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BETHLEHEM COPPER CORPORATION LTD.

DESCRIPTION OF HIGHLAND VALLEY OPERATIONS

Compiled By

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Introduction

Bethlehem Copper Corporation operates an open-pit copper mine in the Highland Valley area of south-central British Columbia. Mine and plant are located at latitude $50^{o}30'$, longitude $121^{o}00'$, and elevation 4,900 feet above sea level in a setting of gently rolling, forested uplands. A 28-mile paved road to the northwest connects with main rail and highway routes at Ashcroft. To the southeast a 44-mile gravel road leads to the town of Merritt. Mine output for the years 1968 to 1971 averaged an annual 50,000,000 lb of copper in concentrate form. All production has been shipped to Japan to the Niihama smelter of the Sumitomo Metal Mining Company.

History

Copper occurrences in the Highland Valley have drawn sporadic attention since early stakings around the turn of the century. Wagon shipments, made in the years 1915 and 1916, amounted to 96 tons of hand-cobbed ore grading 30% copper. In 1917 the operation of the neighbouring O.K. Mine treated 10,000 tons of ore at a grade of 3.5% copper.

The Bethlehem operations grew from the joint efforts of P. M. Reynolds, H. H. Huestis, and J. A. McLallen. These three men started by staking the ground in 1954 and founded the company in 1955. During the period of 1955 to 1961 exploration work and diamond drilling were undertaken on the property and feasibility studies prepared for a plant. In 1961 Sumitomo Metal Mining Company advanced sufficient funds to bring the property into production.

About 50% of the shares of Bethlehem are held by three major companies, Gränges, Newmont, and Sumitomo, who are represented on the board of directors of the company. The balance of the shares are widely distributed among approximately 6,000 shareholders.

Production commenced in December 1962 at an initial rate of 3000 tpd with a grinding plant of one rod mill and two ball mills. There followed a succession of expansions at intervals of 2 to 3 years leading to a 1970 milling rate of 15000 tpd from a grinding plant enlarged to two rod mills and five ball mills. The latest expansion, on stream in mid-1972, involved the addition of two pebble mills sizing 16'6"x32'0", moving the plant capacity to 17000 tpd. Plans for future expansions continue to emerge from the company drawing boards.

The year-to-year increase in mine output has been accompanied by an inverse trend in mill feed grade. From a crest of 1.06% copper in 1963 the grade retreated steadily to a level of 0.51% copper in 1970. The Bethlehem production record during these years established the company as the forerunner of larger scale, low-grade, open-pit copper mines in British Columbia and throughout Canada.

Geology and Orebodies

The major regional geological feature is the Guichon batholith, a north-striking elliptical mass of rock stretching over 40 miles long and 16 miles wide. It consists of several intrusive diorite phases arranged in a concentric pattern around a central core of Bethsaida quartz monzonite. An age between Upper Triassic and Middle Jurassic is given by stratigraphic and isotopic dating. The Highland Valley, trending northwest-southeast, divides the batholith approximately in half. The Bethlehem property, carrying a number of mineral deposits of various extent, lies near the centre of the batholith. Flanking Bethlehem respectively to the west, southwest and south are the neighbouring properties of Valley Copper, Lornex, and Highmont, all of which carry major mineral deposits.

On the Bethlehem property the mineral deposits are associated with two major phases of the Guichon batholith. The prevailing phase is a medium- to fine-grained rock locally called Guichon quartz diorite. It has been intruded by a younger phase called the Bethlehem quartz diorite. The mineral deposits are located close to the contact of these two phases in areas of pronounced faulting, brecciation and porphyry dyke intrusion. Principal rock minerals are quartz and plagioclase. Chalcopyrite and bornite are the important copper minerals, occurring as fracture fillings and disseminated grains. Minor molybdenite is found along slip planes and associated with quartz veining. Pyrite occurs in low concentrations in poorly defined halos on the peripheries of the mineral zones.

During the exploration program that preceded mill construction three physically separate orebodies displaying distinct geological and metallurgical characteristics were outlined. They were the East Jersey, Jersey and Iona zones.

The east Jersey was a relatively low-tonnage (3,000,000 tons milled), high-grade (1% copper), coarsely mineralized orebody in which the main copper mineral was bornite. The host rock was extremely hard.

The Jersey orebody, from which 30,000,000 tons was mined, was somewhat softer. The copper mineralization was a mixture of bornite and chalcopyrite. A very significant metallurgical difference existed in comparison to the East Jersey in that the minerals were very finely disseminated in the host rock. The average grade was 0.55% copper.

The Iona Zone is a tabular-type deposit containing chalcopyrite, bornite, as well as oxide and carbonate copper mineralization. It is relatively small, in the range of 10,000,000 tons and the calculated grade of the ore reserves is 0.55% copper.

When the mill was constructed it was situated so as to allow truck haulage from these three orebodies. After the mill was built a fourth orebody, the Huestis, was discovered. The ore reserve was calculated at 26,000,000 tons at 0.56% copper. The host rock is slightly softer than in the Jersey and the primary mineralization is chalcopyrite, with minor bornite mineralization. It is similar to the Jersey in that the minerals are finely disseminated. Fortunately, it is also within truck haulage distance of the present plant facilities.

In the course of mine development the East Jersey was exploited first, the Jersey was then mined, and the Huestis Zone is presently in the exploitation stage. It is planned to bring the Iona Zone into production in 1974.

In addition to the above zones, within conveyor haulage distance of the present mill Bethlehem has ore reserves in excess of 200,000,000 tons of 0.48% copper contained in its share of the Valley Copper deposit, and approximately 300,000,000 tons at 0.40% copper in the J-A Zone.

Mining

Present ore production at a rate of 17000 tpd is derived from the Huestis Pit, which is situated some 2,000 ft from the primary crusher and mill installation. The current stripping ratio is 2.5:1.

The Huestis Pit is approximately 1,800 ft in diameter at the surface. The ultimate designed depth is 1,000 ft. Mining is carried out on 33-ft benches with slopes designed to 45° in rock and 38° in overburden. Road widths are 60 ft, with a one-mile ore haul at 12% grade. The majority of the waste is taken to waste dumps a short haul from the pit. Some waste is taken for tailings dam construction a distance of one mile at a minus 3.5% grade.

Equipment utilized for drilling consists of two 45-R drills, one operating and one standby. Drill patterns are 25'x25', explosives are an AN/FO product, and the powder factor is 0.25 lb/ton.

Loading is accomplished with four 5½-yd shovels and four 12-yd loaders. Four units operate, usually two shovels and two loaders.

The haulage fleet consists of seventeen 50-ton Wabco Haulpaks, three 50-ton Cat trucks, and three 50-ton Euclid trucks. Fourteen of the Haulpaks are 5 years old and have logged in excess of 30,000 hours of production. The remaining three Haulpaks, the three Cats, and the three Euclids have been purchased within the last

18 months.

The service equipment includes two No. 14 graders, one 824 rubber-tired dozer, three D8H Cat dozers, one fuel truck, one dual-purpose sand and water truck, and one airtrac.

The equipment, for the size of the operation, is generally small. Average daily tonnage moved is between 50,000 and 60,000 tons. Existing facilities, pit shops, roads, etc., as well as the need for mobility between pits, have dictated use of the mobile equipment with smaller capacity than would normally be utilized in this size of operation.

Milling

Coming on stream with the inception of mining in late 1962, the Bethlehem Copper mill has logged 10 years of continuous operation and processed over 38,000,000 tons of ore. High operating times, quaternary grinding, pebble milling, large diameter cyclones, high unit throughput in flotation, and sand-slime scavenging are features of the plant. Downtime was minimal throughout the several expansion stages. The plant is compact but flexible so operations proceed with little disruption during maintenance periods.

No unusual problems have been encountered in treating the Bethlehem ores. Metallurgy for the earlier East Jersey and Jersey ores was satisfactory and ore from the current Huestis Mine responds favourably. Moderate weather conditions prevail, with low annual rainfall, warm summers, and winter temperatures dipping to sub-zero levels for short periods. Fresh water is pumped from nearby deep wells and is adequate in supply and quality. Mill tailings are totally impounded and reclaim water accounts for some 75% of the process water requirement.

Crushing. Two stages of open-circuit crushing and a final closed-circuit stage breaks pit-run ore to a crushed product sizing -½". The crushing plant is not sectionalized. All three stages are housed in a single building on a hillside immediately above the concentrator.

The primary stage is a 42"x65" Allis-Chalmers gyratory breaking to -6". A "Hobgoblin" impact breaker handles occasional oversize blockages. Primary discharge is conveyed to an open coarse stockpile.

In the secondary stage coarse ore is withdrawn by tunnel conveyor to an 8'x16' Allis-Chalmers 2½-deck screen, yielding four size fractions. The partial deck scalps -4"+1½" lumps for grinding media in the concentrator pebble mills. Remaining +1½" material is crushed through a 7-ft Symons standard cone. The cone discharges a -1" product which joins an intermediate screen fraction sizing -1½" +½" to feed the final crushing stage. The screen undersize is a -½" fraction which joins the flow to the fine ore bin.

The tertiary stage consists of a pair of 7-ft Symons shorthead cones closed by 8'x16' Allis-Chalmers single-deck screens. Apertures are ½"x3½" and the decks are vibrated uphill or downhill as dictated by flow and crushing characteristics of the ore. Screen undersize is conveyed to a covered fine-ore stockpile having a capacity of 30,000 tons, of which 10,000 is live. The pile is designed to allow pushing dead storage by dozers.

The crusher is operated on a continuous three-shift basis and is held at full capacity. Capacity in excess of mill requirements is utilized to build coarse and fine stockpiles from which ore is returned during major maintenance periods. This practice contributes to an operating time of over 90% for the secondary-tertiary stages.

Grinding. The concentrator grinding bay encloses four stages of wet grinding carried out in nine Dominion mills. The grinding system is not sectionalized. Arrangement of the mills is shown in Fig. 1. In the primary stage, Mexican-type feeders reclaim fine ore onto two parallel variable-speed conveyors which deliver to the rod mills through a system of secondary belts equipped with Merrick "E" weightometers. Rod mill discharge joins secondary stage ball mill discharge and a 14"x12" G.I.W. pump delivers the combined pulp to a single modified Krebs D50 cyclone which closes the secondary mills. A Milltronics electric ear control system on the primary and secondary mills records grinding conditions and guides the grinding operator in selecting and controlling feed rate by adjustment of feed belt speed.

Overflow from the Krebs D50 cyclone is split three ways to feed the three tertiary stage ball mills. Each of these mills is closed by a Krebs D40B cyclone through a 14"x12" Allis-Chalmers S.R.L. pump.

Overflows from the three Krebs D40B cyclones are combined and split to feed the two quaternary stage pebble mills. Each pebble mill is closed by a cluster of five Krebs D20B cyclones fed through a 16"x16" G.I.W. pump. Pebble grinding media is drawn from a 1,000-ton storage bin and conveyed to the mills on a timed sequence governed by power demand readings. Consumption of -4" +1½" raw pebbles runs 200 to 300 tpd per mill.

Typical data for the quaternary system at a milling rate of 17000 tpd is presented in Table 1. Rod mill feed enters the system at an 80% passing size of 8,250 microns. Grinding with steel in the first three stages consumes 8.90 kwh/ton and registers a Bond Work Index of 17.0. Feed to the fourth stage sizes 80% pass 254 microns and the final product measures 80% pass 118 microns. The pebble mill energy consumption of 5.82 kwh/ton yields a Bond Work Index value of 20.1 for this stage. Total energy consumption in the quaternary system comes to 14.72 kwh/ton for an overall Work Index value of 18.2.

In addition to the main grinding mills the plant has two 7'x8' Allis-Chalmers regrind units, one of which treats concentrate pulp grading near 20% copper, while the other processes scavenger products in the range of 1% to 2% copper.

Application of four-stage grinding and incorporation of pebble milling in the final stage are two unusual features of the Bethlehem reduction circuit.

An interesting note is that the prototype 50" and 40" large-diameter Krebs cyclones were introduced here. Also, the first commercial two-way and three-way Tech-Taylor valves made their appearance at this plant. These features have increased circuit flexibility and contributed to higher unit throughput and to an operating time of over 97% for the rod mills.

Flotation. Flotation feed comes from the pebble mills at a size of 1% to 5% +65 mesh and 65% to 60% -200 mesh and a grade near 0.55% copper. The pulp is treated by roughing and sand-slime scavenging. Rougher concentrate passes through three-stage cleaning and emerges with a grade near 33% copper at 88% to 90% recovery. Scavenger products and the No. 1 cleaner tailing are treated in a middlings circuit. Sand scavenger and slime scavenger tailings exit the circuit as the final waste products and the sand stream is utilized for tailings dam construction.

One-half the rougher pulp flows down an eight-cell No. 120 Agitair machine and the other one-half is split between two parallel lines of sixteen No. 30 Denver DR cells. Net volume of the Agitair machine is 2,100 cu ft for a roughing time of 5 minutes. Volume of the two Denver machines totals 2,800 cu ft, contributing a roughing time of 6 minutes.

The rougher tailing is joined by dilute middling tailing and the combined pulp is pumped through a battery of eight 24" Dorrclones producing feeds to the sand scavenging and slime scavenging sections. Sand scavenging is carried out in an eight-cell No. 96 Agitair machine having a net volume of 1,150 cu ft and a flotation time of 5 minutes. Slime scavenging is carried out in two parallel Forrester-type 90-ft Britannia cells. These air cells have a volume of 5,400 cu ft and contribute 6 minutes slime scavenging time. Arrangement of the sand-slime section is shown in Fig. 2.

Cleaning is carried out in a primary stage of five No. 30 Denver DR cells followed by secondary and tertiary stages of eight No. 24 Denver DR cells. In a departure from normal practice, regrinding is carried out on the primary cleaner concentrate employing a 7'x8' Allis-Chalmers mill closed with Krebs D10 cyclones. The tertiary concentrate is thickened, filtered through a 6'x6' Dorr-Oliver-Long disc filter, and dried through a 4'x28' Lockhead-Haggerty oil-fired rotary kiln.

Tertiary cleaner tailing is recycled through the secondary stage. Secondary cleaner tailing is diverted to the grinding circuit as makeup water. The primary cleaner tailing is joined with the sand and slime scavenger concentrates and this pulp is reground in a second 7'x8' Allis-Chalmers mill closed by Krebs D10 cyclones. The cyclone overflow feeds a middling section of a twelve-cell No. 60 Agitair cleaner machine followed by a twelve-cell No. 66 Wemco scavenging machine. Middling cleaner concentrate is directed to primary and secondary cleaning, while the middling scavenger concentrate is recirculated. A typical and detailed metallurgical balance is included in Tables 1 and 2.

The sand-slime scavenging section is one of the most important features of the flotation circuit. Table 3 presents the salient metallurgical data. The section contributes 5% to the total copper recovery and laboratory test work indicates a premium of 2% recovery over straight scavenger flotation.

A second distinction of the circuit was the early practice of directing large-tonnage pulp flows through individual rows of flotation cells. The more recent designs of large tonnage mills have favoured incorporation of this practice.

Table 1 — Quaternary Grinding Data

Stage	Primary	Secondary	Tertiary	Quaternary
Mill type *	2 rod mills	2 ball mills	3 ball mills	2 pebble mills
Size	12'6"x15'0"	11'0"x14'0" 10'6"x14'0"	2 @ 11'0"x14'0" 1 @ 12'6"x15'0"	16'6"x32'0"
Drawn hp	2,800	2,050	3,850	5,500
Kwh/t	2.59	2.32	3.99	5.82
Bond work index, Wi **	19.4	32.4	12.3	20.1

Screen Analyses	Mill Feed		Mill Discharge		Cyclone O/F		Cyclone O/F		Cyclone O/F	
	Mesh	% Wt	Mesh	% Wt	Mesh	% Wt	Mesh	% Wt	Mesh	% Wt
			+ 8M	9.4	+ 10	6.7				
			+ 10	10.7	+ 14	9.2				
	+.525"	4.0	+ 14	11.5	+ 20	11.2	+ 48	14.2		
	+.371"	10.1	+ 20	10.7	+ 28	10.5	+ 65	12.6	+ 65	3.7
	+ 3M	14.4	+ 28	9.1	+ 35	8.8	+100	10.3	+100	7.8
	+ 4	10.5	+ 35	7.9	+ 48	8.4	+150	10.1	+150	12.8
	+ 6	8.8	+ 48	6.6	+ 65	6.8	+200	8.3	+200	11.3
	+ 8	8.0	+ 65	5.1	+100	6.1	+325	9.3	+325	13.7
	- 8	44.2	- 65	29.0	-100	32.3	-325	35.2	-325	50.7
80% passing size, microns		8,250		1,680		1,030		254		118

* All mills manufactured by Dominion Engineering Ltd.

** Work index values not corrected for mill diameter.

Table 2 — Bethlehem Copper Flotation Metallurgy

Section	Product	Solids, tph	% Cu	Recovery
Complete plant	Mill feed	709	.53	100.0
	Mill concentrate	10	33	88.3
	Mill tailing	699	.063	11.7
Rougher	Feed	716	.55	
	Concentrate	28	12	83.6
	Tailing	688	.090	
Sand-slime cyclone	Feed	723	.094	
Sand scavenger	Feed	253	.13	
	Concentrate	6	2	2.4
	Tailing	247	.085	
Slime scavenger	Feed	470	.074	
	Concentrate	18	.65	2.3
	Tailing	452	.051	
Middling cleaner	Feed	38	1.1	
	Concentrate No. 1	2	14	
	Concentrate No. 2	1	8	
	Tailing	35	.17	
Primary cleaner	Feed	29	12	
	Concentrate	15	22	
	Tailing	14	1.3	
Secondary cleaner	Feed	18	20	
	Concentrate	11	31	
	Tailing	7	3	
Final cleaner	Feed	11	31	
	Concentrate	10	33	88.3
	Tailing	1	5	

Table 3 Sand-Slime Split

Mesh	Cyclone Feed	Underflow, Sand Scavenger Feed	Overflow, Slime Scavenger Feed
+ 48	-	0.6	-
+ 65	3.0	8.2	-
+ 100	10.1	29.2	0.8
+ 150	11.5	24.8	3.6
+ 200	12.6	15.5	10.7
+ 325	11.3	4.9	14.2
- 325	51.5	16.8	70.7
80% passing size, microns	120	180	63
Sand-slime splitting ratio	100.0	34.8	65.2

Fig. 1 Bethlehem Copper quaternary grinding system

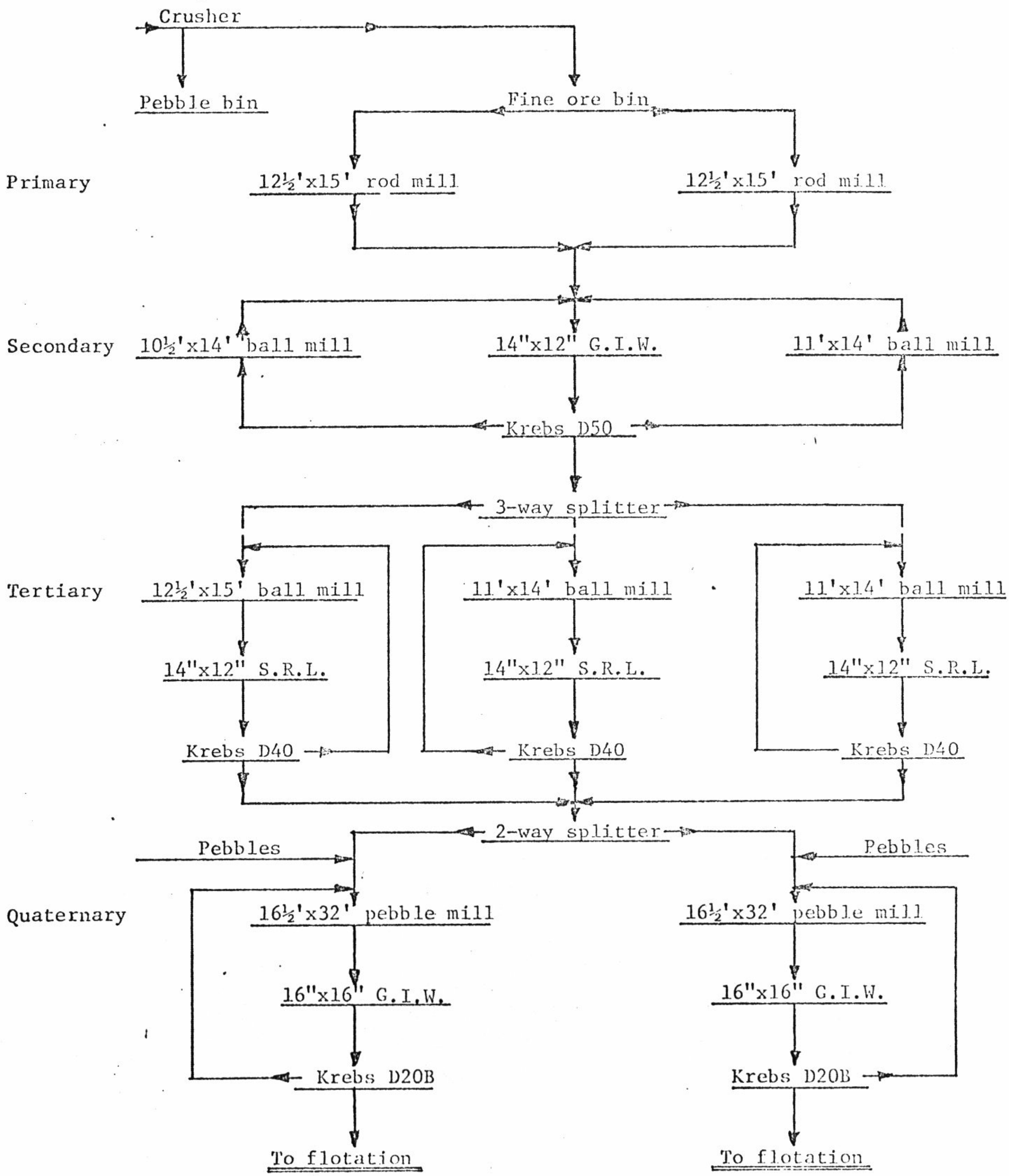

Fig. 2 Bethlehem Copper flotation circuit