CONCENTRATION OF KLUKWAN, ALASKA, MAGNETITE ORE

BY R. R. WELLS AND R. L. THORNE

* * * * * * * * * **Report of Investigations 4984**

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ILLUSTRATIONS

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INTRODUCTION

For several years the Klukwan deposit near Haines, Alaska, has attracted interest as a potential source of iron. Limited field and laboratory investigation has indicated that the deposit contains a large amount of iron that is recoverable as high-grade concentrate.

This report summarizes the results of laboratory beneficiation testing of the Klukwan ore, as represented by six samples submitted to the Alaska Experiment Station of the Bureau of Mines, Juneau, Alaska. Iron is present in the ore as a fine-grained magnetite associated with a pyroxenite-type basic rock. Satisfactory magnetic-separation procedures were developed for the production of concentrates assaying more than 60 percent Fe and 2 to 4 percent TiO_2.

During the investigation many data were obtained and compiled, but for convenience and clarity data of secondary importance have been omitted or condensed; only the more pertinent test results are discussed in detail.

ACKNOWLEDGMENTS

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Special acknowledgment is made to the Geological Survey for permission to use the topographic and geologic map data shown on figure 1.

LOCATION AND DESCRIPTION

The Klukwan magnetic iron deposit is situated near the northern boundary of southeastern Alaska at 59° 26' north latitude and 135° 53' west longitude. At Klukwan, an Indian village, the paved Haines-Cutoff Highway passes over the outwash fan of the deposit approximately 1 mile from the lode. Klukwan is 23 miles by highway from Haines, a deep-water port on the shore of Lynn Canal.

The deposit is a very large mass of basic rock, which conforms mineralogically to a magnetite-enriched pyroxenite. The maximum width of the deposit,

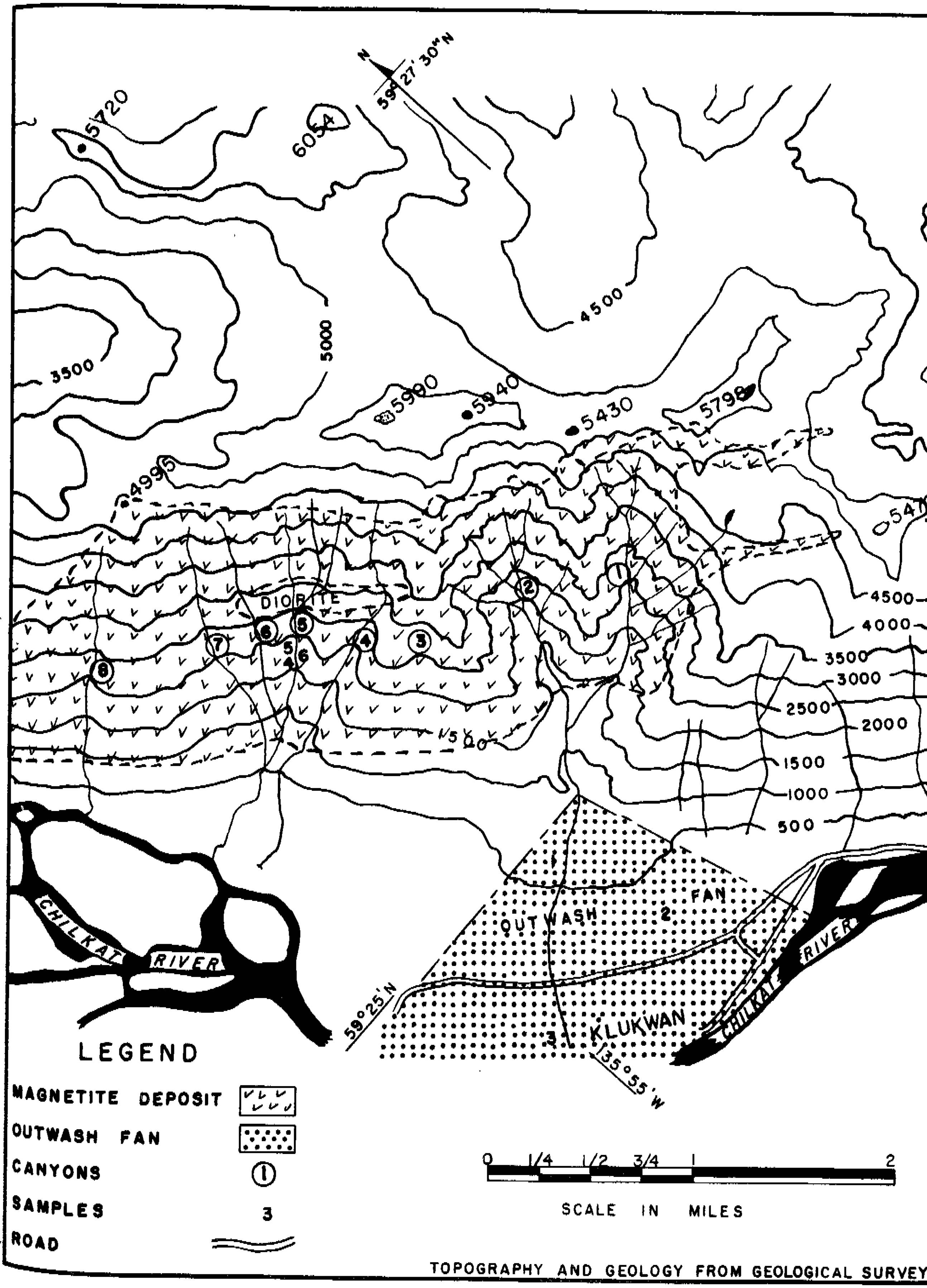

Figure 1. - Map of Klukwan iron deposit.

as mapped, is approximately 1-1/4 miles; the length is approximately 3 miles. Erosion has exposed the deposit throughout a vertical range of about 3,000 feet, much of which is precipitous. A sketch of the deposit is shown in figure 1. Information adequate for a dependable grade-tonnage estimate is not available. The entire mass of magnetite-bearing rock, as mapped by the Geological Survey, is estimated to contain at least 13 billion short tons above the lowest exposures.

Those parts of the deposit that have been examined at close range indicate that magnetite is disseminated uniformly throughout the pyroxenite, except where magnetite or pyroxenite may be segregated into nearly pure lenses. The average magnetic iron content of the magnetite lenses is indicated to be about 45 to 50 percent.

It appears probable that the average magnetic iron content of the deposit will be governed largely by the relative number and size of the magnetite lenses, but neither of those factors has been determined. One series of chip samples taken by engineers of the Bureau of Mines across an 800-foot expanse of uniformly crystallized pyroxenite near the lower end of Canyon 2 (see map, fig. 1) averaged approximately 20 percent magnetic iron and 5 percent iron contained in silicates. The sampled section appeared to be representative. It must be emphasized, however, that only small areas of the deposit have been examined or sampled. Most of the outcrop is concealed by overburden or is inaccessible because of the precipitous topography; consequently, there is no assurance that all parts of the deposit, as mapped, are comparably mineralized.

The deposit may well be a magmatic differentiation from the predominantly dioritic magma that formed the backbone of the mountain chain. The magnetite-enriched pyroxenite is enclosed within the diorite. Diorite crops out within the deposit in canyons 4, 5 and 6, as shown in figure 1.

EXPLORATION AND MINING

Some short-hole diamond-drill exploration has been done by a private company. Conditions for long-hole diamond drilling are favorable; this method of exploration could be utilized for a comprehensive evaluation of the deposit at a very low cost per ton of iron-bearing rock.

Location and weather conditions present no serious problems for year-round mining and shipping. The character of the deposit is such that large-scale, low-cost mining methods can be utilized.

THE ORE

Samples

Three of the samples submitted to the laboratory were chip or channel samples from the Klukwan lode; three others were obtained from the large alluvial fan at the base of the mountain.

Sample 1 and 2 were 1-cubic-yard samples obtained by engineers of the Mining Division, Bureau of Mines, from pits dug in the outwash (alluvial fan) portion of the deposit. Sample 1 was taken near the apex of the fan; sample 2 was taken near one side of the fan about half way between the base and the apex. Sample 3 was a composite of three samples obtained by members of the Geological Survey staff from beds of fine-grained material near the outer edge of the alluvial fan. Samples 4 and 5 were composites of chip samples taken by Bureau of Mines engineers from a section of the lode deposit known as Canyon 5. Sample 6 was a composite of channel samples cut in Canyon 5 and submitted to the laboratory by an engineer representing C. T. Takahashi & Co.

The approximate locations from which the samples were taken are shown on the map of the Klukwan deposit (fig. 1).

Physical Character

Petrographic examination of each of the samples submitted for testing revealed that, in a broad sense, all are mineralogically similar. There is, however, a variation in the relative amounts of the component minerals.

Two rock types were noted in the low-grade ores (samples 1, 2, 3, 4). One type was described as a gneissoid rock that contains hornblende, altered alkalic feldspar (principally albite), some altered pyroxene, and small to trace amounts of biotite, epidote, zoisite, and apatite. The second type is essentially an altered pyroxenite that contains dominantly clinopyroxene (augite and pigeonite) with associated magnetite and sphene and varying amounts of serpentine and chlorite. Minor amounts of calcite and limonite were identified.

The higher-grade ores (samples 5 and 6) essentially contain magnetite, relatively small amounts of clinopyroxene (augite and pigeonite), and hornblende, with only very small amounts of sphene, epidote, clinozoisite, alkalic-calcic plagioclase, quartz, spinel, and apatite.

Minute inclusions of magnetite in pyroxene were observed in all samples in a form known as a schiller structure. This extremely fine-grained magnetite probably is not recoverable by ore dressing but represents only a small portion of the magnetite in the ore.

Microscopic and sizing studies revealed that maximum liberation of recoverable magnetite in the lower grade ore is achieved in the minus-150-plus-200-mesh size range. The amount of locked magnetite in the minus-100-plus-150-mesh fraction is small but increases to considerable in sizes coarser than 100-mesh. In the higher grade ores, however, the recoverable magnetite essentially is liberated in the minus-48- plus-100-mesh size range.

Chemical Character

Representative head samples, carefully prepared from the samples submitted, were analyzed both chemically and spectrographically. Partial chemical analyses of the samples are shown in table 1. Semiquantitative spectrographic analyses revealed the presence and approximate quantities of the metals listed in table 2. Any other elements, if present, are in amounts lower than the minimum detectable by the routine technique employed.

TABLE 1. - Chemical analyses

Sample	Assay, percent									Ounce per ton	
	Fe	TiO_2	SiO_2	P	S	Cu	Ni	L.O.I.	V	Au	Ag
1......	17.4	2.15	39.3	0.08	1/0.02	0.05	0.03	-	0.05	Trace	Trace
2......	15.6	1.5	42.8	.09	1/ .02	1/.02	.03	-	.02	Trace	Trace
3......	13.2	1.7	39.9	.11	.03	-	-	2/5.5	.01	Trace	Trace
4......	16.8	2.0	39.7	1/.02	.03	-	-	-	.05	Trace	Trace
5......	54.0	4.6	8.6	1/.02	.025	-	-	-	.29	Trace	Trace
6......	51.9	4.35	6.0	1/.02	1/ .02	-	-	-	.23	Trace	Trace

1/ Less than.
2/ Mostly wood chips.

TABLE 2. - Spectrographic analyses

Sample	Al	Ca	Cu	Mg	Co	Fe	Mn	Ni	Si	Ti	V	Mo	Na	Zr
1....................	A	A	E	A	E	A	D	E	A	D	D	E	-	-
2....................	A	A	E	A	F	A	E	F	A	D	E	-	-	-
3....................	B	A	E	B	E	A	E	F	A	D	E	-	C	F
4....................	C	A	F	C	-	A	E	-	C	D	E	-	E	F
5....................	C	B	F	C	E	A	D	E	C	D+	D	F	-	E
6....................	D	E	E	D	E	A	E	E	C	D+	E	-	E	-

Legend:

A - over 10 percent.
B - 5 to 10 percent.
C - 1 to 5 percent.
D - 0.1 to 1 percent.
E - 0.01 to 0.1 percent.
F - 0.001 to 0.01 percent.
G - less than 0.001 percent.

Magnetic iron, magnetite, or recoverable iron assays are empirical analyses based on the percentage of total iron recovered in a concentrate by low-intensity wet magnetic separation at a selected grind. Thus, based on treatment of minus-100-mesh ore, samples 1 and 2 contain approximately 11.8 and 9.4 percent magnetic iron, respectively.

Tests later described show that both the grade of concentrate and the percentage of iron in the tailing depend, to a large extent, on the degree of fineness of the feed. For this reason, all recoveries given in this paper have been reported in terms of total iron rather than magnetic iron.

METHODS OF CONCENTRATION

Iron ore is a low-priced commodity. This limits the amount of work that can be expended on beneficiation and necessitates comparatively simple concentration methods.

Crushing and screening often are employed on high-grade ores to produce more satisfactory material for furnace consumption. Washing can be applied to ores in which gangue is present as fine material readily separated from the iron minerals. Jigging and, more recently, heavy-medium sink-float processes have been used successfully to concentrate ores in which gangue and iron minerals are separated relatively coarse sizes. For ores finer than 3/16-inch, tabling and spiral concentration are considered to be the most applicable of the various gravity treatments.

Flotation methods are metallurgically feasible for the beneficiation of some hematite ores, but high reagent and grinding costs have made the process economically unattractive.

Magnetic concentration methods are suitable for ores containing magnetite. Grinding costs are usually high, but magnetic methods often have the advantage over flotation in that it is sometimes possible to concentrate in stages, eliminating waste in each stage, thus reducing the amount of material to each succeeding grinding circuit.

The laboratory studies conducted on the Klukwan samples included preliminary sizing and gravity-concentration tests. Because the ore was fine grained, however, the bulk of the test work was directed toward development of a feasible magnetic treatment method.

Specifications for an iron concentrate vary widely, depending on the purpose for which it is to be used and the process employed to produce the finished metal. For example, hematite ores containing less than 50 percent Fe are acceptable for blast-furnace consumption, but specifications imposed upon magnetite ores often require an iron content over 60 percent. The laboratory testing was directed, therefore, toward developing a treatment method to produce a plus-60-percent Fe concentrate.

Although fine magnetite concentrates require sintering or nodulizing before use as blast-furnace feed, study of this phase of the problem was considered to be beyond the scope of this paper.

Similarly the restrictions placed on titanium content of an iron ore vary with the smelting process to be employed. It is generally held that titaniferous iron ores are undesirable in blast furnaces if the titanium oxide content is above 2.5 to 3.0 percent. It is reported, however, that ores and sinters containing up to 10 percent TiO_2 have been treated successfully by blast-furnace smelting.3/ In addition, electric furnace methods have been developed to effect direct smelting of titaniferous ores. In this report, therefore, the titania content of the concentrate has been reported without an attempt to evaluate the product.

Sizing

Samples 1 and 2, as received, were screen sized dry, using foundry riddles and standard Tyler sieves to produce a series of sized fractions from plus-4-inches to minus-20-mesh. Portions of each of the other samples were roll crushed to minus-20-mesh and wet screened to yield sized products from plus-65-mesh to minus-200-mesh. None of the tests showed any marked concentration

3/ Barksdale, Jelks, Titanium, Its Occurrence, Chemistry, and Technology: The Ronald Press Co., New York, 1949, pp. 409-412.

of iron in any sized fraction. The sizing tests on the low-grade ores showed slight concentration of iron below 100-mesh; on the higher-grade ores slight concentration was noted below 48-mesh. These results corroborated the petrographic reports, which indicated that only partial liberation was effected coarser than 100-mesh for the low-grade ores and coarser than 48-mesh for the high-grade samples.

The results obtained from sizing samples 1 and 2 are shown in tables 3 and 4 to emphasize the uniformity in grade of the various sized fractions.

TABLE 3. - Screen analysis, sample 1

Product	Weight-percent	Assay, percent Fe	Distribution, percent Fe
Plus-4-inch	36.4	17.1	35.6
Plus-2-inch	15.2	16.4	14.3
Plus-1-inch	9.0	16.6	8.5
Plus-1/2-inch	3.0	17.1	2.9
Plus 1/4-inch	5.5	17.2	5.5
Plus-10-mesh	5.4	17.2	5.3
Plus-20-mesh	5.4	17.8	5.5
Minus-20-mesh	20.1	19.45	22.4
Calc. head	100.0	17.5	100.0

TABLE 4. - Screen analysis, sample 2

Product	Weight-percent	Assay, percent Fe	Distribution, percent Fe
Plus-4-inch	4.38	11.6	3.9
Plus-2-inch	16.26	15.9	16.3
Plus-1-inch	14.81	13.5	12.6
Plus-1/2-inch	9.01	13.1	7.4
Plus-1/4-inch	6.44	13.6	5.4
Plus-10-mesh	8.33	13.5	7.1
Plus-20-mesh	8.05	13.4	6.8
Minus-20-mesh	32.72	19.7	40.5
Calc. head	100.0	15.9	100.0

Sink-Float

To determine if either high-grade concentrate or low-grade reject could be made at relatively coarse sizes, a series of heavy-liquid sink-float tests was conducted on portions of sample 1 crushed to minus-3/8-inch. The medium used was tetrabromoethane, alone and in mixtures with carbon tetrachloride. Several medium specific gravities were tried.

Results were poor. No reject was made that assayed less than 11.5 percent Fe, and no concentrate was made higher than 21.5 percent Fe.

Table Concentration

To determine the effectiveness of shaking-table concentration, portions of samples 1 and 2 were crushed to minus-20-mesh and treated, unsized, on a laboratory shaking table. By this method 44 percent of the total iron in sample 1 was recovered in a concentrate that assayed 37.6 percent Fe. Inclusion of the table middling increased the iron recovery to 70 percent; the resulting product assayed 28.7 percent Fe. Treatment of sample 2 yielded a concentrate assaying 48.1 percent Fe and containing 35 percent of the total iron. Combined concentrate and middling contained 76.5 percent of the total iron at a grade of 22.3 percent Fe. In each test, approximately 50 percent of the total weight of material treated was rejected as tailing that assayed about 9.0 percent Fe.

The poor results obtained by table-concentration treatment can be attributed to locked particles that concentrated as a middling product. The gradation between middling and tailing was not sharp; hence, the reject product was not clean. One preliminary spiral-concentration test gave results that were virtually identical.

Table or spiral concentration could not be considered for use in a commercial milling plant except as a possible preliminary beneficiation step if it were determined that treatment of large tonnage was of prime importance and overall recovery of secondary significance.

Low-Intensity Wet Magnetic Separation

Portions of each sample were ground to various sizes, as indicated in the following tabulated summary. Each ground portion was treated in a low-intensity wet magnetic separator to yield magnetic and nonmagnetic fractions. Results showing iron and titania content of the magnetic fractions, together with the recovery of total iron in these fractions, are summarized in tables 5 to 10, inclusive.

TABLE 5. - Low-intensity magnetic separation, sample 1

Grind (mesh)	Product	Weight-percent	Assay, percent Fe	Assay, percent TiO_2	Distribution, percent Fe	Distribution, percent TiO_2
Minus-20........	Magnetic	31.38	38.5	2.9	71.3	42.4
	Nonmag.	68.62	7.1	1.8	28.7	57.6
	Calc. head	100.00	17.0	2.1	100.0	100.0
Minus-35........	Magnetic	24.91	49.5	2.9	69.8	33.5
	Nonmag.	75.09	7.1	1.9	30.2	66.5
	Calc. head	100.00	17.6	2.1	100.0	100.0
Minus-48........	Magnetic	21.22	56.2	2.85	67.7	28.7
	Nonmag.	78.78	7.2	1.9	32.3	71.3
	Calc. head	100.00	17.6	2.1	100.0	100.0
Minus-65........	Magnetic	19.68	60.6	2.4	68.0	21.8
	Nonmag.	80.32	7.0	2.1	32.0	78.2
	Calc. head	100.00	17.5	2.2	100.0	100.0
Minus-100.......	Magnetic	18.80	64.3	1.8	67.7	15.9
	Nonmag.	81.20	7.1	2.2	32.3	84.1
	Calc. head	100.00	17.8	2.1	100.0	100.0
Minus-150.......	Magnetic	18.55	64.5	1.7	66.8	14.6
	Nonmag.	81.45	7.3	2.25	33.2	85.4
	Calc. head	100.00	17.9	2.1	100.0	100.0
Minus-200.......	Magnetic	17.74	64.7	1.65	65.3	13.6
	Nonmag.	83.26	7.4	2.25	34.7	86.4
	Calc. head	100.00	17.6	2.1	100.0	100.0

Results shown in table 5 indicate that grinding to minus-65-mesh was required to produce a plus-60-percent Fe concentrate from sample 1. This product contained 68 percent of the total iron in the sample.

TABLE 6. - Low-intensity magnetic separation, sample 2

Grind (mesh)	Product	Weight-percent	Assay, percent		Distribution, percent	
			Fe	TiO_2	Fe	TiO_2
Minus-20........	Magnetic	23.91	41.0	2.8	64.2	44.4
	Nonmag.	76.09	7.2	1.1	35.8	55.6
	Calc. head	100.00	15.3	1.5	100.0	100.0
Minus-35........	Magnetic	17.39	52.0	2.8	60.6	32.9
	Nonmag.	82.61	7.2	1.2	39.4	67.1
	Calc. head	100.00	15.1	1.5	100.0	100.0
Minus-48........	Magnetic	15.16	60.5	2.65	60.7	26.7
	Nonmag.	84.84	7.0	1.3	39.3	73.3
	Calc. head	100.00	15.1	1.5	100.0	100.0
Minus-65........	Magnetic	14.50	63.3	2.4	60.9	22.5
	Nonmag.	85.50	6.9	1.4	39.1	77.5
	Calc. head	100.00	15.1	1.5	100.0	100.0
Minus-100.......	Magnetic	14.09	64.5	2.1	60.5	19.7
	Nonmag.	85.91	6.9	1.4	39.5	80.3
	Calc. head	100.00	15.0	1.5	100.0	100.0
Minus-150.......	Magnetic	13.01	66.3	1.8	57.3	15.2
	Nonmag.	86.99	7.4	1.5	42.7	84.8
	Calc. head	100.00	15.1	1.55	100.0	100.0
Minus-200.......	Magnetic	12.75	68.0	1.4	57.3	11.3
	Nonmag.	87.25	7.4	1.6	42.7	88.7
	Calc. head	100.00	15.1	1.55	100.0	100.0

The above results show that the iron content of the gangue remained approximately the same as in sample 1. Hence, treatment of the lower grade sample 2 resulted in lower percentage recoveries of the total iron. Plus-60-percent Fe concentrate was produced with a total iron recovery of 60.7 percent by treatment of ore ground to minus-48-mesh.

TABLE 7. - Low-intensity magnetic separation, sample 3

Grind (mesh)	Product	Weight-percent	Assay, percent Fe	Assay, percent TiO_2	Distribution, percent Fe	Distribution, percent TiO_2
Minus-20........	Magnetic	13.49	47.0	2.5	46.9	19.3
	Nonmag.	86.51	8.3	1.6	53.1	80.7
	Calc. head	100.00	13.5	1.7	100.0	100.0
Minus-35........	Magnetic	12.15	52.0	2.5	46.6	17.8
	Nonmag.	87.85	8.25	1.6	53.4	82.2
	Calc. head	100.00	13.6	1.7	100.0	100.0
Minus-48........	Magnetic	11.54	55.0	2.5	46.7	17.1
	Nonmag.	88.56	8.2	1.6	53.3	82.9
	Calc. head	100.00	13.6	1.7	100.0	100.0
Minus-65........	Magnetic	10.34	60.0	2.3	45.8	13.9
	Nonmag.	89.66	8.2	1.65	54.2	86.1
	Calc. head	100.00	13.6	1.7	100.0	100.0
Minus-100.......	Magnetic	10.03	62.3	2.0	46.3	11.6
	Nonmag.	89.97	8.05	1.7	53.7	88.4
	Calc. head	100.00	13.5	1.75	100.0	100.0
Minus-150.......	Magnetic	9.60	64.7	1.65	46.0	9.6
	Nonmag.	90.40	8.05	1.65	54.0	90.4
	Calc. head	100.00	13.5	1.65	100.0	100.0
Minus-200.......	Magnetic	9.71	66.0	1.5	47.3	8.9
	Nonmag.	90.29	7.9	1.65	52.7	91.1
	Calc. head	100.00	13.5	1.65	100.0	100.0
Minus-325.......	Magnetic	9.29	66.2	1.2	45.3	6.7
	Nonmag.	90.71	8.2	1.7	54.7	93.3
	Calc. head	100.00	13.6	1.7	100.0	100.0

Wet magnetic separation treatment of the low-grade sample 3 recovered 45.8 percent of the total iron in a magnetic concentrate that assayed 60.0 percent Fe. Minus-65-mesh grinding was required to produce 60-percent Fe concentrate.

TABLE 8. - Low-intensity magnetic separation, sample 4

Grind (mesh)	Product	Weight-percent	Assay, percent Fe	Assay, percent TiO_2	Distribution, percent Fe	Distribution, percent TiO_2
Minus-20........	Magnetic	26.58	42.9	2.7	65.7	67.2
	Nonmag.	73.42	8.1	1.9	34.3	32.8
	Calc. head	100.00	17.3	2.1	100.0	100.0
Minus-48........	Magnetic	18.69	57.8	2.6	63.3	23.9
	Nonmag.	81.31	7.7	1.9	36.7	76.1
	Calc. head	100.00	17.1	2.0	100.0	100.0
Minus-65........	Magnetic	18.10	59.8	2.4	63.8	20.9
	Nonmag.	81.90	7.5	2.0	36.2	79.1
	Calc. head	100.00	17.0	2.1	100.0	100.0
Minus-100.......	Magnetic	16.46	63.6	1.8	62.9	15.0
	Nonmag.	83.54	7.4	2.0	37.1	85.0
	Calc. head	100.00	16.7	2.0	100.0	100.0
Minus-200.......	Magnetic	15.72	66.1	1.4	60.9	11.1
	Nonmag.	84.28	7.9	2.1	39.1	88.9
	Calc. head	100.00	17.0	2.0	100.0	100.0

By wet magnetic separation treatment of sample 4 ground to minus-100-mesh, approximately 63 percent of the total iron was recovered in a concentrate that assayed 63.6 percent Fe.

TABLE 9. - Low-intensity magnetic separation, sample 5

Grind (mesh)	Product	Weight-percent	Assay, percent Fe	Assay, percent TiO_2	Distribution, percent Fe	Distribution, percent TiO_2
Minus-20........	Magnetic	89.26	60.8	4.5	98.2	83.6
	Nonmag.	10.74	9.5	7.3	1.8	16.4
	Calc. head	100.00	55.2	4.7	100.0	100.0
Minus-48........	Magnetic	85.06	63.6	4.2	97.3	76.8
	Nonmag.	14.94	10.0	7.2	2.7	23.2
	Calc. head	100.00	55.6	4.6	100.0	100.0
Minus-65........	Magnetic	83.51	64.0	4.1	96.7	74.7
	Nonmag.	16.49	10.9	7.0	3.3	25.3
	Calc. head	100.00	55.2	4.6	100.0	100.0
Minus-100.......	Magnetic	79.41	65.6	3.7	95.8	64.4
	Nonmag.	20.59	10.9	7.9	4.2	35.6
	Calc. head	100.00	53.9	4.6	100.0	100.0
Minus-200.......	Magnetic	81.68	65.8	3.6	96.4	62.5
	Nonmag.	18.32	11.0	9.6	3.6	37.5
	Calc. head	100.00	56.3	4.7	100.0	100.0

Plus-60-percent Fe concentrate was produced, with a total iron recovery of 98.2 percent, by magnetic separation treatment of sample 5 ground to minus-20-mesh. Treatment at finer grinds increased the iron grade to as high as 65 percent Fe with only slight decrease in recovery. Titania content of all concentrates was high, decreasing slightly with finer grinding.

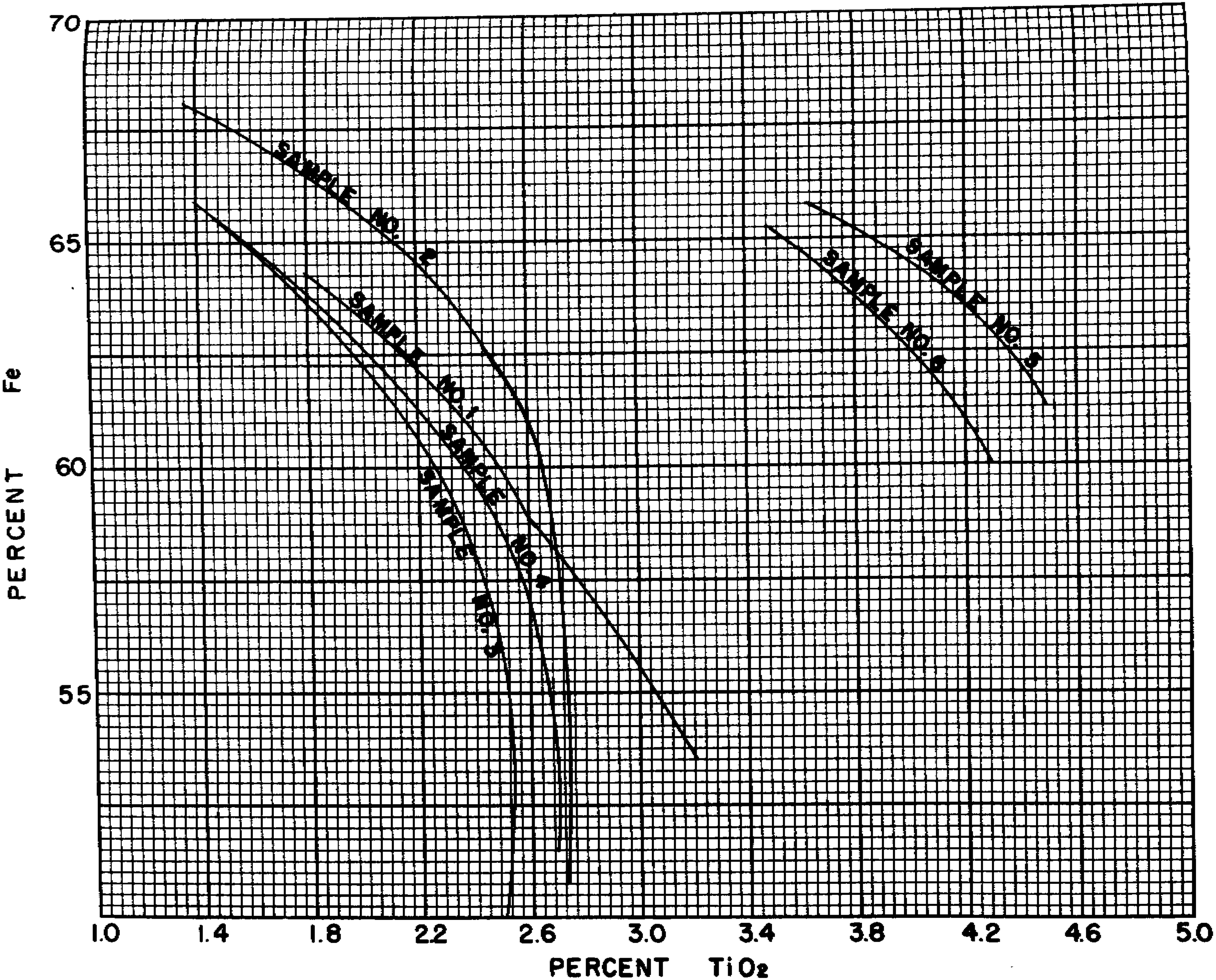

Figure 2. - Iron grade vs. titania content.

TABLE 10. - Low-intensity magnetic separation, sample 6

Grind (mesh)	Product	Weight-percent	Assay, percent		Distribution, percent	
			Fe	TiO_2	Fe	TiO_2
Minus-20........	Magnetic	84.35	60.0	4.3	97.1	82.5
	Nonmag.	15.65	9.5	4.9	2.9	17.5
	Calc. head	100.00	52.1	4.4	100.0	100.0
Minus-48........	Magnetic	80.25	62.6	4.0	96.1	73.0
	Nonmag.	19.75	10.3	6.0	3.9	27.0
	Calc. head	100.00	52.3	4.4	100.0	100.0
Minus-65........	Magnetic	78.03	64.0	3.7	95.5	67.9
	Nonmag.	21.97	10.7	6.2	4.5	32.1
	Calc. head	100.00	52.3	4.3	100.0	100.0
Minus-100.......	Magnetic	77.22	64.7	3.6	95.3	63.5
	Nonmag.	22.78	10.9	7.0	4.7	36.5
	Calc. head	100.00	52.4	4.4	100.0	100.0
Minus-200.......	Magnetic	76.59	65.7	3.5	95.1	63.4
	Nonmag.	23.41	11.1	6.6	4.9	36.6
	Calc. head	100.00	52.9	4.2	100.0	100.0

Results obtained by wet magnetic separation of sample 6 were similar to those obtained by similar treatment of sample 5. Treatment of ore ground to minus-20-mesh recovered 97 percent of the total iron in a concentrate that assayed 60.0 percent Fe and 4.3 percent TiO_2. Treatment of minus-200-mesh material yielded a product assaying 65.7 percent Fe and 3.5 percent TiO_2 with an iron recovery of 95 percent.

In general, it was determined that the iron content of the gangue varies slightly in various parts of the deposit but appears to average 7 to 10 percent Fe. Thus, the recovery obtainable by wet magnetic separation is roughly proportional to the grade of the ore.

The degree of association of magnetite and gangue also varies. The foregoing tests indicated that minus-65-mesh grinding is a requisite for the production of concentrates assaying over 60 percent Fe for low-grade ores but that a similar grade of concentrate can be obtained from high-grade ore by treatment after grinding to minus-20-mesh. The tests also showed that, in general, grinding finer than 100-mesh resulted in an increase in the iron content of the reject, probably owing to sliming of a small amount of the magnetite.

The bulk of the titanium apparently is present as sphene and thus can be removed by magnetic separation treatment. A portion of it, however, seems to be an inherent part of the magnetite. An inverse ratio appears to exist between the grade of iron and the titania content in the cleaner higher-grade concentrates. Although the same ratio does not exist for all samples, plotted curves show the same general trend. (See fig. 2.)

The Bureau of Mines Intermountain Experiment Station at Salt Lake City conducted similar tests on a composite of the eight channel samples cut from

Canyon 2 by engineers of the Bureau of Mines. The composite assayed 25.5 percent Fe. Wet magnetic separation of ore ground to minus-48-mesh recovered 81.6 percent of the total iron in a concentrate that assayed 61.3 percent Fe and 2.5 percent TiO_2.

A study was made of sized fractions of sample 1 to further substantiate the results obtained by wet magnetic separation treatment. Portions of each sized fraction obtained from the previously mentioned sizing test were ground to minus-20-, minus-35-, minus-48-, minus-65-, and minus-100-mesh. Each ground portion was treated in a low-intensity magnetic separator to yield magnetic and non-magnetic products. The results obtained from each sized fraction were almost identical, allowing for limitation of accuracy in grinding, sample prparation, analytical techniques, and the slight difference in iron content of the various fractions. The results indicated that grinding to minus-65-mesh was required to produce iron concentrates assaying 60 percent Fe; about 67.5 percent of the total iron was recovered in a 60-percent Fe concentrate. It will be noted that these average results are virtually identical to those shown in table 5.

Coarse, Dry Magnetic Separation

Visual examination of the ore showed certain particles of relatively coarse size that appeared to be composed almost entirely of magnetite grains.

The minus-1-inch plus-1/2-inch and minus-1/2-inch plus-1/4-inch fractions of sample 2 ore were treated with a hand magnet to concentrate the most highly magnetic particles. The concentrates were sorted visually to select the high grade particles. Typical results are shown in table 11.

TABLE 11. - Hand magnet-sorting treatment, sample 2, minus-1/2-inch

Product	Weight-percent	Assay, percent Fe	Distribution, percent Fe
Sorted concentrate............	2.71	58.4	11.7
Middling......................	33.42	20.6	50.7
Tailing.......................	63.87	8.0	37.6
Calc. head....................	100.00	13.6	100.0

The hand magnet-visual sorting treatment showed that there is only a very small portion of the iron present as large, relatively high-grade particles. The reject, however, assayed only 8.0 percent Fe and contained up to 65 percent of the total weight of the ore. These results indicated that magnetic separation at relatively coarse sizes could be used as a preliminary concentration.

Combined Dry and Wet Magnetic Separation

A series of tests were run in which screen-sized fractions of ores 1 and 2 were treated on a Wetherill-type dry magnetic separator to produce a low-grade concentrate and a clean reject. Results of preliminary tests showed that consistently clean rejects could not be made at sizes above 20-mesh.

A portion of sample 1 was crushed to a minus-20-mesh and screen sized, using 35-, 65- and 150-mesh standard Tyler sieves. The two coarser fractions were treated separately on the Wetherill-type separator at the minimum magnetic intensity possible on the laboratory model. The products of each sized fraction were combined. The combined magnetic product (28 percent of total weight) was ground to pass a 65-mesh screen and added to the original minus-150-mesh portion (21.7 percent of total weight). The combined product was treated on a wet low-intensity magnetic separator to produce a high-grade concentrate and a second reject.

Treatment of sample 2 was identical, except that the minus-150-mesh fraction was not removed, and the entire sample was treated by dry-magnetic separation. Removal of the fines is preferable, however, since they tend to cling to the feed belt of the separator rather than be removed by the cross belts.

Results of these tests are summarized in tables 12 and 13.

TABLE 12. - Combined dry and wet magnetic separation, sample 1

Product	Weight-percent	Assay, percent Fe	Assay, percent TiO_2	Distribution, percent Fe
Concentrate....................	19.57	62.6	2.65	67.5
Wet nonmag.	29.92	7.8	2.45	12.9
Dry nonmag.	50.51	7.05	1.30	19.6
Calc. head.....................	100.00	18.1	1.9	100.0

TABLE 13. - Combined dry and wet magnetic separation, sample 2

Product	Weight-percent	Assay, percent Fe	Assay, percent TiO_2	Distribution, percent Fe
Concentrate....................	14.21	60.4	2.4	58.0
Wet nonmag.	16.55	7.8	2.2	8.7
Dry nonmag.	69.24	7.1	1.0	33.3
Calc. head.....................	100.00	14.8	1.4	100.0

Dry magnetic separation of minus-20-mesh ore followed by grinding and re-treatment of the magnetic portion in a wet low-intensity magnetic separator recovered 67.5 percent of the total iron of sample 1 and 58.0 percent of the iron of sample 2 in concentrates assaying plus-60-percent Fe. The recoveries closely approach those made by fine grinding and magnetic separation. (See tables 3 and 4.) The combination treatment has the added advantage of rejecting a large portion of the ore after only a minus-20-mesh grind.

Wet Magnetic Separation With Re-Treatment

The ore, as mined, would contain some moisture and would require drying if a dry magnetic separation treatment were to be used. Therefore, investigation was made of wet magnetic separation at relatively coarse sizes, followed by regrinding and re-treatment. The results shown in tables 14 to 19, inclusive, were obtained by treatment of ore ground to minus-20-mesh in a wet low-intensity separator, regrinding the magnetic portion to minus-65-mesh, and re-treatment in the same machine.

TABLE 14. - Wet magnetic separation with re-treatment, sample 1

Product	Weight-percent	Assay, percent						Distribution, percent Fe
		Fe	TiO_2	P	S	SiO_2	V	
Concentrate....	19.86	63.1	2.15	1/0.02	0.06	4.7	0.30	67.7
Regrind tail...	8.51	8.1	4.2	-	-	-	-	3.7
Tail...........	71.63	7.4	1.45	-	-	-	-	28.6
Calc. head.....	100.00	18.5	1.8	-	-	-	-	100.0

1/ Less than.

TABLE 15. - Wet magnetic separation with re-treatment, sample 2

Product	Weight-percent	Assay, percent						Distribution, percent Fe
		Fe	TiO_2	P	S	SiO_2	V	
Concentrate....	13.96	62.8	2.2	1/0.02	0.06	4.4	0.40	58.4
Regrind tail...	7.79	8.2	3.15	-	-	-	-	4.3
Tail...........	78.25	7.15	1.3	-	-	-	-	37.3
Calc. head.....	100.00	15.0	1.5	-	-	-	-	100.0

1/ Less than.

TABLE 16. - Wet magnetic separation with re-treatment, sample 3

Product	Weight-percent	Assay, percent						Distribution, percent Fe
		Fe	TiO_2	P	S	SiO_2	V	
Concentrate....	9.67	62.3	2.15	1/0.02	0.02	3.9	0.31	44.6
Regrind tail...	3.82	8.3	3.15	-	-	-	-	2.3
Tail...........	86.51	8.3	1.6	-	-	-	-	53.1
Calc. head.....	100.00	13.5	1.7	-	-	-	-	100.0

1/ Less than.

TABLE 17. - Wet magnetic separation with re-treatment, sample 4

Product	Weight-percent	Assay, percent						Distribution, percent Fe
		Fe	TiO_2	P	S	SiO_2	V	
Concentrate....	16.96	62.5	2.1	1/0.02	0.02	2.9	0.32	61.1
Regrind tail...	9.62	8.2	3.4	-	-	-	-	4.6
Tail...........	73.42	8.1	1.9	-	-	-	-	34.3
Calc. head.....	100.00	17.3	2.1	-	-	-	-	100.0

1/ Less than.

TABLE 18. - Wet magnetic separation with re-treatment, sample 5

Product	Weight-percent	Assay, percent						Distribution, percent Fe
		Fe	TiO_2	P	S	SiO_2	V	
Concentrate....	83.89	64.0	4.2	1/0.02	0.01	0.55	0.31	97.2
Regrind tail...	5.37	10.0	8.8	-	-	-	-	1.0
Tail...........	10.74	9.5	7.3	-	-	-	-	1.8
Calc. head.....	100.00	55.2	4.8	-	-	-	-	100.0
Comb. rougher concentrate..	89.26	60.8	4.5	-	-	-	-	98.2

1/ Less than.

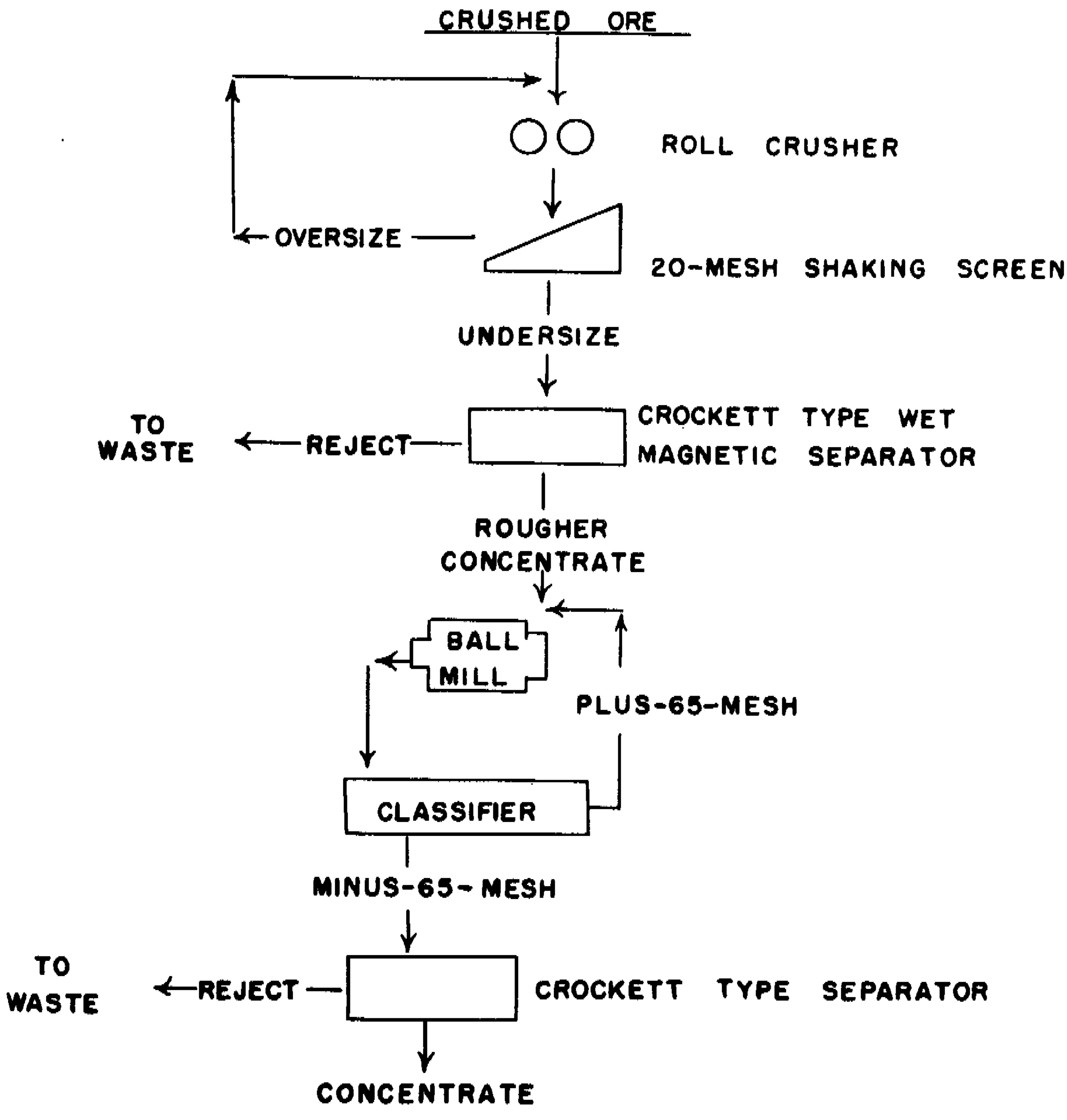

Figure 3. - Proposed flowsheet, Klukwan ore.

TABLE 19. - Wet magnetic separation with re-treatment, sample 6

Product	Weight-percent	Assay, percent						Distribution, percent Fe
		Fe	TiO_2	P	S	SiO_2	V	
Concentrate....	77.53	64.0	3.7	0.02	0.03	0.45	0.32	95.3
Regrind tail...	6.82	14.0	11.1	-	-	-	-	1.8
Tail..........	15.65	9.5	4.9	-	-	-	-	2.9
Calc. head.....	100.00	52.1	4.4	-	-	-	-	100.0
Comb. rougher concentrate..	84.35	60.0	4.3	-	-	-	-	97.1

1/ Less than.

Wet magnetic separation of ore crushed to minus-20-mesh rejected a greater bulk of ore as tailing than comparable dry magnetic treatment, thus further reducing the amount of rougher concentrate for regrinding. Overall recoveries and grades of final concentrates were as good as, and sometimes better than, those obtained by combined dry-wet magnetic treatment or by wet magnetic separation of the entire sample ground to minus-65-mesh.

Since the high-grade ores (samples 5 and 6) yielded 60 percent Fe concentrates by treatment at minus-20-mesh, the re-treatment stage possibly could be eliminated if similar high-grade ores were being treated separately.

The concentrates made from Klukwan ores are similar to Swedish ores in that the sulfur and phosphorus content is low. They should, therefore, be suitable to electric furnace smelting for the production of low phosphorous steel.

Proposed Flowsheet

Treatment by wet magnetic separation followed by grinding and re-treatment of the rougher concentrate could be accomplished by a simple flowsheet such as that shown in figure 3.

SUMMARY

Six samples of ore from the lode and alluvial fan of the Klukwan iron deposit proved to be amenable to beneficiation treatment for the production of concentrates assaying more than 60 percent Fe.

Most satisfactory treatment method appears to be wet magnetic separation of ore ground to minus 20-mesh, followed by grinding and re-treatment of the rougher concentrate. By this method, concentrates assaying 62 to 64 percent Fe were made with total iron recoveries ranging from 45 to 97 percent depending upon the grade of the sample treated. These recoveries correspond to recoveries of about 98 percent of the magnetic iron in all tests.

Titanium oxide content of the concentrates made from low-grade ores averaged about 2.2 percent. Concentrates from higher-grade samples, however, contained up to 4.2 percent TiO_2.