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CONCENTRATION OF IRON AND TITANIUM FROM AN ORE OF TITAN IRON MINES LIMITED, TEMAGAMI ONTARIO

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AUTHORIZED BY

by

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MINERAL PROCESSING DIVISION

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CONCENTRATION OF IRON AND TITANIUM FROM AN ORE OF TITAN IRON MINES LIMITED, TEMAGAMI, ONTARIO

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D. Raicevic *

- - -

SUMMARY OF RESULTS

- The ore sample received contained:

38.56	Total Fe
38.18	Soluble Fe
18.76	% TiO_2
14.26	% Insol

Magnetite was the main iron-bearing mineral while ilmenite and ulvöspinel were the titanium-bearing minerals. Feldspar was the main gangue mineral.

Due to intimate intergrowing of the titanium-bearing minerals with the magnetite the separation of these minerals and formation of a separate iron concentrate and a separate titanium concentrate could not be achieved by conventional mineral-dressing methods.

A magnetite-ilmenite-ulvöspinel (bulk) concentrate suitable for recovery of iron and titanium by pyrometallurgical and/or hydrometallurgical treatment was obtained. This bulk concentrate had the following analysis:

47.05%	Soluble Fe
21.20%	TiO_2
5.34%	Insol

This concentrate comprised 74.3% weight of the original ore and contained 89.0% Fe recovery and 85.6% TiO_2 recovery.

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INTRODUCTION

Titanium is used mainly for the production of TiO_2 pigment and titanium metal. Demand for these products is steadily increasing.

There are two major minerals of economic significance for the production of titanium: rutile (TiO_2) and ilmenite ($FeTiO_3$). The most significant reserves of rutile are in Australia while ilmenite is widely spread in nature. The Canadian titanium industry is based on the use of ilmenite ore.

As a result of the increasing world consumption of titanium, Titan Iron Mines Limited decided to investigate the feasibility of recovering iron and titanium from its low-grade titaniferous ore in Northern Ontario.

Purpose of Investigation

In his letter of April 17, 1969, Mr. A.S. Bayne, Consulting Engineer, requested the Mines Branch to develop a process which would produce: (1) an iron-titanium bulk concentrate suitable for production of pig iron and titania slag by the smelting process, or as an alternative, (2) make an iron concentrate with maximum Fe and minimum TiO_2 content and a titanium concentrate with minimum Fe and maximum TiO_2 content.

Location of Property

The property of Titan Iron Mines is located in Angus and Flett Townships about 5 miles northeast of Bushnell railroad station of the Ontario Northland Railway and about 20 miles southeast of the town of Temagami, Northern Ontario.

Ore Shipment

Two drums of ore, each weighing about 350 pounds, were received on April 23, 1968, from Mr. A.S. Bayne.

The analysis of the combined head sample from both drums is recorded in Table 1.

TABLE 1

Analysis of Ore from Titan Iron Mines

18.76%	TiO_2
38.56%	Total Fe
38.18%	Soluble Fe
14.26%	Insol*
0.36%	V_2O_5
0.032%	Cr_2O_3
0.05%	S
$\angle$ 0.05%	P_2O_5

* Insol = $CaO+MgO+Al_2O_3+SiO_2$

Analysis

All analyses in this investigation were done by the Analytical Chemistry Subdivision, Mineral Sciences Division, Mines Branch, Ottawa.

MINERALOGY (6)

The results of the mineralogical investigation showed that this complex ore is composed largely of feldspar and granular magnetite intimately intergrown with what appears to be ulvöspinel (Fe_2TiO_4). Also present are appreciable quantities of ilmenite, which occur as inclusions in gangue and as inclusions and intergrowths with the magnetite-ulvöspinel. The ore also contains a small amount of hercynite as fine-grained inclusions in magnetite and to a lesser degree in the ilmenite, as well as a small quantity of hematite, goethite, anatase (?), chalcopyrite, pyrite and pyrrhotite, and traces of bornite and violarite. The gangue minerals, in addition to plagioclase feldspar, include relatively coarse grains of olivine and pyroxene, and small amounts of apatite, chlorite, amphibole, biotite and graphite.

Photomicrographs of the polished sections done on the head sample of this ore showing the physical association of the minerals are presented in Figures 1, 2, 3, 4, 5, 6, and 7.

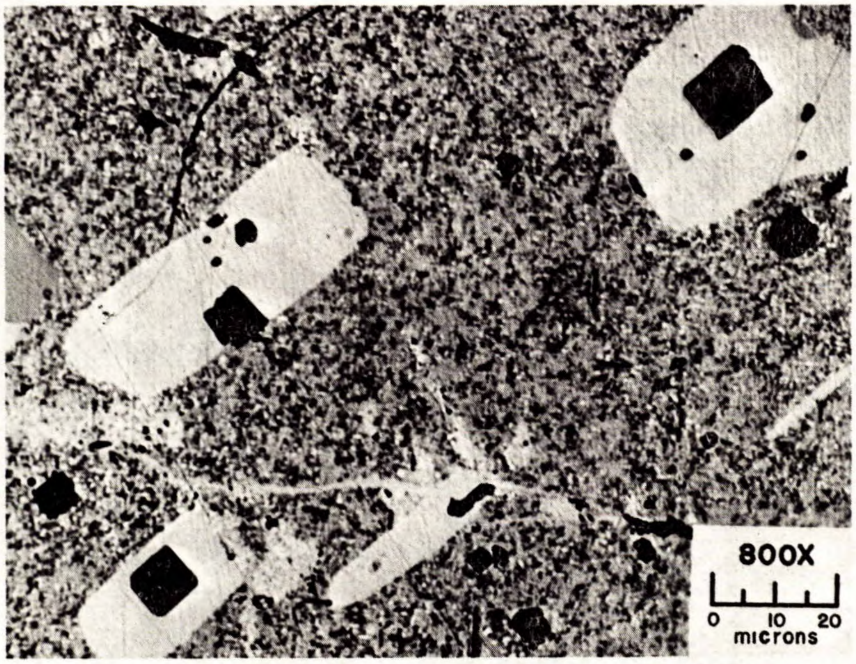

Figure 1 Photomicrograph (in oil immersion) of a polished section showing an intimate mixture of magnetite (greyish white) and ulvöspinel (?) (medium grey). This matrix contains stubby laths of ilmenite (white) and spindle-shaped inclusions of hercynite (black). Both the ilmenite and matrix also contain cubic inclusions of hercynite (black).

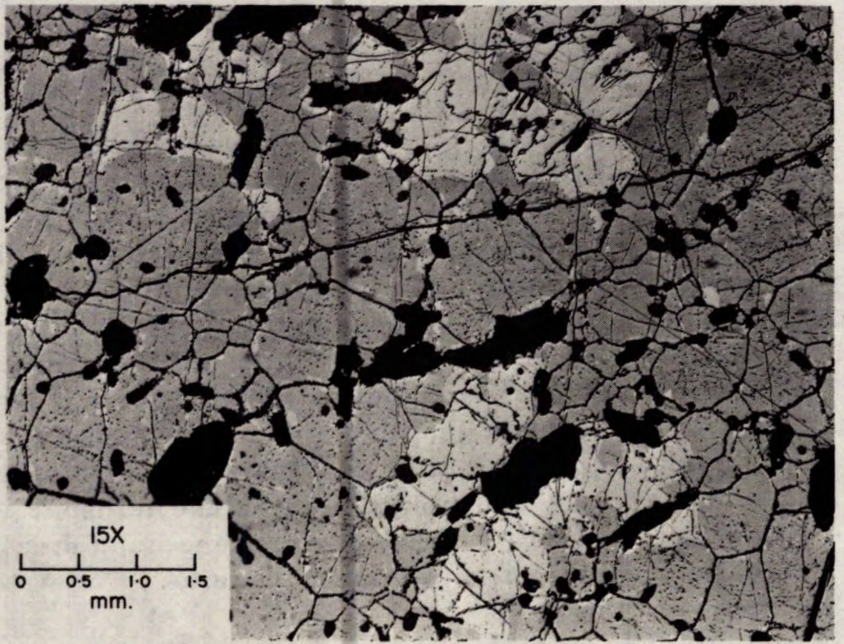

Figure 2 Photomicrograph of a polished section showing granular massive magnetite-ulvöspinel (?) (light grey) with coarse ilmenite (white). Finer grains of ilmenite can be seen along the edges of the magnetite-ulvöspinel (?) grains. The black areas are gangue.

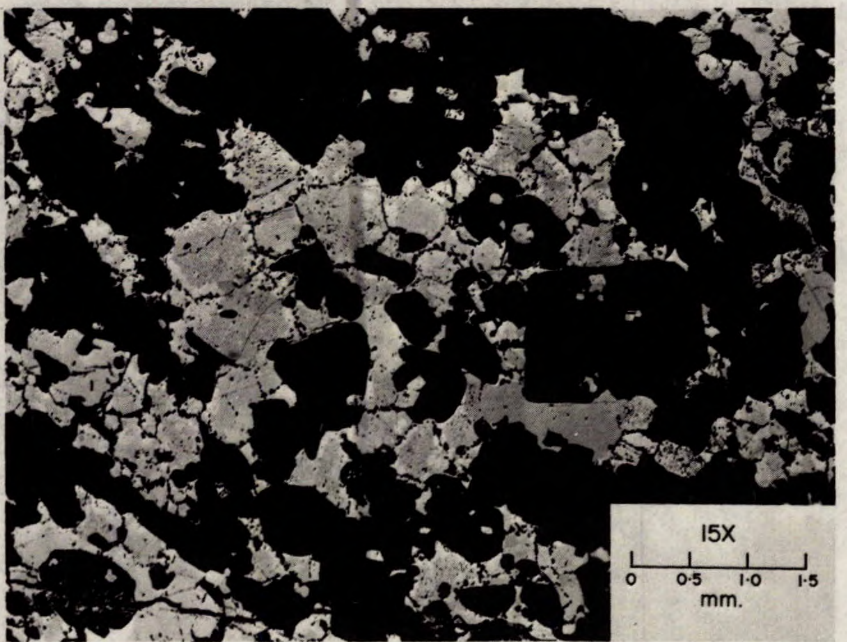

Figure 3. Photomicrograph of a polished section showing combined ilmenite (white and medium grey) with magnetite (light grey) in gangue (black).

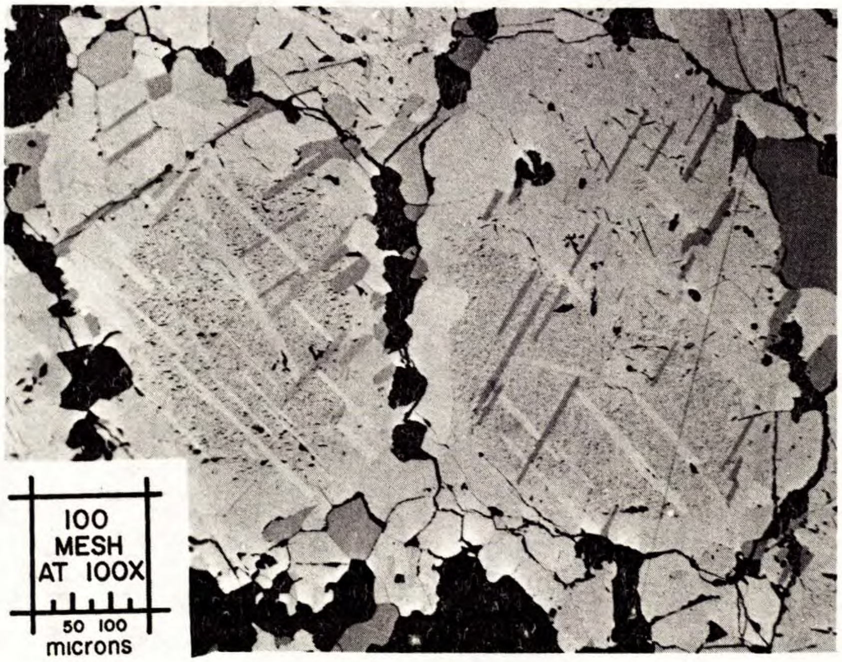

Figure 4. Photomicrograph (in oil immersion) of a polished section showing two grains whose centers consist of magnetite with very small hercynite inclusions (black), and which are rimmed by granular ilmenite (both white and medium grey). The magnetite is penetrated by laths of ilmenite. The black grains are interstitial gangue.

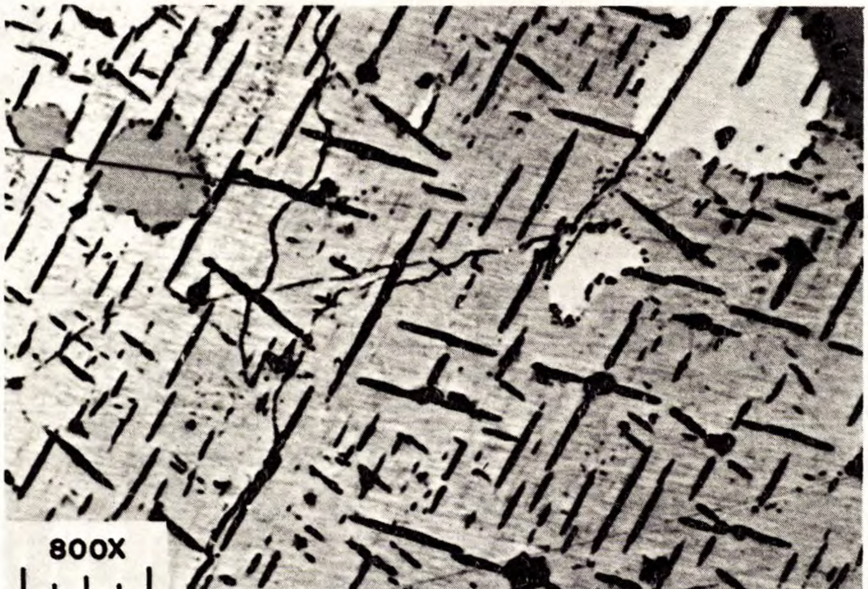

Figure 5. Photomicrograph (in oil immersion) of a polished section showing oriented spindle-shaped inclusions of hercynite (black) in magnetite (greyish-white). A few inclusions of ilmenite (white and medium grey) are also shown.

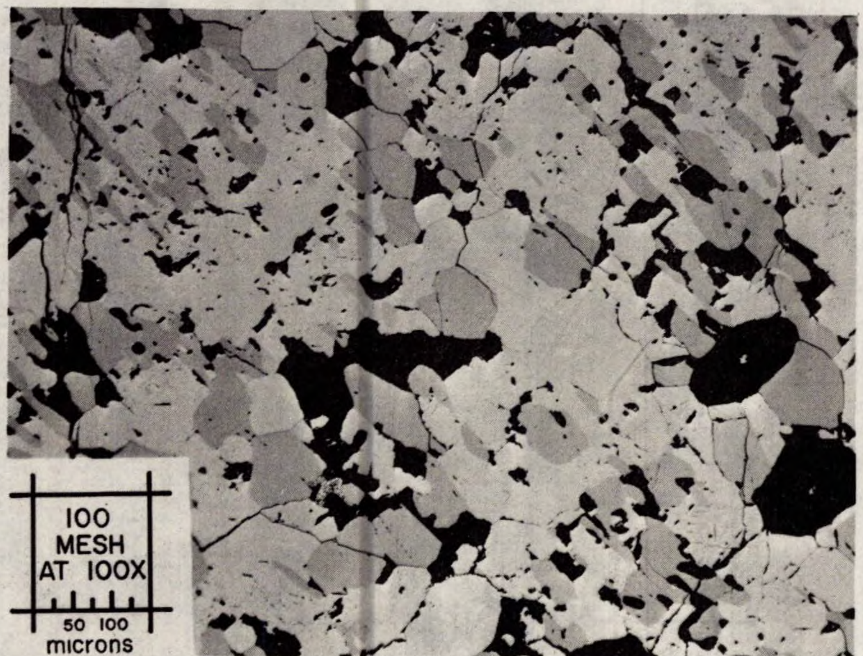

Figure 6. Photomicrograph (in oil immersion) of a polished section showing a granular aggregate of ilmenite (medium grey) and magnetite (white). The black areas are grains of gangue.

Figure 7. Photomicrograph of a thin section showing inclusions of magnetite and ilmenite (black) in a matrix of feldspar (white). The medium-grey fractured grains containing a few metallic in-inclusions are olivine. The olivine and the metallic minerals are rimmed by other gangue minerals.

DETAILS OF INVESTIGATION

Problem of Treating Low-grade Titaniferous Ores

There are three major processes dealing with treatment of titanium-bearing minerals: pyrometallurgical (electric smelting or fluosolid roasting), hydrometallurgical (leaching with sulphuric or hydrochloric acid at atmospheric or elevated pressures), and the chloride process (chlorination of preferably rutile or ilmenite enriched in TiO_2 content).

The ilmenite-bearing ores generally do not have a suffiently high titanium grade for the recovery of titanium by the mentioned processes As a result, they have to be upgraded by various ore dressing methods to produce an ilmenite concentrate, or smelted to produce titania slag, or, in most cases, a combination of both. (2)(3)

A major world producer of titania slag, Quebec Iron and Titanium Corporation in Sorel (Tracy), Quebec, produces its slag by electric arc-furnaces from its ilmenite-hematite ore from the Allard Lake area of Quebec. (3)

Typical analyses of raw and upgraded QIT ore are given in Table 2. (3)(4)

TABLE 2

Composition of QIT Raw and Upgraded Ore

	Ilmenite Ore	Upgraded Ilmenite Ore
TiO_2	34.8 %	35.6 %
Total Fe	40.0 %	41.0 %
Cr_2O_3	0.1 %	0.11 %
V_2O_5	0.2 %	0.30 %
FeO	30.0 %	27.90 %
Fe_2O_3	25.1 %	27.81 %
MnO	0.1 %	0.14 %
SiO_2	3.5 %	2.26 %
Al_2O_3	2.8 %	1.72 %
MgO	2.9 %	2.86 %
CaO	0.5 %	0.46 %
(SiO_2, Al_2O_3, MgO, CaO)	Insol = 9.7%	Insol = 7.3%

Since TiO_2, gangue minerals, as well as chromium and vanadium present in the ore remain in the slag during smelting, the amount of these components is therefore the main factor affecting the TiO_2 grade of the slag from any titaniferous ore, ie., the TiO_2/Insol ratio is the main factor determining the TiO_2 grade of the slag. In the early days (1952), Q.I.T. smelting of the original ore having TiO_2/Insol ratio of about 3.5:1 produced a slag containing 71.9% TiO_2, 8.9% FeO, 17% Insol[3].

The titania slag that could be produced by smelting the original ore from Titan Iron Mines without upgrading, would have an analysis as follows:[5] TiO_2-55.5%, FeO-14.0%, SiO_2-9.8%, Al_2O_3-15%, MgO-5.6%. Since the TiO_2 grade of the slag would be much below the required minimum, it is therefore essential to upgrade the ore from Titan Iron Mines prior to smelting by rejecting a portion of the gangue minerals with minimum iron and titanium losses.

Preliminary Testing

Based on the Mineralogical Investigation [6], preparation of a separate iron (magnetite) concentrate and a separate titanium (ilmenite - ulvöspinel) concentrate did not seem promising due to the intimate intergrowth of magnetite with ilmenite and with ulvöspinel. To find out what kind of iron concentrate could be obtained from this ore, a series of three tests was carried out by grinding samples to minus 100 mesh, minus 200 mesh, and minus 325 mesh respectively, and separating them by a Jeffrey-Steffensen low-intensity fractions. The magnetic fields of the separator's drums were kept at 700 gauss (2.2 amperes) on the first two drums and about 350 gauss (0.7 amperes) on the third drum. The results are recorded in Table 3.

TABLE 3

Results From Low-Intensity Magnetic Separation at Various Grinds

Grind, Mesh	Products	Weight %	Assays %		Distribution %	
			Sol Fe	TiO_2	Sol Fe	TiO_2
	L.I. mag conc	50.9	51.6	19.8	67.7	50.0
	Non-mag	49.1	25.5	20.65	32.3	50.0
-100	Feed (calcd)	100.0	38.84	20.26	100.0	100.0
	L.I. mag conc	47.1	54.2	19.8	64.9	50.7
	Non-mag	52.9	26.1	17.16	35.1	49.3
-200	Feed (calcd)	100.0	39.32	18.40	100.0	100.0
	L.I. mag conc	40.5	55.5	19.0	57.5	41.4
	Non-mag	59.5	27.9	18.32	42.5	58.6
-325	Feed (calcd)	100.0	38.10	18.60	100.0	100.0

These results showed that the magnetite and the titanium-bearing minerals could not be separated even at a very fine grind (-325 mesh) and thus separate iron and titanium concentrates could not be obtained from this ore by conventional mineral-dressing methods. These results also showed that a grind finer than minus 200 mesh was not advantageous.

Based on these results, the treatment of this ore was directed towards producing a bulk iron and titanium concentrate suitable for pyrometallurgical or hydrometallurgical processing, i.e. a bulk concentrate with a TiO_2/Insol ratio of 3.5:1 or better. The objective was to reject a portion of the gangue minerals from the ore with minimum iron and titanium losses and maintain the required TiO_2/Insol ratio in the final bulk concentrate. The methods applied consisted of combinations of tabling, low-and high-intensity magnetic separations and flotation.

Procedure (a). Tabling

This procedure consisted of grinding the ore to minus 100 mesh. tabling with slime-deck tables (primary tabling) and obtaining a primary table concentrate. Tailing from the primary table was then re-tabled on the slime-deck table (scavenger tabling) and a scavenger concentrate obtained. The middling from each tabling was returned to the head of the corresponding table. The primary and scavenger table concentrates combined formed the final bulk concentrate. The results of this simple treatment are given in Table 4.

TABLE 4

Procedure (a). Upgrading of Ore by Tabling
Grind: Minus 100 mesh

Products	% Weight	Assays %			TiO_2/Insol ratio	Distribution %		
		Sol Fe	TiO_2	Insol		Sol Fe	TiO_2	Insol
Table rghr conc	66.2	44.9	21.4	10.14		75.7	73.3	42.6
Table scav conc	5.0	41.05	19.2	15.57		5.2	5.0	4.4
Bulk table conc	71.2	44.6	21.26	11.37	1.87	80.9	78.3	47.0
Table scav tail	28.2	26.1	14.6	32.40		19.1	21.7	53.0
Feed (calcd)	100.0	39.28	19.34	17.64		100.0	100.0	100.0

Results from Table 4 showed that, since the TiO_2/Insol ratio in the bulk concentrate was too low due to high gangue (insol) content, this concentrate would not be suitable for further processing without upgrading.

Procedure (b). Flotation of Gangue

Rejection of gangue material from the minus 100-mesh ore was tried using a cationic flotation reagent, Arosurf MG-83 as collector at a natural pH of 7.8. The collector was added in three stages in order to obtain maximum selectivity and minimum losses of iron-and titanium-bearing minerals to the gangue float product (waste). The results of this procedure are recorded in Table 5.

TABLE 5

Procedure (b). Flotation of Gangue Material from the Ore

Flotation Products	% Weight	Assays %			Distribution %		
		Sol Fe	TiO_2	Insol	Sol Fe	TiO_2	Insol
Bulk rghr conc	69.3	42.87	21.92	11.7	75.5	82.2	55.9
Gangue	30.7	31.30	10.7	20.8*	24.5	17.8	44.1
Feed	100.0	39.20	18.5	14.5	100.0	100.0	100.0

* Calculated.

Results from Table 5 showed that this procedure did not produce a bulk concentrate suitable for further processing.

Procedure (c). Low- and High-Intensity Magnetic Separation

This procedure consisted of grinding the ore to minus 28 mesh (primary grind), and separating (cobbing) it by a Sala low-intensity wet-magnetic separator into magnetic (cobber concentrate) and non-magnetic (cobber tailing) portions. Both cobber concentrate and cobber tailing were ground separately (secondary grind) to minus 200 mesh. The cobber concentrate then was treated by a Jeffrey-Steffensen, three-drum, low-intensity wet-magnetic separator. The magnetic fields of the separator's drums were kept at about 700 gauss (2.2 amperes) on the first two drums and about 350 gauss (0.7 amperes) on the third drum.

The magnetics and middling were combined, forming a low-intensity magnetic concentrate. The low-intensity non-magnetics were deslimed, slimes were discarded, and the remaining portion was treated by a high-intensity wet-magnetic separator at 0 amperes and 5 amperes. The high-intensity concentrates were combined with the low-intensity magnetic concentrate and formed the final bulk concentrate. The laboratory flow-sheet of this procedure is presented in Figure 8, and results in Table 6.

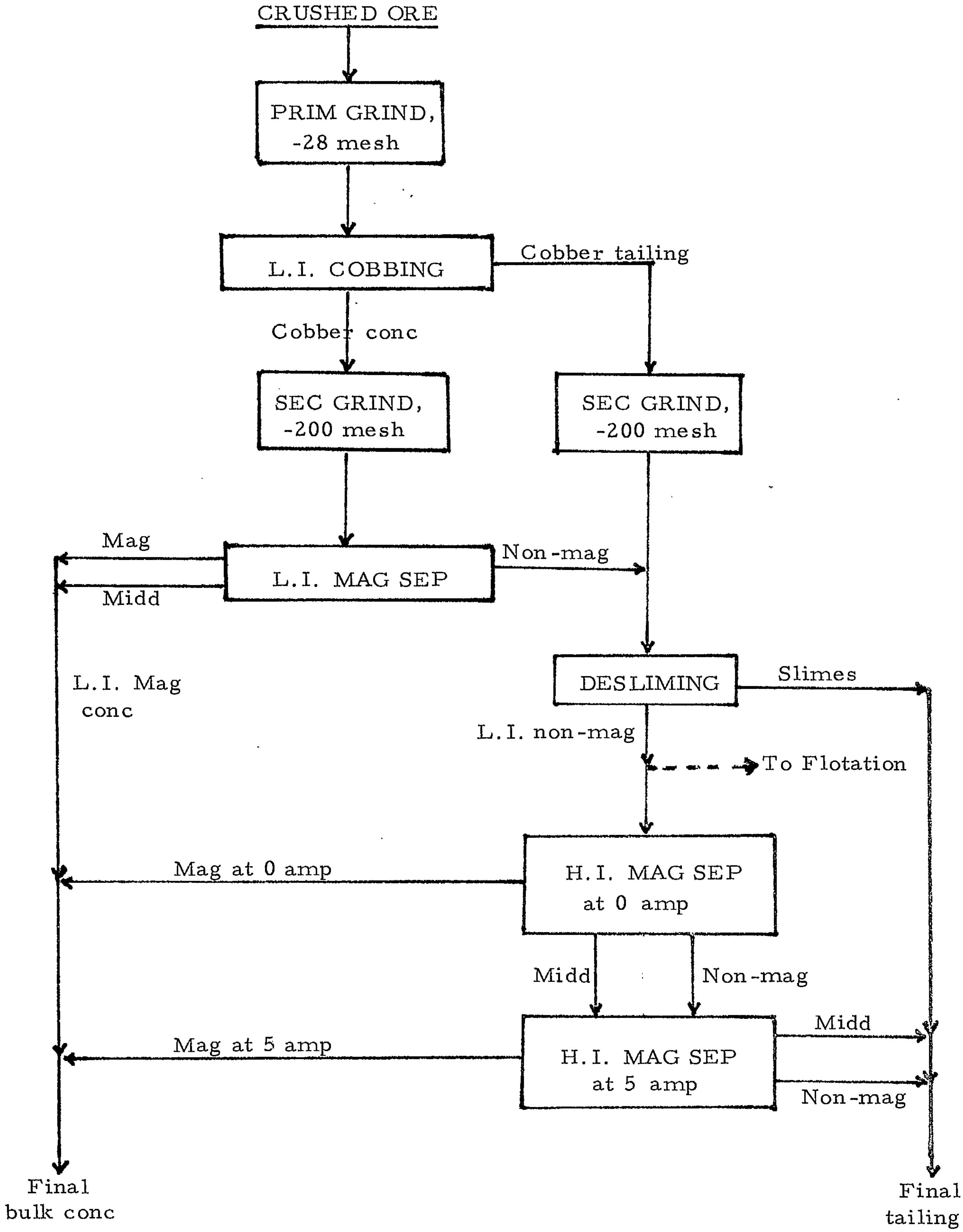

Figure 8. Procedure (c.) Upgrading of Ore by Low- and High-Intensity Magnetic Separation or by Flotation- Procedure (b)).

Procedure (c).

TABLE 6

Upgrading of Ore by Low- and High-Intensity Magnetic Separation
Primary Grind: -28 mesh
Secondary Grind: -200 mesh

Products	% Weight	Assays %			TiO_2 Insol ratio	Distribution %		
		Sol Fe	TiO_2	Insol		Sol Fe	TiO_2	Insol
L.I. mag	32.4	54.45	19.60	0.52		44.9	34.5	1.2
L.I. midd	14.9	53.20	19.92	0.92		20.2	16.1	0.9
H.I. mag at 0 amp	6.2	45.55	19.84	6.82		7.2	6.7	2.9
H.I. mag at 5 amp	20.8	31.6	25.00	15.66		16.7	28.3	22.1
Bulk conc	74.3	47.05	21.20	5.34	4.0:1	89.0	85.6	27.1
H.I. middat 5 amp	12.9	18.45	11.36	39.74		6.0	8.0	39.8
H.I. non-mag at 5 amp	11.6	15.35	9.16	44.92		4.5	5.8	35.4
Slimes	1.2	16.85	10.42	33.20		0.5	0.6	1.8
Bulk rghr tail	25.7	16.96	10.31	41.79		11.0	15.4	72.9
Feed (calcd)	100.0	39.32	18.40	14.73		100.0	100.0	100.0

To determine if primary grinding and cobbing could be eliminated, a test in which ore was ground to minus 200 mesh and then treated by low-intensity magnetic separation using the Jeffrey-Steffensen low-intensity magnetic separator was carried out. The results are given in Table 7.

TABLE 7

Results of Low-Intensity Magnetic Separation
Without Primary Grind and Cobbing

Products	% Weight	Assays %			Distribution %		
		Sol Fe	TiO_2	Insol	Sol Fe	TiO_2	Insol
L.I. mag & midd	49.0	52.14	19.58	3.50	66.2	52.2	11.2
L.I. tailing	51.0	25.50	17.20	26.40	33.8	47.8	88.8
Feed (calcd)	100.0	38.5	18.4	15.2	100.0	100.0	100.0

The gangue content in the low-intensity magnetic concentrate from Table 7 is considerably higher than the gangue content in the corresponding concentrate from Table 6. This shows that primary grinding and cobbing are beneficial for reduction of the gangue content in the low-intensity magnetic concentrate. As a result, primary grinding and cobbing were maintained as part of the procedure for rougher concentration of this ore.

Relationship between insol (gangue) content and TiO_2 and Fe recoveries in the bulk concentrate obtained byProcedure (c), Table 6, is presented in Figure 9.

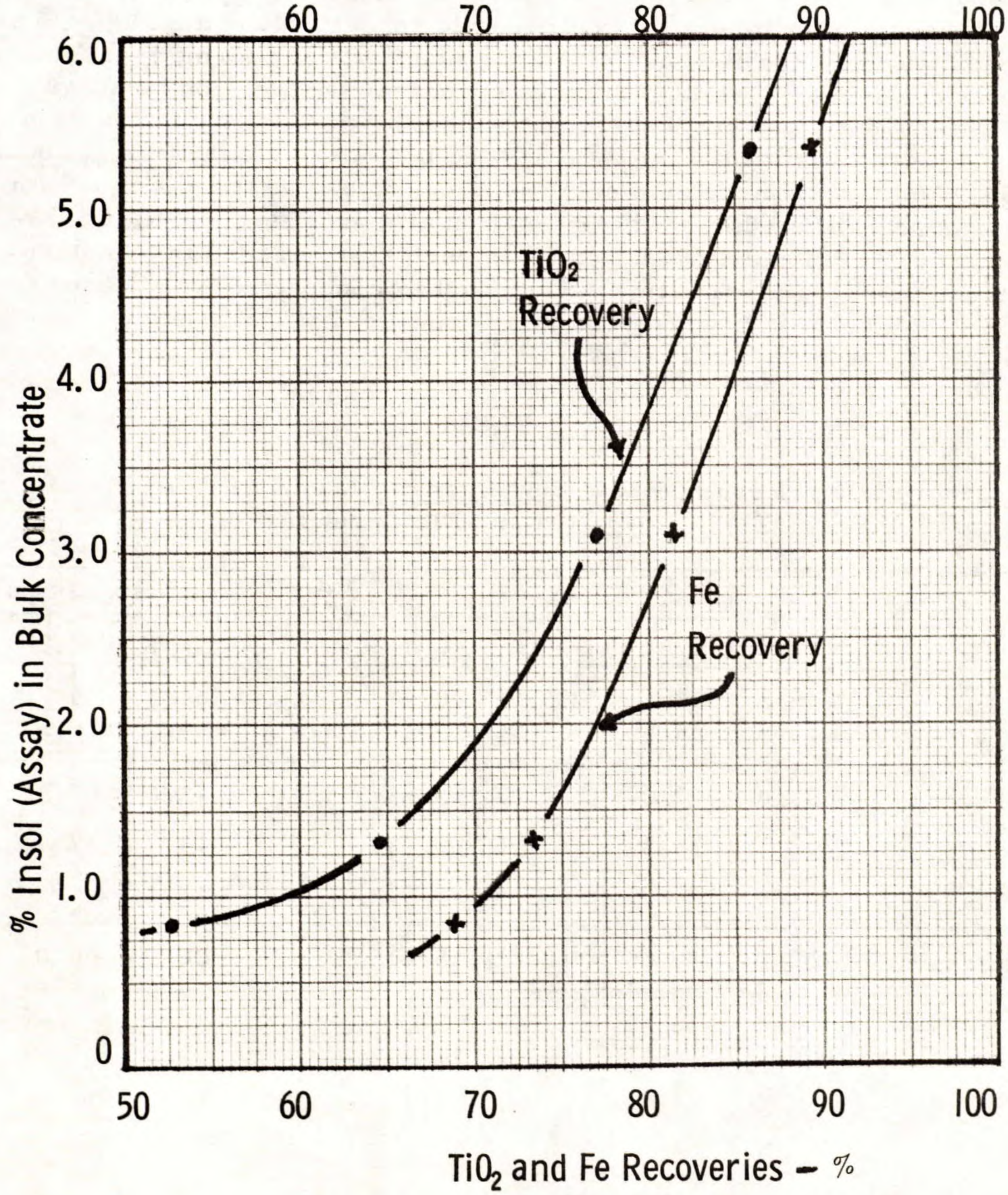

Figure 9 Relationship Between Insol content and TiO_2 and Fe Recoveries in Bulk Concentrate.

Procedure (d). Low-Intensity Magnetic Separation and Flotation of Titanium-Bearing Minerals

The first step of upgrading the ore by this procedure was the same as described in the procedure (c), i.e. applying cobbing, grinding the cobber concentrate to minus 200 mesh and upgrading it by low-intensity magnetic separation. The non-magnetic portion of the ore was treated by flotation instead of by the high-intensity magnetic separation, see Figure 8. Petroleum sulphonates were used as collector. The low-intensity magnetic concentrate and middling were combined with the flotation cleaner concentrate and formed the final bulk concentrate, while the flotation rougher tailing, combined with slimes from the secondary grind formed the final tailing. Flotation procedure consisted of conditioning the non-magnetic tailings at about 50% solids with petroleum sulphonate collector 801 at a pH of 4.5 for 5 minutes followed by rougher flotation at a pH of 5.6 and about 32% solids. Additional amounts of 801 collector were added in two stages during the rougher flotation. The rougher concentrate was cleaned once at a pH of 6.1. The results are recorded in Table 8.

TABLE 8

Procedure (d): Results From Low-Intensity Magnetic Separation and Flotation

Products	% Weight	Assays %			TiO_2/ Insol ratio	Distribution %		
		Sol Fe	TiO_2	Insol		Sol Fe	TiO_2	Insol
L.I. mag & midd	48.1	53.53	19.90	0.81		64.3	50.7	2.5
Flot cl conc	14.5	25.56	21.56	21.16		9.3	16.5	19.9
Bulk conc	62.6	47.04	20.17	5.53	3.64:1	73.6	67.2	22.4
Flot cl tail	15.8	36.3	20.76	25.14		14.3	17.4	25.8
Flot rghr tail	21.6	22.93	13.46	36.96		12.1	15.4	51.8
Feed (calcd)	100.0	40.00	18.82	15.41		100.0	100.0	100.0

Procedure (e). Rougher Concentration and Upgrading of Bulk Rougher Concentrate by Low- and High-Intensity Magnetic Separation and Tabling

This procedure consisted of cobbing the coarse-ground ore by a Sala low-intensity magnetic separator to recover the magnetic portion of the ore; the non-magnetic portion (Sala tailing) was then tabled applying a two-stage (rougher and scavenger) procedure. The middlings of each table were returned to head of the corresponding table. The two table rougher-concentrates obtained were mixed with the cobber concentrate forming a bulk rougher concentrate.

The bulk rougher concentrate then was ground to minus 200 mesh and treated by the Jeffrey-Steffensen wet-magnetic separator in the same manner as described in procedure (c). The non-magnetic tailing was treated by slime-deck tabling. The slimes from the slime-deck tailing were combined with the primary fines and both treated by high-intensity wet-magnetic separators at 3 amperes. The primary-tailing sands, slime-deck tailing, and high-intensity tailing made up the final tailing.

The flowsheet of this procedure is presented in Figure 10.

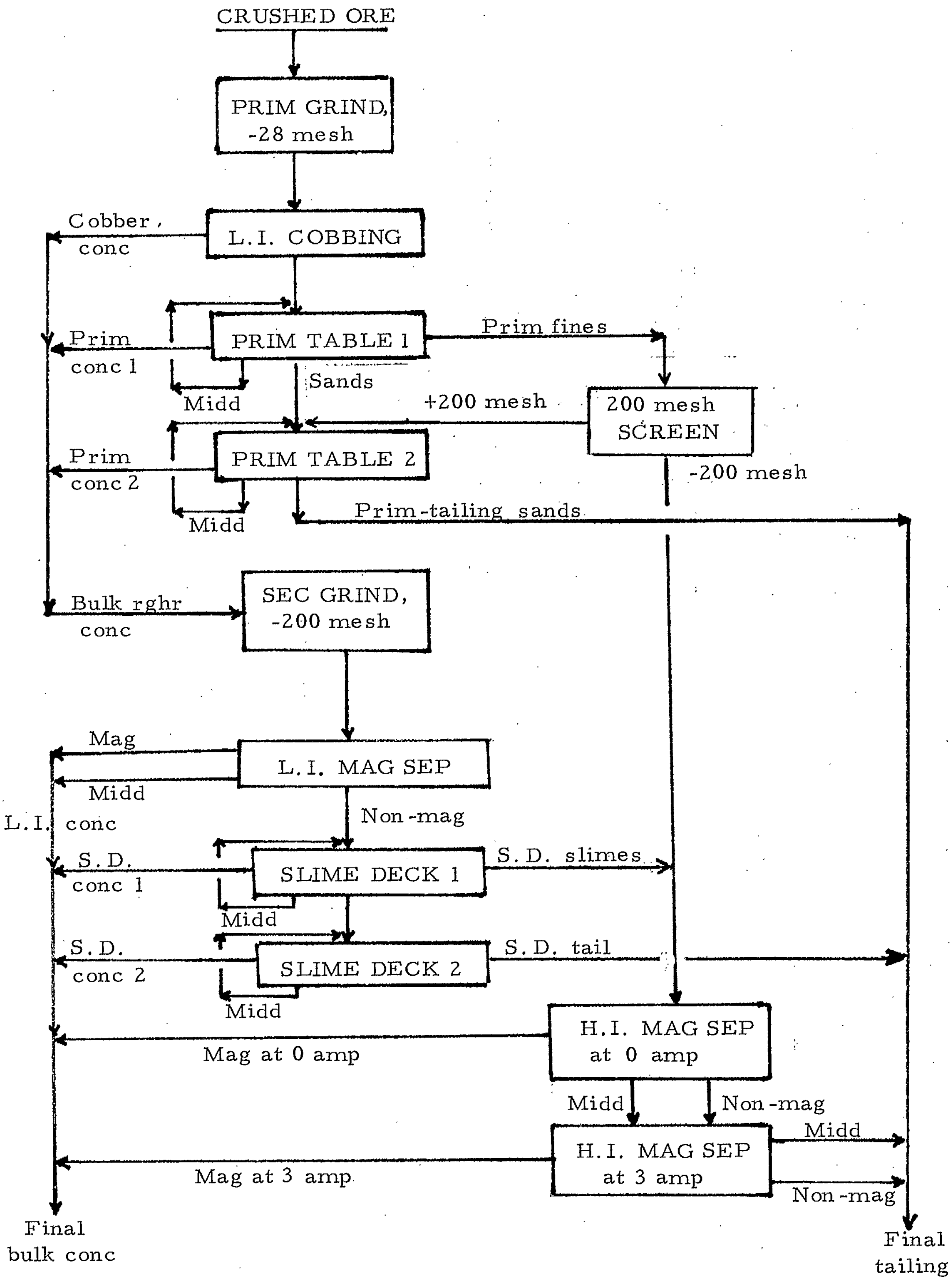

Figure 10. Procedure(e) . Rougher Concentration and Upgrading of Bulk Concentrate by Low- and High-Intensity Magnetic Separation and Tabling.

The results of rougher concentration are given in Table 9.

TABLE 9

Procedure (e). Results of Rougher Concentration
Rougher Grind: -28 mesh

Products	% Weight	Assays %			TiO_2/ Insol ratio	Distribution %		
		Sol Fe	TiO_2	Insol		Sol Fe	TiO_2	Insol
Bulk rghr conc	83.4	43.03	20.23	9.23	2.15:1	93.9	92.9	49.0
Primary table tail	16.6	14.67	7.98	48.14		6.1	7.1	51.0
Feed (calcd)	100.0	38.3	18.2	15.7		100.0	100.0	100.0

Results from Table 9 showed that the TiO_2/Insol ratio in the bulk rougher concentrate was too low (gangue content too high) for smelting or hydrometallurgical processing of this concentrate without upgrading.

To find out where major losses of iron and titanium were occurring in the table tailing, this waste product was screened and each screen-fraction assayed separately. The results of size and assay distribution in the primary rougher tailing are recorded in Table 10.

TABLE 10

Procedure (e). Size and Assay Distribution in Rougher Tailing
Primary (Rougher) Grind: -28 mesh

Size range, Mesh	% Weight		Assays %			Distribution %					
						In Sample			In Orig Ore		
	In sample	In Orig Ore	Sol Fe	TiO_2	Insol	Sol Fe	TiO_2	Insol	Sol Fe	TiO_2	Insol
-28+ 35	7.0	1.1	12.65	3.80	57.70	6.1	3.3	8.4	0.3	0.2	4.2
-35+ 48	17.3	2.9	12.15	3.58	59.14	14.4	7.8	21.4	0.9	0.5	10.7
-48+ 65	16.0	2.7	10.75	2.86	61.30	11.7	5.7	20.1	0.8	0.4	10.3
-65+100	10.1	1.7	9.49	2.20	63.48	6.5	2.8	13.3	0.4	0.2	6.7
-100+150	7.6	1.2	8.60	1.74	64.86	4.4	1.6	10.2	0.3	0.1	5.2
-150+200	6.8	1.2	10.50	2.20	61.16	4.8	1.9	8.6	0.3	0.1	4.9
+200 (sands) (calcd)	64.8	10.8	10.85	3.09	61.08	47.9	23.1	82.2	3.0	1.6	42.0
-200 (fines) (calcd)	35.2	5.8	21.70	17.41	24.31	52.1	76.9	17.8	3.1	5.4	9.0
Total Table-rghr tail	100.0	16.6	14.67	7.98	48.14	100.0	100.0	100.0	6.1	7.0	51.0

Results from Table 10 showed that the highest iron and titanium contents and the lowest insol content were in the fine fraction (minus 200-mesh) of the tailing. The plus 200-mesh fraction of the tailing, comprising 10.8% of the ore by weight, had low iron and titanium contents and a very high gangue (Insol) assay containing 42.0% of the insol from the ore and therefore a very suitable waste product.

The results of upgrading rougher concentrate by this method are recorded in Tables 11 and 12.

TABLE 11

Procedure (e) — Results of Upgrading Rougher Concentrate by Low- and High-Intensity Magnetic Separation and Tabling

Products	% Weight	Assay % Sol Fe	Assay % TiO_2	Assay % Insol	TiO_2/Insol ratio	Distribution % Sol Fe	Distribution % TiO_2	Distribution % Insol
L.I. mag & midd	49.8	53.43	19.16	0.86		69.0	52.7	2.8
Slime-Deck conc	5.3	32.64	41.70	5.66		4.5	12.2	2.0
H.I. conc at 0 amp	3.4	41.02	20.0	7.08		3.6	3.7	1.5
H.I. conc at 3 amp	6.3	29.07	24.0	16.58		4.7	8.4	6.7
Bulk conc	64.8	48.70	21.58	3.10	6.95:1	81.8	77.0	13.0
Prim table sands	10.8	10.19	2.69	61.02		2.9	1.6	42.4
Slime-Deck tail	12.4	26.82	14.48	28.04		8.6	10.0	22.4
H.I. tail	12.0	21.76	17.29	28.68		6.7	11.4	22.2
Final tail	35.2	19.97	11.82	38.38		18.2	23.0	87.0
Feed (calcd)	100.0	38.59	18.18	15.52		100.0	100.0	100.0

TABLE 12

Additional Analyses of Bulk Concentrate

% V_2O_5 = 0.54

% Cr_2O_3 = 0.022

% S = 0.039

% P_2O_5 = $<$0.02

% Ni = 0.14

DISCUSSION OF RESULTS

The mineralogical examination showed that the major iron mineral (magnetite) and the titanium-bearing minerals (ilmenite and ulvöspinel) are intimately intergrown. For this reason, the separation of these minerals and the preparation of separate iron and titanium concentrates could not be achieved. (Table 3).

The concentration of the iron and titanium minerals in a bulk concentrate, by tabling alone (Procedure (a), Table 3), or by a combination of low-intensity wet-magnetic separation and flotation (Procedure (d), Table 8) did not produce suitable concentrates.

Suitable bulk concentrates were obtained by applying Procedure (c), consisting of low- and high-intensity magnetic separation, or by Procedure (e) consisting of rougher concentration and upgrading of the ground rougher concentrate by low- and high-intensity magnetic separation and tabling. The respective iron and titanium recoveries in these bulk concentrates were 89.0% and 85.6% by Procedure (c), Table 6, with 5.34% Insol, (4.0:1 TiO_2/Insol ratio), and 81.8% and 77.0% by procedure (e), Table 11, with 3.10% Insol (6.95:1 TiO_2/Insol ratio).

To obtain a ratio of 3.5:1, the amount of gangue in the bulk concentrates could be increased to about 6% Insol. From Figure 9 this represents 91.5% Fe recovery and 88% TiO_2 recovery. This bulk concentrate would comprise about 76% by weight of the original ore. Although high-intensity magnetic concentration has been used to treat large tonnages of material in some industries, it has not been used on a large scale in the iron-ore industry.

CONCLUSIONS

The mineral-dressing procedures outlined will not separate the iron-bearing minerals from the titanium-bearing minerals.

A bulk concentrate (iron and titanium minerals combined) suitable for the production of pig iron and titania slag by smelting can be obtained by a combination of low-intensity and high-intensity magnetic concentration.

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