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MICA BENEFICIATION

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UNITED STATES DEPARTMENT OF THE INTERIOR
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by

James S. Browning [1]

ABSTRACT

For the past several years, the Bureau of Mines has conducted laboratory and continuous process development work on weathered mica pegmatites and micaceous schist ores to determine the feasibility of recovering commercial-grade mica concentrates by flotation. The research has resulted in the development of two processes for flotation of mica: an acid cationic method for recovery of coarse mica, and an alkaline anionic-cationic method for recovery of fine mica. The research indicated that the two processes may be effectively utilized separately or in combination for flotation of mica from weathered pegmatites and micaceous schists.

Concentrates containing over 98 percent mica, with recoveries ranging from 77 to 92 percent, were obtained from the pegmatite ores. The micaceous schist ores yielded concentrates containing 95 to 98 percent mica, with recoveries ranging from 70 to 83 percent. Part 1 of this report summarizes the process development work and demonstrates the feasibility of producing commercial-grade mica concentrates. The report also includes details of commercial beneficiation and grinding of mica.

INTRODUCTION

In recent years, more than 99 percent of the domestic mica produced has been scrap and flake mica (mica which does not meet specifications for sheet mica and which is used for producing fine-ground mica). There has been a continued increase in mica production for several years. The 1969 production of scrap and flake mica totaled 124,856 tons (*18*)[2] as compared with 97,053 tons produced in 1967.

Mica mining in the United States is confined largely to pegmatites and schists in a few well-defined areas. The largest mica-bearing region extends from central Virginia southward through western North and South Carolina,

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[1] Supervisory metallurgist.

[2] Italicized numbers in parentheses refer to items in the list of references at the end of this report.

northern Georgia, and east-central Alabama (*4*, *12*, *14*). Whereas in western North Carolina these pegmatite dikes are weathered to only a shallow depth, they are deeply weathered in the Carolina Piedmont and in Georgia and Alabama. Particularly in Georgia and Alabama, mica is found in the decomposed slates and schists adjacent to the pegmatites, and in deeply weathered granites.

Most flake mica is obtained as the major marketable product by crushing and milling pegmatites (*16*). To a lesser extent, mica is produced as a byproduct of feldspar (*13*) and spodumene (*15*).

The Bureau of Mines has developed two methods for mica flotation. One method utilizes acid cationic flotation for recovery of mica (*2*, *11*). This method requires thorough desliming of the ore with consequent fine mica losses. The other utilizes an alkaline anionic-cationic process for recovering fine-size mica from pegmatite ores after desliming sufficiently to remove clay materials, but not so drastically as to remove fine mica (*1*, *5–8*, *10*, *17*). This latter process has also been successfully applied to a micaceous schist ore from California (*9*). Part 1 of this report summarizes the results of these research studies. Both of the flotation processes developed by the Bureau of Mines have been adopted by the mica industry and are being commercially utilized separately and in combination for flotation of mica from weathered pegmatite ores.

Also included in part 2 of this report are details of commercial mica production, including methods of mining, recovering, and grinding mica, and information on the production, uses, and prices of mica.

PART 1.—MICA PROCESS DEVELOPMENT

DESCRIPTION OF ORES

Weathered pegmatite ores from Alabama, Georgia, and North Carolina and two schist ores, a California micaceous schist and an Alabama graphitic-mica schist, were studied in these investigations. Petrographic analyses of the various ores are given in table 1.

The weathered mica pegmatite ores used in the investigations were obtained from commercial mica operations in Alabama, Georgia, and North Carolina. The ores contained an average of 14 to 16 percent muscovite. Other major mineral constituents were quartz, kaolin, and minerals of the feldspar group. The ores also contained minor amounts of biotite, limonite, tourmaline, staurolite, garnet, epidote, and kyanite. The muscovite in the ores was completely liberated at 4 to 6 mesh.

The California ore was a micaceous schist containing about 43 percent muscovite. The ore also contained quartz and chlorite, with minor amounts of biotite and various carbonate minerals. The mica was essentially liberated at 65 mesh.

The Alabama graphitic-mica schist ore contained about 33 percent muscovite with quartz and minor amounts of pyrite, biotite, limonite, graphite, sillimanite, kyanite, rutile, and garnet. The mica in the ore was essentially liberated at 4 mesh.

Table 1.—Petrographic analyses of mica ores, percent

Type of ore and location	Muscovite	Quartz	Kaolin	Feldspar	Limonite	Biotite	Carbonate	Chlorite	Pyrite	Graphite	Other [1]
Pegmatite ores:											
Alabama	16.4	77.1	4.5		1.4						0.6
Georgia	15.0	73.0	8.5		1.5	1.5					.5
North Carolina	13.5	69.3	10.4	4.5		1.2					1.1
Schist ores:											
Alabama	33.4	56.9			1.1	1.9			3.5	1.4	1.8
California	43.4	45.2				1.5	1.4	8.5			

[1] Sillimanite, kyanite, rutile, garnet, tourmaline, staurolite.

MICA ANALYSIS METHODS

Various organic heavy liquids have been used in the laboratory for separating minerals of different specific gravities for many years. Sink-float procedures have proven their utility as a rapid and moderately accurate means for determining the mineral content of ores and plant products in certain nonmetallic operations.

Chemical analysis cannot be used for mica determination because of a wide variation in the chemical composition of the various types of mica. Mica determination by petrographic analysis is not completely satisfactory. The shape factor of mica, contrasted with that of quartz, the chief associated mineral, is both large and variable. Petrographic analysis is not normally used in mill control because of the time involved. A standard method of analysis for mica in ore samples has not been accepted generally by the mica industry. Recently the Bureau of Mines published a report on methods for analyzing mica by heavy liquid separation (*3*).

A comparison of the specific gravities of the major constituents of mica ores (muscovite 2.67+, quartz 2.65, kaolin 2.61, and feldspar 2.57) indicates that an effective separation of muscovite from the other minerals can be made in heavy liquids at a specific gravity as low as 2.68. If appreciable quantities of heavier minerals (limonite and tourmaline) occur in the ore, a second sink-float separation at 2.94 specific gravity can be made to separate them from muscovite.

The heavy liquid used in the investigation was acetylene tetrabromide (also known as tetrabromoethane), one of the most widely used heavy liquids for mineral separations. The liquid is miscible with benezene, kerosene, and trichloroethylene in all proportions and has a specific gravity of 2.95. Acetylene tetrabromide can be used without dilution for separating two or more minerals having specific gravities higher and lower than 2.95. If mineral separations are required at specific gravities below 2.95, appropriate mixtures of acetylene tetrabromide and trichloroethylene or kerosene can be used.

The general procedure employed in sink-float separation of mica samples is as follows: approximately 5 grams of the mineral sample was placed in a 50-ml conical centrifuge tube containing 25 to 30 ml of the prepared heavy liquid (2.68 specific gravity). The samples were then stirred with a small glass stirring rod, and the rod and the sides of the tube were washed down using a small quantity of the heavy liquid. The tubes were then placed in the centrifuge and whirled at a speed of about 3500 to 4000 peripheral fpm (feet per minute) for about 5 minutes. The tubes were then removed from the centrifuge and the stratified mineral layers were stirred carefully to release mechanically entrapped particles. The samples were then centrifuged for an additional 3 minutes to insure complete separation. The sink and float fractions were then carefully washed into separate filter funnels, and washed free of the heavy liquid with a solvent such as trichloroethylene. The individual sink and float fractions were then dried and weighed, and the percentage sink and float was calculated. If appreciable quantities of heavier minerals occurred in the sink product, a second sink-float separation at 2.95 specific gravity was made to separate them from the muscovite.

To ascertain the normal accuracy and reproducibility of the method, a number of check determinations were made in the laboratory on several carefully isolated portions of samples containing varying quantities of mica. The results, as shown in table 2, indicate that the maximum deviation from the average was 2 percent, illustrating the accuracy of the method.

Table 2.—Precision of mica analysis by heavy liquid separation

Sample	Mica, percent				Maximum deviation from average, percent
	Analysis			Average	
	Test 1	Test 2	Test 3		
1	6.05	6.05	5.95	6.00	1.11
2	7.60	7.55	7.50	7.55	.66
3	54.5	52.4	53.2	53.4	2.12
4	56.6	56.0	56.4	56.3	.59
5	75.5	76.0	76.1	75.9	.48
6	92.66	91.33	92.83	92.28	1.02

All of the heavy liquids used in the test work are toxic and hazardous. The heavy liquid separations should always be made under a hood equipped with both updraft and downdraft ventilation. The fumes of the liquids should not be breathed or be allowed to contact the skin. For more information regarding the toxicity of the liquids discussed in the text, Sax (*20*) should be consulted. The toxicity and hazards of the liquids and the first aid treatment to be applied in event of exposure to or contact with the liquids are discussed there.

FLOTATION METHODS

Acid Cationic Flotation Method

The acid cationic method of mica flotation provides an efficient method for recovery of coarse mica. Particles as coarse as 14 mesh may be floated by the process. However, the ore must be completely deslimed at 150 to 200 mesh, which results in considerable loss of fine mica.

The process includes conditioning the ground ore pulps at 40 to 45 percent solids with sulfuric acid and floating the mica with a cationic collector. The sulfuric acid is used for pH control and quartz depression. Best mica flotation was obtained in a pulp having a pH of 4.0. Cationic reagents, such as the long-carbon-chain amine acetates, were the most effective collecting agents for floating mica.

Alkaline Anionic-Cationic Flotation Method

The alkaline anionic-cationic method of mica flotation provides a very effective method for recovery of mica in the presence of slimes. The ore is normally deslimed sufficiently to remove the clay slimes, but not so drastically as to remove the fine-size mica and other granular material. Particles as coarse as 20 mesh may be floated by the process.

Briefly described, the process included conditioning the finely ground ore pulps at 40 to 45 percent solids with sodium carbonate and calcium lignin sulfonate and floating the mica with a combination of anionic and cationic collectors. The separation was not particularly sensitive to pulp pH, and excellent mica recoveries were obtained in a pH range of 8.0 to 10.5.

The function of the sodium carbonate is to retard flotation of the gangue minerals and control the pH of the pulp. The exact mechanism of the retarding action of the sodium carbonate is not known. It seems probable, however, that its effectiveness may be due to removal and dispersion of slime coatings on the mineral surfaces.

The mechanism of the retarding action of the lignin sulfonate has not been definitely determined. It seems probable, however, that selective adsorption of the lignin sulfonate at gangue mineral surfaces effectively prevents adsorption-attachment of the collector at these surfaces. On the other hand, mica particles, being rather devoid of adsorbed lignin sulfonate, are free to react with collector and are thus made floatable. The lignin sulfonates are effective slime dispersants and may aid flotation by assisting in proper removal and dispersion of slime coatings on the mineral surfaces.

Anionic-type reagents, such as oleic acid and combinations of oleic and linoleic acid, were found to be the most effective collecting agents for floating mica. Increased selectivity in the presence of slimes was imparted to anionic collectors by incorporating small amounts of cationic amine acetate collecting agents in the system.

The most effective ratio of anionic and cationic collector for mica flotation was 2 to 3 parts fatty acid to 1 part cationic collector. Any appreciable change in the ratio decreased both the grade and the recovery of mica.

A comparison of the advantages and disadvantages of the two processes for mica flotation, acid cationic vs. alkaline anionic-cationic, is given in table 3.

Table 3.—Comparison of the two mica flotation methods

Alkaline anionic-cationic method	Acid cationic method
1. Does not require acid proof equipment.	1. Requires acidproof equipment.
2. Recovers mica from ore pulps containing slimes.	2. Will not tolerate slimes.
3. Depresses limonite and biotite.	3. Does not effectively depress limonite and biotite.
4. Will float finer size material than will acid circuit.	4. Will float coarser size material than will alkaline circuit.
5. When coarse mica is recovered by differential grinding and screening prior to alkaline flotation, the coarse mica is not coated with reagents.	5. Requires more desliming equipment than alkaline circuit, thus increasing operating costs and losses in fine mica.
6. Overall recovery is higher because a larger percentage of mica is subject to recovery by screening and flotation.	

CONTINUOUS FLOTATION PILOT PLANT

Upon completion of preliminary studies, a continuous pilot plant to treat about 300 pounds of ore per hour was assembled. The flowsheet included concurrent grinding, screening, classification, conditioning, and flotation. The pilot plant was designed so that with a minimum alteration of piping and equipment the circuit could be changed to accommodate either the acid cationic flotation procedure, the alkaline anionic-cationic procedure, or combinations of the two procedures. The initial pilot plant operations were devoted to shakedown runs, during which various equipment units and flowsheets were tested and the several unit operations were integrated. Flowsheets of the circuits are shown in the following sections of this report. The continuous test work was conducted on run-of-mine ore obtained from the various mining companies. The method selected for continuous operation was based on the best results obtained in laboratory batch flotation tests.

Pegmatite Ores

Acid Cationic Method

As previously noted, numerous tests were made in the pilot plant, under a variety of conditions, to determine the best flowsheet for recovering mica. Based on the results of the tests, the flowsheet shown in figure 1 ultimately proved best for the acid cationic method.

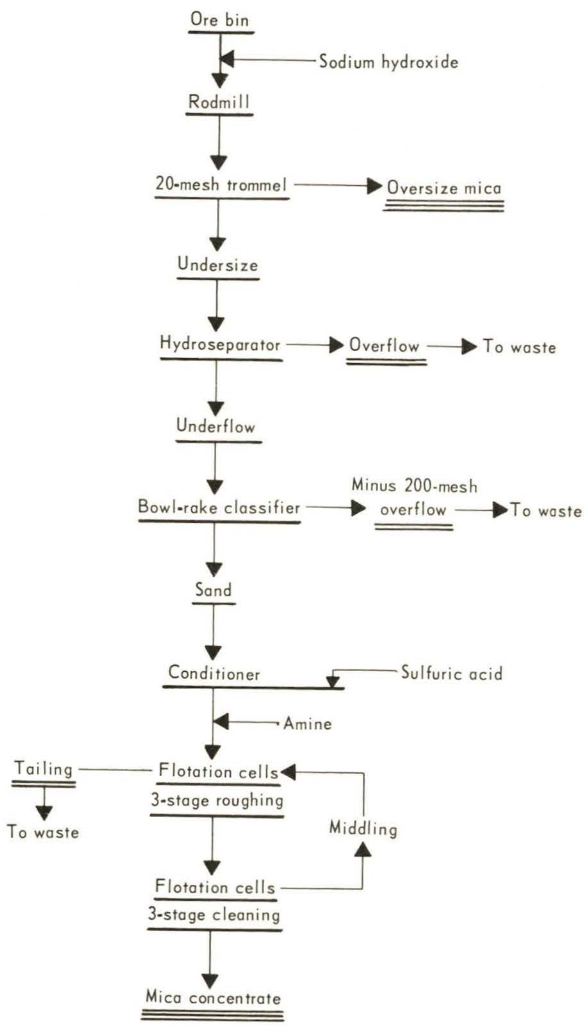

Figure 1.—Flowsheet for recovery of mica using acid cationic method.

The ore was ground in a rodmill in the presence of sodium hydroxide to aid in dispersing and removing clay slimes. The rodmill was equipped with a 20-mesh trommel, and grinding was adjusted to the point where the trommel oversize consisted of high-quality mica.

The trommel undersize was deslimed by two-stage desliming in a hydroseparator and a bowl-rake classifier to remove the minus 200-mesh fines. The ore, after grinding and desliming, contained about 1 percent minus 200-mesh material. The pulp then passed to a conditioner, where the reagent for pH control and quartz depression was added. The pulp from the conditioner flowed by gravity to a bank of rougher flotation cells, where the amine collector was added to the first cell. A rougher flotation concentrate was recovered and cleaned three times to produce a finished mica concentrate. The middlings were recirculated countercurrent to the pulp flow in the cleaner circuit and ultimately joined new feed at the head of the roughing circuit. The mica flotation concentrate and the 20-mesh trommel oversize, when combined, accounted for a recovery of about 77.5 percent of the mica present in the feed in a product containing 98.1 percent mica. The results of the continuous test are presented in tables 4 and 5.

Table 4.—Continuous flotation of mica using acid cationic method

Product	Weight-percent	Mica, percent	
		Analysis	Distribution
Trommel oversize	2.6	99.0	15.5
Flotation concentrate	10.5	98.0	62.0
Composite concentrate	13.1	98.1	77.5
Flotation tailing	58.0	2.0	7.0
Slime	28.9	8.9	15.5
Composite	100.0	16.6	100.0

Table 5.—Reagent schedule for continuous flotation of mica using acid cationic method

	Rodmill	Conditioner	Rougher cell
Reagents, pounds per ton of ore:			
Sodium hydroxide	1.5		
Sulfuric acid		1.5	
Amine (stearyl plus oleyl)			0.3
Conditioning time ... minutes		5	1
Pulp pH		4.0	4.0

Alkaline Anionic-Cationic Method

During the mica process development work, it was determined that the platy shape of the mica could be utilized to preconcentrate the ore prior to flotation. Humphreys spirals [3] were effectively used to remove a large part of the quartz, along with the limonite and other heavy minerals in the ore. Normally, 50 to 55 percent of the ore was rejected in the preconcentration step with only a minor loss of mica. Thus the flotation feed was upgraded from about 16 percent mica to over 35 percent mica. The preconcentration step permitted the size of the flotation section to be scaled down, reduced reagent requirements, and reduced overall costs for processing mica.

Continuous treatment of the ore using the alkaline anionic-cationic method included grinding, trommel screening, preconcentration, classification, conditioning, and flotation. The flowsheet for the process is shown in figure 2.

The ore was ground in a rodmill with sodium hydroxide to aid in dispersing and removing clay slimes. The grinding was adjusted until the 20-mesh trommel oversize consisted of almost pure mica, which was removed as a separate oversize mica concentrate. The minus 20-mesh trommel undersize passed to a Humphreys spiral to concentrate the mica partially and to remove a large part of the quartz, limonite, and heavy minerals. The spiral rejected about 55 percent of the total weight of the ore with a loss of only 3 percent of the total mica. The rougher concentrate was partly deslimed in a bowl-rake classifier to remove clay slimes, which were essentially all minus 325 mesh. The ore contained about 20 percent minus 200 mesh after grinding, preconcentration, and desliming. The pulp then passed to conditioners, where the reagents for pH control and quartz depression and the fatty acid mica collector were added. The pulp from the conditioners flowed to a bank of rougher flotation cells, where the amine collector was added to the first cell. A rougher froth was recovered and cleaned three times to produce a finished mica concentrate. The continuous pilot plant test accounted for a recovery of 91.9 percent of the mica in the feed in a product containing 98.6 percent mica. The test results are summarized in tables 6 and 7.

[3] Reference to specific trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

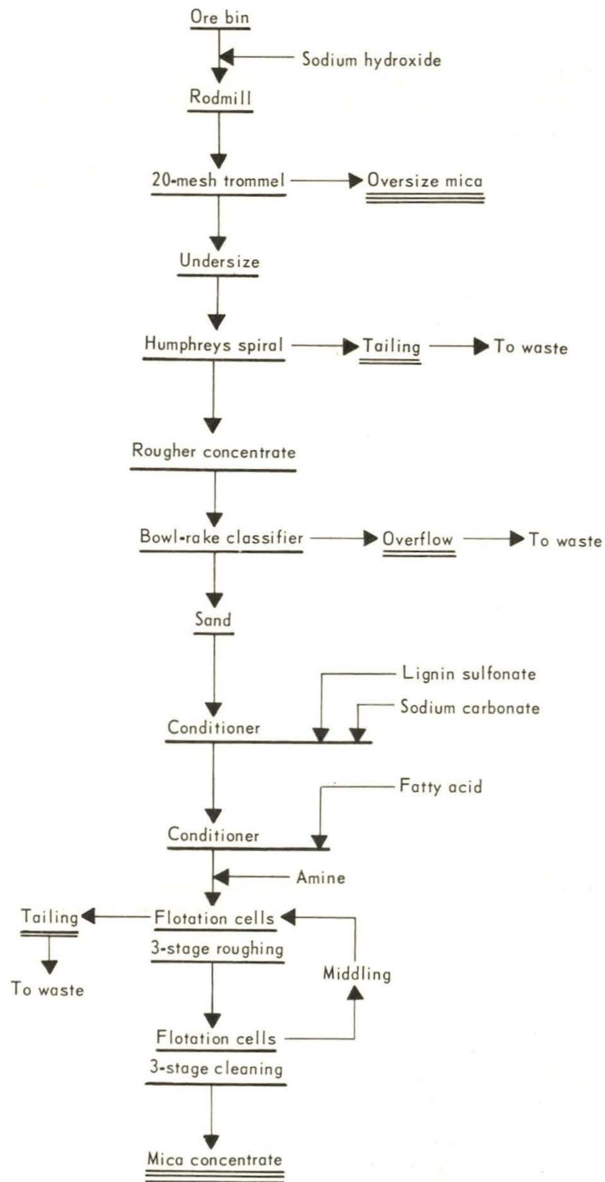

Figure 2.—Flowsheet for recovery of mica using alkaline anionic-cationic method.

Table 6.—Continuous flotation of mica using alkaline anionic-cationic method

Product	Weight-percent	Mica, percent	
		Analysis	Distribution
Trommel oversize	2.8	99.5	16.8
Flotation concentrate	12.6	98.5	75.1
Composite concentrate	15.4	98.6	91.9
Flotation tailing	16.6	1.1	1.1
Bowl-rake classifier overflow	13.5	4.9	4.0
Composite spiral concentrate	45.5	35.2	97.0
Spiral tailing	54.5	.9	3.0
Composite	100.0	16.5	100.0

Table 7.—Reagent schedule for continuous flotation of mica using alkaline anionic-cationic method

	Rod-mill	Condi-tioner 1	Condi-tioner 2	Rough-er cell
Reagents, pounds per ton of ore:				
Sodium hydroxide	1.5			
Sodium carbonate		1.0		
Lignin sulfonate		1.0		
Fatty acid (oleic plus linoleic)			0.5	
Amine (stearyl plus oleyl)				0.3
Conditioning time, minutes		6	6	1
Pulp pH			9.2	9.1

Combination of Acid Cationic and Alkaline Anionic-Cationic Methods

Continuous treatment of the ore using the acid cationic method simulaneously with the alkaline anionic-cationic method included grinding, preconcentration, screening, classification, conditioning, and flotation. The flowsheet for the process is shown in figure 3.

The ore was ground in a rodmill with sodium hydroxide to aid in dispersing and removing clay slimes. The ground ore passed to a Humphreys spiral to concentrate the mica partially and to remove a large part of the quartz. The spiral operation upgraded the mica content of the ore from 16 percent to over 38 percent. In addition to rejecting 60 percent of the weight of the ore with a loss of only 7 percent of the total mica, the spiral also rejected most of the limonite and other heavy minerals in the ore. The rougher concentrate passed from the spiral to an 80-mesh vibrating screen.

The plus 80-mesh material from the screen passed to the rougher flotation cells, where sul-

Table 8.—Continuous flotation of mica using combination of acid cationic and alkaline anionic-cationic methods

Product	Weight-percent	Mica, percent	
		Analysis	Distribution
Acid-circuit flotation concentrate	11.0	99.9	66.3
Alkaline circuit flotation concentrate	3.5	97.5	20.7
Composite concentrate	14.5	98.6	87.0
Flotation tailing	11.8	1.4	1.0
Bowl-rake classifier overflow	13.7	5.0	4.7
Composite rougher spiral concentrate	40.0	38.1	92.7
Spiral tailing	60.0	2.0	7.3
Composite	100.0	16.4	100.0

Table 9.—Reagent schedule for continuous flotation of mica using combination of acid cationic and alkaline anionic-cationic methods

	Rodmill	Acid circuit, rougher cell	Alkaline Circuit		
			Conditioner 1	Conditioner 2	Rougher cell
Reagents, pounds per ton of ore:					
Sodium hydroxide	1.5				
Sulfuric acid		0.7			
Amine (stearyl plus oleyl)		0.3			0.2
Sodium carbonate			0.5		
Lignin sulfonate			0.5		
Fatty acid (oleic plus linoleic)				0.5	
Conditioning time, minutes		1	6	6	1
Pulp pH		4.0		9.1	9.0

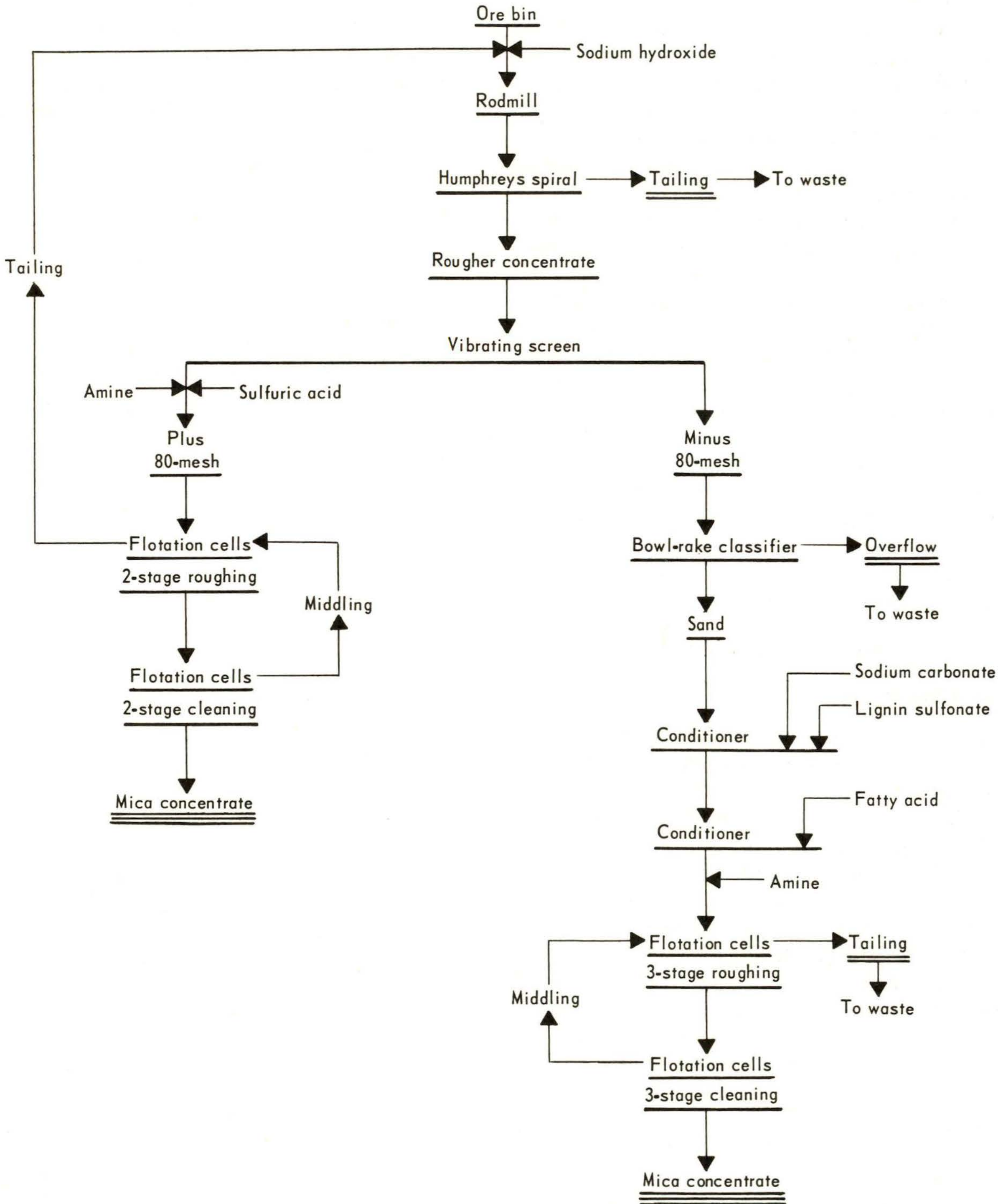

Figure 3.—Flowsheet for recovery of mica using combination of acid cationic and alkaline anionic-cationic methods.

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furic acid for pH control and quartz depression and the amine collector were added to the first cell. A rougher froth was recovered and cleaned twice to produce a finished mica concentrate. The rougher tailing contained considerable coarse, blocky mica and was returned to the rodmill for additional grinding. The concentrate contained 99.0 percent mica, with a recovery of 66.3 percent of the total mica.

The minus 80-mesh material, containing over 20 percent of the total mica, passed from the screen to a bowl-rake classifier to remove clay slimes. The pulp then passed to conditioners where the reagents for pH control and quartz depression and the fatty acid mica collector were added. The pulp from the conditioners flowed to a bank of rougher flotation cells, where the amine was added to the first cell. A rougher froth was recovered and cleaned three times to produce a finished concentrate. The alkaline concentrate contained 97.5 percent mica, with a recovery of 20.7 percent of the total mica. The combined flotation concentrates contained 98.6 percent mica, with a recovery of 87.0 percent of the total mica. The test results are summarized in tables 8 and 9.

Micaceous Schist Ores

Acid Cationic Method

Continuous treatment of the graphitic-mica schist ore included grinding, classification, preconcentration, conditioning, and flotation. The flowsheet for the process is shown in figure 4.

The ¾-inch dry-crushed ore was stored in an ore bin and withdrawn by a feeder onto a vibrating screen. The minus 4-mesh screen undersize passed to a spiral classifier to remove slimes. The spiral classifier overflowed to a 150-mesh vibrating screen. The minus 150-mesh undersize went to waste. The plus 4-mesh screen oversize, spiral classifier sands, and plus 150-mesh screen oversize passed to a rodmill. The ore was ground in the presence of sodium hydroxide to aid in removing and dispersing slimes. The plus 28-mesh trommel oversize consisted primarily of leaves, trash, and other organic matter and was discarded. The minus 28-mesh trommel undersize passed to a Humphreys spiral to partially concentrate the mica and remove part of the quartz. In addition to rejecting 28 percent of the weight of the ore with a loss of only 5 percent of the total mica, the spiral also rejected most of the pyrite, limonite, and other heavy minerals in the ore. The spiral rougher concentrate passed to a bowl-rake classifier for additional desliming. The bowl-rake classifier overflowed to a 200-

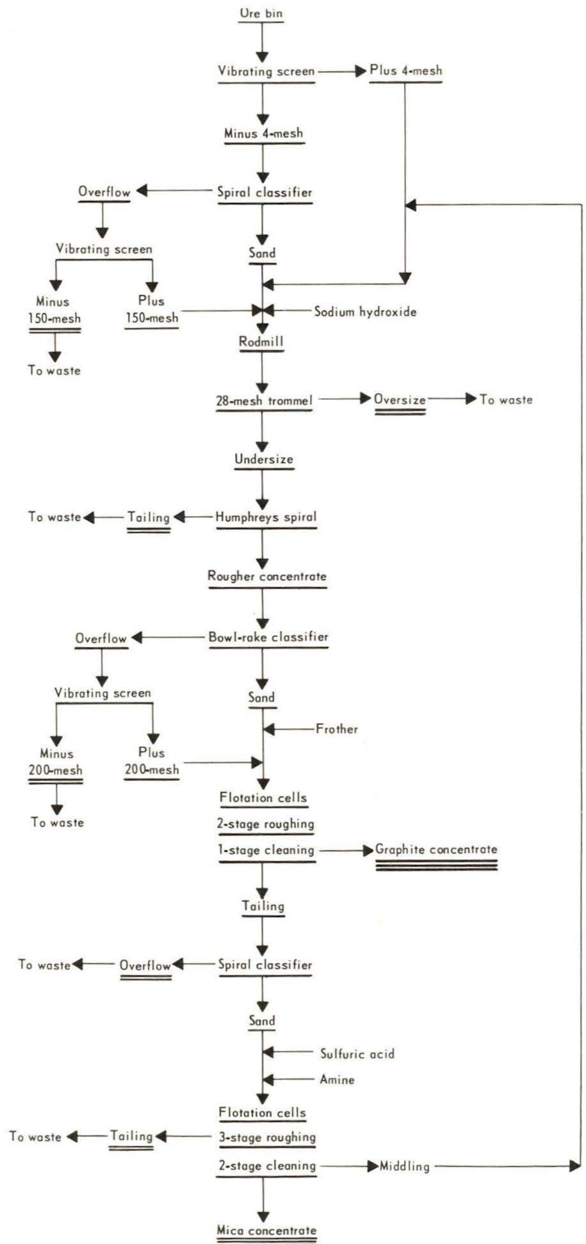

Figure 4.—Flowsheet for recovery of muscovite from graphitic-mica schist ore.

mesh vibrating screen. The minus 200-mesh undersize went to waste. The plus 200-mesh screen oversize and the classifier sands passed to the graphite flotation circuit. A rough graphite product was floated with an alcohol frother, and cleaned once to reject an impure graphite product.

The graphite tailing was dewatered in a spiral classifier. The classifier sands passed directly to the subaeration-type flotation cells, where sulfuric acid for pH control and quartz depression was added. The amine collector (Azamine F10A) was also added in the first flotation cell. A rough mica concentrate was floated in a bank of three rougher cells. The rough concentrate was cleaned twice to produce a finished mica concentrate. The middling product, containing blocky mica, was returned to the rodmill for additional grinding. The flotation process accounted for a recovery of over 83 percent of the total mica in the ore in a product containing 98.7 percent mica. The summarized results of the test are given in tables 10 and 11.

Table 10.—Continuous flotation of graphitic-mica schist ore

Product	Weight-percent	Mica, percent	
		Analysis	Distribution
Mica concentrate	28.3	98.7	83.1
Graphite product	1.9	78.7	4.5
Spiral tailing	28.1	5.9	4.9
Flotation tailing	9.3	1.5	.4
Total slime	32.4	[1] 7.4	7.1
Composite	100.0	33.6	100.0

[1] By reason of its color the mica in this product would not be marketable.

Table 11.—Reagent schedule for continuous flotation of graphitic-mica schist ore

	Rodmill	Graphite cell	Rougher cell 1	Rougher cell 2
Reagents, pounds per ton of ore:				
Sodium hydroxide	2.0			
Alcohol frother		0.05		
Sulfuric acid			0.70	
Amine			0.30	0.10
Conditioning time...minutes			1	1
Pulp pH	10.9	8.7	3.8	

Alkaline Anionic-Cationic Method

The flowsheet for continuous treatment of the California micaceous schist is shown in figure 5. The minus ½-inch dry-crushed ore was stored in an ore bin and withdrawn by a constant-weight feeder for wet grinding in a rodmill. The rodmill operated in closed circuit with a vibrating screen, with the plus 65-mesh ore returning to the rodmill. After being ground to minus 65 mesh, the ore flowed to a hydroseparator to thicken the pulp to about 40 percent solids and to remove part of the extremely fine material. Removal of part of the minus 400-mesh material permitted more efficient flotation of mica without excessive consumption of reagents. The hydroseparator sand was pumped to the first of two conditioners, where sodium carbonate and sodium silicate were added. The discharge from the first conditioner flowed to a second unit, where the fatty acid was added. The retention time in each conditioner was about 5 minutes. The conditioned feed passed to a bank of four flotation rougher cells; tallow amine acetate was added in the first cell. The bank of rougher cells produced a rough mica concentrate and a finished tailing. The rough concentrate was

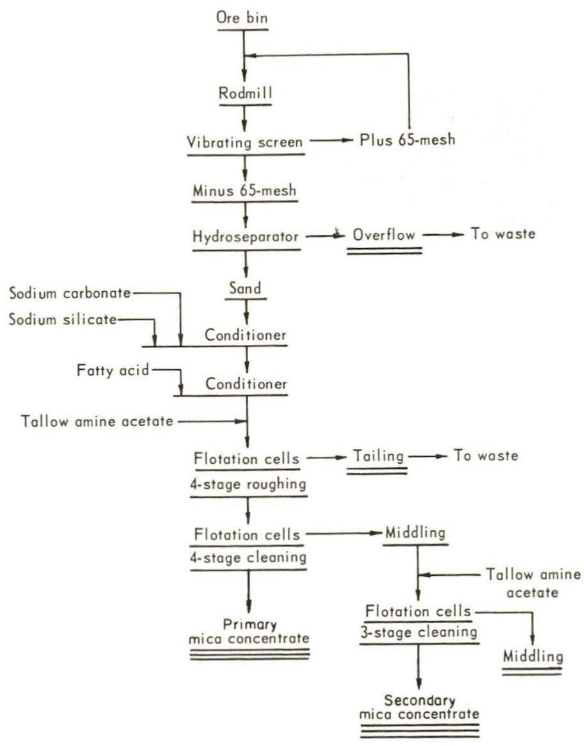

Figure 5.—Flowsheet for recovery of mica from California micaceous schist ore.

cleaned four times to produce a primary mica concentrate. The middling was sent to a bank of three flotation cells, where additional tallow amine acetate was added. The middling was refloated and cleaned three times to yield a secondary mica concentrate. The summarized results of the best continuous test obtained in the plant are given in tables 12 and 13. The combined mica concentrates analyzed 95.6 percent mica and accounted for a recovery of about 70 percent of the mica. Over 99 percent of the mica concentrate is minus 100 mesh and is suitable for many uses without additional grinding.

Table 12.—Continuous flotation of California micaceous schist ore

Product	Weight-percent	Mica, percent	
		Analysis	Distribution
Primary mica concentrate	29.9	95.7	64.9
Secondary mica concentrate	2.4	94.9	5.2
Composite	32.3	95.6	70.1
Middling	2.1	48.5	2.3
Tailing	56.4	14.6	18.7
Hydroseparator overflow	9.2	42.8	8.9
Composite	100.0	44.1	100.0

SUMMARY

The mica process development research demonstrated the feasibility of recovering high-grade mica concentrates from weathered pegmatite ores from Alabama, Georgia, and North Carolina, and from micaceous schist ores from Alabama and California. The research indicated that the acid cationic method may be used for flotation of coarse, deslimed ores. The research also indicated that the alkaline anionic-cationic method may be used effectively for flotation of coarse and fine mica from lightly deslimed ores. These two mica flotation processes are currently being used commercially by the mica industry. The research also showed the effectiveness of using Humphreys spirals to preconcentrate the ore and remove a large part of the quartz and heavy minerals prior to flotation.

Table 13.—Reagent schedule for continuous flotation of California micaceous schist ore

	Conditioner 1	Conditioner 2	Primary circuit, first rougher	Secondary circuit, first rougher
Reagent, pounds per ton:				
Sodium carbonate	1.5			
Sodium silicate	0.9			
Fatty acid (oleic-linoleic)		0.9		
Tallow amine acid			0.5	0.15
Conditioning time, minutes	5	5	1	1
Pulp pH	9.4	9.3	9.3	9.2

PART 2.—INDUSTRIAL MICA PRODUCTION

This second section outlines aspects of industrial mica production. For further information on mica mining and grinding, consult Bureau of Mines Information Circular 8125, Mica. A Materials Survey (*21*). Annual data on the mica industry, including prices, production, and uses, are given in volume I of the Bureau of Mines Minerals Yearbook.

MINING

Mining scrap or flake mica involves handling large tonnages of material. Although some selectivity is possible at times, the entire mica-bearing formation usually is mined and processed for its mica content. The size, attitude, and irregularity of most scrap-mica deposits prevent the use of very large-scale, systematic mining procedures.

Scrap-mica deposits are mined by open-pit methods. Bulldozers or small draglines are used to strip the overburden ahead of the working face. The exposed matrix then is either mined by hydraulic methods, by power-driven equipment, or by a combination of the two.

Because the screening and washing operations essential to recovering flake mica from mine-run material consume large volumes of water, hydraulic mining of flake mica is used when practicable. In this type of mining, one or more streams of water are directed under pressure against the quarry face by means of jets. The ore is broken up by the force of the water, washed from the working face into a sump, and then flumed or pumped to the processing plant.

Most flake-mica deposits are mined by power-driven equipment. In this method the exposed matrix is mined by either (1) a power shovel to remove ore from the face and load it directly into a truck, (2) a bulldozer to scrape up the ore and push it into loading bins, from which it is loaded into dump trucks, or (3) tractor-drawn drag pans to mine and haul the ore.

MICA RECOVERY PROCESSES

The material mined from flake mica deposits requires considerable processing to separate the mica and any byproducts from the gangue. The number of operations varies according to the nature of the deposit and the extent to which the products are recovered.

Three general methods are used to concentrate and recover mica as the primary product from mine-run material. The simplest process separates the mica from the other constituents of the ore by differential crushing and screening in washer plants. Another method concentrates the differentially ground material by employing screens, classifiers, and Humphreys spirals. The third method, developed more recently, concentrates the ground material by the use of screens, classifiers, and flotation. The three recovery methods are discussed in detail in the following sections of this report.

Rolls and Trommels

Conventional washer plants are relatively low-cost units, simple in design, and quite effective for recovering plus 1/4 inch or plus 3/16 inch mica. Mica finer than this cannot be recovered economically in these plants and is discarded. The principal equipment in a washer plant ordinarily consists of a series of roll crushers and trommel screens, and storage facilities. Material moves through the process either by gravity flow or bucket elevators. Large quantities of water are required to recover flake mica by this method.

A simplified flowsheet of a washer plant for recovering coarse flake mica is shown in figure 6. In a typical washer plant, the mine-run ore is disintegrated with streams of high-pressure water. Next the ore is crushed in a jaw crusher and washed through a series of trommel screens and roll crushers. Mica, being flexible and platy, is affected little in its passage through the crushing rolls, but quartz and feldspar, being brittle and more equidimensional, are reduced to fine sizes.

The first trommel has openings of 3/16 inch to remove the fine-size gangue. The undersize is composed mainly of quartz, feldspar, clay, and fine mica that is removed from the circuit. The coarse particles are retained by the screen and discharged to the next processing step. This crushing and screening operation is repeated as many times as necessary to remove as much of the gangue minerals as possible. The wet, relatively clean mica obtained as the coarse product of this operation is then elevated to storage bins.

Mica discharged in the screen undersize from this type of plant can result in a loss of 50 percent of the mica contained in the original ore. This material can be stockpiled for future use if other methods are utilized for recovering the fine-size mica.

Humphreys Spirals

The use of Humphreys spirals permits the recovery of finer size mica than can be recovered from roll and trommel washer plants. Spirals are low in capital cost, operating cost, and in skilled labor requirements. The principal equipment in a spiral plant consists of grinding, classification, screening, spirals, and storage facilities. Figure 7 is a flowsheet of a Humphreys spiral plant for recovering flake mica.

In a typical Humphreys spiral plant, the run-of-mine ore is washed by a high-pressure hose into a bowl-rake classifier for an initial desliming step. The classifier sand is fed to a rodmill that discharges onto a trommel screen. The screen oversize is recycled to the rodmill for additional grinding. The trommel screen undersize is fed to a second bowl-rake classifier for additional desliming. The classifier sand passes to a bank of Humphreys spirals for the initial concentrating step. The spiral rougher concentrate is fed to the cleaner spirals that produce a middling and a cleaner concentrate. The middling product is recycled back through the rougher spirals. The cleaner concentrate passes over a series of launder screens for removal of clay and fine-size gangue minerals. The launder screen oversize is fed to a hammer mill to delaminate the mica and remove fine-size quartz adhering to the mica. The concentrate is then screened, centrifuged, and stored.

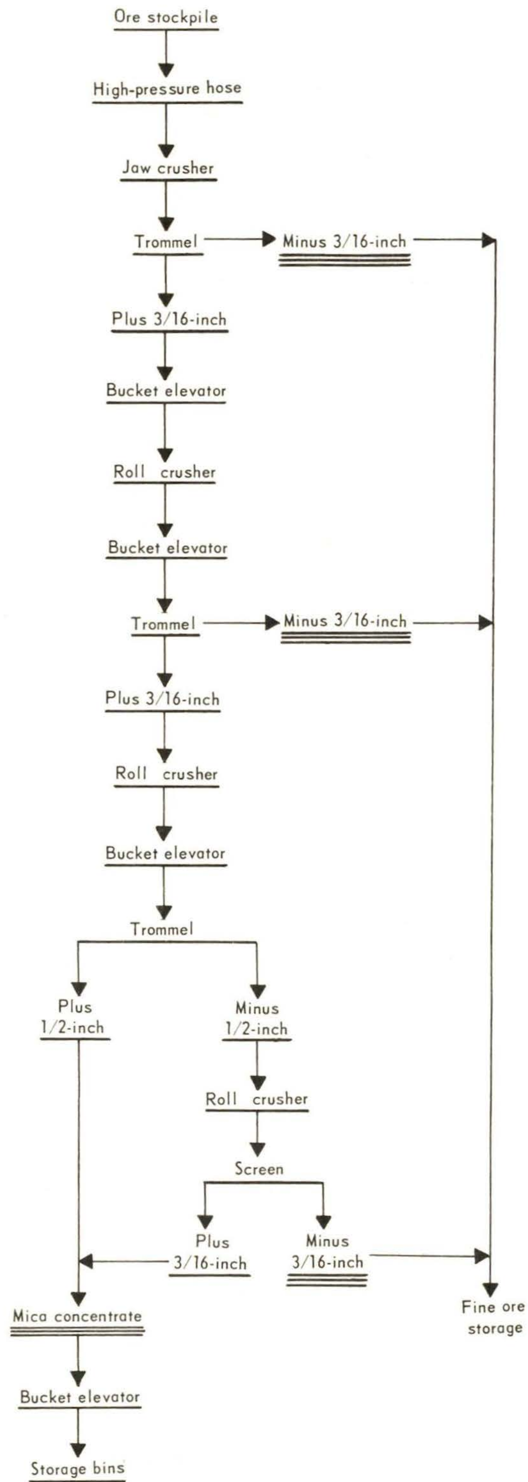

Figure 6.—Flowsheet of roll and trommel plant for recovery of flake mica.

Flotation

The use of flotation permits the recovery of finer size mica than can be processed by roll-and-trommel washer plants or Humphreys spiral plants. Thus the overall recovery of mica from the ore is appreciably higher. In addition, higher quality products can be produced by flotation.

Commercial treatment of weathered micaceous pegmatite ore includes crushing, grinding, classification, desliming, screening, and flotation. Flotation is normally followed by dewatering and drying.

The flowsheets of typical plants utilizing the acid cationic method, the alkaline anionic-cationic method, and a combination of the two methods are shown in figures 8, 9, and 10, respectively.

GRINDING

Mica is one of the most difficult minerals to grind. Some of the same properties that make mica useful make it difficult to grind. Even thin flakes are tough and elastic and resist abrasion and reduction in size by the conventional types of grinding equipment.

Two processes, dry grinding and wet grinding, are employed to produce ground mica. The products of the two processes differ from each other in certain physical properties. Most plants which beneficiate mica have dry-grinding equipment as an integral part of the plant.

Dry Grinding

Buhrmills, rodmills, high-speed hammer mills, and various types of attrition mills, all have been used for dry grinding mica.

At present, high-speed hammer mills are widely used for dry grinding mica. The hammer mill normally operates in closed circuit with an air separator which returns oversize for additional grinding and discharges the fine material to a screening operation. Various sized fractions are bagged for marketing.

Another device that has become widely accepted for dry grinding mica in the fluid energy mill. Mica is fed continuously from a screw feeder into a chamber containing two horizontal, directly opposed jets. The mica particles

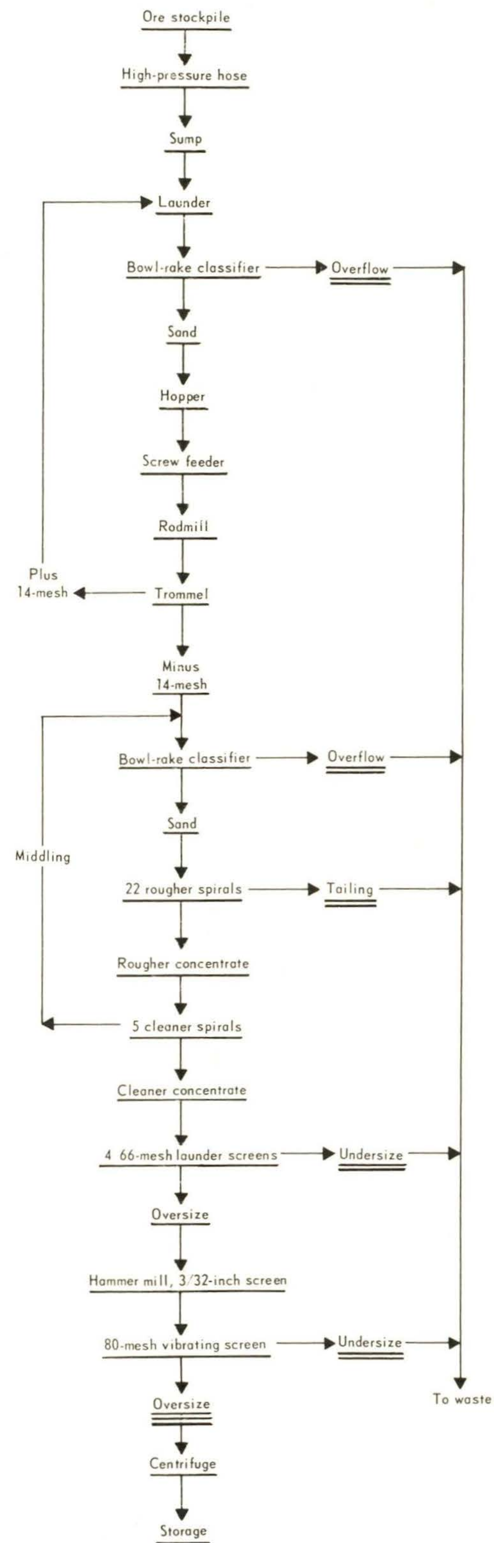

Figure 7.—Flowsheet of Humphreys spiral plant for recovery of flake mica.

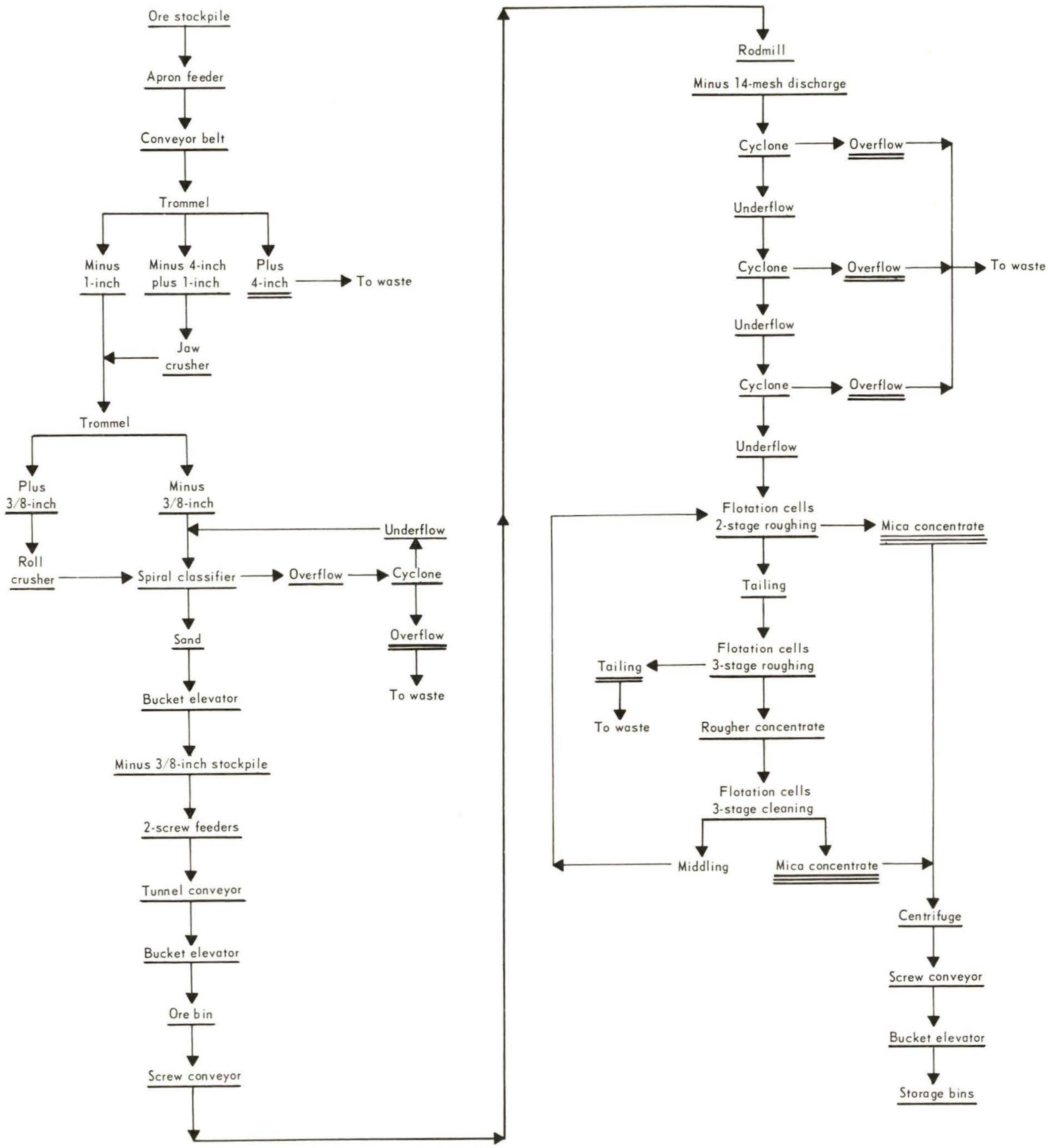

Figure 8.—Flowsheet of plant using acid cationic method.

are entrained in the two directly opposing fluid streams, air or steam, and are ground by the attrition resulting from high-velocity impacts between the particles. The ground mica passes to an air classifier, and the oversize is recycled back through the jet mill. The undersize product is then screened to remove additional oversize material. Material of the required size is stored and bagged. The particle size of the product can be controlled over a broad range down to micron size. A flowsheet of a typical jet mill dry-grinding plant is shown in figure 11.

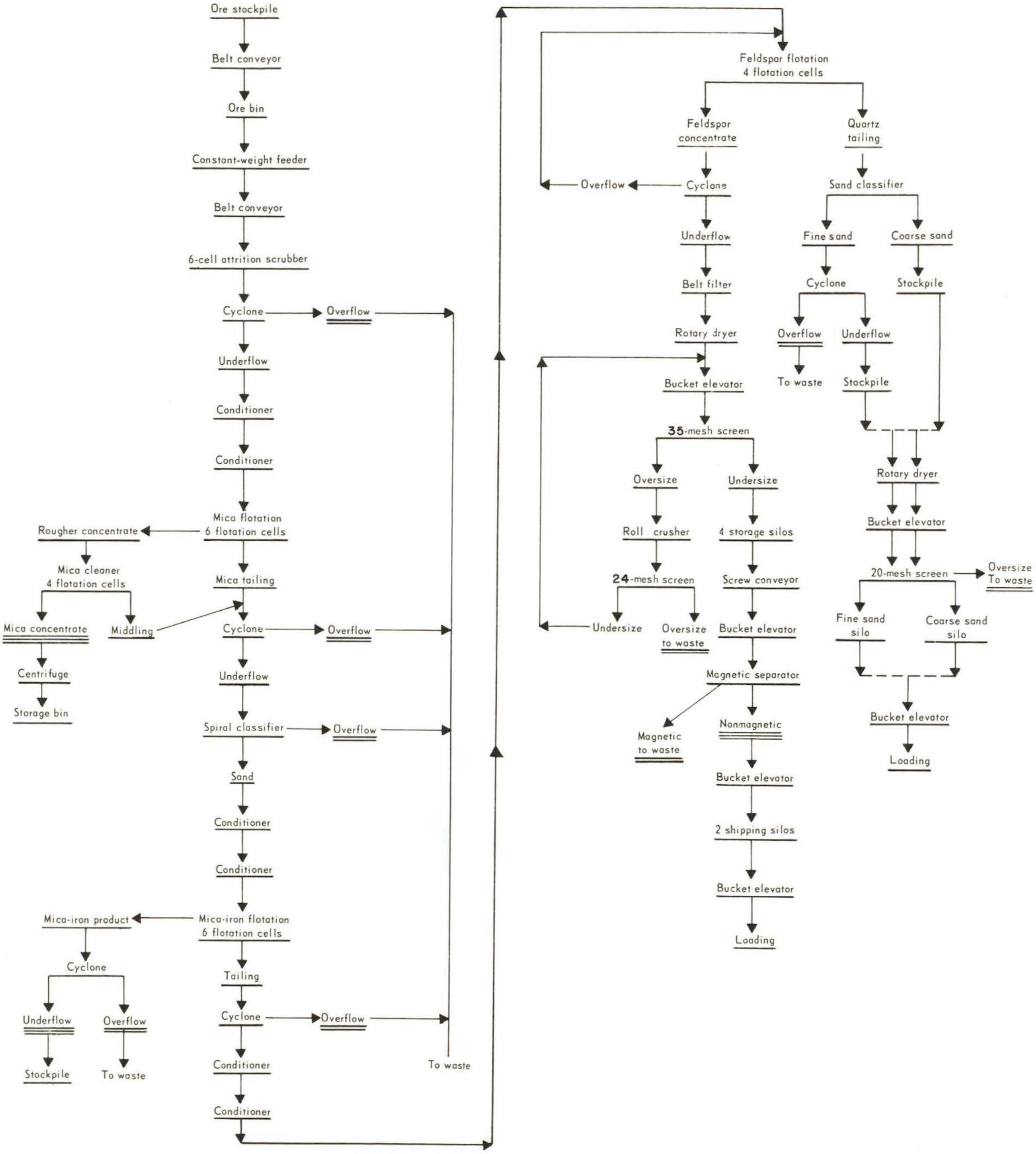

Figure 9.—Flowsheet of plant using alkaline anionic-cationic method.

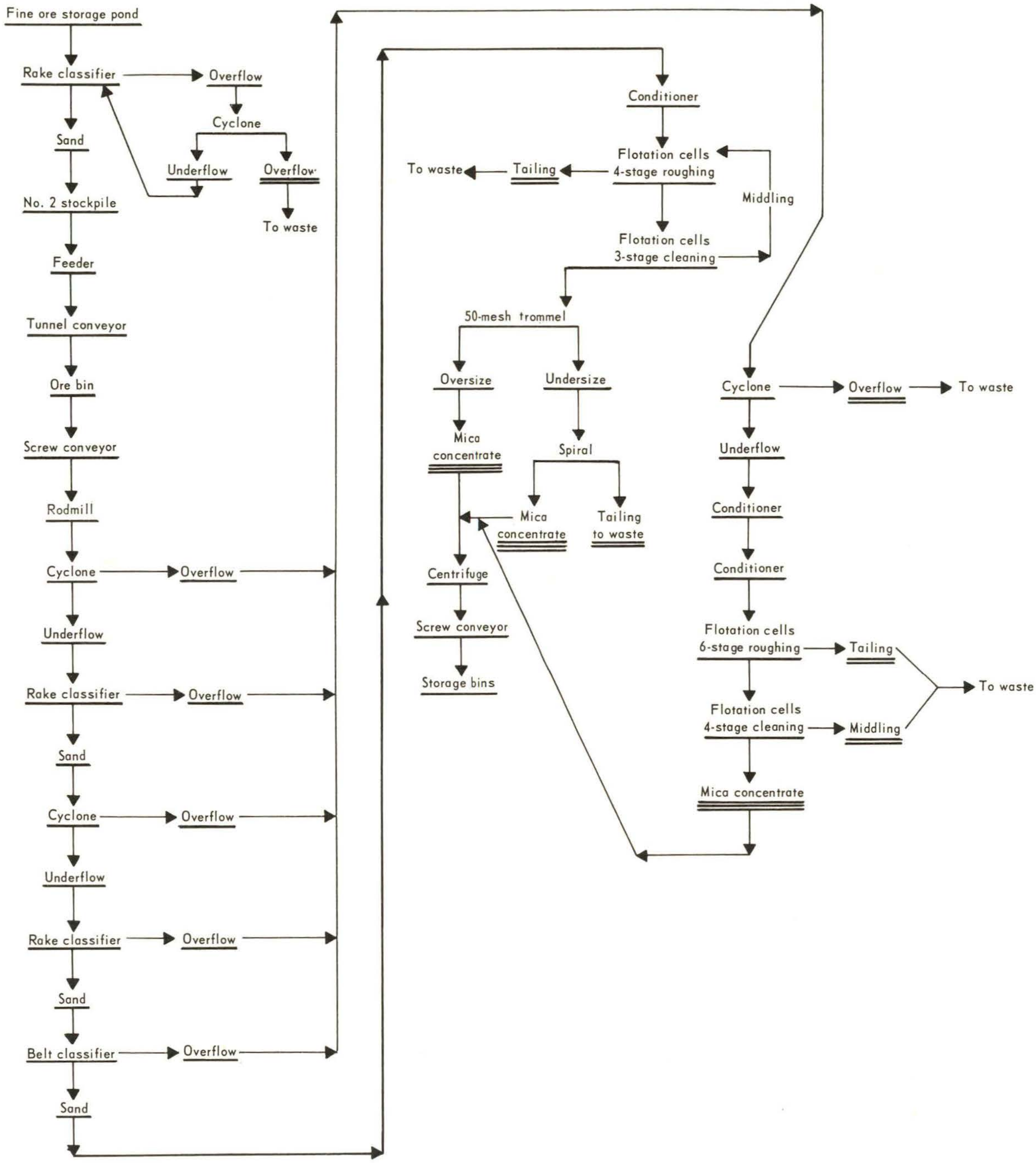

Figure 10.—Flowsheet of plant using combination of acid cationic and alkaline anionic-cationic methods.

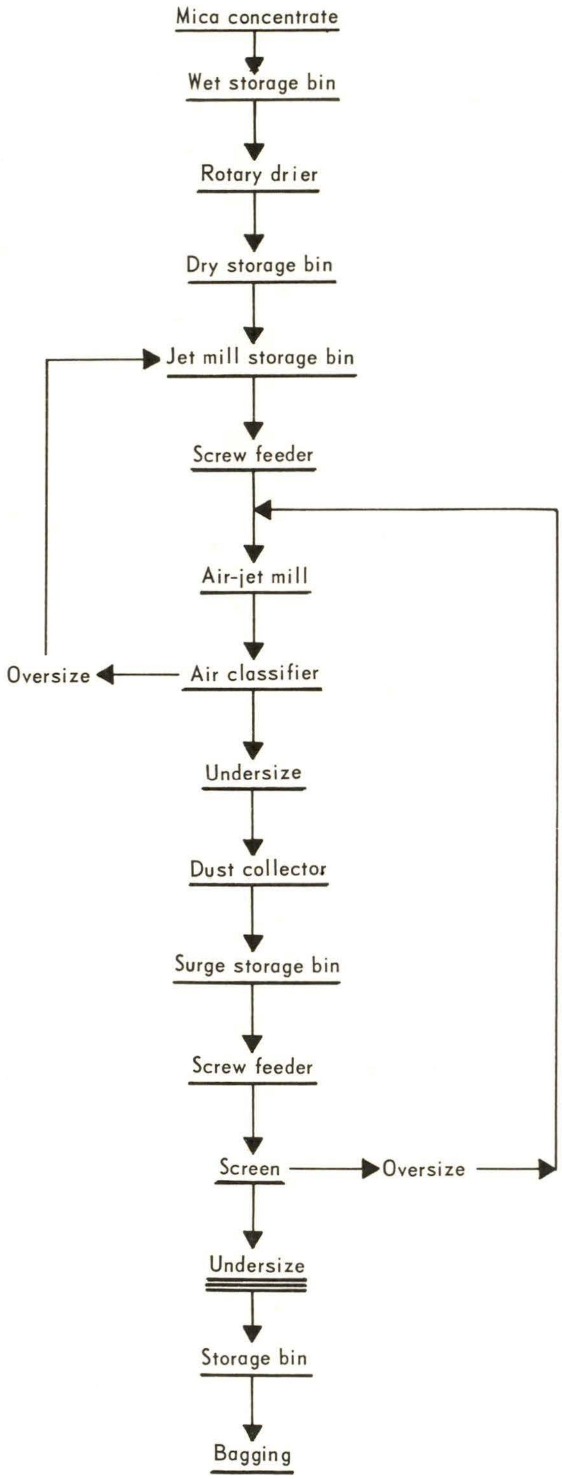

Figure 11.—Flowsheet of plant for dry grinding mica concentrates.

Wet Grinding

Wet-ground mica is produced in mills of the chaser type. Grinding surfaces, which must be such as to preserve the luster or sheen of the mica, usually are made of wood. The type of mill usually employed consists of a steel tank which is lined with wooden blocks laid with the end grain up. The rollers used are usually wooden, and revolve at 15 to 30 rpm. The mica is fed from hoppers to the mill, where water is added gradually to form a thick paste. Each batch is ground 6 to 8 hours depending upon the feed material and the fineness desired. After grinding, the mica is discharged to sediment traps where the coarse mica is recycled to grinding. The fine-size mica is then screened on a trommel to remove undesirable foreign matter. The mica is then thickened, filtered, and dried. The final dried product is then screened and bagged for shipment. The flowsheet of a typical wet-grinding plant is shown in figure 12.

PRODUCTION

The domestic output of scrap and flake mica was almost 125,000 tons in 1969. North Carolina was the major producer, accounting for more than half of the total domestic supply. The remainder was produced in nine other States. Sales of ground mica totaled nearly 125,000 tons. Dry-ground mica accounted for 87 percent of the total production. The production of ground mica sold by producers is given in table 14 (*19*).

USES

Dry-ground mica is used in large tonnages as a filler and surface coating for roofing materials, as a filler in wall board joint cements and as an ingredient in paints. Other uses include rubber, plastics, drilling mud, pipeline enamel, and welding rods. Wet-ground mica is used principally by paint, wallpaper, and tire manufacturers. Table 15 gives a breakdown of the uses of ground mica (*19*).

PRICES

Yearend prices as quoted in the Oil, Paint and Drug Reporter (*18*) for products obtained from dry- and wet-ground mica are shown in table 16.

Table 14.—Ground mica sold by producers in the United States, by method of grinding

Year	Dry ground		Wet ground		Total	
	Short tons	Value (thousands)	Short tons	Value (thousands)	Short tons	Value (thousands)
1965	110, 600	$5, 316	15, 997	$2, 299	126, 597	$7, 615
1966	87, 361	4, 110	16, 089	2, 137	108, 450	6, 247
1967	82, 849	3, 842	14, 204	1, 915	97, 053	5, 756
1968	96, 410	4, 862	14, 979	2, 210	111, 389	7, 072
1969	109, 152	5, 486	15, 704	2, 572	124, 856	8, 058

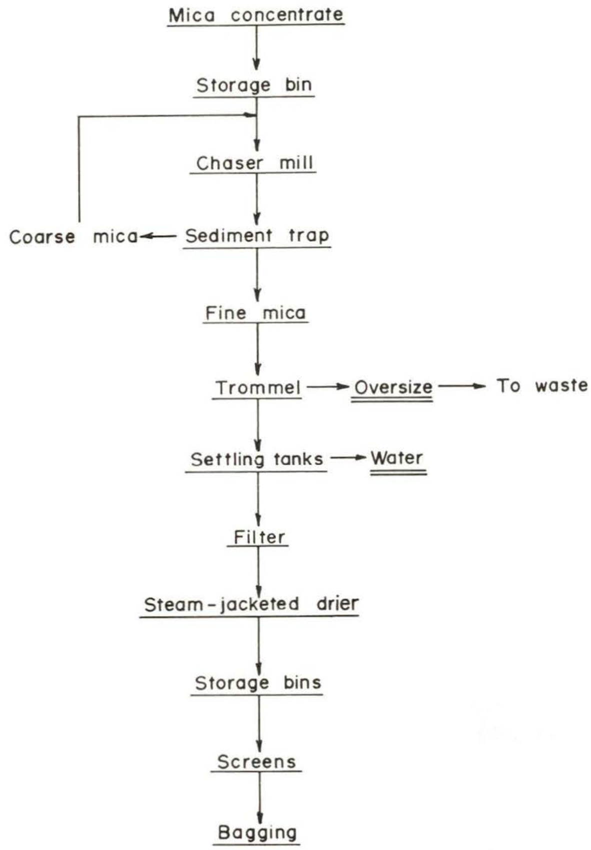

Figure 12.—Flowsheet of plant for wet grinding mica concentrates.

Table 15.—Uses of ground mica in the United States

Use	1968		1969	
	Short tons	Value (thousands)	Short tons	Value (thousands)
Roofing	22,413	$909	41,095	$1,198
Wallpaper	1,049	90	600	79
Rubber	6,962	779	7,348	885
Paint	24,146	2,295	29,081	2,818
Plastics	903	125	684	133
Welding rods	738	35		
Joint cement	30,953	2,227	30,031	2,106
Other [1]	18,225	611	16,017	838
Total	111,389	7,071	124,856	8,057

[1] Includes insulation, well drilling, annealing, etc.

Table 16.—Price of dry-and-wet-ground mica

Product	Cents per pound
Dry-ground mica:	
Joint cement, 100 mesh	3¾
Plastic, 100 mesh	3¾
Roofing, 20 to 80 mesh	2 to 3
Wet-ground mica:	
Biotite	8
Biotite, less than carlots	9
Paint or lacquer, 325 mesh	9
Paint or lacquer, 325 mesh, less than carlots	10
Rubber	9
Rubber, less than carlots	10
Wallpaper	10

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