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Precambrian muscovite from the M. I. C. A. mine, Picuris Mountains, New Mexico

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PRECAMBRIAN MUSCOVITE FROM THE M.I.C.A. MINE, PICURIS MOUNTAINS, NEW MEXICO

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Abstract—The Mineral Industrial Commodities of America (M.I.C.A.) mine is the only domestic muscovite producer west of the Appalachian Mountains. The mine is in quartzofeldspathic muscovite schist that represents strained, metamorphosed, hydrothermally altered rhyolitic flows and/or tuffs of Early Proterozoic age. These schists are probably correlative with the Glenwoody Formation of the Picuris Mountains and other feldspathic schists of the Vadito Group. The orebody consists of a high-grade lower "A" zone and a low-grade upper "B" zone. It ranges in grade from 70–25% muscovite with an average of about 33% over a mined area of 45–75 m by 730 m. The ore is ripped by bulldozers, and moved by front-end loaders to a nearby screening plant. Boulders larger than 10 cm are stockpiled at the mine. Ore that passes through the 10 cm grizzly is crushed to <1.9 cm and shipped 50 km to the mill near Velarde. The ore is processed in a fluid-energy mill and/or a flotation circuit to produce muscovite ranging in size from 1–100 μm and brightness of 80–90% which can be bleached to over 90%. The finished product is used primarily in joint cements for plasterboard and in paints.

INTRODUCTION

The Mineral Industrial Commodities of America (M.I.C.A.) open pit mine in the Peñasco Mining District of the Picuris Mountains of north-central New Mexico is on 22 claims (NMMC 40954) about 3 km northeast of Rio Pueblo (Fig. 1). The mine is on the south side of an isolated hill of schist, in sections 23, 24 and 25, T23N, R12E and sections 19 and 30, T23N, R13E in the Tres Ritos 7.5-minute quadrangle. The claims are in the Carson National Forest at an elevation of about 8600 ft. Sixteen claims were staked in 1959, and 12 were staked in 1962. Nine claims were patented in 1983 and 1984 under Mineral Survey Number 2309 and Mineral Patent Numbers 30-84-0138 and 30-84-0064. An additional claim of 20.52 acres was patented in 1985 under MS 2309 as patent number 30-84-006. The mine property now consists of 10 patented and 12 unpatented claims. The patented area contains 194.65 acres.

M.I.C.A. employs 20–25 full-time employees. The mine is operated as needed by 3–4 workers. The mill operates three shifts on 5–7 days depending on demand. This activity makes M.I.C.A. the second to fourth largest producer of mica in the U.S., depending on output for the year.

INDUSTRIAL MICA

Mica is the name of a platy, hydrous, monoclinic, phyllosilicate mineral group whose members are similar in chemical compositions but more variable in physical properties. Mica contains potassium, aluminum, silica (30–55%) and varying proportions of hydrogen, magnesium, iron, sodium, lithium, vanadium or fluorine (Epperson and Rheams, 1984). Muscovite (white mica), the potassium end-member of the mica group, is nearly transparent and colorless in thin sheets. It may be translucent and is pale gray, brown, yellow, green or ruby when thicker. A perfect basal cleavage allows muscovite to be split into thin sheets having a high degree of flexibility, elasticity and toughness. Hardness ranges from 2.5 to 4.0, and specific gravity is 2.8–2.9. Upon heating, muscovite begins to lose water at about 500°C, but decomposes only in hydrofluoric acid. Muscovite has low electrical conductivity and high dielectric strength and dielectric constant. Sericite is used herein to denote fine-grained muscovite with the same chemical components and structural properties as muscovite. X-ray fluorescence analyses of mica from the M.I.C.A. mine are compared to recalculated and "standard" sericite and muscovite in Table 1.

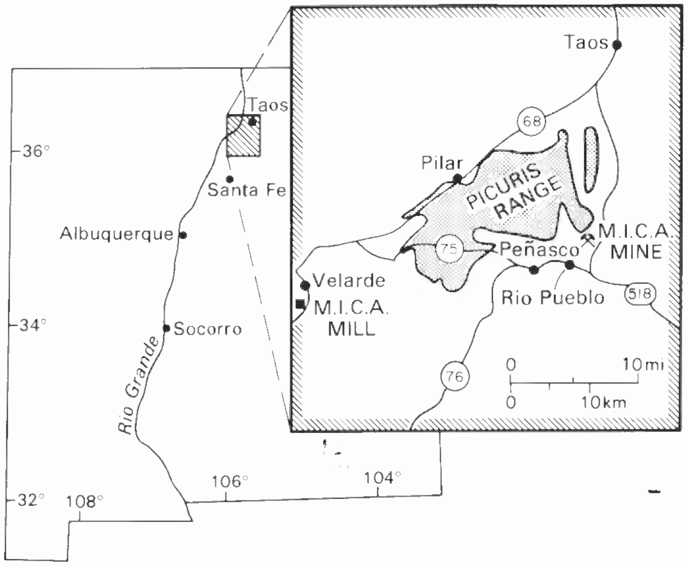

FIGURE 1. Location map of M.I.C.A. mine near Rio Pueblo and the mill near Velarde in north-central New Mexico. Modified from Bauer (1984).

TABLE 1. Comparison of M.I.C.A. mica analyses with NMBM&MR XRF analyses.

	M.I.C.A. wt %	NMBM&MR(1) wt %	Recalculated(2) wt %	Sericite(3) wt %	Muscovite(4) wt %
SiO_2	45.77	65.19	47.53	47.65	45.55
TiO_2	0.10	0.38	0.57	0.10	0.26
Al_2O_3	36.72	19.52	29.50	37.03	36.89
Fe_2O_3*	0.19	3.80	5.75	0.01	1.25
MnO	--	0.05	0.08	trace	0.02
MgO	0.62	0.51	0.77	0.04	0.58
CaO	--	0.20	0.30	trace	0.04
Na_2O	6.02	0.68	1.03	0.76	0.80
K_2O	3.18	6.54	9.89	9.02	10.17
P_2O_5	--	0.06	0.09	--	--
LOI/(H_2O)**	(5.62)	2.72	4.11	5.70	4.62
Total	98.0	99.63	99.62	100.31	100.27

(1) ground and cleaned before XRF analysis
(2) recalculated assuming only sericite and quartz present and 47.53% SiO_2 content; yields 73% sericite and 22% quartz
(3) sericite, $2M_1$ polymorph; analysis YO(-01) in Table 1.10 of Sudo (1978)
(4) muscovite of Ernst (1963); total includes 0.04% BaO and 0.04% F
* total iron after conversion to ferric iron
** combined water

Sheet mica was originally used in windows and in ornaments. It was later used in the electrical industry for its dielectric and mechanical properties (Table 2). Use of sheet mica has declined in the 1980's because of the advancement of solid-state electronics.

Scrap-and-flake mica originally was derived from mining and processing of sheet mica. It included non-sheet mica and poor-quality sheet mica that did not meet specifications. The quality of mica is judged by its hardnesss, size, color, staining and defects (Skow, 1962). In this century, industrial demand for scrap-and-flake mica increased greatly, and some mica deposits are now mined specifically for flakes.

M.I.C.A. is the only domestic primary mica producer west of the Appalachian Mountains, and one of only 12 in the U.S. (Davis, 1988). About 160,000 tons are produced annually in the U.S.; this annual total is increasing (Davis, 1988). Apparent consumption is about 150,000 tons per year, so the U.S. is a net exporter.

Mica is processed by wet-grinding, dry-grinding or micronization. The type of processing is partly determined by the intended end use. Water-ground mica is used in wall paper, nonferrous castings, rubber tires and paint. Dry-ground mica is used in oil-well drilling, joint-cements, surface coatings, asphalt roofing, insulation boards, plasterboard, welding electrodes, plastics and a number of minor uses. Micronized mica is used in paint, plastics and cosmetics. The number of mica end uses is increasing, due, in large part, to methods of treating the surface of the flakes (Table 2). M.I.C.A. processes muscovite by dry grinding with secondary flotation of some fractions. Most of its production is shipped to California, Texas, Colorado, Arizona and Kansas.

GEOLOGY

Stratigraphic relationships

The feldspathic muscovite schist at the mine site was referred to as the Rio Pueblo Schist by Miller et al. (1963) and by Bauer (1988). Both authors agreed the unit is Precambrian in age. Miller et al. (1963) placed it within the lower quartzite member of the Ortega Formation (now called the Ortega Formation of the Hondo Group by Bauer and Williams, 1989). Bauer (1988) assigned it to an uncertain stratigraphic position within or just above the Vadito Group (Fig. 2).

The hill of feldspathic muscovite schist at the M.I.C.A. mine is an isolated exposure (Fig. 3), so direct stratigraphic correlation is not possible. We suggest correlations based on nearby exposures. Just north of the mine, similar feldspathic schists are in contact with Proterozoic granitic rock to the north and massive gray orthoquartzite to the south (Bauer, 1988). Although exposures are poor, several relationships are clear. Granitic rocks intrude the schist along a gradational contact. The schist is stratigraphically below the quartzite along a mineralized, Mn-rich zone containing piemontite (Mn-epidote) and altered porphyroblasts of sericite that may be pseudomorphous after viridine (Mn-andalusite). An identical anomalous Mn-rich horizon appears to be regionally continuous over much of northern New Mexico along the Vadito Group–Hondo Group boundary (Grambling and Williams, 1985; Williams, 1987; Bauer and Williams, 1989). Such a boundary is well-exposed in the northwestern Picuris Mountains, in the cliffs near the village of Pilar, where massive, gray quartzite of the Ortega Formation overlies muscovite-rich feldspathic schist of the Glenwoody Formation. These similarities suggest that schist in the M.I.C.A. mine is part of the uppermost Vadito Group (about 1700 Ma) and is slightly older than the Hondo Group.

TABLE 2. Traditional and potential end uses for flake and ground mica.

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OLD USES FOR MICA (raw mica)

        Filler (increases strength, stiffness, modulus of heat deflection)
             Paint
             Coatings
             Plastics
             Composites (resins; may be heated to improve cross coupling)
             Other (toothpaste, etc.)

        Joint Compound (wallboard)  ┐
        Joint Cement                ├  MAIN USE
        Plaster                     ┘
------------------------------------------------------------------------

NEW USES FOR MICA
(treated mica)

        Conductive Mica (electronics, auto paint)
        Pigments (various grades 5-150 )
             Coatings (powder)
                  solvent based
                  water based
             Plastics
                  polystyrene
                  polyethylene
                  polypropylene
                  PVC
                  ABS
             Printing Ink
                  textile
                  paper/wallpaper
                  plastic
             Cosmetics
                  hair spray/mousse
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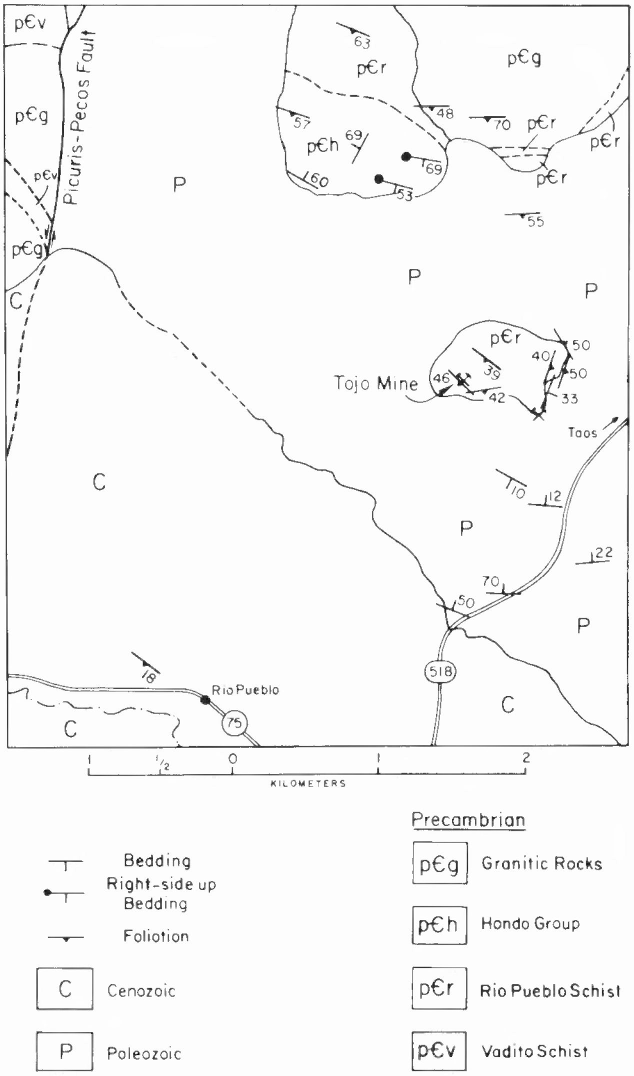

FIGURE 2. Geologic map of the M.I.C.A. mine region. Modified from Miller et al. (1963) and Bauer (1984).

The only isotopic age for the Rio Pueblo Schist is from a sample collected by P. W. Bauer from the "type section" exposure near Comales Campground on NM-518 southeast of the M.I.C.A. mine. This sample yielded a preliminary U/Pb zircon age of about 1680 Ma (S. A. Bowring, Washington University, St. Louis, oral commun., 1988). The schist in this area is gradational with coarser-grained granitic rocks, and we now suspect the dated sample's protolith is sheared granite rather than feldspathic supracrustal rock. Plutonic rocks of similar age (1684 ± 1 Ma and 1674 ± 5 Ma) crop out to the west in the Picuris Mountains (Bell and Nielsen, 1985).

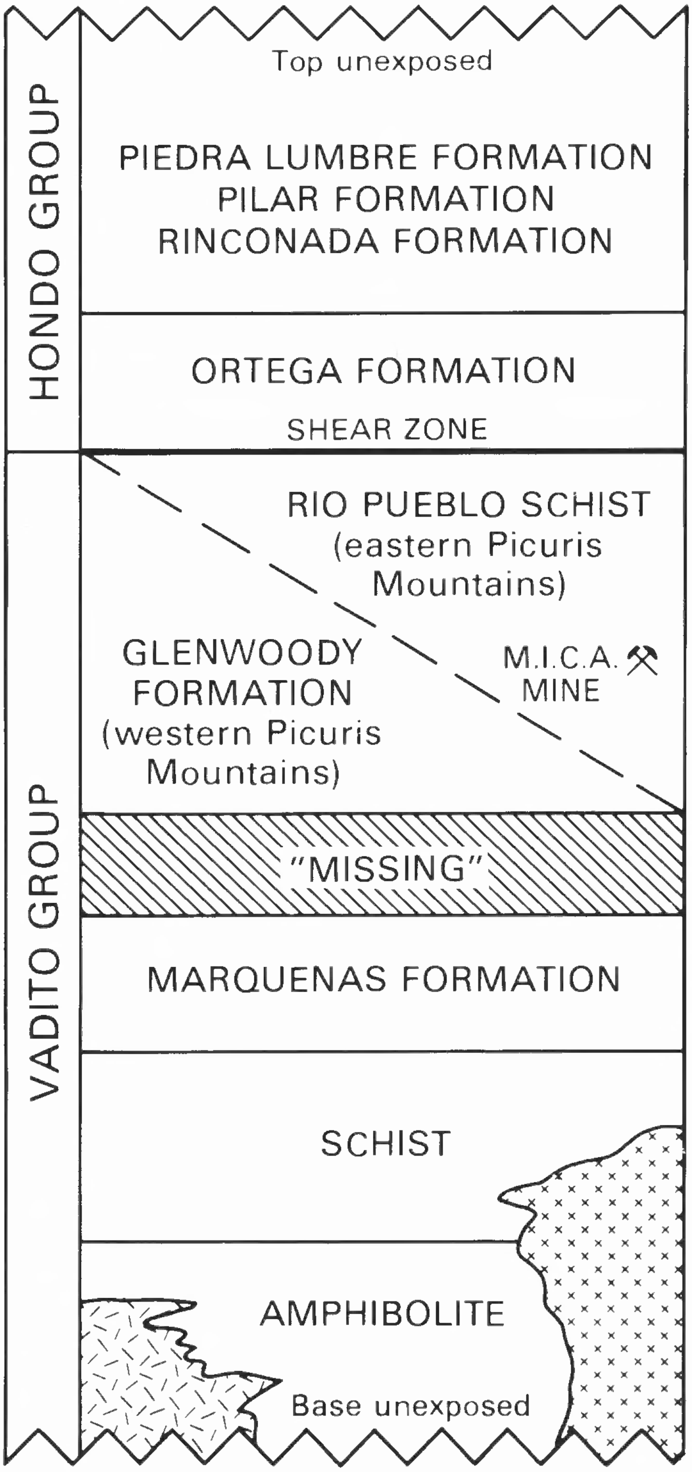

FIGURE 3. Generalized stratigraphic column for Precambrian rocks of the Picuris Mountains showing probable position of Rio Pueblo Schist and the schist at the M.I.C.A. mine.

Petrology and structure

The least-altered schist specimens from the mine consist dominantly of quartz, potassium feldspar and muscovite in various proportions. In general, porphyroclasts of quartz (up to 5 mm) and feldspar (up to 1 mm) are surrounded by a finer-grained matrix of quartz (0.2 mm average), feldspar (0.3 mm average) and muscovite (0.5 mm average). Muscovite grains are invariably aligned in a well-developed schistosity of crenulation cleavage. Quartz-matrix grains commonly display granoblastic texture (120° equilibrium boundaries), suggesting a dynamic recrystallization strain history. Quartz porphyroclasts range from rounded and only slightly flattened to highly flattened in the foliation, and individual quartz subgrains within the porphyroclast mosaics contain serrate subgrain boundaries suggesting high, simple shear strain. In thin sections cut perpendicular to foliation and parallel to extension lineation, kinematic indicators of asymmetric tails on quartz porphyroclasts consistently suggest that the top was sheared southward (Fig. 4).

Hand specimens of muscovite schist typically display at least one dominant foliation and a well-developed down-dip extension lineation. Fine muscovite laminae anastomose around domains of quartz-rich rock, and rarely, asymmetric kinematic indicators are visible.

Vernon (1986) suggested that most, if not all, quartz megacrysts in such fine-grained, feldspathic, deformed rocks are relict phenocrysts rather than porphyroblasts. We agree, and suggest that these schists represent strained, metamorphosed rhyolitic flows and/or tuffs. The prevalence of sericite in much of the Rio Pueblo Schist suggests that this rock may also have undergone extensive post-metamorphic peak hydrothermal alteration. This is consistent with protolith interpretations for similar Proterozoic schist in the cliffs near Pilar and elsewhere in northern New Mexico (Gresens and Stensrud, 1974; Bauer and Williams, 1989).

At the isolated hill of schist (Fig. 3), most dips are outward from the center, suggesting that orientations are controlled at least partly by local, post-Precambrian tectonism. At the M.I.C.A. mine, on the south side of the hill, parallel or subparallel compositional layering and the dominant foliation in the schist generally dip at least 40°S (Fig. 5).

Ore zone

Drill-hole data indicate that southwest-dipping micaceous quartzite underlies and overlies the muscovite-rich ore zone (Beckman, 1975). Stratigraphic and structural relationships among the two quartzites and the schist are unknown. All three units appear to be part of the Rio Pueblo Schist. Beckman (1975) described the quartzite as massive, brownish-gray, slightly micaceous, medium- to coarse-grained and consisting of tightly packed grains of quartz. It is mottled and streaked

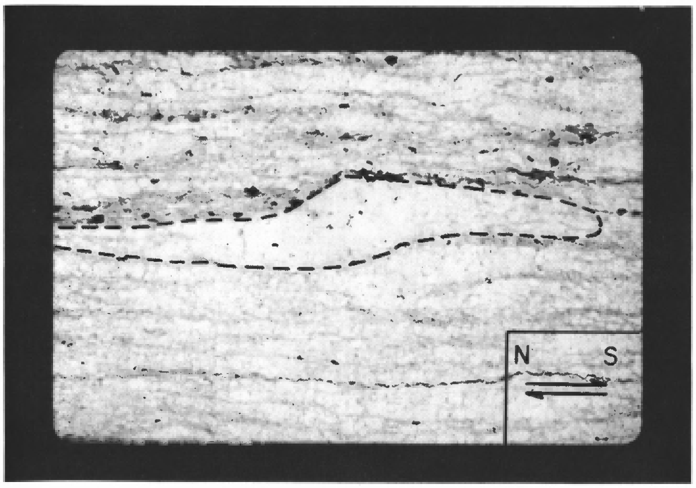

FIGURE 4. Plane-light photomicrograph of quartzofeldspathic schist from the M.I.C.A. mine, Picuris Mountains. Section is cut perpendicular to the foliation and parallel to extension lineation. Asymmetric tails on quartz porphyroclast (outlined by dashed line) suggests dextral shear.

FIGURE 5. View east from the floor of the M.I.C.A. mine toward the southward-dipping ore zone.

with iron oxide along fractures and weathered surfaces, but often is blue-gray and unstained on fresh surfaces. Thin calcite veinlets often fill fractures.

The micaceous orebody is a soft schist with some quartzite interbeds. It contains 30–40% muscovite and includes numerous crosscutting white quartz veins. The muscovite is fine-grained, green-gray in color and exhibits a thick matting of silvery mica flakes surrounding quartz. Small black magnetite and/or ilmenite specks are common on muscovite flakes. Deep red-to-brown iron oxide staining occurs locally in the orebody. Green chlorite is rare. Microcline comprises up to 15% in portions of the orebody.

The mined thickness is highly variable in lithology, ranging from almost pure sericite mica to hard micaeous quartzite. Five separate rock types described by Beckman (1975) at the M.I.C.A. mine are:

1. *Sericite*—40–60% mica, green-gray, very soft, crumbly; contains bouldery vein quartz, local iron oxide stain, and black magnetite/ilmenite specks on mica flakes.
2. *Sericite schist*—20–40% mica, green-gray to gray-brown, moderately soft but competent, thin mica laminae between and along quartz grains; iron staining, if present, due to oxidation of black magnetite/ilmenite specks and/or red garnets.
3. *Sericite-quartz schist*—20–30% mica, gray-brown, moderately hard, thinly laminated; generally more iron staining due to the presence of garnets; black magnetite/ilmenite specks common; wavy quartz blebs and stringers common.
4. *Micaceous quartzite*—10–20% mica, gray-brown to blue-gray, hard, medium-grained with sandy texture, thin micaceous partings rare, with well-cemented quartz; some specks of black magnetite/ilmenite and rare garnet.
5. *Quartzite*—2–10% mica, gray-brown to gray-blue, very hard, dense, medium- to coarse-grained, fractures common and often filled with calcite; typical footwall and hanging wall rock.

Beckman (1975) divides the mined thickness into two different zones. The lower, richer zone "A" consists of 2–18 m of extremely high-grade ore ranging from 40 to 70% mica. This zone pinches out at the east and west ends of the deposit. The upper poorer zone "B" is composed of all five of Beckman's rock types, some of which are too muscovite-poor to make grade. This unit averages about 25% mica across the 45–60 m mined. The combination of zones "A" and "B" results in an average ore grade of about 33% over the mined thickness of 45–75 m.

A north-trending fault truncates the orebody on the east side of the mine, so the ore zone is roughly 730 m long. Beckman (1975) estimated reserves of 2,700,000 tons of ore, at a stripping ratio of 1.10:1.00, with 900,000 tons of recoverable mica. Ore was any material with 25% or more +200 mesh mica. Reserve calculations were based on data from trenching and 18 drill holes and an 80% recovery from a flotation circuit. M.I.C.A. currently uses material containing less than 25% mica, extracts mica less than +200 mesh, and recovers in excess of 90%; additional drilling has laterally extended the orebody. H. W. Rosen of M.I.C.A. states that recoverable mica exceeds the Beckman (1975) estimate (H. W. Rosen, oral commun., 1990).

The New Mexico Bureau of Mines and Mineral Resources examined samples from the M.I.C.A. mine in 1983 for the U.S. Forest Service for the purpose of determining the amount of muscovite present on various claims in the original group. U.S. Forest Service and M.I.C.A. personnel jointly collected 11 samples for x-ray diffraction analysis by NMBM&MR. Maximum weight percentage muscovite ranged from 30–44% (Barker et al., unpubl. report, 1983). These data correspond well with vanning data supplied by M.I.C.A. (H. W. Rosen, oral commun., 1983) and Beckman (1975). Vanning is a semiquantitative assay method for mica in which finely divided mica samples are inspected on a white enameled dish (vanning plaque). X-ray diffraction indicates that all 11 samples are 90–95% quartz and muscovite. Small amounts of potassium feldspar (microcline) and/or plagioclase feldspar occur. Some samples had traces of hematite, limonite, biotite and zircon.

MINING AND MILLING PROCEDURES

Muscovite ore at the M.I.C.A. mine is ripped by bulldozers and moved by front-end loader to the onsite screening plant (Fig. 6). The ore averages 40% muscovite before it is passed over a 10-cm grizzly. Boulders larger than 10 cm are stockpiled at the mine. The <10 cm fraction is crushed to <1.9 cm and passed through a double screen (Fig. 7). The >1.9 cm fraction averages 25–35% muscovite and is stockpiled (Fig. 7). The <1.9 cm fraction averages 60–70% muscovite (Table 3) and is trucked 50 km to the mill in the Rio Grande valley south of the village of Velarde.

At the mill, mica is further reduced in size and delaminated by a cool, dry, opposing airstream technique in a fluid-energy mill. The mica is ground very fine by mutual attrition caused by many high velocity impacts (Fleming, 1976). Fluid-energy mill output is air-sorted, with oversize returned to the mill, and may be further classified in a flotation circuit.

Demand for higher quality and finer grinds has caused flotation to be widely introduced into mica processing circuits. Browning (1973) and Epperson and Rheams (1984) summarize mica processing including flotation. The flotation process used by M.I.C.A. is proprietary, but data on preliminary tests were released in the patent application. The most successful test (no. 5) in a study by Denver Equipment (Hurd, 1982) had these objectives: (1) a reduced dosage of acid to obtain a pH of 4.2 in the conditioning and subsequent flotation at a pH of 5.9; (2) three-step conditioning at 40% solids; and (3) a single stage of concentrate cleaning. Conditions for this test were: (1) scrubbing and

FIGURE 6. View south from the hill north of the M.I.C.A. mine across the pit toward the grizzly, screening plant and mine buildings.

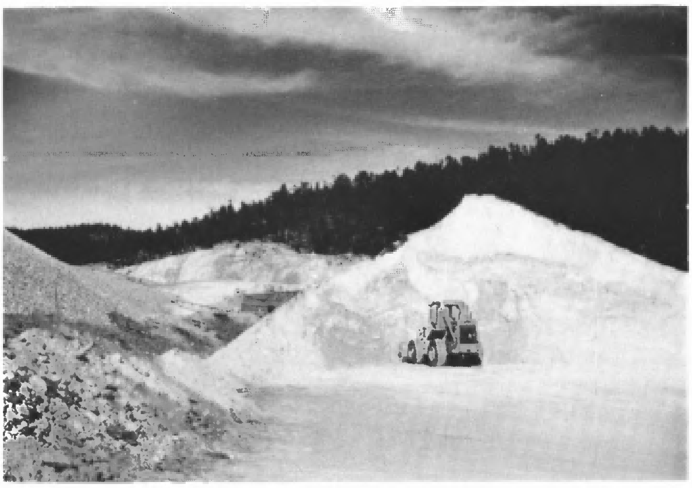

FIGURE 7. Screening plant and conveyor system stockpiling ore to the right.

desliming at 325 mesh; (2) stage conditioning with sulfuric, Armac T, and MIBC at 40% solids and pH 4.2; (3) rougher flotation for six minutes at pH 5.9; and (4) single stage cleaner flotation. Mica flotation in Test No. 5 was very good. It yielded a cleaned mica concentrate with a weight recovery of 20.2%. The mica concentrate contained 21.2% solids. The bulk of the mica settles at 4.25 ft/hr with dirty overflow owing to fine mica in suspension. Small amounts of Superfloc 127 settled bulk solids at 7.25 ft/hr, and overflow was cleaned of fines. Concentrate thickened to 43.5% solids in 30 minutes. Flocculated, thickened concentrate filtered at 132 lbs/ft^2 and yielded filter cake with 23.7% moisture and a thickness of 0.50 inch.

Purcell (1983) used the Hurd (1982) data and older data from New Mexico Bureau of Mines and Mineral Resources to initiate further flotation testing. He used a dry grind of four minutes to achieve 89% passing 35 mesh which was very near the Hurd optimum of 90% passing 35 mesh. Cationic single-stage flotation with an amine collector under acid conditions after desliming was initiated. Armac T was the best collector and, when coupled with five-minute grind and 20% solids, increased recovery from 37 to 54% while increasing grade from 84 to 86%. Recleaning would raise this to over 90%.

Finished products, ranging from 1–100 µm in size, are bagged and shipped by truck to consumers. The mica produced is very white with brightness of 80–90% which can be bleached to over 90%. Tails from prior mining and milling contain 35% muscovite but are not now used. Tailing from the flotation circuit consist mainly of ground washed quartz with some large mica flakes which may later be reclaimed. They are dewatered and stored near the plant along with tailings from the dry-grind circuit.

TABLE 3. Some analyses of mica content and bulk density by Kings Mountain Mica Co. via flotation. The samples were supplied by M.I.C.A. Grit is mainly quartz; bulk density is in lbs/ft^3.

Sample	Sample Type	mica wt %	grit wt %	quartz wt %	feldspar wt %	BULK DENSITY before flotation	after flotation
1	MICA "S" Concentrate	74.38	25.62	--	--	27.89	32.31
2	M-100 Concentrate	84.4	15.6	--	--	22.21	29.68
3	mill feed	70.2	29.8	--	--	--	45.95
4	mine grab	59.6	40.4	--	--	--	48.20
5	Yaple grab	17.6	78.0	--	4.4	--	41.11
6	Tojo grab	47.3	34.0	--	18.7	--	39.36
7	M-20	87.0	13.0	--	--	--	50.22

FIGURE 8. View north toward mine in the background. Screening plant and pit partly obscured by stockpiled boulders (left) and crushed ore (right).

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REFERENCES

Bauer, P. W., 1984, Stratigraphic summary and structural problems of Precambrian rocks, Picuris Range, New Mexico: New Mexico Geological Society, Guidebook 35, pp. 199–204.

Bauer, P. W., 1988, Precambrian geology of the Picuris Range, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report 325, 259 pp.

Bauer, P. W. and Williams, M. L., 1989, Stratigraphic nomenclature of Proterozoic rocks, northern New Mexico—revisions, redefinitions, and formalization: New Mexico Geology, v. 11, pp. 45–52.

Beckman, R. J., 1975, Exploration and testing of the Taos mica deposit: Unpublished report in files of the U.S. Forest Service, Santa Fe, New Mexico, 51 pp.

Bell, D. A. and Nielsen, K. C., 1985, Intrusion and deformation sequence of the Embudo Granites, north-central New Mexico: Geological Society of America, Abstracts with Programs, v. 17, p. 151.

Browning, J. S., 1973, Mica beneficiation: U.S. Bureau of Mines, Bulletin 662, 21 pp.

Chapman, G. P., 1983, Mica; *in* Lefond, S. J., ed., Industrial minerals and rocks, 5th ed.: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 915–929.

Davis, L. L., 1988, Mica (natural), scrap and flake; *in* Mineral Commodity Summaries, 1988: U.S. Bureau of Mines, pp. 102–103.

Epperson, R. S. and Rheams, K. F., 1984, Mica in Alabama: Geological Survey of Alabama, Atlas 18, 63 pp.

Ernst, W. G., 1963, The significance of phengitic micas from low-grade schists: American Mineralogist, v. 48, pp. 1357–1373.

Fleming, R. F. S., ed., 1976, The mica industry—mining, milling, and markets: Industrial Minerals, no. 106, pp. 15–35.

Grambling, J. A. and Williams, M. L., 1985, Correlation of Proterozoic stratigraphy across northern New Mexico: Sixth International Conference on Basement Tectonics, Abstracts with Programs, v. 6, pp. 18–19.

Gresens, R. L. and Stensrud, H. L., 1974, Recognition of more metarhyolite occurrences in northern New Mexico and a possible Precambrian stratigraphy: The Mountain Geologist, v. 11, pp. 109–124.

Hurd, H. C., Jr., 1982, M.I.C.A., Inc., mica flotation: Denver Equipment Div., unpubl. report, 5 pp.

Miller, J. P., Montgomery, A. and Sutherland, P. K., 1963, Geology of part of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 11, 106 pp.

Purcell, G., 1983, A brief investigation of mica flotation: Department of Metallurgical and Materials Engineering, New Mexico Institute of Mining and Technology, Socorro, unpubl. report, 8 pp.

Skow, M. L., 1962, Mica—a material survey: U.S. Bureau of Mines, Information Circular 8125, 240 pp.

Sudo, T., 1978, An outline of clays and clay minerals in Japan; *in* Sudo, T. and Shimoda, S., eds., [Chapter 1 in] Clays and Clay Minerals of Japan: Elsevier, Amsterdam, pp. 1–103.

Vernon, R. H., 1986, Evaluation of the "quartz-eye" hypothesis: Economic Geology, v. 81, pp. 1520–1527.

Williams, M. L., 1987, Stratigraphic, structural, and metamorphic relationships in Proterozoic rocks from northern New Mexico [Ph.D. dissertation]: Albuquerque, University of New Mexico, 138 pp.

Water wheel built by George L. and M. Read Oldham on the Golden Treasure #1 claim in Placer Creek, Red River District, circa 1898. A 2-mi ditch was built to carry water from Goose Creek to this wooden wheel and arrastra (crude mill located to left of wheel) on the East Fork of Placer Creek. Mine shafts on the Golden Treasure were plagued by excessive water, and gold production was unimpressive. As a testimonial to the superb craftsmanship of the Oldham brothers, the 92-year-old water wheel on Placer Creek still stands. This is one of three water wheels said to have operated in the Red River area near the turn of the century. Courtesy of Mrs. Winifred Oldham Hamilton.