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MINES BRANCH INVESTIGATION REPORT IR 71-34

A FEASIBILITY STUDY ON THE CONCENTRATION OF A COMPLEX NICKEL MINERALIZATION FROM ARCTIC GOLD & SILVER MINES LIMITED, B. C.

by

G. I. MATHIEU AND R. W. BRUCE

MINERAL PROCESSING DIVISION

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A FEASIBILITY STUDY ON THE CONCENTRATION OF A COMPLEX NICKEL MINERALIZATION FROM ARCTIC GOLD & SILVER MINES LIMITED, B.C.

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SUMMARY OF RESULTS

Nickel (0.23%) was the only metallic constituent of economic interest found in the sample received for investigation. It occurs largely as pentlandite with small amounts of mackinawite and traces of valleriite. The pentlandite is present as small grains with an estimated average size of 35 microns and as minute inclusions in pyrrhotite, magnetite and chromite. Both the mackinawite and the valleriite are intergrown with the pentlandite.

A series of tests, carried out in attempts to concentrate the nickel by flotation and magnetic separation, gave the following concentrates under optimum conditions:

Method of Concentration	Grade (% Ni)	Recovery (% Ni)
Flotation	0.49	62.6
Magnetic Separation	0.41	63.6
Flotation + Mag. Sep.	0.39	75.9

Attempts to clean these concentrates were made, but this resulted in very little improvement of the grade and this was accompanied by high losses in recovery. The difficulty of producing a satisfactory concentrate from the Arctic ore can be attributed to the intimate association of the nickel from the pyrrhotite and magnetite.

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INTRODUCTION

Property

The sample submitted by Arctic Gold & Silver Mines Limited is from a nickel prospect, known as the "Old Nick" property, and is located in the Greenwood Mining Division, near the town of Bridesville, B.C. The latter is 25 miles east of Osoyoos in the Okanagan or 277 miles by road from Vancouver. The tonnage of the mineralized area is estimated at over 100 million tons. The grade of the deposit averages 0.22% Ni, but this figure might be increased by selective mining according to the company's geological report.

Purpose of Investigation

The investigation was requested by Mr. Egil Livgard, Managing Director, Arctic Gold & Silver Mines Limited, 1300 Marine Building, 355 Burrard Street, Vancouver 1, B.C. Mr. Livgard was interested in a feasibility study on the concentration of the nickel minerals for subsequent bacteriological leaching. The latter was to be carried out by the B.C. Research Council. The present investigation was aimed at finding the best method for producing concentrates of optimum grade and recovery.

Shipment

On September 24, 1970, six bags of lump ore weighing 550 lbs were received from the company for the investigation. The shipment was sent by Mr. Livgard.

Sampling and Analysis

All the sample was crushed to minus one inch and a few representative fragments were selected for minerological examination. The remainder was reduced to minus 10 mesh and a head sample was riffled out for chemical analysis.

TABLE 1

Chemical Analysis of Head Sample*

Nickel (Ni)	-	0.23%
Iron (Fe)	-	4.77%
Sulphur (S)	-	0.65%
Insoluble	-	45.1%

* From Internal Report MS-AC-70-1013.

A semi-quantitative spectrographic analysis on a portion of the head sample indicated the presence of the following elements listed in their approximate order of decreasing abundance.

TABLE 2

Semi-Quantitative Spectrographic Analysis of Head Sample*

I	-	Si, Ca, Mg, Fe (> 1.0%)
II	-	Ni, Al, Cr (1.0 - 0.01%)
III	-	Cu, Mn, Sn, Ti (< 0.01%)

* From Internal Report MS-AC-70-944.

MINERALOGICAL EXAMINATION*

A portion of the head sample and several representative pieces of rock were sent to the Mineralogy Section of the Mineral Sciences Division for identification of the minerals and determination of their grain sizes and textural relationships. Excerpts from the report on this work are included here for convenience.

* From Investigation Report IR 71-5 by D. Owens, January 14, 1971.

Summary

"Mineralogical studies made on a sample of nickel ore from the Old Nick nickel property, show that the ore is composed essentially of a serpentinized mafic rock, in which are disseminated small amounts of iron oxides and nickel-iron sulphides. The nickel is present largely as pentlandite, small amounts of mackinawite and traces of valleriite account for the remainder. Other minerals identified in the ore include pyrrhotite, magnetite, chromite, geothite, marcasite, molybdenite, ilmenite, hematite, pyrite, chalcopyrite, olivine (forsterite), amphibole, serpentine, calcite, asbestos, dolomite, and feldspar.

Textures of the Ore Minerals

The ore minerals in the hand specimens tend to occur in two basic forms: those associated with the fibrous amphibole are typically elongate or acicular, whereas those associated with the serpentine and olivine are more equidimensional.

Nickel-bearing Minerals

Three nickel-bearing minerals were identified in the ore: pentlandite, mackinawite and valleriite, with the pentlandite greatly predominating. Routine electron microprobe analyses were made on all the other ore and gangue minerals to determine if any of them contained trace amounts of nickel. The results were negative in all cases, except for some of the pyrrhotite.

The pentlandite $(Ni, Fe, Co)_9S_8$ is present essentially as inclusions in pyrrhotite and to a lesser extent in magnetite and chromite. Minute amounts of pentlandite also occur as combined grains with pyrrhotite, magnetite and gangue. The pentlandite grains vary from about 5 to 400 microns in size*; those present in the magnetite and chromite have a maximum size of about 100 microns. The majority of the pentlandite grains are between 15 and 100 microns, with an estimated average size of about 30 to 40 microns. A large proportion of the pentlandite that occurs as inclusions in the pyrrhotite is rimmed and penetrated by thin bands of magnetite. This characteristic is also true of some of the pentlandite inclusions in chromite.

The pentlandite is riddled with inclusions, the majority of which consist of mackinawite (Fe, Ni, Co)S, some of magnetite, and a few of pyrrhotite. Almost every grain of pentlandite contains at least a few of these very small and irregularly shaped grains of mackinawite. The mackinawite inclusions vary from 2 to about 35 microns in size, with the majority smaller than 5 microns. Inclusions of other minerals in the pentlandite are of the same order of size. Nearly all of the mackinawite occurs in the pentlandite; the few exceptions are a number of inclusions in magnetite and pyrrhotite, but the amount is insignificant. The composition of the mackinawite, determined from electron microprobe analysis of two of the largest grains, is shown below.

Electron Microprobe Analysis of Mackinawite

Element	Wt %
Fe	57.95
Ni	5.66
Co	0.66
S	35.23
Total	99.50

Valleriite is present in the sample in trace amounts. Its normal composition is given as $(CuFeS_2) \cdot 1.5(Mg, Al(OH)_2)$. All the grains of

* The word "size" as used in this report, refers to the greatest dimension of the mineral grains being described.

valleriite are very small, and range from about 5 to 35 microns in size. Two types of valleriite appear to be present in the ore. The first is a nickel-copper variety occurring as a few inclusions in magnetite and pyrrhotite. The nickel content of the valleriite, based on electron microprobe studies, is slightly less than four per cent; the existence of a nickel-bearing valleriite has not been reported previously. The second type of valleriite consists of very minor disseminations in gangue. These appear to be simply an iron-rich variety, because neither nickel nor copper was detected.

Conclusion

Based on the mineralogical examinations of the ore sample, the following conclusions can be drawn: nickel is represented in the ore chiefly by pentlandite, to a much smaller extent by mackinawite, and only insignificantly by valleriite. The low nickel content of the mackinawite, which is present almost entirely as minute inclusions in the pentlandite, will inevitably reduce the grade of any pentlandite concentrate. In addition, much of the pentlandite will be difficult to liberate, from the other minerals with which it is associated, due to its small average particle size.

DETAILS OF INVESTIGATION

Flotation

This part of the investigation consists of a series of rougher flotation tests with increasing degrees of fineness, concentration of reagents, and time of flotation as variables. The best rougher concentrates were then combined for cleaning.

i) Rougher (Tests 1 to 7)

Each rougher flotation test was carried out on a 2,000-g sample using reagents and conditions shown in Table 3.

TABLE 3

Reagents and Conditions for Rougher Flotation

Test No.	Grinding		Reagents* (lb/ton)			Flotation Time (min)
	min	%-200	$CuSO_4$	Z-6	Dow 250	
1	20	70.5	0.30	0.10	0.08	10
2	30	82.8	"	"	"	"
3	40	88.6	"	"	"	"
4	60	92.8	"	"	"	"
5	90	95.5	"	"	"	"
6	75	93.7	0.45	0.15	0.12	15
7	75	93.7	0.60	0.20	0.16	20

* Added by stages at regular intervals.

TABLE 4

Results of Rougher Flotation

Test	Product	Weight %	Analysis* % Ni	Distribution % Ni
1	Ni conc	7.2	0.75	23.5
	Flot tailing	92.8	0.19	76.5
	Feed	100.0	0.23	100.0
2	Ni conc	6.0	0.70	18.3
	Flot tailing	94.0	0.20	81.7
	Feed	100.0	0.23	100.0
3	Ni conc	6.9	0.64	19.1
	Flot tailing	93.1	0.20	80.9
	Feed	100.0	0.23	100.0
4	Ni conc	7.2	0.75	23.5
	Flot tailing	92.8	0.19	76.5
	Feed	100.0	0.23	100.0
5	Ni conc	9.0	0.73	28.7
	Flot tailing	91.0	0.18	71.3
	Feed	100.0	0.23	100.0
6	Ni conc	15.8	0.71	48.7
	Flot tailing	84.2	0.14	51.3
	Feed	100.0	0.23	100.0
7	Ni conc	29.4	0.49	62.6
	Flot tailing	70.6	0.12	37.4
	Feed	100.0	0.23	100.0

* The nickel contents of the flotation tailing are from Internal Reports MS-AC-1005, 1025 and 1143; those of the concentrates were calculated by difference from the head analysis (0.23% Ni) in order to reduce the analytical work.

ii) Cleaner (Test 8)

Portions of the rougher concentrates produced in Test 6 and 7 were combined for cleaning by flotation. To the cleaner was added 0.03 lb of xanthate (Z-6) and 0.02 lb of Dowfroth 250 per ton of orginal ore. The following results were obtained.

TABLE 5

Results of Cleaner Flotation

Product	Weight %	Analysis* % Ni	Distribution % Ni	
			In feed	Overall**
Ni cl conc	16.0	2.13	56.7	31.6
Cl tailing	84.0	0.31	43.3	24.1
Feed (calcd)	100.0	0.60	100.0	55.7

* From Internal Report MS-AC-70-1006.

** Calculated from the average nickel recovery (55.7%) in the rougher concentrates of Tests 6 and 7.

Magnetic Separation

The approach to this part of the investigation was similar to that of flotation. Rougher magnetic separation was first attempted at increasing degrees of fineness and, then, only the best concentrates were combined for the cleaning stage.

i) Rougher (Tests 9 and 12)

Four 2,000 g samples were ground for 20, 35, 60 and 90 minutes, to 70%, 85%, 93% and 96% minus 200 mesh, respectively. Each sample was then passed through a Jones Separator set at 15 amperes with the results as shown in Table 6.

TABLE 6

Results of Rougher Magnetic Separation

Test	Product	Weight %	Analysis* % Ni	Distribution % Ni
9	Ni conc (Mags)	37.2	0.38	61.8
	Jones tailing	62.8	0.14	38.2
	Feed	100.0	0.23	100.0
10	Ni conc (Mags)	35.5	0.41	63.6
	Jones tailing	64.5	0.13	36.4
	Feed	100.0	0.23	100.0
11	Ni conc (Mags)	33.3	0.43	62.3
	Jones tailing	66.7	0.13	37.7
	Feed	100.0	0.23	100.0
12	Ni conc (Mags)	31.8	0.42	58.5
	Jones tailing	68.2	0.14	41.5
	Feed	100.0	0.23	100.0

* The nickel contents of the Jones tailings are from Internal Report MS-AC-71-96; those of the concentrates were calculated by differences from the nickel head assay.

ii) Cleaner (Test 13)

A 500 g sample was prepared using the concentrates produced in Test 10 and 11. This sample was cleaned with the Jones separator set at 10 amperes. The results obtained are shown below.

TABLE 7

Results of Cleaner Magnetic Separation

Product	Weight %	Analysis* % Ni	Distribution, % Ni	
			In feed	Overall**
Ni cl conc (Mags)	52.0	0.54	69.2	43.6
Cl tailing	48.0	0.26	30.8	19.4
Feed (calcd)	100.0	0.41	100.0	63.0

* Feed Internal Report MS-AC-71-96.

** Calculated from the average recovery in the concentrates of Test 10 and 11.

Flotation and Magnetic Separation

i) Flowsheet I (Test 14)

A 2,000-g sample of ore was treated using the procedure illustrated in Figure 1 and this gave the results shown in Table 8.

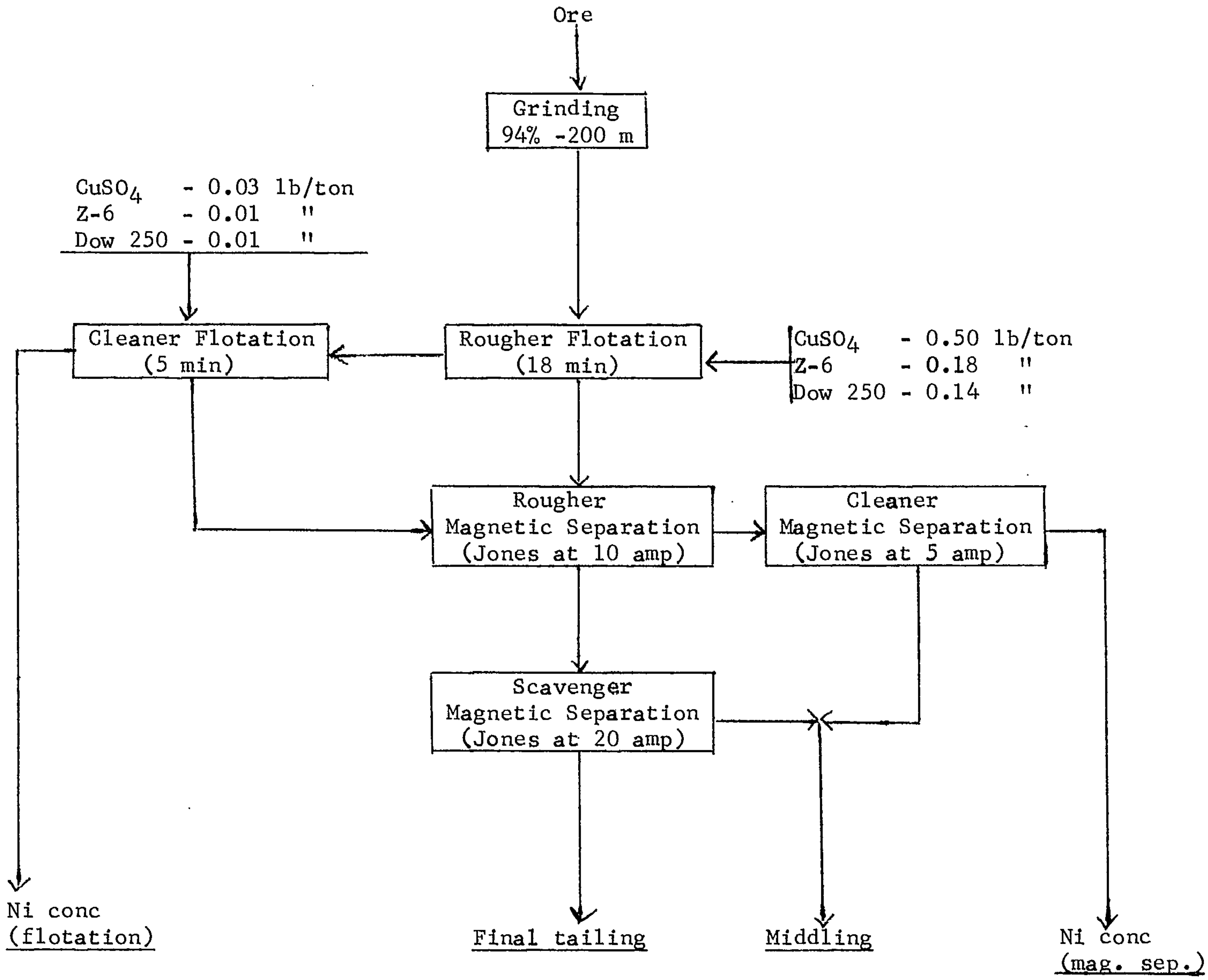

Figure 1 - Flowsheet I

TABLE 8

Results of Flotation and Magnetic

Separation with Flowsheet I

Product	Weight %	Analysis* %		Distribution %	
		Ni	S	Ni	S
Ni conc (flotation)	19.6	0.50	1.73	47.5	52.5
Ni conc (mag. sep.)	26.9	0.19	0.71	24.8	29.6
Middling	12.5	0.13	0.27	7.8	5.2
Final tailing	41.0	0.10	0.20	19.9	12.7
Feed (calcd)	100.0	0.21	0.65	100.0	100.0

* From Internal Reports MS-AC-71-153, 173 and 178.

ii) Flowsheet II (Test 15)

This test was aimed at determining the effect on the nickel concentrates (grade and recovery) of the following changes:

(1) reduction in the reagents and time of flotation,

(2) lowering of the amperage setting for magnetic separation,

(3) elimination of the cleaning stages.

This resulted in a more simple flowsheet, as shown in Figure 2.

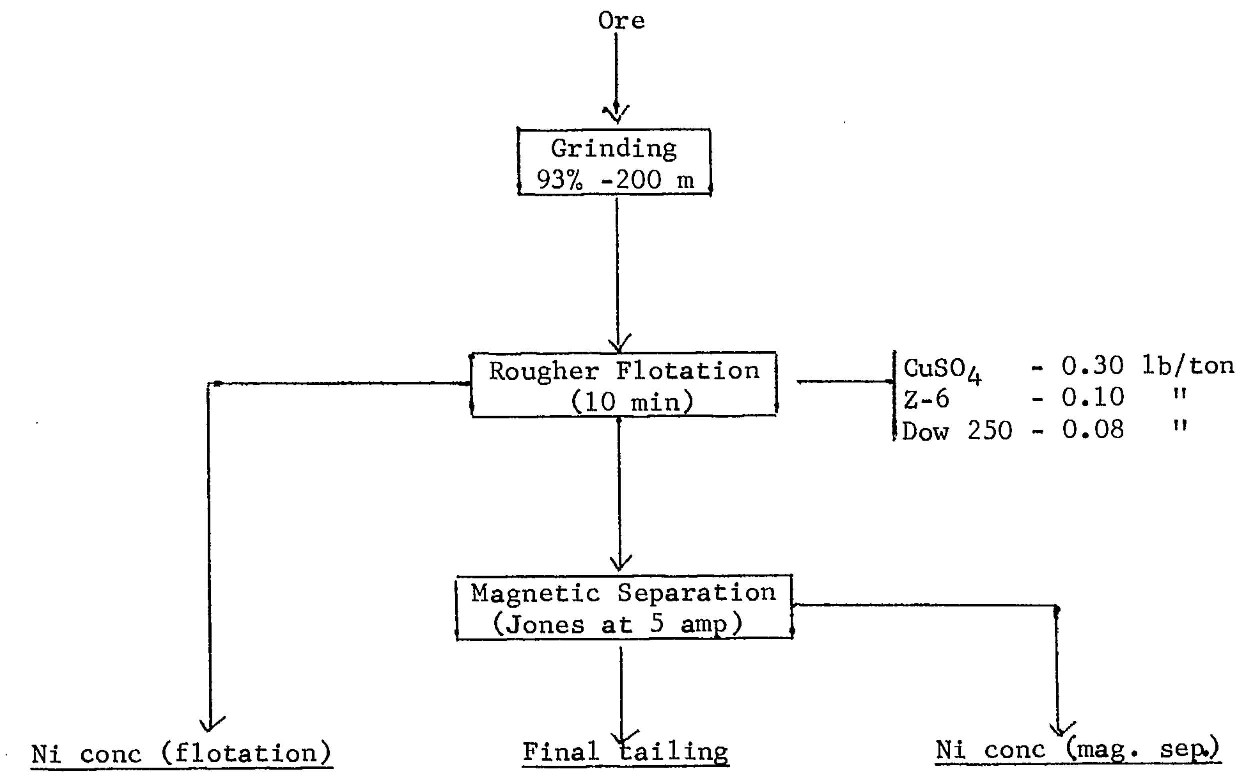

Figure 2 - Flowsheet II

The following results were obtained in this test.

TABLE 9

Results of Flotation and Magnetic Separation with Flowsheet II

Product	Weight %	Analysis* %		Distribution %	
		Ni	S	Ni	S
Ni conc (flotation)	12.7	0.63	1.56	34.7	29.5
Ni conc (mag. sep.)	31.7	0.30	1.05	41.2	49.8
Final tailing	55.6	0.10	0.25	24.1	20.7
Feed (calcd)	100.0	0.23	0.67	100.0	100.0
Ni conc (combined)	44.4	0.39	1.20	75.9	79.3

* From Internal Reports MS-AC-70-1025 and 1158.

Preparation of Nickel Concentrates

In his letter of January 11, 1971, Mr. Livgård requested the preparation of three samples (a flotation concentrate, a magnetic concentrate after preliminary flotation and a magnetic concentrate without preliminary flotation), for bio-leaching tests by B.C. Research Council. In order to have samples representative of the total nickel content, efforts were made to achieve maximum recoveries in the concentrates, while less attention was given to their grade. Each test was made on a 8,000-g sample in order to produce sufficient amounts of concentrate.

The flotation test was carried out using the procedure of Test 7 (i.e. high reagent concentration and long flotation time). The magnetic separation tests (with and without preliminary flotation) were both made on the Jones separator set at 20 amperes. The nickel and sulphur analyses of the concentrates and their corresponding recoveries are shown in Table 10.

TABLE 10

Grade and Recovery of Nickel Concentrates

Produced for Leaching Tests

Method	Analysis* %		Distribution %	
	Ni	S	Ni	S
Flotation and Magnetic Separation	0.47 0.16	1.56 0.49	61.8 19.9	66.9 21.1
Magnetic Separation (without flotation)	0.38	1.32	66.1	81.2

* From Internal Reports MS-AC-96 and 153.

Three, 2,000-g samples from each of the above concentrates were sent to Mr. Livgård.

CONCLUSIONS

The sample from this property contained 0.23% nickel. Most of this nickel occurs as pentlandite and mackinawite finely disseminated in pyrrhotite, magnetite, chromite and gangue. The effect on any concentration process of such a fine mineralization is well expressed in the conclusion of the mineralogical examination: "The low nickel content of the mackinawite, which is present almost entirely as minute inclusions in the pentlandite, will inevitably reduce the grade of the pentlandite concentrate. In addition, much of the pentlandite will be difficult to liberate from the other minerals with which it is associated, due to its small average particle size".

Because of the relatively large amount of pyrrhotite and magnetite in comparison to nickel minerals, it was not possible to achieve high ratios of concentration as shown by the following results:

Method		Concentration Ratio (by weight)	Grade % Ni	Recovery % Ni
Flotation	Rougher	3 : 1	0.45	62.3
	Cleaner	6 : 1	0.54	43.6
Magnetic Separation	Rougher	3.3 : 1	0.49	62.6
	Cleaner	20 : 1	2.13	33.7

A combination of flotation and magnetic separation gave the best overall results. These are shown below:

Product	Weight %	Analysis %		Distribution %	
		Ni	S	Ni	S
Ni conc	44.4	0.39	1.20	75.9	79.3
Tailing	55.6	0.10	0.25	24.1	20.7

Attempts were made to increase the nickel recovery by using higher amperages on the Jones magnetic separation, but only a small improvement in recovery was obtained while the ratio of concentration decreased sharply.

It was not possible in any test to reduce the nickel content in the tailing product below 0.10% Ni. This nickel mostly likely occurs as unliberated inclusions in gangue particles. However, although no intersticial nickel was found in the gangue constituents by electron probe analyses, the constant discrepancy between the sulphur and nickel recoveries suggests that a minor amount of nickel might be present in this form.

ACKNOWLEDGEMENTS

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