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## SAUCONITE—A CLAY MINERAL OF THE MONTMORILLONITE GROUP

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### ABSTRACT

Zinc-bearing clays, commonly called tallow clays, have long been known, and have been reported from numerous localities, but their mineralogic character has been in dispute since they have been described as mixtures of kaolin and hemimorphite, or less commonly as true zinc clays. A study of excellent material from four regions, and a restudy of old specimens has shown that the zinc clays are distinct minerals belonging to the montmorillonite group, and are analogous to the magnesian clay mineral, saponite. The study presents seven new chemical analyses, and the chemical formulas calculated from them. The optical properties and mineralogical relationships of these minerals to other members of the montmorillonite group are discussed.

A zinc clay from Saucon Valley, Pennsylvania, was analyzed by Roepper in 1875 and named sauconite. A restudy of type material collected by Roepper has shown that the material was representative of the zinc-bearing clays, and therefore the name sauconite should be accepted for this member of the montmorillonite group.

Zinc-bearing clay materials, commonly referred to as "tallow clays," have long been known, and have been reported from numerous localities, but reports on them have not been in agreement about their character. They have been regarded by some writers to be definite minerals, but more commonly they have been described as mixtures of kaolinitic or related clays and hemimorphite (calamine), and their true relations have therefore long remained problematical; however, as sometimes happens, both schools of thought prove to have been partly right.

Studies of other members of the montmorillonite-nontronite-saponite group, and the ionic substitutions within the group<sup>1</sup> indicated that a true zinc clay analogous to saponite, the magnesian member of the group, was to be expected, and so led to a detailed study of the zinc-bearing clays.

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<sup>1</sup> Ross, Clarence S., and Hendricks, Sterling B., Minerals of the Montmorillonite Group, *Geological Survey, Professional Paper 205-B* (1945).

## NOMENCLATURE

*Sauconite*

A zinc-bearing clay from the Uberroth Mine, Saucon Valley, near Friedensville, Pennsylvania, was analyzed and named sauconite by Roepper and described by Genth.<sup>2</sup> The material was listed without name by Dana.<sup>3</sup> However, sauconite was included by Chester<sup>4</sup> in the Dictionary of Names and was listed in the Mineralogical Magazine in 1900.<sup>5</sup> A sample of the original material studied by Roepper was made available for study through the courtesy of the Department of Geology of Lehigh University.

*Moresnetite*

Risse<sup>6</sup> described a zinc-bearing material from Altenberge, near Aachen, in 1865. Material from the type locality was made available for study through the courtesy of the National Museum (Specimen C3426). The zinc mineral in this specimen ranges from light gray to dark blue gray, and forms irregular patches or veinlets associated with a brown material made up of micas and chlorite. With this are fine-grained masses of hemimorphite. The following chemical analyses were made by Risse.

## ANALYSES OF ALTENBERGE MORFSNETITE

	(1)	(2)
SiO <sub>2</sub>	29.26	30.31
Al <sub>2</sub> O <sub>3</sub>	13.02	13.68
ZnO	37.98	43.41
FeO*	5.61	.27
NiO	0.24	1.14
MnO	tr	
CaO	.76	
MgO	.54	tr
H <sub>2</sub> O	11.34	11.37
	<hr/>	<hr/>
	98.85	100.18

\* Undoubtedly present as Fe<sub>2</sub>O<sub>3</sub>.

<sup>2</sup> Genth, F. A., *Mineralogy of Pennsylvania: Second Geol. Survey. Penn.*, p. 120-B (1875).

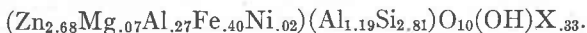
<sup>3</sup> Dana, E. S., *A System of Mineralogy*, 5th ed., 11th sub. ed., John Wiley & Sons (1874).

<sup>4</sup> Chester, A. H., *A Dictionary of the Names of Minerals*, p. 240, John Wiley & Sons, New York (1896).

<sup>5</sup> *Mineralog. Mag.*, **12**, 391 (1900).

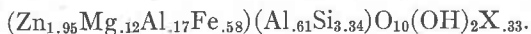
<sup>6</sup> Risse, Hugo, Über den Moresnetite, ein neues Zinkoxyd-Thonerdesilikat von Altenberge bei Aachen: *Naturhistorischen Vereines der Rheinlande und Westphalens Correspondenblatt*, No. 1, pp. 98-99, vol. **22**, Bonn (1865).

The following chemical formula has been calculated from Analysis No. (1), the more complete of the two given by Risse. However, No. (2) gives essentially the same formula:



The summation of ions in octahedral positions (those associated with Zn) in the above formula is 3.44. Only 3 octahedral positions are available within the crystal lattice in minerals of mica-like structure, including those of the montmorillonite group; and hence, this impossible formula shows a large excess of some element—probably zinc as the specimen contains hemimorphite. The Al associated with Si in tetrahedral positions is excessively high for a member of the montmorillonite group, and is high even for a mica.

The following chemical formula of sauconite from the type locality has been derived from analysis No. 10, Table 3—one of the three quoted by Genth<sup>7</sup> when the name sauconite was first published.



The summation of ions in octahedral positions in the foregoing formula is 2.82, and the tetrahedral Al is normal for a member of the montmorillonite group.

The question therefore arises as to the most suitable name for the zinc-bearing clay mineral of the montmorillonite group, which is analogous to saponite. Samples of both the Aachen material (moresnetite), and that from Friedensville (sauconite) have been available for study. Examinations of the Aachen material by means of thin sections, *x*-rays, and differential thermal analysis have indicated the difficulty of securing a pure sample, and this is confirmed by the impossible composition for a member of the montmorillonite group as derived from the original published analyses. On the other hand, these same tests have shown the essential purity of the Friedensville material and the original analyses, although not quite complete, give formulas that conform to those characteristic of members of the montmorillonite group. For these reasons the name sauconite proposed by Roepper and Genth for the mineral from Friedensville, Pennsylvania, seems most suitable for the zinc-bearing clay mineral.

#### *Vanuxemite*

Sheppard<sup>8</sup> described a zinc-bearing clay material from Sterling Hill, New Jersey, in 1876 under the name vanuxemite. A sample of type vanuxemite from the Roebing collection of the National Museum

<sup>7</sup> *Op. cit.*

<sup>8</sup> Sheppard, C. U., Vanuxemite: *Am. Jour. Sci.*, 3rd ser., 12, 231 (1876).

(Specimen R3920) was made available for study through the courtesy of Dr. Foshag. A microscopic study shows that the material is impure, being composed of two or more materials. An  $x$ -ray examination gave only extremely weak lines which were definitely not those of saucnite. Tests by means of differential thermal analysis likewise indicated that the material was not saucnite.

### *Saponite*

Saucnite proves to be a member of the montmorillonite group of minerals in which three bivalent zinc ions proxy two trivalent alumina ions in octahedral positions in the lattice structure, and so is entirely analogous to saponite where three magnesium ions play the same role as zinc. For this reason a comparison of the two minerals seems advisable. Saponite was first described by Cronstedt in Sweden,<sup>9</sup> and later by other mineralogists, and particularly by Heddle<sup>10</sup> in Scotland. An examination of the literature on hydrous magnesian silicates suggested that a mineral originally described as griffithite,<sup>11</sup> material from Cahuenga Pass, Griffith Park, Los Angeles, California, was a high-iron saponite. At the time griffithite was described,  $x$ -ray methods for determining mineral relations were not available and it was tentatively assigned to the chlorite group. However, in a later paper,<sup>12</sup> the authors found that its behavior on dehydration was similar to that of nontronite, another member of the montmorillonite group. The presence of 7.32 per cent of  $\text{Fe}_2\text{O}_3$  is unusual for a saponite, and although the proxying of Mg by ferrous iron is to be expected, the proportion of FeO in griffithite (7.83 per cent) is the highest that has been reported for any member of the montmorillonite-nontronite-saponite group. The Cahuenga Pass mineral occurs in vesicular cavities in basalt, a widely reported type of occurrence. The optical properties determined by Larsen are given in a following section.

### OCCURRENCES OF SAUCNITE

Heywood<sup>13</sup> described zinc clays from the Bertha zinc mines, Pulaski County, Virginia.

<sup>9</sup> Cronstedt, Axel, *Mineralogie*, Stockholm (1758). English translation by John Hyacinth, *An essay toward a system of mineralogy*, p. 98, London (1788).

<sup>10</sup> Heddle, M. F., *The Mineralogy of Scotland*; saponite, 29, 91-102 (1879).

<sup>11</sup> Larsen, Esper S., and Steiger, George, Griffithite, a new member of the chlorite group: *Jour. Wash. Acad. Sci.*, 7, 11-12 (1917).

<sup>12</sup> Larsen, Esper S., and Steiger, George, Dehydration and optical studies of alunogen, nontronite and griffithite: *Am. Jour. Sci.*, 5th ser., 25, 1-19 (1928).

<sup>13</sup> Heywood, B. H., A zinc-bearing clay from the neighborhood of the Bertha zinc mine, Pulaski County, Virginia: *Chem. News*, 44, 207 (1881).

Emmons<sup>14</sup> described zinc clays, locally known as Chinese talc, from Leadville, Colorado, and excellent analyses by Hillebrand were listed. (see Table 3 below.) Later a careful study of zinc clays from the same region was published by Loughlin<sup>15</sup> and the specimens collected by him constitute some of the best materials available for this study.

Branner<sup>16</sup> listed 6 analyses of zinc clays from Arkansas. He believed these to be mixtures of common clays and hemimorphite (calamine), but the compositions correspond so well with material used in this study that it seems probable that Branner's materials were essentially pure saucnite. Adams<sup>17</sup> described "tallow clays" from Arkansas and later these clays were also described by McKnight.<sup>18</sup>

Seamon<sup>19</sup> described zinc clays from Southwest Missouri and listed 15 partial analyses. Most of these correspond closely with the analyzed materials of this paper and it seems probable that the samples of Seamon were essentially pure.

Schönischen<sup>20</sup> described zinc-bearing argillaceous material from Spain in 1863 and gave the following rough analysis: Zn=21.36, Si 31.50, Al 26.43, H=18.32.

#### CHEMICAL COMPOSITION

Seven analyses of zinc clays made in the course of this study are given in Table 1. Three analyses made at the time of the original study of saucnite are given in Table 3, and a formula derived from the analysis by Blake is also given. These original analyses show that the material used was seemingly suitable, although the composition was variable. Two excellent analyses of material from Leadville, published in 1886, showed no iron, but otherwise correspond fully with recent analyses. These are also given in Table 3. In the course of the present study one sample from the Roachdale Mine, Lafayette County, Wisconsin, whose analysis is given in Table 4 (No. 15) proved to be a zincian montmorillonite. In the same table, analyses of a typical saponite, of the iron-rich

<sup>14</sup> Emmons, S. F., *Geology and Mining Industry of Leadville, Colorado: U. S. Geol. Survey, Mono. 12*, 560, 605 (1886).

<sup>15</sup> Loughlin, G. F., *The Oxidized Zinc Ores of Leadville, Colorado: U. S. Geol. Survey, Bull. 681*, 24-28 (1918).

<sup>16</sup> Branner, John C., *The Lead and Zinc Region of North Arkansas (tallow clay)*, 266, *5th Ann. Rept. Geol. Survey Arkansas for 1892*, Little Rock, Arkansas (1900).

<sup>17</sup> Adams, George I., *Lead and Zinc Deposits of Northern Arkansas: U. S. Geol. Survey, Prof. Paper 24*, 40 (1904).

<sup>18</sup> McKnight, Edwin T., *Zinc and Lead Deposits of Northern Arkansas: U. S. Geol. Survey, Bull. 853*, 116, 117 (1935).

<sup>19</sup> Seamon, W. H., *The zinciferous clays of Southwest Missouri: Am. Jour. Sci., 3rd ser.*, **39**, 38-43 (1890).

<sup>20</sup> Ingenieur Schönischen zu Neudorf, *Berg und Hütten. Zeit.*, **22**, 164 (1863).

saponite (griffithite), and a typical montmorillonite are given for purposes of comparison with sauconite.

#### DESCRIPTION OF MATERIALS

The samples, numbers 1 to 7, that form the basis of this study, were all examined microscopically, by means of *x*-rays and differential thermal analysis, and several of them were tested by means of the spectrograph. Microscopic examination is more effective for a determination of impurities in sauconite than for most clay materials. The accessory material that is most commonly associated with sauconite is hemimorphite. The index of refraction of hemimorphite is very much higher than that of sauconite, and thus its purity is readily verified. Even when it is too finely disseminated to be resolved by the highest magnifications, this difference in indices causes such marked dispersion of light that it shows up as unusually opaque areas; in fact, this is a useful test for examining clays in general, and permits the detection of very small amounts of gibbsite in kaolinite. The curve given by the differential thermal analysis of sauconite is similar to that of other members of the montmorillonite group at temperatures below about 600°C., but above that point the formation of new zinc silicates gives distinct exothermic reactions, probably due to the formation of willemite.

Sample Number 1, from the Uberroth Mine, Saucon Valley, near Friedensville, Pennsylvania, secured through the courtesy of the Department of Geology of Lehigh University, represents a part of the original material studied by Roepper. It is pale brownish yellow, compact and massive in habit.

Sample Number 2 was collected by G. F. Loughlin of the Geological Survey from the New Discovery Mine, Leadville, Colorado, and was described and pictured by him<sup>21</sup> in a paper on the oxidized zinc ores of Leadville. The material is now a part of the U. S. National Museum mineral collection (No. 91511). The material is laminated with a very perfectly parallel arrangement of the individual micaceous plates, so that there is good parallel extinction in thin section.

Sample Number 3 (Museum also 91511) was collected by Mr. Loughlin from the Yankee Doodle Mine, Leadville, and was described by him in the same paper, as follows: "It has been found in the Yankee Doodle Mine, where it forms a layer about 2 feet thick immediately beneath a thin bed of silicified shale. These occurrences are of sufficient size to be called small ore bodies." The relations are similar to those of the material previously described by Emmons.<sup>22</sup>

<sup>21</sup> *Op. cit.*

<sup>22</sup> *Op. cit.*

Sample Number 4 from the Coon Hollow Mine, about three-fourths of a mile north of the village of Zinc, Boone County, Arkansas, was collected by James S. Cullison in the course of studies of the zinc deposits of Arkansas for the Geological Survey. A large sample comprising several pounds of excellent reddish-brown material was secured.

Sample Number 5 is from the same source as Number 4. It forms nearly pure white, rather porous, layer-like zones in the reddish-brown material. The zinc content is a little high, and *x*-ray examination indicates a small proportion of some unknown impurity, but the material appears to be essentially pure.

Edwin T. McKnight has given the following description of the occurrence of so-called tallow clays in Arkansas.<sup>23</sup>

The tallow clay in the Zinc district occurs as a filling of seams along the bedding in oxidized zinc deposits. The original mineralized ground was jasperoidized limestone containing disseminated sphalerite which tended to be concentrated along some bedding seams almost to the exclusion of the interstitial jasperoid. Particularly on the bedding planes but also along irregular cross-cutting fractures, flat vugs were formed that contained crystalline sphalerite and a pink coarsely-crystalline form of dolomite. In the oxidation the sphalerite and dolomite were leached or converted in place to hemimorphite which to some extent replaced the dolomite as pseudomorphic crusts. The tallow clay was deposited in the bedding seam vugs that were originally present or that formed through leaching of the sphalerite and the jasperoid.

Sample Number 6 from the Liberty Mine, near Meekers Grove, Wisconsin, was collected by Allen V. Heyl, Jr., while engaged in studies of the zinc deposits of that area for the Geological Survey. It consists of reddish-brown material, with narrow lenses of iron oxide that were scraped away before analysis.

Mr. Heyl describes the occurrence of the material as follows:

All three samples (including the *zincian montmorillonite*) of the zinc tallow clay occurred filling vugs in the primary veins in the zone of incipient oxidation within the area of the fluctuating water table. All the sphalerite in the veins was essentially unaltered, having only a thin film of smithsonite upon it. Apparently, the zinc in the clay came not only from the oxidation of the bordering ore vein, but to a large extent carried down and re-deposited as saucanite at the water table.

Sample Number 7, from the same mine as Number 6, was collected by Charles H. Behre, Jr., of the Geological Survey. It is somewhat darker colored than Number 6, owing to a slightly higher iron content.

<sup>23</sup> Personal communication.

TABLE 1. CHEMICAL ANALYSES OF SAUCONITE

	Friedensville, Pennsylvania	New Discovery Mine, Leadville	Yankee Doodle Mine, Leadville	Coon Hollow Mine, Arkansas		Liberty Mine, Meekers Grove, Wisconsin	Plattsville Dist., Wisconsin
				Brown Clay	White Clay		
	1	2	3	4	5	6	7
SiO <sub>2</sub>	34.46	35.95	37.10	33.40	33.59	38.59	38.70
Al <sub>2</sub> O <sub>3</sub>	16.95	6.57	14.18	7.45	6.01	13.36	16.29
Fe <sub>2</sub> O <sub>3</sub>	6.21	2.36	.30	1.73	.28	3.41	3.91
MgO	1.11	1.26	1.10	.78	.70	1.18	1.62
MnO	—	.04	.02	tr.	.12	—	.06
ZnO	23.10	33.70	28.19	36.73	39.33	23.50	22.48
CaO	—	.62	1.22	1.92	1.90	.94	tr.
Na <sub>2</sub> O	—	.44	.24	.22	.13	.01	.43
K <sub>2</sub> O	.49	.10	.13	.27	.07	.18	.32
CuO	—	—	.02	.13	.10	—	—
TiO <sub>2</sub>	.24	.07	tr.	.15	.03	.31	.30
H <sub>2</sub> O—	6.72	11.34	8.82	9.78	10.68	10.39	7.50
H <sub>2</sub> O+	10.67	7.24	8.90	7.14	6.98	8.05	8.38
	99.95	99.69	100.22	99.70	99.92	99.92	99.99

- No. (1) J. G. Fairchild—analyst.  
 No. (2) J. G. Fairchild—analyst.  
 No. (3) M. K. Carron—analyst.  
 No. (4) M. K. Carron—analyst.  
 No. (5) M. K. Carron—analyst.  
 No. (6) M. K. Carron—analyst.  
 No. (7) S. H. Cress—analyst.

TABLE 2. CHEMICAL FORMULAS FOR SAUCONITE

- (1)  $(Zn_{1.48}Mg_{.14}Al_{.74}Fe'''.40)(Al_{.99}Si_{3.01})O_{10}(OH)_2X_{.33}$   
 (2)  $(Zn_{2.40}Mg_{.18}Al_{.22}Fe'''.17)(Al_{.53}Si_{3.47})O_{10}(OH)_2Ca/2_{.13}Na_{.09}$   
 (3)  $(Zn_{1.85}Mg_{.14}Al_{.79}Fe'''.02)(Al_{.70}Si_{3.30})O_{10}(OH)_2Ca/2_{.23}Na_{.05}$   
 (4)  $(Zn_{2.64}Mg_{.11}Al_{.12}Fe'''.19)(Al_{.75}Si_{3.27})O_{10}(OH)_2Ca/2_{.40}Na_{.04}K_{.04}$   
 (5)  $(Zn_{2.89}Mg_{.10}Al_{.04}Fe'''.02Mn_{.01})(Al_{.65}Si_{3.35})O_{10}(OH)_2Ca/2_{.40}Na_{.02}K_{.01}$   
 (6)  $(Zn_{1.54}Mg_{.15}Al_{.78}Fe'''.23)(Al_{.61}Si_{3.39})O_{10}(OH)_2Ca/2_{.18}K_{.02}$   
 (7)  $(Zn_{1.29}Mg_{.41}Al_{.73}Fe'''.49)(Al_{.80}Si_{3.20})O_{10}(OH)_2X_{.33}$   
 (1)  $\Sigma = 2.77$  (5)  $\Sigma = 3.06$   
 (2)  $\Sigma = 2.90$  (6)  $\Sigma = 2.70$   
 (3)  $\Sigma = 2.71$  (7)  $\Sigma = 2.80$   
 (4)  $\Sigma = 3.00$

$\Sigma$  represents the ions in octahedral positions. Ca/2 represents Ca divided by 2, a necessary procedure for a bivalent exchangeable base.



TABLE 3. CHEMICAL ANALYSES OF SAUCONITE

	Friedensville, Pennsylvania			Lower Waterloo Mine Leadville, Colorado	
	Pale yellow, white	Ochre yellow	Pale yellow	11	12
	8	9	10		
SiO <sub>2</sub>	48.42	46.45	41.36	35.97	35.33
Al <sub>2</sub> O <sub>3</sub>	10.66	7.41	8.04	8.81	10.38
Fe <sub>2</sub> O <sub>3</sub>	3.85	14.28	9.55	—	—
MgO	—	.97	1.02	.80	.71
CaO	2.42		—	—	1.87
ZnO	26.95	22.86	32.34	35.40	33.05
Na <sub>2</sub> O	—	—	—	—	—
K <sub>2</sub> O	—	—	tr.	—	—
H <sub>2</sub> O—	—	—	—	7.20	7.42
H <sub>2</sub> O+	7.06	6.75	7.76	10.26	11.64
	<u>99.88</u>	<u>98.69</u>	<u>99.97</u>	<u>100.31</u>	<u>100.15</u>

(Dehydrated at 105° C.)

(8) W. Th. Roepper—analyst.<sup>1</sup>(9) W. Th. Roepper—analyst.<sup>1</sup>(10) J. M. Blake—analyst.<sup>1</sup>(11) W. F. Hillebrand—analyst.<sup>2</sup>(12) W. F. Hillebrand—analyst.<sup>2</sup><sup>1</sup> *Op. cit.*<sup>2</sup> *Op. cit.*

Formulas based on previous analyses of sauconite

(10) (Zn<sub>1.95</sub>Mg<sub>.12</sub>Fe<sub>.58</sub>Al<sub>1.17</sub>)(Al<sub>.61</sub>Si<sub>3.39</sub>)O<sub>10</sub>(OH)<sub>2</sub>X<sub>.33</sub>(11) (Zn<sub>2.46</sub>Mg<sub>.10</sub>Al<sub>.38</sub>)(Al<sub>.61</sub>Si<sub>3.39</sub>)O<sub>10</sub>(OH)<sub>2</sub>Ca/2.40(12) (Zn<sub>2.32</sub>Mg<sub>.10</sub>Al<sub>.55</sub>)(Al<sub>.62</sub>Si<sub>3.38</sub>)O<sub>10</sub>(OH)<sub>2</sub>Ca/2.34

TABLE 4. ANALYSES OF SAPONITE AND MONTMORILLONITE

	Saponite <sup>1</sup> Ahmeek Mine, Michigan	Iron Rich Saponite <sup>2</sup> (Griffithite), California	Zincian Montmoril- lonite, Wisconsin	Montmoril- lonite, Booneville, <sup>3</sup> Mississippi
	13	14	15	16
SiO <sub>2</sub>	42.99	39.64	40.62	50.53
Al <sub>2</sub> O <sub>3</sub>	6.26	9.05	21.79	19.31
Fe <sub>2</sub> O <sub>3</sub>	1.83	7.32	9.73	7.25
FeO	2.57	7.83	—	—
MgO	22.96	15.80	1.67	2.60
MnO	.11	—	.04	.02
ZnO	—	—	3.82	—
CaO	2.03	2.93	.10	.72
Na <sub>2</sub> O	1.04	.71	.88	.41
K <sub>2</sub> O	tr.	none	.10	.34
TiO <sub>2</sub>	—	—	.66	.75
P <sub>2</sub> O <sub>5</sub>	—	—	—	.15
H <sub>2</sub> O—	13.65	12.31	8.92	10.66
H <sub>2</sub> O+	6.85	4.90	11.59	7.90
	100.29	100.49	99.92	100.64

(13) Helen E. Vassar—analyst.

(14) George Steiger—analyst.

(15) J. G. Fairchild—analyst.

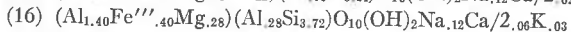
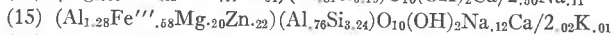
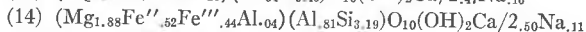
(16) J. G. Fairchild—analyst.

<sup>1</sup> Palache, C., and Vassar, H. E., Some minerals of the Keweenawan copper deposits, 3. Saponite: *Am. Mineral*, **10**, 417–418 (1925).

<sup>2</sup> Larsen, Esper S., and Steiger, George, *op. cit.*

<sup>3</sup> Ross, Clarence S. and Hendricks, Sterling B., *op. cit.*, p. 34.

#### Formulas for saponite and montmorillonite



(13)  $\Sigma = 3.00$

(15)  $\Sigma = 2.28$

(14)  $\Sigma = 2.88$

(16)  $\Sigma = 2.08$

The formulas presented have been calculated according to a procedure described in another paper.<sup>24</sup> X-ray studies have given definite informa-

<sup>24</sup> Ross, Clarence S., and Hendricks, Sterling B., Minerals of the Montmorillonite Group, *Geological Survey, Prof. Paper 205-B* (1945).

tion about the role of different ions in the crystal structure and have shown that Zn, Fe<sup>'''</sup>, Fe<sup>''</sup>, Mn, and essentially all Mg should all be assigned to octahedral positions in the crystal lattice. The Al occupies both octahedral positions, and tetrahedral ones where it proxies Si in part; the distribution between the two positions being such as to balance the valence. The only variable that is not fully determinable from the analyses is that of the interlayer ions, essentially Ca, Na, and K. However, H may proxy bases in interlayer positions and is especially likely to be present in a clay formed in the presence of oxidizing sulfides, as were some of the saucónites. Analyses Nos. 1 and 7 in the foregoing tables are obviously low in bases, and in these the interlayer ions are assumed to have the ratio, tetrahedral ions : exchangeable bases = 4:0.33. This value of  $X_{.33}$  has been found to be a close approximation in a large number of members of the montmorillonite group. There is some variation in the proportion of exchangeable bases; small amounts of impurities may appear among the ions that are characteristically replaceable, but they would have only a small effect on the distribution of Al between tetrahedral and octahedral positions in the crystal lattice.

In the formulas of saucónite (Nos. 1 to 7, 11 and 12) the Al in tetrahedral positions ranges from about 0.50 to 1, and in most of them it lies between 0.60 and 0.80. In formula No. 1 the tetrahedral group (Al<sub>.99</sub>Si<sub>3.01</sub>) is like that in muscovite and is high for a mineral of the montmorillonite group. Most of the saucónite formulas contain more Al than some of the montmorillonites, in which Al may approach 0 while Si may become approximately 4. Zinc is the dominant ion in octahedral positions in all the formulas calculated and ranges from 1.50 to nearly 2.90, varying reciprocally with Al and Fe and to a lesser extent with Mg. The total number of ions in octahedral positions, indicated by  $\Sigma$ , ranges from 2.70 to 3.06. Only 3 octahedral positions are available; No. 5, with  $\Sigma=3.06$ , probably contains a little excess of bases, possibly in hemimorphite, though none was revealed by *x*-ray study. The total of octahedral ions is low in members with the most trivalent ions (Al and Fe<sup>'''</sup>), and high in those composed dominantly of bivalent ones. This is to be expected, as members of the montmorillonite group composed dominantly of trivalent octahedral ions contain from 2 to about 2.2 such ions per one-half unit cell, and those composed of essentially bivalent ones contain about 3 such ions.

The formulas for saucónite are entirely analogous to that of saponite No. 13, with bivalent Zn playing the same role as bivalent Mg. The iron-rich saponite (griffithite) differs from normal saponite in its very high content of ferrous and ferric iron, but gives the same curve by differential analysis.

## OPTICAL PROPERTIES

Clay materials of the montmorillonite group present difficulties that might seem insuperable in the determination of their optical properties, but methods are available by which some of these can be approximated. There are, however, a number of variables that affect the results, and so a definite procedure must be followed if comparisons of indices of refraction are to have significance. The indices of refraction may be determined on definitely oriented aggregates or on films in which the micaceous clay particles had assumed essentially parallel positions. To secure good parallel orientation in such clay films, it is necessary to have essentially complete dispersion of the individual micaceous plates that constitute the clay minerals. This dispersion in general does not occur where calcium, the normal exchangeable base of clays, is present. The first step, therefore, is the substitution of sodium for calcium as the exchangeable base, followed by washing the clay suspension entirely free from excess salts. Such suspensions, in general, give excellently oriented films on drying. When these are broken up or sliced into minute ribbons, optical measurements can be made; however, when the clays stand in immersion oils, these oils slowly permeate the materials and raise the indices of refraction by displacing occluded air. Determinations of the true indices, therefore, demand complete permeation with the particular index liquid that matches the index of the mineral. Another variable is the water film between each pair of molecular sheets, which changes the spacing. The material used in this study was first moistened with acetone; a non-volatile index oil was then added, time (24 hours) was allowed for the acetone to evaporate, the old oil was taken up with filter paper, new oil of the same index was added, and then the preparation was allowed to stand till permeation was complete. The indices determined on 4 samples of sauconite and the indices determined by Larsen<sup>25</sup> for saponite from the Ahmeek Mine, and for griffithite are given in the following table.

<sup>25</sup> Palache and Vassar, *op. cit.*

Larsen and Steiger, *op. cit.*

TABLE 5. OPTICAL PROPERTIES

Sauconite	Indices of Refraction			Optical Character	Color (Ridgeway)
	$\alpha$	$\beta$	$\gamma$		
(1) Friedensville, Pennsylvania	1.575		1.615	(—)	Warm buff 17' O-Y, d
(2) New Discovery Mine, Colorado	1.550		1.592	(—)	Avellaneous 17''' O-Y, b
(4) Coon Hollow Mine, Arkansas	1.564		1.605	(—)	Pinkish Cinnamon 15'' Y-O, b
(6) Liberty Mine, Wisconsin	1.570		1.605	(—)	Drab 17'''' O-Y
Saponite					
Ahmeek Mine, Michigan	1.527	1.525	1.590	(—)	Light buff 17' O-Y, f
Cahuenga Pass, California (Griffithite)	1.485	1.569	1.572	(—)	Pleochroic, pale yellowish—olive green—brownish green

## RARE COMPONENTS

Samples of saucnite from the New Discovery Mine, Leadville, Colo., and the Liberty Mine, Benton, Wis., were examined by means of the spectrograph by K. J. Murata of the Geological Survey.

The material from the Liberty Mine contained Pb, Li, B, Cu, V, and Ni in amounts ranging from traces to less than 0.01%. The saucnite from the New Discovery Mine contained Cr, Ba, Mn and Ni between 0.1 and 0.01 per cent; and Sr, Li, and Cd questionable. The saucnite from the Coon Hollow Mine, Ark., was expressly tested for Cd, and none was recognized; if present at all it is less than 0.01 per cent. An impure zincian montmorillonite from Goodsprings, Utah, was found to contain about 1 per cent of Ni, a few tenths of a per cent of Co and Cu, a few hundredths of a per cent of Cr and V, and no Cd.

RANGE IN COMPOSITION IN THE MONTMORILLONITE GROUP  
OF CLAY MATERIALS

The minerals of the montmorillonite group are characterized by a very wide range in the ions which can proxy Si or Al within the crystal lattice. In tetrahedral positions Al proxies part of the Si (so far as known 1 or less ions out of a possible 4 in the one-half unit cell); and in octahedral positions an unusual number of ions can proxy Al. Other variables in the chemical composition are the interlayer replaceable ions, which may in-

clude almost any of those available in the environmental system; the proxying of OH by F as in the micas; and wide variations in amount of interlayer water. The ions that are known to occupy octahedral positions completely or almost completely are Al, ferric iron, Mg, Cr, and Zn; those which are present in essential but not dominant proportions are ferrous iron, Li, Mn, and Ni.<sup>26</sup> Titanium is known to play the role of Al in the micas, but its ready hydrolysis tends to remove it from the lattice structure of a clay mineral and deposit it as one of the materials known as leucoxene. Vanadium is believed to be an important component in the clay materials associated with some vanadium-bearing phosphate beds, just as it is in roscoelite, but it has not been possible to secure material suitable for chemical analysis.

The state of oxidation of Mn, which is sparingly present in some members of the group, is not directly determinable, but the higher state of oxidation of the iron and the lavender-pink color of some of the manganese-bearing montmorillonites indicates that small amounts (0 to a maximum of 0.18 per cent) are normally present in the higher state of oxidation. The strong tendency of manganese to form oxides (many clays contain small aggregates of manganese oxide) probably limits the amount that enters the crystal structure. Only under very unusual conditions would a clay with essential quantities of MnO be expected to form. Chromium, which is present in spectrographic amounts in a few samples, is a dominant constituent in volchonskoite from Russia and in essential amounts in some beidellites described by Serdiuchenko<sup>27</sup> from the same region. The spectrographic traces of Ba, Pb, and Sr are probably present as replaceable bases.

The Boone County, Arkansas, sauconite came from an area characterized by cadmium, and it was rather surprising that none was revealed by the spectroscope. Cadmium, however, has a large ionic radius (about 1.00 Å) as compared to .57 for Al and .75 for Mg, and it is possible that it is too large to enter the lattice of members of the montmorillonite group in any essential proportions. The role of such elements as Cu and B, which have been reported in very small proportions, is problematical. Only traces of Co have been recognized in clay minerals, but the chemical relationships of cobalt and the ionic radius of Co (.77 Å) suggests that a cobaltian clay would be possible in a suitable environment.

<sup>26</sup> Ross, C. S., Hendricks, S. B., *op. cit.*

<sup>27</sup> Serdiuchenko, D. P., Chrome-nontronites and their genetical relations with the serpentines of the northern Caucasus: *Soc. russe mineralogie Mem. 2nd ser.*, **62**, 376-390 (1933).