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MINES BRANCH INVESTIGATION REPORT IR 65-38

THE RECOVERY OF COPPER AND MAGNETITE FROM NEW IMPERIAL MINES LIMITED, WHITEHORSE AREA, YUKON TERRITORY

by

R. P. BAILEY

MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

The important constituents of this sample were magnetite and sulphide copper minerals (chiefly bornite, chalcopyrite and chalcocite) disseminated in a pyroxene-rich gangue. Analysis of the head sample showed 1.29% Cu, 20.3% Fe, 0.03 oz Au/ton, 0.39 oz Ag/ton.

Due to fine inclusions of copper minerals in the magnetite, no satisfactory separation was obtained by magnetic cobbing.

Best results were achieved by flotation of a copper concentrate from ore ground to about 75% minus 200 mesh, followed by magnetic treatment of the tailing to recover a rougher magnetic concentrate. By magnetic cleaning of the latter after fine regrinding, a high-grade magnetite concentrate, low in copper, was produced. Typical analyses of final concentrates, and overall recoveries, were as follows:

Product	Cu %	Au oz/ton	Ag oz/ton	Fe %
Analyses:				
Copper concentrate	30.4	0.7	7.9	9.1
Magnetite concentrate	0.07	-	-	69.4
Recoveries, %	88.0	86.9	80.4	81.3

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INTRODUCTION

In a letter dated March 22, 1964, Dr. A.C. Skerl, Consulting Mining Geologist, 1758 Western Parkway, Vancouver 8, B.C., asked the Mines Branch to do an investigation on a sample of copper-magnetite ore from the "Little Chief" orebody of New Imperial Mines Limited.

Location of Property

The company holds about 325 claims on the west bank of the Yukon River, northwest and southeast of Whitehorse, Yukon Territory. The principal deposit, about five miles south of Whitehorse and near the centre of the 20 mile long property, is the "Little Chief" orebody where 1,050,000 tons grading about 1.3% copper and 20% iron has been indicated. This ore is reported to be recoverable by open-pit mining methods.

History*

First copper discoveries in the Whitehorse area were made by miners on their way to Dawson in the summer of 1897. The "Little Chief" property was staked late in 1898 by Andrew Oleson and William McTaggart. Although ore was mined at seven different properties in the area at intervals over the next 15 years, only high-grade copper ore was shipped. In 1903 and 1907 small shipments were made from the "Valerie" mine about 1/2 mile south of the "Little Chief". Little interest was shown in the area during the period 1920 to 1945. Noranda Mines, Limited restaked some ground in 1946 and did a little drilling in 1947 and 1948. Imperial Mines commenced exploration in the area in 1956 and began diamond-drilling on the "Little Chief" property on October 18, 1963.

Shipment

On April 22, 1964 one bag of ore weighing 105 pounds net was received from Mr. John W. Britton, Britton Research Laboratories, 755 Beatty St., Vancouver 3, B.C. Marked L.C.2, and consisting of drill core crushed to minus 1/4 inch in size, the sample was described as being from the "Little Chief" orebody and made up of core from drill holes L.C. 13-17, 19-21, 23-29 and 31-33.

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* From Geological Survey of Canada Paper 63-41, by E. D. Kindle

Purpose of Investigation

The company proposes to establish a mill with a capacity of at least 1,000 tons per day for recovery of a copper concentrate and a magnetite concentrate. However, preliminary test work by a commercial laboratory has already indicated the difficulty of treating this ore due to the very fine dissemination of copper minerals in both the gangue and the magnetite. Therefore, Dr. Skerl requested that the Mines Branch conduct a thorough investigation of the ore. This investigation was done with the following objectives:

(a) production of a copper concentrate of grade higher than 20%, containing less than 13% MgO;

(b) recovery of a magnetite concentrate containing about 68% iron, with copper content not exceeding 0.07%;

(c) simplification of the proposed flowsheet.

Sampling and Analysis

After specimens of 1/4" material had been selected for mineralogical examination, the sample was split into two equal parts. One part was crushed to minus 10 mesh and head samples were riffled out for mineralogical tests, chemical analysis and semi-quantitative spectrographic analysis. The remainder of the minus 10 mesh material was reserved for test work.

Quantitative chemical analysis* of the head sample gave the following results:

Copper (Cu), %	1.29	Iron (total Fe), %	20.99
Gold (Au), oz/ton	0.045 (0.031)**	Sulphur (S), %	0.67
Silver (Ag), oz/ton	0.54 (0.39)**	Magnesia (MgO), %	18.60
Iron (soluble Fe), %	20.35	Insoluble, %	41.63

* From Mineral Sciences Division Internal Reports MS-AC-64-539, 685

( )**Average calculated value from test work

Elements indicated by semi-quantitative spectrographic analysis** are listed below in approximate order of decreasing abundance:

I	Fe, Si	(Principal constituents)
II	Ca, Mg, Al	(10 - 1%)
III	Cu, Mn, Ni	(1 - 0.1%)
IV	Ti, Mo, V	(0.1 - 0.01%)
V	Ag	(less than 0.01%)

** From Mineral Sciences Division Internal Report MS-AC-64-104 by Douglas P. Palombo, April 29, 1964.

MINERALOGICAL EXAMINATION *

A representative sample of the ore as received (about 1/4 inch size) and a portion of the head sample crushed to minus 10 mesh were submitted to the Mineralogy Section of the Mineral Sciences Division for microscopic examination.

The head sample was separated into fractions by means of heavy liquids (specific gravities of 2.96, 3.33 and 3.70). Oil immersion mounts were prepared from the float fractions, and polished sections were prepared from the 3.70 G. sink fraction, the crushed drill core sample, and the concentrate and tail samples. The minerals were identified by means of microscopical and X-ray diffraction studies.

The ore is composed of disseminated metallic minerals in gangue. The metallic minerals are magnetite, bornite, chalcopyrite, chalcocite, native copper, covellite and pyrite. The non-metallic minerals are pyroxene, serpentine, amphibole, chlorite, calcite and garnet. No valleriite was found in the samples studied.

Magnetite is the most abundant metallic mineral. It is present in gangue as irregular grains up to several millimeters in size and occasionally contains inclusions and veinlets of chalcopyrite, bornite and chalcocite (see Figures 1 and 2).

The copper-bearing minerals are bornite, chalcopyrite, chalcocite, covellite, and native copper. They occur as irregular inclusions and veinlets in gangue and magnetite, and range from about 2 to 500 microns in size. The bornite and chalcocite are frequently intergrown with each other (see Figure 2).

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* From Mines Branch Investigation Report IR 64-63 by W. Petruk, Mineral Sciences Division, July 3, 1964.

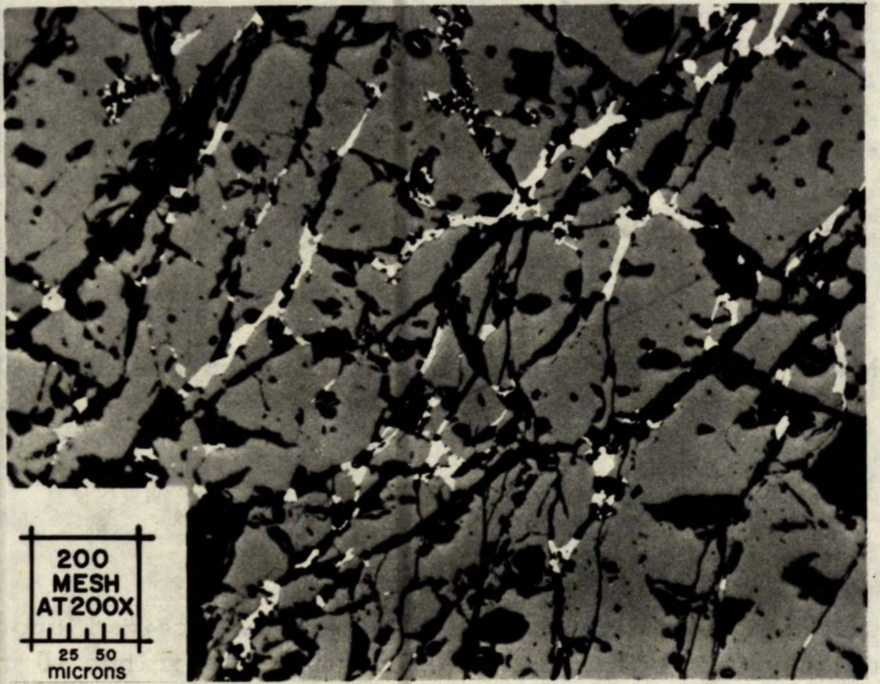

Figure 1 - Photomicrograph of a polished section showing magnetite (grey) with veinlets of chalcopyrite (white) and gangue (dark grey). Pits are black.

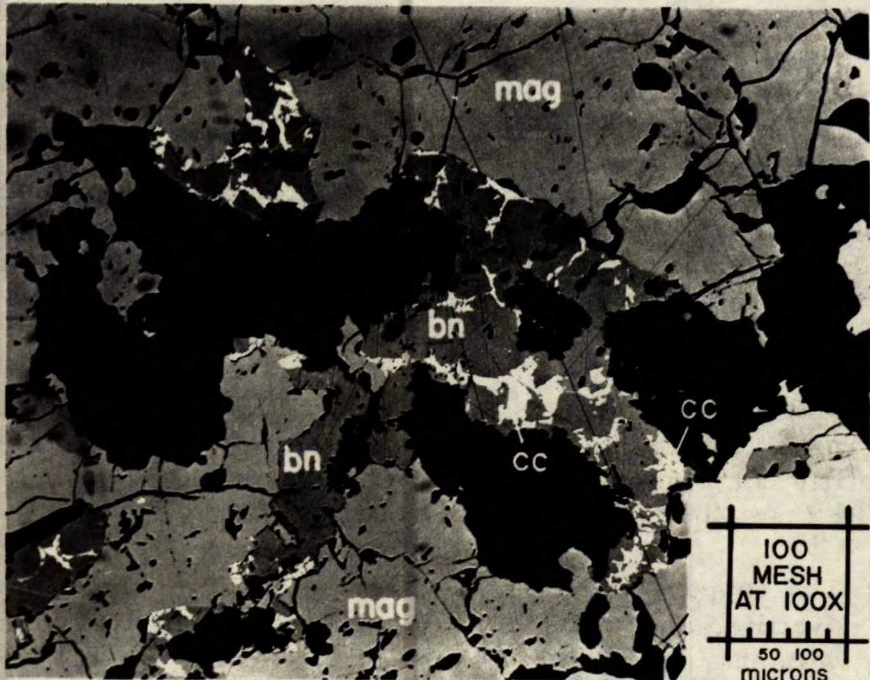

Figure 2 - Photomicrograph of a polished section showing magnetite (mag) with inclusions of bornite (bn), chalcocite (cc), and gangue (black). Note that the chalcocite is intergrown with bornite. Pits are black and indistinguishable from gangue.

SUMMARY OF INVESTIGATION

The main valuable constituents of this ore are magnetite and copper minerals. The latter, chiefly bornite, chalcopyrite and chalcocite, are disseminated in a pyroxene-rich gangue and appear frequently as fine inclusions in the magnetite. Analysis of the head sample gave the following results:

Cu	Sol Fe	Au	Ag
1.29%	20.35%	0.03 oz/ton	0.39 oz/ton

Although dry magnetic treatment of the ore as received (i.e. crushed to minus 1/4 inch) was effective in separating practically all the iron (94.6%), the magnetic concentrate carried 56% of the copper. Even by treating minus 35 mesh ore, 21.4% of the copper reported in the magnetic fraction. Since no effective separation of copper minerals from magnetite was achieved by this means, magnetic cobbing was deemed impractical for preliminary treatment.

In Davis tube tests on more finely ground ore, iron recoveries in the magnetic fractions ranged from 94.2% at minus 65 mesh to 91.1% at minus 325 mesh. However, only in the latter case did the magnetic fraction, containing 66.9% iron and 0.15% copper, approach concentrate grade. Notwithstanding this result, the extremely fine grinding required and the need for further treatment of the magnetic concentrate to reduce its copper content to about 0.07% suggested flotation rather than magnetic separation for primary treatment of the ore.

The effect of successively finer grinding was investigated in a series of copper flotation tests, each of which was followed by magnetic separation of iron from the flotation tailing without grinding. The need for fine grinding to obtain maximum recovery of copper and maximum grade of magnetite is shown by the following comparison of results:

Test No.	Grind % -200 m	Cu recovery (ro + scav) %	Cu cl conc Cu, %	Flot tail Cu, %	Magnetic conc	
					Sol fe, %	Cu, %
9	47.3	75.5	26.8	0.35	61.0	0.29
10	67.8	81.9	31.0	0.27	66.0	0.18
11	84.9	86.3	26.7	0.21	67.1	0.12

Incorporating the best results of preliminary tests into procedures upon which a mill flowsheet might be based, two approaches were taken:

(1) magnetic separation of an iron concentrate, followed by copper flotation from the non-magnetic tailing;

(2) copper flotation, followed by magnetic separation of an iron concentrate from the flotation tailing.

In both methods, primary grinding of the ore was done in stages to pass 100 mesh (about 75% minus 200 mesh).

By magnetic separation followed by flotation (Test 12), 80.4% of the iron (representing about 87% of the magnetite) was recovered in a final concentrate at 68.0% Fe grade containing only 0.07% Cu. However, this was achieved only by supplementary flotation of the copper from the magnetic concentrate. In the subsequent copper rougher and scavenger flotation steps, gangue was poorly depressed, resulting in much greater weight floated, low grade of recleaner concentrate (22.7% Cu) and unsatisfactory overall recovery (82.6%).

By the "flotation first" procedure (Test 13) after grinding to 78.6% minus 200 mesh, a 30.4% copper recleaner concentrate was produced, with rougher recovery of 88%. From the flotation tailing, 81.3% of the iron (equivalent to about 88% of the magnetite) was recovered at a grade of 69.4% Fe, with only 0.065%Cu. This technique, illustrated by the flowsheet in Fig. 3, is preferred not only for improved grade and recovery but also because it involves less grinding than the reverse procedure and requires only a single flotation circuit. In addition, the greater economic importance of the copper minerals encourages their initial recovery.

Copper concentrates all contained magnesia-rich gangues, usually in the range of 10.2% - 11.5% MgO. Use of Aero Depressant 610 had little effect on this gangue, whether added in the recleaner, cleaner or rougher flotation stages. However, it did depress magnetite into the rougher tailing to increase potential recovery of iron. Best grade of copper concentrate was achieved by recleaning with cyanide (Test 10a) to depress copper while floating off a magnesia-rich gangue. This reduced MgO content to 6.5% while increasing copper grade to 39.7% with loss of 4.2% in recovery.

Mineralogical examination of final tailings showed that part of the residual copper, in sulphide form, was present as minute inclusions (mostly under 20 microns in size) in the gangue, and that the remainder of the copper probably occurred as a silicate mineral. This, along with analyses of the screen fractions (Tables 11 and 17), indicated that, within practical grinding limits, the copper content could not be reduced below 0.2% (equivalent to about 90% recovery) by flotation.

Although similar dissemination of extremely fine copper minerals in magnetite was apparent under microscopic examination, no difficulty was experienced in reducing this to specification level (0.07% Cu) by magnetic cleaning after regrinding to minus 325 mesh. However, no significantly lower values could be obtained either by scavenger flotation (Test 13a) or by elutriation (Test 15). Also ineffective were the use of a wetting agent in the magnetic separation circuit and demagnetizing the concentrate before cleaning. Analysis of the infrasizer fractions of the final magnetite concentrates showed clearly that grinding to at least minus 28 micron size would be necessary before the copper content could be reduced appreciably below 0.06%.

DETAILS OF INVESTIGATION

Dry Magnetic Separation (Test 1 to 4)

A 250-gram sample of ore as received (minus 1/4 inch) was passed once over a Ball Norton magnetic separator. Magnetic and non-magnetic fractions were analyzed for copper and HCl-soluble iron. This procedure was repeated on similar samples crushed to pass 10, 20 and 35 mesh screens, respectively. Results are shown in Table 1.

TABLE 1

Results of Dry Magnetic Separation

Test No.	Feed Size	Product	Weight %	Analysis*, %		Distn %	
				Cu	Sol Fe	Cu	Sol Fe
1	-1/4"	Mag	56.3	1.42	33.8	56.0	94.6
		Non-mag	43.7	1.44	2.5	44.0	5.4
		Feed (calcd)	100.0	1.43	20.1	100.0	100.0
2	-10 m	Mag	48.0	1.07	39.2	35.7	93.7
		Non-mag	52.0	1.78	2.4	64.3	6.3
		Feed (calcd)	100.0	1.44	20.0	100.0	100.0
3	-20 m	Mag	43.1	0.93	44.5	29.4	91.4
		Non-mag	56.9	1.70	3.2	70.6	8.6
		Feed (calcd)	100.0	1.37	21.0	100.0	100.0
4	-35 m	Mag	39.4	0.72	49.2	21.4	90.7
		Non-mag	60.6	1.72	3.3	78.6	9.3
		Feed (calcd)	100.0	1.33	21.4	100.0	100.0

* From Internal Reports MS-AC-64-619,660

Davis Tube Concentration (Tests 5 to 8)

Since no effective separation of copper minerals from magnetite was achieved by dry magnetic separation at relatively coarse sizes, this line of investigation was followed into the finer sizes by means of Davis tube tests.

Four 100-gram samples of minus 10 mesh ore were reduced in the Braun pulverizer to -65 m, -100 m, -150 m and -325 m, respectively. Representative 25-gram portions of each were treated in the Davis tube. Magnetic and non-magnetic products were analyzed for copper and acid-soluble iron, with results as shown in Table 2.

TABLE 2

Results of Davis Tube Test

Test No.	Feed Size	Product	Weight %	Analysis *, %		Distn %	
				Cu	Sol Fe	Cu	Sol Fe
5	-65 m	Mag	33.3	0.44	59.2	11.1	94.2
		Non-mag	66.7	1.76	1.8	88.9	5.8
		Feed(calcd)	100.0	1.32	20.9	100.0	100.0
6	-100 m	Mag	31.4	0.38	61.7	8.4	93.6
		Non-mag	68.6	1.90	2.0	91.6	6.4
		Feed(calcd)	100.0	1.42	20.7	100.0	100.0
7	-150 m	Mag	29.2	0.24	65.4	5.1	92.2
		Non-mag	70.8	1.84	2.3	94.9	7.8
		Feed(calcd)	100.0	1.37	20.7	100.0	100.0
8	-325 m **	Mag	27.8	0.15	66.9	3.1	91.1
		Non mag	72.2	1.84	2.5	96.9	8.9
		Feed(calcd)	100.0	1.37	20.4	100.0	100.0

* From Internal Report MS-AC-64-619

** 97.8% -325 m, due to small amount of asbestos-like oversize

These results indicated the possibility of first separating a relatively copper-free iron concentrate by magnetic means. However, because of the extremely fine grinding necessary to do this, and the primary importance of the copper minerals, initial recovery of the latter by flotation was next investigated.

Effect of Grinding on Flotation of Copper and Magnetic Separation of Iron (Tests 9, 10 and 11)

These tests were done to determine the effect of fine grinding on the flotation of copper, and on the liberation of magnetite for recovery by magnetic separation.

Three 2000-gram samples of minus 10 mesh ore were ground, without reagents, for 10, 20 and 30 minutes, respectively, at about 57% solids. Rougher and scavenger flotations were done in a 2000-gram Denver Sub-A, Model D-2, laboratory flotation machine; for cleaning, Model D-1 with a 250-gram cell was used. Reagents and test conditions are summarized in Table 3. For rougher and scavenger flotation, conditions were the same for all three tests. In cleaning the copper concentrates, lime, soda ash and sodium silicate, respectively, were used.

TABLE 3

Flotation Reagents and Conditions (Tests 9-11)

Operation		Reagents, lb/ton		Time, min.	pH
Cu ro:	Conditioning	Soda ash	1.5		10.0
		Aero Xanthate 301	0.1	5	
		Aerofloat 238	0.05	5	
	Flotation	Frother*	0.04	5	
Cu scav:	Conditioning	Soda ash	1.0		10.0
		Aerofloat 238	0.05	2 1/2	
		Aerofloat 208	0.05	2 1/2	
	Flotation			3	
Cu cl:	Conditioning	(Test 9) Lime	0.2		11.0
		(Test 10) Sod. silicate	1.0		9.7
		(Test 11) Soda ash	1.0		10.0
	Flotation			3	

* A 1 : 1 mixture of Dowfroth 250 and pine oil

Products of each test (cleaner concentrate, cleaner tailing and scavenger concentrate) were sampled for analysis for copper only.

In each case, the scavenger flotation tailing, without further grinding, was treated on a Jeffrey-Steffensen three-roll magnetic separator.

The three products (magnetic concentrate, middling and non-magnetic tailing) were analyzed for copper and HCl-soluble iron.

Results of these tests are summarized in Table 4.

TABLE 4

Effect of Grind on Flotation and Magnetic Separation

Test No.	Grind % -200 m	Product	Weight %	Analysis* % Cu	Analysis* % Sol Fe	Distn % Cu
9	47.3	Cu cl conc	3.4	26.80	-	68.1
		Cu cl tailing	2.5	1.58	-	3.0
		Cu scav conc	1.8	3.27	-	4.4
		Mag conc	28.6	0.29	61.0	6.2
		Middling	3.2	0.44	35.7	1.1
		Non-mag tail	60.5	0.38	3.3	17.2
		Feed (calcd)	100.0	1.34	-	100.0
10	67.8	Cu cl conc	3.2	31.06	-	72.0
		Cu cl tailing	2.5	2.05	-	3.7
		Cu scav conc	3.2	2.65	-	6.2
		Mag conc	24.5	0.18	66.0	3.2
		Middling	3.3	0.27	47.4	0.7
		Non-mag tail	63.3	0.31	3.5	14.2
		Feed (calcd)	100.0	1.38	-	100.0
11	84.9	Cu cl conc	3.7	26.73	-	74.8
		Cu cl tailing	2.2	1.84	-	3.0
		Cu scav conc	3.9	2.62	-	7.7
		Mag conc	24.1	0.12	67.1	2.2
		Middling	2.7	0.15	55.9	0.3
		Non-mag tail	63.4	0.25	3.0	12.0
		Feed (calcd)	100.0	1.32	-	100.0

* From Internal Reports MS-AC- 64-652,660

Removal of Magnesia-rich Gangue from Copper Concentrate (Tests 9a, 10a)

Considerable magnesia-rich gangue (pyroxene, chlorite and serpentine) was observed in the copper cleaner concentrates produced by flotation. To reduce this refractory mineral content and so to improve the acceptability of the concentrate for smelting, recleaning tests were done.

Because this fine gangue floated so readily in the cleaning stage even when sodium silicate was tried as a depressant (Test 10), recleaning was attempted by reversing the flotation, i.e. by depressing the copper minerals and floating the gangue.

Using the Denver Model D-1 laboratory flotation machine with a 250-gram cell, the copper cleaner concentrates from Tests 9 and 10 were treated, in turn, as follows:

- In Test 9a, sodium cyanide-zinc oxide complex (1:1.25 by weight), equivalent to 4.5 lb NaCN/ton of recleaner feed, was used to depress the copper minerals while inhibiting solution of gold and silver. Aero Promoter 710 (about 1.0 lb/ton) was added to encourage flotation of the non-metallic minerals.

- In Test 10a, the cyanide-zinc oxide complex only was added, at the same concentration as in Test 9a.

In each case three minutes conditioning was followed by three minutes flotation at a pH value of about 10.5. Results are shown in Table 5.

TABLE 5

Effect of Recleaning Copper Concentrate with Cyanide

Test No.	Reagents lb/ton		Product	Weight %	Analysis *%		Distn** %	
	NaCN	710			Cu	MgO	Cu	MgO
9a	0.3	0.08	Cu recl conc (u' flow)	28.6	36.7	7.6	39.3	18.8
			Cu recl tailing (froth)	71.4	22.7	13.1	60.7	81.2
			Feed (calcd)	100.0	26.8	11.5	100.0	100.0
10a	0.3	-	Cu recl conc (u' flow)	74.9	39.7	6.5	95.8	47.5
			Cu recl tailing (froth)	25.1	5.2	21.5	4.2	52.5
			Feed (calcd)	100.0	31.0	10.2	100.0	100.0

* From Internal Report MS-AC-64-660
** Based on feed to recleaning test

The loss of copper (nearly 40%) in the froth in Test 9a might have been reduced by using less promoter. However, the effectiveness of cyanide alone in Test 10a, where more than 50% of the magnesia-rich gangue was eliminated with less than 5% copper loss, showed the promoter to be unnecessary.

In subsequent tests, by conventional recleaning, final concentrates containing 30-34% copper with about 11% MgO were consistently produced. Since the grade of these concentrates exceeded the objectives of the investigation, namely over 20% copper and less than 13% MgO, no further testing of the cyanide depressant technique was done. However, despite the problem of reclaiming copper from the magnesia-rich froth (tailing), the technique of recleaning in cyanide might be useful if magnesia-specification penalties in smelter contracts have to be avoided.

Magnetic Separation of Iron, Flotation of Copper (Test 12)

Before further work was done on the promising technique of Test 11 (flotation followed by magnetic separation), one probing test of the reverse procedure was made. In this test, a 2000-gram lot of minus 10 mesh ore was stage ground, without reagents, to pass 100 mesh and treated as follows:

(a) Magnetic separation on a Jeffrey-Steffensen three-roll separator to recover a rougher magnetic concentrate (combined with a middling) and a non-magnetic tailing. A sample of the latter was retained for a screen test and analysis; the remainder was reserved for copper flotation.

(b) Rougher magnetic concentrate (including middling) was reground in stages to pass 325 mesh, and

(c) cleaned magnetically (Jeffrey-Steffensen) with recovery of a magnetic concentrate, middling and Jeffrey cleaner tailing. The latter was retained for analysis.

(d) Copper was scavenged from the combined magnetic cleaner concentrate and middling by flotation for three minutes at a pulp density of about 33% solids, under the same conditions as for the copper rougher flotation in Tests 9-11. The two products were a black, copper-bearing froth (copper scavenger concentrate # 1) and a final magnetite concentrate (underflow).

(e) The non-magnetic tailing from (a) at about 74% minus 200 mesh, without regrinding, was floated under the conditions of Test 10 to produce a rougher copper and a scavenger concentrate #2. The former was cleaned and recleaned as in Test 10.

Test results are summarized in Tables 6 and 7.

TABLE 6

Results of Magnetic Separation and Flotation (Test 12)

Product	Weight %	Analysis *, %		Distribution, %	
		Cu	Sol Fe	Cu	Sol Fe
Magnetite conc (u'flow)	23.8	0.07	68.0	1.3	80.4
Cu scav conc # 1	1.5	1.19	62.5	1.3	4.7
Jeffrey cl tailing	2.9	1.62	17.4	3.5	2.5
Cu recl conc	4.3	22.75		73.2	
Cu recl tailing	1.3	3.10		3.0	
Cu cl tailing	4.8	1.06	3.5	3.8	12.4
Cu scav conc #2	3.2	1.09		2.6	
Flot tailing	58.2	0.26		11.3	
Feed (calcd)	100.0	1.34	20.1	100.0	100.0

* From Internal Report MS-AC-64-669

TABLE 7

Screen Analysis of Jeffrey Non-Magnetic Tailing (Flotation Feed)

Product	Weight %	Analysis *, % Cu	Distribution, % Cu
-100 + 150 mesh	12.8	1.22	8.5
-150 + 200 mesh	13.0	1.49	10.6
-200 + 325 mesh	20.3	1.87	20.7
-325 mesh	53.9	2.05	60.2
Feed (calcd) **	100.0	1.83	100.0

* From Internal Report MS-AC-64-669

** By analysis: Cu 1.90%; HCl-soluble Fe 3.5%

Although acceptable iron and copper concentrates were produced by this technique, recoveries were slightly lower than those obtained in Test 11. Because of this shortcoming and the need for an additional flotation circuit to scavenge copper minerals from the magnetite, subsequent test work was confined to the flotation-magnetic separation procedure.

Flotation of Copper, Magnetic Separation of Iron (Test 13)

In this test, the procedure of Test 11 was modified by (1) staged grinding of the minus 10 mesh feed to minus 100 mesh to minimize formation of slimes, and (2) regrinding the rougher Jeffrey concentrate to minus 325 mesh before magnetic cleaning to improve iron grade and copper elimination.

A rougher copper concentrate was floated off in two stages, and cleaned and recleaned, under the following conditions:

Operation	Reagents, lb/ton of feed		Time Min	pH
Grinding (to approx. 75%-200 m)	Soda ash	1.5		9.7
Cu rougher				
Conditioning (1st)	Soda ash	0.5		10.0
	Aero Xanthate 301	0.1	5	
	Aerofloat 238	0.05	5	
Flotation	1:1 Dow 250/pine oil	0.04	5	
Conditioning (2nd)	Soda ash	0.2		10.1
	Aero Promoter 425	0.05	5	
Flotation			3	
Cu cleaner				
Conditioning	Soda ash	0.1		10.1
Flotation			3	
Cu recleaner				
Conditioning	Soda ash	0.05		10.1
	Aero Depressant 610	0.02	3	
Flotation			3	

The flotation tailing, without regrinding, was treated on the Jeffrey-Steffensen magnetic separator. The rougher magnetic concentrate (plus middling) was reground in stages to pass 325 mesh and was cleaned once on the magnetic separator to produce a cleaner tailing, a cleaner magnetic concentrate and a small amount of middling. The latter, under microscopic examination, appeared to be of concentrate grade, and was combined with the cleaner concentrate for sampling.

Test results, including gold and silver assays on all products are shown in Table 8.

TABLE 8

Results of Flotation and Magnetic Separation (Test 13)

Product	Weight %	Analysis *				Distribution, per cent			
		%		oz/ton					
		Cu	HCl Sol Fe	Au	Ag	Cu	Sol Fe	Au	Ag
Cu recl conc (1)	3.6	30.45	9.1	0.695	7.9	78.4	1.6	79.6	68.8
Cu recl tailing (2)	0.8	4.22	13.5	0.06	1.6	2.4	0.5	1.6	3.1
Cu cl tailing	5.9	1.70	13.3	0.03	0.6	7.2	3.9	5.7	8.5
Magnetite conc	23.5	0.065	69.4	tr	0.10	1.1	81.3	-	5.6
Jeffrey cl tailing	2.1	0.22	30.4	0.045	0.36	0.4	3.2	2.9	1.7
Jeffrey non-mag tailing	64.1	0.23	3.0	0.005	0.08	10.5	9.5	10.2	12.3
Feed (calcd)	100.0	1.40	20.1	0.031	0.42	100.0	100.0	100.0	100.0

(1) MgO 11.2% (2) MgO 20.0%

* From Internal Reports MS-AC-64-752, 937

Because of the difficulty in reducing the copper content of the final tailing below 0.23% (representing about 11% of the original copper), its mode of occurrence in the tailing was investigated. Analysis of the size fractions, as shown in Table 9, indicated that 63.6% of the residual copper was in the minus 325 mesh fraction.

TABLE 9

Screen Analysis of Jeffrey Non-Magnetic Tailing (Test 13)

Product	Weight %	Analysis*, % Cu	Distn, % Cu
-65 + 150 mesh	9.3	0.25	10.0
-150 + 200 "	12.1	0.18	9.3
-200 + 325 "	23.6	0.17	17.1
-325	55.0	0.27	63.6
Feed (calcd)	100.0	0.23	100.0

* From Internal Report MS-AC-64-733

The dissemination of copper in the extreme fines was confirmed by mineralogical examination** which showed that "bornite, chalcopyrite and chalcocite are present as minute inclusions in gangue. These inclusions range from about 5 to 50 microns in size, with the majority being 0 to 20 microns . . . (but) these minerals are present in small quantities and can account for only some of the copper in the sample. The remainder of the copper, therefore, must occur as a non-metallic mineral".

Scavenger Flotation of Copper from Magnetic Concentrate (Test 13a)

In an attempt to reduce the copper content of the magnetite concentrate, a copper scavenging flotation was done on the combined Jeffrey cleaner concentrate and middling product from Test 13. Flotation, at about 20% solids, was done under the same conditions as for the similar scavenging operation in Test 12. Size analysis of the final magnetite concentrate (underflow) was done on a Haultain Infrasizer and the fractions were analyzed for copper. Test results are shown in Tables 10 and 11.

* * From Mineral Sciences Division Internal Report MS-64-67 by W. Petruk, August 17, 1964.

TABLE 10

Results of Scavenger Flotation of Copper from Magnetic Concentrate

Product	Weight %	Analysis*, %					Distn, %	
		Cu	Sol Fe	Total Fe	S	Insol	Cu	Sol Fe
Magnetite conc (u' flow)	98.0	0.062	69.5	70.0	0.06	0.7	93.3	98.2
Cu "conc" (froth)	2.0	0.22	63.0	-	-	-	6.7	1.8
Feed (calcd)	100.0	0.065	69.4	-	-	-	100.0	100.0

* From Internal Report MS-AC-64-752

TABLE 11

Infrasizer Analysis of Final Magnetite Concentrate

Product	Weight %	Analysis*, % Cu	Distn, % Cu
+ 56 micron	2.1	0.096	3.4
-56 + 40 "	21.4	0.088	32.2
-40 + 28 "	21.5	0.060	22.0
-28 + 20 "	17.8	0.052	15.9
-20 + 14 "	12.8	0.044	9.6
-14 + 10 "	6.9	0.032	3.7
-10 "	17.5	0.044	13.2
Feed (calcd)	100.0	0.059	100.0

* From Internal Report MS-AC-64-957

No significant reduction in copper content of the magnetite concentrate was achieved by this scavenger flotation step. Analysis of the infrasizer fractions indicated that the magnetite concentrate would have to be ground to at least minus 28 micron size before the copper content could be reduced appreciably below 0.06%.

Flotation of Copper, Magnetic Separation of Iron (Test 14).

In this test an attempt was made to achieve maximum copper recovery using the procedure of Test 13, but modified by (a) substitution of a stronger promoter (Dow Z-200 instead of Aero Promoter 425) in the second stage of the copper flotation and (b) regrinding the Jeffrey non-magnetic tailing and scavenging copper by flotation after sulphidization under the following conditions:

Operation	Reagents, lb/ton of feed		Time Min	pH
Grinding (to 88.7% -200 m)			10	9.4
Conditioning	Soda silicate	1.7		
	Sodium sulphide	1.7	5	10.8
	Aero Promoter 425	0.17	5	
Flotation	1:1 Dow 250/pine-oil	0.04	3	10.6

A gangue depressant (Aero Depressant 610) was added in the copper cleaner step (instead of the recleaner) in an effort to eliminate more magnesia-rich gangue from the final concentrate. The Jeffrey cleaner middling, instead of being combined with the cleaner concentrate, was collected separately for analysis. Screen and infrasizer tests were done on the final flotation tailing and final magnetite concentrate, respectively, and the fractions were analyzed for copper.

Results of this test are summarized in Tables 12, 13 and 14.

TABLE 12

Copper Flotation, Magnetic Separation, Copper Scavenger Flotation (Test 14)

Product	Weight %	Analysis * % Cu	Analysis * % HCl sol Fe	Analysis * oz/ton Au	Analysis * oz/ton Ag	Distribution per cent Cu	Distribution per cent Sol Fe	Distribution per cent Au	Distribution per cent Ag
Cu recl conc (1)	3.1	33.04	4.2	0.735	8.5	73.7	0.6	71.1	64.5
Cu recl tailing	0.8	4.27	7.0	0.067	1.6	2.4	0.3	1.6	3.2
Cu cl tailing	9.8	1.79	13.8	0.04	0.7	12.6	6.5	12.2	16.6
Jeffrey cl conc (2) (mag)	21.5	0.084	69.3	0.005	0.03	1.3	71.6	3.4	1.5
Jeffrey cl middling	1.7	0.10	66.2	0.005	0.06	0.1	5.4	0.3	0.2
Jeffrey cl tailing	2.2	0.35	26.5	0.02	0.25	0.6	2.8	1.2	1.3
Cu scav conc	1.4	0.73	3.9	0.02	0.30	0.7	0.2	0.9	1.0
Final tailing	59.5	0.20	4.4	0.005	0.08	8.6	12.6	9.3	11.7
Feed (calcd)	100.0	1.39	20.8	0.032	0.41	100.0	100.0	100.0	100.0

(1) MgO 11.1%
(2) S 0.05%, Insol 1.49%
* From Internal Reports MS-AC-64-961, 1001

TABLE 13

Screen Analysis of Scavenger Flotation Tailing (Test 14)

Product	Weight %	Analysis *, % Cu	Distn, % Cu
-100 + 150 mesh	4.2	0.20	4.0
-150 + 200 mesh	7.1	0.18	6.2
-200 + 325 mesh	20.7	0.31	30.9
-325 mesh	68.0	0.18	58.9
Feed (calcd)	100.0	0.21	100.0

* From Internal Report MS-AC-64-961

TABLE 14

Infrasizer Analysis of Final Magnetite Concentrate (Test 14)

Product	Weight %	Analysis*, % Cu	Distn, % Cu
+56 micron	4.4	0.099	5.6
-56 + 40 "	22.8	0.092	26.9
-40 + 28 "	20.8	0.074	19.7
-28 + 20 "	16.8	0.068	14.6
-20 + 14 "	11.9	0.060	9.1
-14 + 10 "	6.3	0.064	5.1
-10 "	17.0	0.070	19.0
Feed (calcd)	100.0	0.078	100.0

* From Internal Report MS-AC-64-957

The use of a stronger promoter in the rougher flotation resulted in a 33% increase in material floated with no significant increase in copper rougher recovery. Scavenging copper from the non-magnetic tailing (after regrinding and sulphidization) was ineffective, giving only 0.7% additional recovery. Despite the use of Aero Depressant 610 in the copper cleaner step, the MgO content of the final concentrate (at 11.1%) was practically unchanged from Test 13. However, copper grade was increased from 30.4% to 33.0%, apparently by depression of oxide iron minerals as indicated by the reduction of HCl-soluble iron content from 9.1% to 4.2%.

Flotation of Copper, Magnetic Separation of Iron (Test 15)

In this final test, illustrated by the flowsheet in Figure 3, the procedure of Test 13 was repeated with the following minor modifications:

(a) Use of Aero Depressant 610 in both rougher and cleaner copper flotation in an attempt to improve grade and recovery by gangue depression.

(b) Second recleaning of copper concentrate with addition only of soda ash (0.1 lb/ton) to maintain pH at 10.

(c) Addition of a surface active agent (Aerosol OT-75) in both the rougher and cleaner magnetic separation tests to facilitate the rejection of copper-bearing gangue.

(d) De-magnetizing of reground Jeffrey rougher concentrate before magnetic cleaning in an attempt to minimize clustering and trapping of copper-bearing gangue.

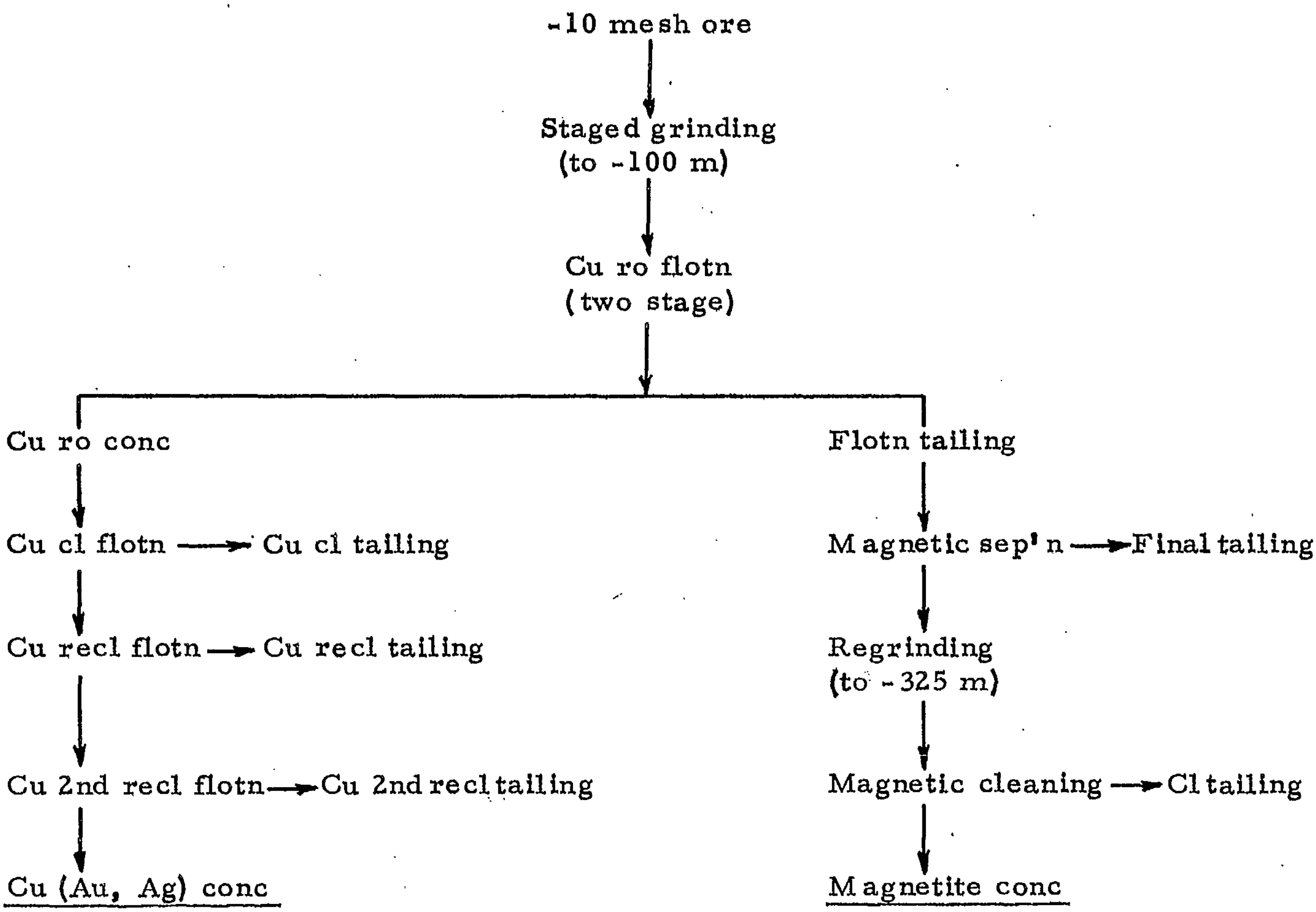

Fig. 3 Flowsheet for Test 15

Results, including gold and silver assays on all products, are summarized in Table 15.

Copper analyses were done on the screen fractions of the Jeffrey non-magnetic tailing and on the infrasizer fractions of the Jeffrey cleaner magnetic concentrate. These results are shown in Tables 16 and 17.

TABLE 15

Results of Flotation of Copper, Magnetic Separation of Iron (Test 15)

Product	Weight %	Analysis *					Distribution per cent			
		%			oz/ton					
		Cu	HCl sol Fe	MgO	Au	Ag	Cu	Sol Fe	Au	Ag
Cu 2nd recl conc	3.1	34.70	3.8	10.9	0.74	8.2	76.9	0.6	74.8	77.2
" " " tailing	0.5	5.88	6.2	14.6	0.08	1.8	2.0	0.2	1.3	2.8
" recl tailing	1.0	1.64	10.3	22.2	0.04	1.0	1.1	0.5	1.3	3.0
" cl "	4.6	1.88	14.0	21.1	0.04	0.6	6.2	3.3	5.9	8.2
Jeffrey cl conc (1)(mag)	22.2	0.075	67.7	-	tr	tr	1.2	76.5	-	-
" " middling	1.9	0.098	63.5	-	tr	0.03	0.2	6.1	-	0.3
" " tailing	5.1	0.38	18.1	-	0.015	0.07	1.4	4.7	2.6	0.9
" non-mag tailing	61.6	0.25	2.6	-	0.007	0.04	11.0	8.1	14.1	7.6
Feed (calcd)	100.0	1.40	19.7	-	0.031	0.33	100.0	100.0	100.0	100.0

(1) S 0.06%, Insol 1.7%
* From Internal Report MS-AC-64-1071

TABLE 16

Screen Analysis of Jeffrey Non-Magnetic Tailing (Test 15)

Product	Weight %	Analysis*, % Cu	Distn, % Cu
-100 + 150 mesh	11.0	0.30	13.0
-150 + 200 "	11.2	0.23	10.4
-200 + 325 "	20.1	0.18	14.4
-325 "	57.6	0.27	62.0
Feed (calcd)	100.0	0.25	100.0

* From Internal Report MS-AC-64-1071

TABLE 17

Infrasizer Analysis of Final Magnetic Concentrate (Test 15)

Product	Weight %	Analysis *, % Cu	Distn, % Cu
+ 56 micron	3.5)	0.103	32.4
-56 + 40 "	20.5)		
-40 + 28 "	20.6	0.080	21.6
-28 + 20 "	17.2	0.048	10.6
-20 + 14 "	12.2	0.045	7.2
-14 + 10 "	6.2	0.048	4.0
-10 "	19.8	0.093	24.2
Feed (calcd)	100.0	0.076	100.0

* From Internal Report MS-AC-64-989

Although a slightly higher grade copper concentrate (34.7% Cu) was produced in this test, the improvement was probably due more to the 2nd recleaning than to the use of Aero Depressant 610 in the rougher flotation, particularly since there was no increase in rougher recovery and no significant elimination of magnesia-rich gangue.

In the magnetic separation step, neither the use of a surface active agent nor de-magnetization of the rougher concentrate before cleaning had any effect in reducing the copper content of the final concentrate. However, the surface active agent appears to have resulted in an increase in iron recovery (to 82.6%) in the final concentrate (including middling).

Elutriation of Magnetite Concentrate (Test 15a)

An elutriation test was done on a portion of the Jeffrey cleaner magnetic concentrate produced in Test 15 to determine if its copper content could be reduced by removal of any chalcocite "slimes" adhering to the magnetite. Results of this operation are given in Table 18.

TABLE 18

Elutriation of Jeffrey Cleaner Concentrate

Product	Weight %	Analysis*, % Cu	Distn, % Cu
Overflow	9.2	0.095	11.9
Underflow	90.8	0.071	88.1
Feed (calcd)	100.0	0.073	100.0

* From Internal Report MS-AC-64-1071

These results show no significant reduction of the copper content of the magnetite concentrate. The almost identical copper values for the elutriated fines (0.095%) and the minus 10 micron fraction (0.093%, Table 17), indicate the practical impossibility of obtaining further elimin- of copper by elutriation.

CONCLUSIONS

Magnetic cobbing is impractical for preliminary treatment of this copper-magnetite ore.

For maximum recovery of copper and magnetite with minimum grinding, the best procedure is flotation of a copper concentrate from ore ground to about 75% minus 200 mesh followed by magnetic separation of an iron concentrate from the flotation tailing. Cleaning of the magnetic concentrate after regrinding to minus 325 mesh is necessary to reduce the copper content to the 0.07% tolerable maximum. Recoveries achieved by this method were: copper, 88.0%, gold, 86.9%; silver, 80.4%; and iron 81.3% (equivalent to about 88% of the magnetite). A suggested mill flowsheet (simplified) is shown in Figure 4.

Because of the prevalence of bornite and chalcocite in the ore, concentrates of 30-34% copper grade can be readily obtained by conventional recleaning, albeit accompanied by considerable fine, magnesia-rich gangue. However, by reversing the flotation (i.e. by depressing the copper sulphides with sodium cyanide — zinc oxide complex) in the final recleaning step, the MgO content can be reduced from as high as 10-12% to less than 7%, with corresponding increase in copper grade to nearly 40%.

Residual copper in the final tailing occurred partly as minute inclusions (under 20 micron in size) in the gangue and partly as a silicate mineral. Therefore, within practical grinding limits, copper recovery by flotation cannot exceed about 90%.

Due to similar fine dissemination of copper minerals in magnetite, the copper content of the iron concentrate cannot be reduced below about 0.06% without grinding to at least 28 micron size.

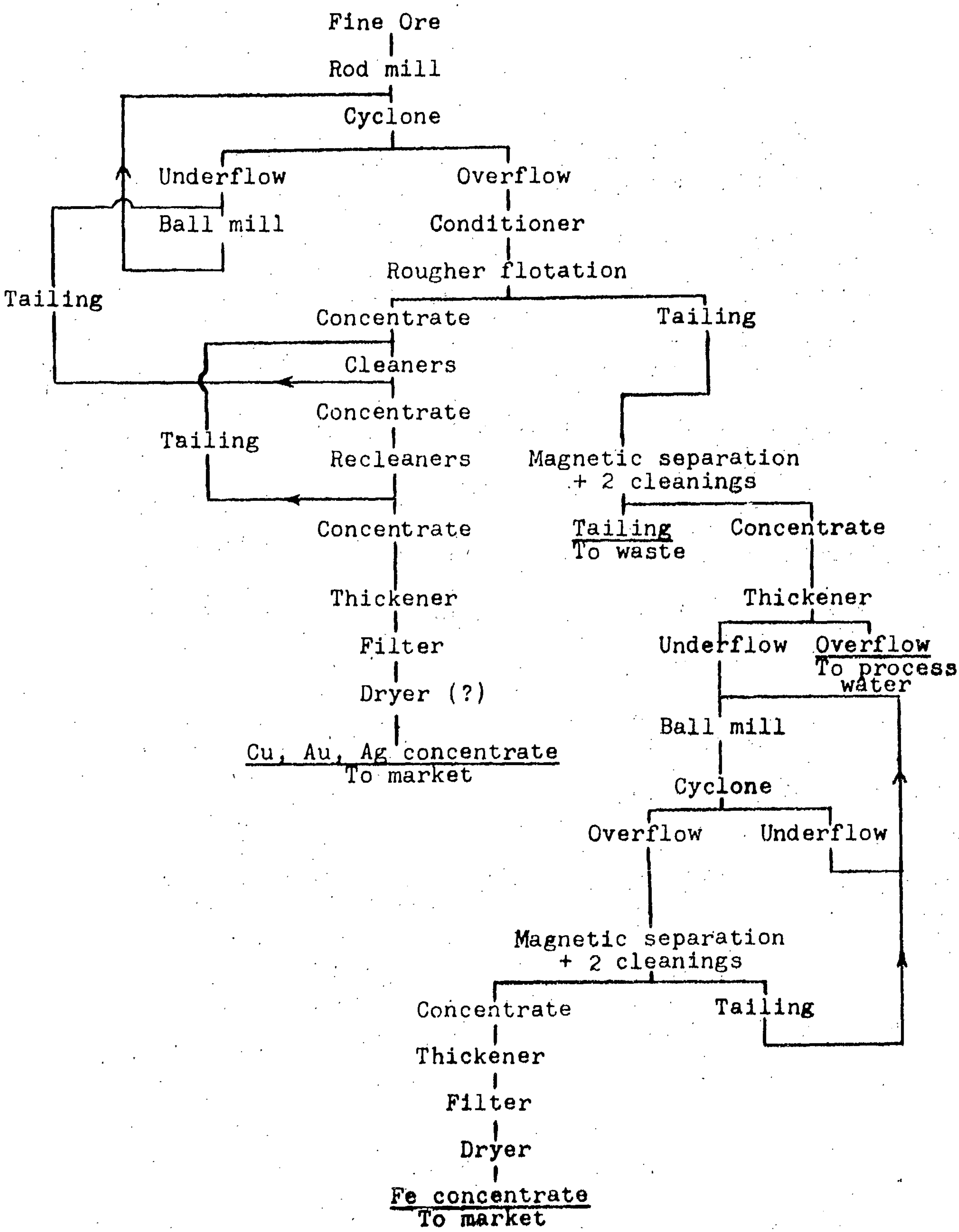

Fig. 4 Suggested Flowsheet - Grinding and Concentration (Simplified)

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