Kirk-Othmer Encyclopedia of Chemical Technology.

MICA

Mica [12001-26-2] is a generic term that applies to a wide range of hydrous aluminum silicate minerals characterized by sheet or plant-like structure, and possessing to varying degrees, depending on composition and weathering, flexibility, elasticity, hardness (qv), and the ability to be split into thin (1 μm) sheets (1). All micas form flat six-sided monochromic crystals, and possess cleavage parallel to the basal plane.

Mica exists in nature in a wide variety of compositions (Table 1) (2). Muscovite and phlogopite are the only natural micas of commercial importance. Vermiculite, although not considered a true mica by most mineralogists, is a micaceous mineral formed from the weathering of phlogopite or biotite and is also of commercial importance. Fluorophlogopite, $K_2Mg_6(Al_2Si_6O_{20})F_4$, is a synthetic mica made from pure chemical oxides.

1. Mineralogy

Mica has been classified into three groups: (*1*) the mica group proper, (*2*) the clintonite or brittle micas group, and (*3*) the chlorite group (3). Supplementary to these are the vermiculites, which are hydrated compounds that result from the alteration of any one of the micas, but usually biotite. All minerals in these groups belong to the monoclinic crystal system, and all show plane angles of 60 and 120° on the basal section. The crystals usually form in hexagonal or rhombohedral-shaped scales, prisms, or plates.

The basic structural unit of mica is a layer composed of two silicon tetrahedral sheets with a central octahedral sheet (4). The tips of the unjoined tetrahedrons in each silica sheet point toward the center of the unit and are shared with the octahedral sheet in a single layer with suitable replacement of OH by O. Varying amounts of other minor elements, including calcium, magnesium, iron, chromium, and lithium, can also be present. The general formula describing the composition of micas is $X_2Y_{4--6}Z_8O_{20}(OH,F)_4$, where X is mainly K, Na, or Ca; Y is mainly Al, Mg, or Fe; and Z is mainly Si or Al (5). In many of the well-crystallized micas one-fourth of the silicons are replaced by aluminum ions (4). The unit layers extend indefinitely in the *a* and *b* dimension or are stacked in the *c* dimension. Potassium ions occur between unit layers fitting into the surface perforations. Adjacent layers are stacked in such a way that the potassium ion is equidistant from 12 oxygens, six in each layer.

Muscovite is dioctahedral, having a theoretical composition of 11.8% K_2O, 45.2% SiO_2, 38.5% Al_2O_3, and 4.5% H_2O (4). Two-thirds of the possible octahedral positions are filled, and the octahedral sheet is populated by aluminum only. Biotite-type micas are trioctahedral where the octahedral positions are completely filled mostly by Fe^{2+}, Mg^{2+}, and/or Fe^{3+}. Examples are biotite, $(OH)_4K_2(Si_6Al_2)(Mg,Fe)_6O_{20}$, having varying proportions of iron and magnesium, and phlogopite, $(OH)_4K_2(Si_6Al_2)Mg_6O_{20}$. It has been found that all micas have six possible polymorphic variations (6). The variations occur as a result of the number of silica–alumina–silica units per unit cell, and the manner in which the unit cells are stacked. Unit cells composed of 1, 2, 3, 6, and 24 silica–alumina–silica units are known, with stackings yielding monoclinic, rhombohedral, or triclinic forms.

Table 1. Mica Group Minerals

Mineral	CAS Registry Number	Molecular formula
muscovite	[1318-94-1]	$K_2Al_4(Al_2Si_6O_{20})(OH)_4$
phlogopite	[12257-58-0]	$K_2Mg_6(Al_2Si_6O_{20})(OH,F)_4$
biotite	[1302-27-8]	$K_2(Mg,Fe)_6(Al_2Si_6O_{20})(OH)_4$
lepidolite	[1317-64-2]	$K_2Li_3Al_3(Al_2Si_6O_{20})(OH,F)_4$
rocoelite	[12271-44-2]	$K_2V_4(Al_2Si_6O_{20})(OH)_4$
fuchsite	[12198-09-3]	$K_2Cr_4(Al_2Si_6O_{20})(OH)_4$
paragonite	[12026-53-8]	$Na_2Al_4(Al_2Si_6O_{20})(OH)_4$

Muscovite mica formed as a primary mineral in pegmatites and granodiorite differs in physical properties compared to muscovite mica formed by secondary alteration (mica schist) (Table 2). The main differences are in flexibility and ability to be delaminated. Primary muscovite is not as brittle and delaminates much easier than muscovite formed as a secondary mineral. Mineralogical properties of the principal natural micas are shown in Table 3. The make-up of muscovite, phlogopite, and biotite are as follows:

Oxides	Muscovite, wt %	Phlogopite, wt %	Biotite, wt %
SiO_2	46.5	40.0	37.0
Al_2O_3	34.0	17.0	18.0
K_2O	10.0	10.0	9.0
Na_2O	0.8	0.5	1.0
MgO	0.5	26.0	8.0
CaO	0.3		
Fe_2O_3	2.5	0.2	21.0
FeO	1.0	2.8	2.0
minor elements		0.5	1.0
H_2O	4.5	3.0	3.0

Table 2. Physical Properties of Natural and Synthetic Micas[a, b]

	Natural			
Property	Muscovite[c]	Phlogopite	Biotite	Synthetic fluorophlogopite
density, g/cm^3	2.77–2.88	2.76–2.90	2.70–3.30	2.8
hardness[d]				
Mohs'	2.0–3.2	2.5–3.0	2.5–3.0	3.4
Shore	80–150	70–100		
optical axial angle, 2 V[e, f], deg	38–47	0–10	0–25	14.6 ± 0.5
refractive index, n^D				
α	1.552–1.570	1.541–1.632	1.541–1.579	1.522
β	1.582–1.607	1.598–1.606	1.574–1.638	1.549
γ	1.593–1.611	1.598–1.606	1.511–1.638	1.549
decomposition, °C	940–980	890–960	1100	1200

Table 2. ***Continued***

	Natural			
Property	Muscovite[c]	Phlogopite	Biotite	Synthetic fluorophlogopite
specific heat, 25°C, J/g[g]	0.049–0.05	0.049–0.05		0.046
thermal conductivity[h], W/(m·h·K)	0.6910	0.6910		
expansion coefficient $^{\circ}C^{-1} \times 10^{-6}$				
perpendicular				
at 20–100°C	15–25	1–1000		
100– 300°C	15–25	200–20000		
300–600°C	16–36	10–3000		
parallel				
at 0–200°C	8.9	13–14.5		10–11.5
200–500°C	10–12	13–14.5		
strength, MPa[i]	225–296	255–296		310–358
water, wt %[j]	4.5	3.2	$\sim 5-6$	0
melting point, °C	decomposes	decomposes	decomposes	1387 ± 3
dielectric				
constant	6.5–9.0[k]	5–6		6.5
strength,[k,l] V/μm	235–118	165–83		235–157
power factor, 25°C, %[m]				
1 MHz	0.01–0.02	0.3		0.02
resistivity, Ω·cm	10^{12}–10^{15}	10^{10}–10^{13}	10^{10}–10^{13}	10^{12}–10^{15}
modulus of elasticity, GPa[i]	172	172		
linear coefficient of expansion at 20–600°C, μm/°C	0.58–0.79	0.79–0.97		

[a]Ref. 1,5,(7–9).
[b]All micas have a vitreous luster; phlogopite luster can range from vitreous to submetallic.
[c]Volume resistivity = 2×10^{13}to1×10^{17}.
[d]Mohs' hardness values may vary; Shore hardness number is derived from rebound height of standard steel ball when dropped on material from standard height.
[e]Interior acute angle between optic axes of biaxial mineral.
[f]Orientation of optical plane to plane of symmetry is parallel; muscovite is perpendicular.
[g]To convert J to cal, divide by 4.184.
[h]Perpendicular to cleavage.
[i]Tensile strength; compression strength for muscovite and phlogopite is 221 MPa. To convert MPa to psi, multiply by 145.
[j]Chemically combined.
[k]Not specified in good quality mica.
[l]Of material from 25–75 μm thick at 21°C.
[m]Value for muscovite at 60 Hz is 0.08–0.09.

Table 3. Mineralogical Properties of Micas[a, b]

Properties	Muscovite	Biotite	Lepidolite	Phlogopite
specific gravity	2.76–3.0	2.7–3.1	2.8–3.3	2.8–2.9
luster	vitreous–pearly	splendent, sometimes submetallic	pearly	pearly
crystal symmetry	rhombic or hexagonal	pseudo-rhombohedral	hexagonal	hexagonal
colors	gray, brown, pale green, violet, yellow, dark olive-green, and ruby	green, black, and yellow	rose red, violet-gray, lilac, yellowish, grayish white, and white	yellow-white, gray to green, pearly, brown, black

[a]Refs. 10 and 11.
[b]Optical signs of micas are negative, crystal system is monoclinic, and the streak is colorless.

2. Mica Deposits

2.1. Sheet Mica

Pockets of mica crystals ranging in size from a few square centimeters to several square meters are found in pegmatite sills and dikes or granodiorite (alaskite) ore bodies. In order to be used industrially, manufacturers must be able to cut a 6 cm^2 pattern in the mica. "Books" of mica, ranging from 12.9 to 645 cm^2 or more, are cut from the crystals. The books can be punched into various shapes and split into thicknesses varying from 0.0031 to 0.010 cm (12). The highest quality micas may be used in aerospace computers, and those of lower quality find use as insulators in electrical appliances.

The pegmatic and granodiorite ore bodies are found as intrusions in surrounding country rock, including granites, gneiss, and schist. They range in color from pink to almost white, depending on which type of feldspar predominates, eg, microcline, orthoclase, or plagioclase. The granodiorite ore bodies are found as irregularly shaped masses and are white in color. The color of the mica varies from ruby to green to almost colorless or clear. Although the granodiorites are considered a coarse textured granite rock, the grain size of the individual minerals is not as coarse as the minerals associated with pegmatites.

Pegmatites range in size from 4-cm^2 wide stringers to dikes and sills several hundred meters wide and over 300 m long; depths vary from a few centimeters to hundreds of meters. Granodiorites are usually larger and less well defined. A general mineralogical composition of a granodiorite is plagioclase feldspar, 40%; microcline feldspar (the primary feldspar mineral), 20%; quartz, 30%; and mica, 10–20%. Garnet and biotite are found in small amounts. Mica crystals occur in size from a few centimeters to several meters. Other natural minerals found in pegmatites are tourmaline, beryl, rare earths, and uranium minerals.

Phlogopite mica is found in areas of metamorphosed sedimentary rocks into which pegmatite-rich granite rocks have intruded. Only a few deposits exist that contain books of phlogopite mica large enough to be mined economically. Phlogopite ore bodies may be classified into vein, pocket, and contact deposits. Vein deposits are narrow and enclosed in fine-to-medium grained pyroxenite. Contact deposits are the primary source of phlogopite sheet mica.

Sheet mica occurs in pockets within pegmatite. When exploring for sheet mica, test pits are sunk to determine the presence of pockets and quality of the mica. The size, shape, and attitude of the pegmatite is determined by stripping and trenching. These procedures are costly and problematic, but the quality can be determined to a sufficient degree (5).

2.2. Scrap and Flake Mica

Flake mica is found either in hard rock pegmatites and granodiorites or the weathered reminants of these ore bodies. The flakes of mica range in size from "thumbnail" (1.5–2.0 cm) to -44 μm. Scrap mica generally refers to waste trimmings resulting from the preparation of sheet mica for punching and machining into electrical parts. Reconstituted mica is a paper produced by forming a mat of thin, well-delaminated flakes of scrap mica. This mat is usually impregnated with an organic binder, but is available unimpregnated (5, 12).

The hard rock deposits are mined mainly for feldspar with mica and quartz being accessory minerals. These deposits are extensive, often covering hundreds of square meters and are recognized by the light-colored, granite-like appearance with shiny mica flakes being a prominent feature. The mica content of these deposits ranges from approximately 6–10 wt %.

The soft weathered granodiorite and pegmatites can vary in color from white to pink, depending on iron content and type of feldspar present. The mica content of these deposits ranges from 6–15% and varies in particle size from tiny ($<44\ \mu m$) specks to thumbnail size. Large books of mica that weigh several hundred kilograms have been found in these deposits.

Mica schist deposits range in consistency from loosely consolidated soil to fairly hard ore and vary in color from brown to almost white. These ore bodies are noted for their micaceous appearance, which results from a 40–90% mica content. Mica sizes vary from $<44\ \mu m$ to ~ 1.5 cm.

Weathered and hard rock pegmatites, granodiorites, schist, and gneisses are evaluated for mica content by first core drilling and then extracting available mica by conventional vanning, magnetic, and flotation techniques. Drill cores are normally 3.8–7.6 cm dia and 15–31 m in length. Auger drilling may also be used in soft material. However, it is difficult to obtain a representative sample of a particular section when using this procedure because of the probability of intermixing foreign material with vein material.

3. Mining

3.1. Flake Mica

Flake mica is mined from weathered and hard rock pegmatites, granodiorite, and schist and gneiss by conventional open-pit methods. In soft, residual material, dozers, shovels, scrapers, and front-end loaders are used to mine the ore. Often kaolin, quartz, and feldspar are recovered along with the mica (see also Clays; Silicon compounds).

Hard rock mining of these ore bodies requires drilling and blasting with ammonium nitrate and dynamite. After blasting, the ore is reduced in size with a drop ball and then loaded on trucks for transportation to the processing plant. Mica, quartz, and feldspar concentrates are separated, recovered, and sold from the hard rock ore.

3.2. Sheet Mica

Sheet mica is mined by both underground and open-pit mining procedures. Underground mining is accomplished by driving a shaft, formed with tungsten carbide-tipped air drills, hoists, and explosives (see Explosives and propellants; Tool materials), through the pegmatite at a suitable angle to the strike and dip. Cross-cuts and raises are developed to follow promising exposures of mica. Small charges of 40–60% strength dynamite are placed around a pocket of mica to shake the mica loose from the host rock without fracturing the books. After blasting, the mica is placed in boxes or bags for transporting to the trimming shed where it is graded, split, and cut to various specified sizes for sale.

Sheet mica is no longer mined in the United States because of high cost, small market, and high capital risk. Most sheet mica is mined in India.

4. Beneficiation Processes

4.1. Flake or Scrap Mica

In the early to mid-1900s, flake or scrap mica was mainly processed by a jigging procedure which consists of hydraulically washing a pile of bulldozed ore across a series of roll crushers and Trommel screens gaped at different size openings (Fig. 1). The ore first passes across a Trommel screen of heavy wire construction with an opening of 2.5–5.0 cm. Large flakes of mica, feldspar, and quartz are discharged from this screen as a mica concentrate. Undersized particles are discarded as waste throughout the procedure. Material that passes through the screen, which still contains considerable mica, flows by gravity across a second Trommel screen having a 0.3-cm opening. This screen concentrates underflow from the first screen by removing most of the water. The $+0.3{-}\mathrm{cm}$ screen fraction then flows through a roll crusher and across another Trommel screen having an 0.3-cm opening. The concentrate discharged from this screen is considered product. The minus (undersize) screen fraction continues to additional Trommel screens and roll crushers (normally four or five) with smaller size openings. The final mica concentrates flow together into a central drainage bin of either metal or wooden construction having drainage holes to allow water to escape.

Mica concentrate is transported by either a front-end bucket loader or screw conveyor to a rotary dryer. After drying, the mica may be crushed again across a role crusher, then screened before being transported by bucket elevator or screw conveyor to metal storage bins. The dried mica concentrate is either sold without further processing or hammer milled, screened on various sieves with various size openings depending on the product being made, and bagged in 110-kg (50-lb) multiwall paper bags for shipment. Other types of jigging operations are similar.

The grade of mica produced by jigging is very poor, usually about 75% concentrate, and recovery of available mica low (50%). Specifications on mica have become more stringent, therefore a more efficient processing method has been devised that provides higher quality mica, as well as more efficient recovery. Mica companies have begun to use rod mills, Humphrey spirals, and froth flotation (qv) to concentrate the ore. Although there is an increase in efficiency, the additional processing increases the cost. To offset the higher cost, by-products are extracted, processed, and sold (see also Mineral recovery and processing).

Because of improved mica processing operations, low cost earthen waste impoundment ponds have been built to store solid waste and thereby provide for a relatively cheap means of meeting new federal and state environmental laws.

There are several methods of preparing ore for beneficiation after it arrives at the plant site (Fig. 2). (*1*) The ore is transferred to rod mills, $1.5\ \mathrm{m\ dia} \times 2.5 - 3\ \mathrm{m\ in\ length}$, hydraulically from a bin at 40% solids. The rod mill crushes the ore to approximately 0.833 mm (-20 mesh). (*2*) The ore is slurried after the initial crushing step (jaw and roll crusher) to about 20–25% solids and pumped to either a hydrosizer or cyclones for desliming, removing 0.147 mm (-100 mesh) material. The roughly $1.168 - 0.833\ \mathrm{mm}\ (14 - 20\ \mathrm{mesh} \times 0.147\ \mathrm{mm})$ (100 mesh) deslimed feed is then either pumped directly or fed from a stockpile to Humphrey spirals where $1.168 - 0.833 \times 0.47\ \mathrm{mm}\ (14 - 20 \times 35\ \mathrm{mesh})$ mica is removed. The tailings from the spirals are dewatered on screw classifiers, then transferred to a rod mill. (*3*) The Humphrey spirals are bypassed and the entire feed fed from the crushed stockpile. (*4*) The ore is dumped directly into a bin from which a rod mill is fed directly with a screw feeder. Water is added to make $\sim 40\%$ solids slurry feed for the mill.

Sodium silicate (41°Bé, 1:3.22 ratio Na_2O:SiO_2) is added in the milling operation to disperse the slime, mostly kaolin. Dispersion also aids the grinding process. The rod mill serves to grind the ore to 0.833 mm (-20 mesh) or to the point where mica, quartz, feldspar, and iron minerals are liberated. Cyclones, or rake, hydraulic, or other types of classifiers, are used after grinding to produce coarse and fine mica fractions that are treated separately.

Coarse mica is separated from coarse quartz on spirals. The quartz tailings from the spiraling process are often upgraded to a commercially saleable product by scrubbing, desliming, and froth flotation. In some

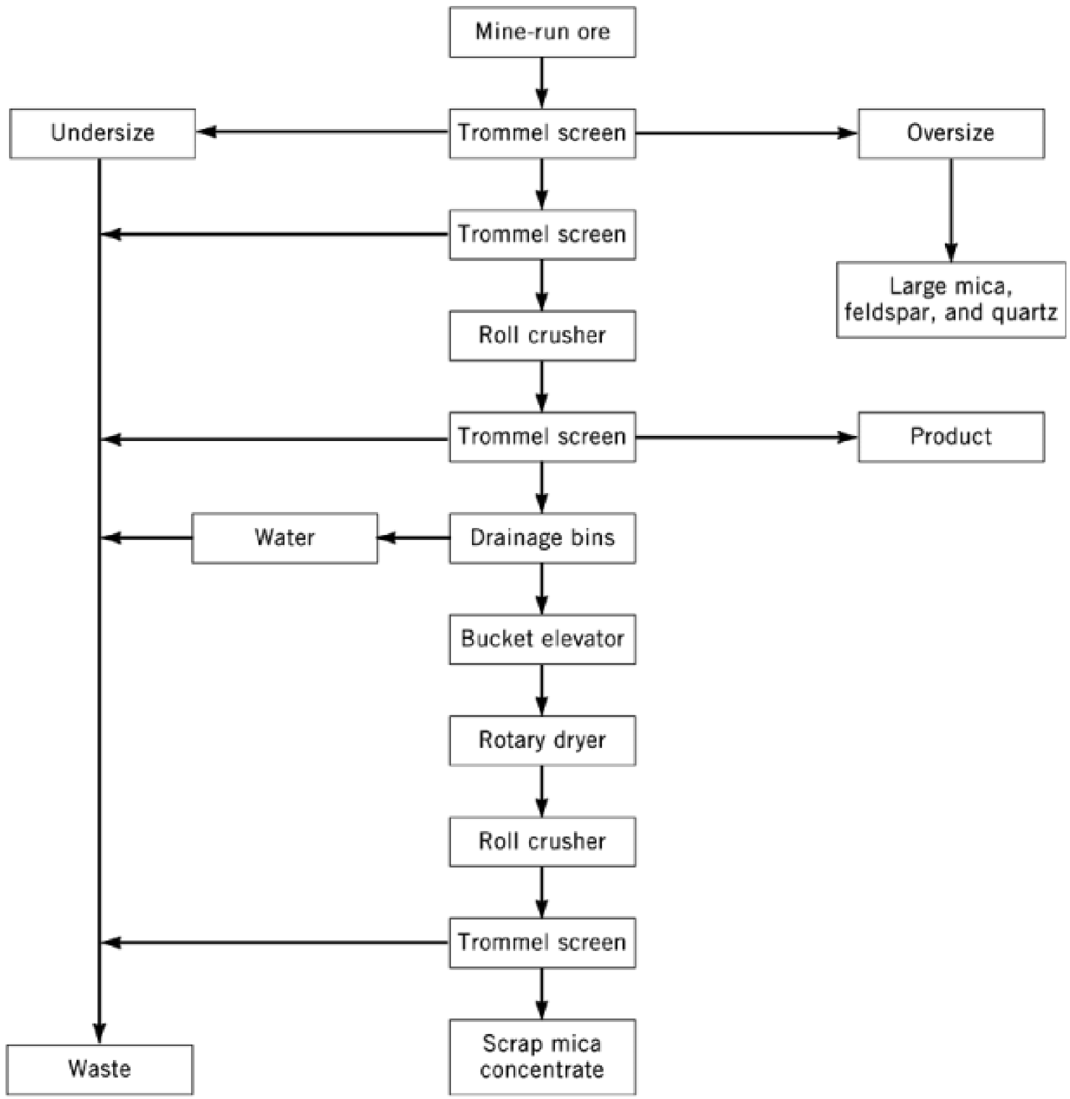

Fig. 1. Flow sheet for conventional scrap mica washer plant. See text.

cases the quartz may lend itself to being processed for high purity quartz, used in making crucibles in which quartz crystals are grown for computer chips (see Electronic materials). Other quartz grades may be used in the manufacture of glass (qv) or porcelain products (see Enamels, porcelain or vitreous).

The coarse mica concentrate is either respiraled to produce a product with a grade suitable for use by wet grinding mica producers, or floated to further upgrade it for specialty high grade dry ground mica products.

The fine mica fraction is deslimed over 0.875–0.147-mm (80–100-mesh) Trommel screens or hydrocylcones, or is separated with hydrosizers. The deslimed pulp ($\leq$0.589 mm (−28 mesh)) of mica, feldspar, and quartz is then fed to a froth flotation circuit where these materials are separated from each other either by floating in an acid circuit with rosin amine and sulfuric acid (2.5–4.0 pH), or an alkaline circuit (7.5–9.0 pH) with tall oil amine, goulac, rosin amine acetate, and caustic soda (see Fig. 2).

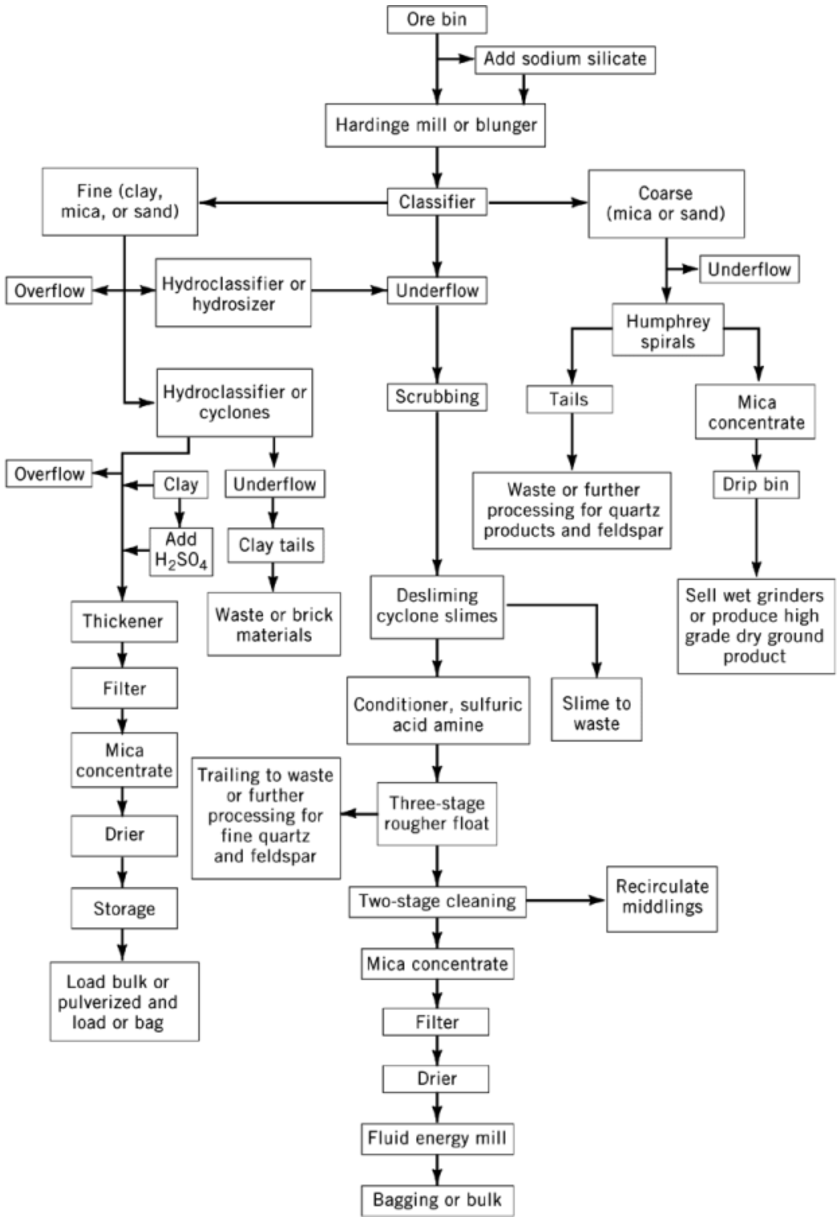

Fig. 2. Flow sheet for the acid circuit processing and recovery of mica from weathered granodiorite ore. An alkaline–cationic circuit may be used by inserting a second conditioner containing lignin sulfonate, adjusting the pH to 8.0, and adding NaOH and DRL (distilled tall oil) fatty acid to the first conditioner.

The floated mica concentrate is dewatered. After dewatering (qv), the mica is either dried in a fluid-bed rotary drier, flash dried in a fluid energy mill, or sold "drip-dry" to other mica grinders. The dry mica is then ground and screened to a size gradation dictated by the customer.

The slime, consisting of kaolin, fine quartz, and feldspar, is sometimes used as is after being dewatered. This material may be used in the manufacture of light-colored brick or may be further processed to produce a high grade ceramic kaolin used in the manufacture of dinnerware, electrical porcelain, or sanitary-ware (see Ceramics). Flocs of kaolin may be sold in bulk from the drier or pulverized and sold in a powdered form.

The remaining tailings left over from the clay fractionation step is either flocculated with alum, high molecular weight polymers, or a weak (pH 3.0) solution of sulfuric acid, and stored in settling ponds as waste, or may be filtered and sold to the brick industry as a coating material. It also may be dried and sold as a filler in plastics and textured paint (qv).

Flake mica is also produced as a by-product from processing feldspar ore (hard granodiorite). This process consists of mining hard rock granodiorite, crushing the large pieces of ore developed from the blasting operation, and producing a flotation feed of ≤ 0.589 mm (-28 mesh). The mica flotation step is followed by a feldspar flotation step. The quartz by-product resulting from the feldspar float is further processed with additional flotation steps to produce either a glass-grade (flat or container glass) product or a feedstock for the production of high purity quartz. Magnetic separation, leaching with a combination of hydrofluoric acid and hydrochloric acid, and chlorination are additional steps necessary to produce the high purity quartz grade.

Flake mica is also produced from mica schist which normally contains from 30–60% recrystallized muscovite mica along with quartz and iron minerals. The quartz is usually not suitable for glass sand or high purity material, however.

4.2. Sheet Mica

The preparation of sheet mica for feedstock for various punching and machining operations involves cobbing mica blocks or books to remove dirt, rock, and defective mica, trimming and splitting into sizes and thicknesses suitable for punching and milling to desired shapes, and grading the finished mica sheets according to size and quality. Classifications such as hardness (qv) and visual qualities may be found in Reference 13. The waste mica resulting from cobbing and trimming (scrap mica) is often mixed with flake mica for processing by dry or wet ground procedures.

The grade determines whether the mica can be used in high technology electronic instruments, eg, computer-aided tomography (CAT) scan (see Medical imaging technology), or in low technology devices, eg, a toaster. Many types of insulators, as well as the base for electronic circuits, are formed from the high quality sheets of mica by a punch pressing operation.

Mica splittings are processed from lower quality blocks and from sheets too thin for blocks and unsatisfactory for producing film. The splittings are packed for sale in three ways: book form, which are laminae split to the desired thickness from the same book of mica, then dusted with mica dust, and restacked in book form; pan packed, in which splitting layers are placed evenly in a pan, and each layer separated by a thin sheet of paper then pressed together; and loose packed, in which splittings are sized with screens then padded loosely in a wooden box for shipment.

The splittings may be used by mica processors to reconstitute large mica sheets, produced by overlapping irregularly shaped pieces to the desired thickness (built-up mica). The sheets are then bound with organic and inorganic binders and heat treated under pressure to complete the binding process. The sheets may also be bound to fiber glass and asbestos (qv) by a similar process. After forming, the built-up mica sheets are cut and punched to the desired shape and design. Built-up mica and reconstituted mica are used for products that do not require the special properties only obtained from high priced sheet mica.

5. Procedures for Production

The general pieces of equipment used in grinding flake mica or mica concentrate into saleable mica products are hammer mills of various types, fluid energy mills, Chaser or Muller mills for wet grinding, and Raymond or Williams high side roller mills. Another method is being developed, called a Duncan mill (J. M. Huber, Inc.), that is similar in many respects to an attrition mill. All of these mills are used in conjunction with sieves, and all but some types of hammer mills incorporate air classifiers as a part of the circuit.

5.1. Ground Mica

This constitutes by far the largest commercial use for mica. It is largely produced from the beneficiation of weathered and unweathered pegmatites, granodiorite, and metamorphic schists, although some higher grades are produced from trimmings of sheet mica or Type A (low quality) mica blocks.

Wet ground mica products account for approximately 15% of the total mica market. These products are produced by grinding either scrap or flake mica or both in a Muller or Chaser mill which consists of a 4.57-m diameter tub containing two 1.22-m diameter steel spiked wheels or rollers. A 1.13 t charge of mica is placed in the tub along with enough water to represent 25–35% of the batch. The necessary water content for good delamination and grinding varies for micas from different deposits. After charging the mill, rollers rotate at 30 rpm through the mica pulp for six to eight hours to cause the mica flakes to slide across each other, and thereby cause delamination by friction while producing a grinding action that reduces particle size.

When grinding is complete, the mica pulp is washed from the Mullers into settling tanks. After allowing the mica to settle for approximately 24 hours, the settled portion is pumped from the settling tanks to a holding tank; the unsettled portion is decanted into additional settling tanks. The settlings are pumped to a leaf-type filter press (700 kPa (100 psig)) or Bird centrifuge where partial dewatering takes place. The filtered cakes (62% solids) are dried in a stream tube at $\sim 100°C$, then passed through a hammer or attrition mill to reduce the pieces to powder. The powdered mica is screened on sieves containing 0.088–0.074 mm (170–200 mesh) stainless steel screen cloth. Oversized mica from the sieves reports back to the raw feed and is reground.

The Muller mill process has not changed significantly in almost a century (7, 14). Although many newer processes have been developed and patented, none has been able to match the quality (slip and sheen) of mica produced by the Muller process. The Duncan mill was developed to process quality wet ground mica. After drying and screening, the wet ground mica products are packaged in 27.72-kg bags and palletized in 1.13 t lots for shipment.

Exact sizing of mica products coupled with surface treatment procedures have led to a greater use for wet ground mica in plastic compositions, particularly automobile bodies. These quality products demand a high dollar value.

5.1.1. Dry Ground Mica

Dry ground mica concentrate is processed into usable products by several different grinding methods. Relatively coarse particle sizes (1.651–0.147 mm (10–100 mesh)) are used in oil-well drilling muds, some types of welding rod coatings, asphalt (qv), roofing shingles, and some other types of fillers (qv). These products are ground on a hammer mill in closed circuit with a sieve. Roofing micas produced from mica schist are often ground in a Raymond or Williams high side roll mill in closed circuit with an air classifier and a sieve. The finer particle-size micas $\leq 0.147 - 0.044$ mm (-100 to -325 mesh), used mainly in textured paints and joint cement compounds, are ground on several types of fluid energy mills, but generally a mill of the Majacs type. The finest dry ground mica product is ground with superheated steam (Micronized, KMG Minerals).

In the fluid energy mill wet mica concentrate (8–35% moisture) is fed to the mill with a screw conveyor attached to a feed hopper. The mica is then conveyed to an air classifier operating at 70–300 rpm, depending on desired particle size, with high pressure superheated air. The high pressure air is furnished by a compressor operating at ca 690 kPa (100 psig). It is superheated in a furnace at 371–427°C. The superheated air is introduced into the mill through opposing ventures, called guns, which direct oversize mica particles, rejected by the air classifier, to impinge upon themselves at high velocity, causing a grinding action. The ground mica is continuously removed from the grinding chamber in the high pressure air stream which circulates in a closed circuit through the mill system. Hot air is also continuously pumped from the furnace through a strip of air fan to the air classifier. This air flash dries the mica as it enters the classifier.

The fines are classified out of the feed and pass through the air classifier into a baghouse, from which they are fed onto sieves, containing 165 μm–0.124 mm (105–120 mesh) stainless steel wire cloth. Oversize mica from the sieves returns to the mill's grinding chamber for further grinding.

Mica passing through the sieves is conveyed to storage bins from which it is bagged in 22.2-kg units and palletized in 1.13 t lots for shipment. Tables 4 and 5 show properties of ground mica products. For all forms of ground mica the index of refraction is 1.58 wt %, Mohs' hardness is 2.5, oil absorption (Brit. Stand. 3483) is 60.75%, water solubility (Brit. Stand. 1765) is $<0.3\%$, the phericity factor is 0.01, and the softening point in °C is 1538. For Micronized and wet ground micas the brightness (green filter), pH, and apparent density in kg/m^3 are 75, 5.2, and 160–224, respectively; for dry ground mica, 66–75, 6.2, and 192–561, respectively (1).

6. Testing of Mica

There are several conventional tests required by consumers of ground mica.

6.1. Screening

A 100-g sample of mica is usually used for this test, plus a rack of six Tyler sieves and a pan. The stack of sieves containing the sample is rotated, and after screening, the mica remaining on each screen is weighed and the percentage retained is calculated. A combination of wet and dry screening may also be used to determine particle size distribution of fine mica ($\leq$0.147 mm (−100 mesh)).

6.2. Bulk Density

Bulk density of fine mica is determined with a Scott-Schaeffer-White volumeter using a 2.54-cm cube. A 7.6−cm diameter cylinder × 12.7−cm long is used to determine the bulk density of coarse mica, eg, oil-well-grade mica.

6.3. True Specific Gravity

This is determined with an air comparison or conventional glass pycnometer using distilled water as the displacement liquid.

6.4. Chemical Analysis

Chemical analysis is determined with conventional atomic absorption methods. Reliable wet techniques are sometimes employed (see Table 5).

6.5. Moisture

Moisture is determined by weighing a 50-g sample, then drying at 110°C. The sample is reweighed after drying. The difference between the two weights divided by the wet weight × 100 equals the percent moisture.

Table 4. Particle Size Distribution of Ground Mica Products[a]

		Water ground mica			Dry ground mica					
					Oil-well					
Sieve analysis, mesh size	Sizes, μm	88 μm (170 mesh)	44 μm (325 mesh)	Micronized mica	Fine	Coarse	Joint cement	High K_2O	No. 160	Special[b] plastics
6	3360					0–10				
16	1190					25–55				
20	850				trace					
28	600									
32	500				10–30					
35	475							trace	trace	
60	250				10–50		trace	5–0		1.0
80	180									
100	150	0.0	0.0	0.00	10–70	25–65	1.5 max	10.0	10.0 max	30.0
140	106	0.5–1.0			10–30[c]	10–20[c]				50.0
200	74	5.0 max	1.0 min				10.0 min	10.0 max	65.0	
270	53			0.00						80.0
325	44	7.0–14.0	3.0–10.0						75.0 max[d]	15.0
−325	≤ 44	75.0–85.0	90% min	99.0 min			50.0 min[e]	40–75		5.0
bulk density, g/cm^3		0.2 max	0.2 max	0.2 max	0.4–0.6	0.18–0.26	0.2–0.2	0.29–0.45		

[a] Information furnished by consumers; percent by weight retained.
[b] Micronized mica and wet ground both used in certain types of plastics.
[c] At 0.147 mm (100 mesh).
[d] Retained on 325 mesh.
[e] Usually run 70–75%.

Table 5. Chemical Analysis of Ground Muscovite Mica[a]

Analysis	Dry ground, wt %	Micronized,[b] wt %	Wet ground, wt %
SiO_2	45.57	46.27	48.65
Al_2O_3	36.10	35.24	32.04
K_2O	9.87	9.87	9.87
$Fe_2O_3^3$	2.48	2.48	3.68
Na_2O	0.62	0.60	0.28
TiO_2	0.20	0.20	0.20
CaO	0.21	0.21	0.21
MgO	0.15	0.16	0.16
H_2O	0.10	0.20	0.20
P_2O_5	0.03	0.02	0.018
S	0.01	0.01	0.010
C	0.44	0.44	0.44
LOI[c]	4.30	4.30	4.30
Total	*100.08*	*100.00*	*100.05*

[a]Ref. 1.
[b]Micronized is a trade name of KMG Minerals (formerly English Mica Co.).
[c]LOI = loss on ignition.

6.6. Free Silica

Free silica down to 1% can be determined with x-ray diffraction techniques (xrd).

6.7. Refraction Index

Refraction index is determined with a petrographic microscope by submersing a sample in emersion oils of known refractive index.

6.8. Oil Absorption

The Gardner rub-out (ASTM D281) method is used for this evaluation. A 5-g sample of mica is placed on a smooth glass plate, and linseed oil is added by drops. The mica is constantly mixed while the oil is being added. The end point is reached when the mica becomes saturated with oil. The amount of oil per 45.4 kg of mica is calculated as follows:

$$(\text{mL} \times \text{specific gravity linseed oil}\,(0.908))\,/5\ \text{g} =$$

$$\text{kg oil}/45.4\ \text{kg mica}$$

6.9. Brightness

The brightness of mica is determined with a Photovoltmeter (Photovolt Co.) or other suitable reflectance meter using a green 550-μm filter. The mica sample is prepared by pressing it into a smooth layer on a smooth glass surface.

6.10. Grit Content

The grit content is determined for fine mica by thoroughly mixing a 50-g sample with 1 L water. After mixing, the mixture is allowed to stand for 15 s, after which one-half of the contents is carefully decanted. The volume is again increased to 1 L, thoroughly mixed, and the slurry allowed to stand for 15 s before one-half of the contents is decanted. This procedure is repeated until the slurry becomes transparent, after which the slurry is allowed to stand for 10 s before being decanted. This is repeated until the water is perfectly clear, at which point the water is carefully decanted as much as possible without removing grit. The grit is washed, dried at 110°C, weighed, and reported as percent grit. In some cases, the grit is screened on a 0.210-mm (70-mesh) sieve and the percentages of ± 0.210 mm (± 70 mesh) grit are reported as separate percentages. Another method of determining grit content of fine mica is with a Frantz isodynamic magnetic separator which provides a magnetic field to remove magnetic mica from nonmagnetic grit.

The grit content of coarse mica is determined by the vanning method. A 25-g sample of dry mica is placed on a vanning plaque or a 21.6×28–cm piece of rough cardboard. The cardboard is cupped and the mica rolled so that sand becomes separated from mica. The sand is removed and the percentage of grit is calculated by dividing the weight of the grit by the weight of the sample $\times 100$.

6.11. Aspect Ratio

The aspect ratio of mica is determined with electromicroscopic image analysis techniques.

7. By-Products of Mica

The main by-products of mica processing plants are kaolin, quartz, and feldspar. Some plants produce all of these products for sale.

Glass-grade silica can be produced from most mica operations with additional beneficiation of the quartz. Ceramic-grade kaolin can be produced from some mica flotation plants by selective mining and additional processing of the clay slime removed prior to mica flotation (see Clays).

8. Mica Market and Consumption

8.1. Sheet Mica

Good quality sheet mica is widely used for many industrial applications, particularly in the electrical and electronic industries, because of its high dielectric strength, uniform dielectric constant, low power loss (high power factor), high electrical resistivity, and low temperature coefficient (Table 6). Mica also resists temperatures of 600–900°C, and can be easily machined into strong parts of different sizes and shapes (1).

Table 6. U.S. Mica Imports for Consumption, $t \times 10^3$ [a]

	Split block		Splittings		Other			
					< 0.55/kg		> 0.55/kg	
Year	Quantity, t	Value, $	Quantity, t	Value, $	Quantity, t	Value, $	Quantity, t	Value, $
1989	158	235	1379	1355	2996	714	79	436
1990	381	364	1204	1419	3829	864	30	268
1991	127	155	1244	1249	2734	608	51	204
1992	273	291	1601	1104	2860	626	180	616
1993	184	337	2625	1754	3656	739	147	433

[a] Refs. 8, (15–17).

Some parts fabricated from sheet include transistor mica, suitable for transistor mounting washers; interlayer insulator mica, used to insulate transformer coils; resistance and potentiometer cards, suitable for winding noninductive resistance cards and in potentiometers; vacuum tube mica, generally replaced by transistors; natural mica bushings and tubes; target and mosaic mica, used in the telecasting industry and in computers; and guided missile micas. High quality natural mica is used for various other special applications, ie, special optical filters, diaphragms for oxygen breathing equipment, washer dials for navigator compasses, microwave windows, and quarterwave plates of optical instruments, pyrometers, neon lasers, and thermal regulators.

8.2. Built-Up Mica

When the primary property needed for a particular application is insulation, built-up mica made by binding layered mica splittings together serves as a substitute for the more expensive sheet mica. The principal uses for built-up mica are segment plate, molding plate, flexible plate, heater plate, and tape (7).

Segment plate, used as insulation between copper commutator segments on direct-current universal motors and generators, accounts for the primary use for built-up mica. Phlogopite built-up mica is preferred for these segments because it wears at the same rate as the copper segments.

Some types of built-up mica are bound to special paper (qv), silk (qv), linen, muslin, glass cloth, or plastic. These products are very flexible and are produced in continuous wide sheets. These sheets are either shipped in rolls or cut into ribbons, tapes, or other desired shapes (Table 7).

Table 7. Built-Up Mica[a] Sold or Used in the United States by Product[b,c]

	1991		1992		1993	
Product	Quantity, t	Value, $	Quantity, t	Value, $	Quantity, t	Value, $
flexible (cold)	105	685	163	794	104	551
molding plate	305	1708	211	1516	210	1718
segment plate	281	1893	262	1729	213	1382
other[c]	148	1415	216	2036	124	1074
Total[d]	*839*	*6022*	*852*	*6075*	*651*	*4725*

[a]Consists of alternative layers of binder and irregularly arranged and partly overlapped splittings.
[b]Refs. 8, (15–17); quantity and $\$\text{value} \times 10^3$.
[c]Includes mica used for heater plate and tape.
[d]Approximate because of independent rounding.

8.3. Wet Ground Mica

Wet ground mica is used because of its unique properties, ie, luster, slip and sheen, and high aspect ratio (1, 13).

8.3.1. Wallpaper and Coated Paper

The shiny particles of mica give a silky or pearly luster when applied to paper. The effect is pleasing to the eye, and in some cases simulates fabric.

8.3.2. Nacreous Pigments

Mica is used as a substrate for coatings (qv) of various metal oxides to obtain a pearlescent effect. Mica coated in this fashion is used as filler and as a coloring agent in certain types of plastics.

8.3.3. Rubber

A thin coating of mica acts as a mold-release compound in the priming of rubber goods such as tires. It prevents the migration of sulfur from the tire to the air bag when the tire is being vulcanized (see Tire cords). Mica is also dusted on rubber inner tubes to prevent sticking.

8.3.4. Outdoor House Paint

Mica acts as a reinforcing pigment to reduce checking and cracking while controlling chalking in outside latex, oleoresinous, alkyd, and alkyl-modified latex exterior paints (see Paint). It also reduces penetration into porous surfaces, provides excellent adhesion, reduces running and sagging, and improves weatherability and brushability.

8.3.5. Aluminum Paints

Mica is substituted for up to 25% of the aluminum in this type of paint (qv) as an economic measure. Mica is inert which tends to protect the more reactive aluminum from corrosive atmospheres, thus helping the paint to maintain its luster.

8.3.6. Sealers

Mica is used in all types of sealers for porous surfaces, such as wallboard masonry, and concrete blocks, to reduce penetration and improve holdout (see Sealants). It permits a thicker film to be applied and at the same time reduces sagging. Cracking is reduced by the reinforcing action of the flakes, and gaps and holes in rough masonry are bridged by the mica flakes.

8.3.7. Plastics

Mica is used as a filler in plastics to improve its electrical and thermal resistance and its insulating qualities. Although dry ground mica is also used as a filler in plastics, wet ground enjoys the higher value market and is used because of its extrusion properties, and because it replaces the higher priced fiber glass in many applications (see Fillers; Plastics processing).

8.4. Dry Ground Mica

8.4.1. Hammer Mill Mica

Dry ground mica produced by hammer milling and screening is used in oil-well drilling, coatings for roofing shingles, roofing felt, and for some types of welding rod flux (see Building materials, survey).

Certain sizes of hammer milled and screened micas are used as a flux coating on the metal wire of welding rods. Fine particle-size, fluid-energy ground mica is also used for this purpose. High heat resistance, excellent mechanical and thermal strength, low moisture absorption, high surface leakage resistance, unusual chemical inertness, and nonhydroscopic properties are some of the distinctive qualities which make mica an indispensable ingredient for use in welding (qv) electrodes. The fluxing property is attributed to the high K_2O content.

8.4.2. Fluid Energy Produced Mica

The largest use for fine, dry ground mica is in the manufacture of wallboard joint cements. Ground mica that is essentially $\leq$0.147 mm ($-$100 mesh) (Table 4) and $\sim$70% passing a 0.044 mm (325 mesh) Tyler sieve is used in the joint compound mixture as a filler and extender. These compounds are used to fill joints between panels of gypsum plaster board (see Calcium compounds). In this particular use, mica contributes to making a nonabsorbing smooth surface that reduces shrinkage and eliminates cracks. It is also used in the finished coating on ceilings and to prepare thermal insulation and acoustical qualities of ceiling tile and prefabricated concrete.

Fine particle-size dry ground mica is also used as an extender and filler in certain texture and traffic paints. Mica particles are stronger than iron and not brittle like other inerts. It is an antifriction, antifouling, antisettling, anticorrosive, antitarnish, and antisiege agent. It is a superior reinforcing pigment that acts as a sealer over porous surfaces and reduces penetration and flushing (see Sealants); moreover, it improves the moisture resistance of protective coatings and adhesion to all types of surfaces.

8.4.3. Micronized Mica

Micronized mica is a trade name (KMG Minerals, formerly English Mica Co.) for a very fine particle-size dry ground product, usually ground with superheated steam in a special fluid energy mill and used as a replacement for wet ground mica in certain types of paints. Micronized mica, preferably calcined, is also used in cosmetic applications, ie, nail varnishes, lipsticks, eyeshadows, and barrier cream, because is has the advantages of high ultraviolet light stability, excellent lubricity, skin adhesion, and compressibility (see Cosmetics). Some of these micas are coated with oxides like titanium and iron (Table 8).

Table 8. Ground Mica Sold or Used in the United States[a, b]

	1991		1992		1993	
Use	Quantity, t	Value, $	Quantity, t	Value, $	Quantity, t	Value, $
joint cement	39	6,173	43	6,819	49	7,549
paint	15	4,428	16	5,227	16	5,416
plastics	1	560	4	1,347	4	1,647
well-drilling mud	4	484	2	281	4	560
other[c]	15	5,642	19	8,082	19	11,814
Total[d]	*75*	*17,289*	*84*	*21,755*	*92*	*26,986*

[a]Refs. 8, (15–17); quantity and $\$\text{value} \times 10^3$.
[b]Domestic and some imported scrap. Low quality sercite is not included.
[c]Includes mica used for molded electrical insulation, roofing, rubber, textile and decoration coatings, welding rods, and miscellaneous.
[d]Approximate because of independent rounding.

9. Economic Aspects

In 1990, North Carolina produced 60% of the total scrap mica; the remainder was produced in Connecticut, Georgia, New Mexico, Pennsylvania, South Carolina, and South Dakota. In 1991, the five largest producers produced 67% of the nation's total output (Table 9) (15).

Table 9. U.S. Producers of Mica, 1991[a]

Company	Location	Capacity, t/yr	Product	Remarks
Spartan Minerals Corp.	Pacolet, S.C.		dry	sold into the joint compound market
Mineral Mining Corp.	Kershaw, S.C.	22,675	dry	product is sericite for paint industry
Franklin Industrial Minerals (MICA Division)	Taos Country, N.M.	18,140	dry	many improvements in dry and wet processing; new flotation plant
Pacer Corp.	Custer, S.D.		flake	70% muscovite mica for oil-well use
Concord Mica		1,633	wet	for paint and lining rubber molds
Franklin Mineral Products	Hartwell, Ga.		wet	

[a]Ref. 16.

The United States imports most of its manufactured sheet mica (muscovite) and paper-quality scrap mica from India, with the remainder coming from Canada, China, Japan, Norway, and others (Table 10).

Consumption of mica splittings increased 90% to 2625 t in 1993 from 1989. The splittings were fabricated into various built-up mica products. Total production of built-up mica decreased 34% from 1989. Molding plates and segment plates were the primary end products, accounting respectively for 32 and 33% of the total. The combined value of all mica imports increased 42% to $21.2 million in 1993, while the combined value of all mica exports increased 28% to $12.2 million. Sheet mica prices ranged from approximately $4.40 to $1100/kg depending on the grade, while splittings were bought for $1.10–$3.30/kg. Wet ground mica selling prices ranged from $440 to $800/t; dry ground mica sold for $110 to $220/t fob the plant site. The average $/t of U.S. produced wet and dry ground micas in 1993 are as follows:

Type	Price, $
joint cement	155
paint	348
plastics	396
well-drilling mud	209
other	616

Table 10. U.S. Mica Trade Data[a]

	Scrap and flake mica				Sheet mica			
	Powder		Waste		Unworked		Worked	
Year	Quantity, t	Value, $	Quantity, t	Value, $	Quantity, t	Value, $	Quantity, t	Value, $
				Exports				
1989	3,628	1,634	1,224	555	60	156	415	7,227
1990	4,319	2,050	580	646	148	272	612	7,568
1991	3,420	1,717	874	331	205	309	411	7,454
1992	3,954	2,054	475	204	170	307	436	7,180
1993	4,614	2,604	335	99	292	511	617	9,019
				Imports for consumption				
1989	8,902	4,971	4,185	1,256	1,616	2,054	1,229	6,711
1990	9,142	5,133	4,034	987	1,615	2,051	1,085	7,431
1991	9,725	5,219	3,630	996	1,422	1,608	918	6,835
1992	11,568	7,479	3,786	974	2,054	2,011	1,407	9,011
1993	13,098	8,070	4,765	1,307	2,956	2,524	1,352	9,338

[a]Ref. 16; quantity and $\$\text{value} \times 10^3$.

10. Transportation

Mica is shipped by truck (20.4 t max) or railroad (27.2 t max). Bulk truckloads and rail shipments, such as palletizing, bagging, and shrink- or stretch-wrapping, are made to avoid extra costs. Mica is usually palletized and shrink- or stretch-wrapped for shipment.

11. Environmental Regulations

Mica mining is subjected to local, state, and federal laws. The Mining, Safety and Health Administration (MSHA) regularly monitors mica mining operations for safety violations.

Both state air and water environmental departments together with the U.S. EPA regulate and oversee air and water quality associated with mica mining operations. Most states have land management departments that regulate dam safety, erosion, sedimentation, and reclamation. The mica mines must control erosion and sedimentation and restore the mined out areas. This is accomplished either by backfilling or contouring and seeding operations, or in cases where this is impractical or undesirable, lakes for water-related recreation may be built. The Corps of Engineers have jurisdiction over laws governing wetlands.

12. Health and Safety Factors

Health regulations are supervised by county and state health departments. There are no known health problems caused by the mica crystal, however, most industrial mica products contain some free silica particles that can cause silicosis and some states require employees who work in mica plants to receive an annual x-ray.

13. Future Applications

The future for mica is in the speciality plastic market, eg, as a molecular barrier in plastic containers and in plastic automobile parts.

Research and testing results have shown that mica can be used successfully in air-conditioner fan blades, dashboard panels, head lamp assemblies, fan shrouds, and floor panels. Mica can also be substituted for more expensive glass flakes to strengthen lightweight plastic seat backs, load floors, grill panels, ignition system parts, and air-conditioning and heater valve housings. Both American and Japanese automakers are incorporating ground mica in place of asbestos (qv) in acoustic compounds that change vibrations and eliminate road and engine noise. Mica is also an environmentally accepted replacement for asbestos in brake linings (see Brake linings and clutch facings).

BIBLIOGRAPHY

"Mica" in *ECT* 1st ed., Vol. 9, pp. 68–75, by P. M. Tyler, Consultant; "Mica, Synthetic" in *ECT* 1st ed., Suppl. Vol., pp. 480–487, by A. Van Valkenburg, National Bureau of Standards; "Micas, Natural and Synthetic" in *ECT* 2nd ed., Vol. 13, pp. 398–424, by H. R. Shell, U.S. Bureau of Mines; in *ECT* 3rd ed., Vol. 15, pp. 416–439, by A. B. Zlobik, U.S. Bureau of Mines.

Cited Publications

1. M. L. Rajgarhia, *Ground Mica*, Mica Manufacturing Co., Private Ltd., Calcutta, India, 1987, p. 30 *British Standards*, British Standards Institute, London.
2. S. W. Mudd, *Industrial Minerals and Rocks*, 2nd ed., AIME, New York, 1949, 551–566.
3. S. W. Bailey, *Reviews in Mineralogy*, Vol. **13**, Mineralogical Society of America, Washington, D.C., 1984, 1–12.
4. R. W. Grim, *Clay Mineralogy*, McGraw-Hill Book Co., Inc., New York, 1968, 596 pp.
5. G. P. Chapman, in S. J. Lefond, ed., *Industrial Minerals and Rocks*, 5th ed., Vol. **2**, AIME, New York, 1983, 915–929.
6. S. B. Hendricks and M. Jefferson, *Am. Mineral.* **24**, 729–771 (1939).
7. A. B. Zlobik, *Mica*, preprint from bulletin 671, U.S. Bureau of Mines, Washington, D.C., 1980, 16 pp.
8. L. L. Davis, *Minerals Yearbook*, U.S. Bureau of Mines, Washington, D.C., 1991–1993, p. 4, 5, 7–9.
9. *Mica Fabricators*, The Tar Heel Mica Co., Plumtree, N.C., 1942, 3 pp.
10. E. J. Dana, *A Text Book of Mineralogy*, 3rd ed., John Wiley & Sons, Inc., New York, 1945, 659–665.
11. C. W. Chesterman and co-workers, *The Audubon Society Field Guide to North American Rocks and Minerals*, Alfred A. Knopf, New York, 1989, 531–536.

12. L. L. Davis, *Mineral Facts and Problems*, preprint from bulletin 675, U.S. Bureau of Mines, Washington, D.C., 1985, 12 pp.
13. *Quality Classification of Muscovite Block Mica*, ASTM D351, ASTM, Philadelphia, Pa., 1961, p. 1046.
14. J. B. Preston, "Mica," *Pigment Handbook*, John Wiley & Sons, Inc., New York, 1971, 30 pp.
15. Ref. 8, 1991, p. 9.
16. *Ibid.*, 1992, p. 4.
17. *Ibid.*, 1993, p. 8.

General References

18. *National Mica for Industry*, The Tar Heel Mica Co., Buffalino, N.C., 1990, 3 pp.
19. S. D. Broadhurst and L. J. Hash, *The Scrap Mica Resources of North Carolina*, Bulletin No. 66, North Carolina Department of Conservation and Development, 1953, p. 6.
20. G. M. Clarke, *Ind. Mineral.*, 27–28 (June 1983).

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