RECOVERY OF HEAVY MINERALS FROM ALABAMA SAND AND GRAVEL OPERATIONS

by

G. V. Sullivan and James S. Browning

Bureau of Mines Nonmetallic Minerals Program

Technical Progress Report - 22

March 1970

U.S. DEPARTMENT OF THE INTERIOR

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G. V. Sullivan[1] and James S. Browning[1]

ABSTRACT

The Bureau of Mines studied 25 samples from 15 Alabama sand and gravel operations to determine their heavy mineral content. All of the samples contained some heavy minerals (4 to 188 pounds per ton), and 80 percent contained 20 or more pounds of heavy minerals per ton of sand and gravel. Valuable heavy minerals, in order of decreasing amounts, were ilmenite, kyanite, zircon, rutile, and monazite.

Large-scale concentration tests were made on samples from three of the State's major producers. Gravity concentration by Humphreys spirals and tables resulted in bulk heavy mineral concentrates that graded from 87 to 91 percent heavy minerals. Mineral recoveries ranged, in percent, as follows: ilmenite, 60-95; zircon, 96-100; kyanite, 37-77; rutile, 89-100; and monazite, 96-100.

Separation studies on a gravity concentrate from an eastern Alabama operation showed it would respond to conventional separation techniques to produce individual mineral concentrates. Individual mineral concentrates obtained were ilmenite, 58.7 percent TiO_2; rutile, 93.7 percent TiO_2; kyanite, 55 percent Al_2O_3; zircon, 58.0 percent ZrO_2; and a rare-earth product containing 66.7 percent monazite and 7.1 percent xenotime.

INTRODUCTION

This Bureau of Mines report summarizes preliminary progress on an investigation to determine the occurrence and recoverability of heavy minerals in sand and gravel operations in Alabama. It was found that the sands and gravels studied contained heavy minerals similar to those recovered from Florida beach sands.[2] The valuable heavy minerals found in the sand and

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[2] Carpenter, J. H., J. C. Detweiler, J. L. Gillson, E. C. Weichel, Jr., and J. P. Wood. Mining and Concentration of Ilmenite and Associated Minerals at Trail Ridge, Fla. Min. Eng., August 1953, pp. 789-795.

Peterson, E. C. Titanium Resources of the United States. BuMines Inf. Circ. 8290, 1966, pp. 52-56.

gravel operations were ilmenite, zircon, kyanite, rutile, and monazite. The domestic production and consumption of these minerals for 1968 is outlined in the following tabulation.

Mineral	Short tons			
	Production	Imports	Consumption	Free world production
Ilmenite[1]	928,509	-	959,558	3,216,063
Rutile[1]	W	160,273	174,366	356,682
Zircon[2]	W	59,900	143,000	355,000
Kyanite[3]	W	[4]20,477	NA	NA
Monazite[5]	W	4,367	NA	10,765

NA Not available.
W Withheld to avoid disclosing individual company confidential data.

[1] Parker, J. G. Titanium. Preprint from the 1968 BuMines Minerals Yearbook, 13 pp.
[2] Parker, J. G. Zirconium and Hafnium. Preprint from the 1968 BuMines Minerals Yearbook, 7 pp.
[3] Sweeney, J. W. Kyanite and Related Minerals. Preprint from the 1968 BuMines Minerals Yearbook, 4 pp.
[4] Exports.
[5] Stevens, R. F., Jr. Thorium. Preprint from the 1968 BuMines Minerals Yearbook, 6 pp.

The domestic supply of these minerals range from rutile in which almost all that is consumed is imported, to zircon in which imports account for 40 percent of consumption, to ilmenite in which production is approximately equal to consumption, to kyanite in which the United States is an exporter.

The increasing consumption of rutile and the minimal domestic production caused the Office of Emergency Planning (OEP) to establish a productive expansion goal of 70,000 tpy in June 1967. The quoted price of rutile has risen from \$120 to \$160 per ton for 96 percent TiO_2 rutile in recent months.[3]

A research program was initiated to determine the occurrence and recoverability of heavy minerals in the sand and gravel deposits of the Southeast. The economic recovery of the heavy minerals would have a threefold effect: (1) provide a domestic supply of materials now being imported, (2) improve the economics of sand and gravel operations, and (3) conserve a potential domestic mineral resource.

ACKNOWLEDGMENTS

The authors wish to thank the personnel of the operations that made samples available for this study. We wish to especially thank the people that allowed the use of and furnished services for the operation of the mobile preconcentration unit. The companies furnishing samples are listed below.

[3] Engineering and Mining Journal. V. 170, No. 5, May 1969, p. 30; No. 9, October 1969, p. 38.

Alabama Gravel Co.	Birmingham, Ala.
Anderson Sand and Gravel Co.	Columbus, Ga.
Builder Supply Co.	Talladega, Ala.
Consolidated Gravel Co.	Columbus, Ga.
Dixie Sand and Gravel Co.	Montgomery, Ala.
Geo. A. Dozier, Contractor	Montgomery, Ala.
Hicks Sand Co.	Mobile, Ala.
John B. Legarde, Inc.	Anniston, Ala.
Radcliff Materials, Inc.	Mobile, Ala.
Riverside Sand and Gravel Co.	Lincoln, Ala.
Vulcan Materials Co.	Birmingham, Ala.
Yazoo Gravel Co.	Tuscaloosa, Ala.

SAND AND GRAVEL OPERATIONS IN ALABAMA

Szabo described the sand and gravel operations in Alabama, including the major geologic sources.[4] The major production comes from the Tuscaloosa and Eutaw Formations, with a lesser production from the Citronelle Formation. Dredges in the Alabama and Chattahoochee Rivers also account for appreciable tonnages of the gravel production.

The Tuscaloosa Formation extends across Alabama, Georgia, and South Carolina, and parts of Tennessee and North Carolina. It extends across Alabama from the Mississippi border on the northwest to the Georgia border. In eastern Alabama the formation consists chiefly of quartz derived from erosion of metamorphic and igneous rocks in the Piedmont province, and in northwest Alabama the gravel consists largely of chert derived from the erosion of chert-bearing formations of Paleozoic age.[5]

South of and adjacent to the Tuscaloosa Formation, the Eutaw Formation extends across the State in a belt approximately 16 miles wide. The formation is composed of massive to cross-bedded medium-grained sand and dark clay.[6] The Eutaw Formation also appears in parts of Tennessee and North and South Carolina.

The major source of sand and gravel in southwestern Alabama is the Citronelle Formation. The material is chiefly iron-stained quartz and chert sand and gravel.[7] Sand and gravel operations are fairly widespread; however, the greatest production is centered in the Montgomery area. The four contiguous counties of Montgomery, Macon, Elmore, and Autauga comprise the major producing area.

RECONNAISSANCE SAMPLES

In obtaining the initial samples for this study, the objective was to include most of the larger and more permanent operations and, at the same time,

[4] Szabo, M. W. Sand and Gravel in Alabama. Geol. Survey of Alabama, Circular 44, 1967, 41 pp.
[5] Page 9 of work cited in footnote 4.
[6] Page 10 of work cited in footnote 4.
[7] Page 11 of work cited in footnote 4.

represent a wide geographical and geological spectrum. As a result the majority of the samples are from the Tuscaloosa and Eutaw Formations. The majority of the samples were of material discarded as waste. However, although the waste material generally contains more heavy minerals than the finished sand products, the clean sand products also contain an appreciable amount of heavy minerals. Many of the samples contained heavy minerals in amounts at or near commercial quantities of 1 to 4 percent.[8]

A total of 25 samples was obtained from 15 plants. The data in table 1 show the property and sample designation and the geographical, geological, and operational source of the samples.

TABLE 1. - Sources of reconnaissance samples from Alabama sand and gravel operations

Property designation	Sample designation	Plant location, county	Sample source	Sample material
1	1-A	Elmore....	Tuscaloosa Formation	Mortar sand.
	1-B	....do....	.........do.........	Waste.
2	2-A	Montgomery	Alabama River.......	Gravel plant undersize.
	2-B	....do....	.........do.........	River dredge underflow.
3	3	....do....	Eutaw Formation.....	Gravel plant undersize.
4	4	Talladega.	Alluvium............	Waste.
[1]5	5	....do....	.........do.........	Do.
6	6-A	Calhoun...	Weisner Quartzite...	Mortar sand.
	6-B	....do....	.........do.........	Waste.
7	7	Tuscaloosa	Tuscaloosa Formation	Do.
8	8-A	Russell...	.........do.........	Stockpile gravel plant undersize.
	8-B	....do....	.........do.........	Clean sand.
	8-C	....do....	.........do.........	Terrace dredge underflow.
	8-D	....do....	Chattahoochee River.	River dredge underflow.
9	9-A	....do....	Eutaw Formation.....	Dredge underflow.
	9-B	....do....	.........do.........	Gravel plant undersize.
10	10	....do....	Tuscaloosa Formation	Waste.
11	11	Macon.....	.........do.........	Do.
12	12-A	Montgomery	.........do.........	Do.
	12-B	....do....	.........do.........	Fine-grained sand deposit.
	12-C	....do....	.........do.........	Clean No. 3 sand.
13	13	Mobile....	Citronelle Formation	Mortar sand.
[1]14	14-A	Montgomery	Tuscaloosa Formation	Gravel plant waste stockpile.
	14-B	....do....	.........do.........	Do.
15	15	Wilcox....	Alabama River.......	Dredge underflow.

[1] Plant no longer operating. Materials sampled are waste stockpiles from gravel operations.

[8] Works cited in footnote 2.

A description of the procedure used to evaluate the individual samples is given below. The total heavy mineral content was determined by separation in heavy liquid at specific gravity 2.94. The heavy mineral fractions were evaluated by the following procedure: (1) Crush all oversize to pass a 28-mesh Tyler screen, (2) screen on 35, 48, 65, 100, and 200 mesh, (3) make microscopic grain count of each size fraction to determine a frequency percent for each mineral, (4) convert frequency percentages for each size fraction to weight percentages based on individual mineral specific gravities, and (5) convert individual weight analyses to a composite weight analysis based on the weights of the individual screen fractions. The results are shown in table 2. In addition to the heavy minerals, most of the samples contained small amounts of gold, generally less than 10 cents per ton. Examination of the gold present showed it to consist of extremely thin flakes, which would make recovery by gravity techniques difficult.

TABLE 2. - Analyses of heavy minerals in reconnaissance samples from Alabama sand and gravel operations

Sample	Total heavy minerals, percent	Heavy minerals, pounds per ton					
		Opaque[1]	Zircon	Kyanite	Rutile	Monazite	Other[2]
1-A	1.1	9.4	0.7	2.1	0.8	0.4	8.6
1-B	1.8	16.3	2.2	.5	1.2	.2	15.6
2-A	1.3	11.6	.7	4.2	1.4	.3	7.8
2-B	1.7	12.2	1.3	3.5	1.6	.2	15.2
3	3.8	44.8	1.4	10.1	4.8	1.2	13.7
4	1.5	25.4	2.3	.1	.1	-	2.1
5	1.6	22.2	4.5	.1	.5	Trace	4.7
6-A	.6	6.0	1.0	2.6	.3	Trace	2.1
6-B	1.0	10.4	1.0	3.9	.5	Trace	4.2
7	.7	9.6	.9	.7	.2	.1	[3]2.5
8-A	2.7	19.5	2.0	16.2	.2	1.1	15.0
8-B	1.1	5.4	.1	4.4	.2	.1	11.7
8-C	9.4	55.6	5.6	2.4	4.3	2.3	117.7
8-D	1.2	8.6	.3	3.2	.3	.2	11.3
9-A	3.0	32.0	4.7	7.9	3.8	3.5	8.2
9-B	.3	2.1	.2	1.7	.2	([4])	1.5
10	3.3	25.7	1.9	6.5	1.3	1.7	28.9
11	3.8	27.8	.8	21.0	2.2	1.2	23.0
12-A	2.9	36.1	3.4	4.4	3.1	2.7	8.3
12-B	.2	1.4	.1	.8	.1	.1	1.5
12-C	2.3	25.9	1.3	6.3	2.3	1.3	8.9
13	.3	1.8	.3	1.8	.3	Trace	1.8
14-A	1.1	9.5	.7	3.7	1.0	.4	6.7
14-B	1.5	14.9	1.2	5.6	1.4	.8	6.1
15	2.8	22.2	3.6	8.0	3.5	.7	18.0

[1] Considered to be primarily ilmenite.
[2] Consists of minerals such as staurolite, garnet, epidote, etc.
[3] Contains about 0.1 pound per ton cassiterite.
[4] Not detected.

The opaque mineral fraction in these samples is considered to be ilmenite. Analysis of the opaque mineral fractions shows that they are chemically similar to ilmenite; however, X-ray diffraction shows that the material is amorphous to poorly crystalline. These characteristics have been previously noted in the opaque minerals from Florida beach sand operations and other locations.[9] A trace amount of magnetite was noted in some samples.

The data in table 2 show an arithmetic average of 2 percent total heavy minerals analyzing, in percent, as follows: ilmenite, 45; zircon, 4; kyanite, 12; rutile, 3; monazite, 2; and others, 34. Carpenter and coworkers, in describing the operation at Trail Ridge, Fla., showed that gravity concentration recovered 2.8 to 3.5 percent heavy minerals from the raw sand.[10] Separation of the bulk concentrate showed that 50 percent was titanium minerals, 20 percent staurolite, 14 percent zircon, and 16 percent other heavy minerals. The analysis of the recovered heavy minerals agrees with the analysis reported for the original exploration program in which an arithmetic average of the drill hole samples showed the following analysis, in percent: titanium minerals, 54; zircon, 15; staurolite, 14; and others, 17.[11] Thus the heavy minerals found in these sand and gravel operations are lower in overall quantity but compare favorably in heavy mineral makeup with the Florida deposits that have been commercially worked. It should also be noted that the Florida operations are based solely on heavy mineral values.

BENEFICIATION STUDIES

To determine the recoverability of the heavy minerals contained in these materials, large-scale gravity concentration tests were run on three samples. The samples, in addition to being from three of the major producers in the State, also represent a wide geographical range. The samples, identified as eastern, central, and western, correspond to samples 9-A, 12-A, and 7 (table 1), respectively. The eastern sample was also selected because the grab sample from this operation contained heavy minerals at particle sizes up to 10 mesh. Sample 7 (western) was the only reconnaissance sample in which cassiterite was found; therefore, the large sample would provide sufficient heavies to determine if it was a chance occurrence. An analysis of the feed materials for each of the samples is given in table 3.

Gravity Concentration

Gravity concentration testing employed a mobile concentration unit. The mobile unit is a self-contained unit with an internal power supply that provides for feed regulating, sizing, and three-stage gravity concentrating.

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[9] Creitz, E. E., and T. N. McVay. A Study of Opaque Minerals in Trail Ridge, Florida, Dune Sands. AIME Tech. Pub. 2426, July 1948, 7 pp.
Stow, S. H. The Heavy Minerals of the Bone Valley Formation and Their Value. Econ. Geol., v. 63, 1968, pp. 973-977.
Temple, A. K. Alteration of Ilmenite. Econ. Geol., v. 61, 1966, pp. 695-714.

[10] First work cited in footnote 2.

[11] Spencer, R. V. Titanium Minerals in Trail Ridge, Fla. BuMines Rept. of Inv. 4208, 1948, p. 17.

TABLE 3. - Analyses of test samples from Alabama sand and gravel operations

Sample	Total heavy minerals, percent	Analyses, pounds per ton					
		Opaque	Zircon	Kyanite	Rutile	Monazite	Other
Eastern.....	2.0	14.6	2.4	10.9	2.7	1.5	7.9
Central[1]....	1.9	11.8	.6	5.2	1.2	.4	18.8
Western.....	.5	6.4	.7	.4	.2	-	2.3

[1] Total heavy minerals and other minerals are high because of sampling procedures.

The flowsheet outlining the gravity concentration of the eastern sample is shown in figure 1. The flowsheet is somewhat more complex than that used for concentration of heavy minerals from beach sands.[12] The presence of heavy mineral in the coarse size ranges dictated the use of a split flowsheet. Lack of sufficient equipment to treat the coarse and fines simultaneously necessitated a few additional steps that would not be encountered in a continuous treatment. The feed rate to the mobile plant was limited to about 300 pounds per hour by the capacity of the screening equipment. At the time these tests were conducted, the screen was an 18-inch-diameter circular vibrating screen. Results of gravity concentration are shown in table 4.

TABLE 4. - Gravity concentration of eastern sample

Product	Weight-percent	Opaque	Zircon	Kyanite	Rutile	Monazite	Other	Total heavy minerals
		Analyses, percent						
Concentrate:								
Coarse:								
Plus 28 mesh.....	0.43	6.1	0.7	64.5	3.3	-	23.7	98.3
Minus 28 mesh....	.25	34.7	4.9	21.9	4.0	1.1	21.8	88.4
Fine..............	1.35	43.5	7.9	6.6	8.2	5.5	11.0	82.7
Tailing:								
Coarse............	40.32	.03	Trace	.21	.001	-	.10	.34
Fine..............	49.65	.05	-	.08	-	Trace	.09	.21
Plus 10 mesh.........	8.00	.02	Trace	.07	.001	-	.16	.25
Composite.......	100.00	.74	.12	.55	.14	.08	.40	2.02
Combined concentrates	2.03	34.5	6.0	20.8	6.6	3.8	15.0	86.7
		Distribution, percent						
Concentrate:								
Coarse:								
Plus 28 mesh.....	.43	3.5	2.5	50.4	10.5	-	25.5	20.9
Minus 28 mesh....	.25	11.8	10.0	10.0	7.4	3.6	13.7	10.9
Fine..............	1.35	79.6	87.5	16.2	81.7	96.4	37.2	55.2
Tailing:								
Coarse............	40.32	1.7	Trace	15.6	.3	-	9.6	6.8
Fine..............	49.65	3.2	-	6.8	-	Trace	10.8	5.2
Plus 10 mesh.........	8.00	.2	Trace	1.0	.1	-	3.2	1.0
Composite.......	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Combined concentrates	2.03	94.9	100.0	76.6	99.6	100.0	76.4	87.0

Gravity concentration of the central and western samples is illustrated by the general flowsheet in figure 2. The minor amount of plus 20-mesh heavy minerals in

[12] Works cited in footnote 2.

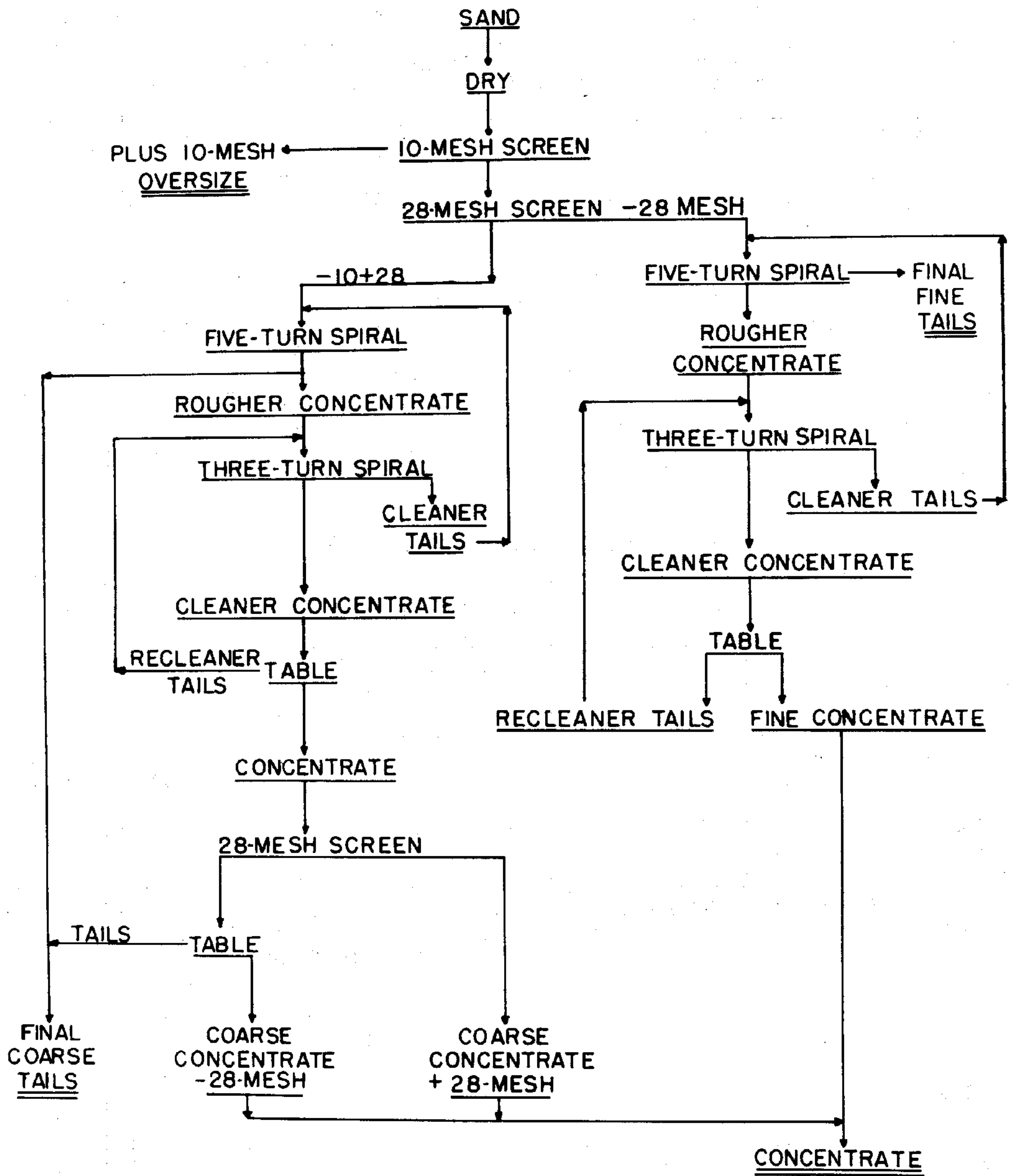

FIGURE 1. - Flowsheet for Gravity Concentration of Eastern Sample.

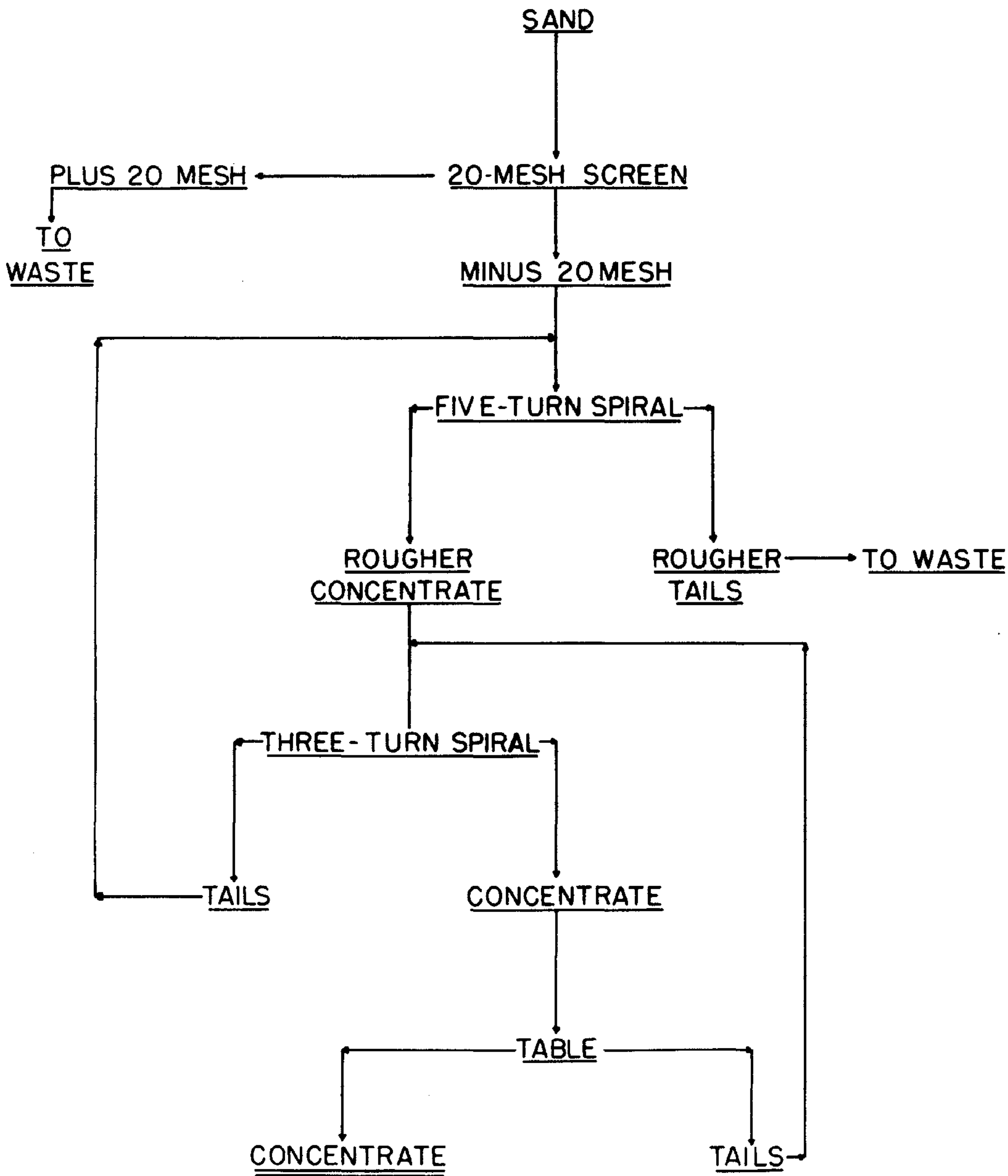

FIGURE 2. - Flowsheet for Gravity Concentration of Central and Western Samples.

these samples permitted the use of the simplified treatment. Results of gravity concentration are shown in table 5 for the central sample and table 6 for the western sample.

TABLE 5. - Gravity concentration of central sample

Product	Weight-percent	Opaque	Zircon	Kyanite	Rutile	Monazite	Other	Total heavy minerals
		Analyses, percent						
Concentrate	0.8	54.4	4.0	8.2	5.9	2.6	15.9	91.0
Tails......	60.5	.10	-	.11	.001	-	.24	.45
Oversize...	38.7	.24	.003	.13	.01	.002	.27	.66
Composite	100.0	.59	.03	.18	.05	.02	.37	1.25
		Distribution, percent						
Concentrate	.8	75.5	97.0	36.5	88.7	95.5	34.0	58.0
Tails......	60.5	10.1	-	35.3	1.9	-	38.4	21.7
Oversize...	38.7	14.4	3.0	28.2	9.4	4.5	27.6	20.3
Composite	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 6. - Gravity concentration of western sample

Product	Weight-percent	Opaque	Zircon	Kyanite	Rutile	Other	Total heavy minerals
		Analyses, percent					
Concentrate....	0.34	44.5	12.1	5.6	4.0	22.5	88.6
Table middlings	.14	10.4	.06	.45	.3	4.3	15.5
Tails..........	92.95	.08	Trace	.006	Trace	.04	.13
Oversize (plus 20 mesh)	6.57	.28	.03	.013	.008	.13	.46
Composite...	100.00	.26	.04	.03	.01	.13	.47
		Distribution, percent					
Concentrate....	.34	58.5	96.3	73.0	93.4	60.1	63.6
Table middlings	.14	5.6	.2	2.4	3.0	4.7	4.6
Tails..........	92.95	28.8	Trace	21.4	Trace	28.5	25.5
Oversize (plus 20 mesh)	6.57	7.1	4.5	3.2	3.6	6.7	6.3
Composite...	100.00	100.0	100.0	100.0	100.0	100.0	100.0

Gravity concentration results in terms of concentrate grade and recovery were generally satisfactory. The main difficulty encountered in the concentration was the poor efficiency in screening. This difficulty was especially noticeable in the treatment of the central sample, where the oversize was 35 percent minus 20 mesh. Most of the heavy minerals lost in the oversize were actually minus 20 mesh. In the treatment of the eastern sample the screening inefficiency did not effect overall recovery; however, it did necessitate the screening of the coarse concentrate and retreatment of the minus 20-mesh material. Because of the small amount (4 percent) of true oversize in the western sample, the effect of poor screening was minimized.

The specific gravity and particle shape of the kyanite resulted in a lower recovery of this mineral in the eastern and central samples. No cassiterite was found in any of the products of the western sample, indicating that the grab sample content was high.

Fractionation of a Gravity Concentrate

Fractionation studies have been concerned primarily with the eastern gravity concentrate. Therefore, these test conditions and results will be given as illustrative. The fractionation followed the general techniques used commercially on beach sand heavy minerals; namely, high-tension, magnetic and gravity separation. A variation from standard beach sand separation techniques was the use of a split flowsheet. A split flowsheet was used because of the wide range of particle sizes present in the material. The procedure is outlined in the flowsheet in figure 3, and the results are shown in table 7. Partial chemical analysis of some of the final products is given in table 8.

TABLE 7. - Fractionation of the eastern sample gravity concentrate

Product	Weight-percent	Opaque	Zircon	Kyanite	Rutile	Monazite	Other
		Analyses, percent					
Magnetite	0.3	100.0	-	-	-	-	-
Ilmenite	26.0	92.8	-	Trace	6.0	0.1	1.1
Rutile	7.6	7.9	0.7	0.2	90.5	-	.7
Coarse kyanite	16.6	Trace	4.3	91.0	1.2	-	3.5
Fine kyanite	2.2	.9	10.1	83.3	.5	-	2.9
Zircon[1]	6.0	.6	88.4	7.4	2.0	-	.5
Monazite[2]	5.1	9.4	1.9	.1	3.2	73.8	11.6
High-tension magnetic middlings	4.4	13.2	14.3	26.6	29.3	.6	16.0
Zircon-kyanite middlings	2.3	3.3	27.9	30.2	15.0	1.0	8.0
Monazite middlings	1.5	35.2	.8	1.0	3.1	4.6	55.3
Coarse kyanite tails	8.1	1.5	-	4.0	.4	.1	94.0
Zircon-kyanite tails[3]	13.2	.1	.2	4.0	-	-	.4
Monazite tails	6.7	16.9	.2	.5	.5	.2	81.7
Composite	100.0	28.0	7.7	20.2	10.7	3.9	16.5
		Distribution, percent					
Magnetite	.3	1.1	-	-	-	-	-
Ilmenite	26.0	86.2	-	-	14.6	0.7	1.7
Rutile	7.6	2.1	0.7	0.1	64.5	-	.3
Coarse kyanite	16.6	-	9.3	74.9	1.9	-	3.5
Fine kyanite	2.2	.1	2.9	9.1	.1	-	.4
Zircon[1]	6.0	.1	68.8	2.2	1.1	-	.2
Monazite[2]	5.1	1.7	1.3	Trace	1.5	95.7	3.6
High-tension magnetic middlings	4.4	2.1	8.2	5.8	12.1	.7	4.3
Zircon-kyanite middlings	2.3	.3	8.3	3.4	3.2	.6	1.1
Monazite middlings	1.5	1.9	.1	.1	.4	1.7	5.0
Coarse kyanite tails	8.1	.4	-	1.6	.3	.2	46.3
Zircon-kyanite tails[3]	13.2	-	.3	2.6	-	-	.3
Monazite tails	6.7	4.0	.1	.2	.3	.4	33.3
Composite	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Contains 6.3 percent quartz.

[2] $\frac{\text{Xenotime}}{\text{Monazite + xenotime}}$ = 9.6 percent.

[3] Contains 95.3 percent quartz.

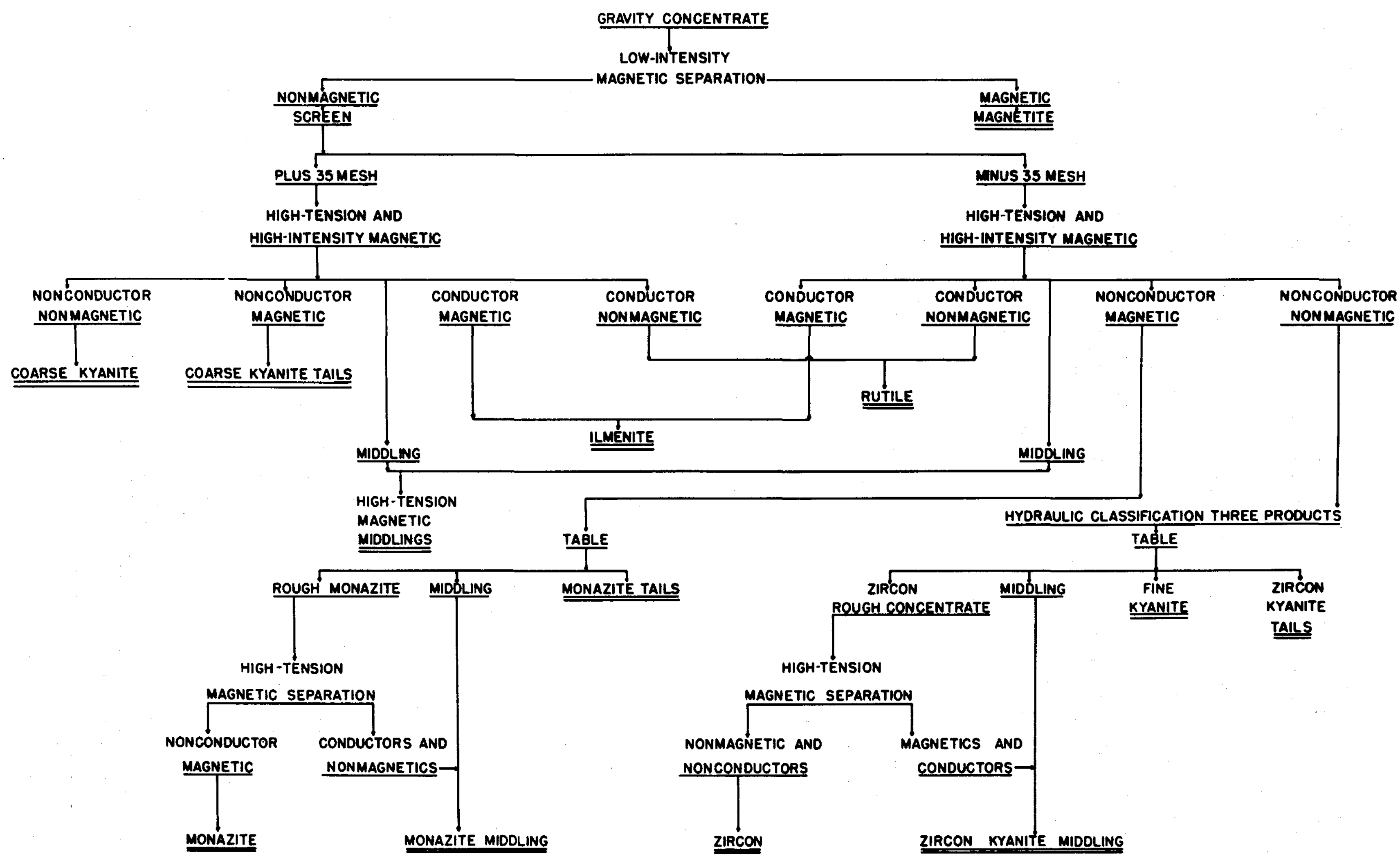

FIGURE 3. - Flowsheet for Fractionation of Eastern Sample Gravity Concentrate.

TABLE 8. - Partial analyses of some final products from fractionation of the eastern sample gravity concentrate

Product	Analysis, percent	Product	Analysis, percent
Ilmenite:		Monazite:	
TiO_2	58.7	ThO_2	4.2
Fe	25.0	Rare-earth oxide	49.7
Rutile:		Rare-earth oxides extracted from monazite:	
TiO_2	93.7		
Fe	.50	La	14.4
Coarse kyanite:		Ce	41.0
Al_2O_3	55.3	Pr	4.5
TiO_2	4.4	Nd	15.4
Acid soluble Fe	.12	Sm	2.9
Fine kyanite:		Eu	.5
Al_2O_3	52.7	Gd	2.3
TiO_2	1.1	Y	6.5
Acid soluble Fe	.04	Dy	1.0
Zircon:		Ho	.3
ZrO_2	58.0	Er	.5
TiO_2	2.1	Tm	.5
		Yb	.3

In general, fractionation was satisfactory. Ilmenite grade and recovery were good. The grade of the rutile concentrate is satisfactory; however, the recovery is somewhat lower than desirable. About 12 percent of the rutile was contained in the middlings, and most of this should be recoverable in a continuous operation. Because of the cost differential between rutile and ilmenite, it may be desirable to reseparate the ilmenite concentrate to recover the contained rutile. The coarse kyanite fraction contains about 10 percent of the total zircon. No attempts were made to treat this coarse material for zircon-kyanite separation. Gravity concentration should produce a kyanite fraction low in zircon; however, production of specification-grade zircon from the coarse fraction would be difficult. The separation of the minus 35-mesh zircon and kyanite was relatively poor. Methods for better separation should be studied. Overall monazite recovery was excellent. The monazite grade should be improved by a classification step prior to final gravity concentration. No attempt was made to produce separate monazite and xenotime concentrates. The quality and quantity of plus 35-mesh kyanite in this material is especially interesting. The particle size of this material would enhance its potential usefulness.

CONCLUSIONS AND RECOMMENDATIONS

These studies show that the occurrence of heavy minerals is widespread in sand and gravel operations in Alabama. Based on the mean heavy mineral content and a sand production of 3.3 million tons per year, some 30,200 tons of ilmenite, 2,800 tons of zircon, 8,300 tons of kyanite, 2,300 tons of rutile, and 1,700 tons of monazite contained in 67,300 tons of heavy mineral concentrate are lost annually in sand and gravel plants in Alabama. The total value of the individual marketable heavy minerals, based on presently quoted prices, is \$1.84 million, or \$27.40 per ton of heavy mineral concentrate, which is equal to 56 cents per ton of raw sand.

Bulk concentrates containing 85 percent heavy minerals were produced by standard gravity concentration methods and further separated into individual mineral products. However, more study is warranted on recovering rutile and separating the zircon-kyanite fraction.

A field examination and sampling program should be initiated south of the "Fall Line" in other Southeastern States from North Carolina to Tennessee to delineate areas where the heavy minerals contained in sand and gravel deposits can be economically recovered as byproducts or coproducts. The most promising areas appear to be exposures of the Tuscaloosa and Eutaw Formations, particularly the streams that traverse them.

The nature of sand and gravel operations is such that, although a gravity plant to produce a bulk concentrate may be feasible for many operations, no one plant or firm can produce a sufficient volume of heavy minerals to support a 200-ton-per-day separation plant, the minimum now required for profitable operation. Studies should be made to determine the economic and technical feasibility of a central separation plant servicing several gravity bulk concentration plants.

INT.-BU.OF MINES,PGH.,PA. 14833