6-13-1945

Vermiculite, Occurrence, Character, and Concentration of Mineral from the Pony District, Madison County, Montana

A. Saterdal

Follow this and additional works at: http://digitalcommons.mtech.edu/bach_theses

Part of the Ceramic Materials Commons, Environmental Engineering Commons, Geology Commons, Geophysics and Seismology Commons, Metallurgy Commons, Other Engineering Commons, and the Other Materials Science and Engineering Commons

Recommended Citation
http://digitalcommons.mtech.edu/bach_theses/206

This Bachelors Thesis is brought to you for free and open access by the Student Scholarship at Digital Commons @ Montana Tech. It has been accepted for inclusion in Bachelors Theses and Reports, 1928 - 1970 by an authorized administrator of Digital Commons @ Montana Tech. For more information, please contact sjuskiewicz@mtech.edu.
VERMICULITE,

OCURRENCE, CHARACTER, AND CONCENTRATION OF MINERAL

FROM THE PONY DISTRICT, MADISON COUNTY, MONTANA

by

A. Saterdal

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
Butte, Montana
June 13, 1945
VERMICULITE,

OCCURRENCE, CHARACTER, AND CONCENTRATION OF MINERAL

FROM THE PONY DISTRICT, MADISON COUNTY, MONTANA

by

A. Saterdal

A Thesis
Submitted to the Department of Geology
in Partial fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
Butte, Montana
June 13, 1945
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>2</td>
</tr>
<tr>
<td>Occurrence</td>
<td>2</td>
</tr>
<tr>
<td>Geology and Topography</td>
<td>2</td>
</tr>
<tr>
<td>Nature of Vermiculite Deposits</td>
<td>3</td>
</tr>
<tr>
<td>Results of Investigation of Other Deposits</td>
<td>4</td>
</tr>
<tr>
<td>Wyoming Deposits</td>
<td>4</td>
</tr>
<tr>
<td>Rainy Creek (Libby), Montana</td>
<td>4</td>
</tr>
<tr>
<td>Western Australia</td>
<td>5</td>
</tr>
<tr>
<td>Pony Deposits</td>
<td>5</td>
</tr>
<tr>
<td>Effective of Pegmatites</td>
<td>6</td>
</tr>
<tr>
<td>Effect of Meteoric Waters</td>
<td>7</td>
</tr>
<tr>
<td>Genesis of Vermiculite</td>
<td>8</td>
</tr>
<tr>
<td>Physical Properties of Pony Vermiculite</td>
<td>8</td>
</tr>
<tr>
<td>Color, Appearance and Texture</td>
<td>8</td>
</tr>
<tr>
<td>Weight of Expanded Vermiculite</td>
<td>10</td>
</tr>
<tr>
<td>Concentration Methods</td>
<td>11</td>
</tr>
<tr>
<td>Reason for Concentration</td>
<td>11</td>
</tr>
<tr>
<td>Gravity Concentration</td>
<td>12</td>
</tr>
<tr>
<td>Flotation</td>
<td>12</td>
</tr>
<tr>
<td>Experimental</td>
<td>13</td>
</tr>
<tr>
<td>Results of Flotation</td>
<td>14</td>
</tr>
<tr>
<td>Examination of Products</td>
<td>15</td>
</tr>
<tr>
<td>Agglomerate Tabling</td>
<td>17</td>
</tr>
</tbody>
</table>
contents (continued)

Uses of Vermiculite .............................................. 18
Production and Statistics ..................................... 19
Conclusions ....................................................... 21
Illustrations

Plate I. Geologic Map of the Pony District, Madison County, Montana.

II. Photographs of the Pony Vermiculite Deposits.

III. A. Photograph of Vermiculite-Bearing Schist.
   B. Micro Photographs of Vermiculite-Bearing Schist.

IV. A. Photograph of Hand Specimens of Vermiculite-Bearing Schist.
   B. Micro Photographs of Expanded Pony and, C. Rainy Creek Vermiculite.

V. A. Box Used in Weighing Vermiculite.
   B. Comparison of Unexpanded Pony Vermiculite to Expanded Pony and Rainy Creek Material.

VI. A. Photograph of Fagergren Laboratory Flotation Cell.
   B. Photograph of Flotation Products and the Distribution of Vermiculite in Each.

Table 1. Screen Analysis of Uncrushed Expanded Pony Vermiculite.

2. Reagents Used and Results Obtained in Preliminary Flotation Testing.

3. Effect of Various ions on the Flotation of Pony Vermiculite.

4. Screen Analysis on Feed to Flotation Cell.

5. Distribution of Vermiculite in Flotation Products.

6. Density (pounds per cubic foot) of Dried Flotation Concentrate.

7. Screen Analysis of Cleaned Expanded Vermiculite Product from the Flotation Cell.

8. Uses of Expanded Vermiculite According to Size.
VERMICULITE, OCCURRENCE, CHARACTER, AND CONCENTRATION OF MINERAL
FROM THE PONY DISTRICT, MADISON COUNTY, MONTANA

INTRODUCTION

The purpose of this paper is to investigate the occurrence and character of the vermiculite deposits approximately four miles northwest of Pony, in T. 1 S., R. 3 W.; Madison County, Montana. The deposits are situated in rolling foothills at the northern end of the Tobacco Root mountains.

Some previous mining of vermiculite has been done on the property. Most of this work has consisted of the removal of several feet of the decomposed vermiculite-bearing schist, apparently by a bulldozer. In addition to this surface striping, one shaft, approximately five feet square and 15 feet deep, has been sunk, probably to investigate the deeper rock. Material piled around the collar of the shaft, assumed to have been taken from this opening, exhibits essentially the same properties as that lying at the surface.

Vermiculite is the name given to a group of hydrated magnesium-aluminum silicate minerals. They are recognized by their characteristic micaceous cleavage, but unlike mica the folia are pliable and inelastic. The most pronounced property of the mineral, and upon which its commercial application depends, is its ability to expand up to 20 times its original volume upon exposure to high temperature. This property is attributed to the rapid expulsion of water of crystallization in the form of steam.
ACKNOWLEDGMENTS

The geologic work was done under the supervision of Dr. E. S. Perry, and the mineral concentration under Dr. S. R. B. Cooke, respectively heads of the department of Geology and Mineral Dressing at Montana School of Mines. Acknowledgment is given them for their generous assistance.

Thanks are also given to Dr. L. L. Sloss and W. L. Swayne, of the Montana School of Mines faculty; to R. W. Kujawa, Universal Zonolite Insulation Company, Libby, Montana, and to Mrs. Loretta Peck, Montana School of Mines Librarian.

OCCURRENCE

Geology and Topography

The Pony vermiculite deposits occur in pre-Cambrian rocks of the Pony series. These rocks form the basal complex of the district and consist of gneisses and schists varying in composition from chiefly quartz and feldspar to amphibole, garnet and mica. Gray and light gray gneisses of granitic composition are the most abundant. The entire complex of schists and gneisses is criss-crossed by igneous injections, both acid pegmatite and quartz veins, and basic intrusions. This area is believed to have been exposed to long weathering in the geologic past, being part of an old Eocene erosion surface.

In the vicinity of the vermiculite deposits the schists of the Pony series dip steeply towards the northeast and the effect

PLATE II

A
PONY VERMICULITE DEPOSITS.

B
LOADING BINS AT PONY VERMICULITE DEPOSITS
of pegmatites is evident in the presence of stringers of quartz and feldspar parallel to the schistosity. The vermiculite apparently occurs in selected bands in the schist and both quantity and quality of the mineral vary in adjacent bands.

No prominent natural outcrops of the vermiculite-bearing rock are evident in the vicinity although examination of the soil shows particles of mica-like mineral.

The deposits lie on the gentle west slope and near the top of one of the hills characteristic of the northern end of the Tobacco Root mountains. The surface is nearly barren of vegetation with the exception of sagebrush, grasses and occasional scrub pine.

Nature of Vermiculite Deposits

The manner of formation of vermiculite deposits has been attributed to different causes in different occurrences, but not necessarily disputed in any one occurrence. In general, its formation has been attributed to the effects of hydrothermal solutions, acting alone, to alter certain basic rock-forming minerals to vermiculite, or acting in part but coupled with the action of weathering to produce the highly hydrated mineral.

One factor tending to obscure the origin of the mineral is that very few known deposits have been worked to a depth of 100 feet. Because of this fact all information obtainable has come from examination of material affected by the action of meteoric as well as hydrothermal solutions. Thus a question has arisen as to the importance of weathering in the formation of vermiculite.
Results of Investigation of Other Deposits

It is interesting to note the manner of occurrence of various deposits of vermiculite and the explanations given for the formation of the mineral.

Wyoming Deposits

"...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 serpentine to vermiculite.

"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.....Commercial vermiculite is restricted to areas of pegmatitic injection.....Meteoric waters are thought to have been of little or no importance in the formation of Wyoming vermiculite."

Reasons given for this last statement include lack of such minerals as limonite, kaolin, opal and chalcedony which would indicate action of meteic water; lack of supergene alteration at depths to 100 feet, and the fact that the vermiculite borders on the pegmatites.

Rainy Creek (Libby) Deposits

"...this body appears to be a dike-like form and at least 100 feet wide and 1,000 feet long. It extends to a depth of at least 100 feet, its lower limit not being shown....The vermiculite is an alteration product of biotite and locally is one of the main constituents of the pyroxenite mass....Changes in the stock by the action of hot solutions have been so widespread and so unusual in character as to deserve special notice. The principal minerals produced by these changes are white mica, aegirite, aegirite-diopide, vermiculite and fibrous amphibole."

Western Australia

"The bronze-colored mica possesses the properties of a vermiculite, since it exfoliates remarkably on heating, but the deeper colored varieties do not exfoliate. This property of exfoliation appears to depend upon the state of weathering reached by the mica since examination shows that both types have the same optical properties... This biotite schist appears to result from the phlogopitization of the hypersthene by potassic solutions or emanations from the intrusive granite (pegmatitic solutions)."

Western Australia

"...Field evidence does not support the view that it (vermiculite) is simply a weathered form of biotite or phlogopite mica, but that it is a mineral formed under deep-seated hydrothermal metamorphic conditions.

"The host rock is invariably a highly sheared, basic igneous rock, consisting of hornblende, actinolite, anthophyllite and usually talc. In every case there is evidence of granitic or pegmatitic intrusive rocks in the immediate vicinity of the deposits. In every case the biotite and other micas, in the highly weathered adjoining granite and gneiss, are not in the vermiculite group. Dark green vermiculite has been found in the centers of fresh microcline feldspar boulders from a pegmatite dike that could not have had access to atmospheric weathering agencies."

The writer of this article also refers to a Mr. H.A. Ellis, a geologist who examined the deposits in the Young River district of Western Australia, as saying that, contrary to the general belief, vermiculite deposits are not confined to the zone of weathering, but continue to depths limited only by the continuity of the host rock and the deformation structures primarily responsible for the formation of the mineral.

Pony Deposits

All of the Pony vermiculite examined was taken from rock

5. Misc. article, "Vermiculite," Chemical Engineering and Mining Review, Jan. 10, 1945
lying at, or near to, the surface, and thus subject to the action of metoric water which easily permeated this porous friable rock. Evidence of this action is shown in the examination of thin sections which show limonite stringers criss-crossing the entire section in places, and in the alteration in part of the andesine feldspar to kaolin.

The Pony vermiculite is believed to be derived, in part at least, from the alteration of hornblende, either with or without an intermediate biotite or phlogopite stage. This is evidenced by the fact that the mica mineral, distinguishable by its parallel extinction, is forming at the expense of biotite. Because of similarity in the optical and color characteristics of the vermiculite and the true micas it is difficult to tell the two apart in thin section. In all examinations made of the platy mineral, however, no mineral was found whose folia were not inelastic and flexible. For this reason it cannot be said definitely that there is any intermediate true mica stage in the alteration of hornblende to vermiculite in the Pony material examined.

**Effect of Pegmatites**

In all the vermiculite deposits noted, the effects of pegmatitic solutions are noticeable and these solutions have been charged either completely or in part with the alteration of biotite, hornblende, etc., to vermiculite. The effect of hydrothermal solutions in the formation of vermiculite appears necessary because to enact the alteration of hornblende, biotite, etc., to vermiculite requires the introduction of certain ele-
ments and the removal of certain others. This is evident from
the formulas for the respective minerals.

Biotite --- K(Mg,Fe)₃ Al Si₃ O₁₀(OH)₂₆
Phlogopite - K Mg₂ Al₂ Si₃ O₁₀(OH)₂₆
Hornblende -- Ca₂ Na(Mg,Fe)₄ (Al,Fe)₃ Si₆ O₂₂(O,OH)₂₇
Vermiculite -- 22 MgO • 5 Al₂ O₃ • Fe₂ O₃ • 22 SiO₂ • 40 H₂O₇

Thus, the alteration of hornblende, for instance, to vermi-
culite involves the introduction of considerable magnesium and
water, and the removal of calcium and sodium. If there were a
transition phase to biotite, as suggested by Hagner with regard
to the Wyoming deposits, the alteration would first involve an
introduction of potassium and the removal of sodium and calcium.
Whether there is a transitional biotite stage or not, consider-
able hydration must be effected before alteration of the miner-
al to vermiculite takes place.

Meteoric Waters

Although the action of metoric waters is evident in the
presence of limonite and kaolin, there is no evidence that the
vermiculite was formed through the action of these waters alone.
If this were the case, universal alteration of hornblende, bio-
tite, etc., at surface exposures to vermiculite would be ex-
pected and this is not the case by far.

This leaves the possibility that metoric waters may have
been a contributing factor after the action of some other factor
upon the ferro-magnesium minerals.

7. Gruner, J.W., "The Structure of Vermiculites and Their
Collapse by Dehydration," Am. Mineral. Vol. 19, No. 12,
1934.
A  
VERMICULITE-BEARING SCHIST

B  
LIMONITE (BLACK) CUTTING HORNBLende (LIGHT) x25

C  
VERMICULITE (DARK) REPLACED BY GARNET AND FELDSPAR x25

D  
VERMICULITE (DARK) ALTERING FROM HORNBLende x25

E  
ALTERATION OF ANDESINE FELDSPAR x25
Genesis of Vermiculite

 Probably the final answer to the problem of the mode of origin of vermiculite deposits lies in an examination of the effect of hydrothermal (pegmatitic) action at depths below the zone of metoric water. Should examination at depth indicate less vermiculite-like and more biotite- or hornblende-like qualities with increasing depth, evidence would point towards a formation due to the action of both hydrothermal and metoric solutions. Should there be no change in the vermiculite with increasing depth, it could be assumed that metoric waters have no effect in the formation of the mineral.

Several facts point toward the first hypothesis, however, First, the high degree of hydration would indicate that the final stage of alteration was supergene rather than hydrothermal. Secondly, in Montana both the Rainy Creek and the Pony deposits are believed to be situated in areas long exposed to erosion and weathering, thus supplying the time element so important in geologic processes.

It is the belief of the writer that the Pony vermiculite deposits are derived from the hydrothermal alteration of hornblende in hornblende schists, followed by hydration caused by the action of metoric water. There was no evidence found of any "true mica" transition step in any of the material examined, although some plates of the mineral showed no tendency to expand upon heating and the possibility of a transition step is not precluded.

PHYSICAL PROPERTIES OF PONY VERMICULITE

Color, Appearance and Texture

The vermiculite-bearing rock is brown to bronze in color.
PLATE IV

A
VERMICULITE-BEARING ROCK

B
EXPANDED PONY VERMICULITE
x8

C
EXPANDED RAINY CREEK VERMICULITE
x8
the bronze being due to the plates of vermiculite while the lower grade material is usually rich in limonite-stained clay. The folia are inelastic and flexible. Pieces of quartz and feldspar, attributed to pegmatitic veins up to one inch in diameter, were noticed in the samples taken. Very small (approximately 0.5 mm in diameter) particles of garnet are also noticeable upon close examination and are easily seen on the polished surface. The specific gravity of the rock ranged from 2.85 to 2.98. The rock is very friable and is broken easily by the hands. The inherent size of the vermiculite plates is small as illustrated by Table 1.

In this test, samples of the consolidated vermiculite-bearing rock were placed in a furnace and maintained at 1800°F for several minutes until expansion of vermiculite was apparently complete. This allowed the mineral to attain its maximum size upon exfoliation, not having been affected by any manner of grinding which might act to break the plates. The expansion also caused the vermiculite to break free of adhering gangue.

A separation of the expanded vermiculite from gangue was then affected by means of a float-sink separation using carbon tetrachloride as the heavy fluid (sp. G. is 1.65), and a screen analysis was run on the expanded vermiculite with the following results:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86 % minus 14</td>
</tr>
<tr>
<td>2</td>
<td>74 %</td>
</tr>
<tr>
<td>3</td>
<td>78 %</td>
</tr>
</tbody>
</table>

Table 1.
Screen Analysis of Uncrushed Expanded Pony Vermiculite
The results of this test indicate that there is an inherent tendency for the rock to yield a fine size grade of vermiculite. In this respect the Pony vermiculite compares unfavorably with that of Rainy Creek (Libby) as it is the large sizes that yield the product which has the least mass per unit volume, and increases its value for certain uses. Another unfavorable property of the Pony vermiculite is its apparent lack of toughness. The expanded product is somewhat brittle and friable, the accordion-like expanded plates being rather easily broken by gently grinding the material between the fingers.

Examination of the thin sections showed considerable limonite criss-crossing the individual plates of vermiculite and this may have some effect upon decreasing the bond between vermiculite particles and thus increasing the friability. As all the samples examined were taken at or near the surface where weathering was more effective than at depth, it is possible that particle size of the mineral might increase with depth.

Weight of Expanded Vermiculite

The most valuable single property of vermiculite is its low mass per unit volume when expanded. The Universal Zonolite Corp., Libby, Montana, which is mining vermiculite from the Rainy Creek district, uses the weight-volume standards for expanded vermiculite:

<table>
<thead>
<tr>
<th>Grade Ore</th>
<th>Mesh</th>
<th>Max. Wt. allowed (Lb./cu.ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3 / 4</td>
<td>7.5</td>
</tr>
</tbody>
</table>

A BOX USED IN WEIGHING VERMICULITE

B EQUAL WEIGHTS
(1) PONY UNEXPANDED -20/28-MESH, (2) PONY EXPANDED -20/28-MESH, (3) RAINY CREEK EXPANDED -20/28-MESH, (4) RAINY CREEK EXPANDED -10/14 MESH
The standard method of testing the density of the expanded vermiculite as specified by the bureau of standards is as follows:

1. Fill a cubic box of one cubic foot capacity with the expanded vermiculite.
2. Jar the box by dropping three times from a height of six inches, thus lowering the level in the box.
3. Refill the box and weigh the contents.

The density of the material is then given in terms of pounds per cubic foot.

All weight-volume measurements on the Pony vermiculite mentioned in this paper were made in this manner with one exception. This exception was in the size of the testing box used. Because of the small amounts of material available, a smaller box was constructed which consisted of a column one inch square by 12 inches high. This resulted in a prism of 1/144 cubic foot capacity instead of the conventional one cubic foot. The column was maintained at 12 inches in height, however, in order to maintain a weight or "head" of vermiculite in the box comparable to that in the one cubic foot box.

CONCENTRATION METHODS

Reason for Concentration

Concentration of vermiculite at, or close to, the site of mining has considerable economic advantages. First, the points
### Table 2.
Reagents Used and Results Observed in Preliminary Flotation Testing of the Pony Vermiculite

<table>
<thead>
<tr>
<th>Reagent</th>
<th>Results Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Oleate and Oleic Acid</td>
<td>Showed no indication of flotating neither when conditioned with sodium carbonate nor when fuel oil was added.</td>
</tr>
<tr>
<td>DP-243 (lorol amine hydrochloride)</td>
<td>Good clean collection both in the presence of sodium carbonate and with H₂SO₄ and Alum.</td>
</tr>
<tr>
<td>Amine 230 (U.C.andC.)</td>
<td>Good non-selective froth when conditioned with sodium carbonate. In H₂SO₄ circuit it produced a poor froth and gave poor collection.</td>
</tr>
<tr>
<td>Amine 12-NAMAC-1181.5-C (mixture of neutral acetates and nitriles)</td>
<td>Fair collection and froth.</td>
</tr>
<tr>
<td>Amine AMAC-1181.5-B</td>
<td>Poor collection and froth.</td>
</tr>
<tr>
<td>Amine 220</td>
<td>No collection, poor froth.</td>
</tr>
<tr>
<td>Amine 220-E</td>
<td>No collection, poor froth.</td>
</tr>
<tr>
<td>Dioctyl aminoethanol</td>
<td>Gave the most favorable results. Without conditioning with H₂SO₄ it had no effect other than to give a white brittle, non-collecting froth. When H₂SO₄ was added, however, an excellent collecting froth formed immediately.</td>
</tr>
</tbody>
</table>
of consumption at present are in eastern cities and, therefore, freight rates absorb a large amount of the profit. It is therefore desirable to ship as little worthless material as possible, that is, to concentrate the mineral.

One alternative would be to expand the vermiculite near the mine and affect a comparatively easy separation by pneumatic classification, the light expanded vermiculite being readily blown free of the gangue. While this would probably be the simplest and cheapest method of concentration, it has the following disadvantages:

1. Expanded vermiculite is generally friable and there is considerable production of undesirable fines in shipping the mineral in this form.
2. The bulk of the expanded mineral is too great in proportion to its weight to obtain the maximum benefit of freight rates.

The remaining alternative is to concentrate and ship an unexpanded product. With this idea in mind the usual concentration methods were tested in the laboratory.

Gravity Concentration

The Pony vermiculite is not amenable to gravity concentration because of the nearness of the specific gravity of vermiculite to the specific gravities of the gangue minerals (vermiculite, approximately 3; quartz, 2.65; feldspar, 2.7; garnet, 4.25). Hydraulic classification followed by tabling gave unsatisfactory results, although several tests were made.

Flotation

Results obtained by flotation may be considered satisfac-
### Table 3.

**Effect of Various Ions in the Flotation of Pony Vermiculite**

<table>
<thead>
<tr>
<th>Reagents in solution other than dioctyl aminoethanol.</th>
<th>Ions in solution other than those supplied by dioctyl aminoethanol.</th>
<th>Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alum</td>
<td>AlSO₄</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. HCl</td>
<td>HCl</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Alum HCl</td>
<td>AlSO₄ Cl</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. H₂SO₄</td>
<td>HSO₄</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. HNO₃</td>
<td>NO₃</td>
<td>good</td>
</tr>
</tbody>
</table>
tory. Considerable time was spent in determining the most efficacious reagents. Testing was done in a 600 cm. standard Fagergren laboratory flotation cell. In the preliminary tests very high pulp dilutions (approximately 20% solids) were maintained because of the shortage of material with which to work.

The reagents tested and the results obtained are listed in Table 2.1.

Furthering testing on the basis of the results obtained in the preliminary tests, investigations were made using pulp conditioned with sulphuric acid and dioctyl aminoethanol as collectors. As other investigations have reported the favorable effect of alum as a depressant for feldspar minerals in the flotation of micas using long chain amines as collectors, the effect of this reagent was also investigated. It was found that both the acidity of the pulp and the presence of the \( \text{SO}_4 \) ion were essential for activation of the vermiculite in the presence of dioctyl aminoethanol. This fact is indicated by the data in Table 3.

**Experimental**

Quantitative tests on the ore for the recovery of vermiculite followed the preliminary testing. The feed to the flotation cell was prepared in the following manner: The vermiculite-bearing rock was crushed to approximately \( \frac{3}{8} \) inch by means of a gyratory crusher. The discharge from the crusher was screened on a 6-mesh sieve and the oversize reduced to pass 6-mesh by hand crushing on a buckboard. This minus 6-mesh pro-

duct was further screened on a 14-mesh sieve. The plus 14-mesh fraction was saved for agglomeration-tabling tests, and the minus 14 fraction was cut into 600 gm. samples for feed to the flotation cell. A screen analysis of the flotation feed is given in Table 4.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Percent of Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>-14 / 20</td>
<td>3.4</td>
</tr>
<tr>
<td>-20 / 28</td>
<td>13.0</td>
</tr>
<tr>
<td>-28 / 35</td>
<td>22.3</td>
</tr>
<tr>
<td>-35 / 48</td>
<td>19.3</td>
</tr>
<tr>
<td>-48</td>
<td>41.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Table 4: Screen Analysis of Feed to Flotation Cell.

Results of Flotation

In the flotation tests, 600 gms. of ore were conditioned in the flotation cell at approximately 22% solids. Table 5 lists reagent quantities and distribution of the products obtained. The tests were allowed to run until the froth was nearly completely clean.

In tests 2 and 4 the ore was agitated for six minutes in the cell and the slimes decanted before conditioning. These tests show a decided decrease in reagent consumption over test 3, in which the slimes were not decanted. This furnishes definite evidence that the clay slimes rob the vermiculite of considerable reagent.

In test 2 and 4 the rougher concentrate was cleaned twice
Table 5.
Distribution of Vermiculite in Flotation Products

<table>
<thead>
<tr>
<th>Reagents (Lb./ton dry ore)</th>
<th>Test 2 (11 min.)</th>
<th>Test 3 (13 min.)</th>
<th>Test 4 (12 min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rough. Cl.1. Cl.2</td>
<td>Rough. Cl.1. Cl.2</td>
<td>Rough. Cl.1. Cl.2</td>
</tr>
<tr>
<td>H₂SO₄</td>
<td>0.5  -  -</td>
<td>0.5  -  -</td>
<td>0.5  -  -</td>
</tr>
<tr>
<td>Alum</td>
<td>0.25  -  -</td>
<td>0.25  -  -</td>
<td>-  -  -</td>
</tr>
<tr>
<td>Dioctyl Aminoethanol</td>
<td>0.5  0.1  0.1</td>
<td>0.5  1.0  -</td>
<td>0.75  0.5  0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conc.</td>
<td>357.0 87.3 97.1</td>
<td>354.5 88.8 97.4</td>
<td>366.0 86.4 96.1</td>
</tr>
<tr>
<td>1st. mids</td>
<td>11.7 3.9 0.1</td>
<td>-- -- --</td>
<td>31.9 17.5 1.7</td>
</tr>
<tr>
<td>2nd. mids</td>
<td>11.7 3.9 0.1</td>
<td>-- -- --</td>
<td>13.8 11.6 0.5</td>
</tr>
<tr>
<td>Tails</td>
<td>156.4 5.1 2.4</td>
<td>171.1 4.9 2.6</td>
<td>121.4 4.5 1.7</td>
</tr>
<tr>
<td>Slimes</td>
<td>67.4 *0.0 0.0</td>
<td>74.4 *0.0 0.0</td>
<td>66.9 *0.0 0.0</td>
</tr>
<tr>
<td>Composite</td>
<td>600.0 53.5 100.0</td>
<td>600.0 53.9 100.0</td>
<td>600.0 54.9 100.0</td>
</tr>
</tbody>
</table>

* It was assumed that there was no vermiculite in the slimes.
** Result of float-sink separation in carbon tetrachloride, specific gravity = 1.65
to remove gangue. In test 3 this cleaning was abandoned because of the general messiness encountered in the flotation of the clayey concentrate.

**Examination of Products**

The products of the flotation tests were analyzed for percent vermiculite by first expanding the vermiculite at approximately 1800°F and then making a float-sink separation using carbon tetrachloride as the heavy liquid. Water could also have been used for this purpose but evaporation of the carbon tetrachloride was more rapid than the drying of the water-wet samples, and as the product was generally easier to handle, the former method was used.

In this method of analysis it was assumed that all material which would float on the carbon tetrachloride was vermiculite and all that sank was gangue.

The dried concentrates were weighed both before and after expansion and the results are given in Table 6.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Unexpanded</th>
<th>Expanded</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>63.0</td>
<td>17.1</td>
</tr>
<tr>
<td>3</td>
<td>63.0</td>
<td>18.6</td>
</tr>
<tr>
<td>4</td>
<td>62.5</td>
<td>18.0</td>
</tr>
<tr>
<td>Average</td>
<td>63.8</td>
<td>17.9</td>
</tr>
</tbody>
</table>

**Table 6.**

Density (pounds per cubic foot) of Dried Flotation Concentrates.

A further test to determine the relative amounts of each size of expanded vermiculite in the flotation concentrate, and
A
FABRICATED
LABORATORY FLotation CELL

B
DISTRIBUTION OF VERMICULITE IN FLotation PRODUCTS
CONCENTRATE  MIDDLENGS  TAILINGS
VERMICULITE AT TOP AND
GANGUE AT BOTTOM
weight per cubic foot of each, was also run. The results are shown in Table 7.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Percent of total weight</th>
<th>Weight (Lb./Cu.Ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 20</td>
<td>2.8</td>
<td>--</td>
</tr>
<tr>
<td>20 -</td>
<td>17.0</td>
<td>12.1</td>
</tr>
<tr>
<td>20 -</td>
<td>26.1</td>
<td>13.6</td>
</tr>
<tr>
<td>35 -</td>
<td>22.1</td>
<td>14.7</td>
</tr>
<tr>
<td>48 -</td>
<td>32.0</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Table 7.

Screen Analysis of the Cleaned*, Expanded Vermiculite Product from the Flotation Cell

On comparing the results in Table 7 with those in Table 4, it first appears that no expansion has occurred on heating. This is probably due to the maximum dimension of the platy, unexpanded vermiculite being unchanged by expansion. In other words, in the unexpanded mineral the plates are commonly five or six times as wide as they are thick. As indicated in Table 6, the expansion is less that four times upon heating, and it is observed that essentially all expansion is at right angles to the plates. Thus, it is seen, that in the vermiculite examined, the mesh through which the expanded vermiculite particle passes is governed by the original diameter of the plates.

Examination of the products showed that the vermiculite in the middlings and the tailings was coarser than that in the concentrates, indicating that for the reagents used, sizes lar-

*The float product of the carbon tetrachloride separation.
ger than 14-mesh would probably not respond to flotation effectively.

The float-sink separation of the concentrate revealed considerable quantities of medium-brown micaceous mineral in the sink product. The folia of this mineral were inelastic and flexible and are thought to be either individual plates which have broken off the expanded vermiculite, or to consist of an incompletely hydrated form of phlogopite mica which had not reached the "vermiculite stage" of alteration. This material was indistinguishable from the expanding material in physical appearance, but no chemical or microscopic tests were made to ascertain whether there were any differences.

Agglomerate Tabling

Insufficient time was available to investigate this method of concentration sufficiently to obtain quantitative data. Considerable time was spent, however, in testing the amenability of vermiculite to certain reagents for agglomeration tabling. Testing was done by conditioning the mineral and observing the results on a vanning plaque. By this method several reagents were found promising when used in combination with oil. The most favorable reagents tried and the results obtained are noted below.

- dioctyl aminoethanol: insufficient bonding to float the larger particles.
- Amine 12-NAMAC 1181.5-C gave the most favorable results. Good collection but some tendency for the gangue to also float.

In addition to these reagents, o-toluidine and xyolidine
showed marked assistance in agglomerating the vermiculite.

USES OF VERMICULITE

The value of vermiculite depends upon such properties of the expanded mineral as low density (measured in pounds per cubic foot), high refractoriness, and low thermal and sound conductivity.

The greatest use of vermiculite under pre-war conditions was as a home insulator, used in loose form. A minor amount was also used in the manufacture of acoustic board, lightweight plaster cements, and coating on rolled roofing paper, etc., where it acted to prevent sticking on rolling.

The war has considerably stimulated the use of the mineral as an aggregate in lightweight and insulating concretes. This concrete is used in the formation of roofs and floors for buildings. Vermiculite is also used as deck covering and in fire walls on oil tankers and other ships exposed to bombing attacks.

Vermiculite concrete is an extremely lightweight building material weighing from 20 to 40 pounds per cubic foot. It has a crushing strength of about 175 to 200 pounds per square inch. Bricks of such material have been used in the construction of the arch in reverberatory furnace roofs because of their refractory properties as well as their lightweight. The weight of a standard brick of this construction is 24 ounces. Where a stronger material is needed a binder is used which increases the weight and the thermal conductivity. This brick weighs 33 ounces and they have found application in the inside walls of cracking units in the petroleum industry.

A plastic insulation composed of vermiculite aggregate
and binder is used for sound insulation in automobiles and airplanes. In combination with bonding materials, vermiculite may also be fabricated into a wide number of other products such as covering for pipes, acoustic plastic and tile, and roof-covering slabs.

A British patent taken out in 1938 provides for the reinforcement of vermiculite particles by coating them with a carbonaceous material. Claims have been made for the post-war use of this mineral in the building of pre-fabricated houses. Other claims for uses of the mineral are as a lubricant, vermiculite, having a melting point of about 2600°F, and other properties comparing favorably with graphite; as a purifying filter for gasoline and oil; in automobile mufflers and high temperature gaskets; as a sub-soil reservoir; a dehydrating agent in air conditioning systems, also in the inner soles of shoes to prevent squeaking. 10

Table 8 illustrates the uses of expanded vermiculite according to size. 11

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Uses of Vermiculite</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼ inch to 20 mesh</td>
<td>House insulation</td>
</tr>
<tr>
<td></td>
<td>Home refrigerators</td>
</tr>
<tr>
<td></td>
<td>Automobile mufflers</td>
</tr>
<tr>
<td></td>
<td>Acoustic plaster</td>
</tr>
<tr>
<td></td>
<td>Safe and Vault lining</td>
</tr>
<tr>
<td></td>
<td>Pipe covering</td>
</tr>
<tr>
<td></td>
<td>Boiler lagging</td>
</tr>
<tr>
<td>20- to 40-mesh</td>
<td>Automobile insulation</td>
</tr>
<tr>
<td></td>
<td>Airplane insulation</td>
</tr>
<tr>
<td></td>
<td>Refrigerator car insulation</td>
</tr>
</tbody>
</table>

11. U.S.B.M. Yearbook, 1936


<table>
<thead>
<tr>
<th>Mesh</th>
<th>Uses of Vermiculite</th>
</tr>
</thead>
</table>
| 20- to 40-mesh (cont.) | Wall board  
Water coolers  
Filters |
| 40- to 120-mesh | Linoleum  
Shingles  
Cornice board  
Dielectric switchboards |
| 120- to 200-mesh | Grease lubricant  
Bakelite products  
Tires and other rubber goods |
| 200- to 270-mesh | Wall paper  
Outdoor advertising paints  
Building up viscosity in oil  
Fireproof cartons for film |
| 270-mesh      | Extender for gold and bronze  
paint and printing ink |

Table 8.

Uses of Expanded Vermiculite According to Size.

PRODUCTION AND STATISTICS

The first production of vermiculite in the United States came in 1915 when a mineral mined in the Turrett district, Colorado was placed on the market.

Production figures for 1943 and 1944 are not available. The Minerals Yearbook for 1942, however, gives the following figures:

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (short tons)</th>
<th>Value (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1941</td>
<td>23,438</td>
<td>125,444</td>
</tr>
<tr>
<td>1942</td>
<td>57,848</td>
<td>319,931</td>
</tr>
</tbody>
</table>

These figures include crude and exfoliated vermiculite produced in seven states. The principal producer, by far, was the Universal Zonolite Insulation Company, Libby, Montana, from
its mines in the Rainy Creek district.

The value of screened and cleaned vermiculite in September, 1942 was $9.50 per short ton F.O.B. mine in North Carolina, and $12. in Montana. The exfoliated mineral was quoted at from $.70 to $1.25 per bag, each containing four cubic feet and weighing 25 pounds. This amounts to $56. to $100. per short ton F.O.B. works.

Known commercial deposits of vermiculite are situated in South Carolina and Montana with intermittent production from Wyoming, California, Nevada and Colorado. Foreign deposits include those in Japan, Russia, Union of South Africa and Tanganyika, Africa, and in the southeastern part of western Australia. Outside of the United States, only the Russian and South African deposits have been worked commercially over a period of years, although the Australian deposits have been developed during recent years.

CONCLUSIONS

The vermiculite-bearing rock examined occurs in highly metamorphosed pre-Cambrian schists of the Pony series, approximately four miles northwest of the town of Pony, Madison County, Montana.

The genesis of vermiculite deposits in general is obscured by the lack of information regarding the physical nature of the mineral at a depth below the zone of meteoric water, although it is generally agreed that vermiculite is an alteration product of one of the common basic, rock-forming miner-

*These figures pertain to a much coarser material than the Pony vermiculite examined in this report, and therefore presumably procures a higher price.*
In the Pony deposits all evidence secured leads to the belief that the vermiculite is derived from the alteration of hornblende. Action of both metoric and hydrothermal solutions is evident and the formation of the vermiculite is believed to have been dependent on both for its hydrous nature and related expanding properties. The hydrothermal solutions are considered to have been necessary in order to enact the chemical change necessary to alter hornblende to non-expanding vermiculite or biotite-phlogopite mica. The metoric water later weathered this hydrothermally altered mineral to the more hydrous vermiculite.

The Pony material has the undesirable quality of the vermiculite to produce fine sizes upon expansion and thereby limiting the use of the product.

Gravity concentration did not appear to be adapted to concentration of vermiculite. Concentration by flotation, however, using dioctyl aminoethanol, sulphuric acid and alum as reagents, produced satisfactory results. Agglomerate-tabling tests also indicate that the Pony vermiculite might be concentrated in this manner, although no quantitative tests were made.