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Vermiculite

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Vermiculite is the name generally applied to the group of hydrated ferromagnesian aluminum silicates that are characterized by the ability to expand when heated. This process, called exfoliation, results in a lightweight product of commercial value. Most uses of vermiculite are for the expanded material. The chief markets are in construction, agriculture, and horticulture, with lesser uses in general industry.

Composition and Properties

Vermiculite, in its natural state, has the characteristic micaceous habit, a perfect basal cleavage which causes splitting into thin laminae that are soft, pliable, and inelastic. The structure of vermiculite is basically that of a talc. The prominent monoclinic crystal faces are often marked by lines at 60° and 120°. Hardness varies from 1.5 to 2 or more; specific gravities are between 2.1 and 2.8; color varies from almost clear to amber, bronze, brown, green, or black. Vermiculite feels like talc, especially when wet.

Although much research has been performed on the chemical and structural composition, there is not yet complete agreement on the exact formula. This is to be expected when different workers have examined the many different varieties. Vermiculite is not considered to be a single mineral species but a family of related minerals. The structural formula for a trioctahedral vermiculite may be written:

$$(H_2O)-(Mg,Ca,K)-(Al_2,Fe,Mg)-(Si,Al,Fe)_4O_{10}(OH)_2$$

Hydrobiotite also occurs with vermiculite and is usually considered a vermiculite for commercial uses.

When heated quickly to elevated temperatures, vermiculite expands by exfoliating at right angles to the cleavage into wormlike particles. The name vermiculite is derived from the Latin *vermiculare*, to breed worms. This characteristic of expansion is the result of the mechanical separation of the layers by the rapid conversion of contained water to steam. The decrease in bulk density of commercial grades is usually approximately 10 times, from 50 to 5 lb/ft^3, but varies depending on the quality, size, and furnace efficiency. Individual flakes may expand up to 30 times. Vermiculite may also be expanded by soaking in chemicals such as hydrogen peroxide, weak acids, and other electrolytes. Color change during expansion is dependent upon the type of vermiculite and furnace conditions. Heating in an oxidizing atmosphere produces a dull gray or tan color, whereas a reducing atmosphere can produce a bronze or gold color.

The expansion of the vermiculite crystal results in large pores being formed between the platelets. Thus, exfoliation makes available a large increase in void volume which is important in the application of vermiculite as a chemical carrier.

Mathieson and Walker (1954) state vermiculite must be regarded as a true clay mineral. The characteristic properties of the mineral, such as high cation exchange capacity, organic complexing ability, and variable interlamellar distance are very similar to those of montmorillonite. The cation exchange capacity of vermiculite is one of the highest of all the clay minerals. The interplatelet space is accessible to penetration by some electrostatically neutral molecules. Water and glycerine are two common substances whose molecules may be so imbibed.

In the natural state and under normal atmospheric conditions, water occupies the spaces between the silicate layers. The crystal *d*-spacing is near 14.2Å. By differential thermal analysis, it has been determined that the water

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is released at three temperature ranges. The "unbound water" is released near 300°F. This water is reversible and comes to equilibrium with the environment. The second water, designated "bound water," is removed at about 500°F. This is the water necessary for exfoliation. The third water is released at approximately 1600°F and is probably hydroxyl. Little of this water is released by commercial exfoliation and when it is, a very noticeable change occurs in the color and physical characteristics of the product.

Vermiculite is closely related to biotite and phlogopite. The essential difference is that the unit cell of vermiculite contains a layer of water and the biotite contains a layer of potassium. Biotite or phlogopite are almost always associated with vermiculite in commercial deposits and are sometimes intermixed within crystals or across a single crystal face. The term *hydrobiotite* has been used for those varieties where the analysis indicates that there is a layered mixture of the two minerals in some definite proportion.

Table 1 shows chemical analyses typical of the three major vermiculite deposits.

TABLE 1—Chemical Analyses of Vermiculite, %

	Libby, Montana	Enoree, South Carolina	Palabora, South Africa
SiO_2	40.16	39.77	39.37
MgO	20.63	18.32	23.37
Al_2O_3	12.01	13.88	12.08
Fe_2O_3	13.00	12.84	5.45
FeO	—	—	1.17
K_2O	5.93	5.11	2.46
CaO	1.54	1.02	1.46
TiO_2	1.44	2.07	1.25
H_2O	5.29	6.99	11.20
Total	100.00	100.00	97.81

Origin

Detailed investigations have been made of the three largest commercial deposits of vermiculite. According to Boettcher (1966), the Rainy Creek alkaline-ultramafic complex near Libby, MT, represents a composite of successive intrusions of igneous rocks emplaced into the Precambrian metasedimentary rocks. Most of the biotite in the inner body of pyroxenite has been altered to hydrobiotite and vermiculite. From his studies, Boettcher suggests the vermiculite is a product of leaching of the biotite by ground waters, whereas the hydrobiotite may represent a higher temperature alteration product.

Stewart (1949) in his report on the vermiculite deposits at Tigerville, SC, states that hydrothermal activity was necessary in the formation of the high grade deposits only to the extent of furnishing the biotite, which was later altered to vermiculite by meteoric waters. Buie and Stewart (1954) determined the paragenetic sequence as:

$$\underset{\text{(hypogene)}}{\text{pyroxene}\rightarrow\text{amphibole}\rightarrow\text{biotite}}\rightarrow\underset{\text{(supergene)}}{\text{vermiculite}}$$

Libby (1975) suggests that the potassic ultramafic plutons of the Enoree, SC, vermiculite district probably were intruded into Late Precambrian to Cambrian sedimentary rocks and subsequently were metamorphosed. Studies indicate that both the vermiculite and hydrobiotite form under weathering conditions.

The Palabora deposit in South Africa at Loolekop is located in a carbonatite complex. Both the hydrothermal and weathering theory have been proposed for the formation of the vermiculite. There is a gradation of vermiculite to phlogopite or biotite with increasing depth.

The Palabora carbonatite complex (Dekun, 1965) is about 4 by 1½ miles in size. The dolomite core is surrounded by a thin inner ring of altered phoscorite (serpentine-apatite-magnetite) and an outer ring of diopside pyroxenite. Outward from this is a discontinuous 1½ mile-wide ring of fenitized gneisses. Numerous alvikite and orthoclasite veins have been injected into the pyroxenite ring. Serpentine, apatite, and magnetite occur in both inner zones, and a pegmatitic pyroxenite zone occupies the center of the northern ultrabasic ring. Vermiculite occurs only in the ultrabasics, especially close to serpentinized patches. Vermiculite also occurs disseminated with apatite. The principal vermiculite areas are located (1) in the north-central pegmatic pyroxenite one half mile from the limit of the carbonatite plug; (2) three quarters of a mile south of the core; and (3) in a zone near the southeastern rim of the pyroxenite.

A vermiculite deposit near Louisa, VA, occurs in a body of basic pyroxenite, about 4 to 5 miles in diameter, surrounded by gneisses and granitoid type rocks typical of the Piedmont. The vermiculite occurs in varying flake size but nearly all are less than 10 mesh. The grade of vermiculite varies considerably within a few feet both laterally and with depth. The vermiculite appears to have been altered from biotite by surface weathering. However, little, if any, geological investigation has been conducted on this deposit.

Distribution of Deposits

Vermiculite occurrences have been reported from many countries of the world. As the mineral has become more widely recognized new occurrences have been reported. Market conditions, location, size, grade, quality, and economics are some of the factors affecting the commercial value and development of a deposit.

In the United States vermiculite deposits or occurrences are found in Alabama, Arizona, Arkansas, California, Colorado, Georgia, Idaho, Kansas, Montana, Nevada, New Mexico, North Carolina, Pennsylvania, South Carolina, Texas, Virginia, and Wyoming. Production has been reported from California, Colorado, Georgia, Montana, Nevada, North Carolina, South Carolina, Texas, Virginia, and Wyoming. However, production is reported today only from mines in Montana, South Carolina, and Virginia.

Other countries where deposits have been reported are Argentina, Australia, Brazil, Canada, China, Egypt, Finland, India, Japan, Kenya, Korea, Mexico, Morocco, Pakistan, Zimbabwe, Republic of South Africa, Spain, Tanzania, Uganda, and the USSR. Minor production has been reported from Argentina, Brazil, China, Canada, Egypt, India, Kenya, Korea, Mexico, Spain, and Tanzania. Some vermiculite is produced in the USSR, but quantitative data are not available.

Prospecting and Exploration

In the United States vermiculite deposits of consequence are located in two principal areas: the Piedmont region from Alabama to Pennsylvania and in the Rocky Mountain Range from Montana southward into New Mexico, including the central mineral region of Texas. A few deposits occur in eastern Canada in the Precambrian shield.

Vermiculite deposits usually are covered by vegetation because the minerals are soft and when weathered have a considerable water-holding ability. Outcrops showing vermiculite are rare, but in some areas the mineral can be recognized in road cuts. Outcrops of associated rocks such as biotite, alkalic pyroxenites, and dikes of carbonatites or syenite, generally are more noticeable. In most instances, the only field evidence will be the presence of vermiculite flakes in the soil or in stream beds.

The larger commercial size deposits usually are found associated with ultrabasic rock, commonly pyroxenite. The pyroxenite may be intruded by numerous dikes such as pegmatites, syenites, and carbonatites. Numerous veins containing vermiculite are found in ultramafic intrusives such as dunites, peridotites, and pyroxenites, but these do not often represent commercial size deposits.

In a vermiculite-bearing formation the rock will vary from barren to a high content of vermiculite. The bulk of the material containing vermiculite will fall in the 20 to 30% content range. Drilling or trenching is necessary to prove the presence of ore in economic quantities and grade. Since the preservation of flake size is most important, auger or large rotary hole drilling is necessary with special attention to bit design. Diamond core drilling is most impractical.

The primary requirement of a commercial deposit is that the vermiculite be of acceptable quality. The concentrate must expand to a high degree without decrepitating, and the expanded particles must be strong enough to withstand handling. The biotite or phlogopite content must be low, or occur in such a form that it can be kept from mixing with the mill feed. The deposit predominantly must contain flake size material larger than 65 mesh, as there is little demand for the minus 65 mesh size.

Another characteristic of a commercial deposit is that the ore body be large enough to be mined with modern earthmoving equipment. Vermiculite production is very energy-intensive, as a high percentage of the commercial cost is for mining, reagentizing, drying, expanding, and transportation.

Deposits are considered to be high grade if their content of plus 65 mesh vermiculite is over 30%, and uneconomical or at least borderline if the content is 20% or below.

Preparation for Markets

Mining and Milling Methods

The two larger operations in the United States are described as examples of the production now in use. Fig. 1 shows the typical flowsheet from mine to shipping.

Montana: In the pyroxenite near Libby the vermiculite occurs in high grade pods and disseminated form. Mining starts on top of the mountain and progresses downslope by slicing off the top of the hill in approximately 27 ft benches. In the exposed faces of the benches,

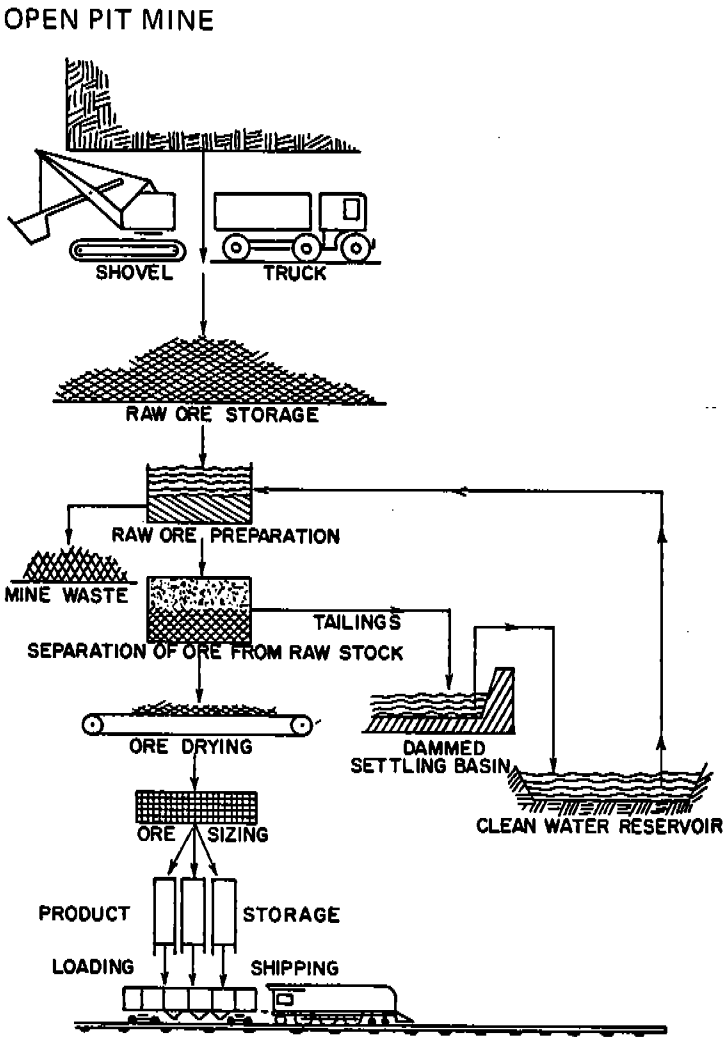

FIG. 1—*Flow diagram of vermiculite ore processing (Strand, 1975).*

vermiculite-bearing ore and waste are removed at the same time. Most of the material is loosened by rotary drilling 6-in. holes and shooting with ammonium nitrate. Large front-end loaders are used to load 85-ton off-highway trucks. Conventional mining and construction equipment, such as dozers, graders, drills, trucks, and loaders, is used. Considerable road building, using the syenite waste rock, is necessary because of the large truck size and the soft pyroxenite. The ore is hauled to a primary screening plant located between the mine and mill areas. At this point the +⅝-in. waste rock is removed and the ore is conveyed to a large storage dome.

Waste from the mine is hauled by truck to the edge of the pyroxenite and dumped downslope into the valley.

The ore is fed to the mill at a closely controlled rate where it is separated into size fractions and beneficiated. All concentrates pass through a dewatering step and then are dried. The minus 65 mesh fraction goes to a tailings pond where the material is settled and the clear water recirculated back to the process. All air or dryer exhausts are passed through bag dust collectors.

Concentrates from the mill are conveyed to a loading station and then hauled by truck to a plant near the railroad where screening separates the standard commercial sizes for storage and shipment.

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South Carolina: The largest of the South Carolina operations is located near Enoree, approximately 35 miles southeast of Greenville. The ore reserves consist of a group of deposits which are mined and blended for feed to the centrally located mill. The mines are relatively small open pit type with sloped benched walls. The overburden and wall material are removed by self-loading scrapers and stacked near the pit for use in reclamation. Weathering is deep and no blasting is required. The ore is usually pushed by dozer to a point for loading by small draglines. Some blending of the ore is accomplished by the dozer as it moves across the area. Hauling is done with tandem rear-axle diesel tractor-trailer dump units. All equipment must be of the size that can travel or be hauled over public highways. Dozers and graders are used to build and maintain the mine roads. Upon completion of mining, the pit is reclaimed by pushing in the walls, returning the waste, terracing, and establishing a cover of vegetation.

The ore from the mines is dumped into piles on the rim of a pit at the head of the mill. The various grades of ore (usually four) are blended and pushed into the pit by a dozer. Two hydraulic monitors are used to break up the lumps and wash the ore into the mill as a wet slurry. The ore goes through a series of scrubbing, desliming, and beneficiating steps. The concentrate is dewatered, dried, screened into the standard sizes, and stored for later shipment. Ponds are maintained for the collection of all mill waste. The clarified water is returned to the mill process in a closed system.

Processing

Vermiculite is sold mostly in the expanded form which has been exfoliated by heating. The expanded material weighs from 4 to 8 lb/ft^3 depending on the particle size and type of furnace used. In the United States the unexfoliated vermiculite concentrate, 50 to 60 lb/ft^3, is usually shipped in 100-ton bulk rail cars from the mills to expanding plants located throughout the United States and Canada.

There are five standard sizes produced by the mills so that when the concentrate is exfoliated at the plants it will be a finished product. The standard commercial screen sizes (Tyler Standard) for the concentrates are -3 $+10$, -6 $+14$, -8 $+28$, -20 $+65$, -50 mesh. At the expanding plant the bulk hoppers usually are unloaded by conveyors and bucket elevators and stored in silos or bins. From the storage areas, the ore is fed at controlled rates into vertical furnaces fired by gas or oil. Processing flame temperature varies from approximately 2000° to 3600°F. The time-temperature relationship is critical in obtaining maximum expansion and good quality. Usually a shorter retention time and higher temperature will produce better expansion. After leaving the furnace the expanded material is passed across a separator where rock impurities are removed and the product is cooled. The product is normally packaged in 3- or 4-ft^3 paper or plastic bags and shipped to customers by truck. Both bulk and bagged material are shipped by rail. Most furnaces are equipped with bag collectors for dust control. Various products are manufactured at selected plants, using the expanded vermiculite as an ingredient.

Tests and Specifications

At the mills samples of drill cuttings, mined ore, mill feed, and concentrates are continuously tested to maintain quality control. Concentrates are checked for expansion loss (water content), impurities of nonexpandable minerals, screen size, and volume yield.

The expanded products must meet many specifications depending on use. Specifications have been established by Underwriter's Laboratories, Inc., the American Society for Testing and Materials, the Food and Drug Administration, the producers, and the customers. Numerous methods for quality control have been devised for testing the expanded vermiculite or manufactured products to ensure that these specifications are met.

Production

Although the mineral vermiculite was described in 1824 the first report of production was in 1913 in the Turrett Mining District near Salida, CO, where eight carloads were produced. In the 1920s commercial production was started at Libby, MT, and grew slowly until 1946. Production was started in South Carolina in 1946, which helped to develop the market in the eastern United States. Production in Virginia commenced in 1978. South Africa began production in the late 1940s.

Table 2 shows the trend of production since 1940, and Table 3 lists vermiculite exfoliating plants in the US in 1980.

TABLE 2—World Vermiculite Production Since 1940 (Thousand Short Tons)

Year	United States	South Africa	Others*	World
1940	22	0	0	22
1950	208	47	0	255
1960	199	69	1	269
1970	285	134	12	431
1971	301	145	13	459
1972	337	163	12	512
1973	365	172	12	549
1974	341	201	15	557
1975	330	210	28	588
1976	304	245	28	576
1977	359	182	29	570
1978	337	230	49	616
1979	346	211	50	607
1980	337	205	41	583
1981	320	210	46	576
1982[e]	310	200	40	550

Source: US Bureau of Mines.

[e] Estimate

* Exclusive of Central Economy countries, for which data are not available.

Markets and Uses

The principal markets for vermiculite are in construction, agriculture, horticulture, and general industry. It is estimated that approximately 70% of the production is used in construction and perhaps 30% in various agriculture and horticulture uses. Most of the products sold to construction are used in nonresidential building.

Construction Uses

These include loose fill used as a pour-in insulation for attics, safes, and block walls. A special water-repellent product is used as a fill in masonry walls.

Vermiculite is used as an aggregate to produce a lightweight insulating concrete roof deck which is poured in place.

Unexpanded concentrate is used extensively in the production of fire-retardant gypsum wallboard.

Special sprayed-on products, in which vermiculite is mixed with gypsum and other ingredients, protect structural steel and concrete members against fire damage.

Agricultural Uses

Manufacturers of lightweight high analysis fertilizers for the home lawn and garden market use vermiculite as the base carrier. It also is used as the carrier for other agriculture chemicals, including pesticides and weed killers. During the past five years the market has been increasing for the use of vermiculite as a growing medium. Mixtures of vermiculite, peat moss, and other ingredients make excellent artificial soil such as potting soils, soil substitutes, soil conditioners, and soils for plant propagation.

The average price per short ton of unexpanded vermiculite concentrate, f.o.b. mine, in the United States for the past five years is given by Meisinger (1981) as:

Year	*Price*
1977	$51.81
1978	58.46
1979	63.58
1980	69.73
1981	81.88
1982 (estimate)	90.00

TABLE 3—Vermiculite Exfoliating Plants in the United States in 1980

Company	City	State
Brouk Co.	St. Louis	Missouri
Cleveland Builders Supply Co.	Cleveland	Ohio
Diversified Insulation, Inc.	Minneapolis	Minnesota
J. P. Austin, Assoc., Inc.	Beaver Falls	Pennsylvania
W. R. Grace & Co.	Irondale	Alabama
	Phoenix	Arizona
	North Little Rock	Arkansas
	Newark	California
	Santa Ana	California
	Denver	Colorado
	Pompano Beach	Florida
	Jacksonville	Florida
	Tampa	Florida
	West Chicago	Illinois
	Newport	Kentucky
	New Orleans	Louisiana
	Muirkirk	Maryland
	Easthampton	Massachusetts
	Dearborn	Michigan
	Minneapolis	Minnesota
	St. Louis	Missouri
	Omaha	Nebraska
	Trenton	New Jersey
	Weedsport	New York
	High Point	North Carolina
	Oklahoma City	Oklahoma
	Portland	Oregon
	New Castle	Pennsylvania
	Enoree	South Carolina
	Travelers Rest	South Carolina
	Nashville	Tennessee
	San Antonio	Texas
	Dallas	Texas
	Milwaukee	Wisconsin
International Vermiculite	Girard	Illinois
Koos, Inc.	Kenosha	Wisconsin
Mica Pellets, Inc.	Dekalb	Illinois
Patterson Vermiculite Co.	Lanford	South Carolina
Robinson Insulation Co.	Great Falls	Montana
	Minot	North Dakota
The Schundler Co.	Metuchen	New Jersey
O. M. Scott	Marysville	Ohio
Strong-Lite Products	Pine Bluff	Arkansas
Verlite Co.	Tampa	Florida
Vermiculite of Hawaii, Inc.	Honolulu	Hawaii
Vermiculite-Intermountain, Inc.	Salt Lake City	Utah
Vermiculite Products, Inc.	Houston	Texas

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