THE GEOLOGICAL SURVEY OF WYOMING

HORACE D. THOMAS, State Geologist

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WYOMING VERMICULITE DEPOSITS

BY

ARTHUR F. HAGNER

UNIVERSITY OF WYOMING
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ARTHUR F. HAGNER

Assistant State Geologist and
Assistant Professor of Geology, University of Wyoming

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ABSTRACT

The commercial vermiculite deposits of Wyoming are described and brief mention is made of other prospects in the state. The known Wyoming deposits occur associated with pre-Cambrian igneous and metamorphic rocks in the eastern, southeastern, and central parts of the state. Commercial deposits are found in four districts—Encampment, Wheatland, Glenrock, and the Sweetwater Uplift.

Commercial vermiculite has formed at the contacts of granite pegmatite with biotite and hornblende schists, meta-diorite, hornblendite, and serpentinite. It is believed that the pegmatites contained sufficient volatile constituents to alter hornblende, biotite, and serpentinite to vermiculite by hydrothermal action.

Data are presented on physical, chemical, and optical properties of vermiculite and on tests and specifications of the exfoliated product. The uses, mining methods, and treatment are briefly considered.

Wyoming has produced between 5,000 and 5,500 tons of vermiculite principally from the Encampment, Wheatland, and Glenrock districts. Some additional production is believed possible from these districts and perhaps from other regions where the mineral has been found but which are undeveloped at present.

INTRODUCTION AND ACKNOWLEDGMENTS

The vermiculite deposits described are in the eastern, southeastern, and central parts of Wyoming and are located in four mineralized districts. One district is in the vicinity of Encampment, one near Wheatland, the third is south of Glenrock, and the fourth is in the Sweetwater Uplift west of Casper (Fig. 1). Several prospects not in these districts are described although no production has been made from them. In all the districts vermiculite is associated with pre-Cambrian igneous and metamorphic rocks and is found at or near contacts of granite pegmatite with basic and ultra-basic igneous rocks or their metamorphosed equivalents.

Wyoming is one of seven states which produces vermiculite. In the past six or seven years between 5,000 and 5,500 tons have been produced from the state. Of this total the Encampment district has supplied about 2,000 tons, the Glenrock district another 2,000 tons, the Wheatland district somewhat over 800 tons, and the remainder came from the Sweetwater Uplift and scattered deposits.

Principally those deposits are described from which commercial vermiculite has been produced. There are numerous vermiculite showings found throughout the state which have never been developed and are therefore only briefly considered here. Accurate estimates of reserves in most cases are impossible because of the extremely irregular distribution of the vermiculite, and due to the tendency of vermiculite bodies to pinch and swell.

In addition to describing the geologic occurrence of Wyoming deposits, data are included on the origin of vermiculite. It is believed that some of the information presented will be of a general interest due to the lack of available data on the state's vermiculite occurences. Chemical analyses and optical properties of Wyoming vermiculites are

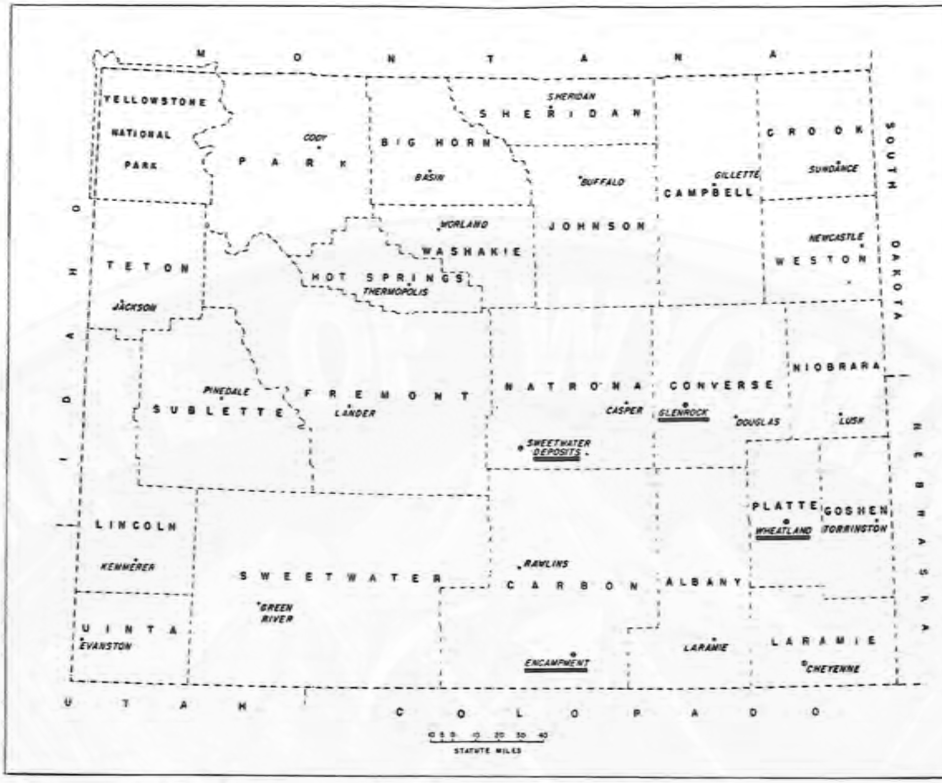


Figure 1. Index map of Wyoming showing principal vermiculite deposits.

included as well as a brief summary of the uses, mining methods, and preparation for the market.

The writer's study is part of the State Geological Survey's investigation of Wyoming mineral resources. A total of about three weeks was spent in the areas discussed during the summers of 1940 through 1943. Geologic maps of some of the more important deposits were made with plane table and alidade.

The writer wishes to thank Drs. Paul F. Kerr of Columbia University and S. H. Knight of the University of Wyoming for critically reading the manuscript and for valuable suggestions. Messrs. Milan Maravich, Raymond Berryman, and Eldon House acted as instrument men during the geologic mapping. Mr. Raymond Ring helped with the photomicrographs and Mr. Victor Muse with some of the drafting. The Geological Survey of Wyoming has generously financed the study.

In addition to the above there are numerous individuals throughout the state who have shown the writer many courtesies. In particular thanks are due the owners of the various properties who are mentioned elsewhere in this article. Also, Dr. Horace D. Thomas, Mr. Frank Huston, and Mr. Charles Stafford have been very helpful.

DESCRIPTION AND EXFOLIATION

Vermiculite is the name applied to a group of micaceous hydrous silicates formed by hydrothermal, and possibly superficial, alteration of several different minerals. Dana[1] lists fourteen vermiculites, some of which are probably mixtures of vermiculite with another mineral, or represent vermiculite in varying stages of alteration.

The principal characteristic of vermiculite is its expansion or exfoliation when heated or acid-treated, which produces long-worm-like shapes. The name vermiculite is derived from the Latin vermiculari, to breed worms. The mineral expands at right angles to the cleavage with an accompanying loss of water on heating. Water is driven off as steam between the layers or flakes of the mineral and forces apart the individual sheets. This explanation is one of several which has been advanced. Vermiculite may be expanded by using cold hydrogen peroxide; other chemicals will also accomplish this result but they do not work so rapidly.[2] Exfoliation has been produced by soaking hydrobiotite in concentrated sulfuric acid for two days and then exposing it to air for two or three days. Expansion in this case is believed to be due to the formation of sulfate crystals which forced apart the mineral flakes.[3] The phenomenon of exfoliation by heat treatment remains to be satisfactorily explained.

The volume of vermiculite may increase during heating as much as 20 times, and crude material weighing approximately 100 lbs. per cu. ft. may expand until it weighs only 5 to 10 lbs. per cu. ft. after exfoliation. The density of crude vermiculite is approximately 2.2 to 2.5, whereas after exfoliation it is 0.087.[4]

Crude vermiculite is usually brown, bronze, greenish, or black, but on expansion the color changes to bronze, gold, silver, or white. Apparently the change of color is caused by oxidation of iron, and can be partially controlled by exclusion of air during heating. A. V. Petar states, "In an atmosphere of diminishing oxygen content the oxidation is incomplete and the color decreased in intensity."[5] Vermiculite which contains only a trace of iron exfoliates to a silver or white color. Tests on vermiculite from several localities indicate that the best golden color is obtained by expansion at 1,840° F. or above in an oxidizing atmosphere; the best silver color is produced under reducing conditions.[6]

During heat treatment increase in temperature decreases the time required for exfoliation. Maximum expansion of North Carolina vermiculite was obtained by sudden exposure of the mineral to a temperature of about 1,840° F. for a short period of time. Preliminary drying or wetting did not improve the product. Exfoliation begins at about 150° C. and at 1,000° C. essentially all of the combined water is driven off.[7] Tests on Montana vermiculite indicate that when expanding "the total free water left in the mineral must not be reduced to less than 5 or 6 per cent to obtain maximum expansibility."[8] In general, volume increases and density decreases with rise

[1]References are at the end of the paper.

in temperature. Details on tests and specifications and the treatment of Wyoming vermiculite are included in other sections of this paper.

Weight, toughness, and friability are determined by the furnace temperature and atmosphere and the time allowed for expansion. Relative toughness decreases at a fairly uniform rate with increase in temperature. For maximum toughness vermiculite should be exfoliated below 1,900° F.[6] The weakest product is formed by expansion at high temperature under reducing conditions, and the amount of expansion is also slightly reduced. Most vermiculite loses its toughness when heated to 650°-850° C. but the toughness is increased by rapid cooling after expansion. Removal of all the water makes the exfoliated product brittle.[9]

Dehydration data on vermiculite are summarized as follows:[6] Some vermiculite contains more than 20 per cent water. The highest rate of water loss occurs between 0° and 212° F. From 212° to 300° F., the rate of loss remains nearly constant. There is another abrupt change in rate from 300° to 500° F., and above 500° F. the rate of loss approaches a constant value until 1,600° F. is reached at which temperature essentially all of the water is driven off.

The variation in amount of expansion of different vermiculites is an important economic consideration. For many purposes the expanded product must weigh no more than 6 lbs. per cu. ft. Some vermiculite on exfoliation is light, blocky, corklike, and produces few fines. Other raw material exfoliates only slightly, is heavier, decrepitates, and a considerable proportion of fines is formed during heat treatment. Usually the latter type also produces abnormal fines during the preliminary crushing and screening so that as much as half of the original raw vermiculite may result in fines upon completion of expansion. Petrographic and chemical studies suggest that the difference in behavior on crushing and exfoliation is due, in part at least, to the degree of alteration of the original mineral to vermiculite. When alteration has been complete the mineral is less brittle, fewer fines result during crushing, and the expanded product is a better grade. Apparently acid treatment of some vermiculites increases the amount of expansion considerably, whereas others do not respond nearly so much. It seems clear that much experimental work remains to be done before the reasons for these phenomena are fully understood.

CHEMICAL COMPOSITION

The vermiculites vary considerably in chemical composition depending upon the source mineral and the amount of alteration. The minerals of the group are essentially hydrated silicates of magnesium, aluminum, and iron. Although Dana lists fourteen minerals under vermiculite, X-ray studies indicate that several of these are hydrobiotite, or mixtures of vermiculite and chlorite.

Gruner[10] concludes that the average composition of the vermiculites may be represented as $22MgO.5Al_2O_3.Fe_2O_3.22SiO_2.40H_2O$. This is in accord with the results obtained by Ross and Shannon.[11] X-ray data indicate that the vermiculites contain silicate layers similar to talc with water molecules between the layers. When alkalies are present the mineral is no longer classed with the true vermiculites but is either hydrobiotite or a mixture of vermiculite and chlorite.[12]

Until such time as X-ray studies can be undertaken the true nature of Wyoming vermiculite will remain uncertain. Chemical and optical data suggest, however, that the mineral corresponds to hydrobiotite, or to vermiculite with interstratified chlorite layers. This is believed to be so because of the presence of alkalies, the relatively low water content, and the high refractive indices. Also, it was not possible to obtain absolutely pure material for analyses, but the foreign matter present was not sufficient to materially affect the results, except, perhaps, in the case of the J. B. C. vermiculite. From a commercial viewpoint the exact nature of the mineral has no economic significance because true vermiculite, hydrobiotite, and the vermiculite-chlorites all exfoliate and have similar uses. The following table contains the chemical composition of three Wyoming vermiculites, three vermiculites from other localities, and one hydrobiotite.

TABLE 1. CHEMICAL ANALYSES

	1	2	3	4	5	6	7
SiO_2	39.82	39.00	37.40	36.12	35.70	34.20	41.0
TiO_2	0.11	0.14	0.19	.24	.....	.....	....
Al_2O_3	15.42	17.32	16.86	13.90	12.00	16.58	18.0
Cr_2O_3	none	trace	trace	.....	.....	.....	....
Fe_2O_3	4.77	9.84	12.15	4.24	3.40	7.41 }	7.0
FeO	1.48	3.96	4.70	.68	.....	1.13 }	
MnO	0.12	0.10	0.27	trace	.....	.....	....
NiO	none	0.05	0.06	.28	5.34	.....	....
CaO	1.74	1.84	2.10	.18	.32	.....	1.0
MgO	19.86	16.27	15.38	24.84	25.90	20.41	21.0
Na_2O	0.35	0.85	0.42	.....	.....	.....	....
K_2O	0.71	1.71	1.01	.....	.....	.....	1.0
P_2O_5	....	0.34	1.12	.....	.....	.....	....
H_2O—130° C.	7.20	3.08	3.00	8.20 }	19.00	21.14	11.0
H_2O+130° C.	7.54	5.20	4.64	10.74 }			

1. Vermiculite, Union Asbestos & Rubber deposit, Platt ranch. W. L. Piers, analyst.
2. Vermiculite, J. B. C. deposit, Wheatland. W. L. Piers, analyst.
3. Vermiculite, Smith deposit, Glenrock. W. L. Piers, analyst.
4. Vermiculite, Bare Hills, Md., E. V. Shannon, analyst. A. J. S. 40, 1928, p. 20-24.
5. Nickeliferous Vermiculite, Webster, N. C. E. V. Shannon, analyst. Am. Min. 11, 1926, 90.
6. "Jefferisite," West Chester, Pa. Schneider, analyst. Dana Syst., 6 ed., p. 665.
7. Hydrobiotite, Libby, Mont. Analysis by Natl. Bur. Standards.

OPTICAL PROPERTIES

The optical properties of the Wyoming vermiculites analyzed correspond fairly closely with published data except that the indices are higher.[13, 14, 15] If it is true that the Wyoming material represents mixtures of vermiculite and chlorite, or is hydrobiotite, as previously suggested, then this may account for the discrepencies in indices. In the case of the J. B. C. vermiculite the indices were considerably higher than published results. It is believed that this is due to incomplete alteration of biotite to vermiculite, the indices falling roughly between the two minerals. In the following table the optical properties of two representative Wyoming vermiculites are listed along with those from several other localities.

TABLE 2. OPTICAL DATA

	1	2	3	4	5
Characters	Biax.	Biax.	Biax.	Biax.	Biax.
Sign	(-)	(-)	(-)	(-)	(-)
2V	0°-v. sm.	0°-v. sm.	0°	0°-8°	
Bx_a	0001	0001	0001	0001	0001
Dispersion	r < v wk.	r < v wk.	r < v wk.	r < v wk.	r < v wk.
Refractive indices					
α =	1.560	1.560	1.525	1.542	1.561
β =	1.590	1.607	1.545	1.573	1.581
γ =	1.590	1.607	1.545	1.573	1.581
Birefringence ($\gamma - \alpha$)	.030	.047	.020	.030	.020
Absorption	Z=Y>X	Z=Y>X	Z=Y>X	Z=Y>X	
Pleochroism					
X =	colorless to pale yellow	pale greenish br.	nearly colorless	pale green	
Y =	pale brown to brown	yellow brown	greenish yellow	pale yel. to br. gr.	

1. Vermiculite, Union Asbestos & Rubber deposit, Encampment, Wyoming.
2. Vermiculite, Smith deposit, Glenrock, Wyoming.
3. Vermiculite, Bare Hills, Md. Data by Shannon, A. J. S. 40, 1928, p. 20-24.
4. Vermiculite (nickeliferous), Webster, N. C. Data by Ross, Am. Miner. 11, 1926, p. 90-92.
5. "Jefferisite," West Chester, Pa., Larsen, U. S. G. S. Bull. 679, p. 93, 1921.

GEOLOGY

General—The pre-Cambrian rock types associated with Wyoming vermiculite deposits include biotite schist, hornblende schist, diorite, and meta-diorite, hornblendite, serpentinite, granite, gneiss granite pegmatite, aplite, and vein quartz. These rocks, with the possible exception of biotite schist and some gneiss, appear to represent original igneous material in various stages of metamorphism. Biotite schist may represent a metamorphosed sediment. The serpentinite is believed to have been an ultra-basic rock which has undergone autometamorphism.

The schists, gneisses, basic, and ultra-basic rocks are the oldest in the vicinity of the vermiculite deposits. They have all been subjected to regional, or dynamothermal, metamorphism and then have been invaded by granitic masses—the Sherman batholith in eastern and southeastern Wyoming and similar granites in central Wyoming. Emplacement of the batholiths has resulted in large-scale assimilation, leaving roof-pendants of undigested older rocks. Following the emplacement of granite the earlier-formed rocks were injected by granite pegmatite, aplite, and vein quartz.

None of the Paleozoic and Mesozoic formations found along the flanks of the pre-Cambrian areas is exposed in the immediate vicinity of the vermiculite deposits.

Hornblende Schist and Meta-diorite—The hornblende schists and meta-diorites are black, fine to medium-grained rocks containing white specks and streaks of quartz. The principal mineral is hornblende with lesser amounts of quartz. Minor constituents are epidote, zoisite, sphene, feldspar, and magnetite.

These rocks show all gradations from a hornblende-quartz diorite with no schistosity to a rock with well-developed parallel orientation of mineral grains. It seems probable that the hornblende schist was originally either a quartz diorite where it occurs as dikes, or a dacite where it appears to have been a flow rock. Although most of the rock is now hornblende, it is possible that originally the hornblende schist was basaltic in composition, but no evidence of this is present.

Hydrothermal alteration of hornblende schist and hornblende-quartz diorite has produced most of the commercial vermiculite in Wyoming. (Plate 1, No. 1). Solutions accompanying pegmatitic invasions acted on hornblende to form vermiculite, apparently either with or without the production of an intermediate biotite. Locally, chlorite and actinolite or tremolite formed during the process. Where chlorite or actinolite is present the rock is mottled green and brown. Other alteration products include small quantities of sericite and kaolin.

Biotite Schist—The biotite schists are brown and white, fine-grained rocks consisting almost entirely of biotite and quartz. Minor amounts of apatite, zircon, and an appreciable quantity of magnetite are present. Schistosity is usually well-developed.

Near pegmatite contacts the biotite may be partly or entirely altered to vermiculite. The schist has been soaked with granitic material producing, in places, a speckled brown and white rock composed of vermiculite and pegmatitic feldspar and quartz. The only other alteration product is kaolin which is present in small quantities and is apparently the result of weathering.

In some of the areas biotite schist is widespread in occurrence and it is not always clear whether it is a meta-sedimentary or meta-igneous rock. Where hornblende schist occurs as narrow bands near granite intrusions it has been assimilated by granite and the hornblende altered to biotite. Biotite schist formed in this manner may in places be seen to grade into hornblende schist. Where biotite schist occurs as narrow, parallel bands several hundred or more feet long, it may represent beds and lenses of an original sediment.

Hornblendite—A gray to greenish-gray, medium-grained rock consisting almost entirely of hornblende. Where fresh the rock has a glistening silky luster but specimens partly altered to vermiculite are brownish and somewhat dull. Locally the rock is schistose and might be called hornblende schist. Thin sections indicate the presence of small amounts of biotite, apatite, magnetite, and limonite. Apparently biotite and magnetite formed as hydrothermal alteration products; limonite occurs as a weathering product.

Hornblendite occurs only in the Glenrock district. It forms an intrusive mass cutting the serpentinite of the area. Locally granite has invaded the hornblendite and produced vermiculite.

Serpentinite—This rock varies considerably in appearance. The color is commonly a non-uniform green changing from pale yellow-green to medium green, and from gray to gray-brown. The texture is also variable but is usually fine-grained. Under the microscope the rock consists principally of serpentine minerals with several per cent of magnetite, chlorite, and limonite. Some specimens show a mesh structure typical of serpentine derived from olivine. In places bastite structure can be seen indicating derivation of serpentine from enstatite.[40] The original rock was probably peridotite which has been altered by autometamorphism to serpentinite. (Plate 1, No. 4).

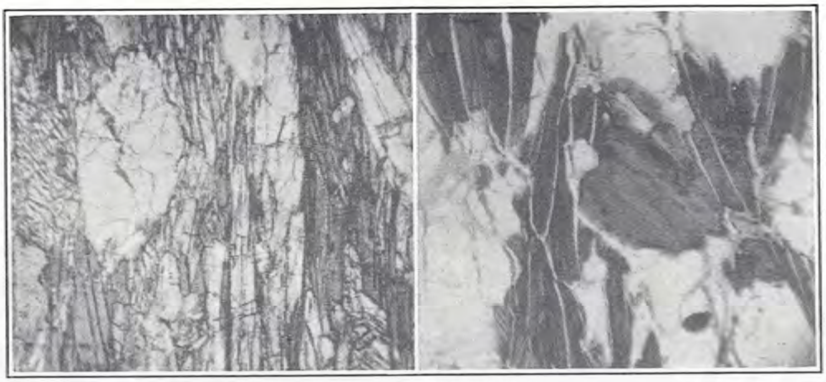
Serpentinite occurs as small and large intrusive masses and is found in the Glenrock district and in the Vaughn deposits west of Wheatland. It forms the principal rock at the Smith deposit near Glenrock. Alterations by solutions derived from granite pegmatite have locally produced vermiculite. In most cases narrow zones of chlorite, tremolite, actinolite, anthophyllite, asbestos, talc, and carbonate occur between the serpentinite and vermiculite. (Plate 1, No. 3). No attempt has been made in this study to determine the percentages and variations of the minerals in these zones.

Granites, Gneisses, and Aplites—The most abundant granite is a white, coarse-grained rock consisting chiefly of quartz, orthoclase, and albite-oligoclase. In the pegmatitic phase it contains appreciable amounts of biotite and muscovite. Locally the rock exhibits a parallel arrangement of mineral grains and should be classed as a granite gneiss. Principal alteration products are sericite, kaolin, carbonate, and chlorite.

Granite is intrusive into the older schists, meta-diorites, serpentinites, and hornblendites, and has partially or largely assimilated these rocks. Somewhat later than the granite, intrusion of pegmatite, aplite and quartz veins took place. Occasionally small amounts of vermiculite have formed where the biotite of a granite has been altered by later pegmatitic solutions. (Plate 1, No. 2).

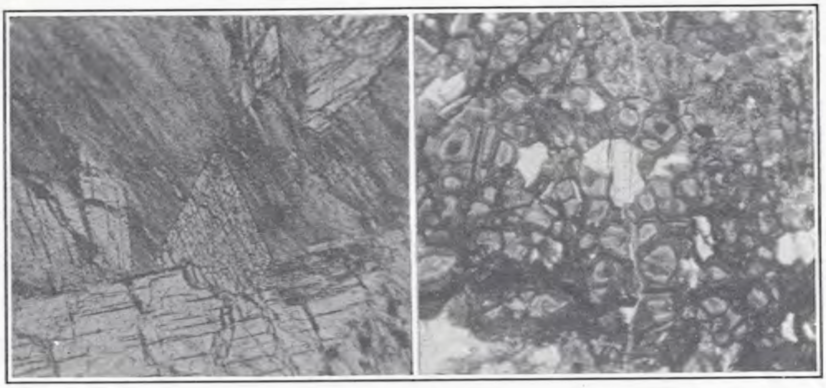
In the general vicinity of the vermiculite deposits, particularly in the Encampment district, a red coarse-grained granite is found. The color varies somewhat with feldspar content. Locally the rock is gneissoid. In thin sections minor amounts of sericite, kaolin, and carbonate may be seen. Since the red granite is outside the immediate vermiculite areas, no attempt was made to determine in detail its relation to the associated rocks. It appears to be younger than the quartz diorites, schists, hornblendites, and serpentinites, and older than the pegmatites, aplites, and quartz veins.

PLATE I



(1) Prismatic hornblende (white) altering to vermiculite (black) in hornblende schist. × 135.

(2) Biotite altering to vermiculite in granite. × 135.



(3) Serpentinite altered to tremolite (white) and talc (dark gray). × 135.

(4) Serpentinite showing mesh structure due to derivation from olivine, and bastite structure (center white grain) due to derivation from enstatite. × 135.

Pegmatites—The pegmatites associated with Wyoming vermiculite deposits are white, medium to coarse-grained rocks consisting principally of quartz, albite-oligoclase, microcline, biotite, and muscovite. Minor amounts of apatite, zircon, zoisite, sphene, tourmaline, and magnetite may be present. In certain cases garnet, kyanite, and corundum are found. Hydrothermal alteration has produced sericite, carbonate, chlorite, and magnetite. Some kaolin and limonite are usually present as weathering products.

The pegmatites occur chiefly as dikelike and lenticular masses from a few inches to several feet in width. Most of the dikes strike and dip concordantly with the schistosity of the metamorphic rocks, but local transections are common. In places the contact of pegmatite with wall rock is sharp but most of the rocks which are altered to vermiculite have been soaked by pegmatitic material.

PLATE II

(1) Xenolith of hornblende schist (black) altered to vermiculite at contact with granite pegmatite (white).

The pegmatites are granitic in composition and appear to be related in origin to the granites of the districts described. Some of the dikes are off-shoots of batholithic masses, others cut across these masses and are definitely younger. The preponderance of albite-oligoclase over microcline suggests a parent magma relatively high in soda rather than potash.

Several features of the pegmatites indicate that they were relatively mobile and produced considerable alteration in the surrounding rocks. Numerous dikes have penetrated the wall rocks for many feet as thin stringers only a fraction of an inch wide. This suggests a highly attenuated magma. The presence of mineralizers is indicated by the occurrence of such minerals as apatite and tourmaline. The soaking of associated rocks by pegmatitic material and change of hornblende, biotite, and serpentinite to vermiculite suggest a mobile magma capable of producing appreciable alteration.

Because of the small size of the pegmatitic bodies which produced vermiculite, rarely more than two or three feet in width, the individual dikes could not be shown on the geologic maps of the deposits. The cross-sections, however, show the relations of pegmatites to vermiculite and the surrounding rocks.

PLATE II—(Continued.)

(2) Inclusions of biotite schist (gray) within granite pegmatite (white). Some of the biotite has altered to vermiculite.

STRUCTURE

All the metamorphic rocks in the vermiculite areas have been strongly folded. The dip of the foliation is steep and frequently changes appreciably in a short distance. Contacts between schists and intrusive rocks are usually vertical or steeply inclined. Considerable local variation in strike occurs in the various deposits studied, but in general the schistosity of the pre-Cambrian rocks in eastern Wyoming trends northeast.

Invasion of the hornblende and biotite schists is largely lit-par-lit but in addition small stringers of pegmatite, aplite, and quartz cut across the schistocity. Minor offsets of metamorphic and igneous rocks are numerous.

The older metamorphic and igneous rocks appear to be roof pendants not entirely digested by the younger pre-Cambrian granites of the districts. Xenoliths are common and frequently exhibit lit-par-lit injection and considerable assimilation by the granites.

OCCURRENCE

Vermiculite of commercial quality and quantity is found at or near the contact of granite pegmatite with hornblende or biotite schist, hornblende-quartz diorite or meta-diorite, hornblendite, and serpentinite. It occurs as streaks, patches, and layers from a fraction of an inch to many feet in width. Occasionally specks or patches are found within pegmatites but never in commercial quantity.

Wyoming vermiculite may be bronze, light or dark brown, brownish green, or black depending upon which mineral has altered to vermiculite and upon the amount of alteration. The color is fairly uniform throughout any one vermiculite body except locally where alteration has been incomplete or where considerable impurities occur.

The distribution of vermiculite is extremely irregular. Individual bodies tend to be lens-shaped and to pinch and swell. In depth vermiculite bodies may enlarge or end abruptly. This is typical of Wyoming vermiculite; the formation and size of the deposits depend upon the location of the pegmatites and the magnitude of the accompanying alteration. This irregularity in distribution makes unreliable any estimate of reserves based on surface evidence alone.

Another unfortunate characteristic of small vermiculite bodies is the variability in capacity of the mineral to expand. In different small deposits of the same district, and even in parts of the same body, the mineral may not expand uniformly. It is this variability that makes it difficult to standardize much of the product for the market. In general, however, the larger bodies react throughout in essentially the same manner.

ASSOCIATED MINERALS

The minerals associated with vermiculite depend upon the character of the original rock which has suffered alteration. Hornblende schist, hornblende-quartz diorite, and hornblendite, where altered to vermiculite, yield a simple group of minerals. Hornblende is altered to biotite and vermiculite, the alteration apparently taking place at a relatively high temperature. At lower temperatures chlorite is developed by alteration of biotite and vermiculite, occasionally with the formation of a small amount of magnetite. Rarely kyanite and sillimanite occur surrounded by vermiculite and probably represent a high temperature phase of activity. Corundum has been found associated with Wyoming vermiculite under similar conditions, and has also been described in literature on deposits in North Carolina.[16, 54]

Where serpentinite is altered to vermiculite a larger and more complex suite of minerals is developed. High temperature hydrothermal solutions appear to have altered serpentinite to hornblende, actinolite, tremolite, anthophyllite, biotite, and vermiculite. Later as the temperatures decreased chlorite, magnetite, talc, and carbonate were formed. The order of formation of these minerals is usually indefinite because of the obliteration of earlier effects by the later minerals. Although not all of these minerals are apt to be found at any one contact, an examination of a district usually reveals the presence of most of them.

The minerals formed by hydrothermal alteration of serpentinite usually occur in fairly distinct zones. It is common to find areas of nearly pure actinolite, anthophyllite, vermiculite, chlorite, and talc in nearly parallel bands. Microscopic examination of samples from the zones, however, shows that individual bands frequently contain minor amounts of the other hydrothermal minerals. Since the lower temperature hydrothermal effects are superposed on products of higher temperature these minor impurities are to be expected. The zonal arrangement of hydrothermal minerals at contacts of basic and ultrabasic with siliceous rocks has been carefully studied by several investigators. Because the zones described in the literature are similar to those existing at the Wyoming deposits, reference is made to these works for additional data.[17, 18, 19]

ORIGIN

As already stated, Wyoming vermiculite is associated with pre-Cambrian basic and ultra-basic igneous rocks and their metamorphosed equivalents, and deposits have formed at or near contacts of these rocks with granite pegmatites. It is believed that the pegmatitic intrusion provided the solutions necessary to alter hornblende, biotite, and serpentinite to vermiculite. (Plate 2, No. 1 and 2). There is microscopic evidence that, in addition to the above minerals, chlorite, tremolite-actinolite, kyanite, sillimanite, corundum, and possibly even garnet—through an intermediate chlorite stage—may have altered to vermiculite during the complex hydrothermal processes which were active. The alteration of these minerals to vermiculite by replacement is strongly suggested by the following criteria observed: (1) Crystals with ragged, embayed, and crenulated margins containing vermiculite along fractures and cleavage directions. (2) Islands of the original mineral in optical orientation and surrounded by vermiculite. (3) Veinlets of vermiculite in the host mineral with unmatched walls which are enlarged at intersections. These alteration products appear to represent intermediate steps in the formation of vermiculite. In the alteration of hornblende to vermiculite an intermediate biotite stage may or may not be present. Thin sections of altered hornblende indicate that vermiculite has formed directly from hornblende in many instances, and that at other times an intermediate stage existed.

It is believed that serpentinite was produced by autometamorphism of an ultra-basic rock such as peridotite. Chlorite, amphiboles, and talc are thought to have formed during a later pegmatitic stage. This is in accord with Hess' work suggesting that ultra-basic magmas are poor in water content, and that hydrous silicates associated with serpentinite are produced by volatiles from granitic or pegmatitic solutions.[20] The fact that serpentinite has altered to vermiculite only where intruded by granite pegmatite, suggests that hydrothermal solutions from the pegmatites were responsible for the formation of vermiculite—not solutions from the serpentinite body itself.

The invasion of igneous and metamorphic rocks by younger pre-Cambrian granites was accomplished by large-scale assimilation and the development of roof-pendants. The granites, however, do not appear to have produced large vermiculite bodies. Commercial vermiculite is restricted to areas of pegmatitic injection, which followed the granite intrusions, and it seems probable that only the pegmatites contained sufficient hydrothermal matter to produce appreciable amounts of vermiculite.

Meteoric waters are thought to have been of little or no importance in the formation of Wyoming vermiculite. The influence of hydrothermal solutions on the formation of vermiculite has been recognized by others.[21-30] An hydrothermal origin is ascribed to the Wyoming deposits for the following reasons:

1. Associated minerals such as amphiboles, biotite, chlorite, talc, carbonate, sericite, and magnetite are common hydrothermal products, and minerals which are characteristic of deposition by meteoric waters are lacking or present in negligible quantities, e.g., limonite, kaolin, opal, and chalcedony.
2. The order of deposition of vermiculite and associated minerals suggests cooling hydrothermal waters.
3. Several vermiculite bodies have been mined to depths of about 100 feet and show fresh exposures without supergene alteration.
4. The repeated formation of high temperature minerals such as kyanite and silimanite and the preservation of such early-formed minerals suggests an hydrothermal origin.
5. In all the deposits studied vermiculite occurs bordering or near pegmatitic intrusions.

DEPOSITS

ENCAMPMENT DISTRICT

The three deposits in the Encampment district are located in Carbon County, in secs. 9 and 15, T. 15 N., R. 83 W., and in sec. 3, T. 13 N., R. 82 W. Two properties are situated near the Encampment River about 6 and 7 miles northeast of Encampment; the third is about 12 miles southeast of Encampment on the Ralph Platt ranch. Each deposit is accessible by dirt road connecting with a paved highway leading into Encampment. The railroad at Encampment is the nearest shipping point except for a spur about one mile from the deposit in sec. 3, T. 13 N., R. 82 W. The deposits are all in the foothills of the Medicine Bow Mountains at an elevation of about 7,500 feet.

Union Asbestos and Rubber Deposit Near Encampment River—This property was formerly owned by the Mikolite Company of Kansas City, Kansas, which has been bought out by the Union Asbestos and Rubber Company of Chicago. The deposit is in sec. 15, T. 15 N., R. 83 W., and is reached by a dirt road 3 miles long which connects with Wyoming State Highway 130 at a point 5 miles northeast of Encampment. It is situated in what is locally called the Baggott Rocks. (Fig. 2).

The deposit was operated from 1937 to 1941 by the Mikolite Company. The main workings include 3 shafts, a drift, and a number of pits which vary in size from a few feet in width and length to one

Figure 2. Vermiculite deposits near the Encampment River. Part of the Union Asbestos & Rubber property in the foreground; Paine deposit on slope across the Encampment River.

about 40 feet by 40 feet. One shaft is 65 feet deep and is connected with a 112-foot drift with another farther up the hill; the latter is 95 feet deep. A third shaft on the hill is about 105 feet deep.

The principal workings are along contacts of hornblende schist and granite pegmatite, though some of the smaller pits are at biotite schist-pegmatite contacts. The pegmatite which has produced the vermiculite is of two kinds. One is a coarse-grained rock composed essentially of quartz and feldspar; the other is fine-grained, aplitic, and contains much the same minerals. The metamorphic rocks of the area strike northwest-southeast.

In addition to vermiculite considerable chlorite and minor amounts of tremolite-actinolite have been produced locally. In two or three places small (average size 1 by 3 inches) areas of kyanite and sillimanite occur enclosed by a narrow zone of vermiculite. A few specks of corundum were also found in one part of the deposit. These areas occur within pegmatite dikes and apparently represent a high-temperature phase of pegmatitic activity.

Vermiculite varies in flake size, is flexible in thin scales, and the color may be bronze, light to dark brown, and a greenish-brown where chlorite occurs in appreciable quantities. The chloritic material is talcose. The presence of chlorite at this property, and of chlorite, biotite, and amphibole at other deposits, interferes with the utilization of considerable vermiculite. If the impurities were removed much of the vermiculite now classed as milling material could be shipped.

Figure 5. Part of the J. B. C. deposit near Wheatland illustrating the occurrence of vermiculite in the foothills of the Laramie Range.

WHEATLAND DISTRICT

There are 9 deposits and prospects in the Wheatland district, located in Platte and Albany Counties, from which small shipments of vermiculite have been made. Production began in the area in 1938 and has continued intermittently since that time. The deposits are located in the Laramie Range in several sections west, southwest, and northeast of Wheatland at elevations from 4,800 to approximately 5,500 feet. Rail facilities are available at Wheatland.

J. B. C. Deposit Southwest of Wheatland—The deposit of the J. B. C. Mining Company is located in sec. 9, T. 23 N., R. 69 W., and is reached by a dirt road about 16 miles long which connects with U. S. Highway 87 four miles from Wheatland. It is owned by N. E. Judd and Jarvis Judd of Laramie, Kenneth Judd of Casper, and Lyle Clay and Albert Bartlett of Wheatland. N. E. Judd is trustee for the group.

The main workings include several pits which vary in size from a few feet in length and width to one about 50 feet long by 10 feet wide by 25 feet deep. (Fig. 6). The pits are situated along contacts of granite pegmatite and hornblende or biotite schist; the latter strike northeast and northwest.

The principal granite throughout the area is gray and varies from a fine-grained aplite to a relatively coarse quartz-feldspar rock. Locally it contains much assimilated biotite schist in parallel streaks giving

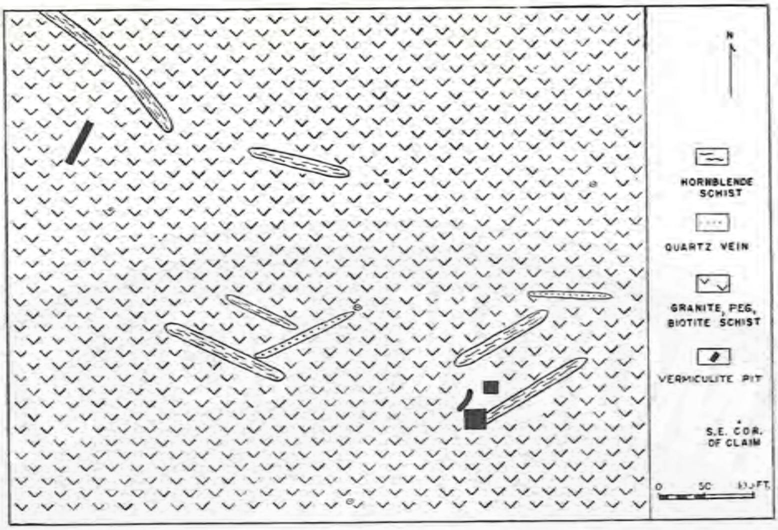


Figure 6. Geologic map of the J. B. C. deposit near Wheatland.

it a schistose or gneissoid structure. The gray granite has been intruded by a white one.

The main pit has yielded, according to Mr. N. E. Judd, between 300 and 400 tons of vermiculite. It is at present caved-in but the structural relations are essentially similar to those at the deposits near the Encampment River described above. Vermiculite is dark brown, occurs in coarse flakes, and is flexible in thin scales. It exfoliates about 8 to 9 times and data on purification are included in the section on tests and specifications of Wyoming vermiculite.

Roff Deposit Southwest of Wheatland—On the same section as the J. B. C. property is a small deposit owned by Raymond Roff, Edward Foreman, and Leonard Logan all of Wheatland. The workings consist principally of a 42-foot shaft in vermiculite at the contact of granite pegmatite and hornblende schist. From the bottom of the shaft a drift has been driven 16 feet south and then 10 feet east and 10 feet west. Geologic relations are similar to those at the J. B. C. deposit. According to Mr. Roff, from 70 to 90 tons of vermiculite have been taken from the property.

MacDougal Deposit Southwest of Wheatland—The MacDougal deposit in sec. 8, T. 23 N., R. 69 W., is 21 miles from Wheatland and is reached by the same road as that to the J. B. C. deposit. The property is leased by Mr. H. E. MacDougal from Mr. Charles Schreyer of Wheatland.

The workings consist of several pits, one of which is about 15 by 17 feet, from which approximately 100 tons of vermiculite have been shipped. Geologic relations at the principal pit are similar to those at the J. B. C. and Roff deposits described above.

Two of the pits on this property have exposed an interesting occurrence of vermiculite associated with garnet-biotite schist. Pegmatite granite has intruded a biotite schist containing appreciable garnet crystals—up to 2 inches in diameter. There is a transition from hard, garnet-biotite schist through a soft, crumpled schist to vermiculite. The vermiculite here is of no commercial value but the association with garnet is well illustrated and relations are better shown than at other deposits where smaller quantities of garnet are present.

Vaughn Deposits West of Wheatland—There are three deposits west of Wheatland in Platte County, owned by Mr. Marlin Vaughn, from which small shipments of vermiculite have been made.

(1) The *Lone Jack* claim is in sec. 6, T. 24 N., R. 70 W., and is about 20 miles from Wheatland by dirt road. The main workings consist of a pit about 25 to 30 feet deep in a lens of vermiculite which varies in width from less than one foot to several feet. Part of this pit was caved-in when visited by the writer.

Vermiculite has formed at or adjacent the contact of granite pegmatite with a rock which has been so intensely altered that its original character could not be determined. The presence of talc in a nearby pit, and the general appearance of the wall rock in the field and under the microscope, suggest an original serpentinite. Considerable actinolite and chlorite occur with the vermiculite. At the pit a gray granite pegmatite has been cut by stringers of white pegmatite.

According to Mr. Vaughn about 40 tons of vermiculite have been shipped from this deposit, all from the above-mentioned pit.

(2) The *Dixie Queen* claim is in sec. 17, T. 25 N., R. 70 W., and is reached by a dirt road out of Wheatland. The property is about 20 miles from Wheatland and is just a short distance southeast of the Lone Jack claim.

The workings consist of one pit, about 25 feet deep, in a lens or pocket of vermiculite. The lens varies in width from less than one foot to about 3½ feet. Geologic relations here are similar to those at the Lone Jack claim described above. Mr. Vaughn estimates that 25 tons of vermiculite have been shipped from the deposit.

(3) The *Palmer Canyon* deposit in sec. 8, T. 24 N., R. 70 W., is 18 miles by dirt road from Wheatland. The workings consist of a shaft 20 feet deep, a pit 5 by 7 by 9 feet, and several pits of smaller size.

Geologic relations at the shaft could not be determined with certainty because of the water present in the bottom, and due to the inaccessibility of much of the pit. At the surface the vermiculite zone is 3 feet wide and increases to 5 or 6 feet at a depth of about 12 feet. Vermiculite occurs as a lens within granite and is similar to several smaller lenses exposed in small prospect pits on the property.

The origin of vermiculite is obscured by completeness of alteration of the original rock. Exposures in some of the smaller pits suggest that the mineral formed by hydrothermal alteration of a rich biotite zone within granite. Considerable chlorite is present along with the vermiculite. The granite on the deposit is a biotite-chlorite granite with areas relatively high in micaceous minerals. It is possible, however, that vermiculite formed by hydrothermal alteration of hornblende schist or biotite schist lenses assimilated by the granite of the region. Such xenolithic masses are common in the pre-Cambrian rocks of Wyoming, and in the largest pit on the deposit there is a small amount of biotite schist soaked with granite and granite pegmatite.

Vermiculite shipments from this deposit, according to Mr. Vaughn, have totaled 50 to 60 tons. Vermiculite on the Lone Jack, Dixie Queen, and Palmer Canyon claims is closely associated with actinolite or chlorite. A simple and economic means of separating these minerals from the vermiculite would permit some additional production.

May Deposit West of Wheatland—About five miles up Palmer Canyon on the north side, in sec. 1, T. 24 N., R. 71 W., Albany County, there is a small vermiculite prospect owned by Mr. E. B. May of Wheatland. A pit 15 feet long, 6 feet wide, and from 4 to 6 feet deep has been dug in anthophyllite which has locally altered to vermiculite. The vermiculite is extremely irregular in occurrence and is found between small nodules or kidneys of anthophyllite. A narrow (1- to 2-foot) granite pegmatite in the south face of the pit probably supplied the volatiles necessary to alter the anthophyllite cores to vermiculite. Although only about 5 tons of vermiculite have been taken from this pit the deposit is of interest because of the geologic relations displayed. No serpentinite is present on the property but a large mass is known to exist less than one mile south of the vermiculite area.

Roff Deposit West of Wheatland—About four miles up Palmer Canyon on the south side, is the Roff property. This prospect is located in Albany County in sec. 18, T. 24 N., R. 70 W., and is owned by Mr. Raymond Roff of Wheatland. Vermiculite has formed in a biotite schist which locally contains chlorite, kyanite, and corundum. The schist is a partly assimilated xenolith within a gneissoid granite and has been cut by a small granite pegmatite dike. At the north end of the pit is a small body of hornblende schist.

Vermiculite in the location pit dips about 65° S. W. and strikes N. 80° W. Apparently a hornblende schist xenolith has been assimilated and altered by granite to biotite schist. Later pegmatitic solutions altered the biotite to vermiculite. The development of kyanite and corundum may have taken place during pegmatitic activity.

Vaughn-Hyslop Deposit Northeast of Wheatland—The Vaughn-Hyslop deposit is in sec. 28, T. 25 N., R. 66 W., at an elevation of about 4,700 feet. It is 14 miles from Wheatland and is reached by U. S. Highway 27 and a dirt road which connects with the highway about 2 miles from Wheatland. The property is owned by Mr. Marlin Vaughn and Mr. Stewart Hyslop of Laramie and Wheatland respectively.

Figure 7. Part of the workings at the Smith deposit near Glenrock.

The workings consist of 3 pits, one of which is 60 feet long and a maximum of 30 feet deep; another is 40 feet long and up to 25 feet deep; the third is 7 feet long and 10 feet deep. The longest pit was originally operated as a shaft from which a drift had been run but the operations have caved-in. Vermiculite in these pits varies from 2 to 7 feet in width, the average being about 3 feet.

Granite pegmatite has intruded hornblende schist and altered the hornblende to vermiculite. The pegmatite is coarse and is composed chiefly of quartz and feldspar with local biotite. A small amount of tourmaline is present in irregular streaks and patches. Field evidence suggests that hornblende altered first to biotite and then to vermiculite.

Mr. Vaughn has informed the writer that approximately 200 tons of vermiculite have been shipped from this deposit. Except for the presence of some biotite the vermiculite is fairly pure and expands well.

GLENROCK DISTRICT

In the Glenrock district there are two deposits from which commercial vermiculite has been shipped, and three on which only a small amount of development work has been done. The properties are in Converse County in sec. 20, 29 and 33, T. 32 N., R. 75 W., and in secs. 13 and 14, T. 32 N., R. 76 W., at an elevation of approximately 6,700 feet. The district is in the Laramie Range about 10 to 12 miles south of Glenrock and is reached by a dirt road leading into

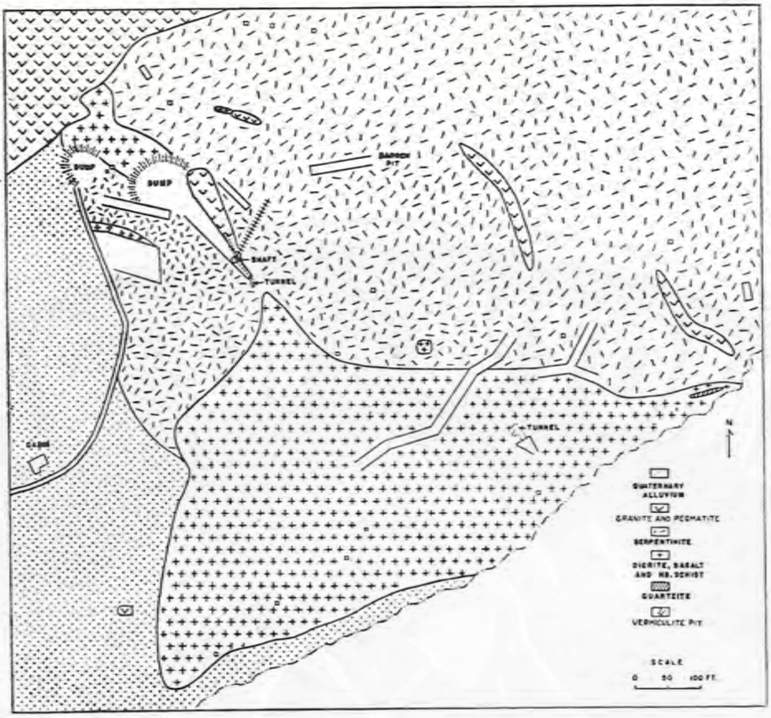


Figure 8. Geologic map of the Smith deposit near Glenrock.

Glenrock. Haulage from all the deposits is down grade and a railroad is located at Glenrock.

The geology at the Glenrock deposits differs somewhat from that in the Encampment, Wheatland, and Sweetwater Uplift districts in that the principal rock is serpentinite. Vermiculite has formed by alteration of serpentinite and hornblende. Even at these deposits, however, the largest vermiculite bodies are associated with a hornblende rock rather than with serpentinite. The vermiculite of the district varies somewhat in expansion and most of it contains appreciable amounts of chlorite and amphibole. Additional vermiculite could be produced if the material were cleaned.

Smith Deposit—The Smith deposit is in sec. 20, T. 32 N., R. 75 W., and is under lease to Messrs. Lewis and Martin Smith of Glenrock. The main workings consist of a 92-foot shaft and a 100-foot drift in addition to a number of large pits. Considerable work has been done since the writer mapped the deposit in 1940 so the data on size of some of the pits shown on the map are inaccurate. The total production of vermiculite from 1938 to 1943, according to Mr. Lewis Smith, is 1,539 tons.

The principal rock in the area is serpentinite which has been cut by intrusions of basic and ultra-basic igneous rocks—chiefly horn-

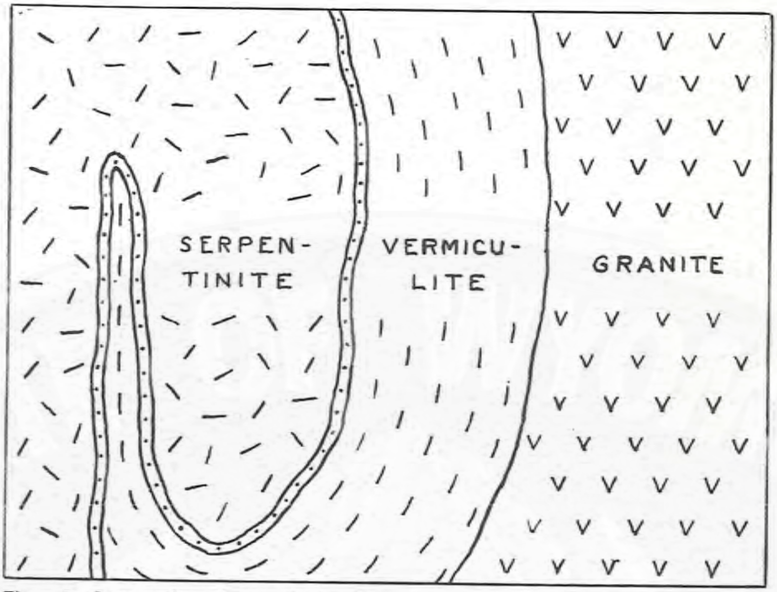


Figure 9. Cross-section of serpentinite kidney enclosed by vermiculite and silicates at Smith deposit near Glenrock. Stippled area indicates silicates.

blendite and hornblende-quartz diorite. Locally the diorite has been metamorphosed to a hornblende schist. Minor amounts of granite and granite pegmatite occur on the property and are present in extensive areas to the north. The granite and pegmatite are the youngest rocks in the region.

Vermiculite is of two kinds from the standpoint of origin; that formed at the contact of serpentinite and pegmatite, and that produced at contacts of hornblende rocks and pegmatite. It is light to dark brown, flexible and varies in flake size.

Where serpentinite has altered to vermiculite there is usually a narrow zone of hydrous calcium-magnesium silicates between it and vermiculite. This zone grades into vermiculite on one hand and serpentinite on the other. Minerals of the zone are chlorite, tremolite, actinolite, anthophyllite, and talc. Usually minor amounts of carbonate, magnetite, biotite, and hornblende are present. The zone varies from approximately one-half inch to several inches in width.

The above cross-section illustrates the alteration of serpentinite to vermiculite with a transition zone of hydrous calcium-magnesium silicates. Occasionally the vermiculite is found completely surrounding serpentinite nodules or kidneys. These kidneys are commonly called "horses" or "lumps" by the miners.

McCoun-Wells-Rhoads Deposit—This deposit is in secs. 13 and 14, T. 32 N., R. 76 W., and is owned by Messrs. H. D. McCoun, Charles Wells, and B. A. Rhoads. The main workings consist of two fairly large pits from which 450 tons of vermiculite have been removed according to Mr. McCoun.

The principal rocks at the deposit are serpentinite and an altered hornblendite or hornblende diorite. Alteration and veining of the latter are so intense that the exact nature of the original rock could not be determined. Both rocks have been altered locally to vermicilite. In the case of serpentinite a zone of hydrous calcium-magnesium silicates may or may not exist between granite pegmatite and the serpentinite. This zone is also found within the serpentinite mass and at contacts of serpentinite and hornblende diorite. In the latter two cases the silicate zone and vermiculite are believed to have formed along fractures and paths in the original rock to which pegmatite solutions had ready access. The silicate zone is similar in mineral content to those formed at the Smith deposit described above. Kidneys or nodules of serpentinite enclosed by vermiculite and silicates also occur at this deposit.

Other Prospects in the District. (1) The *Lucky Lode* claim is adjacent the McCoun-Wells-Rhoads property in sec. 13, T. 32 N., R. 76 W. Messrs. Frank and William Spencer, Lester Smith, George Campbell, and A. MacDonald, all of Glenrock, own the property. In 1940 the principal working consisted of a single fair-sized pit from which a small amount of material had been taken. The geology and origin of the vermiculite are similar to those at the deposit described above.

(2) The *Beach* prospect is located in sec. 33, T. 32 N., R. 75 W., and is owned by Mr. George Beach of Glenrock. There are several small pits on the property which show vermiculite associated with a gray and a pink granite. The origin of vermiculite is in doubt because no serpentinite or hornblende rock was found in the pits examined. The mineral apparently formed either by hydrothermal alteration of the biotite in a granite where intruded by pegmatite, or by rather complete alteration of hornblende schist which was found in the immediate vicinity of the deposit. To the writer's knowledge no vermiculite has been taken from this property.

(3) The *Badger* prospect is in sec. 29, T. 32 N., R. 75 W., and is owned by Mr. and Mrs. Lewis Smith, Mr. Morris Flavin, and Mr. Lem Sone of Glenrock. This property was not visited by the writer but the following data are from unpublished notes made by Page T. Jenkins in 1938 while a student at the University of Wyoming. The notes include all the available information on the deposit. In section 29 "massive unaltered serpentine streaked with dark bands is exposed in pits dug in the top of a hill, locally called Serpentine Hill. No vermiculite was noted here. A few hundred feet to the southwest a large pegmatite dike strikes about S. 30° E. Associated with this and other pegmatite dikes are the vermiculite deposits of the Badger claims. Vermiculite in most of the prospect holes here grades through talc schists into meta-diabase, although altered serpentine was found with vermiculite in some of the holes."

Figure 10. Part of Vermiculite Sales Corporation deposit No. 1 in the Sweetwater district. Looking southwest with pit in foreground and screen and separator in center of photograph.

SWEETWATER DISTRICT

In the Sweetwater district there are two deposits from which vermiculite has been shipped and a number of prospects which have not been developed. The properties are in Natrona County in sec. 6, T. 31 N., R. 86 W., and in sec. 9, T. 30 N., R. 87 W., and are owned by the Vermiculite Sales Corporation of Casper, Wyoming. Messrs. C. O. Battles of Casper, Edward Peck, and Lance Roper of Alcova, Wyoming, comprise the Vermiculite Sales Corporation personnel. The district is in the Sweetwater Uplift, from 26 to 28 miles west of Alcova and is reached by Wyoming State Highway 220 and a county dirt road. Elevation of the properties is approximately 6,300 feet.

Vermiculite Sales Corporation Deposit No. 1—The Vermiculite Sales Corporation Deposit No. 1 is located in sec. 9, T. 30 N., R. 87 W., and is approximately 28 miles west of Alcova. The workings consist of a tunnel about 40 feet long and several pits. According to Mr. Battles production from this property totals about 225 tons and was made in 1941.

Vermiculite occurs at the contacts of granite and granite pegmatite with biotite schist. The biotite schist was originally hornblende schist and in places can be seen grading into the latter. Vermiculite is present as bands and lenses within granite. The granite has assimilated hornblende schist bands and has altered hornblende to biotite. Intrusion of granite pegmatite has changed some of the biotite to vermiculite. Locally small amounts of vermiculite occur in the pegmatite and appear to represent hydrothermal alteration of biotite from the pegmatite.

The granite is gray and consists principally of quartz, orthoclase, microcline, and some plagioclase. Minor constituents include biotite, apatite, garnet, epidote, zoisite, and chlorite. Sericite and kaolin are alteration products of biotite and vermiculite. In places quartz has been veined and replaced by sericite, chlorite, and epidote. In the field this granite is gneissoid and is cut by pegmatite consisting of quartz and feldspar with local biotite.

Vermiculite from this deposit expands well but is fine grained and contains appreciable quantities of biotite. It is dark brown to black, flexible in thin scales, and varies in flake size.

Vermiculite Sales Corporation Deposit No. 2—Deposit No. 2 of the Vermiculite Sales Corporation is located in sec. 6, T. 31 N., R. 86 W., and is about 26 miles west of Alcova. The workings consist of 4 pits, the principal one being about 20 feet long, 3 feet wide, and from 2 to 4 feet deep. About 70 tons of vermiculite were shipped from the property in 1942 according to Mr. Battles.

Vermiculite occurs as narrow zones and lenses in granite and has formed by hydrothermal alteration of hornblende. Hornblende schist bands have been assimilated by granite and changed to biotite schist. Later granite pegmatite has altered the biotite to vermiculite. A transition from hornblende schist to biotite schist and vermiculite is well exhibited on the hill a short distance N. 65° W. along the strike of the vermiculite in the main pit.

Vermiculite from this deposit is similar to that at Vermiculite Sales deposit No. 1.

OTHER WYOMING PROSPECTS

Koch Prospect—The Koch prospect is located in sec. 15, T. 31 N., R. 77 W., in Converse County and is owned by Mr. Charles Koch of Casper. The property is on the north side of the West Fork of Deer Creek about 20 miles southeast of Casper. A tunnel about 300 feet long in a lens of serpentitnite comprises the principal workings. When visited in August, 1942, the adit was caved-in about 50 feet from the portal, but granite pegmatite dikes could be seen cutting the serpentinite. According to Beckwith, "In the first 100 feet of the tunnel, the serpentine is cut by several granite-pegmatite dikes up to two feet wide, bordered by zones of vermiculite up to 8 inches wide."[31] No vermiculite has been produced from this property.

Abernathy Prospect—The Abernathy prospect in sec. 19, T. 30 N., R. 96 W., is located approximately 38 miles southwest of Lander in Fremont County and is owned by Mr. Fred Abernathy of Lander. The workings consist of a tunnel about 70 feet long and several small pits in a serpentinite lens. Near the portal of the tunnel is a zone of vermiculite where the serpentinite has been cut by granite pegmatite. The rock was caved somewhat so that no estimate of width or extent of the vermiculite body could be made. Beckwith, who visited the area in 1935, states that, "In two places in the southern part of the lens the serpentine is cut by pegmatite dikes along the borders of which vermiculite has developed. Prospect pits twelve feet deep show that the vermiculite extends several feet from the dikes and may extend farther. Surface cover prevented observations on the lateral extent of the vermiculite zone parallel to strike of the dikes."[31] No vermiculite has been produced from this property.

Grub Stake Syndicate Prospect—The Grub Stake Syndicate prospect is located in the Big Horn Mountains about 29 miles southwest of Sheridan, Wyoming. A number of pits have been dug exposing small quantities of vermiculite which have formed at the contacts of hornblende schist with granite. No production has been made from this property according to Mr. Albert R. Nelson.

Additional Prospects—In addition to the deposits and prospects described above there are three reported occurences of vermiculite in Wyoming which have not been examined by the writer because information concerning them was received after completion of this work. The occurrences are in the Laramie Peak district, the Saratoga region, and in the Antelope Hills southeast of Lander. Up to the present no development work or production has been reported from any of the properties.

USES

The utilization of vermiculite dates from 1925 when the Zonolite Company marketed material for insulation from their deposit near Libby, Montana.[4] The uses to which the mineral have now been put are many and diverse. The expanded flakes are employed principally as an insulator for heat, cold, and sound. The porous character of expanded vermiculite makes it a highly desirable material for this purpose. The product is fireproof, rodent proof, does not shrink or deteriorate, and is non-absorbent. It has been used to insulate such articles as ovens, fireless cookers, incubators, refrigerators, thermal jugs, pipes and boilers, safes, bank vaults, filing cabinets, etc.[5] Loose fill in wall spaces and over ceilings makes buildings cooler in summer and warmer in winter. It is particularly valuable as a sound insulator in theatres, motion-picture studios, churches, hospitals, libraries, schools, offices, and apartments. It is also employed as a packing material for fruits, glassware, shells, and bombs. It is employed in life preservers as a cork substitute. Vermiculite can readily be mixed with other materials without breaking down, and it possesses an exceptional affinity for binders such as cement, gypsum, bentonite, asphalt, resins, goulac and casein.[32]

Vermiculite substituted for sand in gypsum plaster reduces weight and increases insulation properties.[33, 41] Boards and plasters are said to withstand a temperature of 1700° F. with essentially no expansion or contraction.[34, 42] Insulating cements have a covering capacity as high as 60 sq. ft. per 100 lb. wet and no volume or linear shrinkage when dried. The dry weight per cu. ft. in place will not exceed 20 lbs.[5]

Vermiculite with a suitable binder has been made into insulation brick which has a crushing strength of 175-200 lb. per sq. in. and a density of 22.5 lb. per cu. ft. Such brick withstands exposure of 1850° F. with no effective shrinkage or checking and can be used in boiler settings and furnaces where it will appreciably reduce the weight and thickness of the walls.[5, 51] Inside walls of petroleum refineries have been lined with light vermiculite brick which acts as a refractory and insulator.[35] If structural strength is not necessary a lightweight brick of low conductivity weighing 24 ounces is employed.[52] Vermiculite pipe has recently been made by mixing the expanded mineral with a high-temperature cement.

Vermiculite has been used as an aggregate in lightweight concrete chiefly for prefabricated houses.[42] This aggregate is a good heat and sound insulator and can be sawed, nailed, cut, drilled, and worked essentially like wood.[6] Precast concrete slabs are light in weight and can be used for wall, roof, and floor construction. Recently blocks and slabs of vermiculite concrete have been used in making bomb-proof and fireproof decks for tankers and roofs for military installation.[38] Concrete of this type weighs approximately 20 to 40 lbs. per cu. ft., has a compressive strength of 50 to 250 lbs. per sq. in. and a thermal conductivity of 0.60 to 0.80 B. t. u. at 50° to 90° F.[52]

The bronze, gold, and silver colors of expanded vermiculite are of use in making various paints, pigments, and inks. For this purpose vermiculite takes the place of powdered bronze and aluminum. The package of a popular brand of cigarettes is printed with bronze ink made from vermiculite powder.[36] As an extender for aluminum paints vermiculite increases coverage 25 per cent. The colors of the expanded product make it suitable as a decorative material in wall paper.[5] Experiments indicate that aircraft wings covered with vermiculite paint do not collect snow and ice so rapidly as otherwise.[37]

Vermiculite has been used as a composition roofing with asphalt binders or tar adhesives. It is said to be acid and alkali proof and to protect the finish surface against corrosive action from beneath.

As a lubricant vermiculite compares favorably with flake graphite and can be prepared free from grit or foreign matter. The cohesion and adhesion factors are nearly the same as those of graphite, and the melting point is about 2600° F. Vermiculite coagulates or hardens oils so that it can be used instead of aluminum stearate and, in addition, is a good lubricant. When employed in this manner "the bearing surfaces become coated with the soft, flaky material and approach a true frictionless condition."[33] For this purpose vermiculite is water ground to approximately minus 300 mesh.

Vermiculite has been used as a filter in purifying gasoline and oils.[46] Tails from the refinement process are used to dust tire molds and fabric. Fines are also used in the inner soles of shoes to prevent squeaking.[32] The mineral is employed in automobile mufflers and high temperature gaskets and as a lubricant and coolant in automobile motors and transmissions.[33] It has been applied to the top soil to keep the ground loose and retain moisture. One company advocates its use directly beneath the top soil to act as a sub-soil moisture reservoir. Vermiculite has been used in insecticides as a carrier of the poison and to prevent sticking. Expanded vermiculite has been used as a nest box material for chickens and rabbits. Apparently it has proved successful in chicken and rabbit litter because it is "absorbent and captures odors, and is used later as a garden fertilizer."[48] It has also been employed as a battery-box filler. Its use in the following has been suggested: linoleum, shingles, bakelite products, filters, smelter ladles, annealing steel, cornice boards, dielectric switchboards, and for building up viscosity in oils.[32]

The platy structure of vermiculite and its capacity to remain suspended indefinitely in water are properties which make the mineral suitable as a drilling mud. The plates can be ground to very small size and used to seal off porous formations and prevent loss of circulating fluid. "Since vermiculite exhibits the same suspension and sealing properties in either oil or water, it is suggested that it may be the ideal material for making oil-base drilling fluid, which is considered by many to be the 'mud of the future!' "[35] The light, platy character of vermiculite permitted its use to simulate a dust storm in a motion picture; previously it was difficult to keep sufficient material in the air because of the strong artificial wind that was required.

One company has made a floor compound for garages and machine shops which is "fireproof, non-skid and absorbs several times its own weight of oils, grease and liquids."[48] When the compound becomes liquid soaked it can be used as a fire smotherer. Two types of waterproof cement, a protector against industrial skin irritations, and a dry powder fire extinguisher have also been produced.

The Zonolite Company has recently marketed a product called "Lamisilite" (laminated silica) which is used "as a dehydration agent in the air-conditioning units and industrial appliances."[8] This material absorbs approximately 20 per cent by weight of water and may be renewed by heating. "Lamisilite" is made by "leaching unheated vermiculite with hot concentrated sulfuric acid which leaves nearly pure SiO_2 in flake form."[8] Similar results have been obtained by treating vermiculite with hydrochloric acid to separate silica from the other oxides. In these experiments a silica of excellent adsorptive properties is obtained but of such low density that large quantities of desiccating material are required.[43] Silica prepared from exfoliated vermiculite is slightly superior to that obtained from the raw material.

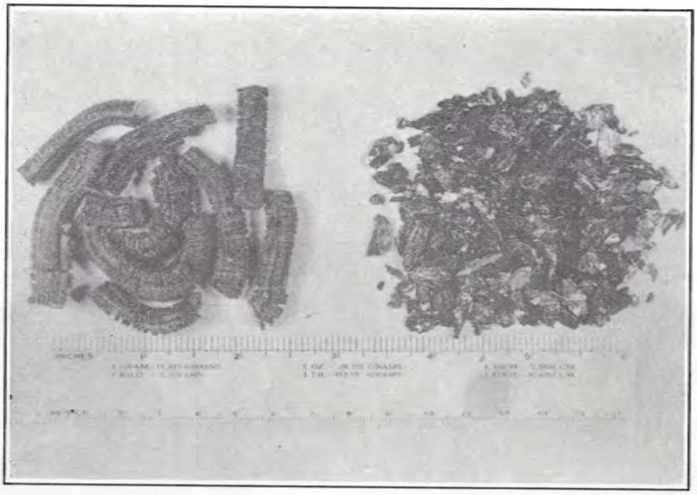
A vermiculite enamel is said to be more resistant to impact than ordinary enamel.[52] Structural clayware has been made using exfoliated vermiculite and a low vetrifying plastic clay bond. "The advantages of this material are its low thermal conductivity, its relatively high strength as compared to its specific gravity, and the ease with which it can be cut and fitted into installations."[53] The properties of such clay-vermiculite bodies are: Firing range is from cones 08 to 04; ratio of clay to vermiculite is 1 to 6 or 1 to 4 by volume: structural units with a compressive strength of 1,000 lbs. per sq. in., thermal conductivity of 1.03, and density of 43 lbs. per cu. ft. have been made; these units can be glazed.

Many of the uses outlined above have been developed in the past two or three years. Additional ones are continually being found and it is expected that larger production will result in the future. The following list of uses from U. S. Bureau of Mines Minerals Yearbook for 1936 is classified according to size or mesh of the expanded product.

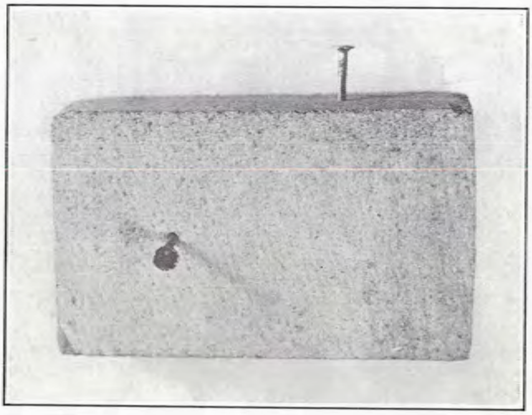
TABLE III. CLASSIFICATION OF EXPANDED VERMICULITE ACCORDING TO SIZE

	¼-inch to 20-mesh	
House insulation	Safe and vault linings	Smelter ladles
Home refrigerators	Pipe covering	Refractory brick
Auto mufflers	Boiler lagging	Insulation cement
Accoustic plaster		
	20- to 40-mesh	
Auto insulation	Passenger-car insulation	Fire extinguishers
Airplane insulation	Wall board	Filters
Refrigerator car insulation	Water coolers	Cold storage
	Annealing steel	
	40- to 120-mesh	
Linoleum	Cornice boards	Dielectric switchboards
Shingles		
	120- to 200-mesh	
Grease lubricant	Bakelite products	Tires and rubber goods
	200- to 270-mesh	
Wall paper printing	Building up viscosity in oil	Fireproof cartons for films
Outdoor advertising paints		
	270-mesh	
	Extender for gold and bronze printing ink or for paint.	

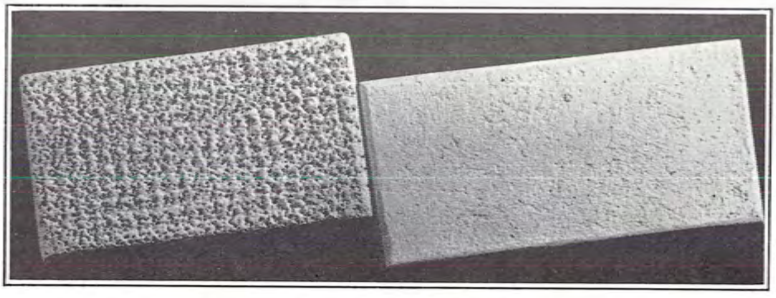
PLATE III



(1) Crude and expanded vermiculite from Glenrock, Wyoming.

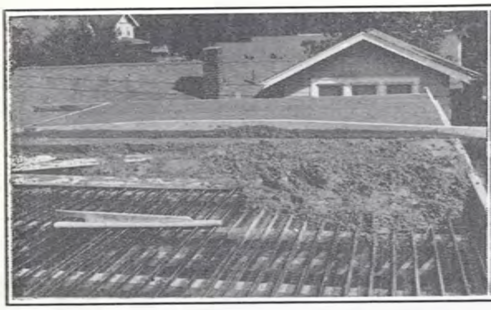


(2) Vermiculite board showing how it can be sawed and nailed. Courtesy of Mr. N. E. Judd.

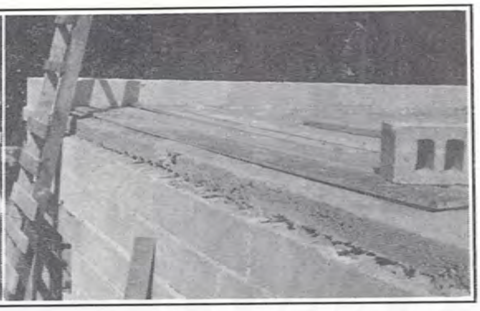


(3) Vermiculite accoustical plaster. Courtesy of Mikolite Company.

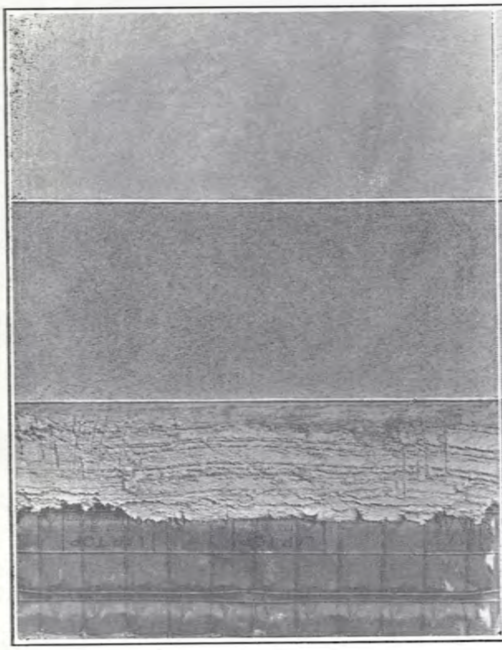
PLATE IV



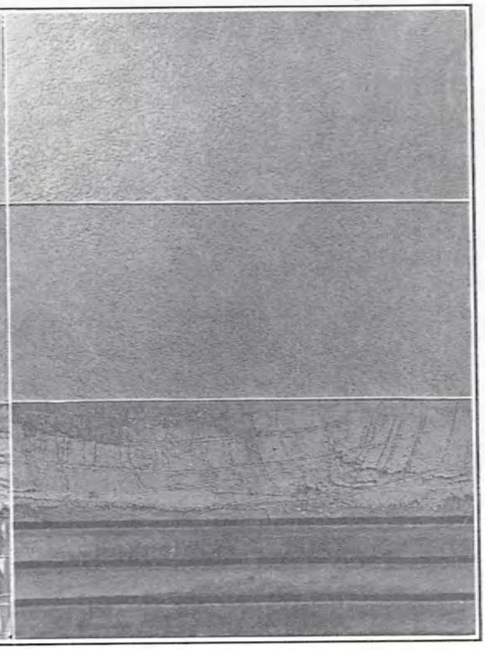
(1) Insulating roof being poured on Hi-rib metal lath deck on concrete joists. Courtesy of Mikolite Company.



(2) Vermiculite insulating cement used structurally as a monolithic roof deck. Courtesy of Mikolite Company.



(3) Scratch, brown, and sand coat on wire lath. Courtesy Mikolite Company.



(4) Scratch, brown, and texture coat on wood lath. Courtesy Mikolite Company.

TESTS AND SPECIFICATIONS OF WYOMING VERMICULITE

The following data on tests made on Encampment vermiculite are condensed from information supplied by Mr. R. W. Rice, president of the former Mikolite Company.

The thermal conductivity of expanded vermiculite in B. T. U. per sq. ft. at a temperature gradient of 1° F. per inch thickness is 0.30. In general the first ¾-inch thickness of insulation (plaster thickness) stops up to two-thirds of the heat loss that can be stopped by 3⅝ inches (wall thickness) of insulation. By applying a ¾-inch thickness of vermiculite, space is conserved and a 50 per cent or higher saving can be made by the elimination of furring out and lathing. Vermiculite plaster is 4 times lighter than sand and hard wall.

A ¾-inch application of Mikolite plaster applied directly to a 10-inch concrete wall reduces heat loss 28 B. T. U. for each degree change in temperature over 100 sq. ft. area. Data are also available on application of this plaster to brick, tile, limestone, sandstone, cinder blocks, hadite blocks, frame construction, and roofing. At 10 lbs. per cu. ft. density, one ton of Mikolite loose fill insulation covers 880 sq. ft. to a recommended thickness of 3 inches for ceiling insulation. Four inches of Mikolite cold storage insulation will reduce heat loss through a 10-inch concrete wall 47 B. T. U. for every degree difference in temperature over an area of 100 sq. ft. One ton of Mikolite cold storage insulation will cover from 600 to 700 sq. ft. per inch of thickness and the material in place will weigh approximately 3 lbs. per sq. ft. per inch of thickness.

One-half inch of Mikolite plaster effectively reduces the noise level from 20 to 25 per cent. A sound absorption test made on a half-inch thickness of Mikolite accoustical plaster gave an absorption range of .28 to .46.

A floor fire test conducted according to the A. S. A. Standard Specifications established a fire endurance limit of 5 hours and 44 minutes for Mikolite insulating plaster on the ceiling under the floor. The material withstood the test approximately 25 per cent longer than ordinary plaster. During the test temperature along the lower flange of an I-beam girder supporting the floor reached 1650° F.

Mikolite insulating roofing cement has a crushing strength of 1,400 lbs. per sq. ft. A 3-inch thickness of this material is equal to a roof composed of 3 inches of concrete slab, 2 inches gypsum fibre concrete, and a 1-inch rigid insulation board. The cost of the Mikolite material is considerably less than that of the other type of roofing. One ton of Mikolite insulating cement will cover 560-666 sq. ft. 1-inch thick.

A laminated roof coating is made of asphalt fortified with Mikolite and asbestos fibre. This spreads into a uniform asphalt film protected against sapping of volatiles from asphalt by actinic or violet rays of the sun. Asbestos fibre adds tensile strength as does the vemiculite. Two gallons will cover 100 sq. ft. when applied in a film 1/40-inch thick.

Mikolite smooth finish plaster is supplied dry mixed, ready to add water and apply. It sets firm and hard in approximately 45 minutes, and may be applied while the plaster it is to cover is still damp, which saves considerable time. The Mikolite Company also makes wall texturals, stucco, and several similar items. Recently vermiculite has been employed by this company as a sub-soil reservoir to condition soils of lawns and gardens. A layer of vermiculite beneath the surface soil retains moisture and keeps the ground loose.

According to Mr. C. O. Battles, the Vermiculite Sales Corporation of Casper, Wyoming, has been marketing a number of vermiculite products.

These include house fill, insulation board, brick, roofing, plaster, and paint. The company has sold vermiculite plaster to the oil refining industry for waterline and boiler insulation. For boiler insulation vermiculite is mixed with plaster of paris and ground asbestos. The plaster is made by grading vermiculite to the same size as sand and substituting it for sand, thus reducing the weight considerably. Recently a 4-inch pipe was developed consisting of vermiculite and Lumnite, a high-temperature cement. By applying a 1½- to 2-inch layer of vermiculite to top soil it is possible to keep the ground loose and moist. Gardens in dry regions thus require less soil loosening and less irrigation.

Mr. Battles has used a method of cleaning vermiculite at the mine which he claims is successful in removing part of the heavier associated minerals, thus eliminating the necessity of shipping much excess waste to the plant. His method consists of screening the crude material to obtain a partial separation of vermiculite and impurities and then blowing the vermiculite off for a further separation. The remaining impurities are removed at the plant after leaving the furnace where a blower carries off the vermiculite; the heavier associated material is dropped. Mr. Battles also states that he has succeeded in chemically treating vermiculite so that certain grades which do not expand sufficiently will do so after treatment. In some cases he claims to have achieved an increase in expansion of two times or more.

Mr. Albert Bartlett of the State Planning and Water Conservation Board of Wyoming has done some experimental work on vermiculite, and the following data have been supplied by him.

Light weight concrete was made by preparing aggregates of Portland cement, water, sand, gravel, and vermiculite. Increasing proportions of vermiculite were substituted for the sand and gravel thus reducing the weight from 28 to 65 per cent. Although strength decreases with increase of vermiculite, weight savings are such that vermiculite can be substituted for all or part of the sand and gravel according to the insulation requirements. By mixing 3 parts vermiculite to one part Portland cement, a weight saving of about 50 per cent was obtained in standard sized bricks. These bricks have sufficient crushing strength to meet building specifications. Similar weight reductions were obtained in experiments with plasters.

Roofing material was made by preparing vermiculite with road oil, asphalt, asphalt emulsion, Portland cement, and bentonite. Bentonite proved to be unsatisfactory and road oil lacks adhesion. Allenite asphalt gave promising results and cut-back asphalt may have possibilities. "Allenite applied hot to metal or wood surfaces with vermiculite pressed into it while hot, gives a surface which will not flow under the heat of the sun and will not crack under extreme cold, as unprotected asphalt does. A cotton cloth such as is used on Southern highways with asphalt, was used as a base for Allenite and vermiculite. This makes a flexible roofing which will not crack or flow, and which has more resistance to tearing than high grade commercial slate-covered roofing."* For this use vermiculite appears to be superior to granite or slate granules.

"British Patent No. 485,512 is for a method of spraying expanded vermiculite granules with hot asphalt, subjecting the coated granules to destructive distillation by roasting, to leave a hard carbon residue on the granules. This increases the strength of the vermiculite, makes it impervious to water, and more valuable in light weight concrete and plaster.*

The following data are from a report by Mr. Frank L. Hess of the U. S. Bureau of Mines made for the J. B. C. Mining Company on vermiculite from their Wheatland deposit. It is printed by permission of the director of the U. S. Bureau of Mines.

"The crude rock as received was a relatively fine grained vermiculite and contained quartz and feldspar as impurities, when soaked in water and broken

*Bartlett letter.

up with the fingers, 26.0% of the whole was retained on a 10-mesh sieve. This plus 10-mesh material contained 85.9% vermiculite, along with 14.1% of gangue, so that 22.3% of the crude was vermiculite coarser than 10-mesh. Exfoliation showed that farther breaking down occurred, and on rescreening after exfoliation, 18.6% of the total remained as exfoliated vermiculite on 10-mesh. These determinations were made to show that the fine particle size of the rock was inherent and not brought about by the mild grind given the crude material in preparation for testing.

The crude vermiculite was passed twice through rolls to disintegrate lumps and to crush gangue to some extent. The rolled product was wet screened with the following results:

Sieve Size	*Weight %*
+ 10-mesh	21.6
− 10 + 20-mesh	37.4
− 20 + 28-mesh	14.1
− 28-mesh	26.9

Wet screening was necessary to break up clumps of adhering vermiculite particles which entrapped gangue.

The + 10-mesh product here was 99 + % vermiculite and after exfoliation, 86.8% of the sample remained on 10-mesh, giving 17.9% of the whole as exfoliated vermiculite on 10-mesh. Comparison of this figure with the 18.5% of the whole sample as exfoliated vermiculite on 10-mesh when no grinding was used shows that very little breaking down of vermiculite was done by rolling. The plus 10-mesh product was considerably purified by rolling, for the unrolled sample contained 14.1% of gangue, while the treated one contained less than one per cent.

The − 10 + 20-mesh, and the − 20 + 28-mesh fractions were treated by gravity and agglomerate tabling.

The − 10 + 20-mesh fraction was passed over a concentrating table and a light mineral cut of clean vermiculite taken. This procedure was repeated with the tailing, or heavy mineral fraction, and another cut of clean vermiculite taken. These two operations gave a heavy mineral fraction which contained a large proportion of blocky vermiculite, but which could not be further fractionated efficiently by gravity methods. Therefore, agglomerate tabling separation was used. The fraction was agitated for two minutes in a flotation cell, and then washed free of liberated slime. The following reagents were then applied, and the sample tabled:

Reagents	*Rougher*	*Scavenger*
Dupont DP 243	0.28 # /Ton	— # /Ton
Sulphuric Acid	0.80	0.80
Potassium Alum	0.80	0.80
Crude Oil	4.6	1.2

Results of the separations were:

Products	*Weight %*	*% Vermiculite*
Light Mineral Concentrate	62.0	95.0
Agglomerate Concentrates	29.1	96.9
Agglomerate Tailing	8.9	22.5

Recovery of vermiculite in light mineral concentrate....66.2%

Recovery of vermiculite in combined light mineral and agglomerate concentrates....97.8%

Grade of combined concentrates....95.7% vermiculite

The −20 + 28-mesh fraction was given the same treatment as the − 10 + 20-mesh fraction, with the exception that the amounts of sulfuric acid and of potassium alum were doubled.

Results of these two separations were:

Products	*Weight %*	*% Vermiculite*
Light Mineral Concentrate	51.5	97.4
Agglomerate Concentrates	31.6	93.3
Agglomerate Tailing	16.9	25.2

Recovery of vermiculite in light mineral concentrate......59.6%

Recovery of vermiculite in combined light mineral and agglomerate concentrates 94.9%

Grade of combined concentrates........................96.0% vermiculite

A flotation test was run on the —28-mesh-fraction to determine if it were amenable to flotation separation. The reagents shown above were used except that crude oil was omitted. The rougher concentrate had to be cleaned twice in order to get nearly complete rejection of grit. A concentrate of 67.0 weight %, and a tailing and middlings combined of 33.0 weight %, were obtained. The separation was nearly complete, and could readily be used if a market for fine vermiculite could be found. The —28-mesh-fraction contained approximately 30% gangue."

MINING METHODS

At most of the Wyoming deposits vermiculite is removed by surface pit operations. Material is usually mined by pick and shovel but at two or three deposits bulldozers are employed. The pits are seldom more than 30 or 40 feet deep because of the shallowness of the deposit, cost of underground mining, or due to the dangers involved in deeper open pit operations. A shaft or tunnel may be dug at the bottom of a pit and these are usually timbered because vermiculite is particularly unsubstantial material. In spite of costs, however, there are several small underground workings in the state. None of these extends more than about 100 feet in depth, and commonly consists of a shaft and a relatively short drift. At the property on the Platt ranch near Encampment a tunnel has been driven in the side of a hill for somewhat over 100 feet and a few short (4-15-foot) drifts extend from the tunnel.

Impurities are largely hand sorted and only the better grade material is removed. At one deposit a partial separation of granitic impurities is effected by screening and then blowing off the vermiculite. At another property fines are eliminated by passage over a set of screens. The vermiculite to be shipped is dried in the sun. At several deposits a considerable tonnage of vermiculite is not mined because of the associated minerals which cannot easily be separated. Much of this milling material could be mined if such impurities as biotite, chlorite, amphibole, and talc were removed at the mine.

Equipment commonly consists of drills, picks, shovels, wheelbarrows, and where hoisting is necessary, buckets and windlasses. Track has been laid only at the Union Asbestos and Rubber properties and at the Smith deposit near Glenrock. At one or two deposits there are storage and loading bins. In some cases the installation of a central loading bin to take care of vermiculite from numerous scattered small pits would have been an improvement over the methods used.

TREATMENT

The treatment of vermiculite includes crushing, sizing, expansion, and cleaning. Individual plants vary somewhat in operation but the general procedure is much the same. The use to which the finished product is put depends largely on size of material and the amount of expansion.

The J. B. C. Mining Company operates a small expanding plant at Wheatland, Wyoming. Raw vermiculite is screened through 4-mesh and over 10. This is then heated in a small rotating kiln over a gas flame at 1600°-2000° F. and expanded. It is then re-screened through 4- and over 10-mesh obtaining a product which is 60 per cent 4-mesh and 40 per cent fines. The 4-mesh product is used for insulation; fines are used for plaster base and aggregate. Expansion is about 8 to 9 times the original volume.

Mr. Lewis Smith operates a small expanding plant at Glenrock. The kiln is 6 feet 4 inches long and has a 12-inch casing. Vermiculite in the kiln is stirred as it rotates. Before burning the material is screened over ¼-mesh and is caught on 1/12-mesh. The vermiculite is fired from the lower end of the kiln where it emerges. After burning the expanded product is again screened over ¼-mesh and on 1/12-mesh. To clean vermiculite from associated material a blower is applied. Heat used varies from 700° to 900° F.

In 1938 and 1939 the Rose-o-lite Insulation Company operated an expanding plant at Glenrock. Crude material was crushed to pass through a ¼-inch screen and then expanded in a small steel rotating kiln fired by natural gas. The finished product was used for house insulation; fines were screened out and burned to be used for plaster aggregate. The expanded product was about 10 times the original volume and weighed approximately 7 to 12 lbs. per cu. ft.

The Vermiculite Sales Corporation operates an exfoliation plant at Casper, Wyoming. Raw material is screened and graded to pass ¼-inch mesh and is caught on ⅛-inch mesh. It is then elevated and dropped into a furnace which consists of a baffled table 9 feet by 6 feet in size. The entire furnace is built of vermiculite. From the furnace vermiculite is removed by gravity float and then blown up to a grader and sacked. The blower is set for 6¼ lbs. so that all waste is dropped in this operation. Furnace temperature is 2200° F. According to Mr. C. O. Battles who operates the plant the important items in getting maximum expansion are instantaneous exposure of vermiculite to heat, and sufficient heat.

In 1938 and 1939 the Wyoming Insulation Company operated a plant at Casper. No data is available except that the amount of expansion varied from 5 to 15 times the original volume and the treated product from 6 to 15 lbs. per cu. ft. in weight.

The Union Asbestos and Rubber Company has acquired the Mikolite plant at Kansas City, Kansas, and moved it to their property on the Platt ranch in the Encampment district. According to Mr. R. W. Rice the oven at the plant is 45 feet high and is operated at a temperature between 2000° and 2200° F. The finished product dries almost as rapidly as normal plaster and is very tough. Mr. Rice states that, "The weight of raw material going into our oven is approximately 80 pounds per cubic foot, and in 16 seconds it comes out from the bottom weighing 8 to 15 pounds per cubic foot. There is a normal moisture loss of about 7%."* Rapid exposure of vermiculite to great heat is the primary requisite for efficient exfoliation.

*Rice letter.

FREIGHT RATES AND PRICES

The freight rates on exfoliated vermiculite are high because of the light weight and bulk of the product. For this reason it is usually not practical to ship expanded vermiculite long distances. Certain sizes of crude material to be expanded for use as insulating plaster, boards, and slabs could be manufactured at the mine. Other vermiculite, however, is best shipped as crude material which has been sized, screened, and dried of free moisture. This practice has several advantages: Sizing and screening at the mine obviate the need for such equipment at each individual expanding plant. Crude vermiculite takes up less storage space than the expanded product. Pre-dried material reduces freight rates by eliminating free moisture which may be as much as 10 per cent.

Screened Wyoming vermiculite is sold to processors at \$5 to \$10 a short ton f. o. b. mine, and expanded vermiculite at \$40 to \$55 a short ton f. o. b. works. These prices depend largely upon the weight per cubic foot because material weighing 6 to 7 lbs. per cu. ft. gets a good price whereas vermiculite weighing 9 lbs. per cu. ft. is priced lower.[39] Recently prices have risen up to \$100 a short ton for expanded material f. o. b. works.[50]

The following table of freight rates has been supplied by the Union Pacific Railroad Company and was in effect in July, 1943.

TABLE IV. FREIGHT RATES
(In dollars per ton; minimum weight 40 tons)

From			
Encampment	*Wheatland*	*Glenrock*	*To*
\$13.05	\$ 7.49	\$ 7.70	Chicago
\$12.80	\$12.80	\$12.80	New York
\$ 8.80	\$ 9.80	\$ 9.80	Salt Lake
\$ 8.80	\$ 9.80	\$ 9.80	Los Angeles

FUTURE POSSIBILITIES

The erratic distribution of vermiculite in all of the deposits discussed makes it impossible to determine accurately the tonnage present at any outcrop or working face. The pinch and swell characteristics of individual bodies, with consequent variations in lateral extent and depth, make specific estimates of reserves essentially valueless. As a generalization it may be said that the possibilities of considerable production are much better when vermiculite is found at the contact of pegmatite with a large igneous or metamorphic mass than when the mass is small. Because of the relatively small size of most deposits the most feasible method of working consists of mining each individual body until it is exhausted.

Vermiculite surface indications other than those described have been reported from all the districts studied. Most of these are too limited to be of value or are unknown in extent. It is probable that in each district further exploratory and development work will uncover sufficient commercial vermiculite for a considerable amount of additional production. Such work depends in a large part on the future price and demand for vermiculite. This is certainly true in the case of deposits which have yielded commercial material and where a fair-sized, unexhausted body has been opened. It is also true in the case of deposits which have been opened to such depth that mining costs have become prohibitive. Considerable additional production could be made if the crude vermiculite were cleaned at the mines so that both shipping and milling material could be handled.

SUMMARY AND CONCLUSIONS

The principal vermiculite deposits of Wyoming have yielded over 5,000 tons of the mineral. They are located in four mineralized districts near the towns of Encampment, Wheatland, Glenrock, and in the Sweetwater Uplift. Commercial vermiculite has formed in pre-Cambrian rocks at or near contacts of granite pegmatite with basic or ultra-basic igneous rocks or their metamorphosed equivalents.

It is believed that the pegmatite produced vermiculite by hydrothermal action on hornblende, biotite, and serpentinite. Some vermiculite appears to have formed by assimilation of the above-mentioned rocks by granite batholiths, but the larger commercial deposits occur where granite pegmatites cut these rocks. Of the several minerals which have altered directly, or through intermediate stages, to vermiculite hornblende is the principal one; an intermediate biotite stage may or may not be present. Where serpentinite has changed to vermiculite it is common to find a complex suite of associated alteration products.

In the deposits studied vermiculite appears to have formed by hydrothermal activity; no evidence of origin by meteoric waters was found. This conclusion is supported by the character and assemblage of minerals, the order of deposition of vermiculite and associated minerals, the depth of some deposits, and the general geologic occurrence and relationships.

As nearly as can be determined optically the vermiculites of Wyoming are not pure vermiculites. They appear, rather, to be mixtures of vermiculite with mica or chlorite. The presence of potassium, the relatively low water content, and the high refractive indices, support this view.

Additional vermiculite undoubtedly can be produced in the state from both undeveloped and proven deposits. Up to the present time only shipping grade material has been produced, but with the installation of cleaning plants at several deposits considerably more vermiculite could be shipped. It is suggested that experimental work on acid-treatment of vermiculite may also lead to increased use in the future.

In addition to information on the geology and origin of Wyoming vermiculite, data have been included on exfoliation, physical, chemical, and optical properties, and on uses. Where available, information on production and preparation of Wyoming vermiculite for the market has been given, in particular under the sections on tests and specifications, mining methods, and treatment.

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