RI 8457

Bureau of Mines Report of Investigations/1980

Pneumatic Concentration of Mica

By C. E. Jordan, G. V. Sullivan, and B. E. Davis

UNITED STATES DEPARTMENT OF THE INTERIOR

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Cecil D. Andrus, Secretary

BUREAU OF MINES
Lindsay D. Norman, Acting Director

Research at the Tuscaloosa Research Center is carried out under a memorandum of agreement between the Bureau of Mines, U.S. Department of the Interior, and the University of Alabama.

This publication has been cataloged as follows:

Jordan, C E

Pneumatic concentration of mica.

(Report of investigations • U.S.Bureau of Mines ; 8457)
Bibliography: p. 24.
Supt. of Docs. no.: I 28.23:8457.

1. Ore-dressing. 2. Mica. 3. Air classifiers. I. Sullivan, G. V., joint author. II. Davis, Broderick E., joint author. III. Title. IV. Series: United States. Bureau of Mines. Report of investigations ; 8457.

TN23.U43 [TN933] 622s [622'.36'74] 79-607934

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PNEUMATIC CONCENTRATION OF MICA

by

C. E. Jordan,[1] G. V. Sullivan,[2] and B. E. Davis[3]

ABSTRACT

The Bureau of Mines is conducting research into the pneumatic recovery of coarse mica and has used this method to produce mica concentrates that contain more than 90 percent mica. This research is being carried out pursuant to the Bureau's objective to develop technology that will help maintain an adequate supply of minerals and metals to meet national economic and strategic needs.

Researchers used a Bureau-designed system of crushers, screens, and zigzag air classifiers to concentrate coarse liberated mica particles from mica-bearing materials. This pneumatic system was used to concentrate four mica ores from Arizona, North Carolina, and South Dakota and three waste tailings from Alabama, Georgia, and South Dakota. Using these samples, it was demonstrated that plus 65-mesh size mica can be effectively recovered by the pneumatic method. Not only were the concentrates high in mica content; it was also demonstrated that this method can be used to recover up to 78 percent of the mica that was originally contained in the samples.

Because it is a dry concentration method, the pneumatic beneficiation technique may be advantageous in areas where water resources are limited.

INTRODUCTION

As part of the Bureau of Mines program for advancing minerals technology, the Bureau studied pneumatic processing techniques as a method for concentrating coarse mica from mica ores and mica waste tailings. The pneumatic processing method was investigated as an alternative to methods currently used for the recovery of both sheet mica and coarse flake mica.

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Although there are two major commercial mica minerals, muscovite and phlogopite, the research described in this report was conducted exclusively with muscovite. Therefore, unless otherwise stated, mica is used throughout this report to mean muscovite.

The two primary forms of commercial mica are (1) sheet mica and (2) scrap and flake mica. Sheet mica is relatively flat and free of structural defects and is used in the electronics and electrical industries. The American Society for Testing and Materials (ASTM) has designated 12 quality groups for sheet mica. These designations are based on the quantity of visible inclusions and structural imperfections; they range from black- and red-stained to perfectly clear. ASTM has also designated 12 grades based on the size of the maximum usable rectangle that can be cut from each piece of sheet mica in the product. Sizes range from grade 6, with one usable square inch, to grade OOEE special, with 100 usable square inches (2).[4]

Scrap and flake mica generally includes any mica of a quality or size that is not suitable for use as sheet mica (5). Most scrap and flake mica is recovered from schists and pegmatites; occasionally, it is also recovered as a secondary product from the beneficiation of feldspar and kaolin. Scrap and flake mica is generally processed into ground mica for various end uses. For example, coarse, dry-ground 5-mesh size mica is used in oil well drilling mud to overcome mud losses when wells are drilled through porous geological formations. Decorative finishes on concrete, stone, and brick are made with 16-mesh size mica. In the manufacture of roll roofing and shingles, 20- and 30-mesh size mica is used to prevent sticking and for weatherproofing. Wallboard joint cements contain 100- and 200-mesh size mica to eliminate cracking and reduce shrinking. Very fine mica is used in paints to improve exterior durability (6).

The domestic supply of scrap and flake mica is reported to be adequate, although there is a short supply of high-quality scrap and flake mica for mica paper production. For its supply of sheet mica, the United States is almost totally dependent on imports (5). The high cost of skilled labor needed to mine and beneficiate sheet mica is prohibitive for many U.S. mica deposits.

Current Beneficiation Methods

Sheet mica is selectively mined and beneficiated by hand. Scrap and flake mica can be recovered by several general methods. The simplest method is to separate the mica from its host rock by differential crushing and screening in washer plants. Crushing has little effect on mica because of its platy, flexible characteristics. This method can effectively recover plus 0.75-inch size mica . Another method utilizes screens, classifiers, and Humphreys spirals to concentrate the mica from the ground ore. This method permits recovery of a finer size mica than is produced by crushing and screening (6). Flotation methods can be used to recover minus 20-mesh size mica. Mica recovery by flotation methods ranges from 70 percent to 92 percent (4).

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

Pneumatic Concentration Methods

An alternative technique designed by the Bureau uses crushers, screens, and zigzag air classifiers to concentrate mica. In either sheet or flake form, mica has two dimensions many times larger than the third dimension. After screening the ore into close size fractions, the mica sheets or flakes are significantly lighter than the gangue particles of the same size fraction. Air classification separates the flat, light mica particles from the heavier gangue particles. Although air classifiers are fairly common in the minerals processing industry, the zigzag air classifier is new to this industry. Zigzag air classifiers have been successfully used in the seed- and grain-cleaning industry, and commercial equipment is now being marketed (3).

The pneumatic concentration method has several advantages over present commercial methods for mica concentration. These advantages are listed below:

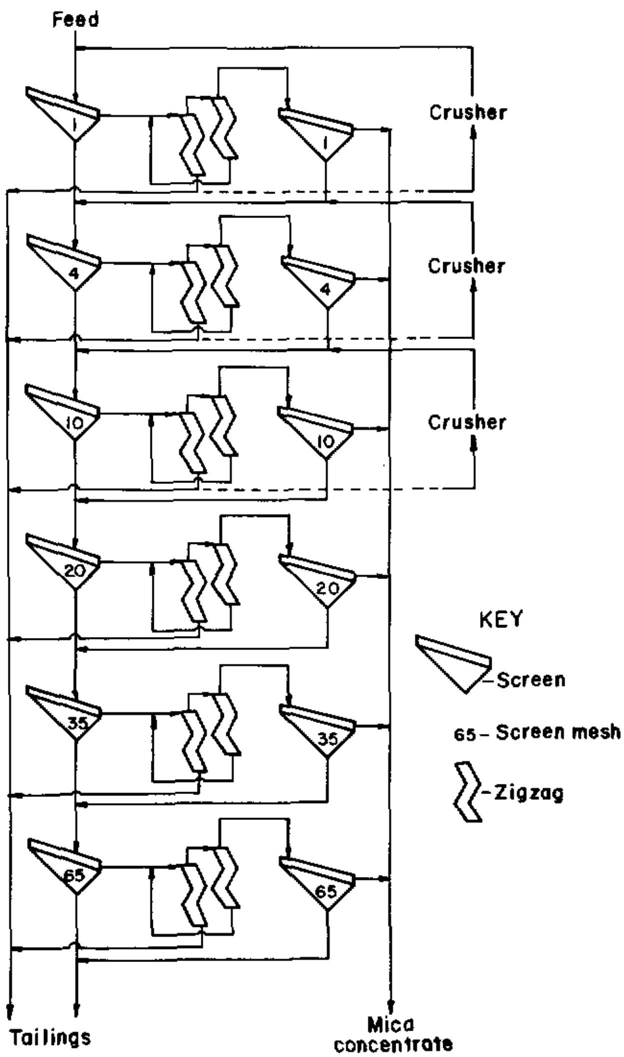

FIGURE 1. - Generalized flow diagram of the Bureau's pneumatic concentration method.

1. Crushing and grinding is limited to the amount necessary to liberate the mica from the host rock.

2. Process tailings are dry, coarse particles that can be easily handled.

3. The method can be used in areas with limited water resources.

4. Use of this method does not result in the water pollution problems associated with the flotation method.

5. Finally, liberated sheet mica particles can be recovered without being subjected to extensive crushing.

DESCRIPTION OF EQUIPMENT AND METHOD

A generalized flow diagram of the Bureau's pneumatic concentration method for mica recovery is shown in figure 1. For this study, three types of ore crushers were employed to liberate mica: a standard jaw crusher, a roll crusher, and a hammer mill. The hammer mill unit was modified by reducing the number of free-swinging hammers from 80 to 10; the 10 remaining hammers were spaced about 3 inches apart. In addition, the crushing screen or grate was removed so that particles received a minimum number of impacts before leaving the unit.

The impact-crushing action of the hammer mill broke and delaminated the mica particles. (Use of the hammer mill without modification resulted in over-crushing of both mica and gangue.) The hammer mill was also used to crush the zigzag tailings from the plus 4-mesh size fractions. Pieces to large to be fed to the hammer mill were broken with a sledge hammer. Only one two-stage zigzag unit was available for this study so that each size fraction was, of necessity, individually processed. The minus 65-mesh fraction could not be effectively treated by this method and was therefore regarded as tailings.

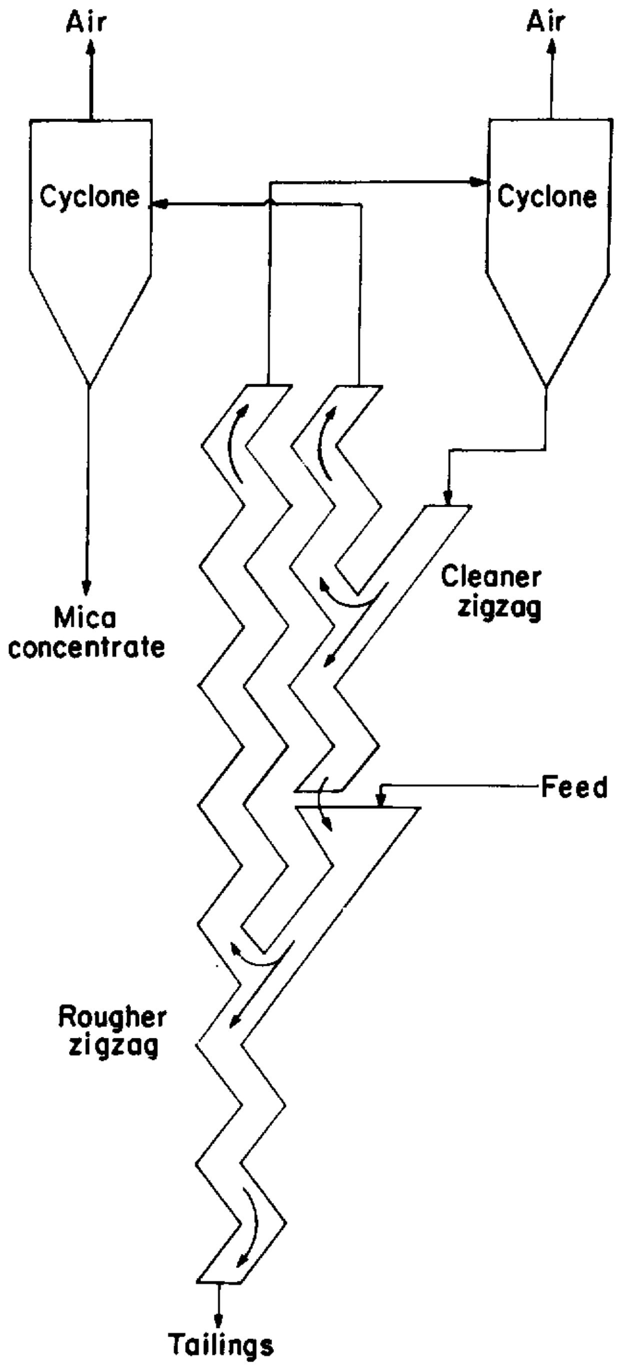

FIGURE 2. - Diagram of two-stage zigzag air classifier.

The Bureau's pneumatic concentration method for mica recovery is designed to process closely sized particles of mica ore. Two screening units and a two-stage zigzag air classifier are used to individually process each size fraction. The oversize particles of the first screen pass through the zigzag air classifier to separate the liberated mica from the host rock. A diagram of the two-stage zigzag air classifier is shown in figure 2. Figure 3 shows the classifier separating mica from gangue minerals, and figure 4 shows a closer view of the separating action.

The ore enters the rougher zigzag section through a rotating air lock. The zigzag sections have a rectangular cross section 1.75 inches wide by 3.75 inches deep. The channel changes direction every 2.5 vertical inches, and the channel sides have a 60° slope from horizontal. Airflow through the classifier can be varied according to the size of the particles being separated. The gangue material falls through the airstream of the rougher zigzag section and is then discarded as tailings. The mica flakes are carried by the airstream to the cyclone shown on the right side of figure 2, where they are collected. This rougher mica concentrate is fed to the cleaner zigzag section through another rotating air lock. The mica particles are again carried by the

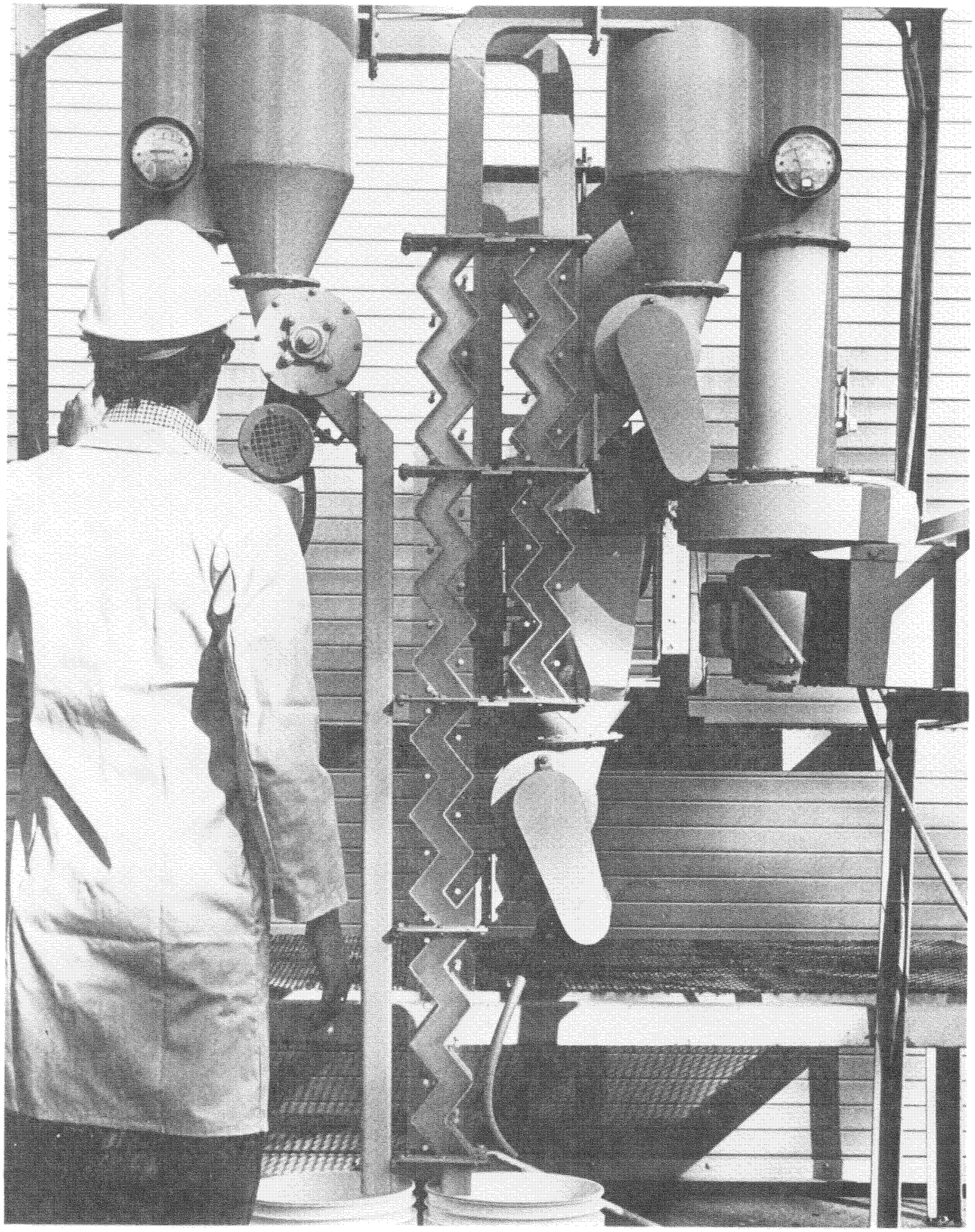

FIGURE 3. -- Two-stage zigzag classifier separating mica from gangue minerals.

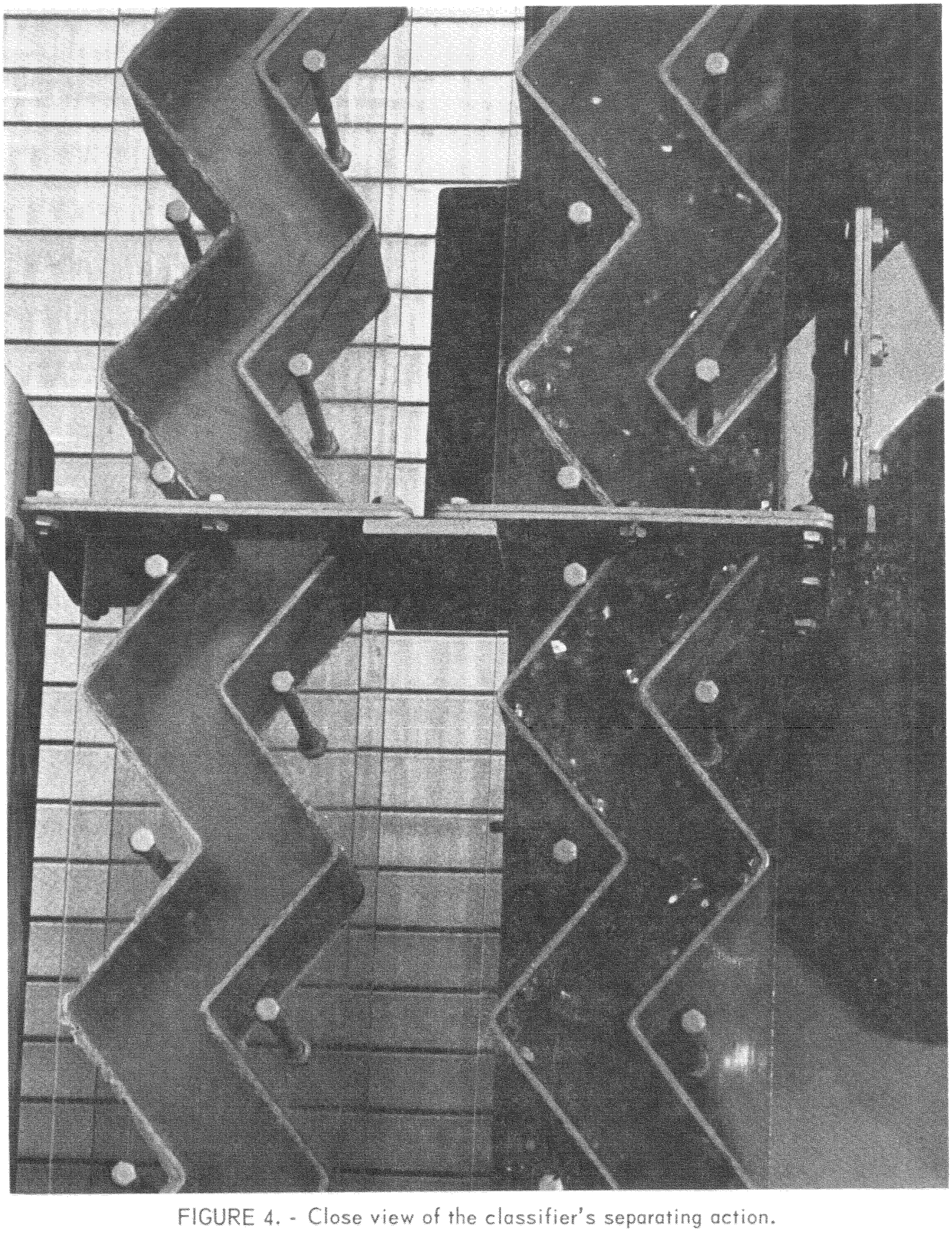

FIGURE 4. - Close view of the classifier's separating action.

airstream but they are now collected in the cyclone on the left side of figure 2. The cleaner concentrate leaves the left-side cyclone through a third rotating air lock and is rescreened to remove undersize material missed by the first screening. The airflow through the cleaner zigzag section is set slightly lower than the airflow through the rougher zigzag section. This allows most of the gangue particles that are unintentionally carried in the rougher section's airstream to fall through the cleaner section and rejoin the feed to the rougher section. The final product of this pneumatic process is generally a high-grade mica concentrate. Undersize screen products are combined and fed into the screen for the next smaller size fraction and then into the zigzag classifier.

In the Bureau's tests, the airflow required for pneumatic concentration in the zigzag air classifier was largely left to the discretion of the operator. For each size fraction, the operator first used an airflow setting that recovered most of the mica in the rougher section, regardless of the amount of gangue carried by the rougher airstream. The airflow in the rougher section was gradually reduced to minimize the gangue content of the rougher concentrate without increasing the mica content of the final tailings. Then, the cleaner section airflow was adjusted until a fairly clean mica concentrate was produced. After a few minutes of operation, the flow rate of the tailings from the cleaner section stabilized. If the quantity of the cleaner tailings did not stabilize, then the airflow to the rougher zigzag section was gradually decreased to lessen the recirculating load. When it was determined that airflow was properly adjusted, both the concentrate and the tailings product were collected, and airflows of both the rougher and cleaner sections were measured and recorded.

METHODS OF ANALYSIS

The minerals industry has not established a standard method of analysis to determine the mica content of a sample. For this study, three methods were used individually and in combination to separate the various products so that their mica contents could be determined. These methods were (1) hand sorting, especially of coarse materials; (2) the inclined-plane, or cardboard, method; and (3) separation in heavy liquids (1). Analyses were made by physically separating and weighing the products. Analytical products were examined with a binocular microscope to detect any misplaced particles. Analyses of the plus 10-mesh products were essentially 100 percent accurate. The precision of the analyses decreased as particle size decreased. A statistical analysis of the measured mica contents of the concentrates indicated a 95-percent confidence interval of plus or minus 5 percent. The same confidence interval of the measured mica content of the tailings was plus or minus 2 percent. It should be understood that all analyses reported in this study were within these boundaries of error.

EXPERIMENTAL RESULTS

The Bureau tested its pneumatic concentration method with four mica ores from Arizona, North Carolina, and South Dakota and three waste tailings from Alabama, Georgia, and South Dakota. These samples represent the major geographical areas where mica is mined.

Arizona Mica Deposit

Description

Two samples of the same mica ore, containing about 22 percent mica, were obtained from an Arizona mica-bearing pegmatite. Several mica sheets with surface areas up to approximately 1.5 square inches were found in the samples, but most of the mica grains had surface areas smaller than 1 square inch. The first sample (ore sample A) was run-of-mine rock that was up to 12 inches in diameter. About 60 percent by weight of this first sample was plus 8-inch size. The second sample (ore sample B) was a rod mill feed already crushed to minus 1-inch size. Table 1 shows the size analysis of this second sample.[5] The mica in this second sample was almost completely liberated in the minus 4-mesh material. Although some of the mica was liberated in the plus 4-mesh material, a significant amount of mica was still locked in particles of the host rock, which was mostly quartz and plagioclase with minor amounts of microcline.

TABLE 1. - Size analysis of Arizona mica ore B

Size, mesh	Wt-pct	Analysis, pct	Distribution, pct
Plus 4...........	35.6	23	36
Minus 4 plus 10..	39.1	23	39
Minus 10 plus 20.	5.1	31	7
Minus 20 plus 35.	10.6	26	12
Minus 35 plus 65.	4.2	18	3
Minus 65.........	5.4	11	3
Composite......	100.0	23	100

Procedure

Ore Sample A

The run-of-mine rock sample was crushed with a hammer mill to about 1-inch size. Rocks too large for the hammer mill (plus 6-inch) were broken with a sledge hammer. The minus 1-inch material was fed to the pneumatic concentration system shown in figure 1. The plus 1-inch circuit was not used. A hammer mill was also used as the crusher in the minus 1-inch plus 4-mesh circuit. The minus 4- plus 10-mesh circuit did not need a crusher because the mica was already liberated in the minus 4-mesh material.

Ore Sample B

The rod mill feed sample was fed as-received into the pneumatic concentration system shown in figure 1. The plus 1-inch circuit was not used. A

[5]Size-analysis tables are not provided for the Arizona mica ore sample A, or for the South Dakota ore and tailings samples described later in this report. Because these samples contained significant amounts of large rocks, and because most of these samples were crushed in the mica recovery process, size-analysis tables for them would not be informative.

jaw crusher was used with the minus 1-inch plus 4-mesh circuit. A roll crusher was used with the minus 4- plus 10-mesh circuit. Although the liberation size was about 4 mesh, this sample was crushed through 10 mesh to determine if mica recovery could be improved by crushing it to a size slightly smaller than the liberation size. A two-stage zigzag classifier was not available for this sample, but the two stages were simulated with a single-stage zigzag classifier to produce a cleaner concentrate, the rougher mica concentrate was treated a second time at a lower airflow than was used the first time. The tailings from the second zigzag operation were mostly gangue particles that were unintentionally carried into the rougher concentrate. The reduced airflow of the second pass through the zigzag classifier allowed these gangue particles to be removed, and also permitted a significant amount of mica to be dropped into the second zigzag tailings. This tailings product is called a middlings product and, in a continuous operation, the middlings product would be recirculated to the rougher zigzag feed.

Pneumatic Concentration Results

A material balance for the concentrates, middlings products, and tailings produced from both samples of the Arizona mica ore is shown in table 2. Table 3 shows the rate of airflow that was used in the zigzag section for each size fraction to obtain the results shown in table 2. For the rod mill feed (sample B), the "two-product" formula[6] gives an approximation--but only a rough approximation--of a continuous operation. In a continuous operation, the middlings product would be recirculated to the rougher feed. Eventually, this material would go either to the concentrate or to the tailings.

The actual mica recovered in the sample B concentrate was only 56 percent of the total mica in the ore; the middlings product contained 25 percent of the total mica. Sample B yielded a higher grade concentrate and lower grade tailings than did sample A, the run-of-mine rock, but a realistic comparison of results for these two samples was difficult. Nonetheless, the results showed that both ore samples produced high-grade concentrates and that from both samples a substantial portion of the mica was recovered. Only 2 percent to 5 percent of the total mica occurred in the untreated minus 65-mesh material. The mica lost in the plus 65-mesh tailings was mostly "book" mica with flakes that were too thick to be carried by the airstream. Like the gangue particles, these mica books were nearly equal in all three dimensions.

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[6]The "two-product" formula is a method for approximating the distribution of two final products as they would be made up without a middlings product. The formula takes into account that in a continuous operation, material from the middlings product would ultimately go to the concentrate or the tailings product. The formula is given below, with WP used to represent weight-percent of concentrate:

$$WP = \frac{100 \text{ percent} \cdot (\text{percent mica of feed} - \text{percent mica of tailings})}{(\text{percent mica of concentrate} - \text{percent mica of tailings})}$$

TABLE 2. - Pneumatic concentration results from two samples of an Arizona mica ore

Product, mesh	Wt-pct		Analysis, pct		Distribution, pct	
	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
Concentrate:						
Plus 4..........	3.8	3.6	100	100	18	16
Minus 4 plus 10.	5.3	6.3	97	99	24	28
Minus 10 plus 20	5.2	2.7	82	90	20	11
Minus 20 plus 35	1.1	.2	94	91	5	1
Minus 35 plus 65	1.0	.1	78	90	4	<1
Middlings:						
Minus 10 plus 20	NAp	4.3	NAp	38	NAp	7
Minus 20 plus 35	NAp	6.4	NAp	52	NAp	15
Minus 35 plus 65	NAp	2.4	NAp	25	NAp	3
Tailings:						
Minus 4 plus 10.	40.4	NAp	6.2	NAp	12	NAp
Minus 10 plus 20	20.1	36.4	3.5	7	3	11
Minus 20 plus 35	6.5	17.2	14.0	3	4	2
Minus 35 plus 65	12.3	10.1	13.0	2	8	1
Minus 65........	4.3	10.3	11.0	11	2	5
Composite.....	100.0	100.0	22.0	22.0	100	100
Composite mica concentrate......	16.4	[1]18.2	92	97	69	78
Composite tailings	83.6	81.8	7.9	6	31	22
Total.......	100.0	100.0	22	22	100	100

NAp Not applicable.
[1]Weight-percent calculated from the "two-product" formula given in text footnote 6.

TABLE 3. - Airflow through zigzag section for concentration of Arizona mica ore, cfm

Ore size, mesh	Rougher		Cleaner	
	Sample A	Sample B	Sample A	Sample B
Plus 4............	160	120	120	NAp
Minus 4 plus 10...	130	115	110	NAp
Minus 10 plus 20..	120	110	100	92
Minus 20 plus 35..	90	105	70	46
Minus 35 plus 65..	70	80	30	33

NAp Not applicable.

To test the significance of the type of ore crusher used to liberate the mica, a small sample of the run-of-mine rock was treated with a jaw crusher taking the place of the hammer mill in the circuit. This modification produced a concentrate containing 82 percent mica, and 50 percent of the mica was recovered. The circuit with the hammer mill produced a concentrate containing 92 percent mica, and 69 percent of the mica was recovered.

Figure 5 shows typical mica concentrates and tailings from the jaw crusher circuit and from the hammer mill circuit. Of these two crushers,

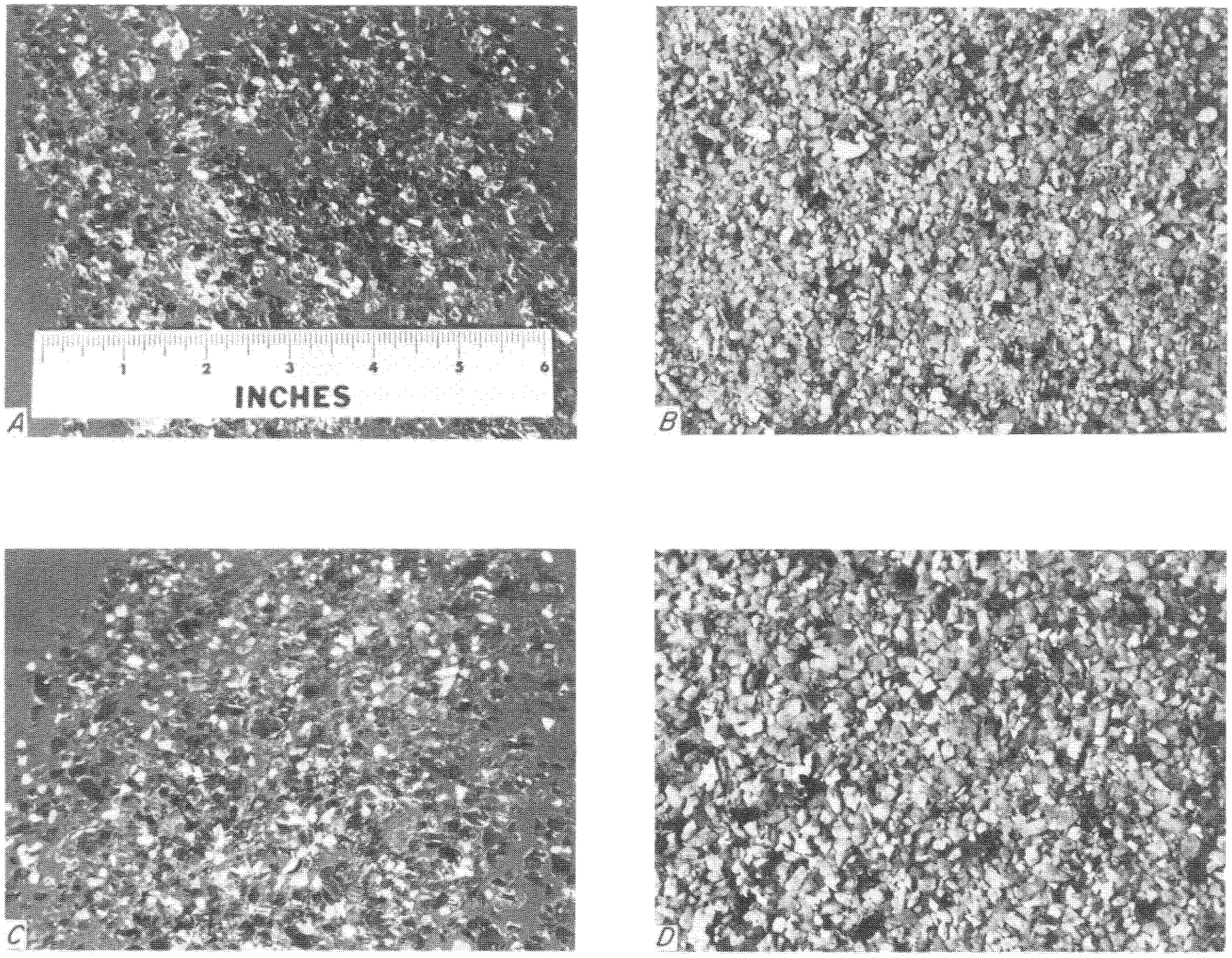

FIGURE 5. - Comparison of hammer mill products and jaw crusher products. *A*, The concentrate from the hammer mill circuit includes only a few pieces of gangue materials. *B*, The tailings from this same circuit include only a few pieces of Mica. *C*, The concentrate from the jaw crusher circuit has many pieces of gangue minerals; they are mostly flat particles. *D*, The tailings from the jaw crusher circuit contain many pieces of book mica.

the jaw crusher tended to produce a greater number of thick mica particles. Also, the concentrate produced from the jaw crusher circuit appeared to contain a greater number of flat gangue particles; this was due to the crushing action of the jaw crusher. These flat particles of gangue cannot be separated from the mica by the zigzag air classifier. In the jaw crusher tailings, there were many pieces of book mica that were not delaminated by the crusher action. Unless this mica is delaminated, it cannot be recovered with the zigzag classifier.

North Carolina Deposit A

Description

A sample of mica ore containing about 7 percent mica was obtained from a mica and feldspar deposit in North Carolina. The sample had already been crushed at the mine and was nearly all minus 20 mesh. The size analysis of the ore sample is shown in table 4. The mica was completely liberated from the host rock and was fairly evenly distributed throughout the different size fractions. The gangue material was primarily quartz, plagioclase, and microcline.

TABLE 4. - Size analysis of North Carolina mica ore A

Ore size, mesh	Wt-pct	Analysis, pct	Distribution, pct
Plus 20.........	1.6	8	2
Minus 20 plus 35	23.6	8	26
Minus 35 plus 65	53.7	7	52
Minus 65........	21.1	7	20
Composite.....	100.0	7	100

Procedure

Since the sample was all minus 10-mesh size, only the minus 10-mesh circuit of the pneumatic concentration system was needed for this sample. No crushing units were used. Each size fraction was individually separated with the two-stage zigzag classifier.

Pneumatic Concentration Results

A summary of the pneumatic concentration results for this ore sample is shown in table 5. Table 6 shows the airflows used in the zigzag section to produce these results. Only 26 percent of the mica from the sample was recovered in the mica concentrate, and the concentrate grade was only 80 percent mica. Examination of the performance of each size fraction revealed that only 12 percent of the mica in the minus 35- plus 65-mesh size fraction was recovered by the zigzag classifier. About 21 percent of the mica in the sample was too small to be recovered by this method.

TABLE 5. - Pneumatic concentration results from North Carolina mica ore A

Product, mesh	Wt-pct	Analysis, pct	Distribution, pct
Concentrate:			
Plus 20................................	0.1	85	1
Minus 20 plus 35.......................	1.8	76	19
Minus 35 plus 65.......................	.5	91	6
Tailings:			
Plus 20................................	1.5	3.2	1
Minus 20 plus 35.......................	21.8	2.6	8
Minus 35 plus 65.......................	53.2	5.9	44
Minus 65...............................	21.1	7.2	21
Composite............................	100.0	7.2	100
Composite mica concentrate...............	2.4	80	26
Composite tailings.......................	97.6	5.4	74
Total.............................	100.0	7.2	100

TABLE 6. - Airflow through zigzag section for concentration of North Carolina mica ore A, cfm

Ore size, mesh	Rougher	Cleaner
Plus 20................................	110	110
Minus 20 plus 35.......................	80	60
Minus 35 plus 65.......................	60	30

North Carolina Deposit B

Description

A sample of mica ore was obtained from another mica and feldspar deposit in North Carolina. The sample was received wet and was air dried prior to any pneumatic processing. It contained 14 percent mica and was essentially minus 1-inch size. A size analysis is shown in table 7. Complete liberation of the mica was observed in particles smaller than 4 mesh. Very few plus 1-inch mica particles were present in this ore. The mica was fairly evenly distributed among the different size fractions. The gangue material was primarily quartz, plagioclase, and kaolinite.

TABLE 7. - Size analysis of North Carolina mica ore B

Ore size, mesh	Wt-pct	Analysis, pct	Distribution, pct
Plus 1.........	1.2	33	3
Minus 1 plus 4..	14.4	10	10
Minus 4 plus 10.	17.8	12	15
Minus 10 plus 20	18.3	15	20
Minus 20 plus 35	16.2	20	24
Minus 35 plus 65	13.1	15	14
Minus 65........	19.0	10	14
Composite.....	100.0	14	100

Procedure

The minus 1-inch size circuit of the pneumatic concentration system was used for this sample. A jaw crusher was used in the plus 4-mesh circuit. No crushing units were used in the minus 4-mesh circuits.

Pneumatic Concentration Results

This ore sample did not respond well to pneumatic concentration techniques. A summary of the test results is shown in table 8. Table 9 shows the airflows used in the zigzag section to obtain these results. An 86-percent-mica concentrate was obtained, and only 53 percent of the mica originally contained in the sample was recovered. About 14 percent of the mica was lost to the minus 65-mesh material. The remaining mica was distributed fairly evenly throughout the tailings of the plus 65-mesh size fractions. Much of this mica was in book form.

The North Carolina ore sample B was tested before a hammer mill became available for the study. The results were similar to those obtained when the jaw crusher was used with the run-of-mine ore sample from Arizona. In that case, an 82-percent-mica concentrate was produced with only a 50-percent recovery of mica. However, when a hammer mill was used on that sample, the grade and recovery were improved. Therefore, because the feed and crusher products of the North Carolina ore sample B and the Arizona sample were similar, it would be expected that hammer milling the North Carolina sample B would likewise improve its grade and recovery.

TABLE 8. - Pneumatic concentration results from North Carolina mica ore B

Product, mesh	Wt-pct	Analysis, pct	Distribution, pct
Concentrate:			
Plus 4	0.3	100	2
Minus 4 plus 10	1.2	99	9
Minus 10 plus 20	1.8	94	12
Minus 20 plus 35	2.8	88	18
Minus 35 plus 65	2.5	71	12
Tailings:			
Minus 4 plus 10	22.8	5.9	10
Minus 10 plus 20	19.6	7.0	10
Minus 20 plus 35	14.3	7.2	7
Minus 35 plus 65	15.7	5.6	6
Minus 65	19.0	10.4	14
Composite	100.0	14.0	100
Composite mica concentrate	8.6	86	53
Composite tailings	91.4	7.2	47
Total	100.0	14.0	100

TABLE 9. - Airflow through zigzag section for concentration of North Carolina mica ore B, cfm

Ore size, mesh	Rougher	Cleaner
Plus 4	120	120
Minus 4 plus 10	120	90
Minus 10 plus 20	110	70
Minus 20 plus 35	100	60
Minus 35 plus 65	60	30

South Dakota Ore Deposit

Description

A sample of mica ore containing about 30 percent mica was obtained from a pegmatite mica deposit in South Dakota. Many of the sample pieces were as large as 12 inches in diameter, but most were between 6 and 8 inches in diameter. The sample contained large sheets of mica with surface areas as large as 6 to 8 square inches. The liberation size of the ore was near 4 mesh. However, a large portion of the mica was also liberated among the 2-inch diameter particles. About 1 percent biotite was also present in this ore; biotite flakes as large as 2 square inches in surface area were observed. The gangue material was mostly quartz and plagioclase and also included a minor amount of microcline and a trace of kaolinite.

Procedure

Due to the 1.75-inch channel width of the Bureau's two-stage zigzag classifier, only the minus 1.5-inch material was treated in the plus 1-inch circuit by the method outlined in figure 1. A hammer mill was used as the crushing unit in the plus 1-inch and plus 4-mesh circuits. Rocks too large for the hammer mill (plus 6-inch) were broken with a sledge hammer. No crusher was used in the plus 10-mesh circuit.

The plus 1.5-inch material was hand sorted rather than separated in the zigzag classifier, but only liberated mica flakes less than 0.25 inch thick were handpicked from the plus 1.5-inch rocks. (Since the plus 1.5-inch mica constituted only 5 percent of the mica concentrate, the overall effect of this hand sorting was minor.) The remaining plus 1.5-inch material was returned to the plus 1-inch circuit and crushed in the hammer mill. This procedure was repeated until all of the ore was minus 1.5-inch size. The minus 1.5-inch size material was treated by the method outlined in figure 1.

Pneumatic Concentration Results

A summary of the results of the pneumatic concentration of this ore sample is shown in table 10. Airflows used in the zigzag section for the South Dakota ore are shown in table 11. Concentration of this ore produced a 93-percent-mica concentrate, and 78 percent of the mica in the ore was recovered. Biotite flakes were included as mica in the analysis of these products. Figure 6 shows a typical mica concentrate from the South Dakota ore. As with the previous samples, most of the mica lost in the tailings was too thick to be concentrated by the airstream. Only 1 percent of the mica was lost in the minus 65-mesh material.

TABLE 10. - Pneumatic concentration results from a South Dakota mica ore

Product, mesh	Wt-pct	Analysis, pct	Distribution, pct
Concentrate:			
Plus 1	2.4	100	8
Minus 1 plus 4	10.1	100	34
Minus 4 plus 10	6.0	95	19
Minus 10 plus 20	5.7	75	14
Minus 20 plus 35	1.0	86	3
Minus 35 plus 65	.3	86	1
Tailings:			
Minus 4 plus 10	37.1	8.3	10
Minus 10 plus 20	18.4	8.1	5
Minus 20 plus 35	6.0	5.2	1
Minus 35 plus 65	10.6	11	4
Minus 65	2.4	≈20	1
Composite	100.0	30	100
Composite mica concentrate	25.5	93	78
Composite tailings	74.5	9	22
Total	100.0	30	100

TABLE 11. - Airflow through zigzag section for concentration of a South Dakota mica ore, cfm

Ore size, mesh	Rougher	Cleaner
Plus 1	160	160
Minus 1 plus 4	160	120
Minus 4 plus 10	140	110
Minus 10 plus 20	120	110
Minus 20 plus 35	80	50
Minus 35 plus 65	60	30

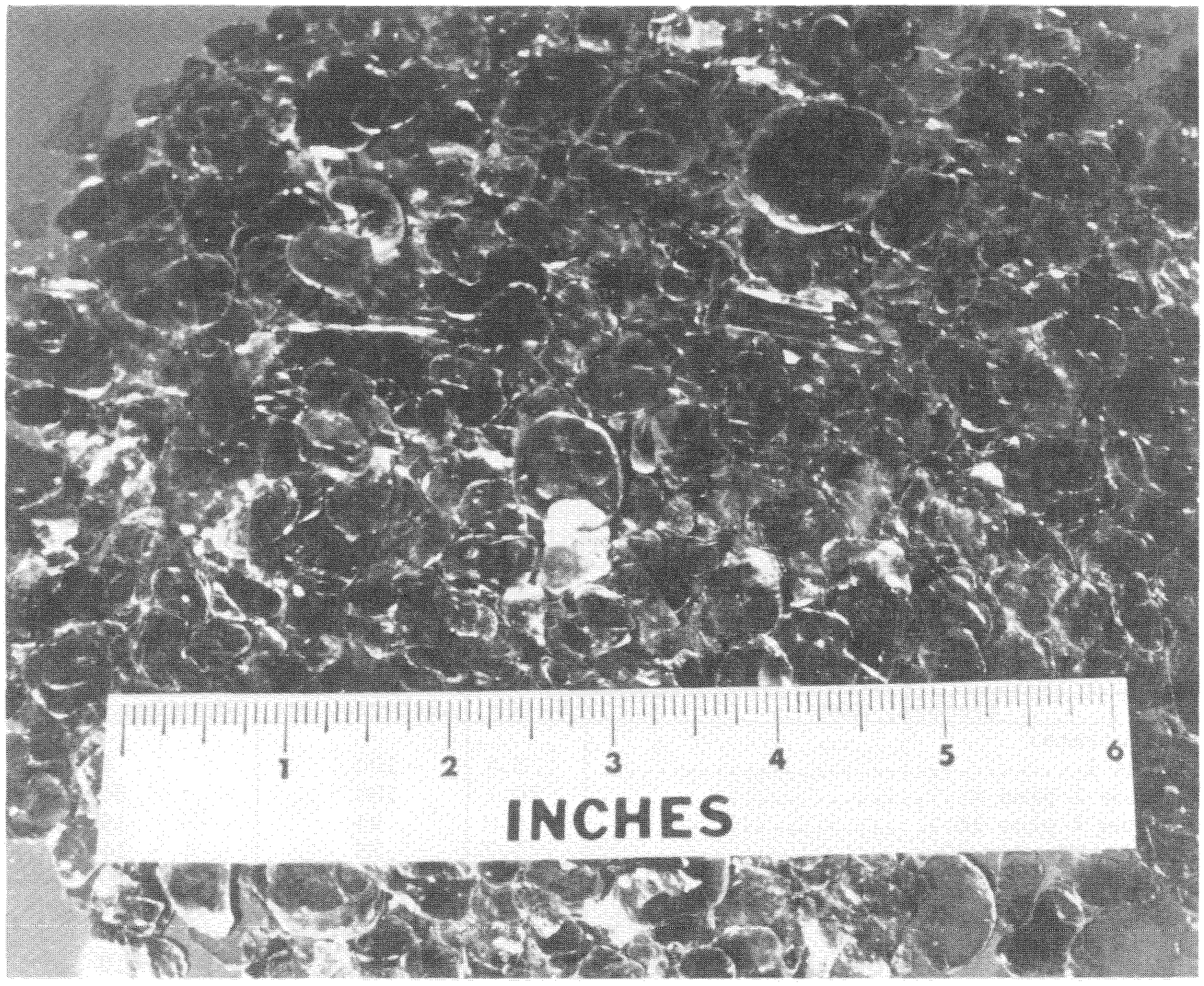

FIGURE 6. - Coarse mica particles recovered by the pneumatic concentration method.

Alabama and Georgia Waste Mica Tailings

Description

Alabama Tailings

A waste sample of mine tailings was obtained from an abandoned mica mine in Alabama. Although the sample contained 7.0 percent mica and was nearly all minus 10-mesh size, the plus 10-mesh size material had a substantially larger percentage of mica than was found in the other size ranges. A size analysis of this sample is given in table 12. Complete liberation of the mica particles was observed throughout the sample. The gangue material was mostly quartz and kaolinite and also included minor amounts of microcline and traces of plagioclase and gibbsite.

TABLE 12. - Size analysis of Alabama mica tailings

Tailings size, mesh	Wt-pct	Analysis, pct	Distribution, pct
Plus 10..................	2.9	27	12
Minus 10 plus 20..........	15.8	11	24
Minus 20 plus 35..........	46.7	4	28
Minus 35 plus 65..........	22.1	9	29
Minus 65..................	12.5	4	7
Composite...............	100.0	7	100

Georgia Tailings

A sample of white quartz sand was obtained from a Georgia mining operation. The material was nearly all minus 10-mesh size and it contained 7.5 percent mica. The mica particles were completely liberated from the host rock particles. The size analysis of this sample is shown in table 13. The mica was fairly evenly distributed throughout the plus 65-mesh material. The gangue material was practically all quartz, but also included minor amounts of microcline and kaolinite.

TABLE 13. - Size analysis of Georgia mica tailings

Tailings size, mesh	Wt-pct	Analysis, pct	Distribution, pct
Plus 10..................	0.6	11	1
Minus 10 plus 20..........	15.8	11	23
Minus 20 plus 35..........	38.1	7	35
Minus 35 plus 65..........	21.5	9	25
Minus 65..................	24.0	5	16
Composite...............	100.0	8	100

Procedure

Only the minus 4-mesh circuit of the pneumatic concentration system was used for the Alabama sample, and only the minus 10-mesh portion was used for the Georgia tailings. No crushers were used on either sample. Since both samples were tested before the two-stage zigzag classifier was available, a single-stage zigzag classifier was used. In both tests, the rougher mica concentrates were reclassified at reduced airflows to produce cleaner concentrates. The tailings from the second zigzag separations were middlings products. As with the ore samples, these products would have been recirculated to the rougher zigzag feed if the operation had been a continuous one.

Alabama Tailings Pneumatic Concentration Results

The results of pneumatic concentration of the Alabama tailings are shown in table 14. The airflow used in the zigzag section for each size fraction of these tailings is shown in table 15. A 97-percent-mica concentrate was produced, and mica recovery was about 30 percent. The middlings product contained 38 percent of the mica in the sample. Using the "two-product" formula, it was determined that the approximate mica recovery for a continuous system would be 58 percent. Most of the mica lost in the tailings was too thick to be concentrated by the airstream. Only 7 percent of the mica was too small to separate by this method.

TABLE 14. - Pneumatic concentration results from Alabama mica tailings

Product, mesh	Wt-pct	Analysis, pct	Distribution, pct
Concentrate:			
Plus 10	0.5	96	7
Minus 10 plus 20	.8	97	11
Minus 20 plus 35	.6	98	8
Minus 35 plus 65	.3	94	4
Middlings:			
Plus 10	.7	36	4
Minus 10 plus 20	4.7	16	11
Minus 20 plus 35	14.9	6	13
Minus 35 plus 65	4.6	16	10
Tailings:			
Plus 10	1.7	3.3	1
Minus 10 plus 20	10.3	1.7	2
Minus 20 plus 35	31.2	1.6	7
Minus 35 plus 65	17.2	6.0	15
Minus 65	12.5	4.0	7
Composite	100.0	7.0	100
Composite mica concentrate	14.2	97	58
Composite tailings	95.8	3.1	42
Total	100.0	7.0	100

[1]Weight-percent calculated from the "two-product" formula given in text footnote 6.

TABLE 15. - Airflow through zigzag section for concentration of Alabama mica tailings, cfm

Ore size, mesh	Rougher	Cleaner
Plus 10	140	120
Minus 10 plus 20	110	80
Minus 20 plus 35	100	70
Minus 35 plus 65	60	40

Georgia Tailings Pneumatic Concentration Results

The pneumatic concentration method produced from the Georgia tailings a mica concentrate that contained 93 percent mica. The results are shown in table 16; airflows used in the zigzag section are shown in table 17. Only 31 percent of the mica originally contained in the sample was recovered in this concentrate. The middlings product contained 40 percent of the mica in the sample. Using the "two-product" formula, the approximate mica recovery for this ore sample was 67 percent. About 17 percent of the mica in the sample was in the untreated minus 65-mesh portion.

TABLE 16. - Pneumatic concentration results from Georgia mica tailings

Product, mesh	Wt-pct	Analysis, pct	Distribution, pct
Concentrate:			
Plus 20	0.7	97.5	9
Minus 20 plus 35	1.0	95.5	13
Minus 35 plus 65	.8	87	9
Middlings:			
Plus 20	6.3	14	12
Minus 20 plus 35	10.8	13	19
Minus 35 plus 65	2.0	33	9
Tailings:			
Plus 20	9.4	2.0	3
Minus 20 plus 35	26.3	.8	3
Minus 35 plus 65	18.7	2.5	6
Minus 65	24.0	5.4	17
Composite	100.0	7.5	100
Composite mica concentrate	[1]5.4	93	67
Composite tailings	94.6	2.6	33
Total	100.0	7.5	100

[1]Weight-percent calculated from the "two-product" formula given in text footnote 6.

TABLE 17. - Airflow through zigzag section for concentration of Georgia mica tailings, cfm

Ore size, mesh	Rougher	Cleaner
Plus 20	130	90
Minus 20 plus 35	100	60
Minus 35 plus 65	60	40

South Dakota Tailings

Description

A waste sample of mine tailings was obtained from an abandoned mica mine in South Dakota. The sample contained 18 percent mica and was mostly minus 4-mesh size. Several large pieces of mica-bearing rock were included in this sample. These pieces, as large as 6 to 8 inches in diameter, amounted to about 25 percent of the sample's weight. Although these pieces could not have been previously treated in the mica beneficiation plant, they apparently were discarded in the tailings disposal area. Several pieces of plus 1-inch size mica were observed, but there were not enough of these pieces to be significant. Complete liberation of the mica particles was observed in the minus 4-mesh size fractions. Besides mica, this sample also contained about 3 percent biotite. The gangue material was mostly quartz and plagioclase and also included traces of kaolinite and gypsum.

Procedure

Only the minus 1-inch circuit of the pneumatic concentration system shown in figure 1 was used for this sample. Prior to zigzag separation, a hammer mill was used to crush the large rocks to minus 1-inch. Since the plus 1-inch size mica made up a very small portion of this sample, it was not treated separately; it too was crushed in the hammer mill. The zigzag tailings were also crushed by a hammer mill in the 4-mesh circuit.

Pneumatic Concentration Results

The results of pneumatic concentration of the South Dakota tailings are shown in table 18. Airflows used in the zigzag section for these tailings are shown in table 19. A 91-percent-mica concentrate was produced, and 69 percent of the mica contained in the sample was recovered. As with previous samples, most of the mica lost in the tailings was too thick to be carried by the airstream. Only 7 percent of the mica from this sample was too small to be recovered by the pneumatic method.

TABLE 18. - Pneumatic concentration results from South Dakota mica tailings

Product, mesh	Wt-pct	Analysis, pct	Distribution, pct
Concentrate:			
Plus 4	4.6	100	25
Minus 4 plus 10	4.0	94	21
Minus 10 plus 20	3.5	78	15
Minus 20 plus 35	1.1	82	5
Minus 35 plus 65	.6	90	3
Tailings:			
Minus 4 plus 10	33.9	4.9	9
Minus 10 plus 20	21.8	5.4	7
Minus 20 plus 35	5.2	3.6	1
Minus 35 plus 65	18.1	6.8	7
Minus 65	7.2	18.0	7
Composite	100.0	18.0	100
Composite mica concentrate	13.8	91	69
Composite tailings	86.2	6.4	31
Total	100.0	18.0	100

TABLE 19. - Airflow through zigzag section for concentration of South Dakota mica tailings, cfm

Ore size, mesh	Rougher	Cleaner
Plus 4	140	120
Minus 4 plus 10	134	108
Minus 10 plus 20	117	90
Minus 20 plus 35	90	60
Minus 35 plus 65	61	33

GENERAL DISCUSSION

Although the mica analyses of the seven concentrates produced by pneumatic concentration varied between 80 and 97 percent mica, the chemical analyses of these concentrates compared favorably with commercial mica products obtained by flotation and with Indian ruby sheet mica, as shown in table 20. Several of the mica concentrates contained less Fe_2O_3 (ferric oxide) contamination than the typical contamination found in Indian ruby sheet mica, and all the concentrates contained less Fe_2O_3 than the commercial flotation mica product.

TABLE 20. - Chemical analyses of pneumatically processed mica and commercial mica

Mica sample	Chemical analyses					
	SiO_2	Al_2O_3	K_2O	Fe_2O_3	MgO	LOI[1]
Arizona mica ore..............	45.6	30.5	9.9	4.2	0.69	5.9
North Carolina ore A..........	52.6	24.9	8.0	1.7	.67	3.0
North Carolina ore B..........	45.2	31.1	7.6	3.7	1.00	7.1
South Dakota mica ore.........	48.7	28.7	8.8	2.6	.44	5.1
Alabama tailings..............	47.7	32.4	9.1	1.7	.38	5.9
Georgia tailings..............	62.0	22.2	6.0	1.2	.33	4.1
South Dakota tailings.........	54.1	25.3	6.6	2.7	.47	4.1
Commercial flotation mica.....	46.0	34.0	9.0	5.0	ND	5.5
Indian ruby sheet mica........	45.8	35.5	10.3	2.0	.56	4.7

ND Not detected.
[1]LOI Loss on ignition at 1,000° C.

Airflows through the zigzag classifier were set by the operator and measured for each separation. The airflows ranged from about 160 cubic feet per minute for the minus 1-inch plus 4-mesh fractions to 30 cubic feet per minute for the cleaner zigzag with the minus 35- plus 65-mesh fractions. Figure 7 graphs the average rougher airflows versus the log of the smallest particle size of each size fraction. The average difference in airflow between each size fraction was about 25 cubic feet per minute. For the three plus 20-mesh separations, the cleaner airflows were generally 75 percent to 85 percent of the rougher airflows. For the two minus 20-mesh separations, the cleaner section airflows were 50 percent to 70 percent of the rougher section airflows.

Feed rates to the zigzag classifier were also set by the operator and ranged from about 20 pounds per hour for the 35- by 65-mesh size fraction to 150 pounds per hour for the 1-inch by 4-mesh size fraction.

In reviewing the results from the seven different samples, several general trends were noted. It was noted that the amount of minus 65-mesh material in the system had a negative influence on mica recovery and product grade. This influence can be seen in table 21, which shows that both mica recovery and the percent of mica analyzed in the product tended to decline as the amount of minus 65-mesh material increased. Several trends were noted

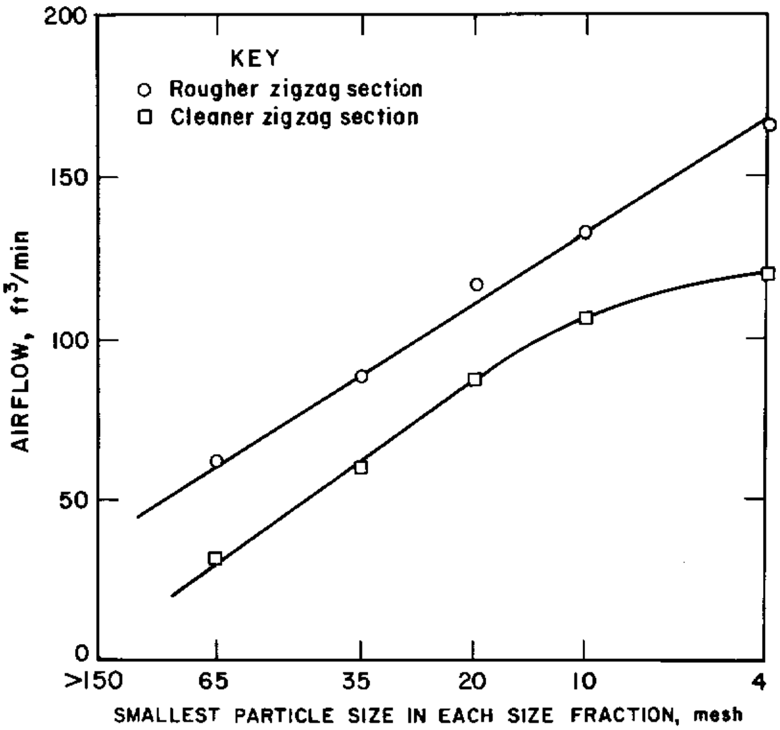

FIGURE 7. - Plot of airflow through the zigzag section versus the smallest particle size in each size fraction.

in the four major size fractions between 4 mesh and 65 mesh. Generally, the concentrate grade for each size fraction tended to decrease as particle sizes decreased. Although this was not the case with every sample, the trend was statistically present. The metallurgical efficiency[7] of the pneumatic concentration method tended to be between 80 percent and 85 percent for each of the three coarse size fractions between 4 mesh and 35 mesh. The minus 35- plus 65-mesh size fraction had a significantly lower metallurgical efficiency of approximately 65 percent.

By limiting ore crushing to the mica liberation size, the amount of minus 65-mesh material produced by the crushers can be minimized. Also, limiting the crushing of ore will minimize energy costs.

TABLE 21. - Comparison of minus 65-mesh materials by product grade, mica analysis, and mica recovery

Mica sample	Minus 65-mesh material, pct	Mica analysis, pct	Mica recovery, pct
Arizona ore....................	4.3	92	69
North Carolina ore A...........	21.1	80	27
North Carolina ore B...........	19.0	86	53
South Dakota ore...............	2.4	93	78
Alabama tailings...............	12.5	97	[1]58
Georgia tailings...............	24.0	93	[1]67
South Dakota tailings..........	7.2	91	69

[1]Approximated from the "two-product" formula shown below, in which R is used to represent recovery percent of concentrate:

$$R = \frac{100\ \text{percent} \cdot \left(\begin{array}{c}\text{percent mica of}\\ \text{concentrate}\end{array}\right) \cdot \left(\begin{array}{c}\text{percent mica}\\ \text{of feed}\end{array} - \begin{array}{c}\text{percent mica of}\\ \text{tailings}\end{array}\right)}{\left(\begin{array}{c}\text{percent mica}\\ \text{of feed}\end{array}\right) \cdot \left(\begin{array}{c}\text{percent mica of}\\ \text{concentrate}\end{array} - \begin{array}{c}\text{percent mica of}\\ \text{tailings}\end{array}\right)}$$

[7]Metallurgical efficiency is the average of the product recovery in the concentrate and the gangue recovery in the tailings.

In these tests, the hammer mill tended to delaminate the thick mica particles, thereby increasing the likelihood that these particles would be recovered by the zigzag air classifier.

The pneumatic concentration method is a dry concentration technique that may be advantageous in areas where water resources are limited or where the cost of drying a mica concentrate precludes the use of a wet mica-concentrating process.

CONCLUSIONS

The Bureau's pneumatic concentration method for recovering mica has been demonstrated as an effective means for coarse mica recovery. Liberated mica as large as 1.5-inch size and as small as plus 65-mesh size was recovered by this method. However, the Bureau's pneumatic concentration system did not recover minus 65-mesh size mica. Therefore, the crushing circuit for this type of system must be designed to minimize the amount of minus 65-mesh size material if the best possible concentration results are to be achieved. When crusher types were compared, it was found that use of a hammer mill increased mica recovery by the zigzag classifier because the hammer mill needed to delaminate the thick mica particles. The pneumatic concentration method produced mica concentrates that contained 80 percent to 97 percent mica, and up to 78 percent of the mica originally contained in the samples was recovered.

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