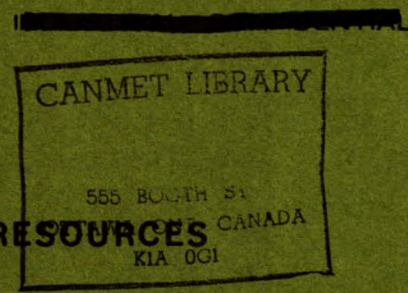


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OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 71-82

IR 71-82

**BENEFICIATION OF A LOW-GRADE
COPPER-NICKEL-ZINC-IRON ORE FROM
BIRD RIVER AREA, NORTHEASTERN MANITOBA**

by

D. RAICEVIC AND R. W. BRUCE

MINERAL PROCESSING DIVISION

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D. Raicevic* and R.W. Bruce**

- - -

SUMMARY OF RESULTS

Two low-grade ore samples, received for this investigation, assayed as follows:

Sample No. 1: 0.40% Cu, 0.50% Ni, 0.28% Zn, 10.34% Fe

Sample No. 2: 0.22% Cu, 0.67% Ni, 0.03% Zn, 15.34% Fe

The metals of major economic interest were copper as chalcopyrite and nickel as pentlandite, violarite and nickeliferous pyrrhotite while iron, present as pyrrhotite and magnetite, was of a minor economic value.

Considerable and troublesome talc was also present in Sample No. 2.

The presence of zinc as sphalerite associated with nickel-bearing minerals is unusual, making this ore rather rare in this respect.

The procedures developed, consisting of flotation and low-intensity magnetic separation, produced separate copper and nickel concentrates, or a combined copper-nickel concentrate, as well as a nickeliferous pyrrhotite concentrate, all with marketable grades suitable for smelting.

The overall recoveries from Sample No. 1 and Sample No. 2 respectively were as follows:

91.9 and 91.8% copper; 70 and 81% nickel; 27 and 54% iron.

Small amounts of platinum, palladium and silver, usually associated with this type of ores, were also recoverable from these ore samples, but the economic benefits from these precious metals would be small.

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INTRODUCTION

Location of Property

The property of the Bird River Mining Company is located approximately one mile north of the junction between the Cat Lake and Bird Lake Roads in northeastern Manitoba, about 135 miles northeast of Winnipeg.

Shipment

Two ore samples of drill cores were received from Dr. D. T. Anderson, Assistant Head, Department of Earth Sciences, The University of Manitoba, Winnipeg. Dr. Anderson is a consultant for Bird River Mining Company.

The minerals of an economic interest in these ore samples are copper as chalcopyrite, nickel as pentlandite, violarite and nickeliferous pyrrhotite, zinc as sphalerite and iron mainly as pyrite, pyrrhotite and magnetite. Small amounts of platinum and palladium which usually accompany copper-nickel ores, were also present.

The chemical analysis of the two ore samples follows:

	Cu	Ni	Zn	Sol Fe	Insol	Ag	Pt	Pd
	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>oz/ton</u>	<u>oz/ton</u>	<u>oz/ton</u>
Sample No. 1:	0.40	0.50	0.28	10.34	60.6	0.350	0.005	0.013
Sample No. 2:	0.22	0.67	0.03	15.34	45.72	0.085	0.005	0.021

Purpose of Investigation

In his letter of January 13, 1970, Dr. Anderson requested the Mineral Processing Division "to determine the separability of the various fractions of the ore".

Sampling and Analysis

About two dozen specimens of the diamond drill cores were obtained from each ore sample for mineralogical examination. The remainder of the samples were then crushed to minus 10 mesh and head samples were riffled out for chemical analysis and mineralogical examination.

MINERALOGICAL EXAMINATIONS*

Ore Sample No. 1

The minerals present in this ore sample occur as disseminations and veinlets in the gangue minerals.

The principal ore minerals are chalcopyrite and pyrrhotite; other sulphides include sphalerite, pentlandite, smythite, pyrite, violarite, and marcasite. Gangue minerals are chiefly amphibole, quartz, and chlorite, with minor calcite. Some talc may be associated with the chlorite.

Copper and Zinc Minerals

The copper occurs entirely as chalcopyrite. It is present from massive portions, comprising most of several of the fragments received, down to tiny veinlets and exsolution particles in sphalerite and in gangue.

Sphalerite appears to be the only zinc mineral present. It occurs as grains and irregular particles from about 2 mm in diameter down to a few microns; the majority, however, appears to be plus 200 mesh. The larger grains of sphalerite generally contain small inclusions (minus 200 mesh) of pyrrhotite, chalcopyrite and gangue minerals.

Nickel Minerals

Nickel occurs in a wide variety of minerals in the ore. In addition to the usual nickel minerals -- pentlandite and violarite -- appreciable nickel is also present in the pyrrhotite, smythite, marcasite and gangue minerals. Complete electron-probe analyses of some of the sulphides are shown in Table 1.

*From Internal Reports MS 71-14 and MS 70-23 by Dr. E.H. Nickel, Mineral Science Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

TABLE 1
Results of Electron-Probe Analyses of Some Sulphides

Ni Minerals	Weight Per Cent				
	Fe	Ni	Co	S	Total
Pentlandite	26.8	37.2	2.8	33.0	99.8
Violarite	24.3	29.6	4.1	42.2	100.2
Smythite	56.3	1.9	0.1	41.1	99.4
Pyrrhotite	59.3	0.8	---	39.6	99.7

(Analyses made by Dr. D.C. Harris)

The pentlandite and violarite are generally intimately intergrown, giving the appearance of pentlandite partially converted to violarite. Together they form grains up to about a millimetre in diameter, generally associated with pyrrhotite or chalcopyrite. The violarite is rather badly pitted and fractured. The pyrrhotite and smythite are also intimately associated, with the smythite forming flame-like particles in the pyrrhotite, generally around the margins of pyrrhotite grains.

Marcasite was found as isolated grains associated with the other sulphides in several of the sections. Electron-probe analyses indicate that it has a nickel content of about 0.4%. Chlorite is the only gangue mineral found to contain appreciable amounts of nickel -- 0.08% Ni on the average. The amphibole may also contain traces of nickel, but in amounts below the limit of quantitative detection (< 0.02%).

The analyses shown in Table 1 are spot analyses made by electron probe on the polished sections; they should not be taken as accurate representations of the average nickel contents of the minerals listed because they are intended to give some indication of the nickel distribution and, thereby, to explain possible tailings losses.

Ore Sample No. 2

The metallic minerals present in this ore sample consist of disseminated sulphides and magnetite in a matrix of gangue minerals. The gangue minerals include calcite, chlorite, talc and amphibole in approximately decreasing order of abundance; talc comprises an estimated 5 to 10% of the sample. The silicate gangue minerals contain an average of 0.05% chemically combined nickel.

Pyrrhotite greatly predominates among the sulphides. It contains an appreciable amount of chemically combined nickel; the average of 31 electron-probe spot analyses gave 0.7% Ni. Pentlandite and violarite are the principal nickel minerals, with pentlandite predominating. A minor amount of chalcopyrite is also present. No smythite or sphalerite, which were noted in the first sample, were observed in this ore sample.

Magnetite is abundant, and a few of the larger grains contain inclusions of chrome spinel. No nickel was detected in the magnetite.

OUTLINE OF INVESTIGATION

Beneficiation of sulphide ores containing copper and nickel minerals by the conventional flotation method does not usually present much difficulty as long as the suitable smelting grades of the copper-nickel concentrate can be obtained (about 6% Cu-Ni combined for INCO's Copper Cliff operation^(1-a) and about 8% Cu-Ni combined for the INCO's Thompson operation²⁾)

The presence of sphalerite in this type of ore as in the Bird River ore Sample No. 1 was unusual, making this ore difficult to adapt to the conventional techniques for the copper-nickel concentration. Because a complete elimination of zinc from the nickel concentrate could not be expected, some zinc as sphalerite would be present in the nickel concentrate. Because no specification of an acceptable zinc content in the nickel concentrate was available, a particular effort was made to keep the zinc content in the nickel concentrate to a minimum in order to minimize penalties.

In some nickel-bearing ores, a considerable amount of nickel is present as nickeliferous pyrrhotite in addition to the common nickel-bearing minerals (pentlandite, violarite and others). This pyrrhotite contains between 0.5 and 2% nickel. If pyrrhotite is concentrated alone, the concentrate produced has a low nickel grade (about 1% Ni). If this low-nickel concentrate is added to the normal nickel concentrate, the grade of the combined concentrate usually is not saleable and is below the smelting specifications; this makes it unacceptable to a smelter. As a result, a separate low-nickel concentrate is usually prepared for separate treatment by the Falconbridge process, for example, in which the reduced ferro-nickel pellets are charged directly into a steel-making furnace (1-b). This process recovers about 97% of iron and about 87.5% of nickel present in the nickeliferous concentrate⁽³⁾.

The nickeliferous pyrrhotite present in the Bird River ore samples assayed about 0.8% Ni and contained between 13 and 22% of the nickel in samples, i.e., a fairly large amount of nickel. The nickeliferous pyrrhotite comprised about 3.5% by weight of ore sample No. 1 but the magnetic portion (pyrrhotite-magnetic combined) of the ore sample No. 2 comprised about 15% of the ore by weight. Due to relatively large amounts of the magnetic materials in these ore samples, the nickeliferous concentrates obtained could not be added to the nickel concentrates or to combined copper-nickel concentrates because the grades of the combined concentrates would be lower than acceptable for smelting.

The presence of large amounts of chlorite and talc, particularly in sample No. 2, presented a major problem but the zinc content in the second sample was low and did not constitute a problem.

Based on these observations and the Company's request, the objectives of this investigation were as follows:

- (i) preparation of a separate copper and separate nickel concentrates, or a combined copper-nickel concentrate with maximum copper and nickel recoveries, the highest Cu-Ni

grades and minimum zinc contents;

- (ii) preparation of a zinc concentrate where feasible;
- (iii) preparation of a separate nickeliferous concentrate.

Preparation of a marketable (50 to 55%) zinc concentrate from No. 1 ore sample was probably possible but the latest diamond drilling results showed that only a small portion of the orebody contains an appreciable amount of zinc and that the major portion of the orebody contains about 0.03% Zn. As a result, the idea of preparing a separate zinc concentrate from the second ore samples was abandoned. In some tests, however, a zinc concentrate was obtained from Sample No. 1.

Due to different characteristics of the samples received, evaluation of each ore sample was carried out separately. The procedures developed for one had to be modified to suit the characteristics of the other. This was particularly true with Sample No. 2 which contained large amounts of talc and magnetite, and a negligible amount of zinc, whereas Sample No. 1 contained ten times as much zinc, little or no talc, and no magnetite. As a result, the evaluation of the milling characteristics of each ore sample will be described separately.

DETAILS OF INVESTIGATION

Evaluation of Ore-Sample No. 1

Preliminary Testing

Three series of preliminary tests applying one-stage magnetic separation and flotation were carried out on Sample No. 1 ground to 89.3% minus 200 mesh.

The first series, consisting of magnetic separation, was done to observe the effect of low- and high-intensity magnetic treatments on the separability of the nickel- and iron-bearing minerals from the other components in the ore using a Davis Tube and a Jones wet high-intensity magnetic separator. Results of this series are recorded in Table 2.

TABLE 2
Results of Low- and High-Intensity Magnetic Separation

Product	Weight %	Assay %				Distribution %			
		Cu	Ni	Zn	Sol Fe	Cu	Ni	Zn	Sol Fe
<u>Davis tube test</u>									
L Int ro mag conc	5.5	0.05	1.30	0.15	56.45	0.7	12.7	2.7	29.5
" " " non-mags	94.5	0.42	0.52	0.32	7.84	99.3	87.3	97.3	70.5
Feed (calcd)	100.0	0.40	0.563	0.312	10.51	100.0	100.0	100.0	100.0
<u>Jones Separ at 2 amps</u>									
H Int ro mag conc	10.8	0.21	1.65	0.18	40.13	6.1	39.1	5.7	41.2
" " " midds	41.7	0.39	0.32	0.33	6.54	43.4	29.4	40.7	25.8
" " " non-mags	47.5	0.40	0.30	0.38	6.42	50.5	31.5	53.6	33.0
Feed (calcd)	100.0	0.376	0.455	0.418	10.57	100.0	100.0	100.0	100.0
<u>Jones Separ at 4 amps</u>									
H Int ro mag conc	13.7	0.21	1.53	0.14	34.08	7.8	45.6	6.5	45.5
" " " midds	43.8	0.38	0.30	0.30	6.40	45.1	28.6	44.5	27.6
" " " non-mags	42.5	0.41	0.28	0.34	6.46	47.1	25.8	49.0	26.9
Feed (calcd)	100.0	0.37	0.461	0.295	10.23	100.0	100.0	100.0	100.0
<u>Jones Separ at 12 amps</u>									
H Int ro mag conc	46.8	0.18	0.55	0.23	13.83	22.6	56.5	32.8	64.6
" " " midds	32.0	0.52	0.35	0.42	6.40	44.1	24.2	40.8	20.4
" " " non-mags	21.2	0.59	0.42	0.41	7.12	33.3	19.3	26.4	15.1
Feed (calcd)	100.0	0.376	0.458	0.329	10.04	100.0	100.0	100.0	100.0

The most interesting results from the first series of tests were from the Davis tube test showing that low-intensity magnetic concentrate had nickel and iron contents similar to the nickeliferous pyrrhotite obtained by the mineralogical examination (see "Mineralogy") i. e., the low-intensity wet magnetic separation recovered most of the nickeliferous pyrrhotite as a separate iron-nickel concentrate having about 5.5% weight of the ore, assaying 1.3% Ni, and containing about 13% of the nickel in the ore. This iron-nickel concentrate had low copper and zinc contents and assayed 56.45% iron.

The Jones high-intensity magnetic separator appears to be too powerful for this purpose.

In the second series of tests, further low-intensity magnetic tests were done. In one test, the rougher concentrate was reground to minus 200 mesh and then cleaned. The results are recorded in Table 3.

TABLE 3

Results from Rougher and Cleaner Low-Intensity Magnetic Separation

Product	Weight %	Assay %					Distribution %			
		Cu	Ni	Zn	Sol. Fe	Insol	Cu	Ni	Zn	Sol. Fe
Mag rgh conc	3.77	0.08	1.17	0.23	56.6	9.43	0.7	9.3	3.0	28.8
Mag rgh conc	4.10	0.08	1.13	0.15	51.85	9.94	0.9	10.2	2.1	31.2
Mag cl conc	3.53	0.05	1.06	0.17	58.20	4.10	0.5	9.1	1.2	29.0

These results showed that an iron-nickel cleaner concentrate with grades of 58% Sol Fe and about 1% Ni could be produced that contained about 29% of the iron and about 9% of the nickel in the ore. It should be noted that INCO's Copper Cliff operation produces a nickeliferous pyrrhotite concentrate containing 58% Fe, 0.75% Ni, and 0.05% Cu^(1-a), i. e., grades similar to those of the cleaner concentrate in Table 3.

A third series of tests, consisting of flotation of copper and nickel sulphides in a Cu-Ni rougher concentrate, was done to observe the effects of zinc sulphate ($ZnSO_4$) and sodium cyanide (NaCN) as zinc depressants. The amount of zinc sulphate used was 0.5 lb $ZnSO_4$ /ton of ore but NaCN was used in amounts up to 0.1 lb/ton. For the purpose of comparison, a pilot test, in which no depressants were added, was also carried out. All tests of this series were done on ore ground to 89% minus 200 mesh and floated at a natural pH of about 8.2 so that no interference of other reagents was involved. Results are recorded in Table 4.

TABLE 4

Effect of NaCN and ZnSO₄ on Zinc Content in Copper-Nickel Concentrates

Test No	Lb/Ton		Product	Wt %	Assay %				Distribution %			
	NaCN	ZnSO ₄			Cu	Ni	Zn	Sol Fe	Cu	Ni	Zn	Sol Fe
BR P	Nil	Nil	Cu-Ni ro conc	10.68	3.43	3.54	0.68	24.20	94.6	73.9	26.4	24.3
			Cu-Ni ro tail	89.32	0.024	0.15	0.22	8.43	5.4	26.1	73.6	75.7
			Feed (calcd)	100.00	0.387	0.512	0.266	9.95	100.0	100.0	100.0	100.0
BR 5	Nil	0.5	Cu-Ni ro conc	7.65	4.57	4.13	0.32	20.64	93.3	68.4	9.0	15.3
			Cu-Ni ro tail	92.35	0.03	0.16	0.27	9.50	6.7	31.6	91.0	84.7
			Feed (calcd)	100.00	0.376	0.462	0.280	10.33	100.0	100.0	100.0	100.0
BR 1	0.01	0.5	Cu-Ni ro conc	12.2	3.00	3.00	0.26	26.11	94.5	79.3	11.6	30.7
			Cu-Ni ro conc	87.8	0.024	0.11	0.28	8.20	5.5	20.7	88.4	69.3
			Feed (calcd)	100.0	0.387	0.462	0.276	10.38	100.0	100.0	100.0	100.0
BR 4	0.03	0.5	Cu-Ni ro conc	10.10	3.61	3.72	0.38	23.91	93.6	73.5	13.9	23.9
			Cu-Ni ro tail	89.90	0.03	0.15	0.26	8.50	6.4	26.5	86.1	76.1
			Feed (calcd)	100.00	0.390	0.512	0.274	10.05	100.0	100.0	100.0	100.0
BR 3	0.05	0.5	Cu-Ni ro conc	10.8	3.43	3.44	0.35	23.01	93.2	73.3	13.7	23.3
			Cu-Ni ro tail	89.2	0.30	0.15	0.27	8.35	6.8	26.7	86.3	76.7
			Feed (calcd)	100.0	0.398	0.507	0.277	9.91	100.0	100.0	100.0	100.0
BR 2	0.1	0.5	Cu-Ni ro conc	7.6	1.59	4.32	0.26	13.85	30.8	64.8	7.0	10.4
			Cu-Ni ro tail	92.4	0.29	0.19	0.288	9.90	69.2	35.2	93.0	89.6
			Feed (calcd)	100.0	0.393	0.506	0.286	10.20	100.0	100.0	100.0	100.0

Results of the third series of the preliminary tests showed that a combination of 0.01 lb NaCN/ton of ore with 0.5 lb Zn SO₄/ton of ore gave the lowest zinc content in the bulk concentrate at the highest copper and nickel recoveries in the Cu-Ni rougher concentrate. As a result, the above reagent combination was used for the sphalerite depression throughout this investigation.

To obtain the most economic benefits for this low-grade ore, it was decided to produce as many marketable concentrates as possible. Two general schemes were applied:

- (a) procedure 1. concentration of nickeliferous minerals prior to flotation of copper, nickel, and zinc minerals;
- (b) procedure 2. flotation of copper, nickel, and zinc minerals prior to concentration of nickeliferous minerals.

Details of these general schemes will be described separately.

(a) Procedure 1

Ground ore (89% minus 200 mesh) was treated with a Sala low-intensity magnetic separator and a magnetic rougher concentrate was obtained. This concentrate was then ground to minus 200 mesh and cleaned with the same separator. The non-magnetic tailings (rougher and cleaner) were combined to form the flotation feed.

Conditioning of the flotation feed and reagents was done at a natural pH ranging between 8.1 and 8.3. To lower the zinc content in the copper-nickel rougher concentrates, 0.5 lb of zinc sulphate and 0.01 lb of sodium cyanide per ton of ore were added to the rougher conditioner (see "Preliminary Testing" - Table 3), while a small amount of Quartec was added to the same conditioner as chlorite-talc depressant.

About 0.01 lb/ton of collector (Potassium Amyl Xanthate) was then added in each of two stages. The first-stage addition of the collector produced a copper-nickel rougher concentrate containing most of the copper and about half of the nickel in the ore, while the second stage addition of the collector produced a nickel rougher concentrate containing the remaining portion of

the recoverable nickel and a small amount of copper.

After obtaining the copper and nickel rougher concentrates, a zinc rougher concentrate was obtained in some tests in the usual manner, i. e., by adding lime, copper sulphate, collector (potassium amyl xanthate) and Dowfroth 250 as frother. In some tests, a scavenger concentrate was obtained after zinc rougher flotation by adding additional copper sulphate, collector, and frother to observe what can be expected from a scavenger flotation.

The copper-nickel rougher concentrate obtained from the first-stage addition of collector was then separated by flotation into a copper concentrate and a nickel concentrate at a high pH for which lime was used. With this procedure, most of the chalcopyrite was floated off as a copper (separator) concentrate while most of the nickel-bearing minerals were depressed by lime and remained in the separation tailing which actually became a nickel concentrate.

The nickel rougher concentrate obtained by the second addition of the collector and the nickel concentrate from the separation step (separator tailing) were then combined to form the final nickel concentrate.

The flowsheet of this procedure is given in Figure 1, flotation conditions are recorded in Table 4, and typical results in Table 5.

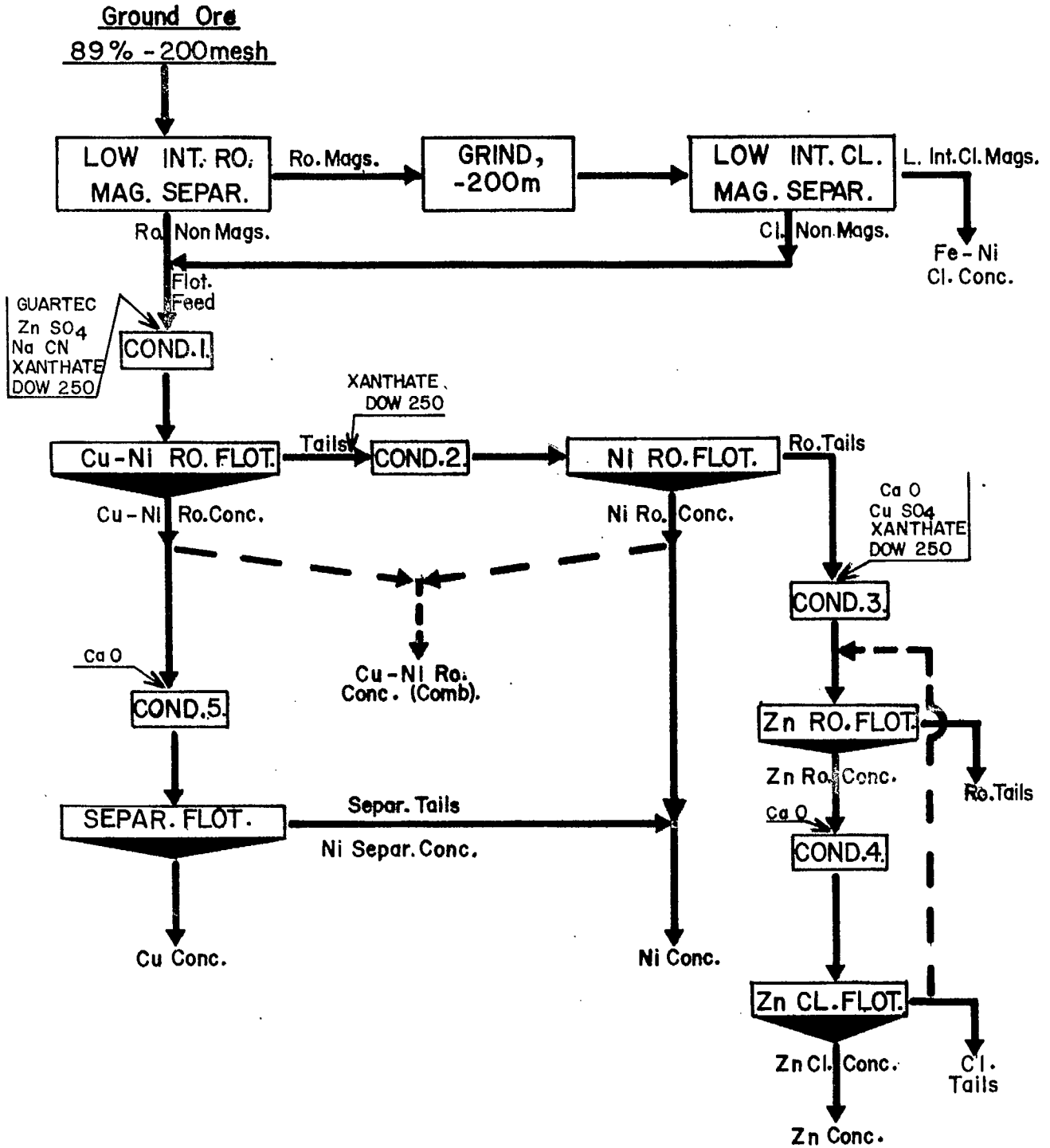


Figure 1

Procedure 1. Concentration of nickeliferous minerals prior to flotation of other sulphide minerals from ore Sample No. 1.

TABLE 5
Flotation Conditions for Procedure 1

Operation	Time Min	Approx % Solids	pH	Reagents - lbs/ton of ore						
				CaO	Guartec	NaCN	ZnSO ₄	Xan- thate*	DF250	CuSO ₄
Cond No 1 Cu-Ni rghr fl	10 2	25	8.2	-	0.077	0.01	0.50	0.01	0.015	
Cond No 2 Ni rghr fl	5 3	24	8.2	-	0.011	-	-	0.01	0.005	
Cond No 3 Zn rghr fl	10 3	20	9.2	0.2	-	-	-	0.005	0.03	0.2
Cond No 4 Zn cl fl	5 2	8	10.1	0.5	-	-	-	-	-	-
Cond No 5 Scav fl	5 2	8	11.5	0.8	-	-	-	-	-	-

* Potassium Amyl Xanthate

TABLE 6
Results from Procedure 1

Product	Wt %	Assay %					Distribution %			
		Cu	Ni	Zn	Insol	Sol Fe	Cu	Ni	Zn	Sol Fe
Fe-Ni mag ro conc	4.10	0.08	1.13	0.15	9.94	56.85	10.9	10.2	2.1	33.0
Cu sep conc	0.81	26.92	2.47	0.43	8.36		58.4	4.4	1.2	
Ni conc (comb)	3.49	3.94	6.80	0.70	36.0		29.9	53.5	8.3	
Cu-Ni ro conc (calcd)	4.30	7.70	6.07	0.65	30.9		88.1	57.9	9.5	
Zn cl conc	0.51	0.38	0.87	33.68	7.8		0.5	0.9	59.0	
Zn cl tail	0.65	0.95	1.64	1.98	28.3		1.6	2.4	4.3	
Scav conc	2.22	0.29	1.45	0.52	27.98		1.7	7.1	4.0	
Scav tail	88.22	0.03	0.11	0.07	65.46		7.0	21.5	21.1	
Feed (calcd)	100.00	0.374	0.45	0.29	60.29	10.34	100.0	100.0	100.0	

The results from Table 6 showed that the concentrates obtained (separate copper and separate nickel or the combined copper-nickel concentrate and nickeliferous concentrate) had acceptable grades with about 88% copper and 58% nickel recoveries in the copper and nickel concentrates and that iron-nickel concentrate contained about 10% of the nickel and about 33.0% of iron in the ore. Because about 87.5% of the nickel and about 97% of the iron in the iron nickel concentrate are recoverable by the Falconbridge process⁽³⁾, the overall copper, nickel and iron recoveries, from this ore sample by applying Procedure 1, were 88% of the copper, 66.7% of the nickel and 31.3% of the iron. It is possible that the zinc cleaner concentrate of 33.68% zinc grade can be upgraded to about 50% zinc by a further cleaning step but the zinc recovery will not exceed 50 per cent.

(b) Procedure 2

This procedure consisted of floating the ore ground to 89% minus 200 mesh by using the best flotation conditions of Procedure 1 (Table 5) to obtain copper, nickel, and zinc concentrates as in Procedure 1. The nickeliferous concentrate was obtained by treating the zinc rougher tailing in a Sala low-intensity magnetic separator.

The flowsheet of this procedure is given in Figure 2. Typical results from two tests are recorded in Table 7. In the second tests shown in this table, the zinc flotation and the magnetic separation steps were omitted.

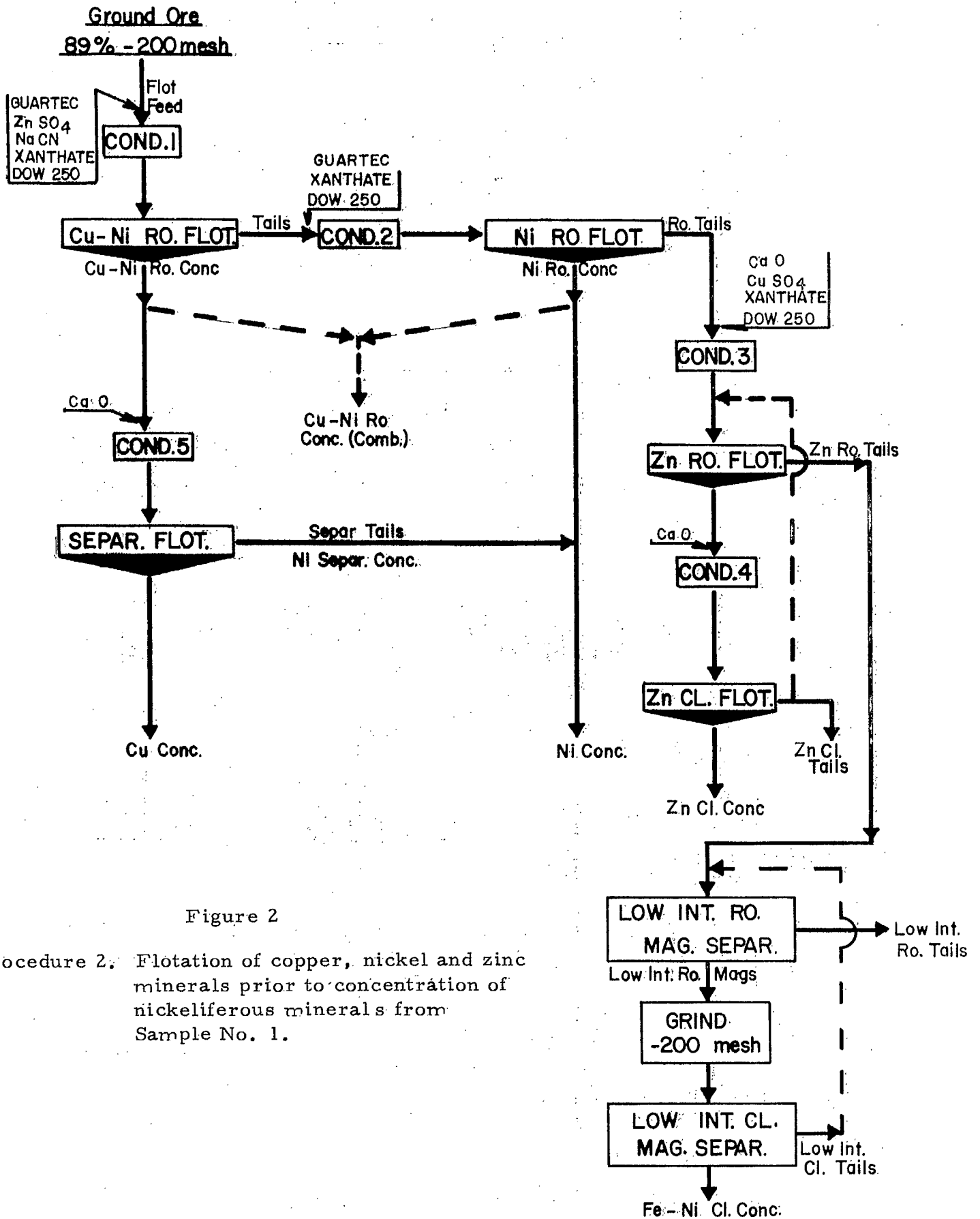


Figure 2

Procedure 2: Flotation of copper, nickel and zinc minerals prior to concentration of nickeliferous minerals from Sample No. 1.

TABLE 7
Results from Procedure 2

Product	Wt %	Assay %					Distribution %		
		Cu	Ni	Zn	Fe	Insol	Cu	Ni	Zn
Cu sep conc	0.92	22.37	0.95	0.60		27.20	50.3	0.2	0.2
Ni sep conc	2.78	4.42	8.00	0.47		33.00	30.1	48.7	4.0
Ni rghr conc 2	3.80	0.62	2.10	0.42		31.44	5.9	17.6	4.8
Ni conc (comb)	6.58	2.23	4.58	0.44		32.50	36.0	66.3	8.8
Cu-Ni rghr conc(calcd)	7.50	4.70	4.14	0.50		31.66	86.3	66.5	9.0
Zn rghr conc	0.70	0.48	0.18	30.00			0.7	0.2	65.0
Fe-Ni rghr mag conc	2.15	0.37	0.80	0.19	57.42		2.0	3.7	1.1
Non-mag rghr tail	89.65	0.05	0.15	0.09			11.0	29.6	24.9
Feed (calcd)	100.00	0.41	0.46	0.32	10.34	60.60	100.0	100.0	100.0
Cu sep conc	0.69	20.87	4.32	0.61		18.52	37.7	6.1	1.4
Ni sep conc	4.49	4.62	6.12	0.48		33.0	54.2	56.0	8.3
Cu-Ni rghr conc	5.18	6.76	5.96	0.54		30.80	91.9	62.1	9.7
Ni rghr tail	94.82	0.17	0.20	0.27		64.8	8.1	37.9	90.0
Feed (calcd)	100.00	0.38	0.49	0.29		60.3	100.0	100.0	100.0

The results from Table 7 showed that copper, nickel and zinc concentrates obtained by this procedure had slightly lower grades but slightly higher recoveries than those obtained by Procedure 1, recorded in Table 6.

These results also showed that only a small amount (3.7%) of the nickel in the ore was left in the iron-nickel concentrate. This means that a considerable amount of the nickeliferous pyrrhotite floated with the other sulphides, mainly with the nickel-bearing minerals, to cause a slight decrease in the grade of nickel concentrate but a higher nickel recovery than by Procedure 1.

It appears that application of the Procedure 2 could make the low-intensity magnetic separation unnecessary because relatively small amounts of recoverable nickel and iron were left in the flotation tailing.

Evaluation of Ore-sample No. 2

Introduction

The mineralogical examination of this ore sample showed that the same copper- and nickel-bearing minerals (except smithite) were present. The other characteristics of this sample, such as high amounts of talc (5 to 10%) and magnetite (10 to 12%) and low amount of zinc (0.03%) made this ore sample considerably different from Sample No. 1. As a result, the flotation procedures developed for Sample No. 1 had to be modified.

To obtain the required grades of the concentrates and to solve the talc problem, the modified procedure (designated as Procedure 3) consisted of the following steps:

- (a) depression of talc during the concentration of copper, nickel, and nickeliferous minerals (Procedure 3a);
- (b) desliming of ore prior to concentration of copper, nickel, and nickeliferous minerals (Procedure 3b)

In each case, the copper-nickel rougher concentrates were cleaned once to obtain a final combined copper-nickel concentrate.

Zinc flotation was not done due to the very low zinc content.

Nickeliferous minerals were concentrated by two-stage low-intensity magnetic separation as described earlier.

The flowsheet for Procedure 3 is given in Figure 3 where dotted lines represent depression of talc (Procedure 3a) and the full lines represent desliming of the ore prior to flotation (Procedure 3b).

Procedure 3a

This procedure consisted of depressing talc during the flotation of copper-nickel sulphides by adding Guartec, Jaguar 703, and Depramin 75 as insoluble depressants. The copper-nickel rougher concentrates obtained from tests where Guartec and Jaguar were used as the talc depressants were cleaned once but the rougher concentrate, obtained by using Depramin, had to be cleaned in three stages to obtain satisfactory copper and nickel grades.

Flotation conditions of this procedure are recorded in Table 8 and the results are recorded in Table 9.

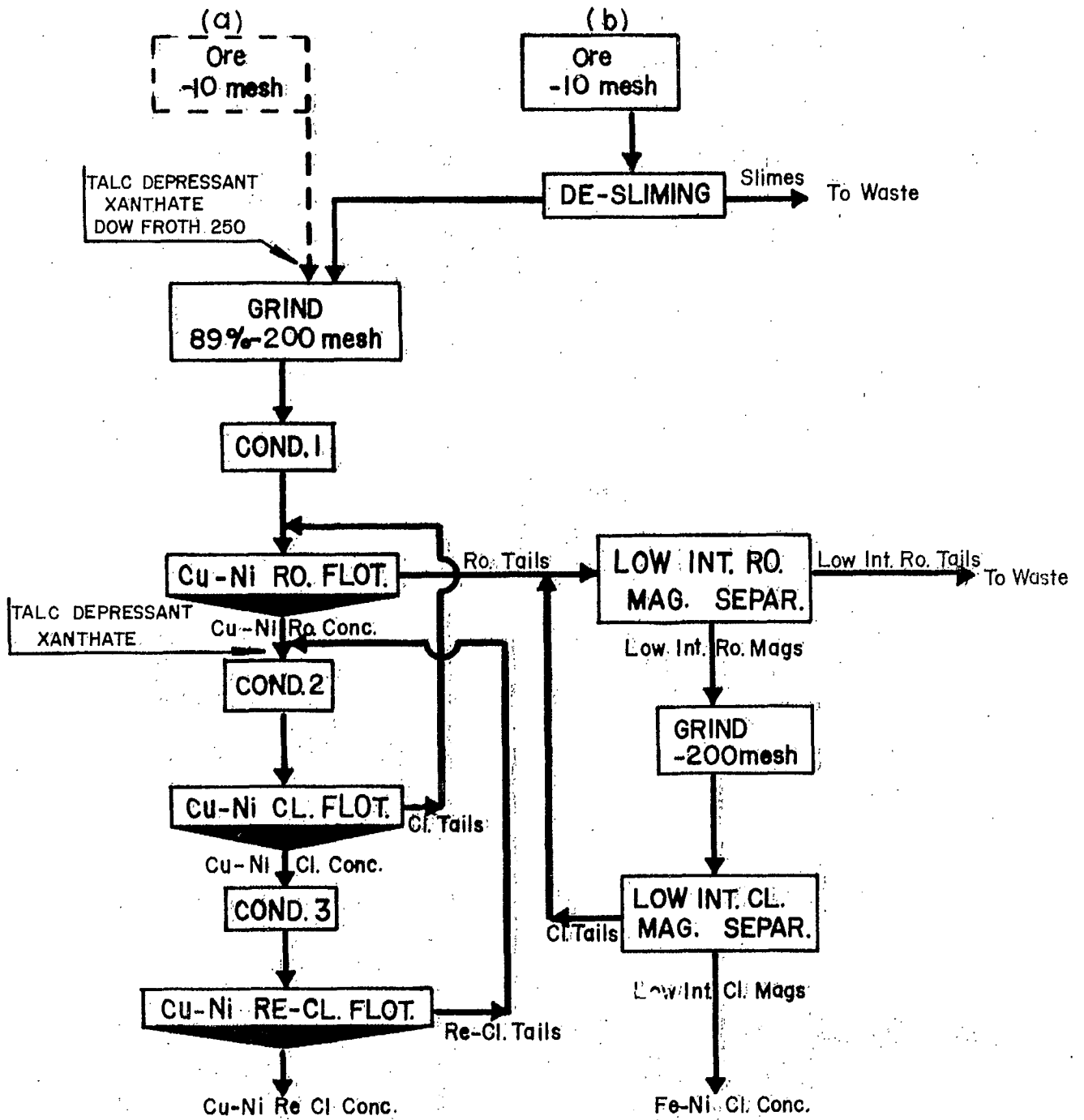


Figure 3

Procedure 3. Depression (a) and Rejection (b) of talc prior to concentration of copper, nickel and iron minerals from ore Sample No. 2.

TABLE 8
Flotation Conditions for Procedure 3 a

Reagents used	Reagents - lb per ton of ore			
	Ro Float.	1st cl.	2nd cl.	3rd cl.
Talc Depressant	0.33	0.11	0.06	0.06
Collector*	0.12	0.04	-	-
Dow froth 250	0.02	-	-	-

* Potassium ethyl xanthate.

TABLE 9
Results from Procedure 3 a

Talc Depressants used lb/ton	Product	Wt %	Assay %				Distribution %		
			Cu	Ni	Sol Fe	Insol	Cu	Ni	Sol Fe
Guartec 0.43 lb/ton	Cu-Ni cl conc	3.44	5.60	9.83		33.5	85.1	47.0	
	Fe-Ni cl mags	15.40	0.02	0.63	58.57	7.04	1.3	13.5	58.8
	Cu-Ni cl tail	22.10	0.05	0.28	--	--	4.9	8.7	
	Fe-Ni cl non-mags	3.38	0.08	1.60	--	--	1.3	7.5	
	Fe-Ni ro non-mags	55.68	0.03	0.30			7.4	23.3	
	Feed (calcd)	100.00	0.23	0.72	15.34	45.72	100.0	100.0	
Jaquar 703 0.43 lb/ton	Cu-Ni cl. conc	3.10	6.07	10.20		30.30	85.9	43.4	
	Cu-Ni cl tail	22.90	0.04	0.18			4.1	5.6	
	Cu-Ni ro tail*	74.00	0.03	0.50			10.0	51.0	
	Feed (calcd)	100.00	0.22	0.73		45.72	100.0	100.0	
Depramin 75 0.50 lb/ton	Cu-Ni ro re cl conc	4.13	4.27	6.29		46.66	81.2	40.6	
	Cu-Ni 3rd cl tail	19.40	0.04	0.29			3.7	8.8	
	Cu-Ni 2nd cl tail	3.53	0.12	0.50			1.8	2.8	
	Cu-Ni cl tail	1.51	0.50	2.38			3.7	5.6	
	Cu-Ni ro tail*	71.43	0.03	0.38			9.6	42.2	
	Feed (calcd)	100.00	0.22	0.64		45.72	100.0	100.0	

* Low-intensity magnetic separation not carried out.

Results from this procedure showed that copper-nickel cleaner concentrates obtained by use of Quartec or Jaguar 703 assayed 15.4 to 16.27% Cu-Ni (combined) with 85 to 86% copper recovery and 43 to 47% nickel recovery.

The iron-nickel cleaner concentrate obtained had satisfactory iron (58.57%) and nickel (0.63%) grades and contained 13.5% of the nickel and 58.8% of the iron in the ore. If the Fe-Ni concentrates were treated by the Falconbridge process⁽³⁾, about 87.5% of the nickel and about 97% of the iron would be recovered.

Procedure 3 b

The initial stage of this procedure consisted of desliming the ground ore prior to flotation of copper and nickel minerals. To investigate the effect of desliming on the copper and nickel losses to the discarded slimes, desliming tests were done in which ore samples were ground to minus 65 mesh, minus 28 mesh, and minus 10 mesh (crushed) and then deslimed by an overflow method. The copper and nickel losses to the rejected slimes resulting from these grinds are recorded in Table 10.

TABLE 10

Effect of Pre-flotation De-sliming on Copper and Nickel Losses to the Slimes

Fineness of grind	Product	% Weight	Assay %		Distribution %	
			Cu	Ni	Cu	Ni
-10 mesh*	Overflow slimes	7.85	0.21	0.44	6.3	5.3
-28 mesh	Overflow slimes	17.10	0.16	0.31	12.6	8.2
-65 mesh	Overflow slimes	24.60	0.17	0.34	18.9	12.6

* Crushed ore.

These results showed that, with the increase in the fineness of grind, the copper and nickel losses to the slimes were increased considerably. The copper and nickel losses from minus 10-mesh ore were considerably lower than from the finer grinds.

Accordingly, the minus 10-mesh crushed ore was deslimed, the slimes rejected, and the deslimed portion of the ore was used as feed to flotation and low-intensity magnetic separation. As mentioned earlier, the flowsheet of this procedure is presented in Figure 3.

The flotation conditions are given in Table 11 and results in Table 12.

TABLE 11

Flotation Conditions for Procedure 3b

Ore Sample No. 2

Reagents Used	Reagent - lb per ton of ore	
	Rougher float	Cleaner float
Talc Depressant	0.20	0.05
Xanthate*	0.12	0.04
Dow froth 250	0.02	- - -

* Potassium ethyl xanthate

TABLE 12

Results from Procedure 3b

Talc Depressant lb/ton	Product	Wt %	Assay %				Distribution %		
			Cu	Ni	Insol	Sol Fe	Cu	Ni	Sol Fe
Guartec 0.23 lb/ton	Slimes*	7.85	0.21	0.44			6.3	5.3	
	Cu-Ni cl conc	4.25	5.43	8.85	35.70		91.6	56.5	
	Fe-Ni cl mags	14.30	0.02	0.98	3.76	60.60	0.1	21.1	56.4
	Cu-Ni cl tail	29.60	0.03	0.31	63.60		0.4	13.8	
	Cu-Ni ro tail	44.00	0.01	0.05			1.6	3.3	
	Feed (calcd)	100.00	0.25	0.67	45.72	15.34	100.0	100.0	

* From 10-mesh crushed ore.

The results from Table 12 showed that this procedure produced a combined Cu-Ni cleaner concentrate that assayed 14.28% Cu-Ni (combined) with 91.6% copper recovery and 56.5% nickel recovery. About one half of each of the copper and nickel in the flotation cleaner tailing could be recovered in the Cu-Ni concentrate because the cleaner tailings would be recircuited in the plant operation; therefore, the copper and nickel recoveries in the Cu-Ni cleaner concentrate would be about 91.8% for copper and about 63.4% for nickel.

The iron-nickel cleaner concentrate obtained by this procedure had suitable Cu-Ni-Insol-Fe grades for smelting and contained about 21% of the nickel and about 56% of the iron present in the ore. Because smelting this kind of iron-nickel concentrate recovers⁽³⁾ about 97% of the iron and about 87.5% of the nickel, the yield of the valuables would amount to about 53.5% iron and about 18.1% of the nickel present in this ore sample.

According to the results of this procedure, it appears that the overall copper, nickel, and iron recoveries (including the nickel recovery from the iron-nickel concentrate) from this ore sample would be about 91.8% copper, 81.5% nickel, and about 53.5% iron.

Recovery of Precious Metals

The chemical analyses of the ore samples showed that both samples contained small amounts of silver, platinum, and palladium (see "Shipment", page 1). To investigate their concentration and recovery, one copper-nickel concentrate from each ore sample (Table 4 to Table 12) was assayed for these precious metals and the recoveries were calculated. The summarized results are recorded in Table 13.

TABLE 13

Results of Concentration of Precious Metals

Assay and Recovery	Ore Sample No. 1					Ore Sample No. 2				
	Cu-Ni ro conc					Cu-Ni cl conc				
	%		oz/ton			%		oz/ton		
	Cu	Ni	Ag	Pt	Pd	Cu	Ni	Ag	Pt	Pd
Assay %	4.57	4.13	4.24	0.052	0.144	5.43	8.85	1.12	0.06	0.24
Recovery %	93.3	68.4	93.0	80.0	85.0	91.6	56.5	51.0	52.0	48.5

These results showed that reasonable recoveries of the precious metals were achieved from these ore samples but that the grades of the concentrates were low. The economic benefits from the precious metals would be small due to their low contents in the ore.

CONCLUSIONS

Recoveries of 91 to 92% of the copper and 62 to 63% of the nickel in the ore were achieved by flotation alone in separate copper-rich and nickel-rich concentrates and in a combined copper-nickel concentrate.

Total nickel recovery can be increased to 70 to 81% by low-intensity magnetic separation.

Between 27 and 54% of the iron in the ore can be recovered as a by-product from the latter concentrate.

Only small economic benefits from the silver, platinum, and palladium can be expected because of their low contents in the ore samples.

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