Dr K. W. Downes

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FURTHER CONCENTRATION TESTS ON MAGNETITE-ILMENITE FROM ROMAINE RIVER VALLEY, P. Q., FOR QUEBEC IRON AND TITANIUM CORPORATION

by

W. S. JENKINS

MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

The magnetite in the sample was concentrated by low intensity magnetic methods to produce a high iron (70% Fe) concentrate at -150m containing about 0.30% TiO_2 and less than 0.01% P_2O_5.

The ilmenite was recovered from the non-magnetic cobber tailing by gravity and/or high intensity wet magnetic concentration.

Cleaning of this ilmenite concentrate by apatite flotation and high intensity wet magnetic separation, after regrinding to -150m, produced finished ilmenite concentrate containing 39 to 40% TiO_2 and 0.05% P_2O_5. However, recovery of ilmenite was low.

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* Senior Scientific Officer, Mineral Processing Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

CONTENTS

TABLES

TABLES (cont'd)

TABLES (cont'd)

INTRODUCTION

Shipment

A shipment of magnetite-ilmenite ore was received at the Mines Branch laboratories, Ottawa, on July 12, 1962. The shipment was designated as Shipment 3. It consisted of two drums of lump ore of 1550 lb net weight. The shipment was sent by Mr. J. M. Noy, Research Director, Quebec Iron and Titanium Corporation, Sorel, Quebec.

Location of the Property

The shipment originated from property in the Romaine River Valley, Saguenay County, Quebec.

Purpose of the Investigation

Two shipments had previously been sent by Mr. Noy from the same property. The results of the investigation of the first two shipments have been reported in Mines Branch Investigation Report IR 62-85, "Concentration of Titaniferous Magnetite Ore from Romaine River Valley, Quebec, for Quebec Iron and Titanium Corporation, Sorel, Quebec", by W. S. Jenkins and D. E. Pickett, dated October 30, 1962.

In his letter, dated July 20, 1962, Mr. Noy said the third shipment was sent to allow some more extensive tests to be made using flow sheets which had been developed in work on Shipments 1 and 2. These tests were to include flotation of apatite from the ilmenite concentrate as well as high intensity magnetic concentration of ilmenite.

The specifications for acceptable grades of concentrates for the proposed special smelting process are as follows:

Magnetite conc less than 1.0% TiO_2
" " 0.1% P_2O_5
" " 0.1% Cr_2O_3
" " 0.3% V_2O_5

Ilmenite conc at least 36% TiO_2
less than 0.03% S
" " 0.05% P_2O_5

SAMPLING AND ANALYSIS OF THE SHIPMENT

The shipment was crushed and a head sample was obtained.

TABLE 1

Analysis* of the Head Sample

Chemical Analysis	
Total iron	19.19 %
Soluble iron	15.14 "
Titanium dioxide	7.18 "
Phosphorus pentoxide	4.18 "
Sulphur	0.47 "
Silica	34.06 "
Insoluble	59.16 "

Semi-Quantitative Spectrographic Analysis**

Elements in order of decreasing abundance:

Major constituents	-	Si, Fe
Intermediate "	-	Ca, Ti, Al, Mg, Na
Minor "	-	Mn, Sr
Trace "	-	Zr, V, Ba, Cu, Ni, Co

* From Internal Report MS-AC-62-907.

** From Internal Reports MS-AC-62-801, SL-62-180.

MINERALOGICAL EXAMINATION

No mineralogical examination was made on the ore of Shipment 3.

SUMMARY OF TEST PROCEDURE AND RESULTS

Three flowsheets were used in the laboratory tests as shown in Appendices 1, 2 and 3. Magnetite was first concentrated by cobbing at 35 mesh either by wet separator (Jeffrey) or dry (Ball-Norton).

In each flowsheet the cobber tailing was treated by either tabling and/or high intensity magnetic separation to recover a coarse ilmenite concentrate at 35 mesh. This coarse ilmenite concentrate was ground to -150m and reconcentrated by Jones high intensity wet magnetic separator and/or flotation to remove apatite and produce a finished concentrate. The differences between the three flowsheets are shown in Table 2.

In all, 8 series of tests were made as listed in Table 3.

TABLE 2

Comparison of Flow Sheets

Process	Flowsheet A	Flowsheet B	Flowsheet C
Magnetic cobbing at -35m	Jeffrey wet sep'n	Jeffrey	Ball Norton dry sep'n
Magnetite cleaning	Jeffrey	Jeffrey	Jeffrey
Ilmenite conc at -35m	Table and Jones	Jones wet sep'n	Table and Stearns dry sep'n
Ilmenite conc at -150m	Jones	Jones	Jones and/or
Ilmenite Recleaning at -150m	Jones	Jones	Flotation

TABLE 3

Summary of Test Series

Series	Flow Sheet	Primary Mag. Sep'n	Concentrate reground to -150m	Finishing Procedure
Tests 1-6	A	Jeffrey 1.5 amp	Jones midd and conc 35m	Jones
Tests 12-17	A	Jeffrey 2.0 amp	Jones conc 35m	Jones
Tests 23-28	A	Jeffrey 1.5 amp	Jones conc 35m	Jones
Tests 7-11	B	Jeffrey 1.5 amp	Jones midd and conc 35m	Jones
Tests 18-22	B	Jeffrey 2.0 amp	Jones conc 35m	Jones
Tests 35-39	C	Ball-Norton	Stearns conc 35m	Flotation
Tests 40-41	C	Ball-Norton	Stearns conc 35m	Flotation
Tests 42-47	A	Dings	Wilfley Table 35m	Jones and Flotation

Results of Magnetic Cobbing

Cobbing at 1.5 or 2.0 amp on the Jeffrey separator did not result in significant differences in final -150m magnetite recovery or grade. It would appear that 1.5 amp will be preferable since 97.4% of the ilmenite (Test 7) remained in the non-magnetic tailing while at 2.0 amp the recovery of ilmenite in the non-magnetic cobber tailing was 86.9 and 95.3% in two tests (Tests 12 and 18). Dry cobbing with the Ball-Norton separator gave almost the same results as the Jeffrey separator with 97.4% of the ilmenite in the non-magnetic tailing, (Test 35). A similar 97.4% distribution of TiO_2 in non-magnetic tailing was obtained in the small pilot plant test using the Dings pilot plant wet magnetic separator in Test 42.

Results of Magnetite Concentration

Table 4 summarizes the results of magnetite concentration. The lowest TiO_2 content obtained was in Test 24. This was cobbed at 1.5 amp.

TABLE 4

Summary of Magnetite Cleaning at -150m

Test	Analysis of Concentrate					Fe Recovery %	Ratio of Concentration
	Fe	TiO_2	P_2O_5	S	SiO_2		
2	69.88	0.35	< 0.01	0.25	0.48	44.8	11.1:1
8	70.44	0.36	< 0.01	0.25	0.42	40.2	10.9:1
13	69.96	0.60	-	0.32	0.28	41.1	11.8:1
19	70.11	0.37	0.013	0.24	0.28	41.1	11.7:1
24	70.08	0.25	0.002	0.26	0.38	40.4	11.7:1
35	69.33	0.40	0.034	0.24	0.25	41.9	11.4:1

Ilmenite Concentration

The best method for ilmenite concentration from the non-magnetic cobber tailing was not determined. Results were affected by table operation, the difficulty of disposing of middlings, and variations in flotation procedure.

In Table 5, the best results with each of the three flow sheets in laboratory tests are summarized for comparison. These test series were selected on the basis of TiO_2 recovery although the 0.05% P_2O_5 content was not attained. In Test 38 the ilmenite concentrate obtained by flotation contained 0.05% P_2O_5 but the recovery of TiO_2 (35.6%) was too low.

In Test 44 a flotation product containing 0.04% P_2O_5 was made by apatite flotation, after regrinding a 35m Jones wet-magnetic concentrate. The -150m concentrate contained 37.84% TiO_2 but recovery of ilmenite was only 45.7%.

In Test 43 using Flowsheet A with two stages of Jones separation at -150m, a concentrate containing 0.05% P_2O_5 was obtained but TiO_2 recovery was only 37.5%.

TABLE 5

Summary of Ilmenite Concentration Results

Flowsheet	A				B				C			
Test Series	12 - 17				18 - 22				35 - 39			
	Wt %	Assay %		Rec % TiO_2	Wt %	Assay %		Rec % TiO_2	Wt %	Assay %		Rec % TiO_2
		TiO_2	P_2O_5			TiO_2	P_2O_5			TiO_2	P_2O_5	
Non-mag tail	87.7	7.47	3.94	86.9	87.8	7.31	4.25	95.3	88.9	7.81	3.77	97.4
35m conc table	50.3	11.75	4.92	77.9					18.8	28.24	2.83	74.5
35m conc H.I. mag.	22.3	23.26	1.14	68.4	27.0	24.4	1.22	89.4	13.1	39.32	0.53	72.3
-150m conc Jones	12.7	33.32	0.16	55.9	14.8	34.64	0.19	70.6				
-150m conc Jones	10.3	37.76	0.065	51.1	11.0	39.21	0.076	59.5				
-150m conc flot									10.0	40.32	0.06	56.2

Flotation Tests

Several flotation tests were made to determine the best flotation procedure for final concentration of the ilmenite which had been separated from the gangue at 35m. The removal of apatite to meet the specification of 0.05% P_2O_5 was the final objective.

TABLE 6

Summary of Flotation Results

Test No.	Table	Concentrate Analysis %		Distribution TiO_2 % from orig feed	
		TiO_2	P_2O_5	In 35m conc	In finished conc
38	26	38.52	0.05	72.3	35.6
39	27	40.32	0.06	72.3	56.2
41	28	40.16	0.09	43.5	37.9
41	28	40.20	0.06	"	33.9
41	28	40.25	0.07	"	38.7

A supply of feed for flotation testing was obtained in a small pilot mill test. The resulting 35m table concentrate was reground, in some cases after an additional high intensity magnetic stage, but the results, shown in Table 37, were not conclusive and in no case produced an acceptable concentrate.

DETAILS OF TESTS

Tests 1 to 6 - Wet Flow Sheet A

A series of tests was made in which the procedure of Wet Flow Sheet A, Appendix 1, was used. A 5000 g sample of -35m ore was concentrated by the Jeffrey-Steffensen 3-drum separator using 1.5 amp on each drum. The products were a magnetic concentrate and a non-magnetic tailing. The magnetic concentrate was ground to -150m and reconcentrated by the Jeffrey-Steffensen separator using 1.5 amp on the first two drums to produce a concentrate and tailing. The concentrate was cleaned on the third drum at 0.7 amp.

The -35m non-magnetic tailing was concentrated on a Deister table which produced a concentrate and tailing. The table concentrate was concentrated at -35m by the high intensity Jones separator at 7 amp to produce a concentrate, a middling and a tailing. The concentrate and middling were combined and ground to -150m and concentrated by the Jones separator at 7 amp. The products were a cleaned concentrate, a middling and tailing. The cleaned concentrate was recleaned by the Jones separator at 7 amp. The products were a cleaner concentrate (finished ilmenite concentrate), a recleaner middling and a tailing.

The results in Tables 7 to 12 were obtained by this procedure.

TABLE 7

Results of Magnetic Concentration of -35m Ore by the Jeffrey-Steffensen Separator at 1.5 amp. (Test 1)

Product	Weight %	Analysis % ☆☆			Distn %			R/C
		Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed☆	100.0	13.68	7.17	3.74	100.0	100.0	100.0	
Mag conc	10.8	62.37	1.74	0.27	49.1	2.6	0.8	9.3:1
Tailing	89.2	7.81	7.83	4.16	50.9	97.4	99.2	

☆ calculated

TABLE 8

Results of Reconcentration of Magnetic Concentrate at -150m (Test 2)

Product	Weight %		Analysis % **			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	10.8	63.84	1.77	0.33	100.0	100.0	100.0	49.1	2.6	0.80	
Mag conc	83.4	9.0	69.88	0.35	<0.01	91.3	16.3	2.8	44.8	0.4	0.02	11.2:1
Midds	1.7	0.2	66.53	1.16	0.08	1.8	1.1	0.6	0.9	0.1	0.01	
Tailing	14.9	1.6	29.68	9.80	2.13	6.9	82.6	96.6	3.4	2.1	0.77	

* Calculated

Additional analyses of Mag conc: S, 0.25%; SiO_2, 0.48%.

TABLE 9

Test 3 - Results of Table Concentration of Non-Magnetic Tailing of Test 1 at -35m

Product	Weight %		Analysis % **			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed*	100.0	89.2	9.20	7.83	4.06	100.0	100.0	100.0	50.9	97.4	99.2
Table conc	54.1	48.2	14.16	13.17	4.79	83.2	90.9	63.7	42.4	88.5	63.2
Table tail	45.9	41.0	3.37	1.55	3.21	16.8	9.1	36.3	8.5	8.9	36.0

* Calculated

** From Internal Report MS-AC-62-1234.

TABLE 10

Test 4 - Results of Jones Concentration of Table Concentrate at -35m

Product	Weight %		Analysis % **			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed*	100.0	48.2	14.16	13.21	4.83	100.0	100.0	100.0	42.4	88.5	63.2
Mag conc	45.5	22.0	26.69	26.56	1.11	85.8	91.5	10.5	36.4	81.0	6.6
Midds	34.5	16.6	4.62	2.61	5.48	11.3	6.8	39.1	4.8	6.0	24.7
Tailing	20.0	9.6	2.09	1.09	12.17	2.9	1.7	50.4	1.2	1.5	31.9

* calculated

TABLE 11

Test 5 - Results of Jones Concentration of Combined Concentrate and Middlings of Test 4, Ground to -150m

Product	Weight %		Analysis % **			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed*	100.0	38.6	17.01	16.10	2.83	100.0	100.0	100.0	41.2	87.0	31.3
Cleaned conc	42.2	16.3	30.96	30.66	0.27	76.8	80.3	4.0	31.6	69.9	1.3
Midds	33.9	13.1	7.17	6.09	3.42	14.3	12.8	40.9	5.9	11.1	12.8
Tailing	23.9	9.2	6.37	4.64	6.51	8.9	6.9	55.1	3.7	6.0	17.2

* calculated

** From Internal Reports MS-AC-62-1234 and 1259.

TABLE 12

Test 6 - Results of Jones Recleaning of Concentrate of Test 5

Product	Weight %		Analysis %**			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	16.3	30.96	30.66	0.27	100.0	100.0	100.0	31.6	69.9	1.3	
Finished conc	71.7	11.7	37.09	36.77	0.09	85.9	85.9	22.7	27.1	60.1	0.3	8.6:1
Recl midds	20.6	3.4	16.29	16.36	0.48	10.8	11.0	36.4	3.4	7.7	0.5	
Tailing	7.7	1.2	13.19	12.24	1.45	3.3	3.1	40.9	1.1	2.1	0.5	

* calculated

** From Internal Report MS-AC-62-1259.

Test 6 - Additional analyses of the finished conc - S, 0.23%
SiO_2, 6.06%

The Jones cleaner concentrate assayed 0.09% P_2O_5, equivalent to 0.039 P. It was decided that the addition of the -35m middling to the -150m grind caused the excess of P_2O_5 in the cleaner concentrate. This middling was excluded in the remaining tests using Flow Sheet A.

Tests 12 to 17 - Wet Flow Sheet A

In this series of tests, the procedure of Wet Flow Sheet A, Figure 1, was used. **The -35m middling was not reground.**

The results are shown in Tables 13 to 18.

TABLE 13

Test 12 - Results of Magnetic Concentration of -35m Ore at 2 Amp

Product	Weight %	Analysis % ⁂			Distn %			R/C
		Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	15.06	7.54	3.52	100.0	100.0	100.0	
Mag conc	12.3	59.60	8.03	0.51	48.8	13.1	1.8	8.1:1
Tailing	87.7	8.80	7.47	3.94	51.2	86.9	98.2	

* calculated

TABLE 14

Test 13 - Results of Reconcentration of Magnetic Concentrate of Test 12 Ground to -150m

Product	Weight %		Analysis % ⁂			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	12.3	57.14	2.96	0.61	100.0	100.0	100.0	48.8	13.1	1.80	
Mag conc	68.8	8.5	69.96	0.60	nd	84.3	14.0	0.0	41.1	1.8	nd	11.8:1
Midds	4.2	0.5	68.13	0.77	0.03	5.0	1.1	0.3	2.5	0.2	0.01	
Tailing	27.0	3.3	22.63	9.33	2.27	10.7	84.9	99.7	5.2	11.1	1.79	

* calculated nd - not determined

⁂ From Internal Report MS-AC-63-163.

Test 13 - Additional analysis of mag conc - S, 0.32%

SiO_2, 0.28%

TABLE 15

Test 14 - Results of Table Concentration of -35m Tailing

Product	Weight %		Analysis % ✱✱			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed✱	100.0	87.7	8.64	7.52	4.04	100.0	100.0	100.0	51.2	86.9	98.2
Table conc	57.4	50.3	12.53	11.75	4.92	83.3	89.7	69.8	42.6	77.9	68.5
Table tailing	42.6	37.4	3.39	1.82	2.87	16.7	10.3	30.2	8.6	9.0	29.7

✱ calculated

TABLE 16

Test 15-Results of Jones Concentration of -35m Table Concentrate

Product	Weight %		Analysis % ✱✱			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed✱	100.0	50.3	12.53	11.75	4.92	100.0	100.0	100.0	42.6	77.9	68.5
Mag conc	44.4	22.3	23.46	23.26	1.14	83.1	87.8	10.3	35.4	68.4	7.1
Midds	35.5	17.9	4.28	3.02	5.56	12.2	9.1	40.2	5.2	7.1	27.5
Tailing	20.1	10.1	2.97	1.77	12.13	4.7	3.1	49.5	2.0	2.4	33.9

✱ calculated

✱✱ From Internal Report MS-AC-63-163.

TABLE 17

Test 16 - Results of Jones Concentration of -35m Concentrate of Test 15, Ground to -150m

Product	Weight %		Analysis % **			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed*	100.0	22.3	23.46	23.26	1.14	100.0	100.0	100.0	35.4	68.4	7.1
Cleaned conc	57.0	12.7	32.48	33.32	0.16	78.9	81.7	7.8	28.0	55.9	0.6
Midds	25.4	5.7	10.16	8.67	1.79	11.0	9.5	39.6	3.9	6.5	2.8
Tailing	17.6	3.9	13.43	11.70	3.42	10.1	8.8	52.6	3.5	6.0	3.7

* calculated

TABLE 18

Test 17 - Results of Jones Recleaning of -150m Concentrate

Product	Weight %		Analysis % **			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	12.7	32.48	33.32	0.16	100.0	100.0	100.0	28.0	55.9	0.6	
Finished conc	80.7	10.3	36.61	37.76	0.065	90.9	91.4	33.0	25.4	51.1	0.2	9.7:1
Midds	13.3	1.7	14.14	13.41	0.16	5.8	5.4	13.3	1.6	3.0	0.1	
Tailing	6.0	0.7	17.72	17.85	1.41	3.3	3.2	53.7	1.0	1.8	0.3	

* calculated

** From Internal Report MS-AC-63-163.

Test 17 - Additional analysis of the finished conc - S, 0.23%
SiO_2, 4.72%

The 2 amp current was too high in the -35m magnetic concentration and pulled too much TiO_2 giving a lower recovery in the table conc and in the final ilmenite conc.

Tests 23 - 28, Wet Flow Sheet A

In this series of tests the procedure of Wet Flow Sheet A was used with the Jeffrey-Steffensen separator operated at 1.5 amp except that the Jones rougher middling (-35m) was rejected. Only the Jones -35m concentrate was ground to -150m and reconcentrated by the Jones separator.

The results of the cobber stage, shown in Table 19, confirmed that 1.5 amp was preferable to 2.0 amp as used in Test 12 and that less ilmenite was lost in the magnetite circuit.

TABLE 19

Results of Magnetic Concentration of -35m Ore at 1.5 amp

Product	Weight %	Analysis % ✡✡			Distn %			R/C
		Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed✡	100.0	14.74	6.90	4.34	100.0	100.0	100.0	
Mag conc	10.5	63.75	1.63	0.14	45.2	2.5	0.3	9.6:1
Tailing	89.5	9.02	7.51	4.83	54.8	97.5	99.7	

✡ calculated

A magnetite concentrate of 70.08% Fe, 0.25% TiO_2 and 0.005% P_2O_5, was produced after regrinding and magnetic cleaning. However, table recovery of TiO_2 was only 68.2% and Jones recovery from the table concentrate was only 59.5%. Final recovery of finished -150m ilmenite represented only 37.4% of the ilmenite in the head sample.

Tests 7 - 11 and 18 - 22, Tests Using Flow Sheet B

In this flow sheet the significant difference from Flow Sheet A was that the Deister table was omitted and the Jones separator produced a -35m ilmenite concentrate directly from the low intensity non-mag tailing.

Two series of tests were made. In Tests 7-11 the Jeffrey-Steffensen separator was operated at 1.5 amp and both Jones -35m middling and concentrate were reground. In Tests 18-22 the Jeffrey-Steffensen separator was operated at 2.0 amp and only the -35m Jones concentrate was reground.

Neither series produced a finished concentrate with P_2O_5 below 0.05% as required.

The results in Table 20 below do not show any significant difference in recovery as the effect of a higher loss of ilmenite at 2 amp in the primary separation was marked by better table operation and the effect of discarding the -35m Jones middling.

TABLE 20

Results of Two Series of Tests Using Flow Sheet B

Product	Tests 7 - 11				Tests 18 - 22			
	Weight %	Assay % TiO_2	Assay % P_2O_5	Recovery TiO_2	Weight	Assay % TiO_2	Assay % P_2O_5	Recovery TiO_2
Feed	100	7.28	3.79	100	100	6.73	3.81	100
Jeffrey-Steffensen								
Mag conc	10.8	1.74	0.31	2.6	12.2	2.60	0.63	4.7
Non-mag tail	89.2	7.95	4.21	97.4	87.8	7.31	4.25	95.3
35m Jones								
Mag conc	27.5	21.52	1.27	83.2	27.0	24.14	1.22	89.4
midd	32.1	2.76	4.40	12.4	33.0	0.88	4.55	4.0
tail	29.6	0.43	6.77	1.8	27.8	0.55	7.14	1.9
-150 Jones								
Mag conc	19.5	28.93	0.35	77.1	14.8	34.64	0.19	70.6
midd	21.8	3.94	3.21	11.7	6.8	11.81	1.84	11.0
tail	18.3	2.73	5.02	6.8	5.4	10.68	3.28	7.8
Jones Recleaning								
Finished conc	13.0	35.96	0.11	63.7	11.0	39.21	0.076	59.5
midd	4.5	17.40	0.53	10.7	2.6	22.08	0.38	7.8
tail	2.0	9.51	1.48	2.7	1.2	19.78	0.87	3.3

Finished magnetite concentrate	Weight recovery - 9.2%	Weight recovery - 8.6%
	Iron recovery - 40.2	Iron recovery - 41.1
	Assay % Fe - 70.44	Assay % Fe - 70.11
	TiO_2 - 0.36	TiO_2 - 0.37
	P_2O_5 - <0.01	P_2O_5 - 0.013

Tests 35 to 39 - Concentration of Ilmenite by the Method of "Dry" Flow Sheet C

A 5000 g sample of -35m ore was cobbed dry on the Ball-Norton separator. The concentrate was ground to -150m and reconcentrated by the Jeffrey-Steffensen separator. The Ball-Norton tailing was concentrated by the Deister table. The table concentrate and middling were dried separately and concentrated by the Stearns high intensity separator. The Stearns concentrates were treated by flotation to remove the apatite.

TABLE 21

Test 35 - Results of Magnetic Concentration by Ball-Norton Separator

Product	Weight %	Analysis % ⁂			Distn %			R/C
		Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	14.96	7.13	3.40	100.0	100.0	100.0	
Mag conc	11.1	63.54	1.66	0.43	47.2	2.6	1.4	9:1
Tailing	88.9	8.89	7.81	3.77	52.8	97.4	98.6	

* calculated

⁂ From Internal Report MS-AC-63-175.

TABLE 22

Test 35a - Results of Magnetic Concentration at -150m by the Jeffrey-Steffensen Separator

Product	Weight %		Analysis % ⁂			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	11.1	61.57	1.89	0.63	100.0	100.0	100.0	47.2	2.6	1.40	
Mag conc	78.9	8.8	69.33	0.40	0.034	88.9	16.7	4.3	41.9	0.4	0.06	11.4:1
Midds	4.4	0.5	66.47	0.84	0.09	4.8	1.9	0.6	2.3	0.1	0.01	
Tailing	16.7	1.8	23.52	9.24	3.58	6.3	81.4	95.1	3.0	2.1	1.33	

* calculated

⁂ From Internal Report MS-AC-63-164.
Additional analyses of the -150m concentrate - S, 0.24 %
SiO_2, 0.25 %

Test 36 - Gravity Concentration of the Ball-Norton Tailing of Test 35 by the Deister Table

The Ball-Norton -35m tailing was concentrated by the Deister Table. A concentrate, a middling and a tailing were produced. The analyses of the table concentrate and middling were calculated from the Stearns products of Test 37.

TABLE 23

Test 36 - Results of Gravity Concentration of Ball-Norton Tailing by the Deister Table

Product	Weight %		Analysis % **			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed*	100.0	88.9	8.89	7.81	3.77	100.0	100.0	100.0	52.8	97.4	98.6
Table conc*	21.1	18.8	28.42	28.24	2.83	67.6	76.5	15.9	35.7	74.5	15.7
" midds*	25.4	22.5	4.84	3.51	5.91	13.8	11.4	39.8	7.3	11.1	39.2
" tailing	53.5	47.6	3.09	1.77	3.12	18.6	12.1	44.3	9.8	11.8	43.7

* calculated

** From Internal Report MS-AC-63-175.

Test 37 - High Intensity Magnetic Concentration of the Table Concentrate and Middling by the Stearns Dry Separator

The table concentrate and middling were dried and concentrated separately by the Stearns separator at 3 amp. The concentrate was re-passed at 0.5 amp. The products of the test were a concentrate at 0.5 amp, tailing 1 at 3 amp, and tailing 2 at 0.5 amp.

After concentrating the middling by the above method, the tailing from 0.5 amp was screened on 48m and the -35+48m and -48m fractions were re-passed at 0.5 amp. The small amount of concentrate from each fraction was added to the original concentrate at 0.5 amp. The tailings were tailing 1, tailing 2, +48m, and tailing 3, -48m.

The concentrate recovered from the table middling contained 30.92% silica and was low in grade due to the locked grains containing various proportions of gangue.

TABLE 24

Test 37 - Results of High Intensity Magnetic Concentration of the Table Concentrate at -35m by the Stearns Separator

Product	Weight %		Analysis % **			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	18.8	28.42	28.24	2.83	100.0	100.0	100.0	35.7	74.5	15.7	
Mag conc	69.7	13.1	38.44	39.32	0.53	94.2	97.0	13.0	33.7	72.3	2.0	7.6:1
Tailing 1	12.5	2.3	3.88	0.17	17.36	1.7	0.1	76.3	0.6	0.1	12.0	
Tailing 2	17.3	3.4	6.47	4.64	1.69	4.1	2.9	10.7	1.4	2.1	1.7	

* calculated

** From Internal Report MS-AC-63-175.

Additional analyses of the conccentrate - S, 0.55 %
SiO_2, 3.03 %

TABLE 25

Results of High Intensity Magnetic Concentration of the Table Middling at -35m by the Stearns Separator

Product	Weight %		Analysis % **			Distn %					
						In test			In orig feed		
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5
Feed*	100.0	22.5	4.84	3.51	5.91	100.0	100.0	100.0	7.3	11.1	39.2
Mag conc	15.8	3.6	16.23	14.13	1.44	53.1	63.6	3.8	3.9	7.1	1.5
Tailing 1	31.7	7.1	0.89	0.19	16.11	5.9	1.8	86.3	0.4	0.2	33.8
Tailing 2 +48m	20.2	4.6	2.99	1.33	0.79	12.5	7.7	2.7	0.9	0.8	1.1
Tailing 3 -48m	32.3	7.2	4.28	2.92	1.32	28.5	26.9	7.2	2.1	3.0	2.8
Combined tailing*	84.2	18.9	2.70	1.52	6.75	46.9	36.4	96.2	3.4	4.0	37.7

* calculated

** From Internal Report MS-AC-63-175.

Additional analyses of concentrate - S, 0.61 %,
SiO_2, 30.92 %.

Test 38 - Flotation of Stearns Concentrate to Remove Apatite

The Stearns concentrate, Table 24, was ground to -150m, and divided into two parts, one part was used in Test 38 and the other in Test 39. The concentrate was conditioned with 0.8 lb/ton of soda ash. The pH of the pulp was 9.4, and its temperature was raised to 89.6°F to facilitate the action of oleic acid. Oleic acid was stage fed 2 drops at a time for 12 additions, equivalent to 1.05 lb/ton of feed. The flotation period was 18 minutes. The rougher apatite concentrate was cleaned twice with 0.2 lb soda ash/ton . The rougher tailing was designated ilmenite concentrate (flotation underflow).

TABLE 26

Results of Flotation of Stearns Concentrate

Product	Weight %		Analysis % **			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed *	100.0	13.1	38.43	38.98	0.57	100.0	100.0	100.0	33.7	72.3	2.0	
Ilmenite conc	49.9	6.5	37.65	38.52	0.05	48.9	49.3	4.4	16.5	35.6	0.1	15.3:1
Apatite "	13.1	1.7	37.15	37.24	3.69	12.7	12.6	85.4	4.3	9.1	1.7	
" cleaner tails 1	30.4	4.0	39.94	40.28	0.13	31.6	31.4	7.0	10.6	22.7	0.1	
Apatite cleaner tails 2	6.6	0.9	39.89	39.92	0.28	6.8	6.7	3.2	2.3	4.9	0.1	
Rougher conc *	50.1	6.6	39.21	39.44	1.08	51.1	50.7	95.6	17.2	36.7	1.9	15.2:1

* calculated

** From Internal Reports MS-AC-62-1385, and MS-AC-63-175.

Additional analyses of the ilmenite conc - S, 0.51 %
SiO_2, 4.79 %

Test 39 - Flotation of Stearns Concentrate to Remove Apatite

The sample of Stearns concentrate, ground in Test 38 above, was conditioned with several additions of soda ash representing 2.4 lb/ton to obtain a pH of 8.4. Oleic acid was staged 1 drop at a time for 6 drops, totalling 0.53 lb/ton feed. The total flotation time was 25 minutes. The final pH was 8.1. The apatite rougher concentrate was cleaned once with 0.02 lb/ton oleic acid.

TABLE 27

Results of Flotation of Apatite from Stearns Concentrate

Product	Weight %		Analysis %**		Distn %				R/C
	In test	In orig feed	TiO_2	P_2O_5	In test		In orig feed		
					TiO_2	P_2O_5	TiO_2	P_2O_5	
Feed*	100.0	13.1	39.75	0.48	100.0	100.0	72.3	2.0	
Ilmenite conc	76.7	10.0	40.32	0.06	77.7	9.5	56.2	0.2	10:1
Apatite conc	7.3	1.0	35.27	4.72	6.5	71.8	4.7	1.5	
" cleaner tail	16.0	2.1	39.10	0.56	15.8	18.7	11.4	0.3	
Rougher Ap conc	23.3	3.1	37.91	1.87	22.3	90.5	16.1	1.8	33:1

* calculated

** From Internal Report MS-AC-63-204.

Additional analyses of the ilmenite conc - SiO_2, 3.24 %.

A considerable amount of ilmenite floated with apatite in the rougher concentrates in both Tests 38 and 39.

Tests 40 and 41 - Flotation of Apatite from 35m Concentrate

The method of Flow Sheet C was used to prepare a stock of -35m ilmenite concentrate for further flotation tests to compare various reagent combinations.

The product was a Stearns high intensity magnetic concentrate obtained from Deister table concentrate after an initial separation of magnetite from ilmenite on the Ball-Norton low intensity dry separator. Its analysis was: TiO_2, 40.84%; P_2O_5, 0.25 %. However, it represented only 43.5% of the ilmenite in the head sample and, therefore, was of higher grade and was probably easier to float than the normal concentrate from this flow sheet. The Stearns concentrate was 9.52% of the original feed weight.

The Stearns concentrate was ground to -150m and split into two parts. Each part was conditioned with soda ash, 1.5 lb/ton, at pH 9.3. Oleic acid

was staged with pine oil. In the first test, concentrate was skimmed for 15 min. The concentrate was repulped and reconcentrated with additional reagents for 15 min. In the second test, concentrate was floated for 30 min.

TABLE 28

Results of Apatite Flotation from Stearns Concentrate

Product	Weight %		Analysis % ★		Distn %			
	In test	In orig feed	TiO_2	P_2O_5	In test		In orig feed	
					TiO_2	P_2O_5	TiO_2	P_2O_5
Feed	100.0	9.52	40.84	0.25	100.0	100.0	43.5	0.39
15 min conc	88.5	8.43	40.16	0.09	87.1	31.9	37.9	0.12
Refloated 15 min conc	89.5	7.54	40.20	0.06	89.5	59.2	33.9	0.07
30 min conc	90.2	8.59	40.25	0.07	88.9	25.2	38.7	0.10

★ From Internal Report MS-AC-63-204.

Additional analyses of concentrates -

15 min concentrate - S, 0.42 %; SiO_2, 1.02 %
30 " " - S, 0.42 %; SiO_2, 1.06 %

Reagents consumed	Soda Ash lb/ton	Oleic Acid lb/ton	Pine Oil lb/ton
15 min test	1.50	0.46	0.10
Refloat	0.96	0.31	"
30 min test	1.46	0.39	"

Test 42 - Pilot Mill Test on Ore of Shipment 3

A pilot mill test was made on one half of Shipment 3 to obtain a supply of feed for apatite flotation tests. The sample was ground to -35m in a ball mill. The product was cobbed by a 2-drum Dings low intensity wet magnetic separator at a feed rate of 1020 lb/hr. The Dings tailing was dewatered and fed to a quarter-size Wilfley table at the rate of 480 lb/hr to produce a table concentrate and a tailing. The middling was returned to the head of the table.

The weight distribution was calculated from the analysis in Tables 29 and 30.

Note: The pilot plant screen used was a nominally 30m Sweco screen with opening equivalent to 35m CGS standard screen series. The product of this screen is designated as -35m in this and following tests.

Pilot Mill Test, Mill Run 1

TABLE 29

Results of Magnetic Cobbing by Dings Separator at -35m

Product	Weight %	Analysis % **			Distn %			R/C
		Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed	100.0	14.93	7.05	3.89	100.0	100.0	100.0	
Mag conc	10.7	62.97	1.67	0.33	45.2	2.6	0.9	9.3:1
Tailing	89.3	9.16	7.70	4.32	54.8	97.4	99.1	

TABLE 30

Results of Wilfley Table Concentration of Cobber Tailing

Product	Weight %		Analysis % **			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	89.3	9.13	7.70	4.52	100.0	100.0	100.0	54.8	97.4	99.1	
Table conc	15.2	13.6	36.35	34.91	1.43	60.6	69.0	4.8	33.2	67.2	4.7	7.4:1
" tailing	84.8	75.7	4.24	2.82	5.08	39.4	31.0	95.2	21.6	30.2	94.4	

* calculated

** From Internal Reports MS-AC-63-248 and 255.
Additional analyses of concentrate - S, 1.19 %
SiO_2, 4.76 %

Tests 43-46 - Reconcentration of Wilfley Table Ilmenite Concentrate

The table concentrate was treated by several methods to produce a finished ilmenite concentrate:

1. Reconcentration at 35m by high intensity Jones magnetic separator followed by regrinding to -150m and cleaning on the Jones separator (Test 43).
2. Reconcentration at 35m by Jones separator followed by regrinding to -150m and flotation (Test 44).

3. Regrinding of table concentrate to -150m followed by flotation (Test 45).

4. Regrinding of table concentrate to -150m and two stages of Jones separation (Test 46).

Test 43 - High Intensity Magnetic Concentration of Table Concentrate

A sample of -35m Wilfley table concentrate was concentrated by the Jones high intensity separator at 7 amp. The concentrate was ground to -150m and repassed on the Jones separator. The -150m rougher concentrate was repassed on the Jones separator.

TABLE 31

Results of Jones Concentration at -35m

Feed -35m Table Concentrate

Product	Weight %		Analysis % ✱✱			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed ✱	100.0	13.6	36.40	33.84	1.55	100.0	100.0	100.0	33.2	67.2	4.7	
Jones conc -35m	78.1	10.6	38.32	36.88	0.38 ✱	82.2	85.1	21.9	27.3	57.1	0.9	9.4:1
Jones midd	19.5	2.7	31.90	25.78	3.39	17.1	14.8	41.1	5.7	10.0	2.0	
" tailing	2.4	0.3	10.94	0.97	24.44	0.7	0.1	37.0	0.2	0.1	1.8	

✱ calculated

✱✱ From Internal Report MS-AC-63-255.

TABLE 32

Results of Jones Concentration at -150m

Feed -35m Concentrate Ground -150m

Product	Weight %		Analysis % **			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed*	100.0	10.6	38.83	35.68	0.38	100.0	100.0	100.0	27.3	57.1	0.9	
Rougher conc -150m *	73.7	7.8	39.95	37.96	0.06	75.8	78.4	11.1	20.7	44.8	0.1	12.8:1
Rougher midds	17.0	1.8	36.18	28.40	1.03	15.7	13.4	45.3	4.3	7.7	0.4	
" tailing	9.3	1.0	34.88	30.86	1.77	8.5	8.2	43.6	2.3	4.6	0.4	

Feed -150m Rougher Concentrate

Feed*	100.0	7.8	39.95	37.96	0.06	100.0	100.0	100.0	20.7	44.8	0.11	
Cleaner conc	82.8	6.5	40.46	38.38	0.05	83.9	83.7	71.1	17.4	37.5	0.08	15.5:1
" midds	13.0	1.0	37.86	36.40	0.07	12.4	12.5	15.6	2.6	5.6	0.02	
" tailing	4.2	0.3	36.24	34.68	0.20	3.7	3.8	13.3	0.7	1.7	0.01	

* calculated

** From Internal Report MS-AC-63-295.

Additional analyses of the cleaner concentrate - S, 0.24 %

SiO_2, 1.14 %

Test 44

This test was made to compare flotation of apatite at -150m with the Jones separation finishing at -150m in Test 43. Feed to flotation was the -35m Jones concentrate (Test 43) reground to -150m.

The pulp was conditioned with soda ash, 1.2 lb/ton, at pH 9.2 and oleic acid was staged, 0.7 lb/ton. Flotation time was 15 min and the concentrate was cleaned once without reagents.

TABLE 33

Results of Flotation of Apatite from -35m Jones Concentrate Ground to -150m

Product	Weight %		Analysis % ✡✡			Distn %						R/C
						In test			In orig feed			
	In test	In orig feed	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	Fe	TiO_2	P_2O_5	
Feed✡	100.0	10.6	38.42	37.58	0.23	100.0	100.0	100.0	27.3	57.2	3.5	
Ilmenite conc	79.4	8.4	38.40	37.84	0.04	79.4	80.0	14.2	21.7	45.7	0.5	11.9:1
Apatite "	5.2	0.6	36.25	34.91	2.76	4.9	4.8	63.3	1.3	2.8	2.2	
Cleaner tailing	15.4	1.6	39.33	37.14	0.33	15.7	15.2	22.5	4.3	8.7	0.8	

✡ calculated

✡✡ From Internal Report MS-AC-63-295.

Additional analyses of ilmenite concentrate - S, 0.58%
SiO_2, 3.34%

The P_2O_5 was reduced to 0.04% in the ilmenite concentrate by combined use of a Jones separator followed by flotation of apatite.

Test 45 - Flotation of Apatite from Table Concentrate

A sample of -35m table concentrate was ground to -150m for flotation feed. This sample had not been concentrated by the Jones separator. The ground concentrate was conditioned in a flotation machine with 1.2 lb of soda ash/ton, pH 9.2. Oleic acid was staged at the rate of 0.7 lb/ton.

A concentrate was skimmed for 15 minutes and cleaned once without reagents. The products of the test were a flotation concentrate, designated apatite concentrate, a cleaner tailing from cleaning the apatite rougher concentrate, and a flotation underflow, designated ilmenite concentrate.

TABLE 34

Results of Flotation of Apatite from -35m Table Concentrate Ground to -150m

Product	Weight %		Analysis % **		Distn %				R/C
					In test		In orig feed		
	In test	In orig feed	TiO_2	P_2O_5	TiO_2	P_2O_5	TiO_2	P_2O_5	
Feed*	100.0	13.6	36.80	0.65	100.0	100.0	67.2	4.7	
Ilmenite conc	83.5	11.3	37.76	0.12	85.7	15.5	57.6	0.7	8.8:1
Apatite conc	9.4	1.3	29.05	5.48	7.4	79.8	5.0	3.8	
Cleaner tailing	7.1	1.0	35.80	0.44	6.9	4.7	4.6	0.2	

* calculated

Additional analyses of ilmenite concentrate - S, 1.10%
SiO_2, 4.52%

Test 46 - Concentration of Table Concentrate by the Jones Separator at -150m

A sample of -35m table concentrate was ground to -150m and concentrated by the Jones separator at 7 amp. The Jones rougher concentrate was repassed on the Jones separator at 7 amp.

TABLE 35

Results of Jones Concentration of -35m Table Concentrate Ground to -150m

Product	Weight %		Analysis %**		Distn %				R/C
					In test		In orig feed		
	In test	In orig feed	TiO_2	P_2O_5	TiO_2	P_2O_5	TiO_2	P_2O_5	
Feed*	100.0	13.6	36.53	1.13	100.0	100.0	67.2	4.7	
Rougher conc*	72.8	9.9	39.58	0.20	78.9	12.6	53.0	0.6	10:1
" midds	16.8	2.3	30.04	2.51	13.8	37.3	9.3	1.7	
" tailing	10.4	1.4	25.68	5.44	7.3	50.1	4.9	2.4	

* calculated

** From Internal Report MS-AC-63-295.

TABLE 36

Results of Jones Cleaner Concentration

Product	Weight %		Analysis %**		Distn %				R/C
					In test		In orig feed		
	In test	In orig feed	TiO_2	P_2O_5	TiO_2	P_2O_5	TiO_2	P_2O_5	
Feed*	100.0	9.9	39.58	0.20	100.0	100.0	53.0	0.6	
Cleaner conc	82.3	8.1	40.54	0.07	84.3	29.5	44.7	0.2	12.3:1
" midds	13.7	1.4	35.36	0.67	12.2	46.6	6.5	0.3	
" tailing	4.0	0.4	34.22	1.16	3.5	23.9	1.8	0.1	

* calculated

** From Internal Report MS-AC-63-295.

Additional analyses of cleaner concentrate - Fe, 40.76 %
S, 0.24 %
SiO_2, 1.48 %

Test 47 - Additional Flotation Tests

In several tests the feed was Wilfley table concentrate from Test 42 (Table 30) ground to -150m as in Test 45. In other tests, the table concentrate was further concentrated by the Jones separator before regrinding as in Test 44. Aerofloat Reagent 710 was used as collector in one test and a 1:1 mixture of tall oil and fuel oil, by volume, was used in another. Under the conditions of the tests, these reagents were ineffective in lowering the apatite content of the ilmenite concentrate. Fairly uniform results were obtained with the oleic acid used in the rest of the tests. Only the ilmenite concentrates were analysed. Results are shown in Table 37.

TABLE 37

Results of Flotation of Apatite from Ilmenite Concentrate Ground to -150m

R. Concentrate source	Collector lb/ton	pH by Soda Ash add'n	Weight Recovery % orig feed	Concentrate Analysis % **	
				P_2O_5	S
-35m Jones conc	Oleic 0.66	8.2	8.3	0.07	-
	Oleic 0.43	8.3	9.1	0.06	0.093
	Oleic 0.54	9.7	9.8	0.061	0.097
-35m Wilfley Table conc	Oleic 1.08	9.3	8.3	.059	0.099
	Oleic 0.80	9.4	9.0	0.065	0.097
	Oleic 0.58	9.5	10.7	0.11	-
	Reagent 710 1.70	9.6	11.3	0.30	-
	Tall Oil + Fuel Oil 0.80	9.8	11.3	0.28	-
	Oleic 0.57	9.5	9.5	0.076	0.19

** From Internal Reports MS-AC-63-414 and 537.

CONCLUSIONS

The results of the investigation show that the required grade of magnetite concentrate can be made at -150m after cobbing at 35m.

The ilmenite can be recovered from the non-magnetic tailing by methods using gravity concentration or high intensity magnetic concentration followed by grinding to -150 mesh and reconcentrating. Either high intensity magnetic concentration of ilmenite or flotation of apatite from ilmenite concentrate could be used to obtain an acceptable grade of ilmenite.

The tests showed that the middling fraction from concentrating the cobber tailings by table and Jones separator should not be combined with -35m concentrate as it appeared to increase the amount of apatite in the ilmenite cleaner concentrates which could not be rejected by two passes on the Jones separator.

In bench tests to float apatite from the ilmenite concentrates, a considerable amount of ilmenite floated with the apatite. In several tests the apatite concentrate was cleaned without reagents to recover the ilmenite.

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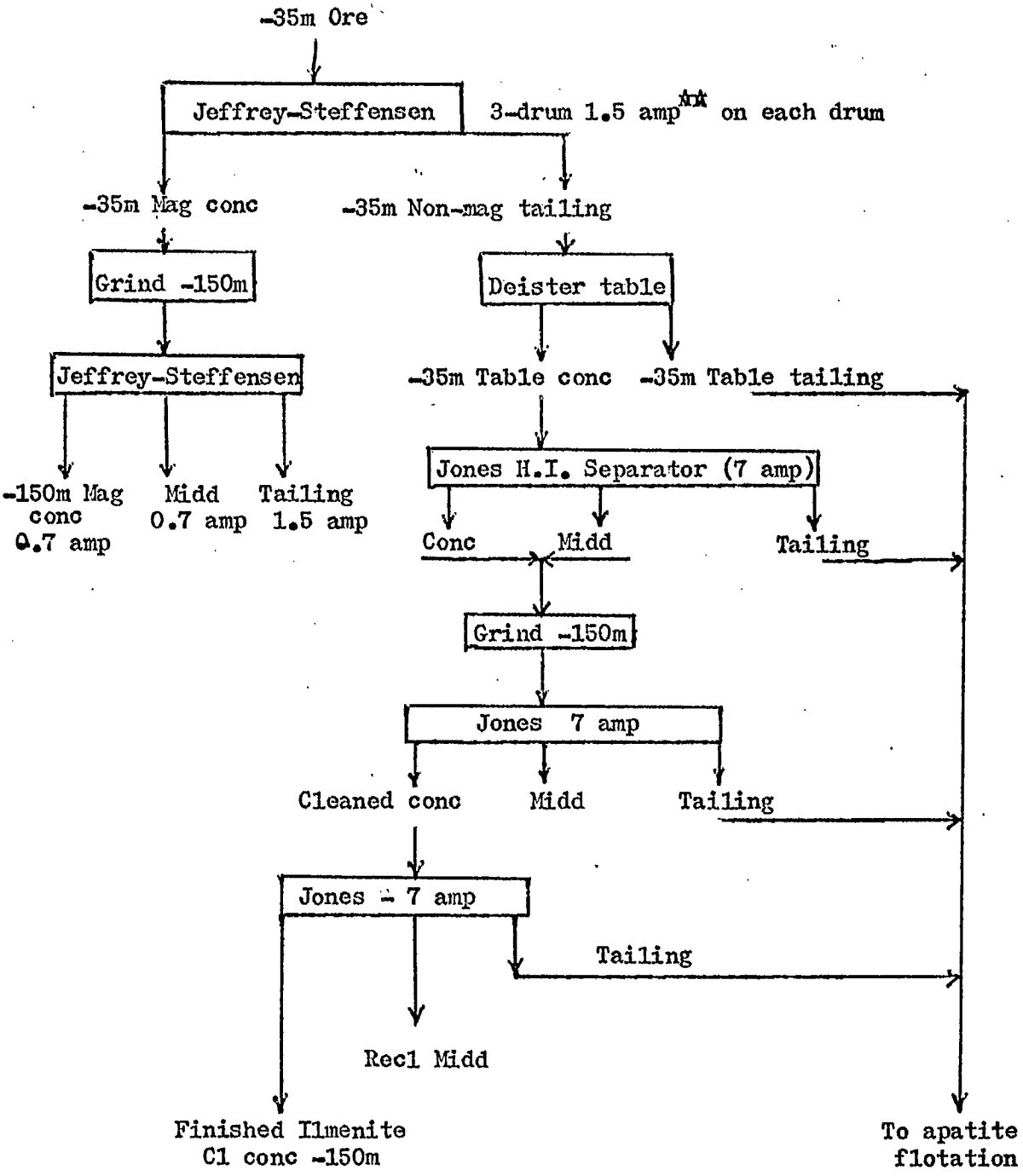
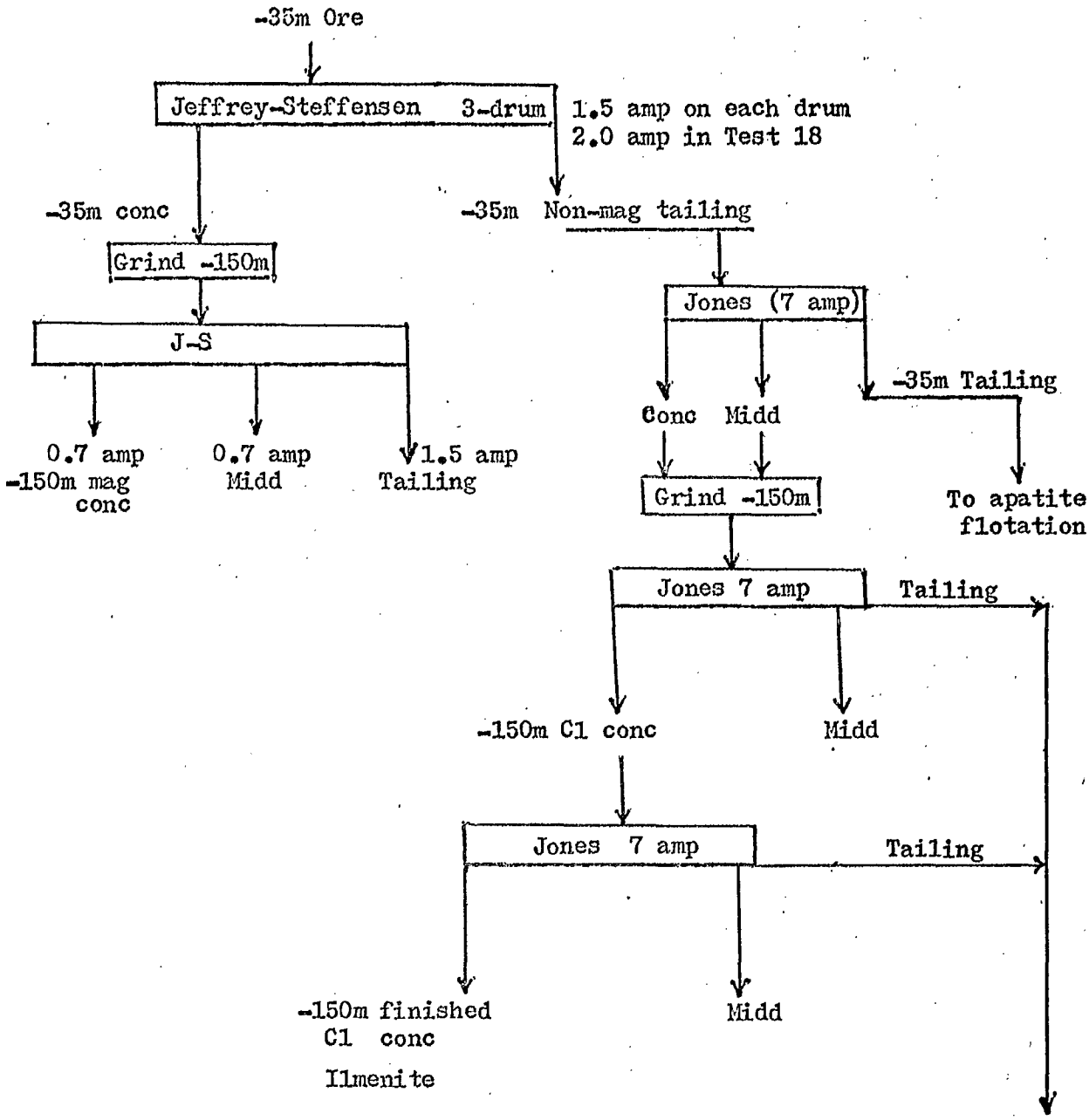
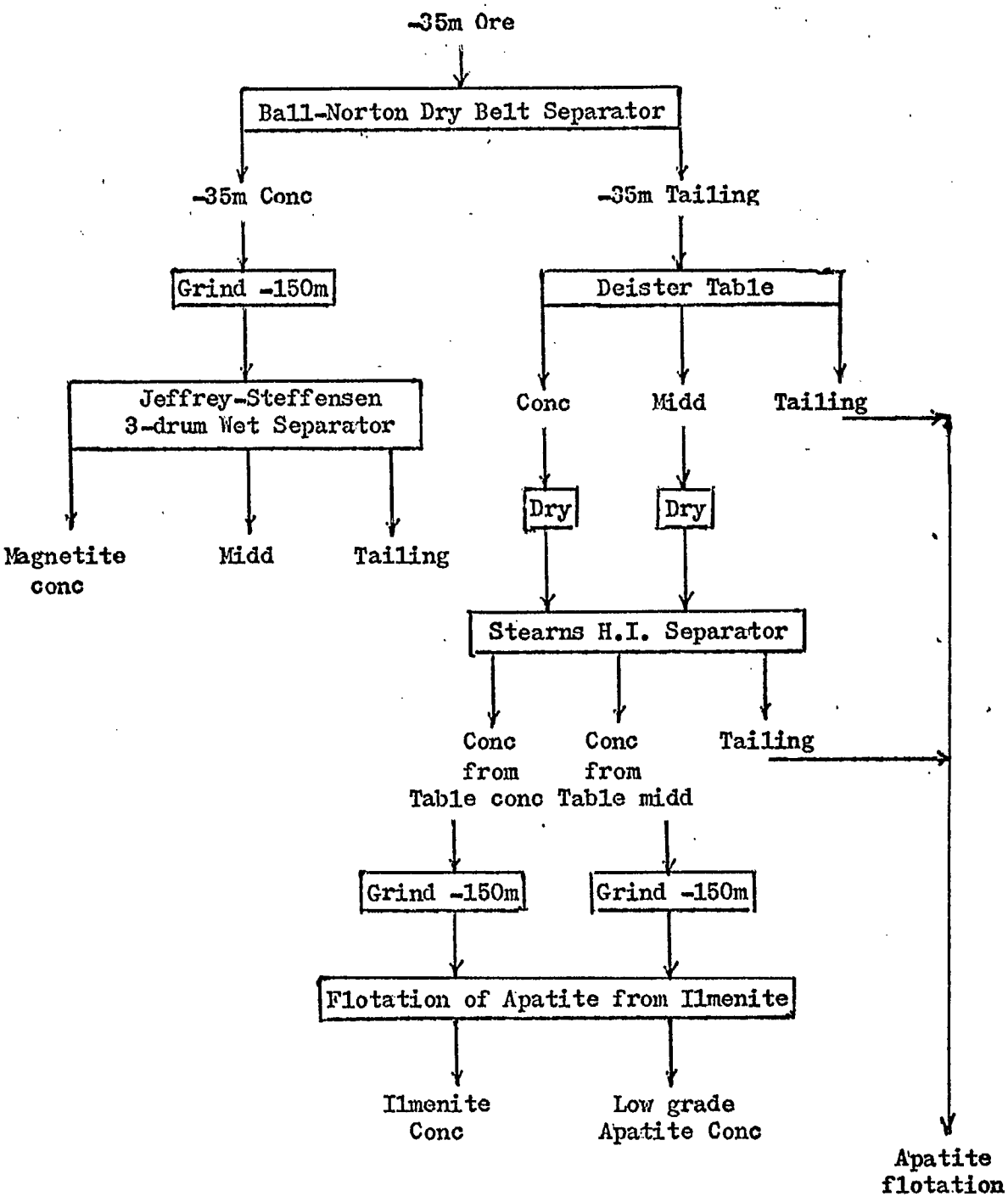
WSJ:EBM



Appendix 1 - Wet Flow Sheet A



Appendix 2 - Wet Flow Sheet B



Appendix 3 - Flow Sheet C