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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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MINES BRANCH INVESTIGATION REPORT IR 74-19

AN INVESTIGATION TO DETERMINE CAUSES FOR THE VARIATION IN THE FLOTATION BEHAVIOUR OF IRON ORE FROM SCHEFFERVILLE, QUEBEC

by

I. B. KLYMOWSKY

MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

Differences were found in the amount of middling particles and in the surface characteristics of the quartz particles in the samples investigated. The samples that responded poorly to flotation contained more middling particles, and two varieties of quartz particles: one, with smooth surfaces, that floated readily; and another, with very rough surfaces, that did not float. The latter variety was not found in the samples that responded well to flotation.

Differences were also found in the texture of the samples. The samples that responded poorly to flotation were oolitic in texture, whereas the samples that responded well to flotation were more granular.

A good correlation was found between magnetic separation and flotation which facilitated evaluation of the ore samples.

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Direction des mines, rapport de recherche IR 74-19

ETUDE QUI A POUR BUT DE DETERMINER LES CAUSES DE VARIATION DANS LA FLOTTATION DU MINERAI DE FER DE SCHEFFERVILLE, QUEBEC

par

I.B. Klymowsky*

RESUME DES RESULTATS

Des différences ont été constatées dans la quantité de particules mixtes et dans les particularités de la surface des particules de quartz des échantillons étudiés. Les échantillons qui ne donnaient pas de bons résultats en ce qui concerne la flottation contenaient d'avantage de particules mixtes et deux variétés de particules de quartz: les surfaces des particules de la première sont douces et celles-ci flottent facilement; dans l'autre variété les surfaces sont très rudes et les particules ne flottent pas. On n'a pas trouvé de particules de cette variété dans les échantillons qui réagissaient bien à la flottation.

On a aussi trouvé des différences de textures des échantillons. Les échantillons qui flottent mal sont de texture oolithique, tandis que ceux qui flottent bien sont de structure plus granulaire.

On a constaté une bonne corrélation entre la séparation magnétique et la flottation, ce qui a facilité l'évaluation des échantillons de minerai.

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INTRODUCTION

For over 18 years, the Iron Ore Company of Canada has been mining and shipping iron ores directly from Knob Lake with an overall silica content of 7 to 8 per cent. To meet shipping grade requirements, leaner ores were left behind or stockpiled. Tests indicated that lean blue ores, which represented approximately 2/3 of the total lean ore reserves, could be concentrated quite easily by flotation, and that the more refractory lean yellow and red ores could be treated by blending with the blue ores[1]. In 1971, after extensive testing, construction began on a beneficiation plant in Sept Iles to treat the lean ores.

In the meantime, the lean ore reserves, which had included ores containing up to 20 per cent silica, were extended to include blue ores containing up to 30 per cent silica (so called "treat-rock") because tests showed that this lower grade material could be concentrated as easily as some of the higher grade material. Although most of the samples of "treat-rock", tested at that time, responded well to flotation, some later samples did not, and reasons for the variation in the flotation behaviour of these samples were not clear.

Purpose of Investigation

The Mines Branch was asked to find causes for the variation in the flotation behaviour of the different ore samples.

Ore Shipments

On September 30, 1971, three samples of low-grade blue ore ("treat-rock") were received at the Mines Branch, Ottawa, from Mr. S. H. Ng, Research Engineer, Technical Services Division, Iron Ore Company of Canada, Schefferville, Quebec. Each sample weighed approximately 20 lb, and consisted of material minus 1/2-inch in size. Sample 603-M-1079 was said to be representative of samples that responded well to flotation, and samples 603-194 and 603-199 representative of samples that did not respond well to flotation.

On November 9, 1972, fifteen different samples, representing a wide variety of ores from "treat-rock" to "direct-shipping" ore, were received for testing, and on January 25, 1973, two samples of low-grade iron ore from the Wishart Mine were received for testing.

Analysis

With the exception of samples 603-M-1496, 1500, 1501, 1502 and the Wishart Mine samples, the analyses of the ore samples given in Table 1 were provided by the Iron Ore Company of Canada.

OUTLINE OF INVESTIGATION

A detailed investigation was done on samples 603-M-1079, 603-194, and 603-199 which included:

(1) mineralogical examination of the samples,

(2) flotation tests,

(3) screen analyses of the feed and products,

(4) heavy-liquid tests to determine whether there were any significant differences in liberation,

(5) measurement of the electrokinetic surface potential of the quartz in the different ore samples,

(6) examination of the quartz surfaces using an electron microscope,

(7) measurement of surface areas,

TABLE 1

Analysis and Description of Ore Samples

Sample No.	Ore Type	Rock Type	Wt (lb)	Analysis,% Fe	P	Mn	SiO_2	Al_2O_3	Loss on Ignition
603-M-1079	TRX	PGC+URC	19	49.5	0.02	0.07	27.7	0.2	1.2
603-194	TRX	LRC	20	44.7		1.19	31.4	0.8	1.29
603-199	TRX	LRC	20	45.4		1.30	31.9	1.1	0.68
	(Direct-Ship)								
603-M-1469	Blue Ore	LIF	8½	63.5	0.04	0.19	6.8	0.8	1.8
603-M-1470	TRX	RUIF	8	54.1	0.05	0.06	18.6	3.0	1.76
603-M-1471	Yellow Ore	SCIF	6	56.0	0.26	0.76	6.2	1.2	11.2
603-M-1472	Yellow Ore	SCIF	7	45.2	0.05	0.62	25.7	1.8	6.8
603-M-1473	Blue Ore	-	8½	58.9	0.08	0.14	6.0	6.1	2.8
603-M-1474	Yellow Ore	SCIF	4½	49.0	0.08	0.14	24.5	1.0	4.0
603-M-1475	Yellow Ore	SCIF	5	60.3	0.12	0.27	3.6	1.2	8.9
603-M-1478	Red Ore	LIF	11	59.1	0.04	0.15	11.6	1.2	3.0
603-M-1484	TRX	LRC	6	56.0	0.02	0.59	15.6	0.4	1.69
603-M-1485	TRX	PGC+URC	8	48.3	0.04	0.03	26.2	0.2	2.85
603-M-1496	Yellow Ore	-	6	54.3			7.7		
603-M-1500	TRX	LRC	10	49.2			18.5		
603-M-1501	TRX	LRC	11	55.4			18.7		
603-M-1502	TRX	LIF	9	49.6			26.8		
603-M-1503	TRX	LIF	5	51.6	0.02	0.05	24.5	0.3	0.19
Wishart Mine									
Trenching Sample			21	37.4			43.9		
Stockpile Drill Sample			17	51.1			25.0		

TRX Treat - Rock
PGC Pink - Grey Cherty
URC Upper Red Cherty
LRC Lower Red Cherty
LIF Lower Iron Formation
RUIF Red Upper Iron Formation
SCIF Silicate - Carbonate Iron Formation

(8) magnetic separation tests using a Jones high-intensity magnetic separator.

On the remaining samples, the investigation was limited to establishing a correlation between high-intensity magnetic separation and flotation.

DETAILS OF INVESTIGATION

Mineralogical Description of Samples 603-M-1079, 603-194 and 603-199*

The principal iron minerals in the samples were hematite, goethite, and magnetite. They occurred in different proportions in each sample, reflecting differences in alteration.

Goethite was most abundant in sample 603-M-1079, where it appears to have been formed as a result of extensive alteration of the iron and silicate minerals in the ore. The magnetite in this sample occurred only as remnants in the goethite, and much of the hematite was altered to goethite. Alteration of the hematite was most pronounced in areas surrounding quartz inclusions, and in areas where quartz and hematite were in contact. Very little quartz could be found intergrown with hematite. The hematite in this sample showed a strong euhedral mineral habit which resulted in well segregated silica and iron-oxide grains.

In samples 603-194 and 603-199, there was very little alteration of the hematite to goethite, and there was more magnetite. Some of the hematite was altered to martite and there was some evidence of martitization of the magnetite, but in general, the hematite maintained its original, very fine-grained texture.

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* Based on Internal Report MS-73-27, by R. G. Pinard.

The quartz in sample 603-M-1079 appears to have been completely recrystallized. It occurred as discreet, equiangular grains that were fairly uniform in size and relatively free of iron oxide inclusions, with goethite filling interstices between most of the quartz grains. In samples 603-194 and 603-199, the quartz was found concentrated in oolitic-like nodules that were rimmed with hematite, and contained numerous hematite inclusions. Some of the quartz in the centre of these nodules appears to have been recrystallized to a coarser grain size, but the remainder was extremely fine-grained, and intimately intergrown with hematite. The only evidence found of alteration of the hematite to goethite was in these extremely fine-grained areas.

Figures 1 to 4 show the differences in texture between samples 603-M-1079 and 603-194. (Sample 603-199 was very similar to sample 603-194).

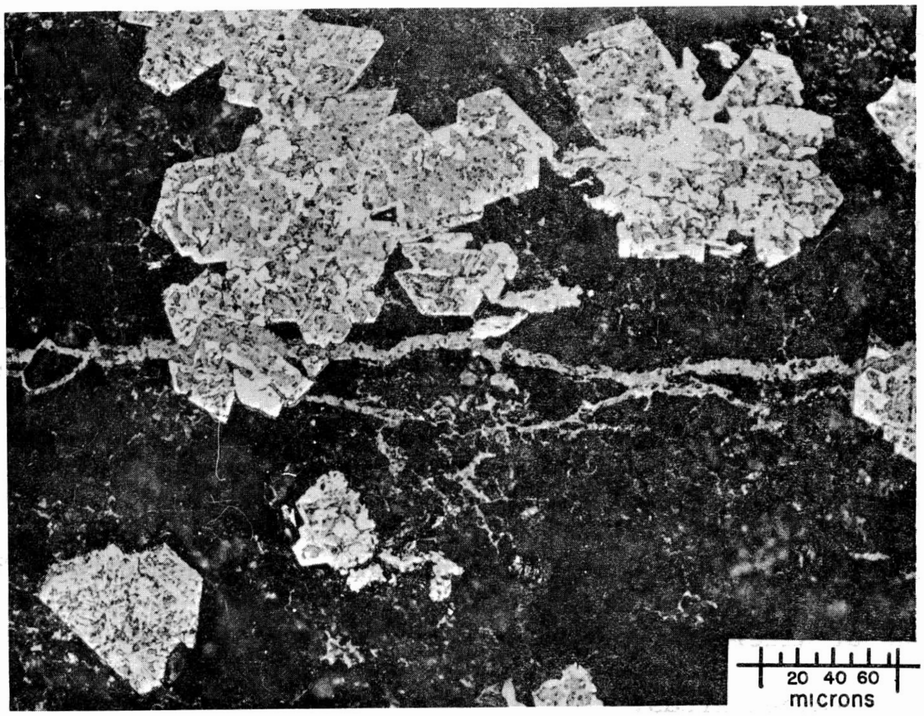


Figure 1. Photomicrograph of sample 603-M-1079 showing goethite (light grey) replacing hematite (white) in a quartz matrix (black). The veinlet cutting across the section is goethite.

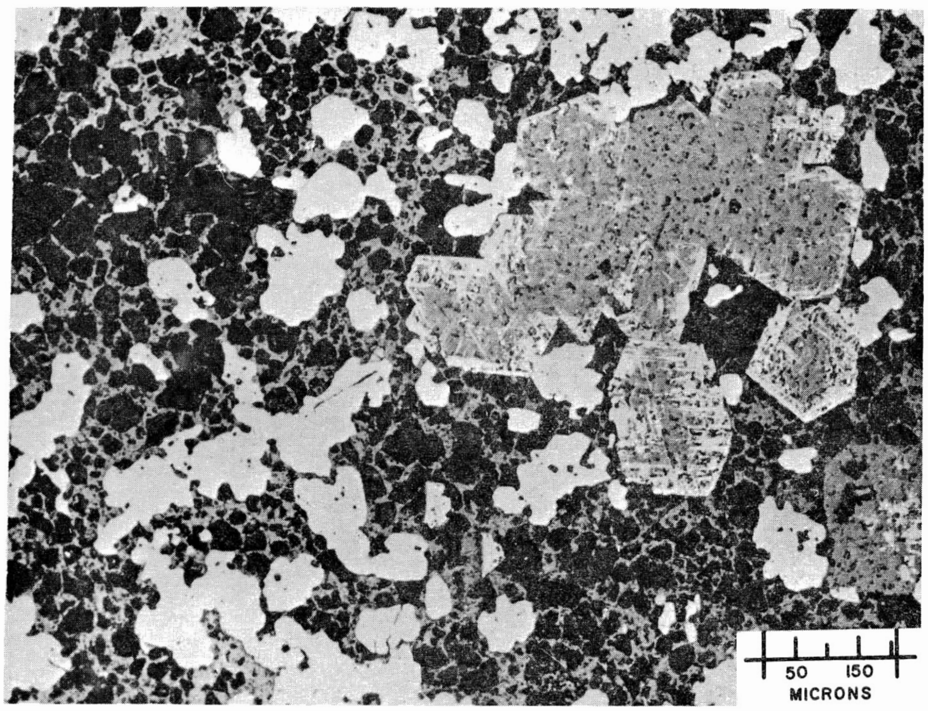


Figure 2. Photomicrograph of sample 603-M-1079 showing goethite (grey) replacing hematite (white) and as interstitial filling between the quartz grains (black). The white grains are hematite.

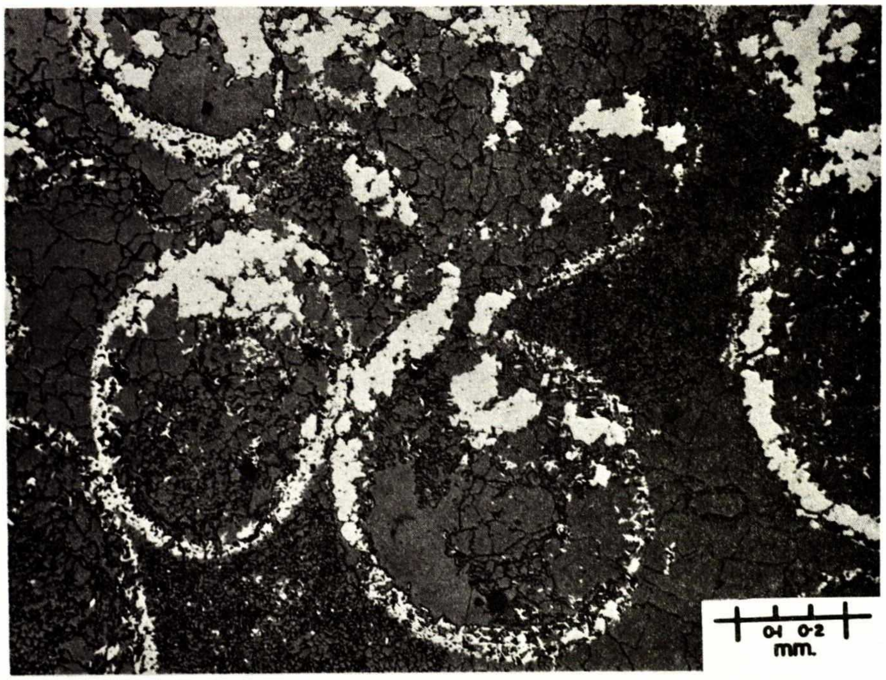


Figure 3. Photomicrograph of sample 603-194 showing hematite (white) outlining the quartz nodules. The fine-grained areas are a mixture of quartz, goethite, and hematite.

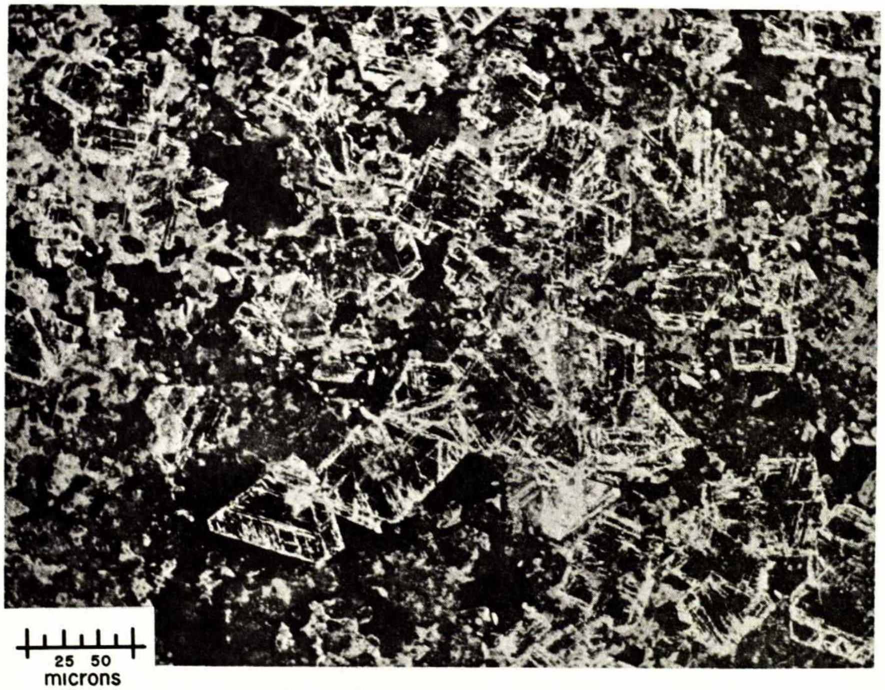


Figure 4. Photomicrograph of the fine-grained areas in sample 603-194 showing hematite (white) outlining quartz grains (black) with patches of goethite (light grey).

Flotation Tests

The samples were crushed to minus 10 mesh and subdivided into smaller 2000-gram lots. The 2000-gram samples were screened on a 100-mesh screen, and the screen oversize was stage-ground to minus 100 mesh, and recombined with the minus 100-mesh material from screening. The samples were then subdivided into 800-gram lots for flotation.

The Iron Ore Company had adopted a standard flotation test procedure in testing all their samples. In order to obtain results similar to those achieved by the Iron Ore Company, this procedure was modified at the Mines Branch by using slightly higher quantities of collector. Full details of the procedure are given in Table 2.

The results obtained at the Mines Branch on samples 603-M-1079, 603-194, and 603-199 are given in Table 3.

TABLE 2

Details of the Standard Flotation Test Procedure

Operation	Time (min)	% Solids	pH	Unit Used	Reagents, lb per short ton			
					NaOH	WW82	MG-83	A-65
Stage Grinding		Dry		8 x 8-in Ball Mill				
Conditioning	2	25	9.0	500-gram Fagergren Cell	0.375			
"	2½		10.0		0.75	0.9		
"	½						0.4	0.125
Rougher Flotation	2			"				
Conditioning	½		9.5	"			0.2	
Scavenger Flotation	2			"				
Conditioning Rougher Froth Product	½		9.5	250-gram Denver Cell		0.2		
Cleaner Flotation	2							

TABLE 3

Flotation Test Results

Sample 603-M-1079

Product	Wt %	Analysis, %		Distribution, %	
		Fe	SiO_2	Fe	SiO_2
Iron Concentrate	53.3	62.84	5.46	69.8	10.2
Scavenger Float	7.4	51.69	37.56	8.0	9.8
Cleaner Underflow	11.6	59.67	9.12	14.4	3.7
SiO_2 Cleaner Float	27.7	13.57	78.54	7.8	76.3
Feed*	100.0	48.00	28.51	100.0	100.0

Sample 603-194

Product	Wt %	Analysis, %		Distribution, %	
		Fe	SiO_2	Fe	SiO_2
Iron Concentrate	60.0	56.07	15.92	74.9	29.8
Scavenger Float	6.6	29.94	54.06	4.4	11.1
Cleaner Underflow	14.6	43.45	32.92	14.1	15.0
SiO_2 Cleaner Float	18.8	15.72	75.20	6.6	44.1
Feed*	100.0	44.92	32.70	100.0	100.0

Sample 603-199

Product	Wt %	Analysis, %		Distribution, %	
		Fe	SiO_2	Fe	SiO_2
Iron Concentrate	52.9	58.98	11.82	69.1	20.0
Scavenger Float	7.6	41.20	36.24	6.9	8.8
Cleaner Underflow	8.2	54.27	16.02	9.8	4.2
SiO_2 Cleaner Float	31.3	20.44	66.88	14.2	67.0
Feed*	100.0	45.18	31.25	100.0	100.0

* Calculated.

Screen Analysis of Samples 603-M-1079, 603-194, and 603-199

Screen analyses of the flotation feed and iron concentrates are given in Tables 4 and 5 of the Appendix. The size distributions are shown in Figure 5. There were no significant differences in the size distributions of the feed, however, there were differences in the size distributions of the concentrates. The concentrates of samples 603-194 and 603-199 were coarser than the concentrate of sample 603-M-1079. The iron distributions of the concentrates were similar; however the silica distributions differed in that more silica was found in the coarse size-fractions of the coarse concentrates, 603-194 and 603-199, than in the fine concentrate, 603-M-1079. This indicated that there may be differences in liberation between the samples.

Heavy - Liquid Tests

Heavy - liquid tests were done on the -100+500 mesh size fractions of the flotation feed and iron concentrates, and the results are given in Tables 6 and 7 of the Appendix. The separations were made at a specific gravity of 2.96 using tetrabromoethane, and polished sections were made of each of the products for mineralogical examination. The float products consisted essentially of free quartz particles; the sink products consisted of a mixture of free iron oxide particles and quartz-hematite middling particles. There were very few quartz - goethite middling particles in these samples. Polished sections of some of the sink and float products are shown in Figures 6 to 11.

The quartz shown in Figure 6 (sample 603-M-1079) was relatively free of hematite inclusions; there were more inclusions in the quartz shown in Figures 8 and 10 (samples 603-194 and 603-199). There were also more middling particles in the sink fractions of samples 603-194 and 603-199 than in sample 603-M-1079.

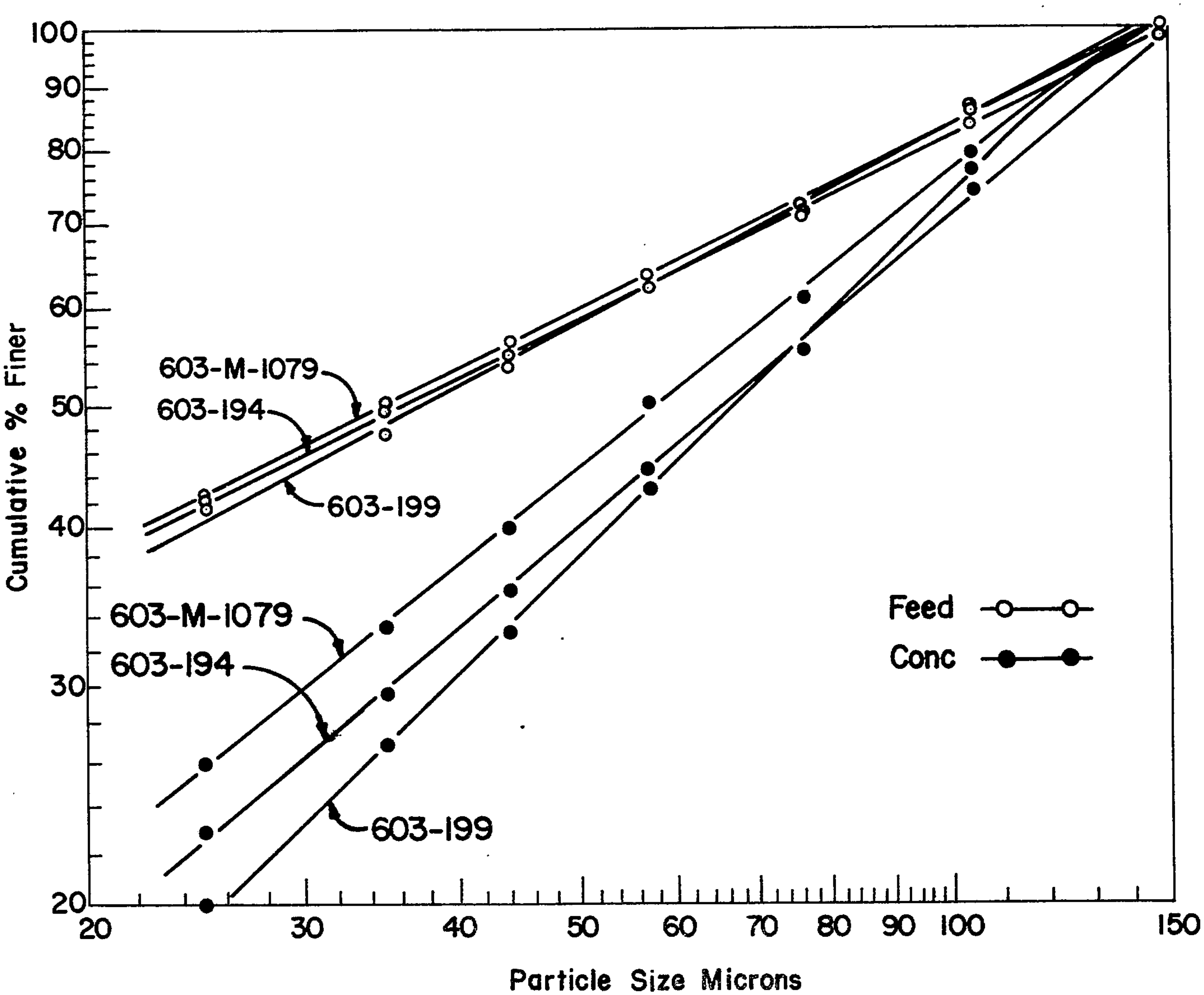


Figure 5. Size distributions of the flotation feed and iron concentrates.

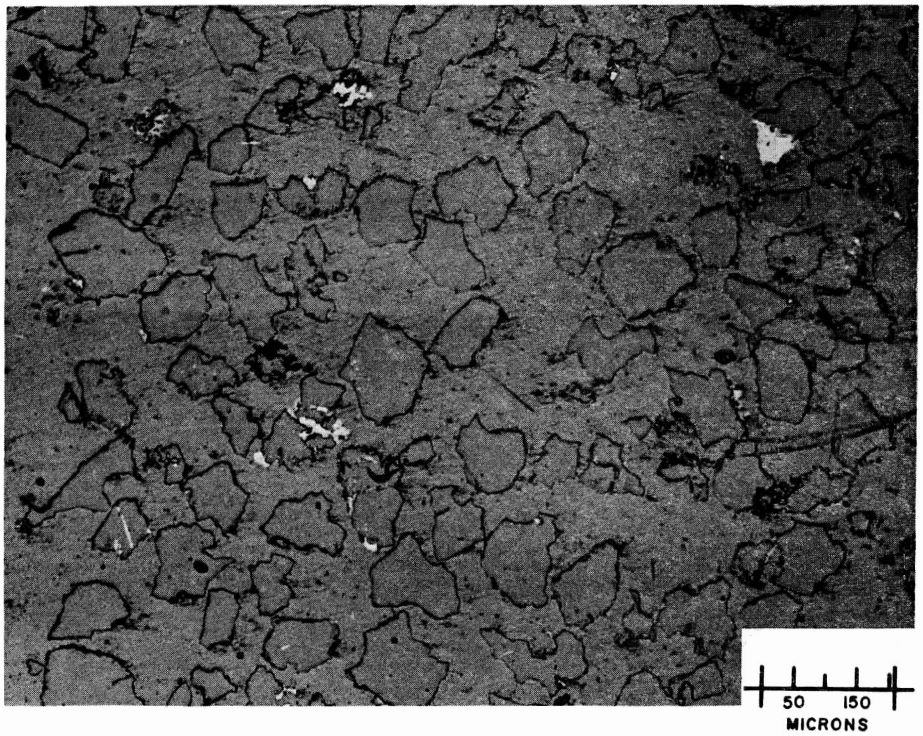


Figure 6. Photomicrograph of the float 2.96 gravity +150 mesh product of sample 603-M-1079. The white grains are hematite and the light grey grains are quartz.
65x

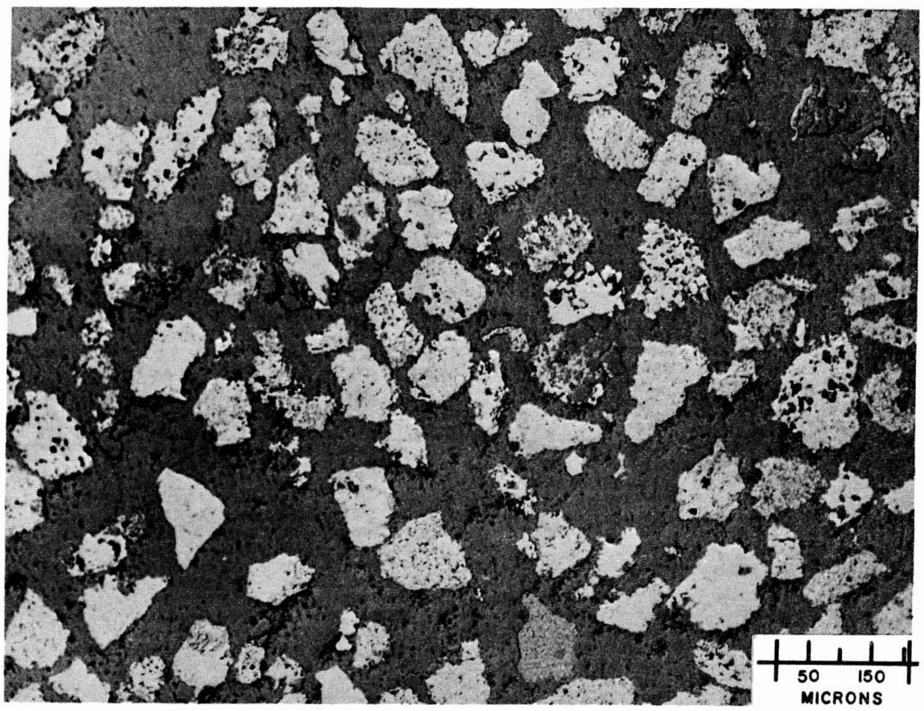


Figure 7. Photomicrograph of the sink 2.96 gravity +150 mesh product of sample 603-M-1079 showing hematite (white), goethite (grey) and quartz (black).
65 x

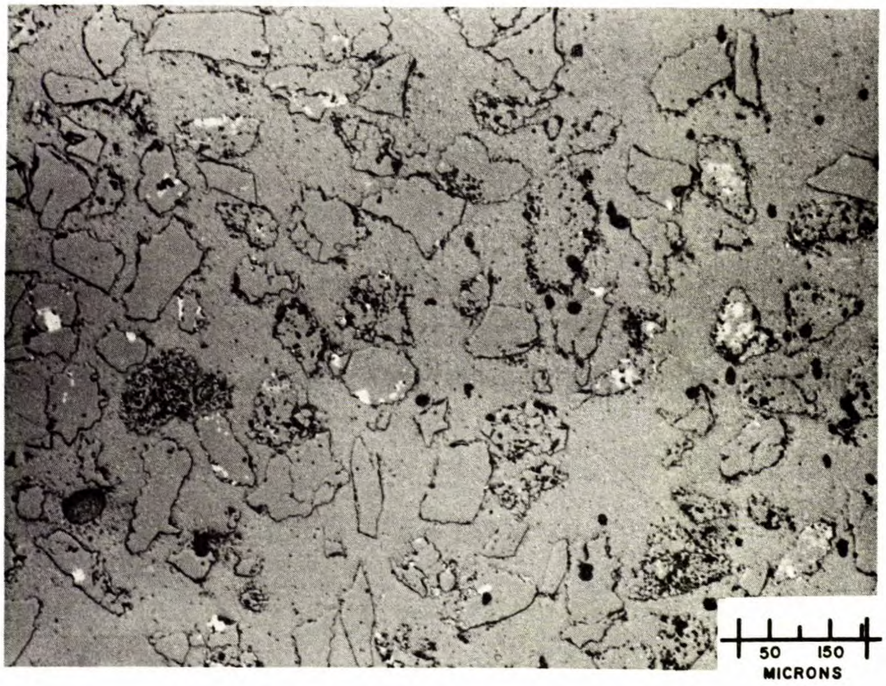


Figure 8. Photomicrograph of the float 2.96 gravity +150 mesh product of sample
65x 603-194 showing fine grained inclusions of hematite (white) in quartz (black).

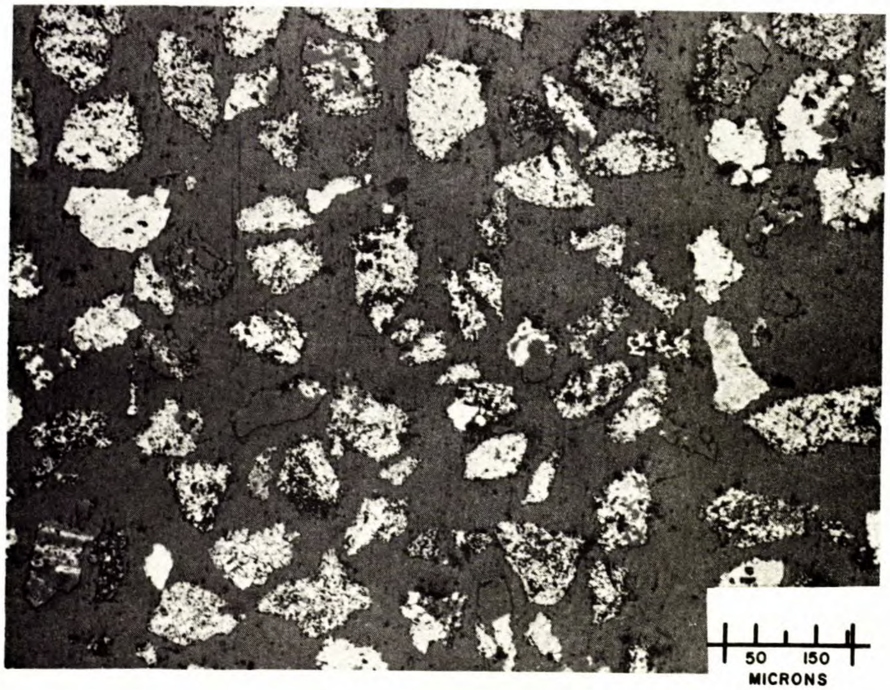


Figure 9. Photomicrograph of the sink 2.96 gravity +150 mesh product of sample
65 x 603-194 showing hematite (white) and goethite (light grey) with inclusions of quartz (dark grey).

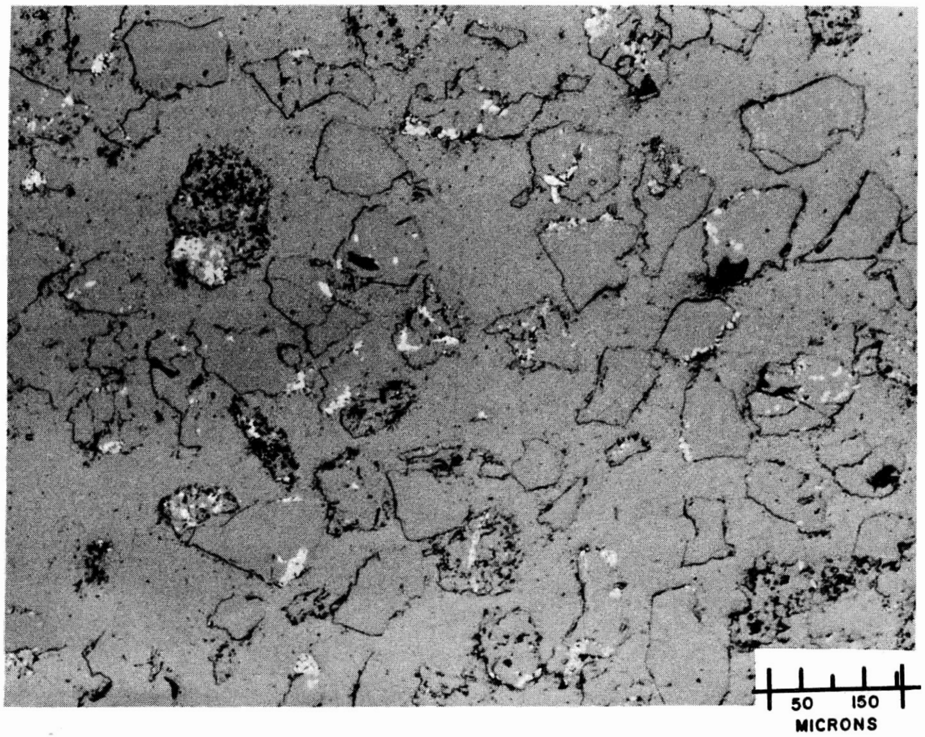


Figure 10. Photomicrograph of the float 2.96 gravity +150 mesh product of sample
65x 603-199 showing fine grained inclusions of hematite (white) in quartz (black).

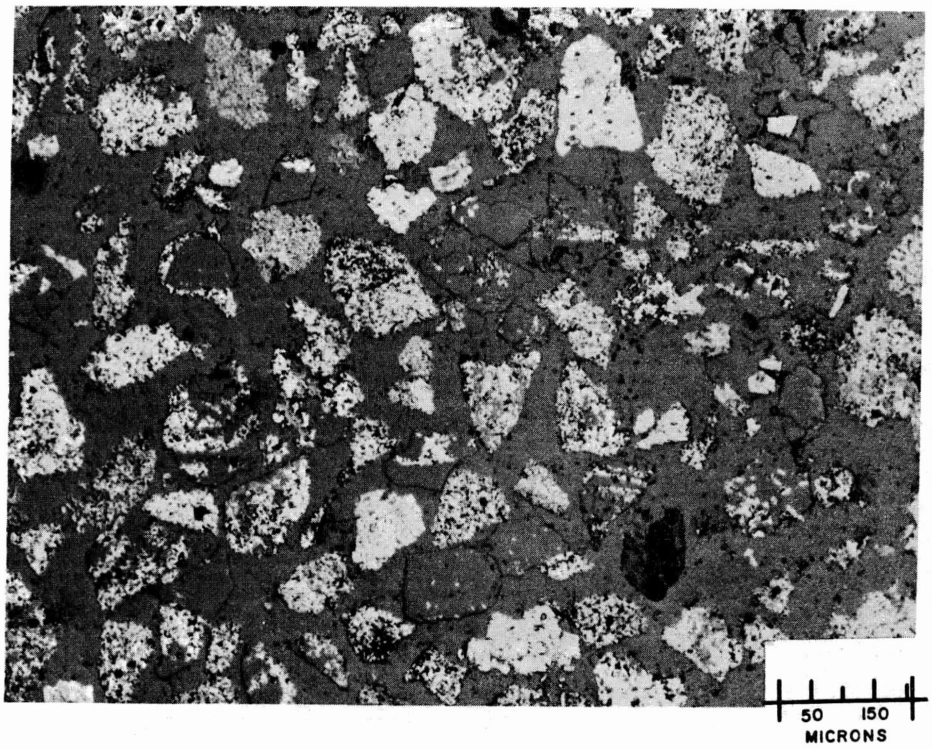


Figure 11. Photomicrograph of the sink 2.96 gravity +150 mesh product of sample
65x 603-199 showing hematite (white) and goethite (light grey) with quartz (dark grey).

To facilitate comparison of the results given in Tables 4 to 7, block diagrams were made (Figure 12) showing the size distribution of the silica in the feed and in the iron concentrates, and the proportion of silica in each size fraction occurring in the form of free quartz particles and in the form of quartz-hematite middling particles. The distribution of the silica in the iron concentrates in Figure 12 was calculated in terms of the original feed.

Figure 12 shows that in sample 603-M-1079, the silica in the feed was distributed uniformly between the -100+500 -mesh size fractions, and most of it was in the form of free quartz particles; whereas, in samples 603-194 and 603-199 the silica in the feed tended to be concentrated in the coarser size fractions, and a large proportion of it was locked in quartz-hematite middling particles. Most of the middling particles in the feed reported to the iron concentrate in flotation, and much of the variation in the silica content of the iron concentrates was due to differences in the amount of middling particles in the samples. However, middlings did not account for all the silica found in the concentrates. Figure 12 shows that approximately half of the silica found in the concentrate of sample 603-194 was in the form of free quartz particles. To determine why these free quartz particles did not float, the surfaces of these particles were examined and compared with surfaces of particles that floated.

Investigation of Differences in the Quartz Surfaces

Figures 6 to 11 showed that there were more hematite inclusions in the quartz from samples 603-194 and 603-199 than in the quartz from sample 603-M-1079, and it was thought that these inclusions may have some effect on the floatability of the quartz. However, examination of the quartz in the silica froth products showed that there were just as many fine hematite

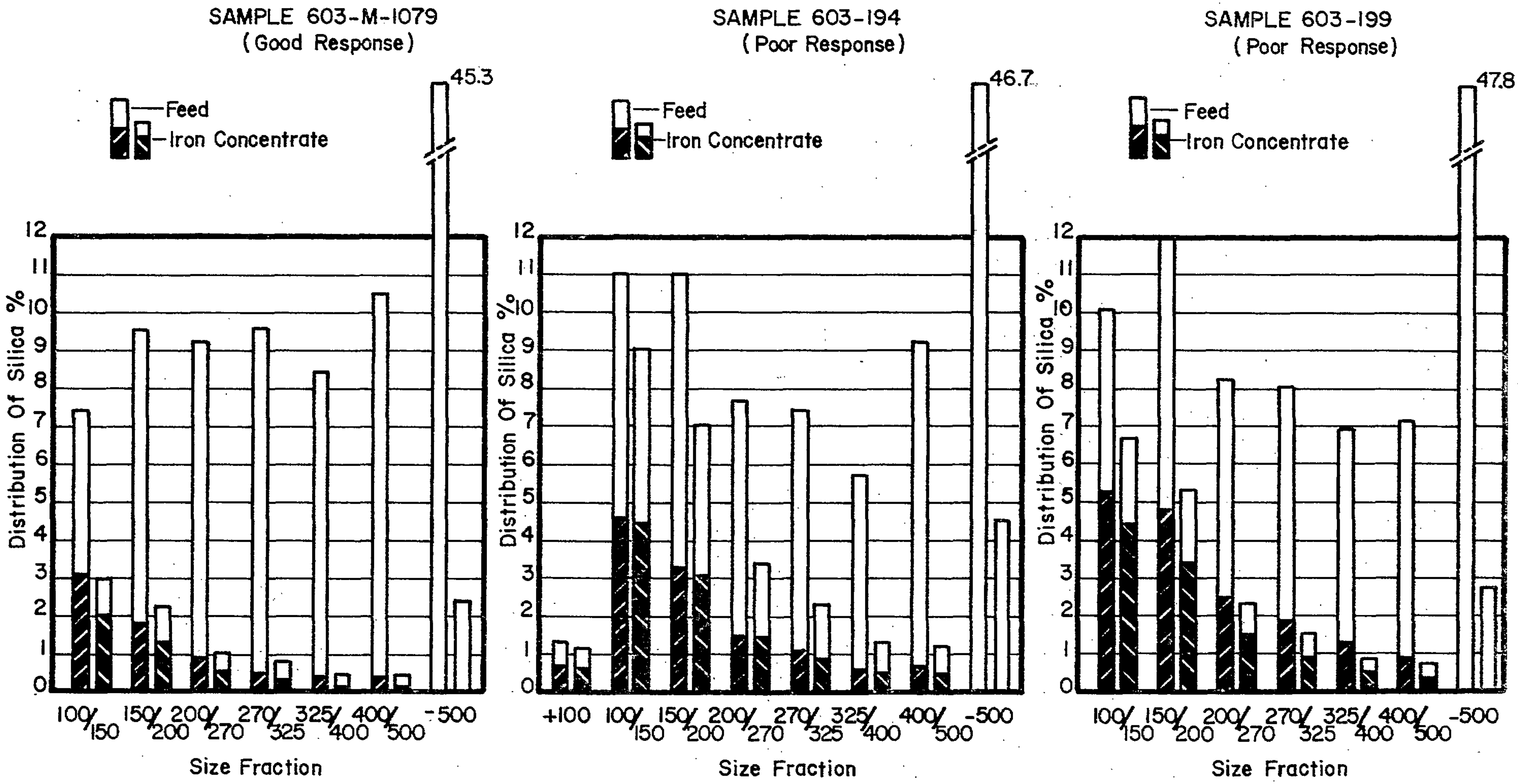


Figure 12. DISTRIBUTION OF SILICA IN THE FEED AND IN THE IRON CONCENTRATE.

(Shaded portions represent the amount of silica locked in middling particles; unshaded portions represent the amount of free silica in each size fraction.)

inclusions in the quartz in these products, and apparently these inclusions had had little effect on the floatability of the quartz.

Measurements were made of the zeta potential of the quartz in the different ore samples, but the results were inconclusive. The quartz in each case was found to have a negative charge somewhat lower than that of pure silica at the pH of 10, and this was attributed to the fact that there were fine hematite inclusions in the quartz samples tested; however there were no significant differences in the magnitude of the negative charge between samples.

The surfaces of the free quartz particles found in the iron concentrate of sample 603-194 were examined with an electron microscope, and compared with surfaces of quartz particles found in the silica froth product of that sample, and of sample 603-M-1079, which showed a good response to flotation. Photomicrographs of the different quartz surfaces are shown in Figures 13 to 15. The surfaces of the quartz particles found in the froth products appeared to be smoother than the surfaces of the quartz particles found in the iron concentrate. The latter appeared to be too rough for bubble attachment. Examination of these particles showed that many were made up of clusters of very fine quartz crystals.

Measurements were made of the surface areas of -270+325 mesh quartz particles found in the iron concentrate and in the silica froth product of sample 603-194, using a gas adsorption apparatus. The quartz in the iron concentrate was found to have a much higher surface area, 0.63 m^2/g, than the quartz in the silica froth product, 0.34 m^2/g, proving that the surfaces of the particles that did not float were much rougher. Surface area measurements were also made of -270+325 mesh hematite particles found in the iron concentrate of sample 603-194. The surface area of these hematite

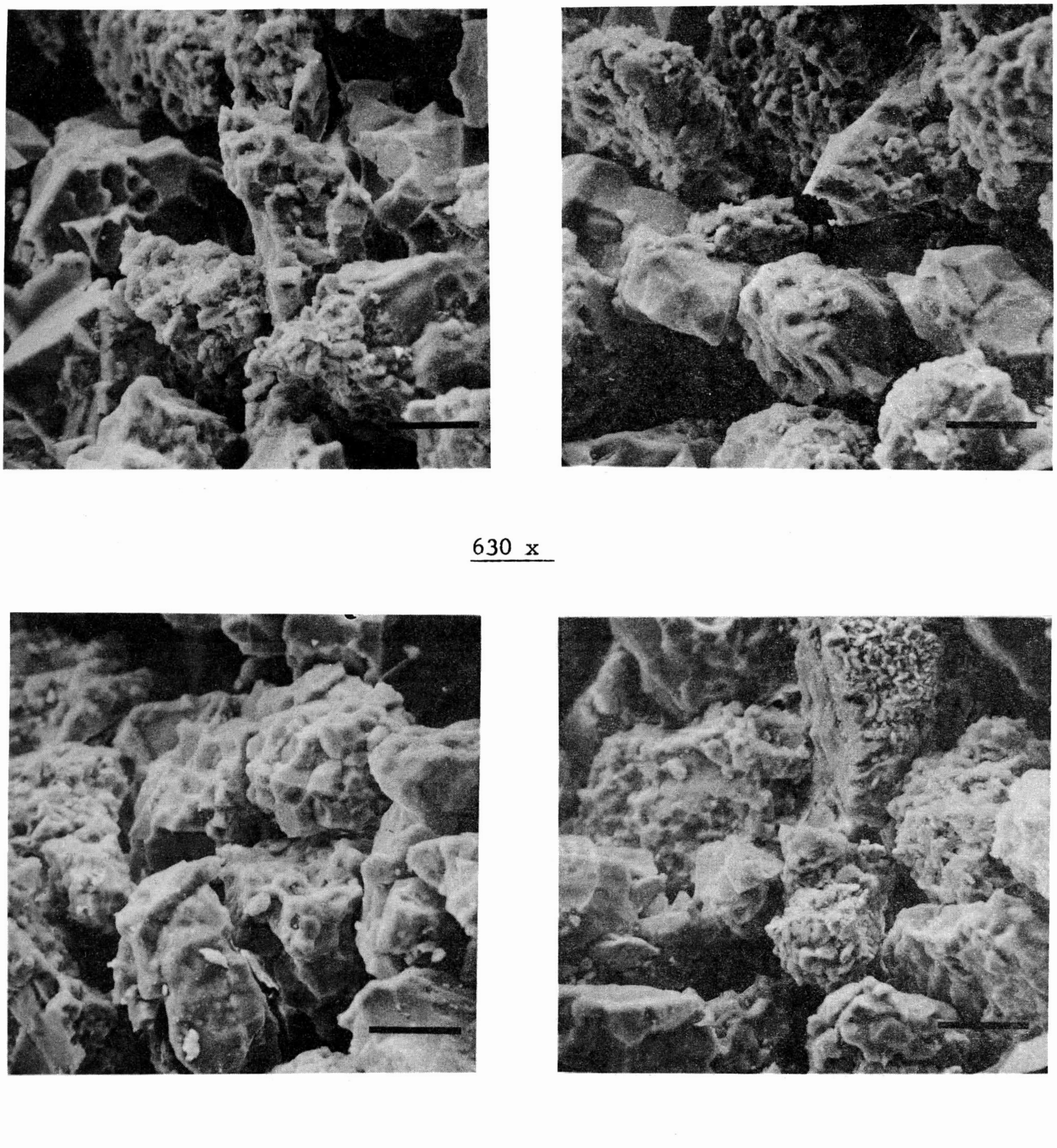
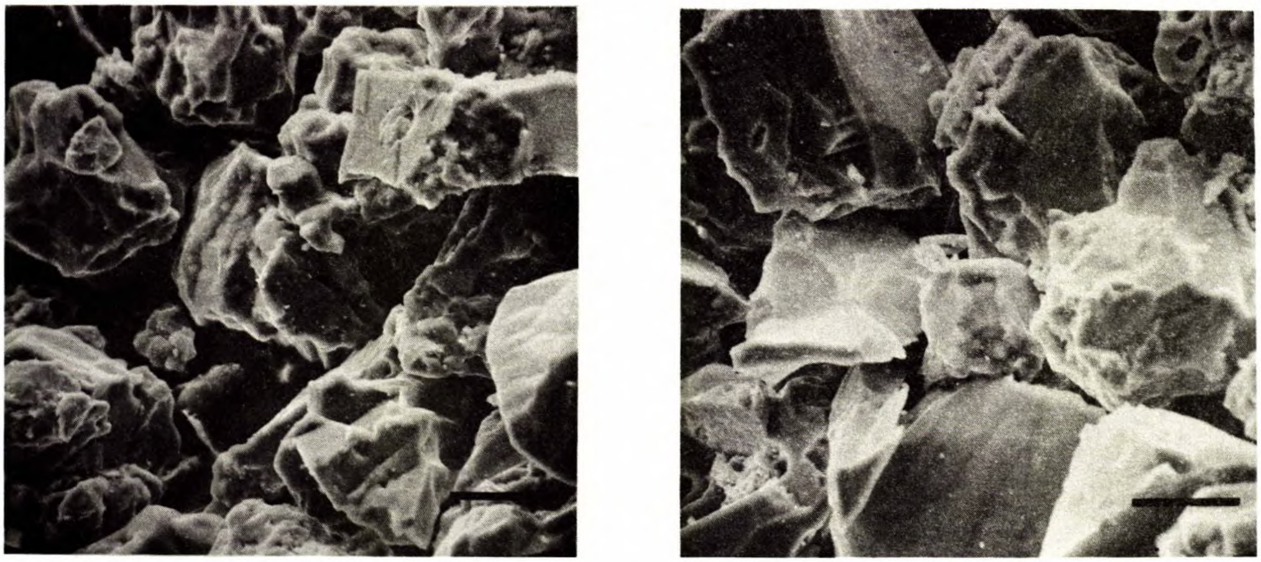


Figure 13. Photomicrographs of the quartz (-270+325 mesh) found in the iron concentrate of sample 603-194.



660 x

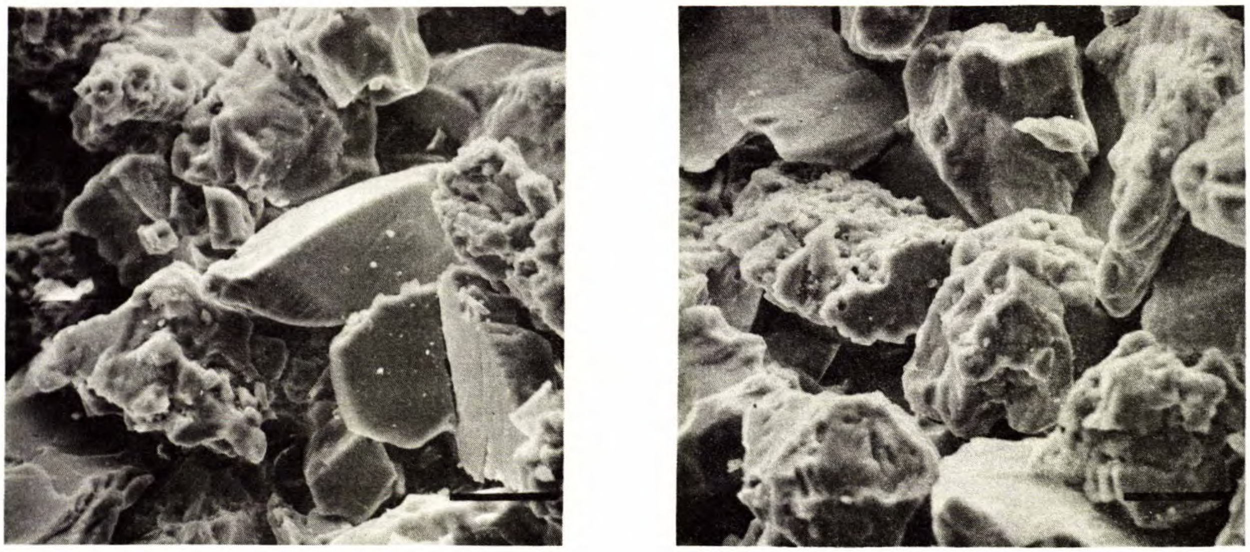
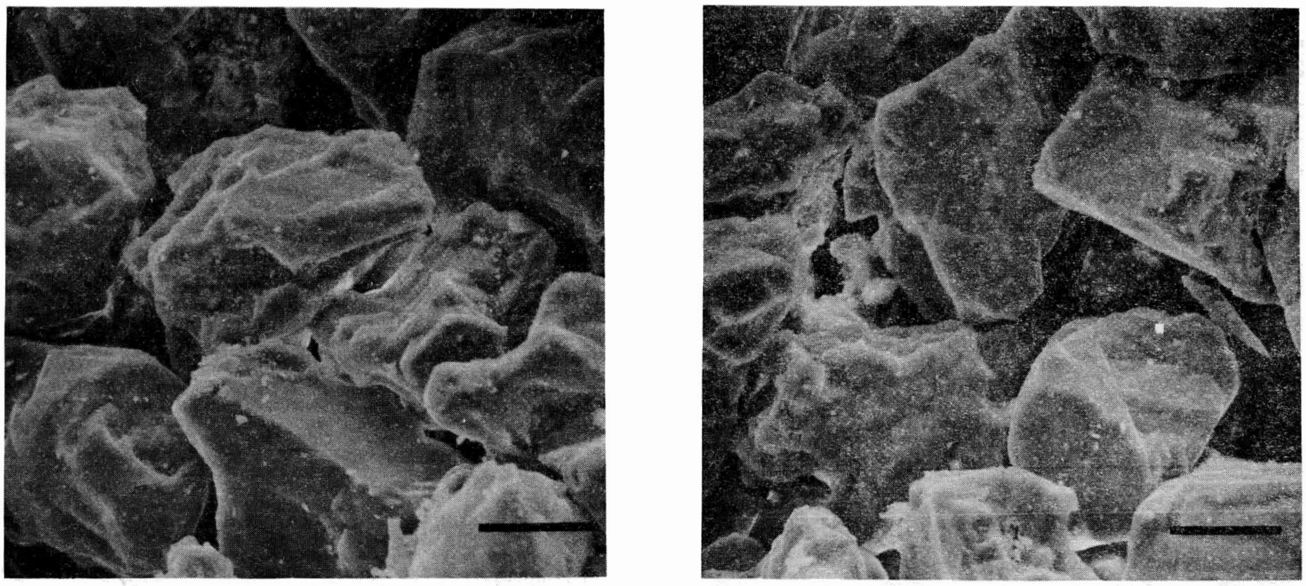


Figure 14. Photomicrographs of the quartz (-270+325 mesh) in the silica cleaner float product of sample 603-194.



780 x

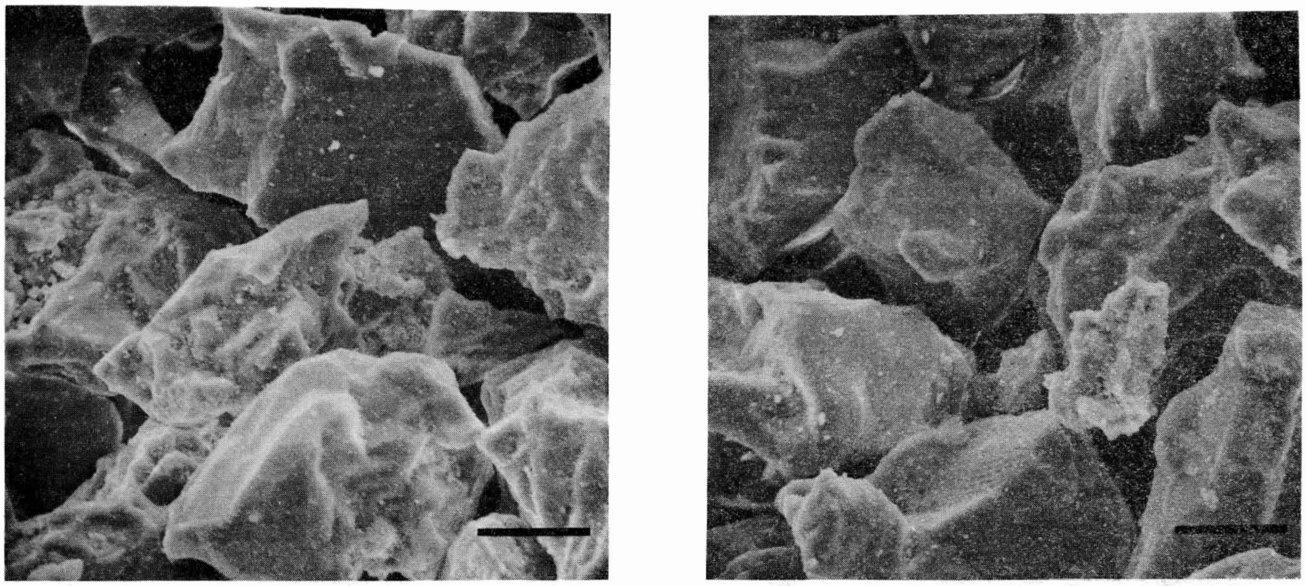


Figure 15. Photomicrographs of the quartz (-270+325 mesh) in the silica cleaner float product of sample 603-M-1079.

particles, 4.73 m^2/g, was approximately 10 times the surface area of the quartz particles, and the surfaces of the hematite particles were found to be very rough, as shown in the photomicrographs of Figure 16. This roughness of the surfaces may also explain why the quartz-hematite middling particles were difficult to float.

Magnetic Separation Tests

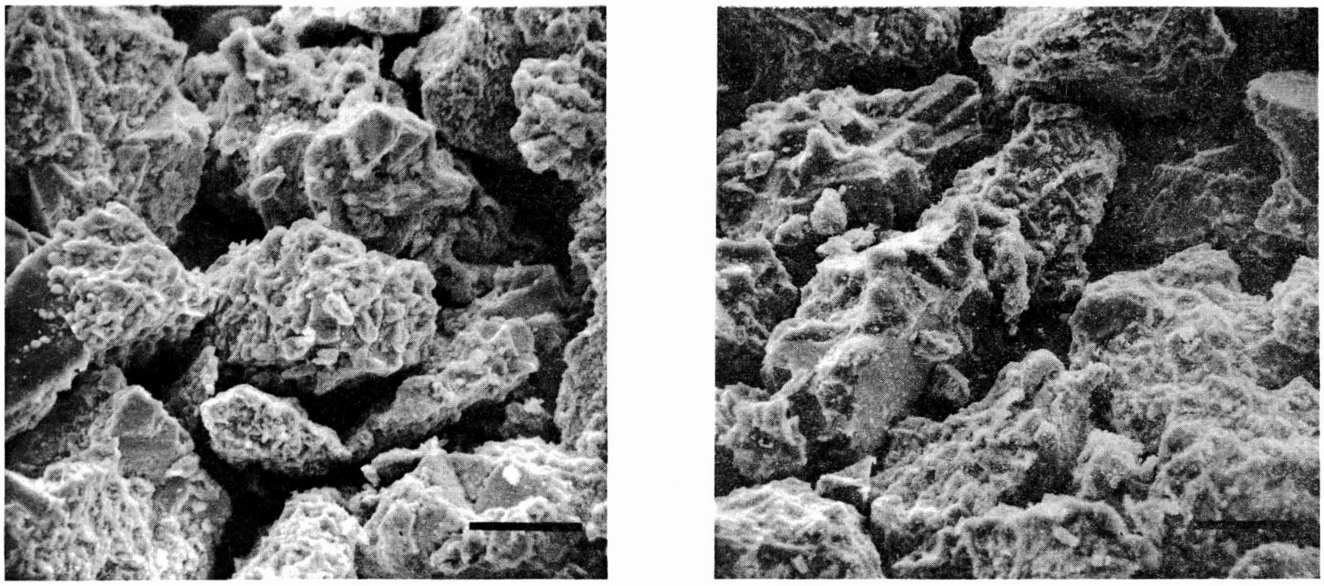
Magnetic separation tests were done on samples of the flotation feed from all the ore samples, using a Jones high-intensity wet magnetic separator. The samples were dispersed with sodium silicate, and fed to the separator at a pulp density of 10%. To prevent the magnetite in the samples from blocking the plates, the samples were first passed through the separator at 0 amperes, then re-passed at 10 amperes. The magnetic concentrates at 0 and 10 amperes were combined. The chemical analyses of the magnetic concentrates are given in Table 8.

A good correlation was found in most of the samples between magnetic separation and flotation. Chemical analyses of the flotation concentrates are also given in Table 8 for comparison.

On several of the samples, the magnetic separation tests and flotation tests were repeated at a 5 to 15% finer grind, however, the results obtained were not significantly different.

In the second shipment, samples 603-M-1472 and 603-M-1500 yielded the poorest concentrates. (Sample 603-M-1472 was a sample of lean yellow ore). In the third shipment, both samples of Wishart Mine ore yielded poor concentrates.

Samples 603-194, 199, 1472, and 1500 all contained relatively large amounts of magnetite; the other samples contained very little magnetite.



680 x

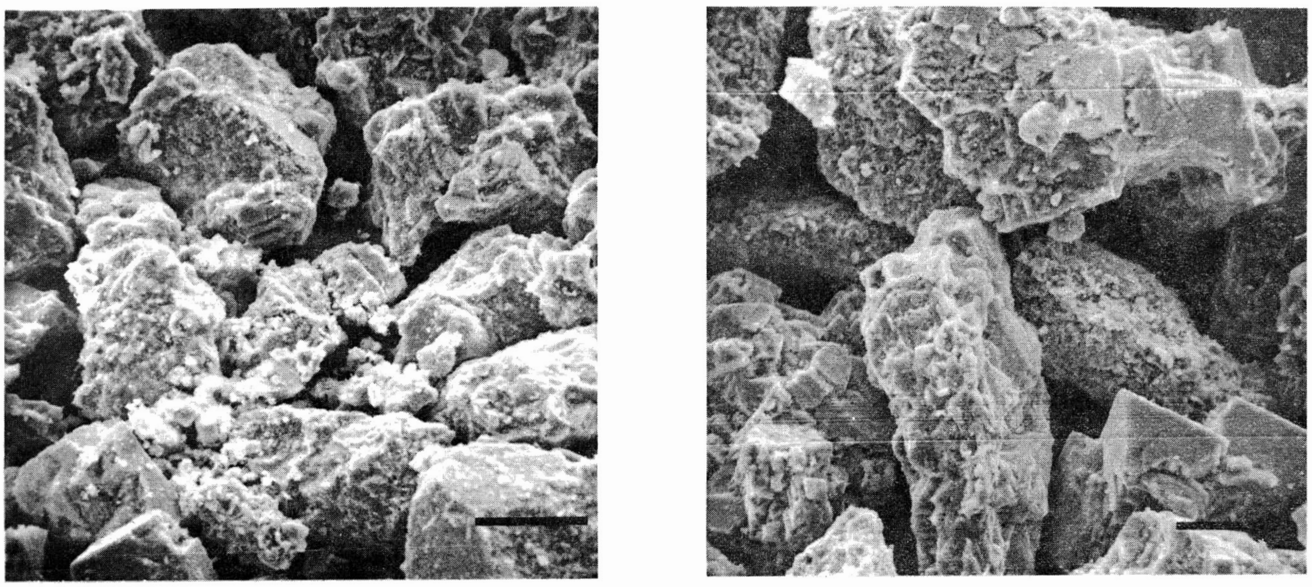


Figure 16. Photomicrographs of the hematite (-270+325 mesh) in the iron concentrate of sample 603-194.

TABLE 8

Analysis of Magnetic Concentrates and Flotation Concentrates

Concentrate	Magnetic		Flotation	
Sample No.	Analysis,%		Analysis,%	
	Fe	SiO_2	Fe	SiO_2
603-M-1079	62.65	5.79	62.84	5.46
603-194	57.31	14.13	56.07	15.92
603-199	55.91	14.98	58.98	11.82
603-M-1469	65.19	2.49	64.1*	4.4*
603-M-1470	64.08	4.11	63.62	4.96
603-M-1471	58.27	2.98	58.0*	3.2*
603-M-1472	55.43	8.60	54.9*	10.1*
603-M-1473	63.17	3.00	60.7*	4.6*
603-M-1474	61.14	5.84	60.3*	6.0*
603-M-1475	61.22	2.02	61.2*	1.8*
603-M-1478	65.56	2.42	64.4*	3.9*
603-M-1484	66.23	2.79	66.1*	2.4*
603-M-1485	63.00	5.62	64.3*	2.9*
603-M-1496	55.38	3.99	55.92	3.40
603-M-1500	59.47	6.54	57.28	7.60
603-M-1501	65.57	5.25	65.83	5.43
603-M-1502	65.52	4.67	65.19	4.58
Wishart				
Trench Sample	59.81	12.02	52.73	20.12
Stockpile	64.21	6.41	61.18	8.80

* From flotation test results reported by the Iron Ore Company of Canada.

DISCUSSION

The amount of upgrading that could be done on the samples appeared directly related to the texture and mineralogy of the samples, and to the degree of alteration which has taken place in the ore. Sample 603-M-1079, which responded well to flotation, appeared to be from a highly altered zone in the iron formation, where the quartz and hematite were completely recrystallized to form well segregated grains, with goethite filling interstices between the quartz grains. As a result, in grinding, this sample tended to produce fewer middling particles. On the other hand, samples 603-194 and 603-199 appeared to be from relatively unaltered zones in the iron formation, where the original oolitic texture of the ore was preserved. The quartz in these oolitic nodules was intimately intergrown with hematite, and although some of it appeared to have been recrystallized, much of the quartz was extremely fine-grained, as shown in Figure 4. In grinding, these samples tended to produce more middling particles, and the fine-grained quartz produced particles with very rough surfaces, that were difficult to float.

Samples 603-M-1472 and 603-M-1500 also appeared to be from relatively unaltered zones in the iron formation, indicated by the high proportion of magnetite found in these samples. In general, the magnetite content may be used as a measure of the degree of alteration which has taken place in the ore.

The Wishart Mine samples contained a considerable amount of goethite, and smaller amounts of magnetite, but the texture of these samples was oolitic, and much of the quartz was extremely fine-grained with rough surfaces as in samples 603-194 and 603-199. The results obtained by magnetic separation were significantly better than those obtained by flotation, which indicated that liberation was not a problem in treating these samples, but the flotation of the fine-grained quartz particles with rough surfaces was.

CONCLUSIONS

The principal causes for the variation in the flotation behaviour of the samples were:

(1) differences in the amount of middlings in the feed to flotation, and

(2) differences in the surface characteristics of the quartz particles.

The degree to which the ores could be upgraded could be predicted from a mineralogical examination of the samples, and from magnetic separation tests on the samples.

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Figures 5 and 12 were drawn by J. McLeod of the Mineral Processing Division.

REFERENCES

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APPENDIX

TABLE 4

Screen Analysis of Flotation Feed

Sample No.	603-M-1079					603-194					603-199				
Size Fraction	Wt %	Analysis, %		Distribution, %		Wt %	Analysis, %		Distribution, %		Wt %	Analysis, %		Distribution, %	
		Fe	SiO_2	Fe	SiO_2		Fe	SiO_2	Fe	SiO_2		Fe	SiO_2	Fe	SiO_2
+100						2.0	51.94	21.08	2.3	1.3					
-100+150	14.8	57.05	13.66	17.6	7.5	14.5	50.04	24.88	16.4	11.0	13.6	51.94	22.34	15.6	10.1
-150+200	13.1	52.17	19.66	14.3	9.5	13.1	48.82	27.44	14.4	11.0	15.3	50.44	23.48	17.0	11.9
-200+270	8.7	47.17	28.64	8.5	9.2	8.4	46.50	30.04	8.8	7.7	9.1	48.68	27.00	9.8	8.2
-270+325	7.5	43.30	34.56	6.8	9.6	7.3	45.19	33.14	7.4	7.4	8.3	46.72	29.12	8.6	8.0
-325+400	6.0	40.73	38.18	5.1	8.4	5.2	42.78	36.00	5.0	5.7	6.5	44.59	32.06	6.4	6.9
-400+500	7.6	41.77	37.38	6.6	10.5	7.5	40.26	40.06	6.8	9.2	5.9	41.31	36.42	5.4	7.1
-500	42.3	46.58	29.04	41.1	45.3	42.0	41.07	36.28	38.9	46.7	41.3	40.76	34.90	37.2	47.8
Total*	100.0	47.55	27.69	100.0	100.0	100.0	44.40	32.67	100.0	100.0	100.0	45.25	30.15	100.0	100.0

*Calculated.

TABLE 5

Screen Analysis of Iron Concentrates

Sample No.	603-M-1079						603-194						603-199					
		Analysis, %		Distribution, %, in				Analysis, %		Distribution, %, in				Analysis, %		Distribution, %, in		
				Concentrate		Feed				Concentrate		Feed				Concentrate		Feed
Size Fraction	Wt %	Fe	SiO_2	Fe	SiO_2	SiO_2	Wt %	Fe	SiO_2	Fe	SiO_2	SiO_2	Wt %	Fe	SiO_2	Fe	SiO_2	SiO_2
+100							2.9	53.10	20.69	2.8	3.8	1.1						
-100+150	20.7	61.00	7.62	20.2	29.2	3.0	22.4	52.26	21.60	20.9	30.4	9.1	22.2	55.16	17.26	20.8	33.1	6.6
-150+200	18.5	62.00	6.32	18.3	21.7	2.2	19.6	53.95	18.95	18.9	23.3	6.9	23.1	57.58	13.32	22.6	26.6	5.3
-200+270	10.6	62.51	5.16	10.6	10.1	1.0	10.7	55.61	17.03	10.6	11.4	3.4	12.0	59.19	11.14	12.1	11.6	2.3
-270+325	10.3	63.51	4.24	10.5	8.1	0.8	8.8	57.46	14.08	9.0	7.8	2.3	9.7	61.40	8.80	10.1	7.4	1.5
-325+400	6.3	64.02	3.44	6.4	4.0	0.4	6.1	59.54	11.29	6.5	4.3	1.3	6.3	61.90	7.38	6.6	4.0	0.8
-400+500	7.6	64.72	2.86	7.9	4.0	0.4	6.5	60.46	9.62	7.0	3.9	1.2	6.9	62.41	6.10	7.3	3.6	0.7
-500	26.0	62.86	4.76	26.1	22.9	2.4	23.0	58.99	10.48	24.3	15.1	4.5	19.8	61.00	8.00	20.5	13.7	2.8
Total*	100.0	62.56	5.40	100.0	100.0	10.2	100.0	55.96	15.94	100.0	100.0	29.8	100.0	58.89	11.57	100.0	100.0	20.0

* Calculated.

TABLE 6

Results of Heavy-Liquid Separation Tests on the Flotation Feed

Sample No.		603-M-1079					603-194					603-199				
		Wt	Analysis,%		Distn,%		Wt	Analysis,%		Distn,%		Wt	Analysis,%		Distn,%	
Size Fraction	Product	%	Fe	SiO_2	Fe	SiO_2	%	Fe	SiO_2	Fe	SiO_2	%	Fe	SiO_2	Fe	SiO_2
+100	Sink						88.5	58.2	11.9	99.0	50.1					
	Float						11.5	4.6	91.0	1.0	49.9					
							100.0	52.04	21.00	100.0	100.0					
-100+150	Sink	91.6	61.65	6.02	99.6	41.3	84.4	58.51	12.16	98.6	41.9	87.9	57.48	13.58	98.7	52.6
	Float	8.4	2.90	93.35	0.4	58.7	15.6	4.62	91.18	1.4	58.1	12.1	5.74	88.74	1.3	47.4
		100.0	56.71	13.35	100.0	100.0	100.0	50.10	24.48	100.0	100.0	100.0	51.21	22.68	100.0	100.0
-150+200	Sink	82.0	62.81	4.84	99.1	18.9	80.0	59.80	10.08	98.2	30.5	84.8	58.95	11.00	98.5	40.6
	Float	18.0	2.48	94.82	0.9	81.1	20.0	4.28	92.06	1.8	69.5	15.2	5.03	89.82	1.5	59.4
		100.0	51.95	21.04	100.0	100.0	100.0	48.70	26.47	100.0	100.0	100.0	50.75	22.98	100.0	100.0
-200+270	Sink	72.8	63.97	3.52	98.5	9.0	73.7	61.64	7.80	97.4	19.3	79.2	59.98	10.40	97.8	30.5
	Float	27.2	2.56	94.62	1.5	91.0	26.3	4.64	91.36	2.6	80.7	20.8	5.03	90.26	2.2	69.5
		100.0	47.27	28.30	100.0	100.0	100.0	46.65	29.77	100.0	100.0	100.0	48.55	27.01	100.0	100.0
-270+325	Sink	66.0	64.12	2.88	98.3	5.5	70.2	62.65	7.16	97.3	15.4	75.1	60.91	9.20	97.5	23.4
	Float	34.0	2.22	94.96	1.7	94.5	29.8	4.18	92.64	2.7	84.6	24.9	4.58	91.04	2.5	76.6
		100.0	43.07	34.19	100.0	100.0	100.0	45.22	32.62	100.0	100.0	100.0	46.88	29.58	100.0	100.0
-325+400	Sink	61.7	64.72	2.74	97.7	4.4	64.9	63.11	5.32	96.1	9.7	71.5	60.67	8.94	97.7	19.4
	Float	38.3	2.46	95.06	2.3	95.6	35.1	4.70	91.08	3.9	90.3	28.5	3.52	92.90	2.3	80.6
		100.0	40.87	38.10	100.0	100.0	100.0	42.61	35.42	100.0	100.0	100.0	44.38	32.84	100.0	100.0
-400+500	Sink	62.5	65.33	2.50	97.6	4.2	59.8	63.37	5.26	94.9	8.0	64.5	61.97	7.36	95.9	12.9
	Float	37.5	2.66	94.98	2.4	95.8	40.2	5.07	90.06	5.1	92.0	35.5	4.88	90.62	4.1	87.1
		100.0	41.83	37.18	100.0	100.0	100.0	39.94	39.35	100.0	100.0	100.0	41.70	36.92	100.0	100.0

TABLE 7

Results of Heavy-Liquid Separation Tests on the Iron Concentrates

Sample No.		603-M-1079					603-194					603-199				
Size Fraction	Product	Wt %	Analysis, %		Distn, %		Wt %	Analysis, %		Distn, %		Wt %	Analysis, %		Distn, %	
			Fe	SiO_2	Fe	SiO_2		Fe	SiO_2	Fe	SiO_2		Fe	SiO_2	Fe	SiO_2
+100	Sink						90.2	58.37	13.05	99.2	56.9					
	Float						9.8	4.6	91.0	0.8	43.1					
							100.0	53.10	20.69	100.0	100.0					
-100+150	Sink	97.4	62.56	5.32	99.9	68.0	88.1	58.70	12.22	98.9	49.9	93.5	58.64	12.20	99.4	66.1
	Float	2.6	2.5	94.0	0.1	32.0	11.9	4.6	91.0	1.1	50.1	6.5	5.0	90.0	0.6	33.9
		100.0	61.00	7.62	100.0	100.0	100.0	52.25	21.60	100.0	100.0	100.0	55.16	17.26	100.0	100.0
-150+200	Sink	97.2	63.71	3.80	99.9	58.4	88.6	60.29	9.68	99.0	45.3	94.6	60.58	8.94	99.5	63.5
	Float	2.8	2.5	94.0	0.1	41.6	11.4	4.6	91.0	1.0	54.7	5.4	5.0	90.0	0.5	36.5
		100.0	62.00	6.32	100.0	100.0	100.0	53.95	18.95	100.0	100.0	100.0	57.58	13.32	100.0	100.0
-200+270	Sink	97.3	64.17	2.69	99.9	50.8	89.3	61.72	8.16	99.1	42.8	95.5	61.74	7.42	99.6	63.3
	Float	2.7	2.5	94.0	0.1	49.2	10.7	4.6	91.0	0.9	57.2	4.5	5.0	90.0	0.4	36.4
		100.0	62.51	5.16	100.0	100.0	100.0	55.61	17.03	100.0	100.0	100.0	59.19	11.14	100.0	100.0
-270+325	Sink	97.2	65.27	1.65	99.9	38.0	90.7	62.89	6.20	99.3	39.9	96.0	63.75	5.42	99.7	59.1
	Float	2.8	2.5	94.0	0.1	62.0	9.3	4.6	91.0	0.7	60.1	4.0	5.0	90.0	0.3	40.9
		100.0	63.51	4.24	100.0	100.0	100.0	57.47	14.08	100.0	100.0	100.0	61.40	8.80	100.0	100.0
-325+400	Sink	97.3	65.72	0.92	99.9	26.2	92.1	64.26	4.46	99.4	36.3	96.9	63.70	4.74	99.7	62.2
	Float	2.7	2.5	94.0	0.1	73.8	7.9	4.6	91.0	0.6	63.7	3.1	5.0	90.0	0.3	37.8
		100.0	64.02	3.44	100.0	100.0	100.0	59.54	11.29	100.0	100.0	100.0	60.90	7.38	100.0	100.0
-400+500	Sink	97.5	66.32	0.52	99.9	17.8	93.5	64.34	3.96	99.5	38.5	97.1	64.12	3.59	99.8	57.2
	Float	2.5	2.5	94.0	0.1	82.2	6.5	4.6	91.0	0.5	61.5	2.9	5.0	90.0	0.2	42.8
		100.0	64.72	2.86	100.0	100.0	100.0	60.46	9.62	100.0	100.0	100.0	62.41	6.10	100.0	100.0