that has a large tonnage of low grade ore which can be mined economically using mass mining methods in an open pit.

The mines we will be visiting are representative of the 2 main age groups in B.C. (ie. Endako - about 140 m.y., and Bethlehem and Lornex - about 200 m.y.).

The Intermontane Belt is principally formed of Late Paleozoic, Triassic, and Jurassic volcanic and sedimentary rocks covered in part by successor basins. Copper-molybdenum deposits are typical of the Intermontane Belt. The porphyry type of deposit is also characteristic of this Belt.

Two unconnected epochs of mineralization have been recognized. The one extending from Later Permian through to mid-Tertiary is dominated by copper and molybdenum mineralization.

The Intermontane Belt contains approximately 70% of both the total copper and molybdenum reserves of British Columbia.

Mineralized porphyry intrusions in the Canadian Cordillera may belong to either of 2 magma series; normal quartz-rich or potash-rich clans (Sutherland Brown, et al, 1971). The difference between the potash-rich clan and the quartz-rich clan is that the former: 1) has virtually no associated molybdenum or tungsten, 2) has fracture stockworks free of quartz, 3) has particularly strong potassic feldspar alteration, and 4) has breccia fillings which are characterized by coarse biotite rather than quartz or tourmaline (eg. Copper Mountain, Cariboo-Bell, Lorraine).

Porphyries in British Columbia have been tentatively classified into the following types by Sutherland Brown (1969); simple, elaborate, complex and plutonic. The Highland Valley bodies (including Lornex and Bethlehem) are comples, i.e. they have dyke swarms, contain multiple phases, have breccia bodies, are irregular in plan, exhibit a spatial relation of ore to faults, and are centred on a zoned medium-sized pluton. The Endako orebody is a plutonic porphyry deposit, i.e. is associated with a largely equigranular pluton, does not have breccia bodies, and has associated porphyritic or pegmatitic dykes. Both types belong to the calc-alkaline clans.

Porphyries in British Columbia show a pervasive mineralization which is sparsely distributed in stockworks and fractures or veinlets, breccias, or disseminations. They are intimately associated with intermediate to felsic intrusions, almost invariably porphyritic. Mineralization is accompanied by a characteristic alteration sequence and both this and the mineralization show broad zonal patterns clearly related to intrusive character.

ENDAKO

INTRODUCTION:

Endako is siutated north of the east end of Francois Lake, approximately 185 km west of Prince George (see Map 1). A merger with Placer Development Limited took place in 1971. Endako is the largest molybdenum producer in Canada and the second largest in the world after Climax, Colorado.

The original discovery was made in 1927 but the large tonnage potential wasn't recognized until 1962. Drilling began in late 1962 and by March 1964 the decision was made to prepare for production. The official opening was held on June 8, 1965. The total production to the end of 1970 was approximately 39,000 tons of molybdenite. The normal daily production is 27,500 tons of ore at an average grade of 0.16% molybdenite from an open pit with a low stripping ratio. Reserves in 1971 are estimated at 209 million tons of ore averaging 0.15% molybdenite, calculated at a cut-off grade of 0.08% molybdenite.

REGIONAL SETTING

The Endako orebody lies within the Endako phase of the Topley Intrusions. The Topley Intrusions are Jura-Cretaceous in age (about 125 to 150 m.y. and extend west-northwest from Quesnel to Babine Lake (about 290 km). In the southwest, they intrude the Cache Creek Group of Permo-Pennsylvanian age and also Lower Triassic to Middle Jurassic rocks. Nine phases of Topley Intrusions have been recognized (Carr, 1960). All are predominantly quartz monzonitic plutons of Upper Jurassic or Youngest, Late Jurassic age (137 - 141 m.y.). They are representative of a relatively short period of differentiation of the parental Topley magma. As in other porphyry deposits, the youngest phases are enriched in silica and alkalies.

The Topley Intrusions are overlain by extensive, flat-lying andesite and basaltic flows of Eocene Age.

LOCAL GEOLOGY

The Endako quartz monzonite of Upper Jurassic age (141 ± 5 m.y.) and three types of acidic pre-ore dykes form the host for a mineralized stockwork. The Endako quartz monzonite is subporphyritic to equigranular and has the following average mode:

microperthitic pink orthoclase	- 44.5%
quartz	- 22.6%
grey-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 crosscut the quartz-monzonite, the pre-ore dykes, and the mineralized stockwork.

STRUCTURE:

The Endako orebody is an elongate elliptically shaped zone of stockwork that occurs wholly within the Endako quartz monzonite (see Map 2). The orebody, which is 3,500 metres long and 380 metres wide, consists of a series of major E-W veins arranged en echelon to form a NW zone.

ALTERATION

Three phases of alteration exist (Drummon & Kimura, 1969)

1) envelopes with potash feldspar
2) envelopes with sericite
3) pervasive kaolinization

This type of alteration pattern with molybdenum in the centre of veins is characteristic of the great majority of porphyry-type deposits.

VEIN MINERALOGY

Primary metallic minerals include

1) molybdenite)
2) pyrite) + minor chalcopyrite plus trace sphalerite, bornite, hematite and scheelite.
3) magnetite)

Molybdenum occurs in two types of veins.

a) large, 15 cm to 1.25 metres wide quartz veins containing laminae and fine disseminations of molybdenum.

b) fine fracture fillings and veinlets of quartz-molybdenum as stockworks adjacent to major veins.

AGE RELATIONS OF VEIN AND ALTERATION MINERALS

There is no significant correlation between vein mineralogy and a specific type of alteration envelope or intensity of pervasive kaolinization. However, within the orebody, potash feldspar envelopes are more commonly developed around quartz-molybdenite veins, sericitic envelopes commonly enclose quartz-magnetite veins, and weak to moderate kaolinization is common,

HIGHLAND VALLEY PORPHYRY COPPER DISTRICT

REGIONAL SETTING

The Highland Valley is 40 km southeast of Cache Creek and 54 km southwest of Kamloops (see Map 1). All deposits lie within the Guichon Creek batholith which has a surface area of approximately 1,000 sq. km. (400 sq. miles). The batholith is a semi-concordant domal body elongated slightly west of north. It intrudes sedimentary rocks and volcanic rocks of Mississippian to Permian age of the Cache Creek Group and Upper Triassic rocks of the Nicola Group and is overlain unconformably by sedimentary rocks and volcanic rocks ranging in age from Middle Jurassic to Middle Tertiary. The batholith appears to be bounded on its east and west sides by faults of regional extent. The batholith consists of several nearly concentric phases of similar age (about 198 $\pm$ 8 m.y., geologically younger inwards) with sharp or gradational contacts. Copper appears ubiquitous throughout.

On the basis of composition and texture, 10 phases have been recognized (Northcote, 1969) of which we will only try and recognize 5.

1) Hybrid (border) - contamination with country rock
2) Guichon) granodiorites (12 - 15% mafics)
3) Chataway)
4) Bethlehem - granodiorite (about 8% mafics)
5) Bethsaida - quartz monzonite (about 6% mafics)

The Highland Valley porphyry copper deposits are all near the northern part of the core of the batholith (see Map 4). They adjoin either Guichon-Bethlehem or Bethlehem-Bethsaida contact. The deposits were apparently introduced into extensively fractured permeable zones which were prepared by fault action and/or breccia formation. Ore emplacement is post-Bethsaida but is presumably related to the late stages of crystallization of the batholith because the porphyry ore deposits occur in and adjacent to the youngest phases of the batholith.

HISTORY

Mining claims were recorded before the 1900's and by 1914, copper showings had been discovered on or close to many of the known major deposits.

During World War I, two vein deposits (now Alwin and Bethlehem) produced approximately 12,000 tons of bornite-rich ore.

Present activity started in 1955 with the founding of Bethlehem Copper Corporation Limited.

Five major orebodies are located within the area of the Highland Valley (see Map 4). They include:

Capital Cost Est. ($ million)		1971 Production (tons / day)	Grade	Reserves (tons)
?	BETHLEHEM	approx. 16,000	0.51% Cu	49,000,000
27	* Lake Zone	" 11,000	0.48% Cu	190,000,000
	* New J-A Zone	" 11,000	0.45% Cu	150,000,000
138	* LORNEX	" 38,000	0.427% Cu 0.014% MoS_2	293,000,000
150	* VALLEY COPPER	" 40,000	0.5% Cu	870,000,000
66	* HIGHMONT	" 25,000	0.285% Cu 0.051% MoS_2	150,000,000
3.4	*ALWIN	" 500	2.51% Cu	1,000,000
Approx 385 plus				

* Projected estimates

Within 3 or 4 years time approximately 141,000 tons of ore/day may be mined for an annual production of greater than $200 million.

BETHLEHEM COPPER CORPORATION LIMITED

INTRODUCTION

The Bethlehem Copper Corporation Ltd. was incorporated in 1955, its principal mineral holding at the time was a large block of claims covering some old copper occurrences in the Highland Valley. This ground was optioned to Asarco in 1956 who carried out a detailed diamond drilling program, drove an addit and carried out some bulk sampling. Asarco terminated the option in 1958 and the property lay dormant until 1961 when Sumitomo Metal Mining Company loaned Bethlehem $5,000,000 to put the property into production at a rate of 3300 tons per day. The first shipment of copper concentrates left the mine on December 1st, 1962.

LOCAL GEOLOGY

The Bethlehem Copper property straddles a complex part of the contact between the Bethlehem and Guichon granodiorites. It contains 5 separated low-grade deposits; the East Jersey, Jersey, Huestis, Iona, and White zones. All lie close to the Bethlehem-Guichon contact, all are in areas of closely spaced joints and fractures, several contain zones of intrusive breccia, and most are crossed by swarms of north striking porphyry dykes (see Map 6).

In addition, Bethlehem owns 20% of the new Valley Copper, Lake Zone orebody which has approximately 1 billion tons ore reserves at 0.48% Cu.

Drilling is presently underway on a new zone which was just recently discovered. This new zone is 2 miles southeast of the mill, in the valley of Witches Brook. A total of 14 diamond drill holes have been completed and have outlined a zone 1600 N-S by 2000 E-S, which is overlain by 400 to 750 feet of overburden. This zone is open to the south and west, the most westerly hole is estimated to average 0.6% Cu over a 1000 feet whereas the most southerly hole is estimated to average 0.90% Cu over 700 feet.

ORE MINERALOGY

Chalcopyrite and bornite are the major ore minerals. Molybdenum is most abundant in breccia zones and on slickensided faults. Alteration and ore grade are apparently directly related to faults and fracture intensity.

In 1969, Bethlehem produced 23% of the copper in British Columbia.

BETHLEHEM STATISTICS

	1970	1971
Net earnings	$ 10,277,342	$ 7,434,932
Proven ore reserves (tons available to present mill	55,000,000	49,000,000
Ore grade % Cu		0.57
available to Lake Zone project	190,000,000	190,000,000
Ore grade % Cu		0.48
available to new J-A zone project		150,000,000
Ore grade % Cu		0.45
Total possible reserves		389,000,000

Period Dec. 1, 1962 - Feb. 28, 1971

Export sales	$ 129.2 million (U.S.)
Capital Expenditures made	19.4
Exploration Costs	4.8
Direct Taxes paid by Company	20.9
Salaries and Wages paid	15.0
Supplies & Services Purchases	49.7
Employee Income Taxes	2.8
Dividends to Shareholders	16.9

February 1970 - 1971 15,426,716 tons waste/ 6,004,438 tons ore

stripping ratio 2.57:1

Costs:

$$\frac{\text{Direct cost + depreciation of plant and mine equipment + exploration}}{\text{ton milled}}$$

= \$2.30 + 25¢ + 17¢ = \$2.72/ton milled

LORNEX

INTRODUCTION:

The Lornex orebody, which is 1300 metres long and 500 metres wide with a northwesterly axis, lies mainly within Bethlehem granodiorite adjacent to a contact with Bethsaida quartz monzonite. Mineralization occurs in both phases. The western boundary of the orebody is the major north-south Lornex fault which also forms the eastern boundary for the Valley Copper deposit.

ALTERATION:

Alteration is controlled by faults and fractures. Sulphide mineralization is most abundant where faults and fractures are most closely spaced and thus with most intense alteration.

ORE MINERALOGY:

The main ore minerals are chalcopyrite, bornite and molybdenum. They occur either in quartz-carbonate veins which are completely enveloped by sericite-chlorite alteration zones or along dry joints, slips and fractures.

ZONING:

A broad mineral zoning exists within the orebody. The central core is richer in bornite than chalcopyrite, whereas the reverse is the case in the mantling ring. A halo of pyrite surrounds the orebody.

ECONOMICS:

The estimated life of Lornex is 21 years with a metal production of 300,000 lbs/day copper and 5,000 lbs/day molybdenite. Production will involve 38,000 tons/day.

Production is scheduled for the second part of 1972 with an estimated $138 million dollars being spent to bring it into production.

As of 1971, $70,000,000 has been spent on development.

Reserves are estimated at 293 million tons grading 0.427% copper and 0.014% molybdenite.

Copper recovery is expected to be 92% and molybdenum as molybdenite to be 65%.

Lornex copper concentrates will go to Japan for the next 12 years.

Mining will require the removal of 80 million tons of overburden and 252 million tons of waste rock.

GENERAL COMMENTS:

For the United States to keep up with the current production rate of copper (1970) it must find a "Valley Copper" orebody every 3 years.

i.e.	U.S. annual production of Cu	= approx. 1.7 million tons
	Valley Copper reserves	= approx. 1 billion tons
	at a grade of approx. 0.5% Cu	= approx. 5 million tons of Cu/year

OUTLOOK:

Copper

Over the past decade, consumption of copper has increased at a rate of nearly 4.5%/year and this is likely to continue for the next 5 or 6 years. The future of the copper market depends largely on the growth of copper consumption in the United States, Japan and West Germany. The United States consumes greater than one third of free world copper.

World Copper Prices (¢/lb)	London Metal Exchange	United States
1967	51.1	38.1
1968	56.3	41.2
1969	66.5	47.5
1970	64.0	58.2
1971	47.0	52.8