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MINERALOGIC NOTES

SERIES 3

BY

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ILLUSTRATIONS.

MINERALOGIC NOTES, SERIES 3.

By WALDEMAR T. SCHALLER.

INTRODUCTION.

The results of the smaller, independent pieces of mineralogic research work carried out by the writer in the chemical laboratory of the United States Geological Survey from July 1, 1911, to December 31, 1913, are here assembled. Earlier reports of a similar nature have been published as "Mineralogical notes" (1903-4), in Bulletin 262, 1904; "Mineralogical notes, series 1" (1905-1909), as Bulletin 490, 1911; and "Mineralogical notes, series 2" (1910-11), as Bulletin 509, 1912. In addition to these papers a report on the crystallography of ferberite from Colorado was revised for publication in Bulletin 583, and a report on the gem tourmaline field of southern California has been submitted for publication as Professional Paper 92.

The writer spent the summer of 1912 in Europe and obtained a considerable amount of valuable material, especially from the collection in the Vienna Hof-Museum, and the results of study of two minerals thus obtained—koechlinite, a new species, and schneebergite, analyzed completely for the first time—are here presented. The papers on custerite and on hodgkinsonite were first published in conjunction with other investigators, and their contributions have been briefly summarized in the present notes.

The papers preceding the one on the crystallography of fremontite, except the one entitled "The composition of cebollite," have not been previously published.

KOECHLINITE (BISMUTH MOLYBDATE), A NEW MINERAL.

ORIGIN OF INVESTIGATION.

Some years ago the writer[1] described a crystallized bismuth mineral from Nevada which occurred in hexagonal rhombohedral crystals and was optically uniaxial. Analysis of this mineral showed the presence of considerable water, and in accordance with the results obtained on bismuth ocher from California[2] the mineral from Nevada was considered to have the composition expressed by the formula $Bi_2O_3.3H_2O$. The crystals from Nevada are very different from those assigned to the anhydrous oxide of bismuth, Bi_2O_3, as given in Dana's Mineralogy.[3] It seems doubtful, therefore, whether the anhydrous oxide exists in nature as such, and a sharp outlook has been kept for natural occurrences of crystallized Bi_2O_3.

While the writer was at Vienna in 1912 he made an inquiry as to the presence of such specimens in the collections, and the custodian of the mineral collection of the Hof-Museum, Dr. Rudolf Koechlin, called particular attention to a specimen showing small greenish rectangular crystals which had been supposed to be torbernite but which Dr. Koechlin had found to give a strong bismuth reaction. On request, and on the approval of Dr. F. Berwerth, director of the mineralogic and petrographic division of the Hof-Museum, part of the specimen was given to the writer for study, and it is a great pleasure for him to express his thanks for the kindness and liberality of Drs. Berwerth and Koechlin in furnishing this valuable material.

The investigation showed that the mineral contained essentially only the oxides of bismuth and molybdenum, and the analyses yielded results from which the simple formula $Bi_2O_3.MoO_3$ was deduced.

The acquisition of the specimen by the Vienna Museum is thus described by Dr. Koechlin. The specimen was bought in 1884 from a Mr. Kulda who carried on a small trade in natural-history objects. The specimen of koechlinite, No. D. 3478 in the Vienna catalogue, was labeled torbernite. As Dr. Koechlin had found considerable bismuth in the mineral, however, it had been relabeled bismuth ocher. According to him the mineral somewhat resembles uranospinite. The only observed phase of the mineral consists of sharp, minute tabular crystals which are described in detail below, under the heading "Crystallography."

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[1] Schaller, W. T., Bismite from Nevada: U. S. Geol. Survey Bull. 490, p. 33, 1911. Compare also Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, p. 121, 1909,

[2] Schaller, W. T., Bismuth ochers from San Diego County, Cal.: Am. Chem. Soc. Jour., vol. 33, p. 162. 1911.

[3] Dana, E. S., System of mineralogy, 6th ed., p. 200, 1892.

NOMENCLATURE.

The services of Dr. Rudolf Koechlin, both as investigator and as custodian of the mineral collection in Vienna, are too well known to call for any extended remarks, and in proposing the name koechlinite for the new bismuth molybdate herein described the writer takes a double pleasure, for not only the scientific attainments of Dr. Koechlin are thereby recognized, but in addition his charming personality and great willingness to help others, which were so manifest during the writer's stay in Vienna.

The formula of koechlinite is a simple one, but no other minerals were noted with which it could be closely related, and for the present it must be placed with other molybdates, although from analogy one might expect to find minerals similar in type but differing chemically, as, for example, the unknown compound $Fe_2O_3.SO_3$.

LOCALITY.

The locality as given originally by Mr. Kulda is the Daniel mine, Schneeberg, Saxony, Germany, and the already long list of secondary bismuth minerals found at this classic locality is now further extended.

PARAGENESIS.

The character of the matrix and its geologic relations are not known, but the specimens appear typically like parts of a mineralized quartz vein, rich in cavities lined with well-developed quartz crystals, upon which rest the crystals of koechlinite.

The associated minerals are massive white quartz and quartz in colorless crystals, forming the main part of the specimen; abundant native bismuth, in cleavable masses, in part strongly iridescent; abundant smaltite, in cubic crystals ({100}, {111}) about 1 millimeter thick (wrongly described as chloanthite by Mr. Kulda); a red mineral (realgar?) occurring sparsely as minute seams in the massive quartz; a few needle-like prisms of a gray metallic mineral (bismuthinite?, stibnite?) in the cavities with koechlinite; and three unidentified minerals found directly associated with the koechlinite.

The contents of some of the cavities were removed, and the larger crystals were picked out for measurement and analytical purposes. The remaining fine material was then embedded in cooked balsam dissolved in chloroform, which was then allowed to harden by gradual evaporation of the chloroform. The material in these microscopic slides was therefore not subjected to any heat. Many perfect crystals of koechlinite were found in this fine material, and their habit and optical properties could be well studied under the microscope. A group of three such crystals in parallel position is shown in figure 1. The very high index of refraction of the mineral gives all the crystals a thick black border, due to total reflection. The striations on the tabular crystals are vertical and the bounding faces of the crystals are those of the unit pyramid. The angle of the edges $(111)-(\bar{1}11):(1\bar{1}1)-(\bar{1}\bar{1}1)$ is 90° 08′, thus giving the rectangular shape to the crystals.

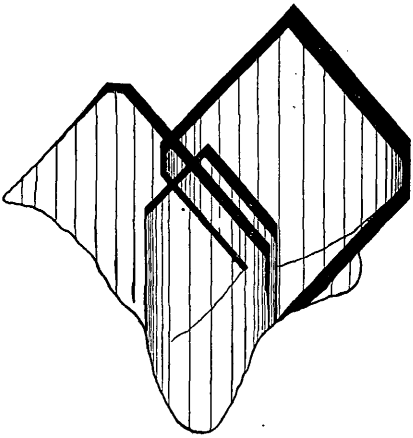

FIGURE 1.

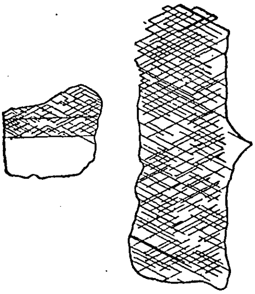

FIGURE 2.

FIGURE 1.—A group of three crystals of koechlinite in parallel position. The heavy black border is caused by total reflection due to the very high refractive index of the mineral.
FIGURE 2.—Sketch of unknown mineral A associated with koechlinite.

The associated minerals became concentrated in the material forming the slides by the removal of the larger koechlinite crystals, and the description of these associated minerals is based entirely on the microscopic observations made on the slides.

The metallic associaets have already been given. Besides quartz, three nonmetallic minerals, none of which could be identified, were observed with the koechlinite. It does not necessarily follow, however, that any of them are new. For convenience of description these three associated minerals are called unknown A, B, and C, respectively.

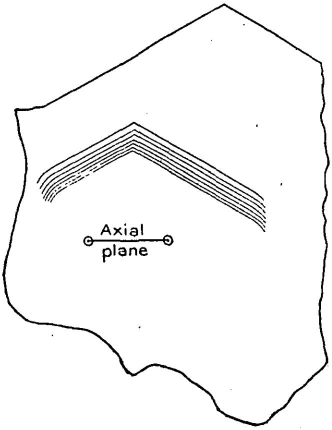

FIGURE 3.—Sketch of unknown mineral B associated with koechlinite.

Unknown mineral A was observed in about half a dozen pieces. Nearly all of them have an irregular outline which in small part is bounded by cleavage directions. A single fragment showed one apparently straight outline, bisecting the cleavage lines. The cleavage is very prominent and permeates the entire mineral, breaking up the fragment into numerous rhombs with an acute angle of about 52°. Figure 2 is a diagrammatic sketch of two such fragments. The color of the transparent and isotropic mineral is a light to dark brown. No interference figure could be obtained from any of the fragments.

Unknown mineral B is abundant as small mica-like scales, which for the most part are devoid of any regular outline, although here and there are scales that have a more or less regular boundary. The most perfect of these have a hexagonal shape and extinguish parallel to one pair of sides. One of the larger fragments observed is sketched in figure 3. The two straight sides at the top are inclined to each other at an angle of about 57°, and each was inclined about 62° to the extinction. The mineral is colorless and transparent and has a moderate to low double refraction. The parallel markings shown are parallel to the two straight sides. The axial angle is small and negative.

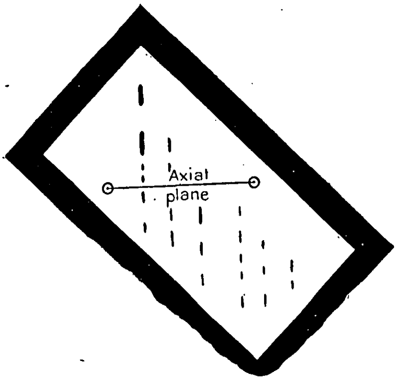

FIGURE 4.—Sketch of unknown mineral C associated with koechlinite.

Unknown mineral C was observed about a dozen times, either as well-formed isolated crystals or intergrown with koechlinite. The crystals have the same shape and orientation as those of koechlinite and consist of the macropinacoid {100} large, bounded by faces of the unit pyramid {111}. The crystals of unknown mineral C are at once distinguished from koechlinite by their lack of color and much lower double refraction. The very high index of refraction and the comparative thickness gives these crystals a very broad border of black, due to total reflection, as shown in figures 4 and 5. They have a more constant habit than koechlinite, nearly all of them being about twice as long as wide. The vertical striations are not prominent, and one crystal showed vertical lines of minute inclusions, as shown in figure 4, which well illustrates the shape and appearance of the crystals. The crystals of unknown mineral C are twinned similarly to those of koechlinite. One crystal, between crossed nicols, showed a complex twinning (as illustrated in fig. 5) very similar in kind to that exhibited by koechlinite and shown in figure 20 (p. 24).

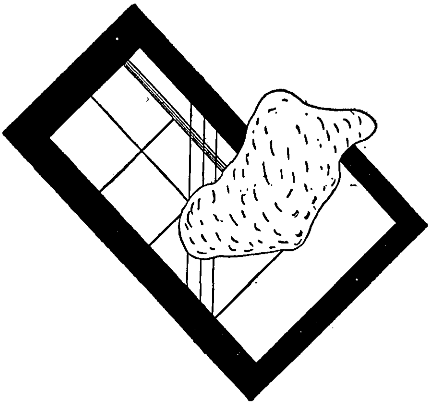

FIGURE 5.—Sketch of complex twin of unknown mineral C associated with koechlinite.

The crystals of unknown mineral C have a low birefringence, the interference colors being generally of the first order, even on the thicker crystals, whereas the thinnest cleavage plates of koechlinite seldom show colors below the third order. The axial plane of unknown mineral C is parallel to *c*{001}, as in koechlinite, and the axial angle is very large, *2E* being greater than the field of the microscope.

Koechlinite is clearly a secondary mineral formed in the cavities of the quartz rock by the reaction of different solutions, one containing bismuth and the other molybdenum. Some of the cavities lined with quartz crystals are free from any other mineral.

CRYSTALLOGRAPHY.

GENERAL CHARACTER OF CRYSTALS.

All the koechlinite occurs in distinct crystals. Eight of these were measured on the goniometer, but in addition a large number were examined under the microscope, for with the knowledge obtained from the goniometer measurements the combinations of the crystals seen under the microscope could be easily deciphered. The crystals measured average about 0.5 millimeter in greatest length. The crystals on the specimens range in size from minute ones to those having a length of about 1 millimeter. The width of the crystals is either equal to or about half the length, and the third dimension is very small, as the crystals are all very thin and tabular in habit. The combinations observed on many of the crystals are simple, and in fact most of the crystals show only two or three forms. The general appearance of the crystals is shown in figure 6, and as the angle between the opposite pyramids is nearly 90°, the crystals appear as rectangular plates with diagonal striations. A marked feature of these crystals which heightens the impression that they are rectangular plates is a tendency for distortion in that the crystal is elongated parallel to one of the intersection directions of *a*{100} with *p*{111}, thus producing the effect shown in figure 7.

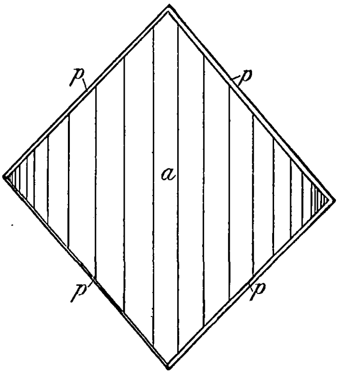

FIGURE 6.—Common appearance of crystals of koechlinite, simulating rectangular plates. Forms: *a*{100}, *p*{111}.

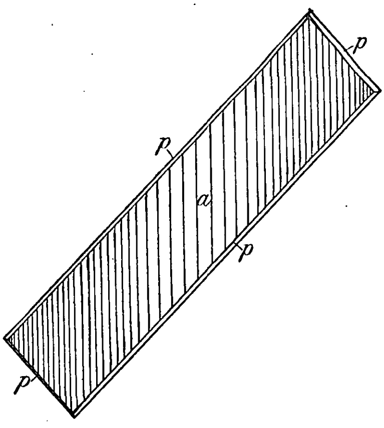

FIGURE 7.—Distorted crystal of koechlinite, elongated parallel to one of the intersected directions of *a*{100} with *p*{111}.

Apparently the crystals should be so oriented that the edges *a*{100}: *p*{111} are vertical and horizontal, but the direction of the striations on *a*{100} shows the true position, which is verified by the angle measurements. The crystals are both simple and twinned.

CALCULATION OF ELEMENTS.

The crystals of koechlinite are orthorhombic, and the measurements of the unit pyramid are utilized for the calculation of the elements. The prism zone being vertically striated, the crystals were readily adjusted in polar position, and measured on the two-circle goniometer. The value for v_0 was found by averaging the readings on $a\{100\}$ and the theoretic readings on $b\{010\}$ obtained by averaging the corresponding pairs of v readings of the unit pyramids $\{111\}$. The signals reflected from the large faces of $a\{100\}$ were sharp and bright, whereas those from the very narrow pyramid faces were mostly faint and not very distinct. The measurements on five crystals show fairly good agreement, though future measurements of larger and better crystals would doubtless yield more accurate results. The values obtained are as follows:

Measurements of unit pyramid.

Crystal 1.		Crystal 2.		Crystal 5.		Crystal 7.		Crystal 8.	
ϕ	ρ	ϕ	ρ	ϕ	ρ	ϕ	ρ	ϕ	ρ
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
45 42	55 02	45 40	55 07	45 26	55 00	45 20	55 59	46 10	54 58
45 27	54 55	45 42	55 10	45 47	55 05	45 51	55 04	45 48	54 59
45 26	55 08	45 27	55 01	45 49	55 09	45 58	55 10	47 34	54 59
45 38	55 21	45 50	55 08	45 36	55 05	45 48	54 33	45 03	55 20

From the average of these measurements the values $p_0 = 1.0258$, $q_0 = 1.0026$, and the axial ratio $a : b : c = 0.9774 : 1 : 1.0026$ are obtained. The axial ratio of koechlinite is very close to the 1 : 1 : 1 ratio of the isometric system, but in its tabular habit and perfect cleavage parallel to $a\{100\}$, the mineral differs greatly from one of isometric character.

FORMS AND ANGLES.

A total of 13 forms was determined on the crystals of koechlinite. These are as follows:

Pinacoids: $b\{010\}$, $a\{100\}$.
Prisms: $l\{130\}$, $n\{230\}$, $j\{450\}$, $m\{110\}$, $h\{430\}$, $k\{210\}$.
Pyramids: $p\{111\}$, $r\{322\}$, $s\{533\}$, $u\{131\}$, $x\{362\}$.

The average of the measured angles as compared with the calculated values is shown in the following list:

Measured and calculated angles of koechlinite.

No.	Letter.	Symbol.		Measured.		Calculated.	
		Goldschmidt.	Miller.	ϕ	ρ	ϕ	ρ
				° ′	° ′	° ′	° ′
1	*b*	0∞	010	0 29	90 00	0 00	90 00
2	*a*	∞0	100	90 00	90 00	90 00	90 00
3	*l*	∞3	130	17 46	90 00	18 50	90 00
4	*n*	$\infty\frac{3}{2}$	230	34 55	90 00	35 32	90 00
5	*j*	$\infty\frac{5}{4}$	450	39 20	90 00	39 18	90 00
6	*m*	∞	110	44 09	90 00	45 39	90 00
7	*h*	$\frac{4}{3}\infty$	430	53 10	90 00	53 45	90 00
8	*k*	2∞	210	65 07	90 00	63 57	90 00
9	*p*	1	111	45 39	55 07	45 39	55 07
10	*r*	$\frac{3}{2}1$	322	55 56	60 54	56 55	61 26
11	*s*	$\frac{5}{3}1$	533	58 55	62 55	59 37	63 14
12	*u*	13	131	18 22	72 09	18 50	72 32
13	*x*	$\frac{3}{2}3$	362	27 13	73 21	27 06	73 31

a{100}. The macropinacoid, parallel to which there is a good cleavage, is the dominant form of koechlinite, and all the crystals are tabular parallel to this form. The faces are vertically striated. Nearest the prism faces the striations become prominent enough to round the face and to give a blurred distended reflection, but the larger part of the face gives a bright and clear reflection. The macropinacoid and the unit pyramid are the only two forms which were observed on all the crystals examined.

b {010}. The brachypinacoid was observed on four crystals, as small and narrow faces. The reflections were very poor and the ϕ measurements gave −0°07′, +0°22′, +2°06′, −0°27′, instead of 0°00′. On crystal 8 the face was uneven and vertically striated.

l {130}. The single face of this form is a short line face giving a very poor reflection.

n {230}. The prism *n* is the third most prominent form, and although it was observed on only five of the eight measured crystals, it was determined to be present on many of the crystals studied microscopically. In fact, it is the dominant prism form of the mineral, many crystals showing only the three forms *a*, *p*, *n*. (Compare figs. 12, 13, and 14, on pp. 21, 22.) The measurements of this form are as follows:

Measurements of ϕ angle of n{230}.

Crystal No.	Size.	Reflection.	Measured.	Calculated.
			° ′	° ′
1	Minute	Glimmer[a]	34 18	35 32
1	do	do	34 50	35 32
1	do	do	33 03	35 32
2	Short, broad line face.	Poor	36 22	35 32
5	Line face	Glimmer[a]	36 04	35 32
5	do	do	36 09	35 32
6	do	do	37 42	35 32
6	do	do	33 03	35 32
6	do	Poor	35 00	35 32
7	do	Glimmer[a]	33 13	35 32
7	Broad line face.	Poor	34 26	35 32

[a] Measured by position of brightest illumination, which was generally only a glimmer.

j {450}. The two observed faces of *j* are mere line faces giving an exceedingly faint reflection. The measured ϕ angles (39°22′ and 39°18′) agree well with each other and with the calculated angle (39°18′).

m {110}. The unit prism was seen only once as a line face giving a poor reflection.

h {430}. The four faces of *h*, observed on as many crystals, are all line faces giving poor reflections. The measured ϕ angles are 51°41′, 52°33′, 53°41′, 54°46′ (calculated 53°45′).

k {210}. The single face of *k* is a line face yielding only a glimmer of light.

p {111}. The unit pyramid is the dominant terminal form, and is present on all crystals examined. It is as a rule long and narrow, rarely becoming broader, whereby the whole crystal becomes thicker. It is striated in the zone (100): (111): $(\bar{1}11)$: $(\bar{1}00)$.

r{322}. This pyramid occurs as a very narrow line face between *a* and *p*. The reflections were considerably distended on account of the minute width of the faces, and they could not be measured with great accuracy. The form was definitely determined on only one crystal (No. 2) but is probably present on some of the other crystals. The measured angles are as follows:

ϕ meas. = 56°33′ ϕ calc. = 56°55′. ρ meas. = 61°10′ ρ calc. = 61°26′.
ϕ meas. = 55°19′ ρ meas. = 60°37′

s{533}. The faces of *s*, like those of *r*, are the merest line faces, and their measurements are likewise not very accurate. The form was identified positively on four crystals but may be present on several more. The two forms *r*{322} and *s*{533} were not both determined on the same crystal. The measurements for *s* are given in the following table:

Measurements of s{533}.

Crystal No.	Measured.		Calculated.	
	ϕ	ρ	ϕ	ρ
	° ′	° ′	° ′	° ′
5	59 09	63 32	59 37	63 14
5	58 52	62 50	59 37	63 14
5	58 48	62 50	59 37	63 14
5	59 23	62 50	59 37	63 14
7	58 57	62 37	59 37	63 14
8	58 22	62 50	59 37	63 14

The following interfacial angles were measured on crystal 3. Only *a*{100} gave good reflections.

Interfacial angles measured on crystal 3 of koechlinite.

Angle.	Measured.	Calculated.
	° ′	° ′
$a:p=(100):(111)$	54 27	54 05
$a':p'=(\bar{1}00):(1\bar{1}1)$	54 10	54 05
$a':p''=(\bar{1}00):(1\bar{1}\bar{1})$	54 00	54 05
$a:p'''=(100):(11\bar{1})$	54 05	54 05
$a:s=(100):(533)$	40 08	39 38
$p:s=(111):(533)$	13 52	14 27
$p:r=(111):(322)$	....	11 28

u{131} and *x*{362}. These two pyramids were measured only once, both forms showing a well-developed face on crystal 7 (fig. 28, p. 26). It is believed that additional occurrences of these forms were seen on other crystals under the microscope, but they could not be positively identified. On crystal 7 the face of *u*(131), although striated somewhat in the zone *u a*, gave a fair reflection. The face of *x*(362) is a line face between *u* and *a* and gave a poor reflection. The measured and calculated angles (given on p. 16) agree well.

From their occurrence the thirteen forms may be grouped as follows:

Common forms: *a*{100}, *p*{111}, *n*{230}.
Less common forms: *b*{010}, *h*{430}, *j*{450}, *s*{533}.
Rare forms: *m*{110}, *l*{130}, *k*{210}, *r*{322}, *u*{131}, *x*{362}.

COMBINATIONS.

The combinations observed on the eight crystals measured are shown in the following table:

Combinations of koechlinite crystals.

Form.	Crystal No.								Percentage of occurrence.	Illustrated in figures—
	1	2	3	4	5	6	7	8		
a{100}	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	100	6, 7, 11–14, 21, 23–29.
b{010}	*b*	....	....	*b*	....	....	*b*	*b*	50	11, 28.
l{130}	....	....	....	....	....	*l*	....	....	13	
n{230}	*n*	*n*	....	....	*n*	*n*	*n*	....	63	11–14, 21, 23–29.
j{450}	....	....	....	....	....	....	*j*	*j*	25	
m{110}	....	....	....	....	....	*m*	....	....	13	
h{430}	*h*	....	....	....	....	*h*	*h*	*h*	50	
k{210}	....	....	....	....	*k*	....	....	....	13	
p{111}	*p*	*p*	*p*	*p*	*p*	*p*	*p*	*p*	100	6, 7, 11–14, 21, 23–29.
r{322}	....	*r*	....	....	....	....	....	....	13	26.
s{533}	....	....	*s*	....	*s*	....	*s*	*s*	50	25, 28.
u{131}	....	....	....	....	....	....	*u*	....	13	28.
x{362}	....	....	....	....	....	....	*x*	....	13	28.

The common combinations observed on many crystals not measured are *a p, a n p, a b n p,* with occasional modifications due to rarer forms such as probably *h* and *s*.

ZONAL RELATIONS AND MARKINGS.

All the 13 forms of koechlinite lie in three zones, the prism zone, with *b l n j m h k a;* the pyramid zone *m p* with *m s r p;* and the pyramid zone *a x u,* as shown in figure 8. The three zones above named are all striated, and the intensity of the striation varies directly as the number of forms in that zone.

In addition to the regular striations there are markings of two other kinds on some of the crystals of koechlinite which deserve brief mention. Both kinds were observed under the microscope on the *a*{100} faces.

The surfaces of a few of the crystals are crowded with a mass of acute-angled markings, nearly equal in angle and nearly parallel. The acute points all face in one direction, as shown in the freehand sketch reproduced in figure 9. The symmetry of such markings indicates hemimorphism.

The markings of the second kind consist of straight lines, forming regular closed figures, one side of which is parallel to the vertical axis and the other side parallel to the intersection edge *a p* (shown in fig. 10). The vast majority of the lines parallel to the intersection edge *a p* are in one direction. In the drawing shown in

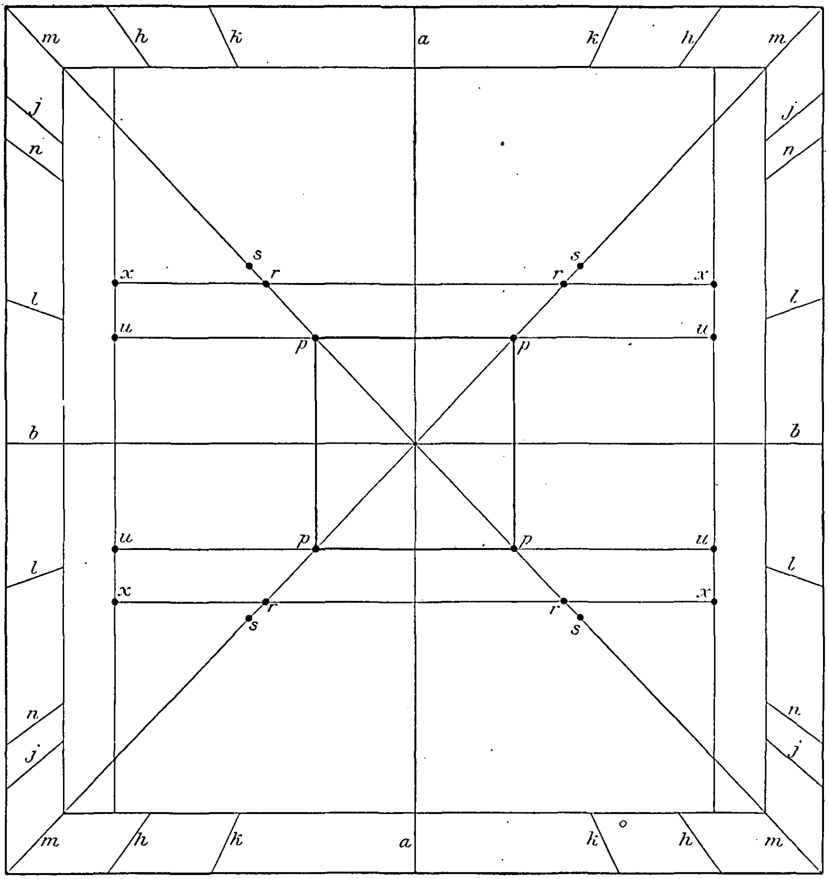

FIGURE 8.—Gnomonic projection of koechlinite forms.

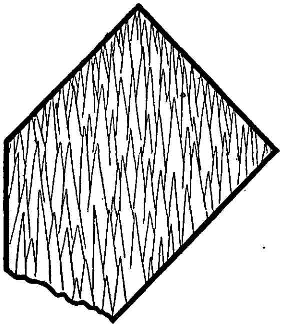

FIGURE 9.

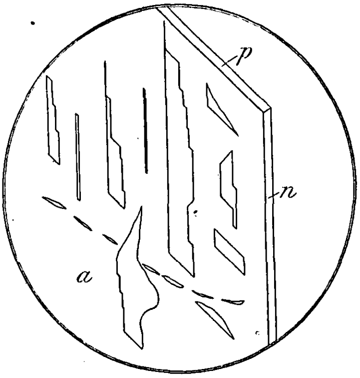

FIGURE 10.

FIGURE 9.—Acute-angled markings on $a\{100\}$, koechlinite.
FIGURE 10.—Regular markings on $a\{100\}$, koechlinite. Note excessive development of lines parallel to intersection $a(100)$-$p(111)$ over those parallel to intersection of $a(100)$-$p'(1\bar{1}1)$.

figure 10 only two of these lines are parallel to the edge (100)–$(1\bar{1}1)$, whereas, as drawn, there are 31 lines parallel to the edge (100)–(111). The string of bubbles shown in the lower part of the figure are also approximately parallel to the edge (100)–(111). Such a preference to one of two supposedly equal directions naturally suggests hemimorphic development. The markings shown in figure 9 suggest hemimorphism in the direction of the vertical axis, whereas those shown in figure 10 suggest hemimorphism in the direction of the edge *a p*, which is inclined 45° to the vertical axis. The peculiarly distorted crystals (shown in fig. 7) in which the crystals are elongated parallel to one of the intersection edges of *a* and *p* also suggest the possibility of a hemimorphic development. Opposed to such an idea, however, are the holohedral distribution of the faces as determined on many crystals and the lack of conclusive evidence from the etch figures.

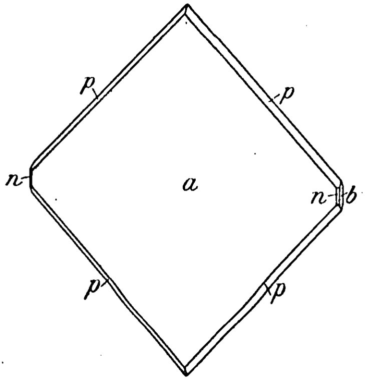

FIGURE 11.

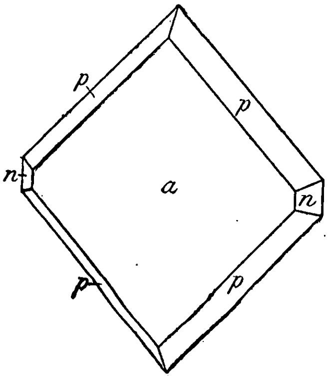

FIGURE 12.

FIGURE 11.—Square tabular habit of koechlinite (crystal 1). Forms: *a*{100}, *b*{010}, *n*{230}, *p*{111}.
FIGURE 12.—Stout tabular crystal of koechlinite. Forms: *a*{100}, *n*{230}, *p*{111}.

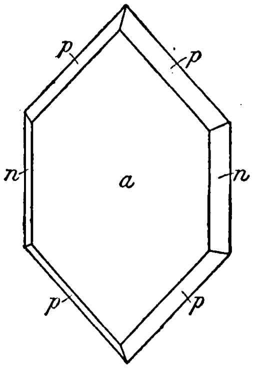

FIGURE 13.—Intermediate habit of koechlinite.

HABITS.

All the crystals of koechlinite are tabular in habit, but the thin tablets vary in shape from square ones to elongated ones, as already shown in figures 6 and 7.

The square tablets are very abundant and either consist of only the two forms *a*{100} and *p*{111} (see fig. 6, p. 14) or else have two of their edges modified by forms of the prism zone, as for example the first crystal measured, shown in figure 11.

A few crystals are not so thin as this one, and these slightly stouter crystals are also somewhat elongated parallel to the vertical axis. Such crystals were observed only under the microscope, but their combination could be determined to be *a n p*, with possibly other forms present as line faces that would not modify the habit of the crystals. The approximate relative thickness and size of three such crystals, chosen to show the variation in habit, are reproduced in figures 12, 13, and 14.

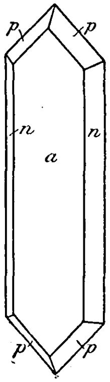

FIGURE 14.—Koechlinite crystal elongated parallel to the vertical axis.

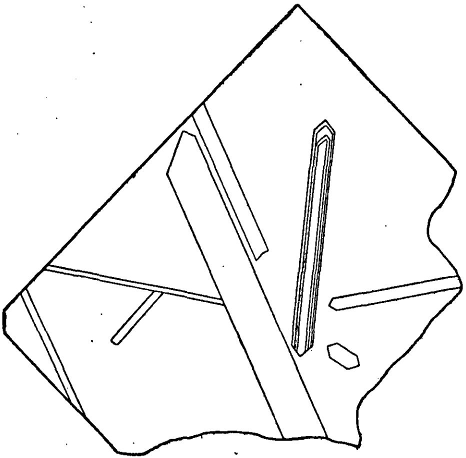

FIGURE 15.—Small prismatic crystals of koechlinite included in a larger square one.

Included in larger square crystals are a few small prismatic crystals which are an extreme example of elongation parallel to the vertical axis, as shown in figure 15. Such crystals were not observed by themselves, but as inclusions in larger ones they are not rare. They have a characteristic platy structure that was not seen on the individual short prismatic crystals (fig. 14). Figure 15 shows a sketch of a number of such minute prismatic crystals included in a larger square one. Some of these included prismatic crystals may be in twin position, either to each other or to their larger host, but not all of them are thus regularly oriented.

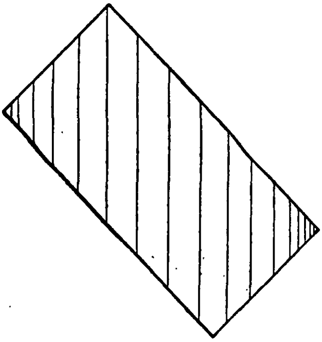

FIGURE 16.

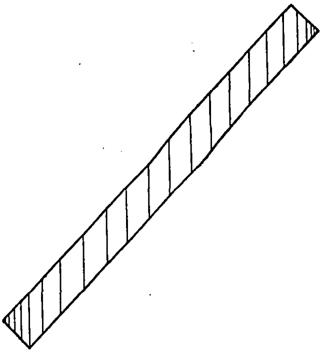

FIGURE 17.

FIGURE 16.—Common extent of elongation parallel to edge $a(100) \cdot p(111)$ of crystal of koechlinite.
FIGURE 17.—Extreme case of distorted elongation parallel to edge *a p* noted on crystal of koechlinite.

Some of the tabular crystals are grouped together in parallel position and the individual crystals show neither exactly the same habit nor the same combination, although in general they are very similar. One such group, as it appeared under the microscope, is reproduced in figure 1 (p. 11). In this group the central crystal is decidedly elongated parallel to the vertical axis, whereas the one on the right is nearly square.

In addition to the vertical extension of the prismatic crystals (figs. 13 and 14), the elongation parallel to one set of intersection edges of the unit pyramid *p* with the macropinacoid *a* is prominently developed. An example of such elongation has already been shown in figure 7 (p. 14), but the most abundant of such distortions occur where the elongation is about twice the width of the crystal, as shown in figure 16.

It is to be noted that contact twins of square habit will yield a crystal of similar shape to that shown in figure 16, but the difference in direction of the striations on *a*{100} at once differentiates these twin crystals (compare fig. 18) from the simple ones. The extreme observed distortion in a single crystal along the edge *a p* is shown in figure 17. The elongation of this crystal is 11 times its width.

TWINNING.

Twinning is common for koechlinite, and both contact and penetration twins occur. The twinning plane is the unit brachydome {011}, a form not observed on any of the crystals. By such twinning the faces of the macropinacoid *a* remain in the same plane, and as the angle (010) : (011) is 44° 56′, the angle between the twinned and untwinned adjacent faces of (011) is only 0° 08′, being thus so small as to be hardly detectable under the microscope. Consequently the different parts of a twin crystal extinguish so nearly the same that no difference can be seen under the microscope. In fact, in thin cleavage pieces a twin crystal can not be told from a simple one. On the thicker crystals a slight difference in shade of color, due to the pleochroism, can be noticed for the parts of a twin crystal. If the natural faces of *a*{100} are present, the striations on it at once furnish a satisfactory means of deciphering the twinning structure.

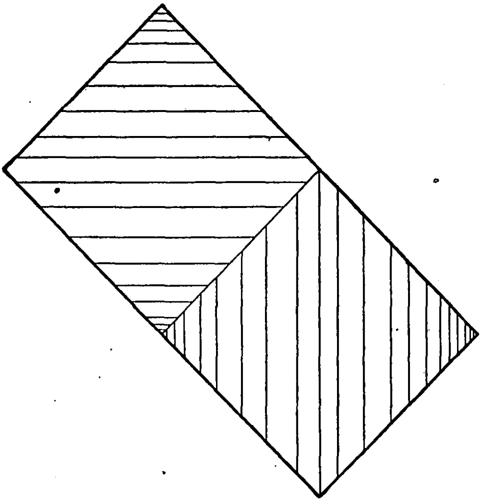

FIGURE 18.—Contact twin of koechlinite. Composition face is {011}. Compare figure 16.

In the contact twins the composition face is either {011} or {100}. If the twinning plane is the composition face, then the twinned crystal resembles in shape a simple crystal elongated parallel to the edge *a p* (as shown in fig. 16), but the difference in striations on *a*{100} suffices to differentiate them. Twins in which the composition face is *a*{100} are rare. These two varieties of contact twins are shown in figures 18 and 19.

By a repeated or synthetic twinning with {011} as composition face, a complex crystal may be built up. Figure 20 represents a cleavage piece of such a twinned koechlinite observed under the microscope. In the absence of the guiding striations on *a*{100} it is impossible to determine whether this is a repeated twin with {011} as composition face or a simple crystal with cleavage or parting lines parallel to *p*{111}. As no such cleavage or parting lines have been found on the mineral, however, it is more reasonable to refer the observed structure to repeated twinning.

A symmetrically twinned fourling, with {011} as composition face, would yield a regular figure, in which the parts would only lack a few minutes of forming a theoretically closed solid, such as is shown in figure 21. This sketch explains the structure of the penetration twins described in the following paragraphs. An example of a twin, with {011} as composition face, is afforded by crystal 6, drawn in clinographic projection (fig. 29, p. 27).

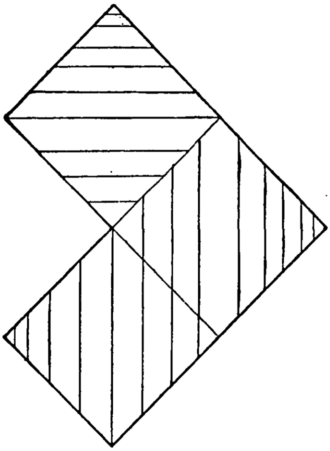

FIGURE 19.

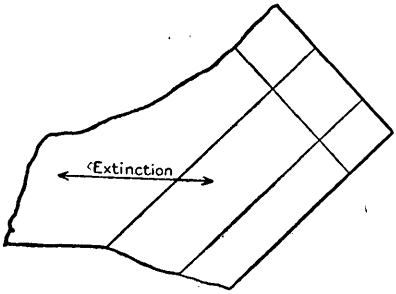

FIGURE 20.

FIGURE 19.—Contact twin of koechlinite. Composition face is *a*{100}.

FIGURE 20.—Cleavage piece of koechlinite, probably a polysynthetic twin with {011} as composition face.

Crystal 3 is an example of a crystal in which the two parts of a twin do not have the same combination. It is shown as it appeared under the microscope in figure 22.

The larger individual, elongated parallel to the edge *a p*, has the combination *a p*, whereas the smaller individual shows a prominent prism zone development. (Compare fig. 1, p. 11.)

The penetration twins are probably abundant, but unless the striated macropinacoid is present their detection is very difficult. Such a crystal, observed under the microscope, is shown in clinographic projection in figure 23.

A somewhat similar condition is presented by the imperfect crystal shown in figure 24 in orthographic projection on *a*{100}. The central part of the crystal (I) is in normal position, and III may be considered as belonging to the untwinned central part (I). Part II, in twin position to I, lies between it and III. Part III may nevertheless be just as well considered as twinned to II, even though this brings it into parallel position with I. The crystal is thus similar to the one just described and illustrated in figure 23. By referring back to the theoretical twin shown in figure 21, it is seen that this can be interpreted in two ways. First I and III (fig. 21) may be considered as the same untwinned unit, to which II and IV (as one unit) are twinned. A preferable explanation, however, is that the drawing represents a fourling, in which I is twinned on IV, II on I, and III on II. A similar explanation is believed to hold for the crystals shown in figures 23 and 24.

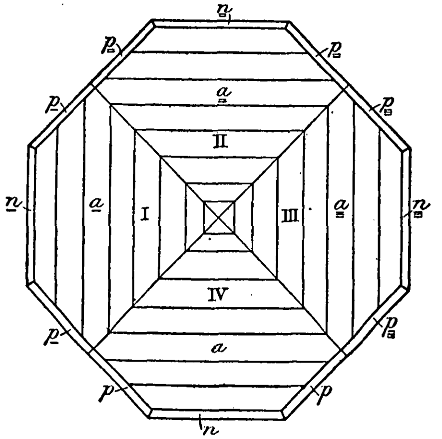

FIGURE 21.

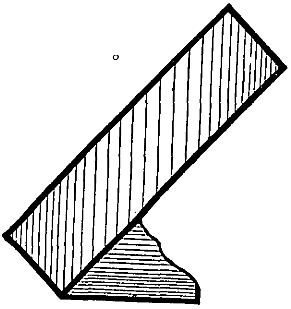

FIGURE 22.

FIGURE 21.—A theoretical fourling of koechlinite. Orthographic projection on $a\{100\}$. Forms: $a\{100\}$, $n\{230\}$, $p\{111\}$.

FIGURE 22.—Crystal 3, koechlinite. Contact twin with $\{011\}$ as composition face. The smaller individual has a different combination of forms from the larger one.

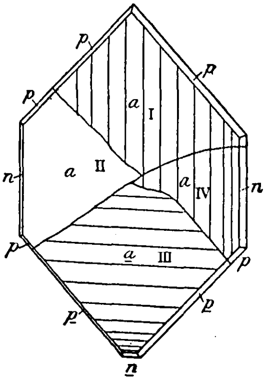

FIGURE 23.

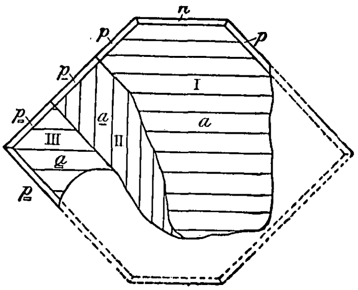

FIGURE 24.

FIGURE 23.—Clinographic projection of a penetration twin of koechlinite. The clear field (II) is free from striations, and its orientation is not known. The lower quadrant (III) is twinned on the upper one (I), and the remaining one (IV) may be considered as twinned on III, although it is in parallel position with the untwinned I. The continuity of the striations of I and IV would seem to indicate, however, that IV is not twinned but belongs inherently to I. Forms: $a\{100\}$, $n\{230\}$, $p\{111\}$.

FIGURE 24.—Orthographic projection on $a\{100\}$ of a penetration twin of koechlinite. Part II is twinned on I, and apparently III is twinned on II, yet III and I are in parallel position. Compare figure 23. Forms: $a\{100\}$, $n\{230\}$, $p\{111\}$.

MEASURED CRYSTALS.

Crystal 1, representing one of the square habit, with *a*{100}, *n*{230}, *b*{010}, and *p*{111}, is shown in figure 11 (p. 21). The form *h*{430} is not shown in the drawing.

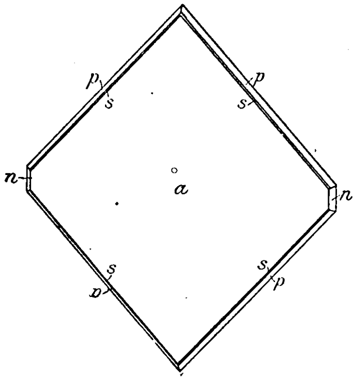

FIGURE 25.

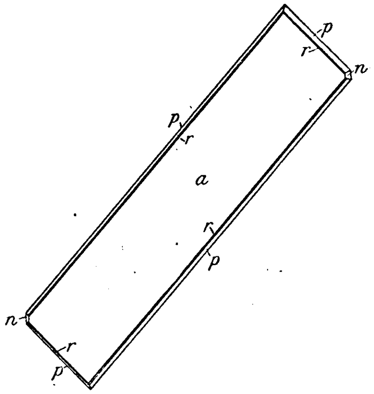

FIGURE 26.

FIGURE 25.—Crystal 5, koechlinite. Forms: *a*{100}, *n*{230}, *p*{111}, *s*{533}.
FIGURE 26.—Crystal 2, koechlinite. Forms: *a*{100}, *n*{230}, *p*{111}, *r*{322}.

Crystal 5 (fig. 25) represents one of similar habit, showing the line faces of *s*{533}. The rare prism *k*{210}, not shown in the figure, was observed only on this crystal.

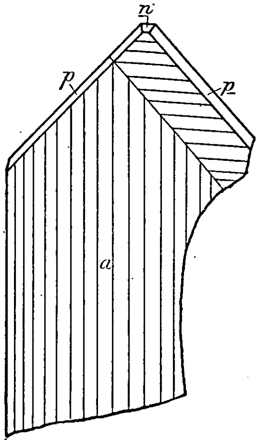

FIGURE 27.

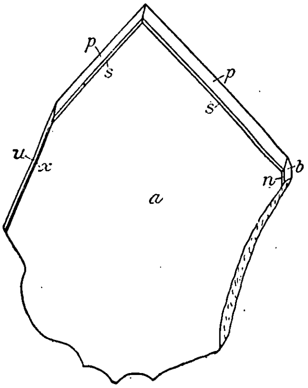

FIGURE 28.

FIGURE 27.—Crystal 4, koechlinite. Forms: *a*{100}, *p*{111}, *n*{230}.
FIGURE 28.—Crystal 7, koechlinite. Forms: *a*{100}, *b*{010}, *n*{230}, *p*{111}, *s*{533}, *u*{131}, *x*{362}.

Crystal 2 (fig. 26) is one of the distorted habit, elongated parallel to the edge *a p*. The pyramid *r*{322} is present with *p*{111}.

Crystal 4 (fig. 27) is interesting as showing a twinned portion of the crystal with a face of *n*{230} in the position of a macrodome.

The angle *a*{100}: *n*{230} (54° 28′) is close to the angle *a*{100}: (203) (56° 10′).

Crystal 7 (fig. 28) is the only one on which the two pyramids *u*{131} and *x*{362} were definitely determined. In addition to the forms shown in the drawing, the two prisms *j*{450} and *h*{430} were observed on this crystal.

Crystal 6 is shown in orthographic projection on *a*{100} in figure 29. The crystal is a well-developed contact twin with an irregular composition face, part of which appears to be *b*{010} in the upper part of the drawing, but which is more likely rather irregular. In addition to the forms shown in figure 29, faces of *l*{130}, *m*{110}, and {430} were determined on this crystal.

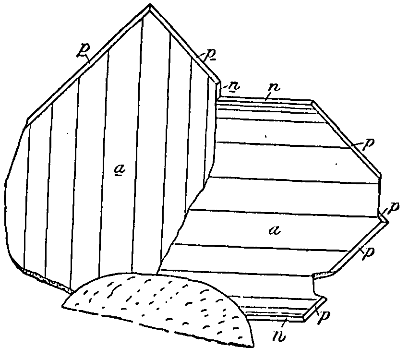

FIGURE 29.—Crystal 6, koechlinite. Orthographic projection on *a*{100} of twin crystal. Forms: *a*{100}, *n*{230}, *p*{111}.

ETCH FIGURES.

The symmetry of the markings observed on some of the crystals, coupled with the prominent distortion along one set of intersection edges of *a* and *p*, strongly suggested a deviation from holohedral symmetry, and the concealing twinning might give the distribution of the faces an apparently higher grade of symmetry than the mineral in reality possessed. Recourse was therefore had to the effect of etching by dilute hydrochloric acid, and very interesting results were obtained, although the evidence is of an apparently conflicting nature and is thought not to justify decisive conclusions.

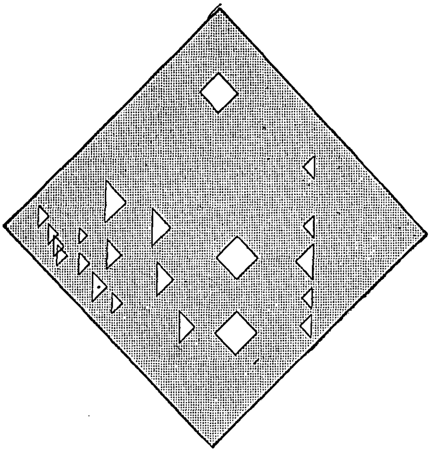

FIGURE 30.—First stage of etch figures produced on a symmetrically etched crystal of koechlinite.

Minute pits or etch figures are produced on the *a*{100} faces of koechlinite in a few minutes when a crystal is immersed in cold dilute hydrochloric acid (about 1:5). If the acid is drained off and weaker acid substituted the progress of the etching can be retarded and regulated. The effects produced can be readily studied by covering the crystal (on a glass slide) with a cover glass which, by its own weight, removes all but a film of solution from the *a* faces. The cover glass is then removed and fresh acid added to the crystal whenever it is desired to have the process of solution continue.

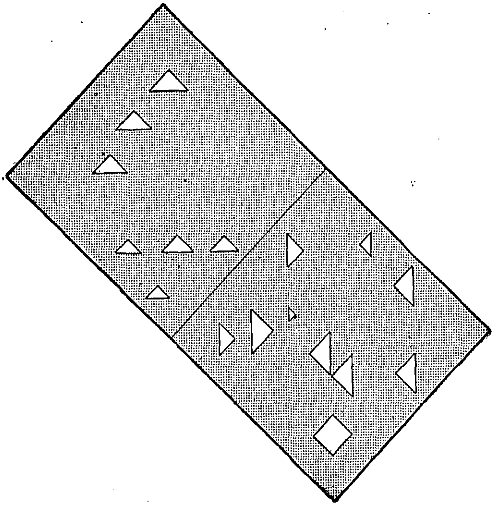

FIGURE 31.—First stage of etch figures produced on a twinned crystal of koechlinite.

The process of solution of the crystal in hydrochloric acid, as observed, was not continuous, nor were the conditions constant, as the concentration of the acid, for example, was changed a number of times. It is not believed, however, that these interruptions are the cause of the apparent inconsistent facts observed.

The first etch figures produced are triangular and rectangular in shape. The triangular ones are symmetrical to a horizontal plane but not to a vertical plane. Moreover, some face to the right and others to the left. The rectangular figures may be conceived as a combination of right and left triangular ones. The distribution of these three kinds of figures does not necessarily bear any relation to the crystal itself. Each kind has been observed scattered over part of the entire crystal. An exceptionally symmetrically etched crystal is sketched in figure 30. As can readily be seen, the right-facing triangles are all on one side and the left-facing triangles are all on the other side. The rectangular figures, which may be built up of right and left triangles, occur only in the center.

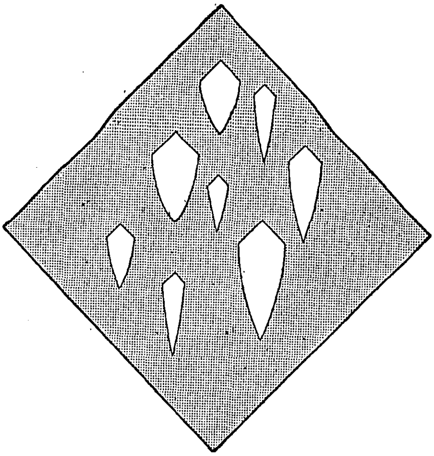

FIGURE 32.—Second stage of etch figures produced on koechlinite after the triangular figures.

A twin crystal shows similar etch figures, oriented in position with the twin part of the entire crystal, as shown in figure 31.

It is to be specially noted that these triangular etchings parallel with one another have an apparent hemimorphic symmetry in the direction of the *b* axis.

A little later etch figures are developed which, while hemimorphic in character, show this hemimorphism not in the direction of the *b* axis, like the triangular figures just described, but in the direction of the vertical or *c* axis. These etch figures are sketched in figure 32.

At a still later period the triangular etch figures have all developed into rectangular ones and the vertically hemimorphic figures into hexagonal ones. They are shown in figure 33 as they were observed on a twin crystal. In a number of instances the gradual change in shape and symmetry from an original hemimorphic etch figure to the final rectangular or hexagonal one was continuously observed under the microscope, and the changes, as noted, are given in figure 34.

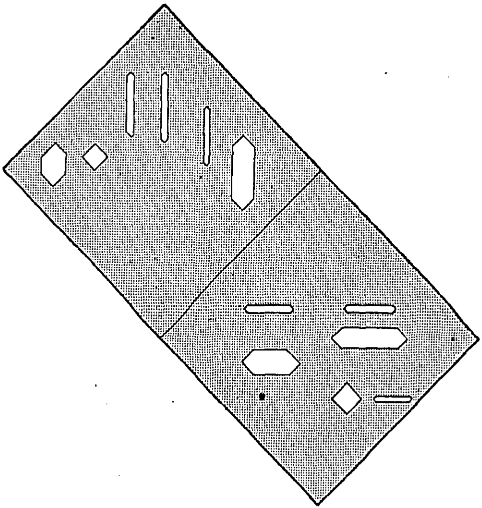

FIGURE 33.—Third stage of etch figures produced on a twinned crystal of koechlinite. All the figures now have holohedral symmetry.

The final effect observed was most remarkable. The remnant of the crystal was bounded by sharply rectangular lines and its interior was full of similarly sharply bounded rectangular holes, and the process of solution of the crystal continued in this way until the entire crystal was dissolved. The appearance of a corner of the crystal at a given moment is shown in figure 35.

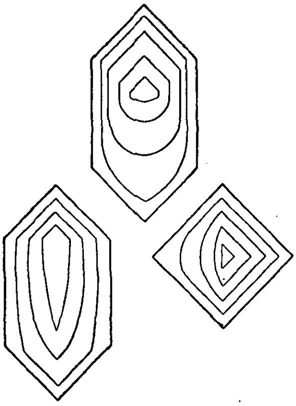

FIGURE 34.

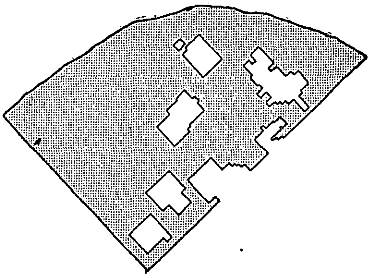

FIGURE 35.

FIGURE 34.—Last stage of etch figures produced on koechlinite. Change in shape and symmetry from figures with an original hemimorphic symmetry (inner outlines) to the final holohedral figures (outer outlines).

FIGURE 35.—Appearance of a corner of an etched and dissolving crystal of koechlinite.

The final etch figures developed on koechlinite by dilute hydrochloric acid are strictly holohedral in their symmetry, whereas those first produced are strongly hemimorphic. Is the symmetry of the figures first produced to be regarded as having no bearing on the symmetry of the mineral itself, or are the later holohedral etchings to be considered as twinned hemimorphic figures, thus ascribing to the mineral an intricate polysynthetic twinning? (See p. 21.)

The following observed facts seem to lend support to the idea of hemimorphic symmetry for koechlinite: The hemimorphic character of the markings observed on $a\{100\}$, the common distortion in untwinned crystals along one pair of edges *a p;* the unequal size of the different faces of a form on the same crystal; and the hemimorphic symmetry of the artificially produced etch figures, as shown in figures 30, 31, and 32.

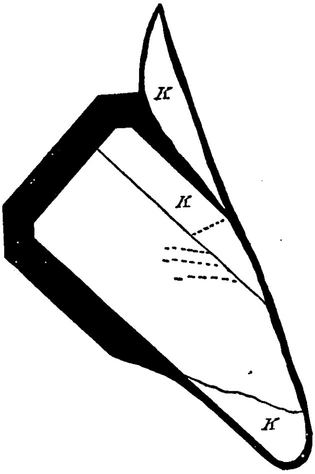

FIGURE 36.

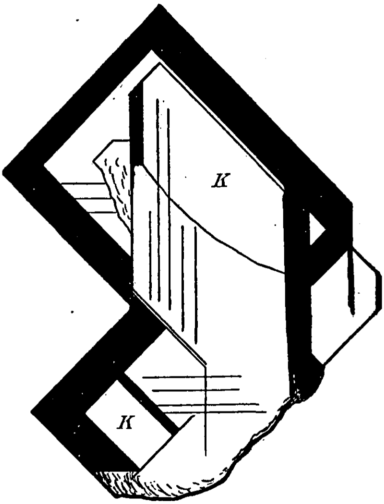

FIGURE 37.

FIGURE 36.—Intergrowth of unknown mineral C with koechlinite. The areas occupied by koechlinite are marked *K*.

FIGURE 37.—Intergrowth of unknown mineral C with koechlinite (*K*).

Opposed to the idea of hemimorphic symmetry of the crystals are the facts that the final etch figures are strictly holohedral in their symmetry and that the distribution of faces on the crystals favors holohedral symmetry, although it must be said that the measured crystals were not developed perfectly enough nor were the terminal faces sufficiently large to warrant a definite conclusion.

INTERGROWTHS.

Intergrowths of koechlinite with the colorless mineral described on page 13 as unknown mineral C were observed several times. The two minerals are, so far as the observations go, in parallel untwinned position, the striations being parallel. The contact line is straight in some intergrowths and very irregular in others. In the typical example of an intergrowth shown in figure 36 the main mass of the crystal consists of the colorless unknown mineral C and there are three smaller portions of koechlinite.

In the best developed example of this intergrowth, reproduced in figure 37, the main mass of the crystal consists of unknown mineral C twinned, and each twin portion contains intergrown koechlinite.

RELATION TO OTHER MINERALS.

There are no known minerals with which koechlinite shows a close analogy in type of chemical formula. The mineral jeremejevite has the formula $Al_2O_3.B_2O_3$, which, in type, conforms to the formula of koechlinite, but jeremejevite is hexagonal, although the so-called eichwaldite, intergrown with jeremejevite, has been interpreted as orthorhombic, with axes which, if doubled, are not far from those of koechlinite:

Eichwaldite, $2a:b:2c=1.1046:1:1.0868$.
Koechlinite, $a:b:c=0.9774:1:1.0026$.

A number of hydrous minerals are analogous to koechlinite in composition except for the water, but crystallographically they seem to show no close relation to koechlinite. These hydrous minerals are listed below.

Koechlinite	$Bi_2O_3.MoO_3$	Orthorhombic.
Montanite	$Bi_2O_3.TeO_3.2H_2O$.	
Ferritungstite	$Fe_2O_3.WO_3.6H_2O$	Hexagonal.
Utahite	$Fe_2O_3.SO_3.\frac{4}{3}H_2O$?	Hexagonal.
Planoferrite	$Fe_2O_3.SO_3.15H_2O$	Orthorhombic.
Aluminite	$Al_2O_3.SO_3.9H_2O$.	

Attention may be called to a furnace product which in composition is similar in type to koechlinite but of which unfortunately few crystallographic data seem to be available. This is a crystalline compound described by Pearce [1] and having, according to his analysis, the composition expressed by the formula $As_2O_3.SO_3$. The crystallographic data are too meager to warrant any conclusion as to the relation of the compound to koechlinite. Pearce describes it as follows:

> The usual condition of the material was small spear-shaped crystals of a pearly luster. * * * These crystals were in many cases more than 1 inch in size and

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[1] Pearce, Richard, On a remarkable crystalline compound of arsenious and sulphuric acids: Colorado Sci. Soc. Proc., vol. 3, p. 255, 1888-1890.

beautifully modified. The form will, in all probability, be found to be monoclinic. They are semitransparent to transparent; color, white; cleavage, perfect; luster, somewhat pearly and adamantine.

PHYSICAL PROPERTIES.

The cleavage of koechlinite is perfect parallel to the macropinacoid *a*{100}. A second imperfect cleavage seems to exist after some other form in the prism zone. The crystals are very brittle, breaking readily under the slighest pressure. The extreme thinness of most of the crystals naturally increases their tendency to break. The hardness and density are not known.

OPTICAL PROPERTIES.

The body color of the crystals is greenish yellow and corresponds to "oil-yellow" on Plate V of Ridgway's "Color standards.."[1] When heated but not fused the greenish-yellow crystals become brown, but on cooling they revert to their original color. The fused mineral becomes dark brown and on cooling suddenly changes to a very pale yellow which becomes white when cold. The luster is vitreous, slightly adamantine. The streak is pale greenish yellow. The crystals are transparent, the transmitted color being greenish yellow, like the body color.

A bisectrix emerges normal to the macropinacoid, and the trace of the axial plane is normal to the striations and therefore parallel to *c*{001}. The axial angle seen on *a*{100} is very large and the obtuse bisectrix probably emerges normal to *a*{100}. On this assumption the orientation of the mineral is as follows:

$$a \text{ axis} = Z$$
$$b \text{ axis} = X$$
$$c \text{ axis} = Y$$

If the *a* axis is the direction of the obtuse bisectrix, then the mineral is negative.

The refractive indices are very high. Mr. Esper S. Larsen kindly determined the index by the embedding method[2] and found $\beta_{Li} = 2.55$ with an estimated birefringence of about 0.1.

The crystals have a very slight pleochroism, observable only on the thicker ones. As observed on *a*{100}, the mineral is not pleochroic, except that on the thicker crystals the color is slightly deeper normal to the striations than parallel to the striations.

---

[1] Ridgway, Robert, Color standards and color nomenclature, Washington, 1912.

[2] Merwin, H. E., and Larsen, E. S., Mixtures of amorphous sulphur and selenium as immersion media for the determination of high refractive indices with the microscope: Am. Jour. Sci., 4th ser., vol. 34, p. 42, 1912.

CHEMICAL PROPERTIES.

PYROGNOSTICS.

The mineral fuses readily in a closed tube without giving off water or any sublimate. The color changes are described on page 32. The crystals dissolve readily in HCl but not so readily in HNO_3. The deep-blue color of a lower oxide of molybdenum is readily obtained by heating the mineral with concentrated H_2SO_4 and evaporating nearly to dryness in a white porcelain crucible. The bismuth iodide sublimate on charcoal is strong and characteristic.

QUANTITATIVE COMPOSITION.

The material analyzed was nearly free from inclusions except for admixed quartz. The three unknown minerals already described were present in only minute amounts in the samples analyzed, as the crystals of koechlinite were separately picked out of the material removed from the cavities. The mineral was at first taken to be Bi_2O_3, and as the first analysis totaled only 78.2 per cent, it was thought that a mistake had been made in the determination of bismuth. On a second sample a determination of bismuth gave the same result. As each analysis totaled less than 100 per cent, it was evident that an unrecognized constituent was present. Nearly all the remaining material was sacrificed in the determination of this unknown constituent, which was finally identified as molybdenum. Another specimen of the mineral had then to be utilized to obtain material for a quantitative determination of the molybdenum. The absence of the common bases and of any sulphate, phosphate, carbonate, borate, or tungstate radicle was qualitatively determined. The results obtained are shown below.

Analyses of koechlinite.

	1	2	3
Weight of sample......gram..	0.0925	0.1003	0.0424
Bi_2O_3	73.0	51.6	71.9
MoO_3	Not det.	Not det.	21.2
H_2O (loss on ignition)	.2	....	....
Quartz	5.0	34.1	5.4
	78.2	85.7	98.5

The results are restated below with the admixed quartz deducted, being thus reduced to a comparative basis.

Analyses and ratio of koechlinite with quartz deducted.

	1	2	3	Average.	Ratio.	Calculated.
Bi_2O_3	76.8	78.3	76.1	77.1	0.166 or 1.00	76.36
MoO_3			22.4	22.4	.155 or .93	23.64
H_2O	.2			.2		
	77.0	78.3	98.5	99.7		100.00

The ratio obtained leads to the formula $Bi_2O_3.MoO_3$, which can be interpreted as bismuthyl molybdate $(BiO)'_2.MoO_4$.

DIAGNOSTIC PROPERTIES.

The rectangular crystals with diagonal striations, and particularly the elongated distorted crystals, are very characteristic of koechlinite. The absence of water and a qualitative determination of bismuth and molybdenum on such crystals would positively identify koechlinite.

AREAL GEOLOGY

STATE OF OHIO
JUDSON HARMON, GOVERNOR
C.E.SHERMAN, INSPECTOR

U.S.GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

OHIO
COLUMBUS QUADRANGLE

LEGEND

SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines)

Period	Group	Symbol	Formation
CARBONIFEROUS	Mississippian	Cbh	Black Hand formation *(red to buff coarse sandstone)*
		Ccy	Cuyahoga formation *(bluish-gray argillaceous shale interbedded with fine-grained sandstone)*
		Cs	Sunbury shale *(black fissile bituminous argillaceous shale)*
		Cb	Berea sandstone *(fine-grained gray to buff sandstone)*
			UNCONFORMITY
		Cbf	Bedford shale *(bluish-gray to red clay shale)*
DEVONIAN	*Probably equivalent to Genesee, Portage, and Chemung formations*	Doh	Ohio shale *(bituminous black shale with large concretions)*
	Equivalent to Marcellus and Hamilton shales	Do	Olentangy shale *(soft blue calcareous and argillaceous shale)*
		Ddw	Delaware limestone *(blue cherty limestone and brown calcareous shale)*
	Equivalent to Onondaga limestone	Dc	Columbus limestone *(massive gray limestone, brown and magnesian towards base, with a basal limestone conglomerate)*
			UNCONFORMITY
SILURIAN	*Equivalent in part to Cayuga group*	Sm	Monroe formation *(compact drab banded limestone and much gypsum near the base not exposed)*

The rocks are largely concealed by glacial and alluvial deposits which are separately mapped on the Surficial-geology map

⚒ *Stone quarry*

Note: *Columbus limestone yields material suitable for building stone lime, flux, ballast, and road making. Delaware limestone for ballast and road making. Olentangy, Ohio, and Bedford shales may be used for making tile, brick, and building block. Cuyahoga formation yields some building stone.*

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

Topography and control by U.S. Geological Survey.
Reduced from Dublin, East Columbus, West Columbus, and Westerville atlas sheets.
Surveyed in 1899, 1901, and 1902.

SURVEYED IN COOPERATION WITH THE STATE OF OHIO.

Electric railroads added in 1912
from data supplied by State Geologist.

Scale $\frac{1}{125000}$
1 ½ 0 1 2 3 4 5 Miles
1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.
Edition of Jan. 1913

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Geology by Clinton R. Stauffer.
Surveyed in 1906 and 1907.

SURVEYED BY THE STATE OF OHIO.
J. A. Bownocker, State Geologist.

INYOITE AND MEYERHOFFERITE, TWO NEW CALCIUM BORATES.

RELATION OF MEYERHOFFERITE TO INYOITE.

Two specimens of large crystals having a rhombic shape were collected by Hoyt S. Gale, of the United States Geological Survey, in the Death Valley region of California. The fact that the mineral was a borate was determined, but its specific relation could not be fixed. As a preliminary examination failed to identify the specimens with any known mineral, they were delivered to the writer, who would here express his gratitude to Mr. Gale for his kindness in allowing the free use and description of the material.

The large crystals, whose rhombic shape could not be correlated with that of any known borate mineral, are opaque and covered with small shining, transparent colorless prismatic crystals. A broken surface of the rhombic crystals shows a peculiar reticulated structure formed by a white silky fibrous material. The inner structure of the large crystals, as revealed on the broken surfaces, indicated that a change had taken place and that the material now forming the crystals was different from that of which they were originally composed. The chemical investigation has confirmed this inference. When one of the large crystals was broken up a nucleus of fresh, unaltered glassy material was found in its center. By alteration this glassy material has changed into the silky fibrous material that now forms the bulk of the specimens.

The investigation has shown that both parts of the specimen are mineralogically new and that two distinct mineral species are present. The glassy material, of which the large rhombic crystals were originally formed, is here named inyoite. It is a hydrous calcium borate having the formula $2CaO.3B_2O_3.13H_2O$. Inyoite alters to a similar hydrous calcium borate with only seven molecules of water, which is here called meyerhofferite. The silky fibrous masses and the shining transparent prisms are but two different forms of meyerhofferite. Inyoite is therefore the parent mineral which has altered to an aggregate of fibrous and prismatic crystals of secondary meyerhofferite.

The two specimens are shown in Plate I and the forms of the secondary meyerhofferite are shown in Plate II.

NOMENCLATURE.

The name inyoite is derived from the locality where the specimens were found—Inyo County, Cal. The second of the new borates is named meyerhofferite after Wilhelm Meyerhoffer, who with J. H.

van't Hoff worked for many years on the composition of the saline minerals and so about 1906 came to study the calcium borates. His death occurred soon after he began his investigation of these borates and it seems that one of the very last of the salts studied by him was the compound $2CaO.3B_2O_3.7H_2O$. Now that this compound has been found in nature as a mineral, it is appropriately named after him.

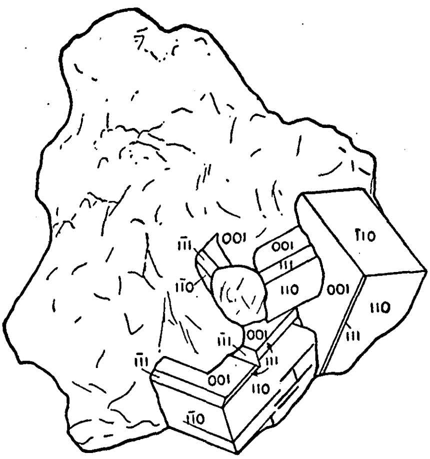


FIGURE 38.—Diagram illustrating crystal forms of inyoite shown in Plate I, *A*. The large crystal on the right was broken up, and glassy unaltered inyoite was obtained from its center. Nearly the entire specimen has altered to meyerhofferite.

LOCALITY AND PARAGENESIS.

The exact locality from which the specimens were obtained is a prospect tunnel in the Mount Blanco district, on Furnace Creek, near Death Valley, Inyo County, Cal. The following notes on the occurrence of the minerals have been supplied by Mr. Gale. The tunnel was referred to by Mr. Corkill, in charge of developments on the property, as the "jewelry shop," because of the display of beautifully crystalline colemanite throughout the greater part of its length. The tunnel had penetrated what Mr. Gale considered to be vein material in a rather unusual crystalline form. The glassy colemanite lay as if crystallized in large geodes formed of broad horizontally disposed cavities lined with coarsely drusy botryoidal bunches, the surfaces of which were completely covered with transparent crystals, with sharp edges and corners. In the light of the candles used to examine the tunnel the reflections from the myriads of minute sparkling crystal faces made a very brilliant display.

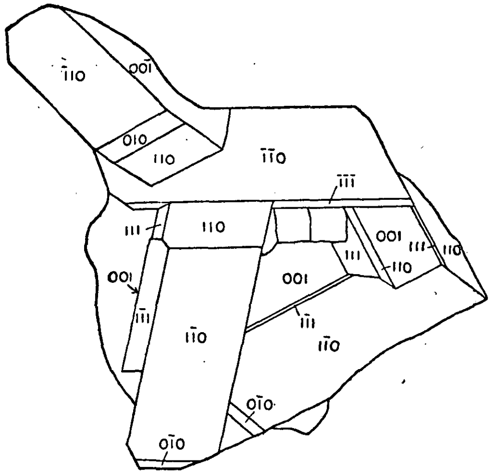
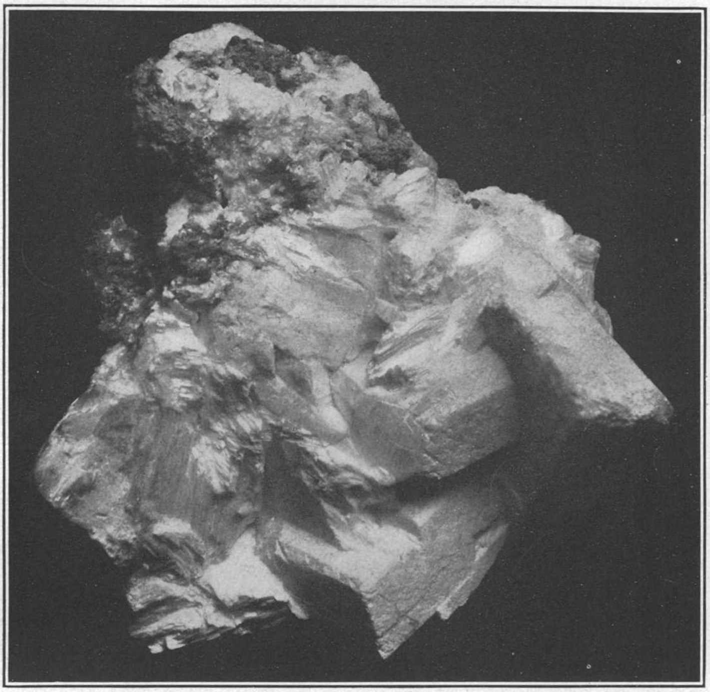
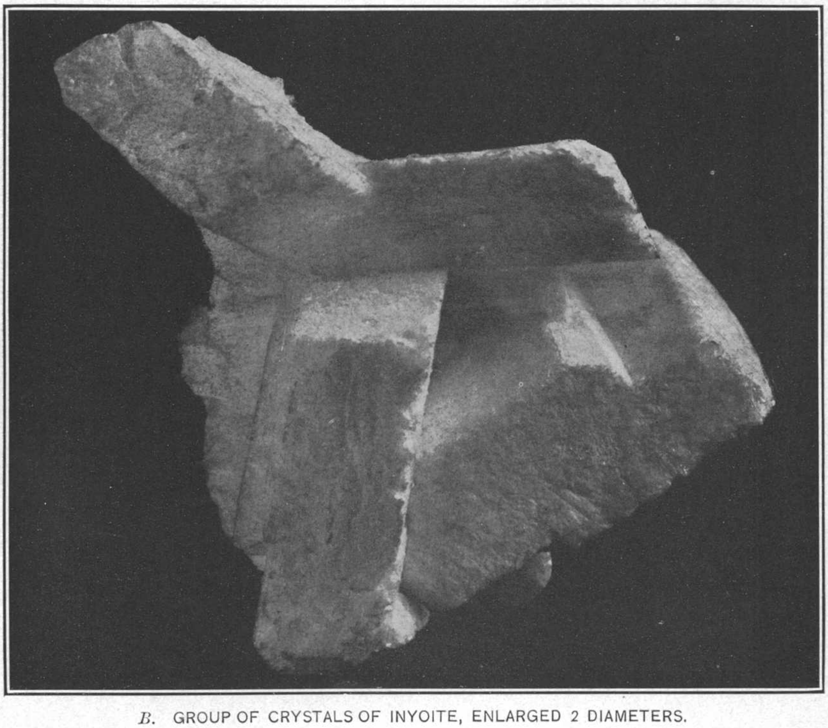


FIGURE 39.—Diagram illustrating crystal forms of inyoite shown in Plate I, *B*.

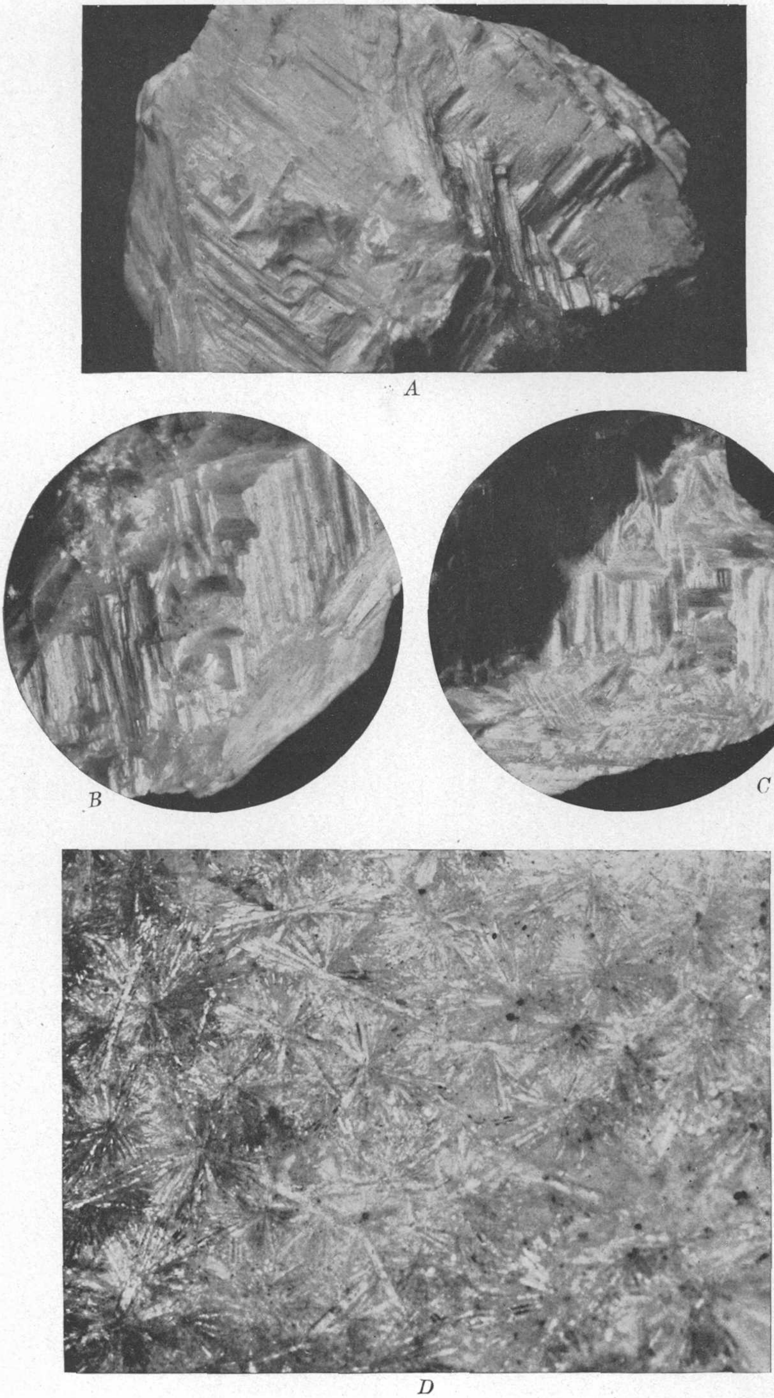
The two new minerals, inyoite and meyerhofferite, were directly associated with this colemanite, the particular specimens collected having been pried off in the geode-like cavities.



A. CRYSTALS OF INYOITE ON MASSIVE MINERAL, NATURAL SIZE.



B. GROUP OF CRYSTALS OF INYOITE, ENLARGED 2 DIAMETERS.



ALTERATION OF INYOITE TO MEYERHOFFERITE.

A, *B*, *C*. Reticulated structure of altered inyoite. Enlarged 2⅔ diameters. *D*. Stellate groups of crystals of meyerhofferite on the surface of cyrstals of inyoite. Enlarged about 7 diameters.

The new minerals are probably of similar origin to the colemanite, which is apparently an open-space vein filling, the deposit being in fissures cutting shales and sandstones composed largely of tuffaceous material, variously referred to in California and Nevada under the terms Rosamond series, Esmeralda series, and Siebert "lake beds." The veins are closely associated with interbedded volcanic flows, which consist of vesicular and locally amygdaloidal basalt, also with dikes of similar composition.

The colemanite from these deposits has not yet been mined commercially, and all the properties are still in the prospect stage. The Mount Blanco deposit has, however, often been referred to as the largest in the United States. Besides colemanite, it contains a very considerable quantity of pandermite. It is said that ulexite found in the surface soils of the hills below the colemanite vein was originally scraped and worked for borax along with the ulexite deposits in the valley.

INYOITE.

CRYSTALLOGRAPHY.

GENERAL CHARACTER OF CRYSTALS.

The large crystals of inyoite, as shown in Plate I, are so grown together that only a few angles could be measured on each crystal. Moreover, the alteration to meyerhofferite, particularly the development of stellate groups of prismatic crystals on the surfaces of the original inyoite crystals, as shown in Plate II, *D*, makes it difficult to obtain good measurements. A further trouble was found in that the only pyramidal form observed on inyoite was narrow and became considerably uneven and rounded by the alteration. The discovery of better crystals of inyoite, especially if unaltered, would necessitate a revision of the crystallographic data here presented.

Six crystals which afforded the most suitable material for measurement were utilized. The crystals are all simple and had the same general rhombic habit, as shown in Plate I and figure 40 (p. 38).

CALCULATION OF ELEMENTS.

The crystals are monoclinic, and the elements were calculated from the average of the following measurements made with a simple contact goniometer:

Measurements of angles of inyoite.

Angle.	1	2	3	4	5	6	Average.
(001):(110)	68°, 67°, 68°	71°, 70°	......	......	......	72°	69° 20′
(110):($1\bar{1}0$)	80°	79°	......	80°	80°	......	79° 45′
(110):(111)	35°	35°	38°	......	37°	......	36° 15′
(010):(001)	....	....	91°	......	......	......	....

From the three fundamental angles given, namely, (001) : (110) = 69° 20′, (110) : (1$\bar{1}$0) = 79° 45′, and (110) : (111) = 36° 15′, the axial elements were calculated and found to be as follows:

$$a : b : c = 0.9408 : 1 : 0.6665;\ \beta = 62^\circ\ 37'.$$

FORMS.

The total number of forms observed is four, as follows:

Pinacoids: *c*{001}, *b*{010}.
Prism: *m*{110}.
Pyramid: *p*{111}.

The basal pinacoid *c*{001} is the dominant form and the crystals are tabular parallel to this form. (Compare fig. 40.) It is also a direction of cleavage. The brachypinacoid is small and the least prominent form. It was observed on about half the crystals examined. The unit prism is medium in size and approximately one-third as large as the base. The unit pyramid varies in size, even on the same crystal, but is always much smaller than the prism.

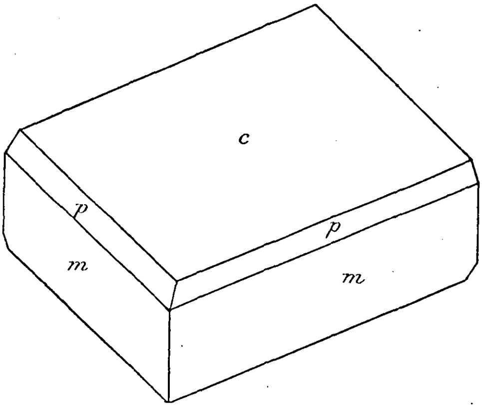


FIGURE 40.—Inyoite crystal. Forms: *c*{001}, *m*{110}, *p*{111}.

The relative size of the different forms and the general tabular habit are shown in figure 40.

PHYSICAL PROPERTIES.

The cleavage of inyoite is good parallel to the basal pinacoid *c*{001}. The lower crystal of the group shown in Plate I, *A*, shows this cleavage, and so do the fresh pieces of inyoite found in the interior of the large crystals. The fracture is irregular, and the mineral is brittle. The hardness is about 2. The density, determined by means of Thoulet solution, is 1.875.

OPTICAL PROPERTIES.

The fresh inyoite is glassy and colorless; the altered material (meyerhofferite) is white. The luster is vitreous, and the mineral is transparent, although the progressing alteration soon clouds the fresh mineral, making it opaque.

The optical orientation could not be determined, as the fresh pieces found in the interior of the large altered crystals showed no crystal boundaries. Cleavage pieces, parallel to the basal pinacoid, showed the emergence of an inclined bisectrix. The axial angle is large and negative. The angle *2E* for sodium light was measured as 118°. No change in this result could be observed for lithium or thallium light. Numerous markings on the base are nearly rectangular, having measured angles between 80° and 90°. These markings are apparently parallel to the unit prism and may represent the traces of an imperfect prismatic cleavage. On the assumption that the orientation of these markings on the basal cleavage is correct, the optical orientation of inyoite can be stated as follows: Axial plane parallel to *b*{010}; acute negative bisectrix obliquely emergent on *c*{001}.

The refractive indices were kindly measured by the immersion method by Mr. Esper S. Larsen, who obtained the following results:

$$\alpha=1.495. \quad \beta=1.51. \quad \gamma=1.520. \quad (\gamma-\alpha)=0.025.$$

CHEMICAL PROPERTIES.

PYROGNOSTICS.

Heated before the blowpipe, the mineral decrepitates and fuses with much intumescence, giving a greenish boron flame. When it is heated in a closed tube abundant water is readily given off. The mineral is easily soluble in acids.

QUANTITATIVE COMPOSITION.

The transparent glassy material was free from any inclusions of other minerals, and the sample analyzed was free from adhering meyerhofferite. The total available amount of unaltered inyoite was very small, and for the analysis only 0.1037 gram could be obtained. The boric acid was not determined, and qualitative tests showed the absence of silica, alumina, magnesia, alkalies, phosphate, sulphate, carbonate, etc. The analysis and ratios deduced therefrom are as follows:

Analysis and ratios of inyoite.

	Analysis.	Ratios.	Calculated.
CaO	20.5	0.366 or 2.02 or 2×1.01	20.2
B_2O_3	[37.2]	.531 or 2.93 or 3× .98	37.8
H_2O below 110°	26.1	1.450 or 8.01 or 8×1.00	25.9
H_2O above 110°	16.2	.900 or 4.97 or 5× .99	16.1
	100.0		100.0

The ratios conform closely to the numbers 2 : 3 : 8 : 5, giving the formula $2CaO.3B_2O_3.13H_2O$. Of the water $\frac{8}{13}$ goes off below 110°, so that in the conventional way the formula may be written $2CaO.3B_2O_3.5H_2O+8H_2O$.

ALTERATION.

The specimens shown in Plate I were very largely altered when collected and should perhaps be called "meyerhofferite pseudomorph after inyoite," rather than inyoite. The alteration to meyerhofferite has changed the large rhombic crystals of the inyoite from a colorless transparent and glassy material to a compact aggregate of white, opaque, silky fibers. These fibers are arranged either in irregular masses, in radiating groups, or more commonly and characteristically in parallel oriented groups, which for the most part form a rectangular network, such as is shown in Plate II, *A*, *B*, and *C*. In this network are areas of parallel fibers which lie at an angle of about 45° to the rectangular ones, as is well shown in Plate II, *A*. Most of these fibers are silky white and opaque, although embedded in them are numerous transparent glassy prisms of the same material. The lower portion of the specimen shown in Plate I, *A*, is similarly composed of these compact fibers of meyerhofferite.

It would be a most interesting study to trace the orientation of the individual meyerhofferite crystals, both with regard to the reticulated structure of the entire mass as well as to the original inyoite crystals, but such a study could not be undertaken for lack of time.

A second mode of occurrence of the meyerhofferite crystals is as stellate groups on the surface of the large crystals of altered inyoite. These radiating clusters appear both singly and in groups, and a particularly rich and well-developed cluster is shown enlarged in Plate II, *D*. These prismatic meyerhofferite crystals are transparent and glassy. It was at first thought that the opaque, white, silky, fibrous crystals were different from the transparent, colorless glassy prisms, but they have been proved to be identical.

Meyerhofferite contains less water than inyoite, and it might be expected that the crystals would show a further loss of water on long exposure to the air, but no such loss has been observed. Under the conditions which existed at the place of formation of the specimens meyerhofferite seems to be the stable compound

DIAGNOSTIC PROPERTIES.

The rhombic shape of the large crystals, now altered to a fibrous aggregate of white and colorless prisms, and the low refractive index of the mineral (1.5) serve to distinguish inyoite from the other known borates.

MEYERHOFFERITE.

CRYSTALLOGRAPHY.

GENERAL CHARACTER OF CRYSTALS.

The 21 crystals measured averaged about 2 to 3 millimeters in length and about 0.3 to 0.5 millimeter in thickness. Crystals 1 millimeter thick and 1 centimeter long are not rare. All the crystals examined are prismatic in habit. No twins were detected.

CALCULATION OF ELEMENTS.

The triclinic crystals were measured by the two-circle goniometer, the prismatic habit rendering it very easy to adjust the crystals in polar position. The excellent clinopinacoidal cleavage was usually developed enough to give a good reflection, and its measurement, aided by the readings on the other faces of the prism zone, gave good results for v_0. The few forms whose measurements could be used for a calculation of the elements were as follows: $a\{100\}$, $m\{110\}$, $M\{1\bar{1}0\}$, $t\{101\}$, $y\{\bar{1}01\}$, $p\{111\}$. The measurements of these six forms yielded nine angles, of which only five are necessary. The method of two-circle measurement allows the use of all the available angles, and all nine were therefore used, the final results being a better average of all the measurements than could be obtained by the arbitrary selection of only five angles.

Details of the method of calculation are given in the publications of Borgström and Goldschmidt[1] and of Moses and Rogers.[2]

The angles of $t\{101\}$, $y\{\bar{1}01\}$, and $p\{111\}$ were used for obtaining an average value for x'_0, and $p'_0 \sin v$, from which, as v is known $(=\phi(100))$, p'_0 is readily calculated. An independent value of v is also obtained from the values of $t\{101\}$ and $p\{111\}$. Values for y'_0 are obtained from $t\{101\}$, $y\{\bar{1}01\}$ and $p\{111\}$ and for q'_0 from $p\{111\}$. Independently from the terminal forms, v and $\frac{p'_0}{q'_0}$ are calculated from the measurements of the prisms $m\{110\}$ and $M\{1\bar{1}0\}$. By taking the value found for p'_0 from the terminal faces, a second value for q'_0 can be found from the ratio of $\frac{p'_0}{q'_0}$, obtained from the prisms.

The averages of the measured angles of the six forms used are as follows, and from these figures average values for the crystallographic elements are calculated.[3]

---

[1] Borgström, L., and Goldschmidt, V., Krystallberechnung im triklinen System illustriert am Anorthit: Zeitschr. Kryst. Min., vol. 41, p. 63, 1905.

[2] Moses, A. J., and Rogers, A. F., Formulæ and graphic methods for determining crystals in terms of coordinate angles and Miller indexes: School of Mines Quart., vol. 24, p. 1, 1902.

[3] The writer wishes to express his gratitude to Prof. Victor Goldschmidt, of Heidelberg, who kindly verified the crystallographic calculations of meyerhofferite.

Averages of measured angles of meyerhofferite.

Form.	Number of measurements.	ϕ	ρ
		° ′	° ′
$a\{100\}$	26	93 12	90 00
$m\{110\}$	19	54 15	90 00
$M\{1\bar{1}0\}$	13	129 49	90 00
$t\{101\}$	9	94 01	38 35
$y\{\bar{1}01\}$	8	87 00	50 22
$p\{111\}$	9	47 34	46 54

The values obtained are as follows:

$x'_0 = -0.2049$ from $t\{101\}$ and $y\{\bar{1}01\}$.
$x'_0 = -0.2085$ from $y\{\bar{1}01\}$ and $p\{111\}$.
$y'_0 = 0.0036$ from $t\{101\}$ and $y\{\bar{1}01\}$.
$p'_0 = 1.0005$ from $t\{101\}$, $y\{\bar{1}01\}$, and $p\{111\}$.
$q'_0 = 0.7769$ from $p\{111\}$.
$q'_0 = 0.7761$ from value of p'_0 and $\frac{p'_0}{q'_0}$ (prisms).
$\frac{p'_0}{q'_0} = 1.2940$ from $t\{101\}$, $y\{\bar{1}01\}$, and $p\{111\}$.
$\frac{p'_0}{q'_0} = 1.2870$ from $m\{110\}$ and $M\{1\bar{1}0\}$.
$v = 93° 12'$ from $a\{100\}$.
$v = 93° 14'$ from $m\{110\}$ and $M\{1\bar{1}0\}$.

The elements obtained from the average of these values, with their proper weights, are shown in the following table. The figures given were not obtained by arbitrarily assuming certain values as correct, but by averaging all the available results obtained directly from the measurements. It will be found, therefore, that the angles calculated from these elements are not the same as those with which the determinations originally started but vary slightly therefrom.

Axial elements of meyerhofferite.

Projection elements.	Polar elements.	Linear elements.
$x'_0 = -0.2067$	$p_0 = 0.9798$	$a_0 = 1.0222$
$y'_0 = 0.0036$	$q_0 = 0.7602$	$b_0 = 1.2902$
$p'_0 = 1.0005$	$r_0 = 1$	$c_0 = 1$
$q'_0 = 0.7763$	$\lambda = 89° 48'$	$a = 0.7923$
$v = 93° 13'$	$\mu = 101° 41'$	$b = 1.0000$
$h = 1$	$v = 93° 13'$	$c = 0.7750$
	$x_0 = -0.2024$	$\alpha = 89° 32'$
	$y_0 = 0.0036$	$\beta = 78° 19'$
		$\gamma = 86° 52'$

On a gnomonic projection carefully plotted directly from the measurements the elements could be read off and showed a close agreement with the calculated results.

Comparison of calculated and graphic values.

	Calculated.	Measured on gnomonic projection.
x'_0	−0.2067	−0.206
y'_0	.0036	.005
p'_0	1.0005	1.01
q'_0	.7763	.772
ν	93° 13′	93° 30′

The measurements from which these averages are obtained are as follows:

Measurements of a{100}, meyerhofferite.

Crystal No.	Reflection.	Size of face.	ϕ	Crystal No.	Reflection.	Size of face.	ϕ
			° ′				° ′
1	Good	Large[a]	93 10	15	Fair	Large	[d]93 45
1	Good	Large[a]	93 18	16	Fair	Large[c]	93 09
2	Good	Large	93 06	16	Poor	Large	93 17
2	Poor	Large	93 11	17	Fair	Large[c]	93 11
4	Excellent	Small[a]	[b]93 34	17	Excellent	Medium	93 11
6	Fair	Large	93 15	18	Fair	Medium[c]	93 17
7	Fair	Large	93 06	18	Fair	Large[c]	93 10
7	Poor	Large	93 07	19	Good	Medium	93 03
9	Fair	Large[c]	93 03	20	Good	Large	93 12
9	Fair	Large	92 48	21	Poor	Line face.	93 13
10	Good	Large[c]	[b]93 40	21	Poor	Line face.	93 09
10	Fair	Large[c]	93 17				
11	Fair	Large[c]	[d]93 41	Average of 26 measurements			93 12
12	Fair	Large[c]	[d]93 45	Average of good and excellent reflections			93 16½
13	Good	Large	93 14	Average of fair reflections			93 09
13	Fair	Large	93 32	Average of poor reflections			93 11
14	Good	Large	93 17	Calculated			93 13
14	Fair	Medium	92 48				
15	Poor	Large	[d]93 36				

[a] Cleavage (?) face.
[b] High, but included because of good reflection.
[c] Striated face.
[d] Excluded from average.

Measurements of t{101}, meyerhofferite.

Crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
6	Poor	Minute	[a]90 04	39 00
9	Poor	Narrow	93 56	38 26
10	Poor	Small	93 40	38 58
11	Poor	Medium	93 41	38 49
12	Fair	Medium	94 08	38 18
15	Poor	Large	94 12	38 18
16	Good	Large	94 07	38 14
19	Poor	Large	94 03	38 39
20	Poor	Medium	94 22	38 37
Average			94 01	38 35
Calculated			93 48	38 27

[a] Excluded from average.

Measurements of $y\{\bar{1}01\}$, meyerhofferite.

Crystal No.	Reflection.	Size of face.	φ	ρ
			° ′	° ′
2	Poor	Minute	87 35	50 23
6	Poor	Minute	89 56	50 16
9	Poor	Medium	87 30	50 22
12	Good	Medium	87 21	50 19
15	Poor	Line face	85 20	50 35
16	Poor	Minute	85 53	[a] 49 42
18	Poor	Minute	87 34	50 31
20	Poor	Line face	84 48	50 44
Average [b]			87 00	50 22
Calculated			87 10	50 21

[a] Excluded from average.

[b] The φ values vary so much that a general average was taken of all the angles.

Measurements of $m\{110\}$, meyerhofferite.

Crystal No.	Reflection.	Size of face.	φ	Crystal No.	Reflection.	Size of face.	φ
			° ′				° ′
1	Fair	Small	54 34	14	Poor	Narrow	54 04
2	Good	Large	54 30	14	Fair	Narrow	54 05
2	Poor	Line face	[a] 54 09	15	Good	Medium	54 01
5	Poor	Small	54 30	16	Good	Medium	54 10
5	Good	Small	54 28	17	Good	Medium	54 05
6	Fair	Medium	[a] 55 12	18	Fair	Narrow	54 18
6	Fair	Medium	[a] 55 03	18	Fair	Medium	[b] 54 28
9	Good	Large	53 50	19	Fair	Medium	54 19
10	Poor	Small	[a] 55 10	20	Fair	Medium	54 42
10	Poor	Medium	[a][b] 54 59				
11	Fair	Narrow	54 01	Average of measurements			54 15
11	Poor	Narrow	[b] 54 14	Average of good reflections			54 08
12	Fair	Medium	54 06	Average of fair reflections			54 19
12	Poor	Line face	[a] 54 38	Average of poor reflections			54 16
13	Fair	Medium	[b] 54 22	Calculated			54 13
13	Good	Medium	53 54				

[a] Excluded from average.

[b] Striated.

Measurements of $M\{1\bar{1}0\}$, meyerhofferite.

Crystal No.	Reflection.	Size of face.	φ	Crystal No.	Reflection.	Size of face.	φ
			° ′				° ′
1	Good	Small	129 49	16	Fair	Medium	129 53
2	Good	Small [a]	129 55	18	Fair	Medium	129 54
6	Fair	Medium	129 48	18	Poor	Line face	[c] 129 20
9	Good	Medium [a]	129 33	19	Fair	Large [b]	129 51
9	Poor	Medium [b]	[c] 129 11	20	Poor	Medium	129 49
10	Good	Medium [a]	129 57	21	Poor	Narrow	[c] 130 10
11	Fair	Narrow	129 33				
12	Fair	Medium [b]	[c] 129 12	Average of 13 measurements			129 49
12	Fair	Narrow	129 45	Average of good reflections			129 49
13	Poor	Narrow	130 57	Average of fair reflections			129 47
15	Fair	Narrow	129 46	Calculated			129 48

[a] Cleavage (?) face.

[b] Striated face.

[c] Excluded from average.

FORMS AND ANGLES.

A total of 27 forms was determined on the measured crystals of meyerhofferite. These may be grouped as follows:

Pinacoids: *a*{100}, *b*{010}, *c*{001}.
Positive prisms: *k*{370}, *l*{120}, *A*{350}, *j*{450}, *m*{110}, *q*{210}, *n*{520}, *s*{310}, *B*{510}, *r*{810}.
Negative prisms: *v*{$3\bar{5}0$}, *M*{$1\bar{1}0$}, *w*{$4\bar{3}0$}, *h*{$3\bar{1}0$}.
Positive domes: *t*{101}, *d*{12.0.11}, *e* {706}, *f*{605}, *g*{504}, *i*{705}, *x*{302}, *z*{12.0.1}.
Negative dome: *y*{$\bar{1}01$}.
Pyramid: *p*{111}.

The average of the measured angles is shown in the table below.

Measured and calculated angles of meyerhofferite.

No.	Letter.	Number of crystals.	Number of measurements.	Symbol.	Measured.		Calculated.	
					φ	ρ	φ	ρ
					° ′	° ′	° ′	° ′
1	*c*	6	6	001	−89 47	11 48	−88 59	11 41
2	*b*	20	33	010	0 00	90 00	0 00	90 00
3	*a*	20	37	100	93 12	90 00	93 13	90 00
4	*k*	2	2	370	29 33	90 00	29 39	90 00
5	*l*	1	1	120	33 51	90 00	33 44	90 00
6	*A*	2	3	350	39 01	90 00	38 55	90 00
7	*j*	1	1	450	46 58	90 00	47 32	90 00
8	*m*	16	29	110	54 15	90 00	54 13	90 00
9	*q*	1	1	210	71 56	90 00	71 37	90 00
10	*n*	3	4	520	75 31	90 00	75 43	90 00
11	*s*	2	2	310	78 50	90 00	78 32	90 00
12	*B*	1	1	510	84 13	90 00	84 20	90 00
13	*r*	2	2	810	87 54	90 00	87 39	90 00
14	*v*	3	4	$3\bar{5}0$	143 20	90 00	143 30	90 00
15	*M*	16	23	$1\bar{1}0$	129 49	90 00	129 48	90 00
16	*w*	3	3	$4\bar{3}0$	122 41	90 00	122 26	90 00
17	*h*	5	6	$3\bar{1}0$	107 55	90 00	107 30	90 00
18	*t*	13	13	101	94 01	38 35	93 48	38 27
19	*d*	1	1	12. 0. 11	94 16	40 53	93 44	41 30
20	*e*	1	1	706	94 03	43 45	93 42	43 50
21	*f*	2	2	605	93 40	44 35	93 40	44 50
22	*g*	2	2	504	93 52	45 56	93 39	46 14
23	*i*	1	1	705	93 45	49 50	93 36	50 03
24	*x*	1	1	302	93 45	52 12	93 34	52 18
25	*z*	1	1	12. 0. 1	93 03	84 21	93 15	85 09
26	*y*	10	10	$\bar{1}01$	−87 00	50 22	−87 10	50 21
27	*p*	15	15	111	47 34	46 54	47 35	47 01

c{001}. The basal pinacoid is represented in most of its occurrences as a broad line face between the positive and negative unit domes. On one crystal, No. 6, it is a large face lying between the line faces of the two domes. Its average size relative to the other terminal forms is shown in the orthographic projection of crystal 12 shown in figure 49 (p. 53). The angles on which the form is based are shown below:

Measurements of c{001}, meyerhofferite.

Crystal No.	Reflection.	Size of face.	Measured.		Calculated.	
			ϕ	ρ	ϕ	ρ
			° ′	° ′	° ′	° ′
6	Fair	Large	−89 56	11 51	−88 59	11 41
7	Poor	Small	−88 37	11 50	−88 59	11 41
8	Poor	Line face	−86 00	12 00	−88 59	11 41
9	Poor	Small	−89 36	12 00	−88 59	11 41
12	Poor	Line face	−85 52	11 37	−88 59	11 41
20	Poor	Line face	−89 41	11 45	−88 59	11 41

b{010}. It is not always possible to determine whether a certain face of *b* is natural or due to the perfect cleavage which is parallel to this form. The natural faces are mostly line faces, very narrow as compared with the other faces in the prism zone. Rarely they become broader, though most of the occurrences of broad *b* faces are clearly due to cleavage.

a{100}. The macropinacoid is the dominant form of the mineral and is developed on many crystals as a broad face vertically striated. The relatively large size of the *a* face causes the crystal to become tabular parallel to it, as shown in figures 42, 46, 49, 50, and 51. On a few crystals it is equaled in size by some other form in the prism zone. On 8 of the 10 crystal drawings of meyerhofferite chosen to show the various habits and combinations *a*{100} is the largest form. The measurements of the faces of *a*{100} have already been given under the calculation of the elements.

m{110} and *M*{1$\bar{1}$0}. The unit prisms are of medium size, varying from line faces to faces nearly as large as those of *a*{100}, but generally are about half as large or somewhat less. The faces are striated vertically, although not so strongly as those of *a*{100}. The average size of *m*{110} is somewhat larger than that of *M*{1$\bar{1}$0}.

The other prism forms, with the exception of *A*{350}, *j*{450}; *n*{520} and *v*{350}, are all line faces. Some of these prisms were observed but once and their measured angles are shown in the table just given. The values for those prisms which were measured more than once are given in the following table:

Measurements of rare prisms of meyerhofferite.

Form.	Crystal No.	Reflection.	Size of face.	ϕ	
				Measured	Calculated
				° ′	° ′
A (350)	4	Good	Small	39 01	38 55
	4	Poor	Small	38 11	38 55
	9	Poor	Line face	39 50	38 55
n (520)	3	Poor	Broad, striated	76 00	75 43
	5	Good	Small	75 20	75 43
	5	Good	Small	75 16	75 43
	18	Poor	Line face	75 54	75 43
s (310)	12	Poor	Line face	78 41	78 32
	21	Poor	Line face	79 00	78 32
r (810)	18	Poor	Line face	87 57	87 39
	20	Poor	Line face	87 50	87 39
v (3$\bar{5}$0)	4	Good	Small	143 20	143 30
	14	Poor	Narrow	143 30	143 30
	14	Fair	Narrow	143 29	143 30
	21	Poor	Line face	143 01	143 30
w (4$\bar{3}$0)	1	Poor	Line face	122 35	122 26
	7	Poor	Line face	122 45	122 26
	19	Poor	Line face	122 43	122 26
h (3$\bar{1}$0)	12	Poor	Line face	107 13	107 30
	12	Poor	Line face	108 16	107 30
	13	Poor	Line face	107′ 54	107 30
	14	Poor	Line face	107 21	107 30
	17	Poor	Line face	108 43	107 30
	18	Poor	Line face	108 05	107 30

t{101}. The positive unit macrodome is one of the three dominant terminal forms, the other two being *y*{$\bar{1}$01} and *p*{111}. The faces of this form are generally large, though on a few crystals it occurs as a narrow face. The form is shown on a number of the crystal drawings (figs. 46, 47, 48, 49, 50, and 51). It has not been observed as the only terminal form, although crystal 13 is terminated by a single form, namely *f*{605}. which is very near *t*{101}.

y{$\bar{1}$01}. The negative unit dome occurs nearly as frequently as *t*{101} but is smaller in size and in several crystals is present as a line face. The form is the only negative dome observed. It is shown in figures 48 and 49.

The remaining domes, seven in number, form a remarkable series in that five of them are very close to *t*{101} and, if each one occurred separately on a distinct crystal, would be considered as all belonging to a single form vicinal to the unit dome. The faces of these domes, however, are distinct and yield separate reflections and occur in such a way as not to allow their being grouped together as one form. The occurrence of the forms in the zone *a*(100), *c*(001), *a*′($\bar{1}$00) is shown below for the crystals containing domes other than the unit domes.

Occurrence of forms in the zone a{100}: a′{$\bar{1}$00}, meyerhofferite.

Crystal 11.	Crystal 13.	Crystal 19.	Crystal 20.
$\bar{1}$00	$\bar{1}$00	$\bar{1}$00	$\bar{1}$00
....	....	....	$\bar{1}$01
....	....	....	001
101	....	101	101
....	....	....	12.0.11
....	....	....	706
....	[a] 605	....	605
504	....	....	504
....	....	705	....
....	....	302	....
....	....	12.0.1	....
100	100	100	100

[a] The only terminal form on this crystal.

The occurrence of the two series of domes shown on crystals 19 and 20 is very unusual for these crystals.

The two measurements for *f*{605} and *g*{504} are shown below.

Measurements of f{605} and g{504}, meyerhofferite.

Form.	Crystal No.	Reflection.	Size of face.	Measured.		Calculated.	
				ϕ	ρ	ϕ	ρ
				° ′	° ′	° ′	° ′
f{605}	13	Poor...	Large......	93 16	44 26	93 40	44 50
	20	Poor...	Line face...	94 03	44 43	93 40	44 50
g{504}	11	Poor...	Line face..	93 41	45 37	93 39	46 14
	20	Poor...	Line face..	94 03	46 14	93 39	46 14

The remaining domes are all line faces giving poor reflections and the angles measured are shown in the table on page 45.

Crystal 20, with its wealth of domes, is shown in figure 51 (p. 53).

The common forms of meyerhofferite, or those observed on at least ten crystals, are *b*{010}, *a*{100}, *m*{110}, *M*{1$\bar{1}$0}, *t*{101}, *y*{$\bar{1}$01}, and *p*{111}. The less common forms, observed on three to nine crystals, are *c*{001}, *n*{520}, *v*{3$\bar{5}$0}, *w*{4$\bar{3}$0}, *h*{3$\bar{1}$0}. The remaining forms, 15 in number, are all rare; 9 of them were observed only once.

COMBINATIONS.

The combinations observed on the 21 measured crystals of meyerhofferite are shown in the following table:

Combinations of forms on meyerhofferite crystals.

Letter.	Symbol.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
c	001						*c*	*c*	*c*	*c*			*c*								*c*	
b	010	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*		*b*	*b*	*b*	*b*	*b*	*b*	*b*
a	100	*a*	*a*	*a*	*a*		*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
k	370	*k*																*k*				
l	120												*l*									
A	350				*A*					*A*												
j	450																				*j*	
m	110	*m*	*m*			*m*	*m*			*m*	*m*	*m*	*m*	*m*		*m*	*m*	*m*	*m*	*m*	*m*	*m*
q	210																		*q*			
n	520			*n*		*n*													*n*			
s	310												*s*									*s*
B	510																		*B*			
r	810																		*r*		*r*	
v	$3\bar{5}0$				*v*										*v*							*v*
M	$1\bar{1}0$	*M*	*M*				*M*	*M*	*M*	*M*	*M*	*M*	*M*	*M*		*M*	*M*		*M*	*M*	*M*	*M*
w	$4\bar{3}0$	*w*						*w*												*w*		
h	$3\bar{1}0$												*h*	*h*	*h*			*h*	*h*			
t	101			*t*			*t*	*t*	*t*	*t*	*t*	*t*	*t*		*t*	*t*	*t*			*t*	*t*	
d	12.0.11																				*d*	
e	706																				*e*	
f	605													*f*							*f*	
g	504											*g*									*g*	
i	705																			*i*		
x	302																			*x*		
z	12.0.1																			*z*		
y	$\bar{1}01$		*y*				*y*	*y*	*y*	*y*			*y*			*y*	*y*		*y*		*y*	
p	111	*p*	*p*	*p*				*p*	*p*	*p*	*p*	*p*	*p*		*p*	*p*			*p*	*p*	*p*	*p*

ZONAL RELATIONS.

The zonal relations are very well developed on the crystals of meyerhofferite, all the forms lying in three zones, and 96 per cent of the forms lying in two zones, namely, the prism zone with 16 forms and the macrodome zone with 11 forms, as shown in figure 41. The unit pyramid $p\{111\}$ lies in such zones as $c\{001\}$, $p\{111\}$, $m\{1\bar{1}0\}$, and $t\{101\}$, $p\{111\}$, $b\{010\}$.

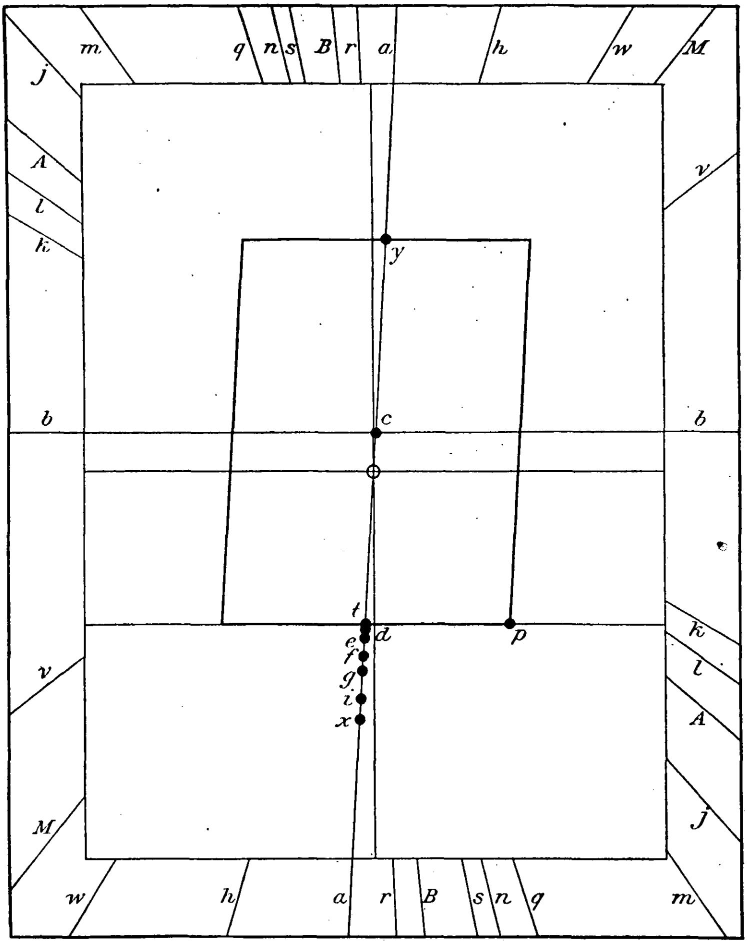


FIGURE 41.—Gnomonic projection of meyerhofferite forms. The form $z\{12.\ 0.\ 1\}$, not shown, falls outside of the projection.

The prism zone is characteristically striated vertically, and the macropinacoid shows the striations most prominently.

HABITS.

The crystals of meyerhofferite are all prismatic, but a distinction may be made between the tabular prismatic crystals and those with equal horizontal thickness. The tabular habit is caused by the large development of the macropinacoid *a*{100}, as shown in figure 42. The prisms *m*{110} and $M\{1\bar{1}0\}$ are both very narrow on such tabular crystals. As the crystals become thicker the *a*{100} faces decrease in size, with a consequent enlargement of the prisms, as shown in figure 43. When one or both of the prisms equals the macropinacoid in size, the crystal becomes of nearly the same horizontal thickness in every direction, as shown in figure 44 and also in figure 50 (p. 53). A crystal (No. 17) which has a nearly square cross section is shown in orthographic projection in figure 45. Only the prism zone is developed on this crystal. The faces of *b*{010} do not seem to be cleavage faces, and in the large development of the faces of the clinopinacoid *b* the crystal is unusual.

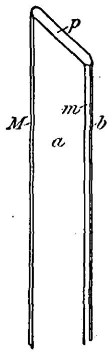


FIGURE 42.

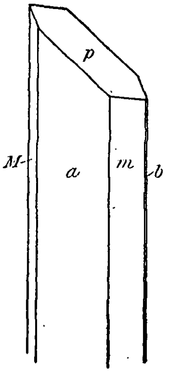


FIGURE 43.

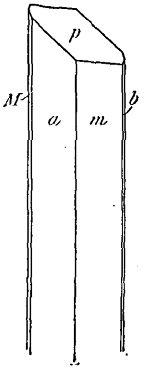


FIGURE 44.

FIGURE 42.—Tabular prismatic crystal (No. 1) of meyerhofferite. Forms: *b*{010}, *m*{110}, *a*{100}, $M\{1\bar{1}0\}$, *p*{111}.

FIGURE 43.—Crystal 21, meyerhofferite. Intermediate in habit.

FIGURE 44.—Crystal 2, meyerhofferite. Nearly equally thick in horizontal directions.

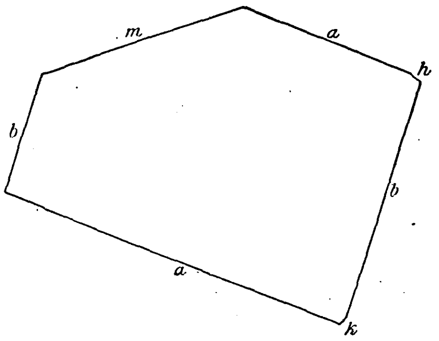


FIGURE 45.—Orthographic projection of crystal 17, meyerhofferite. Only the prism zone is shown on this crystal. Forms: *b*{010}, *a*{100}, *m*{110}, *k*{370}, $h\{3\bar{1}0\}$.

The terminations of meyerhofferite crystals consist either of a single large face or of three large faces, with perhaps one or two minute accompanying line faces. A termination showing a richer combination is very rare.

The single termination consists of the unit pyramid *p*{111} (crystal 1, fig. 42) and in one crystal of the dome *f*{605}. In a crystal whose termination is composed of two forms they may be either *t p* (as in crystal 10, fig. 46, and crystal 3, fig. 47), *t y* (as in crystal 16, fig. 50, in which the rear dome *y*{101} is not shown), or *p y* (as in crystal 2, fig. 44, in which the rear dome *y*{101} is likewise not shown). The presence of three large terminal faces (*t y p*) is shown in clinographic projection in figure 48 (crystal 8) and in orthographic projection in figure 49 (crystal 12). In crystals in which the three forms all show large faces the basal pinacoid *c*{001} is usually present as a line face. None of the terminal faces can be said to exert a decided influence on the habit of the crystals. The forms *t y* and *p* exert an equal influence, the faces of the other terminal faces being small.

MEASURED CRYSTALS.

The tabular to thicker crystals have already been illustrated in figures 42 to 45, which show the chief forms on crystals 1, 21, 2, and 17.

Crystal 2, figure 44, shows only $y\{\bar{1}01\}$ in addition to the forms figured, whereas on the other crystals a number of other forms, especially line-face prisms, are present.

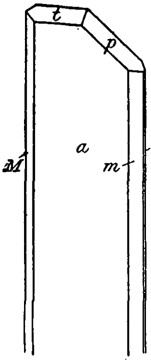


FIGURE 46.

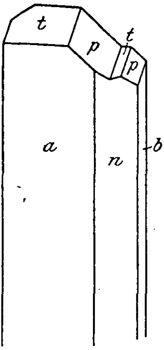


FIGURE 47.

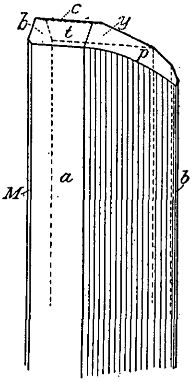


FIGURE 48.

FIGURE 46.—Crystal 10, meyerhofferite. Forms: *b*{010}, *m*{110}, *a*{100} $M\{1\bar{1}0\}$, *t*{101}, *p*{111}.

FIGURE 47.—Crystal 3, meyerhofferite. Forms: *b*{010} cleavage, *n*{520}, *a*{100}, *t*{101}, *p*{111}.

FIGURE 48.—Crystal 8, meyerhofferite. Forms: *b*{010} *a*{100}, $M\{1\bar{1}0\}$, *t*{101}, $y\{\bar{1}01\}$, *c*{001}, *p*{111}. The large unlettered prism is so rounded and striated as to be undeterminable.

Crystal 10, figure 46, has only the two terminal forms shown in the drawing, which in fact represents the complete combination of the crystal as determined.

Crystal 3, figure 47, similarly has only the two terminal forms *t* and *p*, which have developed in a steplike form. The clinopinacoid faces, which may possibly be due to cleavage, are unusually large. The large development of the single face of *n*{520} is noteworthy. The face is strongly striated.

Crystal 8, figure 48, shows a similar large striated face between *a*{100} and *b*{010}, which, however, is so rounded and striated that it could not be determined. It may be a face of *n*{520}, like that on crystal 3 (fig. 47), or it may be the unit prism or a combination of several prisms. One side of the crystal is determined by a large cleavage face of *b*{010}. The termination shows *t*{101}, $y\{\bar{1}01\}$, and *p*{111}, all large, with the basal pinacoid, *c*{001}, between the domes as a line face.

A terminal combination, similar to that on crystal 8, shown in figure 48, is present on crystal 12, and is shown in figure 49 in orthographic projection, in order to show better the relative size of the four forms.

In addition to the forms shown in figure 49, line faces of the rare prisms *l*{120}, *s*{310}, and *h*{3$\bar{1}$0} are present on the crystal.

Crystal 16, figure 50, shows a large face of *t*{101} and a minute one (not shown in the figure) of *y*{101} as the only terminal forms. In general appearance, crystal 13 (not shown) is very similar to crystal 16 (fig. 50), except that the large terminal face is not *t*{101} but the rare dome *f*{605}.

A series of domes are well developed on crystals 20 and 21, and crystal 20 is shown in figure 51. The forms *c*{001} and *y*{$\bar{1}$01} are present as line faces, but are not shown in the drawing. The presence of a single large face of *j*{(450} is notable, and a line face of *r*{810} (not shown in the figure) was also determined.

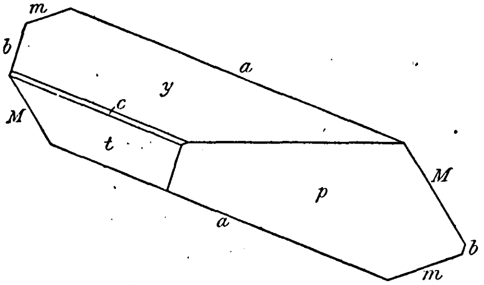


FIGURE 49.

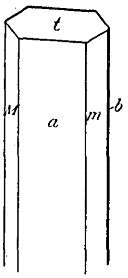


FIGURE 50.

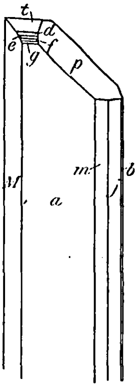


FIGURE 51.

FIGURE 49.—Orthographic projection of crystal 12, meyerhofferite. Forms: *b*{010}, *m*{110}, *a*{100}, *M*{1$\bar{1}$0} *t*{101}, *c*{001}, *y*{$\bar{1}$01}, *p*{111}.

FIGURE 50.—Crystal 16, meyerhofferite. Forms: *b*{010}, *m*{110}, *a*{100}, *M*{1$\bar{1}$0}, *t*{101}.

FIGURE 51.—Crystal 20, meyerhofferite. The series of domes is notable. Forms: *b*{010}, *j*{450}, *m*{110}, *a*{100}, *M*{1$\bar{1}$0}, *g*{504}, *f*{605}, *e*{706}, *d*{12.0.11}, *t*{101}, *p*{111}.

Crystal 6, not shown, is unusual in having a large face of the basal pinacoid *c*{001}, while both domes *t* and *y* are minute line faces.

PHYSICAL PROPERTIES.

The cleavage of meyerhofferite is perfect parallel to the clinopinacoid, *b*{010}. Indications of other less perfect cleavages in the prism zone were encountered during the measurement of the crystals. Such indications were noted a number of times for *a*{100} and *M*{1$\bar{1}$0}. The perfect clinopinacoidal cleavage causes the crystals to break readily in thin prisms. The hardness of the mineral is about 2.

The density of meyerhofferite, determined on colorless, transparent crystals by means of heavy solution, is 2.120. The same value was obtained on the artificial mineral by Van't Hoff and Meyerhoffer.[1]

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[1] Van't Hoff, J. H., Untersuchungen über die Bildung der ozeanischen Salzablagerungen, LI. Künstliche Darstellung von Colemanit: Preuss. Akad. Wiss. Sitzber., 1906, p. 689.

The white opaque prisms of meyerhofferite have apparently a slightly lower density, but the lower value is more apparent than real and is probably due to a small amount of air inclosed in the partly cleaved crystals.

OPTICAL PROPERTIES.

Meyerhofferite crystals that have not been affected by outside influences are colorless; others are white. The luster is vitreous and on the opaque white masses somewhat silky. The colorless crystals are transparent; the white ones translucent to opaque.

The extinction on $b\{010\}$ is $c \wedge X' = 33°$; on $a\{100\}$ it is $c \wedge Z' = 25°$. The plane of the optic axis is across the elongation (c) and the obtuse bisectrix (Z) makes a moderate angle with the normal to the face (100). The axial angle $2V$ is nearly 90°, but the bars are perceptibly curved. The mineral is optically negative.

The refractive indices, as determined by the immersion method by Mr. Esper S. Larsen, for sodium light, are as follows: $\alpha = 1.500$, $\beta = 1.535$, $\gamma = 1.560$. The birefringence ($\gamma - \alpha$) is high, 0.060.

CHEMICAL PROPERTIES.

PYROGNOSTICS.

Meyerhofferite when heated in a blowpipe flame fuses readily without decrepitation but with intumescence to an opaque white enamel, imparting a greenish color to the flame. Heated in a closed tube, it fuses, giving off abundant water. The mineral is readily soluble in acids.

QUANTITATIVE COMPOSITION.

Two analyses were made of meyerhofferite, one on 0.0607 gram of the colorless transparent crystals, and one on gram and half-gram portions of the abundant opaque white variety. The boric acid had to be determined by difference in the colorless crystals. Both analyses yield the same result, as shown above.

Analyses and ratios of meyerhofferite.

	Opaque, white, fibrous mass.					Colorless, transparent crystals.	Calculated.
	1	2	3	Average.	Ratios.		
CaO	25.23	25.66	....	25.45	2.05 or 2	25.6	25.02
B_2O_3	46.40	....	....	46.40	2.99 or 3	[45.6]	46.85
H_2O (below 110°)	1.01	....	....	1.01	....	.3	.00
H_2O (above 110°)	[a] 27.75	[a] 28.00	[b] 27.49	27.75	6.96 or 7	28.5	28.13
	....	....	....	100.61	....	100.00	100.00

[a] Loss on ignition.

[b] Loss on ignition with ignited CaO.

The ratios yield the formula $2CaO.3B_2O_3.7H_2O$, and the analysis of the colorless transparent crystals agrees well with that of the opaque, white, fibrous mass. Both analyses are also in close agreement with the calculated composition given in the last column.

The new minerals meyerhofferite and inyoite belong to the colemanite series of compounds. Of the compounds of $2CaO.3B_2O_3$ with water the following are known:

$2CaO.3B_2O_3.5H_2O$ (artificially prepared), colemanite.
$2CaO.3B_2O_3.7H_2O$ (artificially prepared), meyerhofferite.
$2CaO.3B_2O_3.9H_2O$ (artificially prepared).
$2CaO.3B_2O_3.11H_2O$.
$2CaO.3B_2O_3.13H_2O$, inyoite.

SYNTHESIS.

Meyerhofferite was artificially prepared by Meyerhoffer and Van't Hoff[1] by the following method. The hexahydrate of calcium monoborate, $CaO.B_2O_3.6H_2O$, was treated with boric acid solution at 100°, when the compound $2CaO.3B_2O_3.9H_2O$ was formed in well-crystallized augite-like forms. By heating this enneahydrate with a 3 per cent boric acid solution at 100° the compound $2CaO.3B_2O_3.7H_2O$ was formed in well-crystallized long rectangles.

DIAGNOSTIC PROPERTIES.

The prismatic, partly tabular crystals, perfect cleavage, and inclined (triclinic) extinctions serve, with the chemical tests, to distinguish meyerhofferite from all other natural borates.

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[1] Meyerhoffer, Wilhelm, and Van't Hoff, J. H., Krystallisirte Calcium-borate: Annalen der Chemie, vol. 351, p. 100, 1907

LUCINITE, A NEW MINERAL: A DIMORPHOUS FORM OF VARISCITE.

ORIGIN OF INVESTIGATION.

A short time after the description of crystallized variscite from Utah[1] had been finished, Messrs. Edison & Bird, of Lucin, Utah, kindly furnished, in response to a request from the writer, several specimens which showed minute octahedral crystals associated with the tabular crystals of variscite. Preliminary measurements showed a close resemblance, in angular values, to variscite, and in a short note[2] these octahedral crystals were referred to as variscite. Subsequent more extended measurements showed, however, that although the angular values were close, they could not be referred to those of variscite. The mature consideration of the problem has led to the conclusion that the octahedral crystals belong to a second modification of the same chemical compound as variscite, and the new mineral is named lucinite. The specimens that show crystals of lucinite are scarce, but it is not improbable that a search at the locality for more material would show that the new mineral occurs in some abundance. In the compact granular phase lucinite is not distinguishable from variscite. In fact, it is impossible from our present knowledge of these two minerals to say whether the compact material used in jewelry[3] is variscite or lucinite.

Mr. G. W. Fiss, of Philadelphia, kindly sent to the writer a quantity of variscite from Lucin, Utah, in which were found several specimens of lucinite that were a welcome addition to the meager quantity at hand.

NOMENCLATURE AND LOCALITY.

The name lucinite is derived from the locality, the specimens having been found in the northern part of Utahlite Hill, 5 miles northeast of Lucin, Boxelder County, Utah.

PARAGENESIS.

Lucinite occurs in compact massive pieces that in thin section are seen to be composed of small equidimensional areas which, while optically units, only here and there show distinct crystal outline.

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[1] Schaller, W. T., Crystallized variscite from Utah: U. S. Geol. Survey Bull. 509, p. 48, 1912.

[2] Schaller, W. T., The crystallography of variscite: Washington Acad. Sci. Jour., vol. 2, p. 143, 1912.

[3] Sterrett, D. B., Gems and precious stones: U. S. Geol. Survey Mineral Resources, 1910, pt. 2, pp. 894-896, 1912.

Numerous cavities are present in this massive phase and these cavities are lined with minute crystals of lucinite and variscite. Cavities can be seen containing only lucinite, others have only variscite, and in many others both minerals are present. The crystals of lucinite are found only in the cavities of the massive granular material, and on many specimens are directly associated with variscite crystals. In some of the material several crystals of lucinite were perched on a larger tabular crystal of variscite (fig. 52), and again a variscite crystal was seen to rest on a bed of smaller lucinite crystals (fig. 53). Such associations would indicate a more or less similar condition of formation of the two modifications. In many cavities lucinite forms the lining, and the variscite crystals are perched on this lining and seem, therefore, to be of later formation.

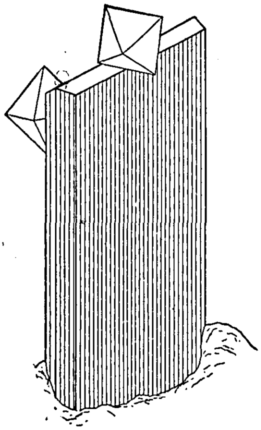

FIGURE 52.

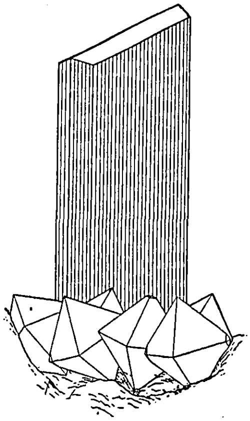

FIGURE 53.

FIGURE 52.—Octahedral crystals of lucinite perched on a larger tabular crystal of variscite.
FIGURE 53.—Tabular crystal of variscite resting on a bed of smaller crystals of lucinite.

The paragenesis of lucinite is the same as that of variscite, and the description given for variscite applies as well for the lucinite. The only identified associated minerals are variscite and massive quartz.

CRYSTALLOGRAPHY.

GENERAL CHARACTER OF CRYSTALS.

The crystals of lucinite are minute, the largest having a diameter of about 1 millimeter and most of them being much smaller. The six measured crystals were all less than 1 millimeter thick, ranging in size from about 0.2 to 0.5 millimeter. No twins were observed, and the crystals all had the same general octahedral habit.

CALCULATION OF ELEMENTS.

The minute crystals presented even and highly polished surfaces which gave distinct reflections that could be accurately measured. The basal pinacoid was present on most of the crystals and served to adjust them in polar position on the two-circle goniometer. The different faces of the same form were then utilized for further adjustment, and by a process of averaging the crystals were finally placed in correct polar position.

After the symmetry of the crystals had been determined, the two crystals yielding the best reflections, Nos. 1 and 2, were remeasured after being accurately adjusted in polar position. The measurements of the pyramids then gave values from which the axial ratio was calculated. The average of p_0 and q_0, obtained directly from the angles ϕ and ρ, are $p_0=1.1225$, $q_0=0.9788$. From these values, the axial ratio $a:b:c$ is calculated and found to be 0.8729:1:0.9788.

Values of p_0 and q_0, lucinite.

Crystal No.	Form.	p_0	q_0	Crystal No.	Form.	p_0	q_0
1........	$i\{112\}$	1.1208	0.9760	1........	$s\{121\}$	1.1269	0.9786
1........	$i\{112\}$	1.1186	.9799	2........	$i\{112\}$	1.1233	.9662
1........	$i\{112\}$	1.1307	.9812	2........	$i\{112\}$	1.1046	.9876
1........	$i\{112\}$	1.1143	.9698	2........	$i\{112\}$	1.1429	.9935
1........	$p\{111\}$	1.1124	.9716	2........	$i\{112\}$	1.1105	.9796
1........	$p\{111\}$	1.1120	.9707	2........	$p\{111\}$	1.1343	.9878
1........	$p\{111\}$	1.1270	.9791	2........	$p\{111\}$	1.1345	.9978
1........	$p\{111\}$	1.1318	.9821	2........	$p\{111\}$	1.1180	.9765
1........	$s\{121\}$	1.1373	.9849	2........	$p\{111\}$	1.1093	.9654
1........	$s\{121\}$	1.1270	.9806				
1........	$s\{121\}$	1.1147	.9679	Average..	....	1.1225	.9788

The interfacial angles in the zone $c\ p$ were also measured on many of the crystals, and by expressing the measured angles in terms of the angle $c(001):p(111)$,[1] the following values were obtained:

Interfacial measured angles in zone c p expressed as the angle c(001): p(111), lucinite.

Crystal 1.		Crystal 2.	Crystal 4.	Crystal 5.	Crystal 6.
° ′	° ′	° ′	° ′	° ′	° ′
56 07	56 06	56 03	56 10	56 23	56 08
56 05	56 08	56 06	56 09	56 06	56 02
56 09	56 04	56 11	56 10	56 03	56 07
56 11	56 00	.. ..	56 18	56 19	56 08
56 01	56 05	.. ..	56 15	56 13	55 57
55 55			56 12		
Av.	56 03.7	56 06.7	56 12.3	56 12.8	56 04.4

---

[1] For instance, the measured angle $p(111):p(11\bar{1})=67°\ 47'$ would be changed to $90°-\frac{1}{2}(67°\ 47')=56°\ 06\frac{1}{2}'$.

The average of 30 measurements on five crystals gives the value 56° 07.3′, whereas the angle (001): (111) calculated from the axial ratio $a:b:c=0.8729:1:0.9788$, as given above, is 56° 06.4′, thus serving as a check on the correctness of the axial ratios as given. Further evidence of the same fact is afforded by the close agreement between measured and calculated angles, as given on the following page.

FORMS AND ANGLES.

Eight forms were established for lucinite. These are distributed as follows:

Pinacoids: *c*{001}, *a*{100}.
Prism: *d*{120}.
Brachydome: *e*{012}.
Pyramids: *r*{113}, *i*{112}, *p*{111}, *s*{121}.

The averages of the measured angles as compared with the calculated values are shown in the following table:

Measured and calculated angles, lucinite.

[a=0.8729, c=0.9788, p_0=1.1225.]

No.	Letter.	Symbol.	Number of crystals.	Number of faces measured.	Measured.		Calculated.	
					φ	ρ	φ	ρ
					° ′	° ′	° ′	° ′
1	*c*	001	6	9	....	0 00	....	0 00
2	*a*	100	2	3	90 11	90 00	90 00	90 00
3	*d*	120	2	3	30 14	90 09	29 48	90 00
4	*e*	012	3	7	0 00	26 13	0 00	26 05
5	*r*	113	1	2	48 42	26 35	48 53	26 33
6	*i*	112	6	26	48 51	36 39	48 53	36 39
7	*p*	111	6	28	48 55	56 07	48 53	56 06
8	*s*	121	5	14	30 00	66 07	29 48	66 06

c{001}. The basal pinacoid is present on all the crystals measured but is not present on many of the lucinite crystals seen on the specimens. It is rectangular in shape and always small in comparison with the other forms.

a{100}. The macropinacoid was observed on only two crystals as minute faces. It is shown in the drawing of crystal 4 (fig. 61, p. 64).

d{120}. The prism *d* is also a rare form, being likewise observed on only two crystals. It forms a line face, as shown in figure 61, and the measurements of the three faces gave the following φ angles: 31° 00′, 29° 19′, 30° 23′; calculated, 29° 48′.

e{012}. The brachydome *e*{012} was determined on half the measured crystals as minute faces giving poor reflections. It is shown in figures 58 and 61. The measurements of the form are as follows:

Measurements of e{012}.

Crystal No.	Measured.		Calculated.	
	ϕ	ρ	ϕ	ρ
	° ′	° ′	° ′	° ′
2.......	0 00	26 28	0 00	26 05
2.......	0 10	26 30	0 00	26 05
4.......	0 07	26 07	0 00	26 05
4.......	0 00	26 10	0 00	26 05
6.......	0 04	26 05	0 00	26 05
6.......	0 04	26 02	0 00	26 05

r{113}. The pyramid *r* was determined on crystal 4, on which it occurred with two faces, in the zone *cp*. The ρ measurements of two faces gave 26° 35′, 26° 35′, the remaining two faces surrounding the rectangular base not being measurable because of their minute size. The form is shown in figure 61 (p. 64).

i{112}. This form is present on all the measured crystals as a narrow or broad line face surrounding the rectangular base. It is shown on many of the drawings illustrating the crystals of lucinite.

p{111}. The unit pyramid *p* is the dominant form of lucinite and determines the octahedral shape of the crystals. On many crystals it is evidently the only form, and, the axial ratio of the mineral being close to unity, crystals of lucinite showing only *p*{111} (fig. 55) closely resemble the octahedron of the isometric system (shown in fig. 87, p. 90, with which fig. 55 may be compared). Although the faces of *p* generally have a triangular shape, the large development of the faces of *s*{121} causes the *p* faces to become rhombic in shape, as shown in figures 59, 60, and 61.

s{121}. The pyramid *s* is the second largest form on the lucinite crystals and seems to be present on nearly all crystals which show any form in addition to *p*{111}. The faces of *s*{121} range in size from minute ones to some nearly as large as those of *p*{111}.

A number of other forms, of very simple indices—three of them, in fact, belonging to the "unit forms"—were observed and measured, but they were so minute that their measurements are several degrees from the calculated values. The forms are therefore not further described, but are given for comparison with possible future measurements. They are {010}, {110}, {101}, {102}.

COMBINATIONS.

The combinations observed on the six measured crystals are as follows:

Combinations on measured crystals of lucinite.

Form.	1	2	3 (fig. 57).	4 (fig. 61).	5	6 (fig. 58).
c{001}	*c*	*c*	*c*	*c*	*c*	*c*
a{100}	....	....	....	*a*	....	....
d{120}	....	....	....	*d*	....	*d*
e{012}	....	*e*	....	*e*	....	*e*
r{113}	....	....	....	*r*	....	....
i{112}	*i*	*i*	*i*	*i*	*i*	*i*
p{111}	*p*	*p*	*p*	*p*	*p*	*p*
s{121}	*s*	*s*	....	*s*	*s*	*s*

Besides the combinations given above, the following were commonly observed on crystals not measured but carefully examined with a hand lens: *p* (fig. 55), *p s* (fig. 56), *p c i* (fig. 57). The combination *p c i* is very common.

ZONAL RELATIONS.

The chief zone of lucinite is *c p*, with four forms in it, namely, *c*, *r*, *i*, and *p*. The zone (100) : (012) contains *a*, *i*, and *e*, and the zone (010): (101) the forms *s* and *p*. The prism zone has only *a* and *d*. The paucity of known forms on lucinite renders it difficult to say what are the chief zones. The relative positions of the zones can be seen in figure 54 (p. 62).

HABITS.

The crystals of lucinite show only the octahedral habit, somewhat modified by the large development of forms other than the unit pyramid. If *p*{111} is the only form present, then the crystals resemble an octahedron very much, as shown in figure 55. On some crystals small faces of *s*{121} are present (fig. 56), and on still others small faces of *c*{001} and *i*{112} appear (fig. 57). On many crystals both modifications occur together, as shown in figures 58, 59, and 60.

The large development of the faces of *s*{121}, although retaining the octahedral habit, causes the crystals to have a somewhat different appearance, as shown in figure 59. Many such crystals were seen on the specimens with a hand lens. Distorted crystals of this combination are very abundant, the faces of *s*{121} being large at one end and small at the opposite end. The faces of the basal pinacoid *c*{001} are likewise of different size on many crystals, one of which, as seen with a hand lens, is reproduced in figure 60 (p. 63).

Crystal 4, shown in figure 61, has all the observed forms of lucinite, and the combination, drawn in ideal symmetry as near like the actual crystal as possible, shows well the relative size and shape of the different forms of lucinite.

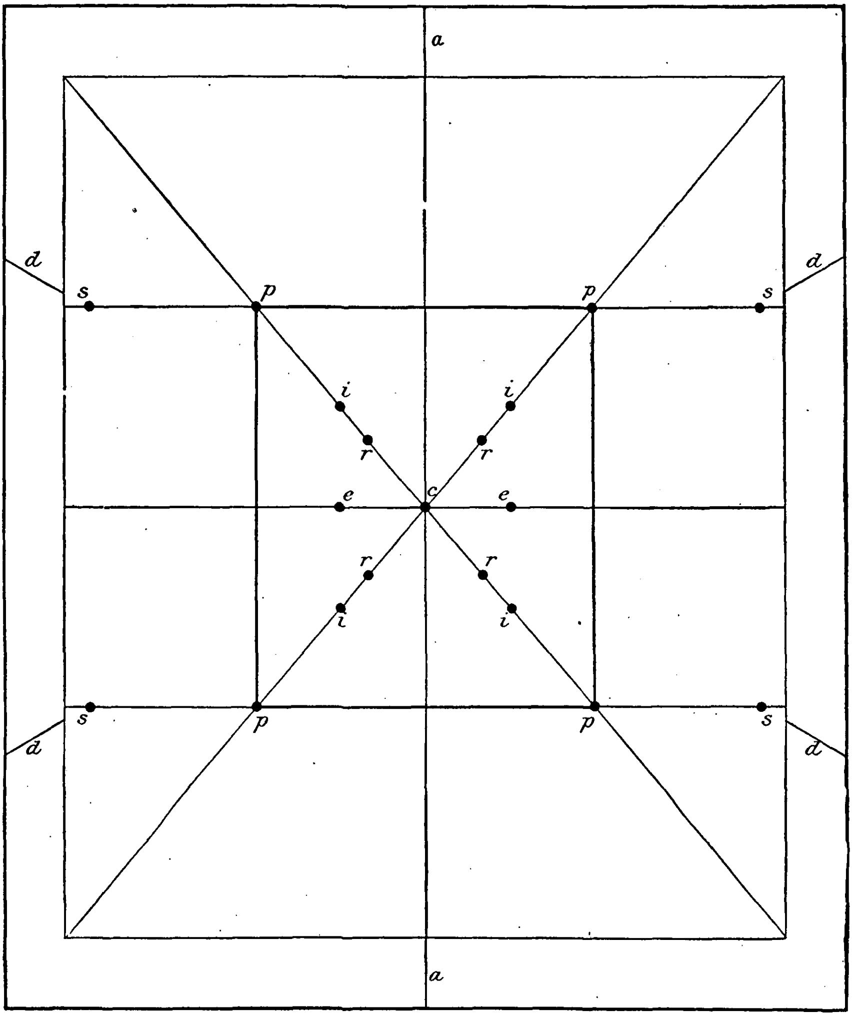

FIGURE 54.—Gnomonic projection of lucinite forms.

MEASURED CRYSTALS.

Crystal 1, not shown in any of the drawings, resembles the crystals shown in figures 59 and 60 in the large development of $s\{121\}$ and consequent rhombic shape of $p\{111\}$. The right half of figure 60 represents closely the habit and development of the forms on crystal 1.

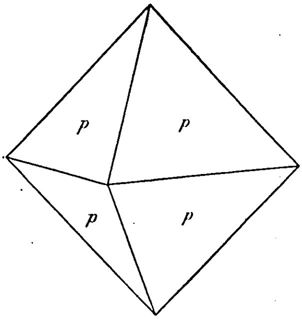

FIGURE 55.

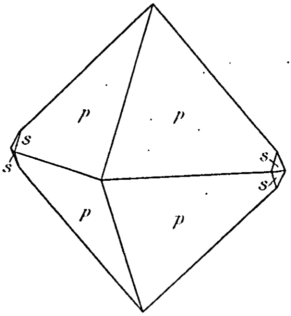

FIGURE 56.

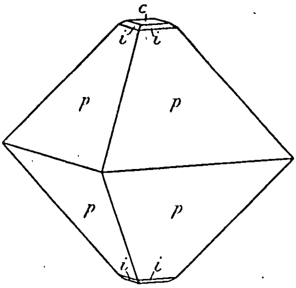

FIGURE 57.

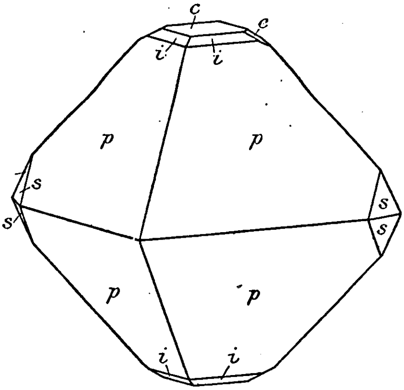

FIGURE 58.

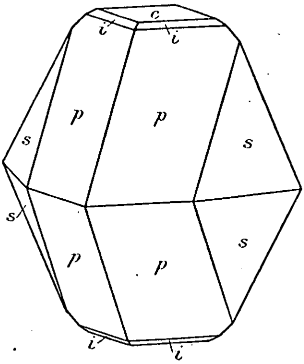

FIGURE 59.

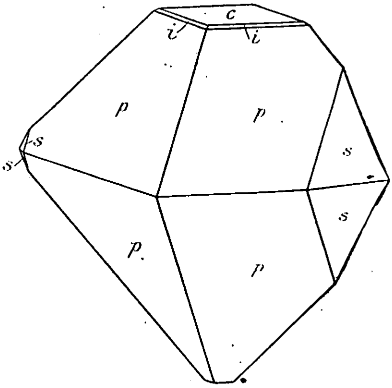

FIGURE 60.

FIGURE 55.—Octahedral crystal of lucinite. Form: $p\{111\}$. Compare with figure 87 (p. 90).
FIGURE 56.—First modification of simple octahedral crystal of lucinite. Forms: $p\{111\}$ and $s\{121\}$.
FIGURE 57.—Second modification of simple octahedral lucinite on crystal 3. Forms: $p\{111\}$, $c\{001\}$, and $i\{112\}$.
FIGURE 58.—Both modifications occurring on lucinite crystal 6. Forms: $c\{001\}$, $e\{012\}$, $i\{112\}$, $p\{111\}$, $s\{121\}$.
FIGURE 59.—Lucinite crystal with large development of $s\{121\}$, with $c\{001\}$, $i\{112\}$, and $p\{111\}$.
FIGURE 60.—A distorted crystal of lucinite. Same combination as shown in figure 59.

Crystal 2 is like that shown in figure 58 except that the faces of *s*{121} are perhaps still smaller. Both crystals 1 and 2 are well developed and the plane and brilliant faces give good reflections, which were measured for the calculation of the axial ratios of the mineral.

Crystal 3, figure 57, shows the simple combination *c i p*, which was also observed on many crystals that were not measured.

Crystal 4, figure 61, is remarkable for the many forms found on it; in fact, all the eight forms determined for lucinite were measured and identified on this crystal. Figure 61 represents a symmetrical development of the forms given, with their relative size as they occur on the crystal.

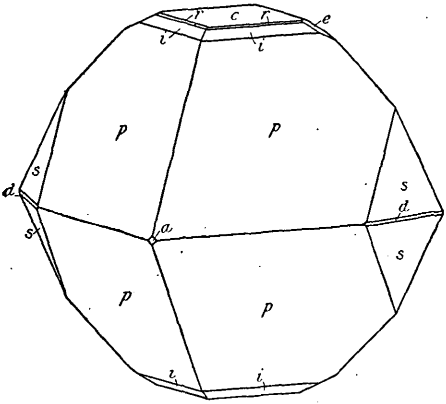

FIGURE 61.—Crystal 4, lucinite, showing all the eight forms of the mineral. Forms: *c*{001}, *a*{100}, *d*{120}, *e*{012}, *r*{113}, *i*{112}, *p*{111}, *s*{121}.

Crystal 6, figure 58, shows a line face of the prism *d*{120}, not shown in the drawing. The faces of *i*{112} are somewhat broader than usual on this crystal. The three uncertain unit forms, given in the last line on page 60, were measured on this crystal.

RELATION TO OTHER MINERALS.

Lucinite falls naturally into the same mineral group as scorodite, as shown in the following table:

Scorodite group of minerals.

Name.	Formula.	*a* axis.	*c* axis.
Scorodite	$Fe_2O_3.As_2O_54.H_2O$	0.8658	0.9541
Strengite	$Fe_2O_3.P_2O_5.4H_2O$	.8652	.9827
Lucinite	$Al_2O_3.P_2O_5.4H_2O$	.8729	.9788
Phosphosiderite [a]	$Fe_2O_3.P_2O_5.3\frac{1}{2}H_2O$?	.8772	1.0660
Variscite	$Al_2O_3.P_2O_5.4H_2O$	.8944	1.0919
Vilateite [b]	?	.8479	.8886

---

[a] This orientation of phosphosiderite is obtained by interchanging the *a* and *c* axes in the position given by Dana and then doubling the new *a* axis.

[b] Vilateite is supposed to be similar to strengite in composition and is described as monoclinic, with $\beta = 89° 27'$, but the angular differences from orthorhombic symmetry are slight, and Lacroix (Mineralogie de la France, vol. 4, p. 477, 1910) states that optically the mineral behaves somewhat like an orthorhombic substance. Half of the *a* axis, as given by Lacroix, has been taken in the above table.

The close agreement in the axial ratios for strengite and lucinite on the one hand and those for variscite and phosphosiderite on the other, suggests that perhaps phosphosiderite is a dimorphous form of strengite and not identical with it, as the writer has previously suggested.[1] The formula would then, however, have to be like that of strengite and not $Fe_2O_3 \cdot P_2O_5 \cdot 3\frac{1}{2}H_2O$, as given in the literature. The varying data given for the angles of scorodite also strongly suggests the possibility that dimorphous minerals have been grouped together under the common name scorodite.

The angular relations of lucinite and variscite have been carefully studied, and it has not been possible so to orient them as to make both minerals referable to one axial ratio.

If the *b* and *c* axes of lucinite are interchanged, the *a* axis being retained as such, then the symbols of the forms change as follows, the axial ratio of lucinite, as given, being expressed as $a:b:c$, whereas the new orientation, due to the interchange of the *b* and *c* axes, is expressed as $a':b':c'$.

$a:b:c$	$a':b':c'$
100	100
010	001
001	010
110	101
101	110
011	011
111	111

The new axial ratio, $a':b':c'$, then becomes 0.8918 : 1 : 1.0217, which is closer to the ratio of variscite, namely, 0.8952 : 1 : 1.0957, than the ratio adopted for lucinite. The value of a' (lucinite) is nearly identical with a' (variscite), the ϕ angles of {110} being 48° 17′ and 48° 10′, respectively. It is to be noted, however, that the difference in the *c* axes is considerable.

c' (lucinite)=1.0217, $\rho\{011\}=45° 37'$
c (variscite)=1.0957, $\rho\{011\}=47° 37'$

The fact that the crystals of lucinite and of variscite are not identical in angular value can also be readily shown by the comparison of the angle between the unit pyramid $p\{111\}$ and the three pinacoids. There are only three pinacoids and of course only one unit pyramid in the orthorhombic system, so that the angles *a p*, *b p*, *c p* would show at once any identical values between two orthorhombic minerals, no matter how they were oriented. As earlier given, the angle between one pinacoid and the unit pyramid was accurately measured on the lucinite crystals. In the orientation

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[1] Schaller, W. T., Crystallized variscite from Utah: U. S. Geol. Survey Bull. 509, p. 61, 1912.

adopted for that mineral this is the angle $c\{001\} : p\{111\}$. This angle has a measured value of 56° 07′. The three pyramid-pinacoid angles of variscite are calculated to be $\{001\}:\{111\} = 58° 36′$, $\{010\}:\{111\} = 55° 20′$, $\{100\}:\{111\} = 50° 29′$, with none of which does the lucinite angle of 56° 07′ agree. The closest value is $\{010\}:\{111\} = 55° 20′$, which, however, differs 47′, or nearly 1°, from the lucinite angle.

The fact that the two modifications of a mineral occur together, as shown in figures 52 and 53 (p. 57), is by no means unusual. Compare, for instance, the occurrence of rutile, anatase, and brookite, described by Palache.[1]

PHYSICAL PROPERTIES.

Lucinite does not show any cleavage, and in that respect it resembles variscite. No indication of twinning was seen on the octahedral crystals of lucinite, whereas twinning on the associated variscite is by no means rare. (The twinning of variscite is described on p. 77.) The hardness of lucinite is about 5.

The density of lucinite was not accurately determined. The crystals are so minute that it is difficult to obtain a crystal absolutely free from any adhering gangue. The density was therefore determined on fragments of the granular material, which on analysis was found to contain 26.29 per cent of quartz. The results obtained were not altogether satisfactory. They are as follows, 25 small fragments about 2 millimeters in diameter being suspended in Thoulet solution:

Density.	Sank.	Floated.
2. 576	3	22
2. 573	9	16
2. 558	19	6
2. 548	24	1

The results indicate that the density of the specimens lies between 2.57 and 2.56, with perhaps 2.566 as an average value. Correcting these values for the 26.29 per cent admixed quartz (density 2.66) gives the density of lucinite as between 2.52 and 2.53. It is therefore nearly identical with that of variscite, which was determined on 1.3 grams of the tabular crystals by the pycnometer method to be 2.536, or in round numbers 2.54. The assumption that the granular material is lucinite and not variscite is based on the fact that all the drusy crystals coating cavities are lucinite. No tabular variscite crystals were seen on this material.

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[1] Palache, Charles, Anatas, Brookit und Titanit von Somerville, Mass.: Rosenbusch Festschrift, p. 311, 1906.

OPTICAL PROPERTIES.

Lucinite is green and on being heated undergoes the same color change to deep lavender as the associated variscite. The luster is vitreous; the streak white or gray. The small fragments are transparent when bounded by parallel faces.

The optical orientation could not be determined.

The refractive indices are slightly higher than those of variscite. For instance, in crushed material all the indices are higher than 1.555, whereas for variscite $\alpha=1.546$, $\beta=1.556$, $\gamma=1.578$. The results of the examination have yielded minimum and maximum values for the indices and these may be tentatively given for the mineral as $\alpha=1.56$, $\gamma=1.59$. The birefringence, $\gamma-\alpha=0.03$, is high, about the same as that of variscite. On one section, an interference figure was observed with $2E$ large (at least about 100°). Its sign is negative, whereas variscite is positive.

The crystals are practically nonpleochroic, the color of the transmitted light being a pale green.

CHEMICAL PROPERTIES.

The pyrognostic properties of lucinite are the same as those of variscite.

A sample of the granular material whose cavities were lined with crystals of lucinite was analyzed and found to contain 26.29 per cent of silica, due to admixed quartz which was later identified in a thin section. The close similarity in crystal angles of lucinite and variscite made it imperative that the crystals of lucinite be analyzed. With great difficulty a sample was prepared which contained about 10 per cent of tabular variscite crystals, 10 per cent of granular material (lucinite or variscite?), and 80 per cent of octahedral crystals of lucinite. The entire sample analyzed weighed only 25 milligrams, but the results verified the fact that the composition of the octahedral lucinite crystals was the same as that of the tabular variscite crystals. The results obtained are shown below.

Analyses of lucinite.

	Granular material.	Same with quartz deducted.[a]	Octahedral crystals.[b]	Variscite tabular crystals.	Calculated for $Al_2O_3.P_2O_5.4H_2O$.
Al_2O_3	25.82	34.97	29	[c] 32.96	32.31
P_2O_5	31.56	42.75	44	44.73	44.93
H_2O	16.80	22.75	22	22.68	22.76
SiO_2	26.29	....	1	....	....
	100.47	100.47	96	100.37	100.00

[a] Other impurities may have been present in the sample, but no allowance is made for them.

[b] Probably had about the following composition: Octahedral crystals, 80 per cent; tabular variscite crystals, 10 per cent; granular material, 10 per cent.

[c] The percentage of Al_2O_3 is 32.40. The figure given includes V_2O_3, 0.32; Cr_2O_3, 0.18; Fe_2O_3, 0.06.

The analyses agree well enough with the calculated values for the formula $Al_2O_3.P_2O_5.4H_2O$ to show that the chemical composition of lucinite and variscite are the same.

The amount of water given off by the granular mass of lucinite (which can not be told from granular variscite in the absence of crystals) at 100° is about the same as that found for variscite. At least, the available data are not sufficient to show whether or not the water is combined in a different way in lucinite than in variscite. All the water in lucinite is given off below 180°.

Lucinite contains a small amount of vanadium. No test was made for chromium, though doubtless it also is present. In fact, the chemical properties of lucinite and variscite have not shown any difference so far as they have been determined.

DIAGNOSTIC PROPERTIES.

The octahedral shape of the lucinite crystals serves to differentiate the mineral from the other crystallized aluminum phosphates.

THE CRYSTALLOGRAPHY OF VARISCITE.

PREVIOUS DESCRIPTION.

The crystallography of variscite was described by the writer[1] in 1912 as determined on material from Lucin, Utah. A collection of specimens was later sent to the Survey by Messrs. Edison & Bird, of Lucin, and on these specimens were noted numerous crystals of variscite which showed several different habits from that given in the original description. Knowledge of the crystallography of variscite has been considerably extended by the study of the new material, on which the following description is based.

The variscite crystals either form coarsely granular masses which are only loosely coherent or partly fill cavities in the granular material. Some of these cavities contain only variscite crystals; in others the variscite is intermingled with crystals of lucinite. (Compare description of occurrence of lucinite crystals, p. 57.)

GENERAL CHARACTER OF CRYSTALS.

Eighteen crystals were detached and measured on the two-circle goniometer. The crystals averaged about 1 millimeter in length and were much smaller in their other dimensions. They are both simple and twinned crystals. The general habit is tabular, with several modifications, as described beyond.

CALCULATION OF ELEMENTS.

The measured crystals of variscite yielded additional angular values which are close to those earlier obtained. The fundamental angles from which the axial ratio was calculated in the published description of the variscite crystals are shown below, with the present measurements given immediately beneath them.

Former measurement: (010):(110)=48° 10′.6, (010):(012)=61° 17′.
Present measurement: (010):(110)=48° 12′.6, (010):(012)=61° 25′.5.

A new value for variscite was therefore calculated by combining the former and the present measurements. The new axial ratio varies but slightly from the published ratio but is somewhat more accurate. From the 22 good measurements of *m*{110} here given an average value of 48° 12′.6 is calculated for the ϕ angle. This is almost identical with the value earlier calculated as the average of 26 measurements, namely, 48° 10′.6. The average of these two values gives 48° 11′.5, from which the *a* axis is calculated as 0.8944. From the

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[1] Schaller, W. T., Crystallized variscite from Utah: U. S. Geol. Survey Bull. 509, p. 57, 1912.

17 good measurements of $e\{012\}$ is obtained an average of 28° 34′.5, which is slightly different from the previous value of 28° 43′. An average value of 1.0919 is obtained for c, as follows:

Average of 17 measurements,	ρ (012)=28° 34′.5,	c=1. 0893
Average of 12 measurements,	ρ (012)=28° 43′,	c=1. 0957
Average of 29 measurements,		c=1. 0919

The new value for the axial ratio of variscite, as calculated, is therefore

$$a:b:c=0.8944:1:1.0919.\quad p_0=1.2208.$$

The former value was $a:b:c=0.8952:1:1.0957$.

The measured angles of $m\{110\}$ and $e\{012\}$, from which the axial ratio was calculated, are given in the following table. For comparison the measurements of those faces which gave poor reflections are also included, but they were excluded from the average value of the good reflections.

Measurements of m{110} and e{012} variscite.

Crystal No.	$m\{110\}$		$e\{012\}$	
	Good reflection.	Poor reflection.	Good reflection.	Poor reflection.
	° ′	° ′	° ′	° ′
1	48 28	48 06	28 37	
1		47 27	28 26	
2	48 22	47 47	28 39	28 31
3	48 23	48 19	28 34	
3			28 36	
5			28 34	
6	48 06			
6				
7			28 39	
8	48 08			28 49
9			28 29	
11	48 05	48 19	28 43	28 58
12	48 09			28 33
12	47 49			
12	48 14			
13	48 15		28 31	
13	48 04		28 36	
13	48 13			
13	48 27			
15	48 09		28 35	
15			28 31	
16	48 32		28 32	
16	48 04		28 36	
16	48 16			
16	47 51			
17	47 51	47 36	28 33	28 31
18	48 26		28 35	
18	48 21			
18	48 24			
Average	48 12. 6	47 56	28 34. 5	28 40

FORMS AND ANGLES.

In the writer's first work on variscite only four forms were determined, namely, *b*{010}, *a*{100}, *m*{110}, and *e*{012}. The study of additional crystals has extended this list to 14 forms, 9 new ones having been found on the 18 measured crystals and the presence of the base *c*{001} on crystals from Arkansas having been verified. The forms now established for variscite are as follows:

Pinacoids: *c*{001}, *b*{010}, *a*{100}.
Prisms: *l*{130}, *j*{250}, *d*{120}, *h*{340}, *m*{110}, *q*{210}, *f*{520}.
Domes: *e*{012}, *g*{032}, *t*{102}.
Pyramid: *p*{111}.

The average of the measured angles, as compared with the calculated values, is shown in the table below:

Measured and calculated angles for variscite.

[New forms are marked with a star.]

No.	Letter.	Symbol.	Number of crystals.	Number of measurements.	Measured.		Calculated.	
					ϕ	ρ	ϕ	ρ
					° ′	° ′	° ′	° ′
1	*c*[a]	001	....	....	....	....	....	0 00
2	*b*	010	18	22	0 00	90 00	0 00	90 00
3	*a*	100	5	5	90 00	90 00	90 00	90 00
4	**l*	130	4	6	20 30	90 00	20 26	90 00
5	**j*	250	3	4	24 08	90 00	24 06	90 00
6	**d*	120	3	3	29 20	90 00	29 12	90 00
7	**h*	340	2	2	40 10	90 00	39 59	90 00
8	*m*	110	18	45	48 13	90 00	48 12	90 00
9	**q*	210	1	2	65 51	90 00	65 54	90 00
10	**f*	520	2	4	70 10	90 00	70 19	90 00
11	*e*	012	18	30	0 00	28 35	0 00	28 38
12	**g*	032	6	12	0 00	58 22	0 00	58 36
13	**t*	102	1	1	90 07	31 54	90 00	31 24
14	**p*[b]	111	3	1	....	....	48 12	58 36

[a] The form *c*{001} not found on the crystals from Utah, is discussed on p. 79.
[b] The faces of *p*{111} were not measured by their coordinate angles. See p. 73.

c{001}. For description of the basal pinacoid, see p. 79. The form is not present on the crystals from Utah.

b{010}. The brachypinacoid *b* is the dominant form of variscite and is by far the largest form observed on all of the crystals. It is vertically striated, although on some crystals the striations are so faint as to be hardly discernible. The striations are strongly developed on the twin crystals.

a{100}. The macropinacoid *a*, a rare form, was seen on only five crystals, on all of which a single line face represented the form. The ϕ angle, theoretically 90° 00′, was measured as 89° 41′, 90° 05′, 90° 08′, 89°, 90° 08′.

m{110}. The unit prism is the second largest form on variscite. A faint vertical striation was noted on a few faces, whereas generally the faces of *m* are smooth and give good reflections. The measurements of the form have been already given.

The occurrences and measurements of the new prisms *l*, *j*, *d*, *h*, *q*, and *f* are given in the following table:

Occurrences and measurements of new prisms on variscite.

[Bold-faced figures show calculated values. Reflections poor. All line faces.]

Form and crystal No.	φ	Form and crystal No.	φ
	° ′		° ′
l{230}	**20 26**	*h*{340}	**39 59**
1	19 08	1	40 29
2	21 24	2	39 52
3	21 12		
3	19 38	*q*{210}	**65 54**
3	20 34	2	65 50
15	21 05	2	65 51
j{250}	**24 06**	*f*{520}	**70 19**
1	24 06	13	69 42
1	24 08	13	69 26
12	25 23	13	71 13
13	22 55	16	70 17
d{120}	**29 12**		
1	29 37		
2	28 35		
16	29 49		

e{012}. The brachydome *e* is the third largest form on variscite and, with *m* and *b*, forms the combination of most of the crystals of the mineral. The measurements of *e* have already been given.

The new brachydome *g*{032} is very characteristic of the nearly square crystals, whose combination is *b*, *m*, *e*, *g*. On some crystals the faces of *g* are smaller than those of *e;* on other crystals they are much larger. The occurrences and measurements are shown below.

Occurrences and measurements of g{032}, variscite.

Crystal No.	Reflection.	Size of face.	ρ calculated 58° 36′.
			° ′
4	Poor	Small	57 42
4	Poor	Medium	57 41
6	Fair	Medium	58 18
6	Fair	Medium	58 28
7	Poor	Line face	57 40
7	Fair	Medium	58 23
8	Poor	Small	58 10
9	Fair	Small	58 17

The new dome *t*{102} was observed only once, on crystal 1, as a medium-sized face giving a good reflection. It lay in the zone of and between *c*{001} and *a*{100}.

The unit pyramid *p*{111} was observed on three crystals as minute faces truncating the corners of the rectangular face of *b*{010}. It was measured on only one crystal, on which the angle *b*{010}: *p*{111} was found to be 55° 34′ (calculated 55° 20′). The unit pyramid was also observed under the microscope on several additional crystals which were obtained by crushing the coarsely granular mineral.

COMBINATIONS.

The combinations observed on the 18 measured crystals from Utah are shown in the table below.

Combinations on variscite crystals from Utah.

Letter.	Symbol.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
b	010	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*
a	100	*a*	....	*a*	....	*a*	....	....	....	....	....	*a*	....	....	....	*a*	....	....	....
l	130	*l*	*l*	*l*	....	....	....	....	....	....	....	....	....	....	....	*l*	....	....	....
j	250	*j*	....	....	....	....	....	....	....	....	....	....	*j*	*j*	....	....	....	....	....
d	120	*d*	*d*	....	....	....	....	....	....	....	....	....	....	....	....	....	*d*	....	....
h	340	*h*	*h*	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
m	110	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m*
q	210	....	*q*	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
f	520	....	....	....	....	....	....	....	....	....	....	....	....	*f*	....	....	*f*	....	....
e	012	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*	*e*
g	032	....	....	....	*g*	*g*	*g*	*g*	*g*	*g*	*g*	*g*	....	....	....	....	....	....	....
t	102	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	*t*	....	....
p	111	....	....	....	....	*p*	....	*p*	*p*	....	....	....	....	....	....	....	....	....	....

ZONAL RELATIONS.

The zonal relations of variscite can be seen on the accompanying gnomonic projection (fig. 62, p. 74), which is to be compared with the projection of lucinite forms shown in figure 54 (p. 62). The prism zone is by far the richest, as it contains 9 out of a total of 14 forms. The other three zones are: *c e g b*, *c t a*, *c p m*.

HABITS.

All the crystals examined are more or less tabular in habit, but several modifications were noted, as described below.

Very thin, elongated plates, tabular parallel to *b*{010}.
Short prismatic crystals.
Stout prismatic, nearly equidimensional crystals.
Long prismatic crystals.
Stout rectangular plates.

Very thin, elongated plates, tabular parallel to *b*{010}, are abundant on some of the specimens. A simple combination, *b m e*, is shown in figure 63, whereas a somewhat thicker crystal with a richer combination is shown in figure 64. A much stouter tabular crystal, intermediate between the very thin plates and the short prismatic crystals, is shown in figure 65.

Other crystals are much stouter than the one shown in figure 65, and these crystals are also much shorter, so that their habit may be described as short prismatic. The combination observed on crystals of this habit is always *b m e*. The variation in habit of the short prismatic crystals to the stout prismatic, nearly equidimensional crystals is shown in figures 66 and 67.

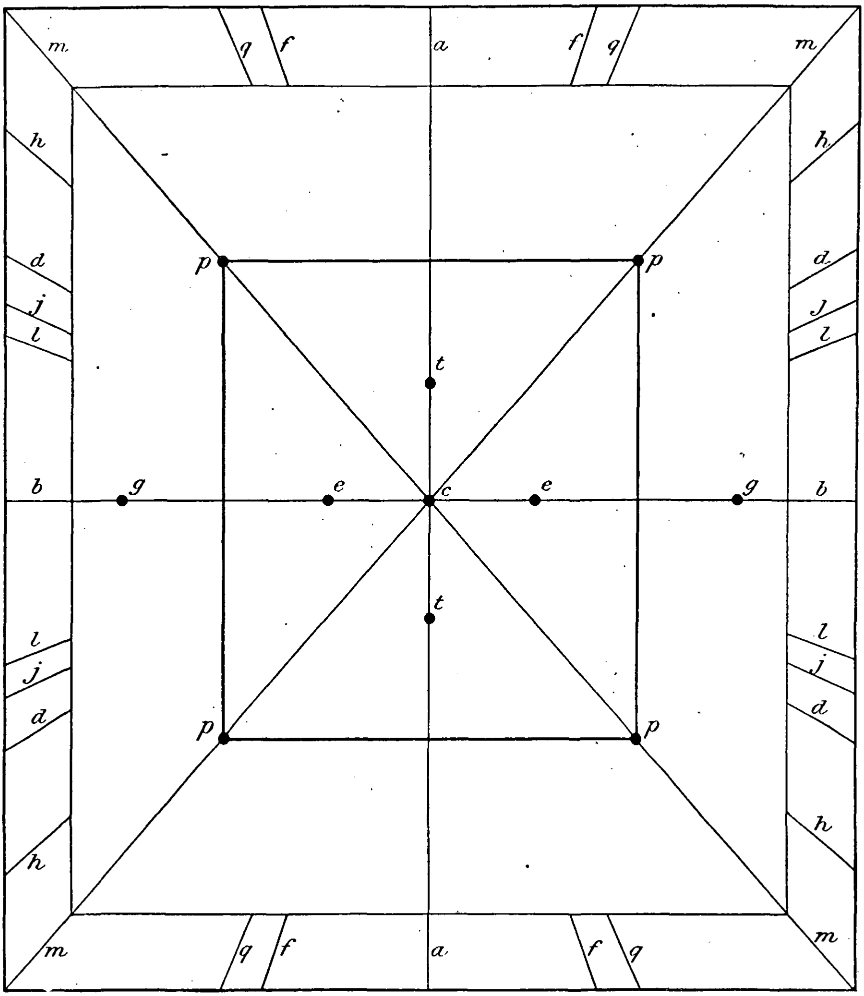

FIGURE 62.—Gnomonic projection of variscite.

The stout prismatic, nearly equidimensional crystals (fig. 67) are rather rare, but such habits as are illustrated in figures 63 to 66 are much more common.

On a few specimens were noticed long prismatic crystals, similar in combination to those shown in figures 66 and 67, except that they are elongated parallel to the vertical axis. Such a long prismatic crystal is shown in figure 68.

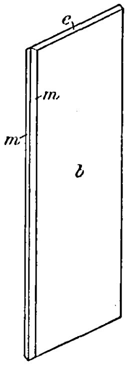

FIGURE 63.

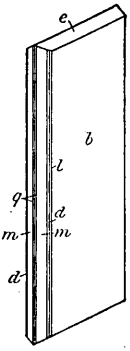

FIGURE 64.

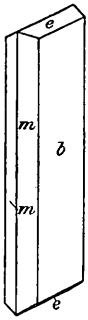

FIGURE 65.

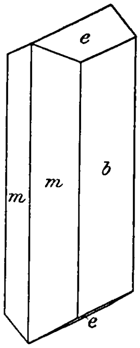

FIGURE 66.

FIGURE 63.—Very thin, elongated plates of variscite, tabulated parallel to b{010}. Forms: b{010}, m{110}, e{012}.

FIGURE 64.—A thicker crystal of variscite with a richer combination. Forms: b{010}, l{130}, d{120}. m{110}, q{210}, e{012}.

FIGURE 65.—A much stouter, tabular crystal of variscite. Forms: b{010}, m{110}, e{012}.

FIGURE 66.—Short prismatic habit of crystal of variscite. Forms: b{010}, m{110}, e{012}.

A very few crystals of a short to stout prismatic habit showed large development of the new brachydome $g\{032\}$, as shown in figure 69, and serve as a connecting link between the prismatic tabular crystals (figs. 63 to 66) and the stout rectangular plates (figs. 70 to 72).

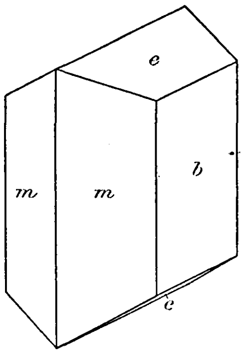

FIGURE 67.

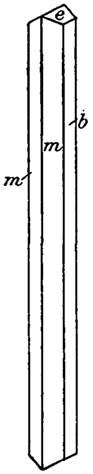

FIGURE 68.

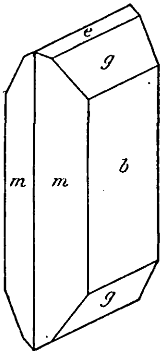

FIGURE 69.

FIGURE 67.—Stout prismatic, nearly equidimensional crystal of variscite.

FIGURE 68.—Long prismatic crystal of variscite.

FIGURE 69.—Short prismatic crystal of variscite with new dome. Forms: b{010}, m{110}, e{012}, g{023}.

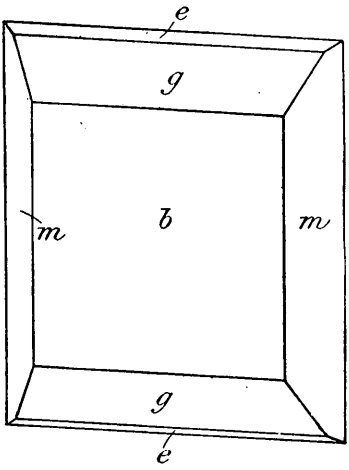

FIGURE 70.

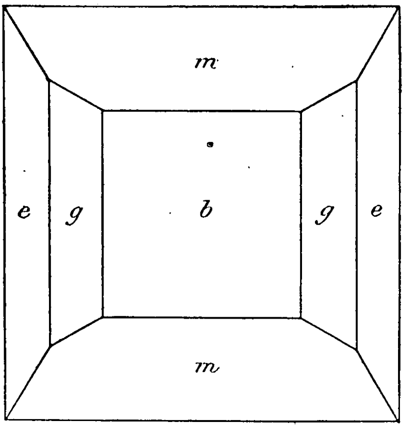

FIGURE 71.

FIGURE 70.—Clinographic projection of a stout rectangular crystal of variscite, with *b*{010} drawn in front. Forms: *b*{010}, *m*{110}, *e*{012}, *g*{023}.

FIGURE 71.—Orthographic projection on *b*{010} of a stout rectangular crystal of variscite. Same forms as in figure 70.

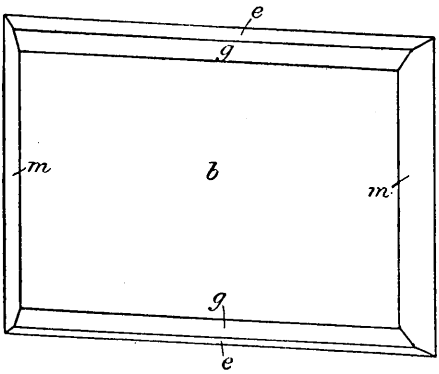

FIGURE 72.—Crystal of variscite elongated parallel to the *a* axis. Drawn with *b*{010} in front. Forms: *b*{010}, *m*{110}, *e*{012}, *g*{023}.

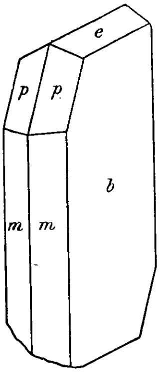

FIGURE 73.

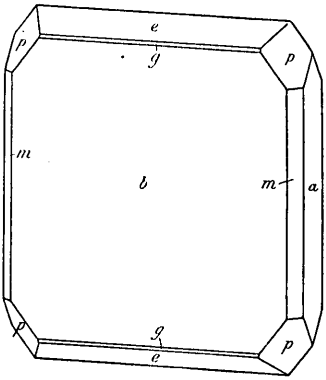

FIGURE 74.

FIGURE 73.—Short prismatic crystal of variscite, with faces of *p*{111}.

FIGURE 74.—Stout rectangular crystal of variscite (No. 5), drawn with *b*{010} in front. Forms: *b*{010}, *a*{100}, *m*{110}, *e*{012}, *g*{023}, *p*{111}.

The stout rectangular plates, nearly as wide as high, are abundant on a few specimens, but do not occur directly with the prismatic forms. The combination of these stout rectangular plates is essentially *b m e g;* rarely a line face of *a*{100} or a minute face of *p*{111} is also present. A clinographic projection of such a stout rectangular crystal, drawn with the brachypinacoid *b*{010} in front, is shown in figure 70. A similar crystal, in orthographic projection on *b*{010}, is shown in figure 71, in which the relative sizes of the four forms *b*, *m*, *g*, and *e* can be well seen.

An extreme case, in which the crystal is elongated parallel to the *a* axis, is shown in figure 72. Only one such crystal was noted. Figure 73 represents a crystal observed under the microscope. It has a short prismatic habit and is noteworthy for the large development of faces of the unit pyramid *p*{111} which are unequally developed in their size, for the rear upper faces are very small.

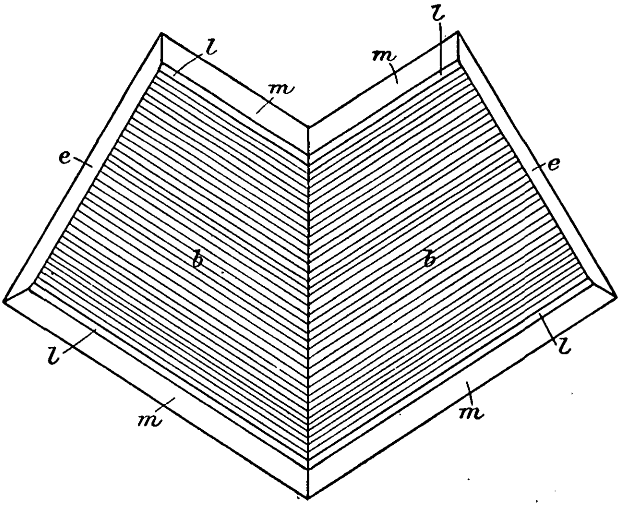

FIGURE 75.—Twin crystal of variscite. Twinning plane and composition face *t*{102}. Forms: *b*{010}, *m*{110}, *l*{120}, *e*{012}.

A stout rectangular crystal with well-developed small faces of *p*{111} is shown in figure 74, with *b*{010} drawn in front.

TWINNING.

Twinning is by no means rare for the crystals of variscite, and several such twins have been measured. The prism-zone is generally well developed on these twins, and several prisms, notably *l*{120}, are to be found on them in addition to *m*{110}.

The twinning plane is *t*{102}, and all the twins seen are contact twins with the twinning plane as the composition face. Such twins have been observed previously under the microscope, but on the present material they occur in measurable crystals. A contact twin of variscite is shown in figure 75, with the twinning plane {102} vertical.

RELATION TO VARISCITE CRYSTALS FROM ARKANSAS.

The crystals of variscite from Arkansas were described in 1878 by Chester,[1] whose crystal drawing is here reproduced as figure 76. Chester describes these crystals as follows:

> The crystals are rarely distinct but are usually found in complicated groups, sometimes forming clusters of a sheaf form. Very rarely single prismatic crystals are found, sufficiently distinct to admit of measurement. Figure 1 [fig. 76] gives the most common form, belonging to the orthorhombic system, and showing faces of *I* [*m*{110}], *iī* [*a*{100}], *iĭ* [*b*{010}], and *O* [*c*{001}]. In this crystal *I*:*I*=114° 6′. In general but one termination is seen, but crystals showing both ends are sometimes found lying on the quartz matrix, the bases being similar to each other. The face *iī* [*a*{100}] is very small and therefore easily overlooked, and *iĭ* [*b*{010}] is about the same size as *I*, so that these crystals may readily be mistaken for hexagonal prisms. Crystals showing a simple termination like that in figure 1 [fig. 76] are seldom seen. More frequently the basal plane is * * * more complicated. These planes are often covered with a thin opaque white coating, probably of quartz.

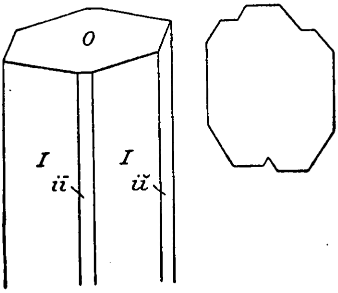

FIGURE 76.—Crystal of variscite from Arkansas. (After A. H. Chester.) The interpretation of the forms, after Chester, is O={001}, I={110}, *iī*={100}, *iĭ*={010}. Probably a more correct interpretation is to make I={210}.

Although Chester does not mention any striations on his prismatic crystals, yet the "sheaf forms" composed of "prismatic crystals" would indicate a vertical striation in the prism zone. From the angle (110): (110)=114° 06′, as given by Chester, the angle of a pinacoid to the unit prism is 57° 03′. An attempt to correlate this angle with an angle on the Utah variscite or lucinite has not led to any conclusive correlation, as shown in the table below.

Comparison of angles of variscite.

Arkansas variscite measured by Chester.	Utah variscite.	Utah lucinite.
° ′	° ′	° ′
(010) : (110)=32 57	(010) : (130)=20 26	
57 03	(010) : (250)=24 06	
	(010) : (120)=29 12	(010) : (120)=29 48
	(010) : (340)=39 59	
	(010) : (110)=48 12	(010) : (110)=48 53
	(010) : (210)=65 54	(010) : (210)=66 25
	(010) : (520)=70 19	

The only form of Utah variscite which approaches in angular value the measurement of Chester (32° 57′) is *d*{120}, whose ϕ angle, 29° 12′, is 3° 45′ less. Chester makes the statement that the

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[1] Chester, A. H., Note on the crystallization of variscite: Am. Jour. Sci., 3d ser., vol. 15, p. 207, 1878.

faces of *b*{010} and *m*{110} are of about the same size, and it seems not impossible that the angle Chester measured is not, as he gives it, prism to prism, *m* : *m*, but brachypinacoid to prism, *b* : *m*, or (010) : (110). If this is true, his measurement, 114° 06′ or 65° 54′, is identical with the angle (010) : (210) = 65° 54′ of the Utah variscite. It seems probable, therefore, that Chester's unit prism is in reality the prism (210), for with this change the Arkansas variscite becomes identical in angular value with the Utah variscite.

The question still remains whether the basal pinacoid, *O* of Chester, is in reality a distinct form or only a coalescence of numerous nonparallel faces of some other form or forms.

The collection of the late Albert F. Holden, which is now in the Mineralogical Museum of Harvard University, contains several specimens of the Arkansas variscite which on visual inspection seemed to possess measurable crystals. Through the kind permission of Mr. Holden several of the crystals were detached and measured. It was soon found, however, that nearly all the crystals consisted of barrel-like or sheaf-like groupings of numerous crystals, hardly any two of which were in parallel position. Finally a crystal was found that allowed approximate measurement, with the following result. The crystal was not a single unit, but was built up of several in nearly parallel position. The faces being defined by their size, the measurements may be given as follows: What is here described as a face, however, consists of numerous faces in approximate parallel position, the reflections of which varied several degrees from one another. The measured angle represents the center of these masses of reflections.

Measurement of prism zone of variscite from Arkansas.

Angle.		Interpretation.		
		Form.	Calculated angle.	
	°		°	′
From first large face (100) to next small face	57	120	60	48
To next medium face	29	010	29	12
To next small face	33	$\bar{1}20$	29	12
To next large face	58	$\bar{1}00$	60	48
To next small face	61	$\bar{1}\bar{2}0$	60	48
To next medium face	29	$0\bar{1}0$	29	12
To next small face		$(1\bar{2}0)$		
Back to first	93	100	90	00

If the interpretation above set forth is correct, then the prism forms on the crystal measured are *b*{010}, *a*{100}, and *d*{120}, whereas, according to the interpretation here given of Chester's measurements, the combination in the prism zone on his crystal was *b*{010}, *a*{100}, *q*{210}. The coincidence of the first measured angle (57°) with Chester's measurement (57° 03′) is more apparent than real, for the different values of the same angle as measured on the crystal here described are 57°, 61°, 57°, 62°, 61°, average 59° 50′.

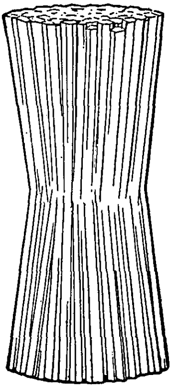

FIGURE 77.—Crystal of variscite from Arkansas, showing sheaf-like structure. The forms present are probably: *c*{001}, *b*{010}, *a*{100}, *d*{120}.

Although the base was convexly rounded, the series of reflections ceased at a ρ angle of 17° on one side and 14° on the other—that is, the outermost reflecting face on one side of the base was inclined about 17° to the main axis of the composite crystal, and the outermost reflecting surface on the other side of the base was inclined about 14° from the main axis. The crystal can readily be seen to have a sheaf form, as shown in figure 77, and as the known forms nearest to the base are inclined thereto at considerably more than 17°—(001) : (102) = 31° 24′; (001) : (012) = 28° 38′—it is concluded that the terminal face is in reality the basal pinacoid. The form *c*{001} must therefore be included in the form system of variscite.

The approximate appearance of one of these sheaf-like crystals, with the interpretation of the forms as deduced from the measurements, is shown in figure 77.

SCHNEEBERGITE.

ORIGIN OF INVESTIGATION.

Schneebergite, which was incompletely described in 1880 by its discoverer, was considered to be closely related to atopite until Eakle and Muthmann[1] in 1895 put it in the garnet group. Koechlin in 1901 showed that such a conclusion was not correct, and the true status of schneebergite has remained in uncertainty ever since.

When the writer was in Vienna in 1912 Dr. Koechlin brought out the specimens of schneebergite and readily agreed to furnish the material for a reexamination of the mineral. With his customary liberality he sent his entire collection of specimens to Washington, where they were studied as time afforded. Hearty thanks are due to Dr. Koechlin for his willingness to sacrifice his valuable material in order to have the properties of schneebergite determined.

The results obtained may be briefly summarized as follows: Schneebergite is an isometric mineral crystallizing in octahedra which show anomalous double refraction. Chemically it is an iron-calcium-antimony compound, of the empirical formula $CaSbO_3$. The antimony exists in two states of oxidation, and the formula, written $2CaO.Sb_2O_4$, is interpreted as $2CaO.Sb_2O_3+2CaO.Sb_2O_5$. Although related to romeite and atopite, it is very distinct from them and forms a well-characterized, definite mineral species. In order to correlate schneebergite with the other known calcium antimonates, it became necessary to investigate also romeite and atopite, and the results obtained are stated in the following paper. For comparative purposes it may be stated here that in romeite the antimony does not exist in two states of oxidation as given by Damour but only in the higher state. The formula for romeite is $5CaO.3Sb_2O_5$. The formula for atopite, based only on Nordenskiöld's analysis, is $2CaO.Sb_2O_5$. The Brazilian so-called atopite is romeite. Possibly the Swedish atopite is the same as romeite.

Although some of the writers who have described schneebergite confused that mineral with garnet and gave therefore not a description of schneebergite but of garnet, the results obtained by them are of interest and value and have been abstracted at some length, especially the descriptions of the paragenesis. The following historical sketch is thereby somewhat extended, but the facts already published are best given in one section and can then be conveniently referred to as a whole.

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[1] See page 85 for bibliography.

HISTORICAL SKETCH.

Schneebergite was first described by Brezina in 1880. It was found at the Pockleithner-Halde, Schneeberg, Tyrol, Austria, in transparent honey-yellow octahedra, which had a vitreous to adamantine luster. The average of nine measurements of the octahedral angle was 70° 31.9′ (calculated 70° 31.7′), the limits being 70° 26.5′ and 70° 36.6′. The small octahedra, ranging in size from 0.5 to 1 millimeter, occurred isolated in anhydrite, gypsum, or chalcopyrite. The mineral also formed layers in the chalcopyrite. Other associated minerals were magnetite, sphalerite, and pyrrhotite. Many of the octahedra of schneebergite had microscopic inclusions of magnetite or of negative crystals, and the mineral was then birefringent; otherwise it was isotropic. The crystals were brittle with a conchoidal fracture and showed traces of a cleavage after {110}. The hardness is 6.5. The density was determined on 0.17 gram as 4.1 (average of 3.9, 4.1, 4.3). When heated before the blowpipe, the crystals turned slightly brown but did not fuse. Long-continued fusion with sodium carbonate finally dissolved them. Qualitative tests showed the presence of much antimony and lime, a small amount of iron, and traces of copper, bismuth, zinc, magnesia, and sulphuric acid.

The material studied by Elterlein, who was the second writer on schneebergite, was similar to that used by Brezina, except that calcite and breunnerite took the place of anhydrite and the schneebergite occurred not as individual crystals, but only as a crystalline aggregate, in part in reniform masses. Most of Elterlein's schneebergite was garnet. The paragenesis of the ores of Schneeberg are given in detail by Elterlein, and the following paragraphs contain notes taken from his description.

The chief ore at Schneeberg is a massive, mostly deep-black sphalerite, which occurs either in pure masses or in intimate mixture with one or more of the other materials, particularly with breunnerite and quartz, but also with tremolite (called Strahlstein in German), galena, garnet, etc. Galena is the second most abundant ore mineral, followed by pyrite, chalcopyrite, magnetite, pyrrhotite, boulangerite, tetrahedrite, and others. The chief nonmetallic minerals are quartz, breunnerite, and calcite. The general succession of minerals in the ore veins of Schneeberg is given as (1) quartz, (2) sulphides, (3) carbonates. In more detail, the order of succession is given as quartz, sphalerite (rarely pyrite or breunnerite), breunnerite (rarely galena), galena.

In addition to the above-named minerals, the following have been found in the Schneeberg veins: Silver, greenockite, arsenopyrite, argentite, ilmenite, brown iron ore, fluorite, dolomite, goslarite, malachite, gypsum, schneebergite, apatite, almandite, biotite, muscovite, and chlorite.

Out of the 39 mineral successions given by Elterlein, schneebergite is given in only one, No. 20, which is (1) breunnerite, (2) schneebergite, granular [doubtless garnet and not schneebergite]. He also claims to have traced under the microscope the alteration of calcite and breunnerite into schneebergite and in fact considers the breunnerite as the mother mineral of schneebergite [doubtless garnet]. He also remarks that garnet correspondingly disappears as the breunnerite increases in amount. Elterlein describes the garnet as red and showing either {110} or {110} with {211}, and his garnet is a different variety from what he called schneebergite. As will be pointed out later, what Elterlein called schneebergite was in fact garnet. The view is supported by the fact that the analysis of Eakle and Muthmann was made on material from a series of specimens collected by Elterlein.

Many of the ore veins, as figured by Elterlein, consist of parallel even layers of pure quartz, sphalerite, galena, or pyrite, or of mixtures of these with other minerals. Other occurrences show a concentric filling of open spaces (fig. 79, p. 86) with the same minerals, and many of the specimens of schneebergite at the writer's disposal show a concentric arrangement of the mineral layers. (Compare figs. 78 and 80.)

The material analyzed by Eakle and Muthmann is described by them as follows:

> Most of the mineral appears as crystalline aggregates upon the ore, which latter consists of a mixture of magnetite, zinc blende, and chalcopyrite; the gangue mineral is massive quartz. The aggregates are partly kidney shaped and consist of rounded crystal grains, with scarcely recognizable form. The color varies from honey-yellow to bright wine-yellow; the surface is often brown from a slight decomposition, the color being due to a thin coating of iron hydroxide. The perfectly fresh, undecomposed crystals are isotropic and occasionally show weak and abnormal double refraction, especially when they contain inclusions of fine particles of the ore.
>
> On other ore specimens the mineral appears as thin coatings or as a deposit; occasionally well-defined crystals can be observed, all of which show the single form of the octahedron. The crystals are generally accompanied by calcite and breunnerite, from which the mineral has evidently originated, as has been shown by v. Elterlein; commonly the schneebergite surrounds the calcite, if it has not entirely replaced it. The paragenesis can be followed still better in sections under the microscope. It can be seen that the calcium-iron carbonate changes at first to a light-yellow double-refracting mineral of indefinite composition, which by further change becomes granular and isotropic and finally passes into the pure schneebergite.

The description of what Elterlein calls schneebergite is so similar to that of the material analyzed by Eakle and Muthmann (and found to be garnet) that there can be no question that what Elterlein called schneebergite was in reality a garnet. Eakle and Muthmann found the density of their material to be 3.838. In a blast flame it fused to a dark-brown liquid, whereas Brezina describes schneebergite as infusible. The analysis of Eakle and Muthmann showed their material to be a pure lime-iron garnet.

Analysis of garnet (supposed to be schneebergite).

[Eakle and Muthmann, analysts.]

	Found.		Calculated for $3CaO.Fe_2O_3.3SiO_2$.
	1	2	
SiO_2	....	35.45	35.43
Fe_2O_3	32.33	32.11	31.50
CaO	32.58	....	33.07

The facts which indicate that Elterlein and also Eakle and Muthmann confused garnet with schneebergite are briefly summarized as follows:

1. Elterlein's succession No. 20—(1) breunnerite, (2) schneebergite, which should read (1) breunnerite, (2) garnet—was observed by the writer on many specimens (figs. 83 and 84).
2. The alteration of breunnerite to schneebergite as described by Elterlein and by Eakle and Muthmann could not be found by the writer, whereas the derivation of garnet from breunnerite is common.
3. The reciprocal abundance of red dodecahedral garnet and breunnerite, as noted by Elterlein, suggests the derivation of garnet from the carbonate mineral and makes the view plausible that the yellow octahedral garnet (the so-called schneebergite) may also have been derived from breunnerite.
4. Elterlein's garnets showed only {110} and {211}. Therefore he did not recognize the presence of octahedral garnet and took such a rare form of garnet to be schneebergite.
5. The specimens in Munich, which furnished the material on which Eakle and Muthmann made their analysis, were originally collected by Elterlein and doubtless formed in part the basis of his own description.

As a result of the analysis given by Eakle and Muthmann, schneebergite was considered as a garnet and was included as such in the textbooks of mineralogy. In 1902 Koechlin reviewed the history of schneebergite and, after pointing out some inconsistencies between the results obtained by Eakle and Muthmann and those given by Brezina, gave the results of his own interrupted investigation of the mineral. Koechlin quotes a letter from Fr. Löffler, who said that schneebergite occurred in anhydrite only in the first specimens found. Moreover, anhydrite and gypsum have been found only rarely. Most of the specimens were obtained from the dump, and those most likely to contain schneebergite consist of drusy sphalerite, which contains also pyrite, chalcopyrite, ankerite (the breunnerite of Elterlein), or calcite. The druse was coated with secondary calcite which, when removed with acid, showed the schneebergite crystals. Koechlin found schneebergite on about a quarter of the specimens supplied by Löffler; the others show only the garnet of Eakle and Muthmann.

A distinct succession was observed by Koechlin as follows: The lower part of the specimens consists of pure sphalerite. Next follows a layer consisting chiefly of breunnerite and calcite, but containing also quartz, tremolite, sphalerite, chalcopyrite, and magnetite. In this layer occurs also the garnet. Above this is a layer in which magnetite and chalcopyrite predominate, but the carbonates are hardly visible. Toward the upper portion of this layer the sulphides are drusy, and on this drusy layer and embedded therein is the true schneebergite. The layer of secondary calcite which originally coated the schneebergite had been completely removed by acid when the specimens were received by Koechlin. The schneebergite was therefore the next to the last mineral to form in the "Hohlraumausfüllungen mit concentrischkrustenförmiger Textur," which are abundant in the veins at Schneeberg. The schneebergite was never seen in the lower layers or bands.

Koechlin made a partial analysis of schneebergite, with the following result: CaO, 20.14 per cent, 19.91 per cent; Fe_2O_3, 8.48 per cent; MgO, 0.18 per cent; traces of bismuth, alumina, potassium, sodium, arsenic, tin, and lead. Silica, copper, zinc, and sulphuric acid were absent. Moreover, antimony, though not quantitatively determined, was found to be present in large amount.

A determination of the refractive index of schneebergite gave Hlawatsch the result $n=2.10$, thereby confirming the work of Koechlin and disposing of the erroneous conclusion that schneebergite was only a lime-iron garnet.

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The following is a list of the publications cited discussing schneebergite:

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Eakle, A. S., and Muthmann, W., Ueber den sogenannten Schneebergit: Zeitschr. Kryst. Min., vol. 24, p. 581, 1895; Am. Jour. Sci., 3d ser., vol. 50, p. 244, 1895.

Koechlin, R., Zur Schneebergitfrage: Min. pet. Mitt., vol. 21, p. 15, 1902.

Hlawatsch, C., Der Brechungsexponent des Schneebergits: Min. pet. Mitt., vol. 21, p. 21, 1902.

PARAGENESIS.

The following descriptions of the paragenesis of schneebergite are based entirely on the specimens obtained from Dr. Koechlin. No data are available to indicate the relation of the specimens to the vein or rock of the region. The descriptions apply therefore only to the specimens themselves.

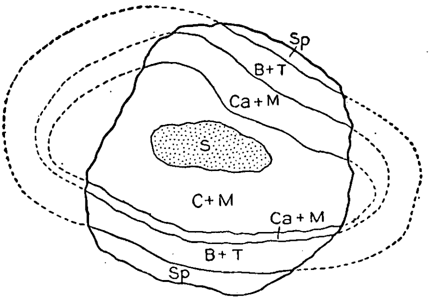


FIGURE 78.—Sketch of specimen of schneebergite with concentric bands. Compare figure 79. S, Schneebergite; C, chalcopyrite; M, magnetite; Ca, calcite; B, breunnerite; T, tetrahedrite; Sp, sphalerite.

A very marked feature of nearly all the specimens is a distinct banding. The bands are nearly parallel on some specimens and decidedly concentric on others. The parallel bands, in fact, may be only apparently parallel and may be part of an elongated concentric structure. One specimen in particular had an ellipsoidal arrangement of the bands, as is shown diagrammatically in figure 78. Elterlein describes the occurrence of "concentrischkrustenförmige Textur" in the "Hohlraumausfüllungen," and the structure of the specimen, as shown in figure 78, shows this same concentric arrangement of the cavity filling. According to Elterlein many of these lens-shaped bodies are built up of alternating layers of breunnerite and of galena. Figure 79 is a copy of Elterlein's sketch illustrating this relation. It is believed that the specimens of schneebergite represent similar "filling in" of cavities, although the concentric structure is not well shown on most of the specimens. It is to be remarked, however, that many small specimens from a filled-in cavity of the shape shown in figure 79 could be obtained that would show only parallel bands in which the concentric structure would be lost.

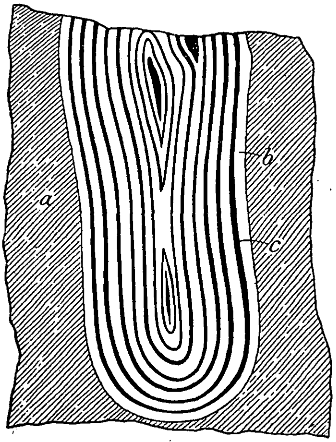


FIGURE 79.—A lens-shaped cavity in sphalerite (*a*) filled in by alternating layers of breunnerite (*b*) and galena (*c*). One-fourth natural size. (After Elterlein.) Compare with figure 78.

Two other specimens also show well the concentric arrangement of the bands and are sketched in figures 80 and 81. A part of the original calcite covering the schneebergite still remains on the specimen shown in figure 80. The presence of two small bodies of garnet (shown in solid black in fig. 80), one of them completely embedded in the schneebergite, is anomalous, but there is no reason why a secondary mineral like this garnet should not migrate and finally be deposited wherever conditions were favorable. The specimen illustrated in figure 80 is the only one ever seen by Dr. Koechlin that shows the direct association of garnet with schneebergite.

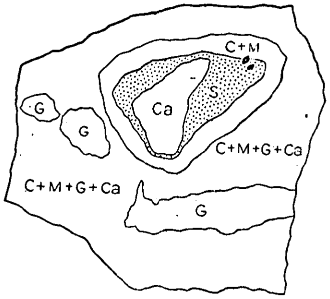


FIGURE 80.—Concentric structure of bands of minerals on specimen of schneebergite. C, Chalcopyrite; M, magnetite; S, schneebergite; G, garnet; Ca, calcite. Solid black, garnet embedded in schneebergite.

Figure 81 represents a portion of a specimen so broken as to show the granular calcite, which has been removed on most of the specimens.

Four specimens show the associations of schneebergite very well and are therefore briefly described. They are illustrated in Plate III, *A*, *B*, *C*, and Plate IV, *B*. Figures 82, 83, 84, and 86 give the necessary explanation.

Plate III, *A*, shows a small specimen which has four distinct bands—a lower band containing a mixture of quartz and sphalerite, then magnetite with inclosed nodular masses of garnet, a thin layer of white calcite, and on top an aggregate of chalcopyrite and magnetite. On the upper surface of this aggregate isolated crystals of schneebergite are to be found. No chalcopyrite is present in the bands below the chalcopyrite and magnetite mixture but galena in small specks is scattered through all the bands except the lower one.

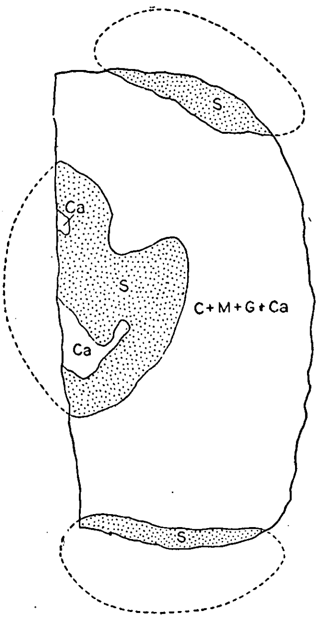


FIGURE 81.—Granular calcite (Ca) filling cavity in banded arrangement of schneebergite (S) and associated minerals. C, Chalcopyrite; M, magnetite; G, garnet.

The specimen illustrated in Plate III, *B*, is very rich in schneebergite, and the material used for the chemical analysis was in part obtained from the left-hand corner of the upper layer of this specimen. The lower portion of the specimen is an aggregate of chalcopyrite and garnet in which are two large remnants of breunnerite (mixed with chalcopyrite). Above this is an aggregate of chalcopyrite and magnetite which is somewhat porous in its upper part, and it is here that an abundant schneebergite is found, intimately mixed with the chalcopyrite and magnetite.

Plate III, *C*, shows the following succession of minerals: The lower portion, a little less than half of the specimen, is quartz, above which is an irregular band of breunnerite. Isolated masses of quartz occur in the breunnerite, and breunnerite is also found as inclusions in the quartz. An incomplete small band of magnetite lies partly between the breunnerite and quartz and partly in the breunnerite. Above this is a black layer of calcite and magnetite, which is followed by a layer of white calcite. The bands of breunnerite, calcite, and magnetite, with included small quartz masses, do not show sharp boundaries, but grade into one another. Several nodular masses of garnet are inclosed in this series of bands. Chalcopyrite is also scattered irregularly through these bands. Above these bands, but not sharply separated from the white calcite, is a layer of chalcopyrite and magnetite containing schneebergite in its upper portion.

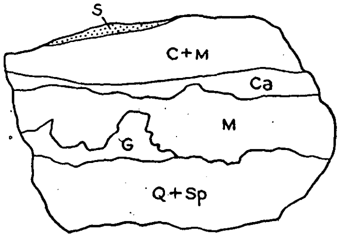


FIGURE 82.—Diagram of specimen shown in Plate III, *A*. Sp, Sphalerite; Q, quartz; G, garnet; M, magnetite; Ca, calcite; C, chalcopyrite; S, schneebergite.

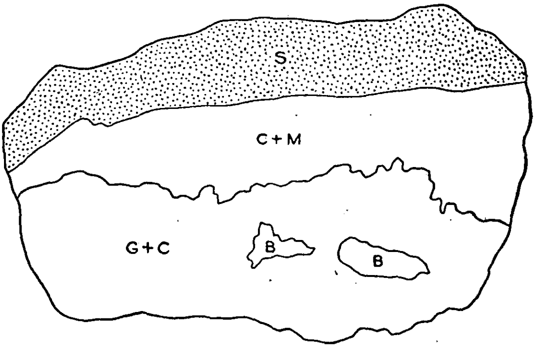


FIGURE 83.—Diagram of specimen shown in Plate III, *B*. G, Garnet; C, chalcopyrite; B, breunnerite; M, magnetite; S, schneebergite

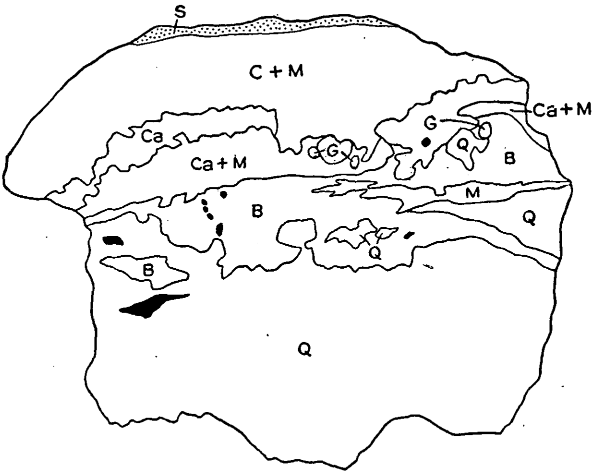
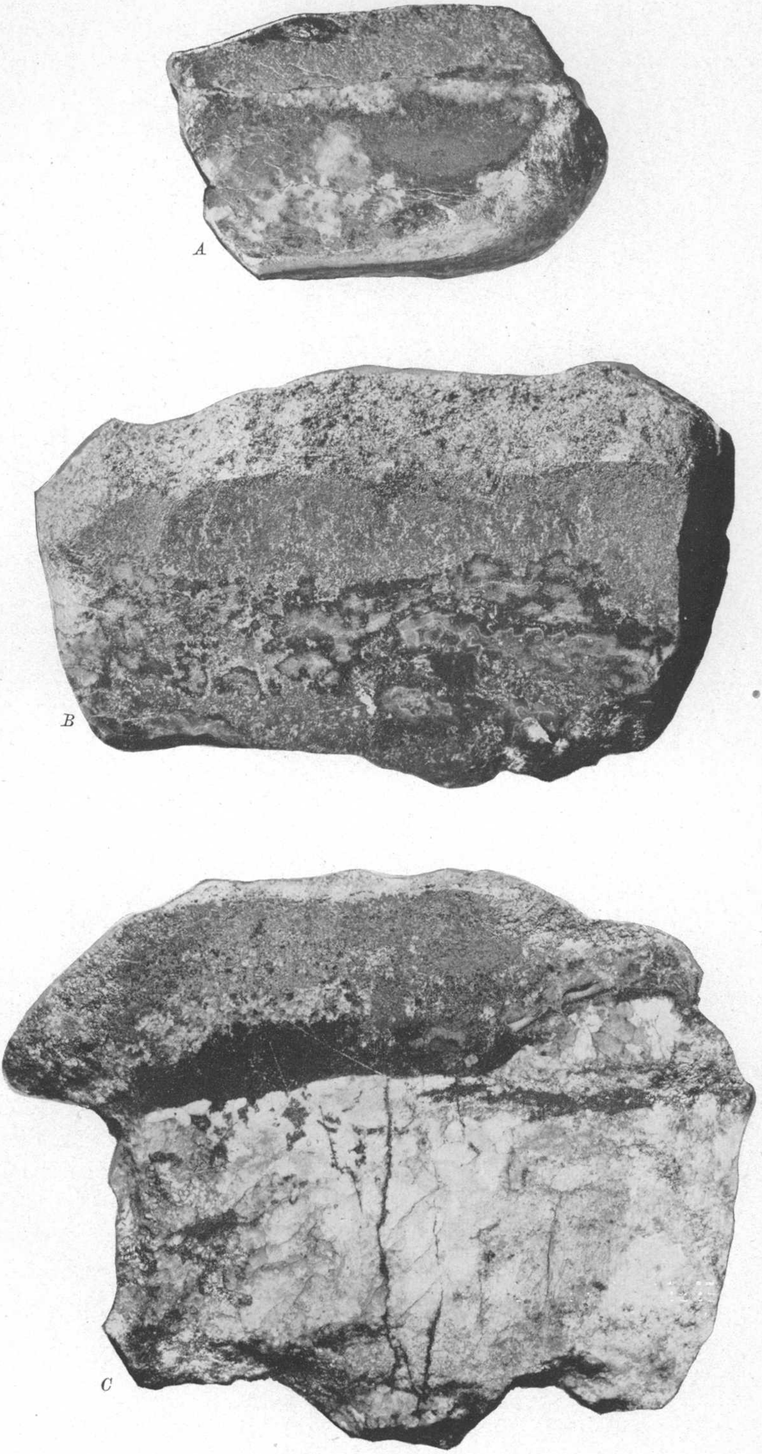


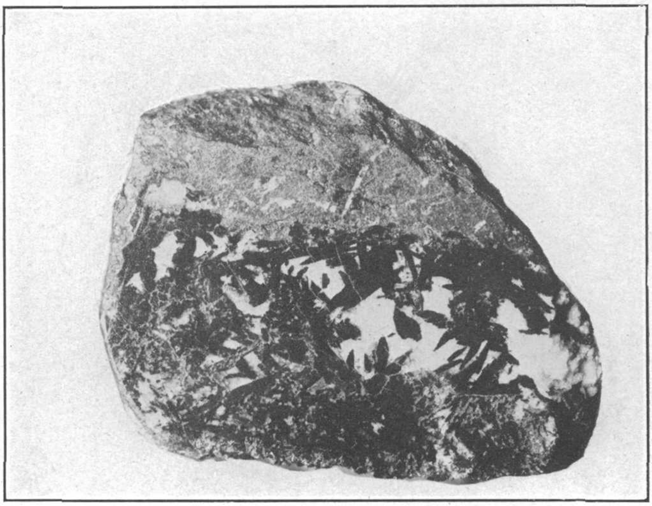
FIGURE 84.—Diagram of specimen shown in Plate III, *C*. Q, Quartz; B, breunnerite; M, magnetite; G, garnet; Ca, calcite; C, chalcopyrite; S, schneebergite; solid blank, galena.

In the specimen pictured in Plate IV, *B*, massive black sphalerite forms the lower third. Above it lies a broad band composed essentially of a mixture of sphalerite, galena, magnetite, and breunnerite. Some tremolite is also present. An irregular narrow band of magnetite overlies this broad band and is in turn followed by one of quartz or quartz and breunnerite. A band



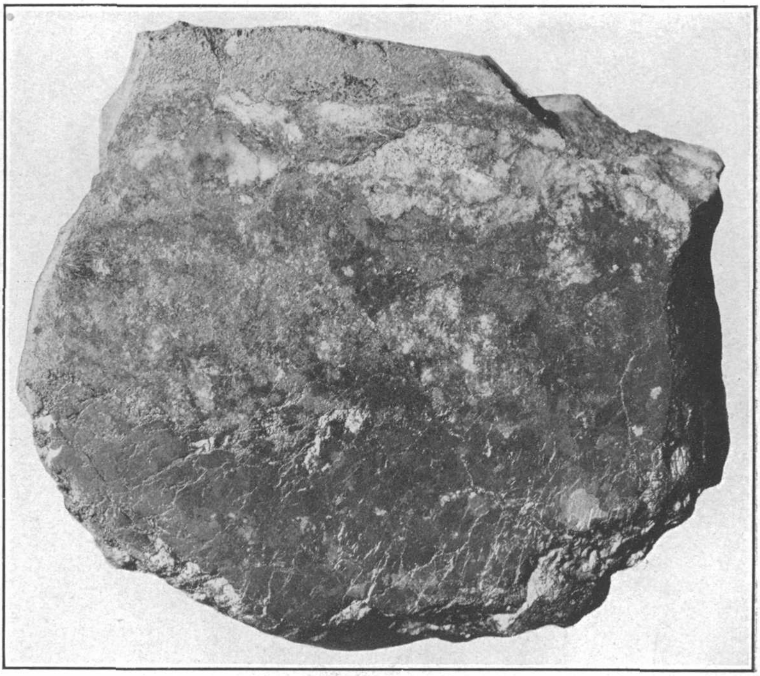
ORE SPECIMENS WITH SCHNEEBERGITE FROM SCHNEEBERG, AUSTRIAN TYROL.

For explanation see figures 82 to 84. All natural size.



A. ROMEITE FROM ITALY.

For explanation see figure 85. Natural size. Described on page 96.



B. SCHNEEBERGITE FROM AUSTRIAN TYROL.

For explanation see figure 86. Natural size.

of calcite and magnetite comes next, and over it is a mixture of chalcopyrite and magnetite containing schneebergite in its upper portion. No garnets were seen on this specimen, but they may well be present, especially in the band of quartz and breunnerite. No chalcopyrite occurs below the upper layer, but galena is scattered throughout the specimen.

The succession of minerals on the schneebergite specimens as described and illustrated in Plates III and IV and figures 82, 83, 84, and 86 may be summarized as follows:

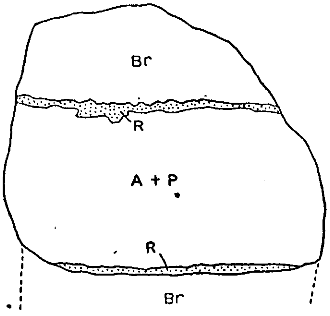


FIGURE 85.

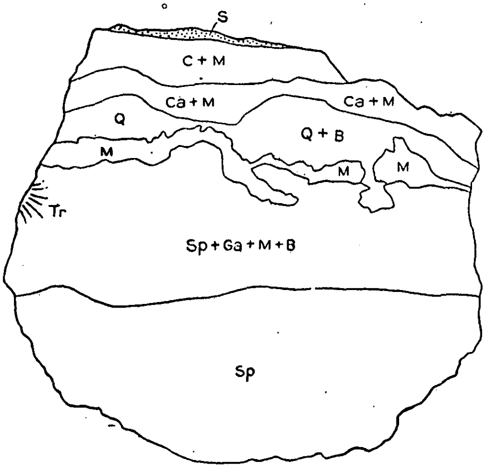


FIGURE 86.

FIGURE 85.—Diagram of specimen shown in Plate IV, *A*. Described on page 96. Br, Braunite; R, romeite; A+P, albite and piedmontite.

FIGURE 86.—Diagram of specimen shown in Plate IV, *B*. Sp, Sphalerite; Ga, galena; M, magnetite, B, breunnerite; Tr, tremolite; Q, quartz; Ca, calcite; S, schneebergite.

Succession of minerals on specimens of schneebergite.

	Pl. III, *A*.	Pl. III, *B*.	Pl. III, *C*.	Pl. IV, *B*.
10	Calcite[a]	Calcite[a]	Calcite[a]	Calcite.[a]
9	Schneebergite Chalcopyrite Magnetite	Schneebergite Chalcopyrite Magnetite	Schneebergite Chalcopyrite Magnetite	Schneebergite. Chalcopyrite. Magnetite.
8	Chalcopyrite Magnetite	Chalcopyrite Magnetite	Chalcopyrite Magnetite	Chalcopyrite. Magnetite.
7	White calcite		White calcite	White calcite.
6	Magnetite		Black calcite and magnetite.	Black calcite and magnetite.
5	Garnet	Garnet Chalcopyrite Breunnerite	Garnet	Garnet?
4	Quartz Sphalerite	Quartz	Breunnerite	Quartz. Breunnerite.
3		(?)		Magnetite.
2		(?)		Sphalerite. Galena. Magnetite. Breunnerite.
1	Sphalerite	(?)	Quartz	Sphalerite.

[a] Now removed.

This succession shows a marked uniformity. The first mineral of the specimens was either quartz or sphalerite. After this came bands composed of more than one mineral, such as sphalerite, quartz, magnetite, and breunnerite. Garnet occurs on all the specimens, either with or directly above the breunnerite, but always directly associated with it. The garnet is the only mineral which occurs not as distinct bands but as nodular masses, and it is found only in the breunnerite bands, from which it is probably derived, as stated both by Elterlein and by Eakle and Muthmann. All these writers, however, considered the garnet to be true schneebergite. Above the garnet comes a mixture of black calcite and magnetite, over which is a small band of purer white calcite. This white calcite grades into the mixture of chalcopyrite and magnetite which is the matrix of the schneebergite.

That the succession of minerals is not the reverse of that given is proved by their mode of occurrence as concentric fillings, in which, as shown in figure 78, the schneebergite is the nucleus. The mode of occurrence, as described by Elterlein, shows that they could not be concretions, growing from the center outward.

The association of schneebergite is characteristic. It lies on and embedded in the mixture of chalcopyrite and magnetite, which is surrounded by bands of minerals in a well-defined succession. The garnet, mistaken for schneebergite, has a different place in the order of succession.

There is also a gradual change in the state of oxidation of those elements existing in more than one form. The mineral first formed—sphalerite—has all its iron in the ferrous condition. The breunnerite likewise contains only ferrous iron. The next iron minerals to form, garnet and magnetite, have both ferrous and ferric iron, and in harmony with this partial oxidation to a higher valency, the mineral last formed, schneebergite, has its antimony in two states of oxidation.

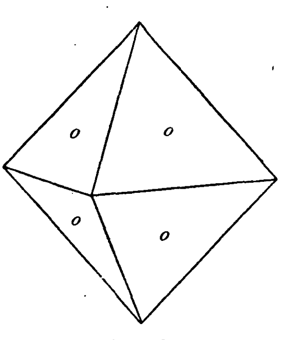


FIGURE 87.—Crystal of schneebergite, *o*{111}.

CRYSTALLOGRAPHY.

The crystals of schneebergite show only the octahedron *o*{111} and have the appearance shown in figure 87. The measurements of Brezina, as given on page 82, show a very close agreement with the octahedral angle of the isometric system.

Nearly all the faces of the crystals measured were uneven and gave several indistinct reflections. The best measurement gave $o : o' = 109^\circ\ 24'$ (calculated, $109^\circ\ 28'$). By placing a crystal in polar position on the two-circle goniometer, it was seen that the reflections from the four octahedral faces fell in a vertical line which had the correct ρ position for the isometric octahedron. Schneebergite is therefore, without question, isometric in its geometric symmetry.

PHYSICAL PROPERTIES.

Brezina gives a doubtful cleavage after {110}. No such cleavage could be detected by the writer, but a distinct cleavage parallel to the octahedron *o*{111} was found. The cleavage is by no means as good as that of romeite from Brazil (the so-called atopite).

The density was given by Brezina as 4.1 (determined on 0.17 gram). The material used by him was without question not pure, and the amount of material used very small. A new determination of the density was made with a pycnometer on 2.0676 grams of pure material and found to be 5.41.

OPTICAL PROPERTIES.

The color of a mass of pure crystals is "honey-yellow" according to Ridgway's Color standards,[1] and the color of the powdered crystals is "baryte-yellow." The luster is adamantine. When examined optically, the crystals seem to be free from inclusions, and the suggestion arises that the magnetite inclusions observed by Brezina occurred not in the schneebergite but in the garnet, where such inclusions were also found by Eakle and Muthmann.

Schneebergite, being isometric, should be isotropic, but many of the crystals show anomalous low double refraction. The compound is probably dimorphous, the high temperature form being isometric.

The refractive index was determined by the embedding method by Mr. E. S. Larsen and found to be 2.09.

CHEMICAL PROPERTIES.

PYROGNOSTICS.

Schneebergite would be classed as infusible, but in fine splinters the edges are with difficulty fused and rounded. In closed and open tubes no reactions occur. The mineral is insoluble in acids, but it is decomposed without difficulty in a sodium carbonate fusion. It becomes readily reduced when heated in hydrogen.

HOMOGENEITY OF SAMPLE ANALYZED.

The microscopic examination did not reveal any inclusions of foreign matter in the crystals of schneebergite. Pieces of the specimens were crushed so as to separate the individual minerals, and by a long-continued process of hand picking, by the use of the electromagnet and of heavy solutions, and by treatment with acids, a pure sample was finally obtained. The acids used were hydrochloric, aqua

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[1] Ridgway, Robert, op. cit., p. 32.

regia, and hydrofluoric. The concentration, of the acids used was not great nor was their use long continued at any one time. It was found that schneebergite was slightly attacked by aqua regia, but as all the products of attack went into solution no differential separation of the constituents took place and moreover the total amount of material dissolved was very slight. The crushed material was finally subjected to another careful examination under a magnifying glass, and the few impurities which remained were picked out by hand.

The purification of the material, although not worked on continuously, extended over several months. A final sample of 2.0676 grams was obtained, in which no impurities could be detected by a microscopic examination.

ANALYTICAL METHODS USED.

The density of the sample was first determined with a pycnometer. The mineral was then air dried for several weeks and finally was ground in a mechanical grinder for several hours, as it was thought necessary to have the mineral in a state of very fine subdivision in order to obtain decomposition. The results of the analyses have indicated that for schneebergite and also for romeite (including the the Brazilian "atopite") a very fine powder is not necessary and that the difficulty of decomposition of these minerals has been exaggerated.

Part of the sample was fused in a platinum crucible with sodium carbonate, and in the resulting acid solution antimony was thrown out by hydrogen sulphide. In the filtrate iron and calcium were determined as usual. A special search was made for the elements reported by earlier investigators, and the following elements could not be detected in the sample: Copper, lead, bismuth, tin, arsenic, aluminum, zinc, magnesium, and potassium. These elements, as found by earlier analysts, doubtless owed their presence to admixed minerals. Another portion of the sample was reduced in hydrogen and the water formed was collected and weighed. The 0.5-gram samples were placed in a nickel boat, inserted in a hard-glass tube properly arranged, and a current of dried carbon dioxide was passed through the apparatus for an hour. The glass tube with its boat containing the finely powdered schneebergite was then dried by being gently heated, the current of carbon dioxide being continued. After cooling, hydrogen was passed through the apparatus for half an hour, after which, the weighed calcium chloride tube being attached, the mineral was gently heated until decomposition began. Toward the end of the operation the boat and its contents were heated to a dull red. The hydrogen used was generated by the action of sulphuric acid on zinc. The gas, first washed, was then passed through an alkali solution of pyrogallic acid, then through sulphuric acid, and then through a tower of calcium chloride. Both gases passed through a different final series of three calcium chloride tubes placed just before the ignition tube containing the mineral. The percentage of water occurring as such in the mineral powder was determined by loss on ignition, as it did not belong to the mineral, but was introduced or absorbed by the very fine powder during the grinding of the sample. Individual unground crystals did not yield any water when ignited, as special tests on this point were made.

QUANTITATIVE COMPOSITION.

The results of the analysis are stated below. The antimony is reported as the metal (calculated from the weighed Sb_2S_3), and the oxygen combined with the antimony (calculated from the weighed H_2O) is given as such.

Analysis and ratios of schneebergite.

	Analysis.	Ratio.		
Sb	57.40	0.478		1.02 or 1
O	15.19	.948		2.03 or 2
FeO	8.51	.118		
CaO	17.42	.322	0.441	.94 or 1
Na_2O	.10	.001		
Insoluble [a]	.30			
H_2O [b]	1.67			
	100.59			

[a] A small residue of undissolved larger grains from the sodium carbonate fusion.

[b] Determined by loss on ignition. The water was absorbed by the finely ground powder, as special tests showed that the unground crystals yielded no water on ignition.

The amount of oxygen as actually determined by collecting the water given off on decomposing the mineral in hydrogen is 17.83 per cent. The amount of oxygen combined with the iron, or 1.90 per cent, is to be deducted from the 17.83 per cent, leaving 15.93 per cent of oxygen combined with the antimony. At the time this determination was made it was not known that the powdered substance had absorbed water during grinding. The tube containing the powdered schneebergite was heated before the quantitative determination was made, but it is not known whether the heat was sufficient to drive off all the absorbed water in the schneebergite powder. On the assumption that all the water was driven off, the figure above given for oxygen combined with antimony, namely, 15.93 per cent, is correct. If, however, none of the absorbed water was driven off, then the percentage of oxygen obtained is to be lowered by the amount of oxygen in the absorbed water, namely, 1.48 per cent, giving for oxygen combined with antimony 14.45 per cent. As it is not known which condition is the true one, and as it is believed that an intermediate condition is probably more correct—that is, that some of the water was driven off and some retained—an average of the two figures, or 15.19 per cent, is taken as the true value.

The ratios of the analysis show that the oxidation of the antimony must be that expressed by the oxide Sb_2O_4. That such a result is obtained by either one of the three interpretations just given for the percentage of oxygen in the mineral is shown by the following calculation. With the determination of antimony (57.40 per cent Sb) as a basis, the required percentage of oxygen for the three possible states of oxidation of the antimony has been calculated. As can readily be seen, the determinations of oxygen agree only with the value calculated from the Sb_2O_4 state of oxidation.

Comparison of oxygen percentages in schneebergite.

	Per cent of oxygen.	
	Calculated.	Found.
Sb_2O_3	11.48	
Sb_2O_4	15.31	15.93 maximum. 15.19 average. 14.45 minimum.
Sb_2O_5	19.14	

The ratios yield the formula $SbO_2(R''O)$ or $R''SbO_3$, in which R″ is one-fourth Fe″ and three-fourths Ca. The formula may then be written more exactly $Fe''Ca_3Sb_4O_{12}$. The analyses of romeite, however, have shown that in these minerals the bases Ca, Fe″, Mn″, and Na_2 must be considered as isomorphously replacing one another, and the formula for schneebergite is therefore written in its simplest form as $CaSbO_3$. The antimony exists in two states of oxidation and the formula $4CaO.2Sb_2O_4(=4CaSbO_3)$ is interpreted as $2CaO.Sb_2O_3+2CaO.Sb_2O_5$.

Schneebergite, empirically $CaSbO_3$, is most simply regarded as a mixed salt, namely a calcium pyro-antimonite, $2CaO.Sb_2O_3$, with a calcium pyro-antimonate, $2CaO.Sb_2O_5$. To regard the trivalent antimony as a base, to be added on to the calcium, throws too heavy a burden on the pentavalent antimony, which must then serve as acid for an overwhelming base.

ROMEITE.

ORIGIN OF INVESTIGATION.

In order to compare the composition of schneebergite with that of romeite and atopite, it was necessary to undertake a reexamination, with analysis, of these two later minerals. Through correspondence a collection of romeite specimens was obtained from Capt. Albert Pelloux, of Genoa, which furnished the material for this description. The writer's thanks are due to Capt. Pelloux for his liberality in furnishing these rare and valuable specimens.

Atopite from the original locality at Långban, Sweden, described by Nordenskiöld, was not available, but as Hussak had stated that the results of his study of the later-described Brazilian material agreed with the description and composition of the original Swedish atopite, specimens of the Brazilian atopite were purchased from Groebel & Wendler, of Geneva, Switzerland, and form the basis of the writer's work on the mineral. Unexpectedly, the analysis of the Brazilian atopite showed that mineral to have the same composition as the Italian romeite, and a critical review of Hussak's data showed that his statement that the Brazilian mineral agrees completely with the original atopite is incorrect.

HISTORICAL SKETCH.

Romeite was described by Damour[1] in 1841, and as the result of a later analysis, published in 1853, the composition of the mineral has been given in all textbooks as $CaSb_2O_4$. Moreover, as a result of Dufrénoy's contribution to Damour's first article, the mineral has always been considered as tetragonal, with angles very close to the isometric octahedron. The tetragonal character of the mineral was considered verified by Bertrand's observation of strong double refraction and uniaxial interference figure. Bertrand considered the tetragonal octahedron as built up of a group of eight 90° rhombohedra grouped around a point.

The measurements of Dufrénoy, published in 1841 and made by means of the sun's reflection, are not confirmed by the recent work of Pelloux, whose measurements agree closely with those required for isometric symmetry. Pelloux measured (111): (110) as 35°13′ (for isometric system this angle is 35° 16′); and (311): (131) as 50° 20′ (for isometric system this angle is 50° 28½′). He remarks, moreover,

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[1] See p. 96 for bibliography.

that the octahedron is too uneven to yield good measurements, a statement also made by Dufrénoy and confirmed by the writer. Pelloux has determined the forms *d*{110}, *m*{311}, and *n*{211}, in addition to the octahedron *o*{111}.

Nordenskiöld, in 1877, described a new mineral from Långban, Sweden, which he named atopite, and showed wherein, if Damour's results were correct, atopite differed considerably in chemical composition from the older known mineral.

The paper by Hussak, describing the Brazilian so-called atopite, is the last published contribution dealing with the chemical composition of the mineral. Hussak claimed that his analysis agreed with that of the Swedish atopite and fully verified the formula $2CaO.Sb_2O_5$, but, as is shown later in this paper, his analysis leads not to the atopite formula just given but to the formula of romeite, $5CaO.3Sb_2O_5$. The Brazilian so-called atopite is in fact identical with the romeite from Italy.

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PARAGENESIS.

A simple inspection of the specimens received from Capt. Pelloux showed that the Italian romeite occurs in minute veins traversing the associated minerals or more abundantly lying along the boundary of masses of two different minerals. A characteristic association seems to be that figured in Plate IV, *A* (p. 89), where minute veins of romeite lie between the braunite and the aggregate of albite and piedmontite. The mineral is also found as nests and veins in the associated braunite, albite, piedmontite, etc. The nests seem to be local enlargements of the veins rather than distinct isolated bodies—at least, the specimens at the writer's disposal all show the romeite in distinct veins. The occurrence of romeite as the main constituent of a vein seems therefore to be somewhat different from that of schneebergite, which is not known to occur as veins but only as the filling of ellipsoidal cavities.

The romeite from Brazil (the so-called atopite) occurs in cavities and also as isolated crystals scattered through the secondary manganese oxides of the Miguel Burnier manganese district. The specimens obtained from Groebel & Wendler show the romeite as isolated crystals or groups of crystals embedded in the compact manganese oxide, which is associated with quartz on some of the specimens. The occurrence of the well-formed isolated crystals of romeite in the massive compact manganese ore recalls the occurrence of well-formed pyrite crystals in compact schists and shales and suggests a similar origin.

CRYSTALLOGRAPHY.

The crystals of the Italian romeite at the writer's disposal are not suitable for accurate measurement. The octahedron is the only form identified, but its surfaces are all uneven and give a group of reflections on the goniometer. It could be shown, however, on the two-circle goniometer that the angles of the octahedron of romeite are very close to those of the isometric octahedron.

The crystals of romeite from Brazil, on the other hand, show even and brilliant faces which yielded perfect reflections. Although Hussak does not give any measured angles, he states that the mineral is isometric and holohedral and shows predominantly the octahedron $o\{111\}$, with $d\{110\}$, $a\{100\}$, and more rarely $m\{311\}$. Pelloux gives o d m with $n\{211\}$ for the Italian romeite.

On the Brazilian romeite the ρ angle of the octahedron was measured as follows:

Measurements of the ρ angle of the octahedron $o\{111\}$ on romeite from Brazil.

[Calculated ρ=54°44′.]

1		2
° ′	° ′	° ′
54 41	54 44	54 42
54 43	54 44	54 44
54 47	54 45	54 44
54 44	54 45	54 46

The angle o to o' was also measured directly as 109° 27′ (calculated 109° 28′). The isometric symmetry of the romeite from Brazil is therefore established, and the isometric form of the mineral from Italy, as indicated by Pelloux's measurements, is confirmed.

The form $v\{133\}$, found by Schröder on the Brazilian romeite, was also observed once as a line face by the writer.

Measured ϕ, 45° 00′; calculated ϕ, 45° 00′. Measured ρ, 76° 11′; calculated ρ, 76° 44′.

PHYSICAL PROPERTIES.

An imperfect octahedral cleavage was noted on the crystals from Italy, whereas the Brazilian romeite showed a good octahedral cleavage.

The density was determined by Damour for small crystalline grains as 4.714 and 4.711 and for very fine powder as 4.675. The value given in textbooks, namely, 4.713, is the average of the first two of Damour's determinations. In his analysis, made presumably on material similar to that used for his determinations of density, Damour gives 2.86 per cent of soluble silica and foreign siliceous material (quartz, albite?). If an arbitrary density of 2.7 is assigned to the 2.86 per cent of foreign matter in his sample of romeite, and the density (4.713) is corrected, a new value of 4.77 (Damour) is obtained for the pure romeite. The even higher value 5.074 was obtained by the writer by determining the density of 2.6768 grams of pure romeite from Italy with the pycnometer. The density of the Brazilian romeite (given by Hussak as 5.1) was determined by the writer on 6.7372 grams to be 5.044.

OPTICAL PROPERTIES.

The color of uncrushed romeite from Italy, freed from the interfering effect of the strongly colored associated minerals, is a "russet" according to Ridgway's "Color standards." The color of powdered romeite is a "seashell-pink." The color of the Brazilian romeite is "old gold," and the color of its powder is "very light buff." The luster is vitreous to greasy and not as adamantine as that of schneebergite.

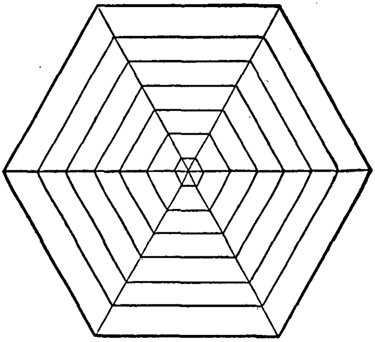
FIGURE 88.—Optical structure of crystal of romeite.

Optically the mineral is doubly refracting, although the material examined shows low double refraction and not high double refraction, as found by Bertrand and by Pelloux. The interference colors are seldom above a yellow of the first order. The structure of the Brazilian romeite as revealed between crossed nicols is shown in figure 88. The mineral, like schneebergite, is probably dimorphous, the high-temperature form being isometric.

The refractive index was determined by Mr. E. S. Larsen as 1.87 on romeite from Italy and 1.83 on romeite from Brazil. The Brazilian romeite varied somewhat in its index of refraction and birefringence.

CHEMICAL PROPERTIES.

PYROGNOSTICS.

When heated before the blowpipe, romeite is infusible. In the closed and open tubes no reactions take place. The mineral is insoluble in acids, although readily decomposed by fusion with sodium carbonate.

QUANTITATIVE COMPOSITION.

Pure samples were obtained by the same procedure as was used for schneebergite. The methods of analysis were also the same. The results of the quantitative analysis of romeite from Italy are as follows:

Analysis and ratios of romeite from Italy.

	Analysis.	Ratios.		
Sb	56.15	0.467		5.99 or 6×1.00
O	18.57	1.161		14.88 or 15×0.99
FeO	1.12	.016	.399	5.12 or 5×1.02
MnO	6.27	.088		
CaO	15.81	.282		
Na_2O	.81	.013		
H_2O	1.39			
	100.12			

The ratios yield the formula $5R''O.Sb_6O_{15}$, in which R'' is composed chiefly of Ca but contains also smaller amounts of Fe'', Mn'', and Na_2. The formula may be written, considering all of the R'' as Ca, as $5CaO.3Sb_2O_5$ or $Ca_5Sb_6O_{20}$.

Romeite can not be directly interpreted as a salt of any of the six acids given on page 104, if all the antimony is considered as an acid. The mineral can be regarded as a salt of a partly dehydrated pyro-antimonic acid, $3Sb_2O_5.6H_2O - H_2O = 3Sb_2O_5.5H_2O$ or $H_{10}Sb_6O_{20}$. Another interpretation would be to consider it a salt of a mixed acid, two parts of pyro-antimonic acid with one of meta-antimonic acid, $2(Sb_2O_5.2H_2O) + (Sb_2O_5.H_2O) = H_8Sb_4O_{14} + H_2Sb_2O_6$. It is preferred to regard romeite as a pyro-antimonate.

The interpretation of the percentage of oxygen in the mineral, as determined by reduction in hydrogen, is affected in a similar way to that of schneebergite (p. 93), on account of the small amount of water absorbed by the fine powder during grinding. The results are treated in the same way as was done for schneebergite, and the figures obtained are as follows:

Comparison of oxygen percentages of romeite from Italy.

	Per cent of oxygen.	
	Calculated.	Found.
Sb_2O_3	11.21	
Sb_2O_4	14.95	
Sb_2O_5	18.69	17.95 minimum. 18.57 average. 19.18 maximum.

The above results show that the amount of oxygen combined with the antimony is such that the state of oxidation of the metal is that expressed by the formula Sb_2O_5.

The analysis of romeite from Brazil gave the following results:

Analysis and ratios of romeite from Brazil.

	Analysis.	Ratios.		
Sb	56.02	0.466		5.95 or 6×0.99
O	18.70	1.169		14.93 or 15×1.00
FeO	1.29	.018	0.401	5.12 or 5×1.02
MnO	2.62	.037		
CaO	14.81	.264		
Na_2O	5.08	.082		
H_2O	1.12			
	99.64			

The ratios yield the same formula as was obtained from the analysis of the Italian romeite, namely, $Ca_5Sb_6O_{20}$. The ratio of Na_2O to $CaO+FeO+MnO$ is 1 : 3.89, or nearly 1 : 4, so that the formula could be written $NaCa_4Sb_6O_{20}$. To judge from the analyses, however, it seems necessary to regard the Na_2O, FeO, and MnO as replacing the CaO and to group them together under CaO

Interpretation of the percentage of oxygen found yields the following results for the Brazilian romeite:

Comparison of oxygen percentages of romeite from Brazil.

	Per cent of oxygen.	
	Calculated.	Found.
Sb_2O_3	11.18	
Sb_2O_4	14.92	
Sb_2O_5	18.64	18.20 minimum. 18.70 19.19 maximum.

The results show that, in complete conformity with the analysis of the Italian romeite, the antimony in the Brazilian mineral is in its highest state of oxidation, namely, Sb_2O_5.

Hussak stated that the formula of atopite (from Sweden), namely, $2(Ca, Mn, Na_2).Sb_2O_7$ or $2R''O.Sb_2O_5$, also accorded with his analysis of the Brazilian mineral. That such assumed accordance does not exist can be readily shown.

The analysis of the Swedish atopite, as given by Nordenskiöld, is as follows:

Analysis and ratios of atopite from Sweden.

[A. E. Nordenskiöld, analyst.]

	Analysis.	Ratios.		
Sb_2O_5	72.61	0.227		1.00
FeO	2.79	.039		
MnO	1.53	.022		
CaO	17.85	.319	0.460	2.03
K_2O	.86	.009		
Na_2O	4.40	.071		
	100.04			

The ratios yield the simple formula $2\ R''O.Sb_2O_5$, in which $R = Fe''$, Mn'', Ca, K_2, and Na_2. Another analysis would definitely determine whether this simple formula is correct or whether, as a possibility, the Swedish atopite is not the same as romeite. There seems to be no reason, however, for questioning Nordenskiöld's analysis, but his figures are very similar to those obtained for romeite.

The analysis of the mineral from Brazil, by Hussak, gave the following results:

Analysis and ratios of romeite (wrongly called atopite) from Brazil.

[E. Hussak, analyst.]

	Analysis.	Ratios.		
Sb_2O_5	76.20	0.238		2.99 or 3
FeO	Trace.			
MnO	5.70	.080		
CaO	12.68	.226	0.398	5.01 or 5
Na_2O	5.70	.092		
K_2O	Trace.			
	100.28			

The ratios yield the formula $5R''O.3Sb_2O_5$, which is identical with that obtained from the writer's analysis of romeite from Brazil and from Italy. If the ratio of Sb_2O_5 is made 1.00, then the ratio for

R''O becomes 1.67 and not 2, as would be required if Hussak's analysis led to the same result as Nordenskiöld's analysis. The mineral from Brazil is therefore not atopite but romeite, as proved by the independent analyses made by Hussak and by the writer. The three analyses of romeite given above are shown together in the following table, to which is also added Damour's last analysis:

Analyses of romeite.

	Italy.		Brazil.	
	Damour.	Schaller.	Hussak.	Schaller.
Sb_2O_5	[a] 77. 61	74. 72	76. 20	74. 72
FeO	1. 70	1. 12	Trace.	1. 29
MnO	1. 21	6. 27	5. 70	2. 62
CaO	16. 29	15. 81	12. 68	14. 81
Na_2O	....	. 81	5. 70	5. 08
K_2O	....	....	Trace.	....
H_2O	....	1. 39	....	1. 12
SiO_2, etc	2. 86	....	....	....
	99. 67	100. 12	100. 28	99. 64

[a] This represents the percentage of what Damour considered $Sb_2O_3+Sb_2O_5$.

The last three analyses all yield the same formula, namely, $5CaO.3Sb_2O_5$. The results of Damour's analysis must be considered inaccurate so far as the determinations of the antimony and of the oxygen combined with it are concerned. The analyses show, moreover, the variability in the replacement of CaO by the other bases and the improbability that one of these bases (soda, for example) should be considered by itself.

The last analysis of romeite made by Damour (in his two earlier analyses he did not determine the state of oxidation of the antimony) is reproduced below with the ratios derived therefrom.

Analysis and ratios of romeite from Italy.

[A. Damour, analyst.]

	Analysis.	Ratios.		
Sb	62. 18	0. 517		3. 13 or 3×1. 04
O	15. 43	. 964		5. 84 or 6×0. 97
FeO	1. 70	. 024		
MnO	1. 21	. 017	0. 332	2. 01 or 2×1. 01
CaO	16. 29	. 291		
SiO_2, etc	2. 86			
	99. 67			

The ratios obtained give the formula $Ca_2Sb_3O_8$ or $4CaO.3Sb_2O_4$, which, as stated by Dana,[1] agrees closer with the analysis than the simpler formula $CaSb_2O_4$ usually given in textbooks.

Nordenskiöld failed to get decisive results on atopite by reducing the mineral at a low temperature in hydrogen and determining the state of oxidation of the antimony by the loss in weight of the mineral, as was done by Damour, and ascribes his failure to three conditions—the volatility of some of the antimony, even at a low temperature; the incompleteness of the reduction even after long-continued heating in hydrogen; and the fact that a part of the unreduced mineral seemed to be soluble, after the treatment in hydrogen, in hydrochloric acid, whereas the untreated material is not soluble in acids.

Whatever may be the reason to which the difficulty is assigned, Damour's results were not verified by the writer's analysis, and as his figures yield the rather improbable formula $4CaO.3Sb_2O_4$, it must be concluded that his figures do not accurately represent the composition of the Italian romeite.

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[1] Dana, E. S., System of mineralogy, 6th ed., p. 862, 1892.

THE NATURAL ANTIMONITES AND ANTIMONATES.

The acids of antimony are six in number, as follows:

Acids of antimony.

Name of acid.	Name of salt.	Formula.
Ortho-antimonous	Ortho-antimonite	$Sb_2O_3.3H_2O=H_6Sb_2O_6$.
Pyro-antimonous	Pyro-antimonite	$Sb_2O_3.2H_2O=H_4Sb_2O_5$.
Meta-antimonous	Meta-antimonite	$Sb_2O_3.H_2O\ =H_2Sb_2O_4$.
Ortho-antimonic	Ortho-antimonate	$Sb_2O_5.3H_2O=H_6Sb_2O_8$.
Pyro-antimonic	Pyro-antimonate	$Sb_2O_5.2H_2O=H_4Sb_2O_7$.
Meta-antimonic	Meta-antimonate	$Sb_2O_5.H_2O\ =H_2Sb_2O_6$.

Hypo-antimonic acid, $H_2Sb_2O_5$, is supposedly derived from antimony tetroxide, Sb_2O_4, but this tetroxide may be just as well considered a salt, namely, antimonous ortho-antimonate, $Sb_2'''\ (Sb'''''O_4)_2$.

The natural antimonites and antimonates are grouped according to the acid in the following tabulation. In addition to the antimonites and antimonates, shown in heavy type, the list includes some examples of corresponding arsenates, phosphates, vanadates, columbates, tantalates, nitrates, and titanates.

Ortho-antimonites, salts of ortho-antimonous acid, $H_6Sb_2O_6$:

No minerals known.

Pyro-antimonites, salts of pyro-antimonous acid, $H_4Sb_2O_5$:

No minerals known. Schneebergite may be a salt of a mixed acid corresponding to $H_4Sb_2O_5+H_4Sb_2O_7$.

Meta-antimonites, salts of meta-antimonous acid, $H_2Sb_2O_4$:

Nadorite..............$(PbCl)'_2Sb_2O_4$.

Schneebergite may be a salt of a mixed acid corresponding to $H_2Sb_2O_4+H_6Sb_2O_8$.

Ortho-antimonates, salts of ortho-antimonic acid, $H_6Sb_2O_8$:

Monimolite	$(Pb,Fe,Ca)''_3Sb_2O_8$	Isometric.
Berzeliite	$(Ca,Mg,Mn)''_3As_2O_8$	Isometric.
Pseudoberzeliite	$(Ca,Mg,Mn)''_3As_2O_8$	Orthorhombic (?).
Caryinite	$(Pb,Mn,Ca,Mg)''_3As_2O_8$	Monoclinic (?).
Fergusonite	$Y'''_2Cb_2O_8$	Tetragonal.
Pucherite	$Bi'''_2V_2O_8$	Orthorhombic.
Triphylite	$(LiFe'')'''_2P_2O_8$	Orthorhombic.
Wagnerite	$(MgF)'_2Mg_2P_2O_8$	Monoclinic.
Amblygonite	$(AlF)''_2Li_2P_2O_8$	Triclinic.
Cervantite	$Sb'''_2Sb'''''_2O_8$	Orthorhombic.
Stibiconite	$Sb'''_2Sb'''''_2O_8.2H_2O$	Amorphous.
Flajolotite	$Fe'''_2Sb'''''_2O_8.xH_2O$	Amorphous.

Schneebergite may be a salt of a mixed acid corresponding to $H_6Sb_2O_8+H_2Sb_2O_4$.

Pyro-antimonates, salts of pyro-antimonic acid, $H_4Sb_2O_7$:

Atopite	$Ca_2Sb_2O_7$	Isometric.
Microlite[1]	$Ca_2Ta_2O_7$	Isometric.
Tripuhyite	$Fe''_2Sb_2O_7$	Biaxial.
Bindheimite	$Pb_2Sb_2O_7.xH_2O$?	Amorphous.
Romeite	$Ca_5Sb_6O_{20}$	Isometric.

Schneebergite may be a salt of a mixed acid corresponding to $H_4Sb_2O_7+H_4Sb_2O_5$.

Meta-antimonates, salts of meta-antimonic acid, $H_2Sb_2O_6$:

Stibianite[2]	$H_2Sb_2O_6$(?).	
Lewisite	$3(CaSb_2O_6)$ $2(CaTiO_3)$	Isometric.
Mauzeliite	$(CaSb_2O_6)$ $((CaF)_2TiO_3)$ (?)	Isometric.
Perovskite	$CaTiO_3$	Isometric.
Pyrochlore	$(CaTiO_3.n(CaCb_2O_6)$ (?)	Isometric.
Derbylite	$(Fe''Sb_2O_6)$ $5(Fe''TiO_3)$	(?)Orthorhombic.
Columbite	$Fe''Cb_2O_6$	Orthorhombic.
Niter	$K_2N_2O_6$	Orthorhombic.

Lewisite (with which mauzeliite is identical) seems to be predominantly $CaSb_2O_6$ with a small amount of perovskite isomorphously mixed with it.

Derbylite seems to represent an orthorhombic modification of $(Fe''TiO_3)$, already known in a tetragonal form (in iserite), a trigonal form (ilmenite), and possibly in an isometric form (in pyrochlore, dysanalyte, or knopite?).

Mixed antimony acids:

Schneebergite	$2CaO.Sb_2O_3$ $2CaO.Sb_2O_5$	Isometric.

Romeite may be a salt of a mixed acid corresponding to $2(H_2Sb_2O_6)+H_6Sb_2O_8$.

Schneebergite may be a salt of a mixed acid corresponding to $H_2Sb_2O_6+H_6Sb_2O_6$.

Relations not clear:

Ochrolite	$Pb_6Cl_4Sb_2O_7$	Orthorhombic.

The relations of ochrolite and ecdemite ($Pb_6Cl_4As_2O_7$) are not clear.

Manganostibiite	$9MnO.Sb_2O_5$?	Orthorhombic (?).

The other antimonates of Igelström are too indefinite for consideration.

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[1] Apparently essentially $Ca_2Ta_2O_7$. Sodium, fluorine, and other elements seem to be present in some varieties of microlite.

[2] According to the formula given stibianite would not be an antimonate but the antimonic acid itself. The composition of stibianite can not be considered as conclusively determined.

VELARDEÑITE, A NEW MEMBER OF THE MELILITE GROUP.

The compound $2CaO.Al_2O_3.SiO_2$ has been found to play an important part as one of the members of an isomorphous series of minerals whose mixtures are well known under the names of melilite and gehlenite. The relations of the members of the melilite group are given in the following paper. A review of the literature on the composition of melilite and gehlenite has shown that the "gehlenite" from the Velardeña mining district, in Mexico, described by Wright[1] in 1908, is in fact the compound $2CaO.Al_2O_3.SiO_2$, mixed with about 20 per cent of åkermanite. This compound also occurs in quantity in several melilites and gehlenites. It therefore deserves to be recognized as a mineral species, which is appropriately named velardeñite, after the locality.

Velardeñite was artificially prepared by Weyberg[2] in 1904 by fusing kaolin with a small amount of calcium bromide. The material, after the soluble portion of the melt had been dissolved, consisted of minute square prisms, which gave parallel extinction and in cross section were uniaxial, negative. The prisms were therefore a combination of a tetragonal prism with the basal pinacoid. Two analyses of material, not entirely pure, were made by Weyberg and, together with the calculated percentages of the formula $2CaO.Al_2O_3.SiO_2$, are reproduced in the table below.

Analyses of artificial velardeñite.

[Z. Weyberg, analyst.]

	1	2	Calculated.
SiO_2	25.79	22.56	21.99
Al_2O_3	36.66	37.06	37.23
CaO	37.42	40.30	40.78
	99.87	99.92	100.00

Some years later the same compound was artificially prepared by Shepherd and Rankin,[3] who also give the chief properties of the material. (The optical determinations were made by F. E. Wright.)

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[1] Wright, F. E., On three contact minerals from Velardeña, Durango, Mexico [gehlenite, spurite, and hillebrandite]: Am. Jour. Sci., 4th ser., vol. 26, p. 545, 1908.

[2] Weyberg, Z., Ueber einige basische haloidhaltige Calciumalumosilicate: Centralbl. Mineralogie, 1904, pp. 729-734.

[3] Shepherd, E. S., and Rankin, G. A., Preliminary report on the ternary system $CaO-Al_2O_3-SiO_2$; a study of the constitution of Portland cement clinker: Jour. Ind. and Eng. Chemistry, vol. 3, p. 211, 1911.

The following table shows a comparison between the properties of velardeñite from Mexico, as given by Wright, and the properties of artificial pure velardeñite:

Properties of velardeñite.

	Velardeñite from Mexico (80 per cent pure velardeñite, 20 per cent pure åkermanite).	Artificial pure velardeñite.
Symmetry	Tetragonal	Tetragonal.
Cleavage	{001} imperfect,[a] (prism) poor	{001} distinct.
Density	3.039	3.038.
Sign	Negative	Negative.
ω	1.666	1.667.
ϵ	1.661	1.658.
$\omega-\epsilon$	0.0055	0.009.

[a] Well marked in thin section.

The other properties of velardeñite, as given by Wright, are as follows: Color, dark gray or gray-black from minute inclusions of magnetite and other particles, rarely amber-yellow; luster, resinous to greasy; translucent to transparent in thin flakes; fracture, uneven and irregular, conchoidal to splintery; hardness about 5.5; gelatinizes readily with acid and fuses with difficulty.

The interpretation of Allen's analysis, as quoted by Wright, is shown in the table below. The analysis has been recalculated by combining TiO_2 with SiO_2, Fe_2O_3 with Al_2O_3, $FeO+MnO$ with MgO, and K_2O+Na_2O with CaO, neglecting the water (1.85 per cent), and reducing the analysis to 100 per cent. The formula of åkermanite is $4MgO.8CaO.9SiO_2$. (See p. 116.)

Comparison of velardeñite analyses.

	Original analysis by E. T. Allen.	Analysis recalculated.	Calculated composition, 79.8 per cent velardeñite, 20.2 per cent åkermanite.	Difference.
SiO_2	26.33	26.98	27.03	+0.05
Al_2O_3	27.82	29.53	29.68	+ .15
CaO	39.55	40.70	40.46	− .24
MgO	2.44	2.79	2.83	+ .04
TiO_2	.03			
Fe_2O_3	1.43			
FeO	.50			
MnO	.01			
Na_2O	.21			
K_2O	.10			
H_2O	1.85			
	100.27	100.00	100.00	

The interpretation of the analysis of the mineral from Velardeña shows a close agreement between the analytical figures and the figure calculated for the assumed mineral composition.

Of the seventeen analyses of members of the melilite series given in the following paper, six show no velardeñite and the remaining eleven show that it is present, in isomorphous mixture, to the following percentages: 6.5, 9.5, 9.8, 11.3, 15.0, 15.8, 43.5, 44.7, 55.6, 63.8, 79.3.

As three of the analyses show the compound $2CaO.Al_2O_3.SiO_2$ to be present in natural minerals in excess of 50 per cent, it is justifiable to consider it a definite mineral species, velardeñite, with the properties given.

THE MELILITE GROUP.

HISTORICAL SKETCH.

REVIEW OF OLD THEORIES.

The composition of the melilite group has never been satisfactorily explained. The earlier writers assigned definite formulas to melilite and to gehlenite, although these are, as Dana[1] says, "uncertain, since the analyses fail to agree." The analyses of gehlenite, as listed by Dana, agree better with a single definite formula than those grouped under melilite.

Vogt[2] suggested that the natural melilites were mixtures of gehlenite ($3CaO.Al_2O_3.2SiO_2$) and an artificial product of the general formula $4R''O.3SiO_2$, to which the name åkermanite[3] was given. Calcium was the predominant base of this compound, and the formula of åkermanite has been written $4CaO.3SiO_2$, with appreciable amounts of MgO and other bases replacing, in part, the CaO. The failure of Vogt's theory to find general acceptance is due to the facts that (1) he assumed gehlenite, $3CaO.Al_2O_3.2SiO_2$, as one of the end members, whereas gehlenite is not a distinct and definite species but is itself a variable mixture of definite end members; and (2) he assumed the formula $4CaO.3SiO_2$ for åkermanite, whereas the correct formula is $4MgO.8CaO.9SiO_2$.

Bodlaender[4] found that the analyses of natural melilites did not agree with Vogt's theory and suggested that the optically negative melilites were mixtures of $R''SiO_3$ with $R''R'''_2O_4$, whereas the optically positive melilites represented mixtures of $R''SiO_3$ with $R''_3R'''_2O_6$.

Zambonini[5] has adopted Bodlaender's theory, although in an earlier paper[6] he had considered three possible explanations of the composition of the melilite group. If gehlenite ($3CaO.Al_2O_3.2SiO_2$) is considered as one end member, then, according to Zambonini, the other end member is $CaSiO_3$ and melilites are mixtures of the two types of compounds $R''_3R'''_2Si_2O_{10}$ and $R''SiO_3$. On the other

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[1] Dana, E. S., System of mineralogy, 6th ed., p. 475, 1892.

[2] Vogt, J. H. L., Mineralbildung in Schmelzmassen, p. 96, 1892.

[3] Åkermanite was named after R. Åkerman and, as originally given by Vogt, is spelled with only one n. The spelling åkermannite, sometimes seen, is erroneous. The å is pronounced like long o.

[4] Bodlaender, G., Die Zusammensetzung des Meliliths: Neues Jahrb., 1892, Bd. 1, p. 53; 1893, Bd. 1, p. 15.

[5] Zambonini, F., Mineralogia Vesuviana, p. 254, 1910.

[6] Zambonini, F., Über eine krystallizierte Schlacke der Seigerhütte bei Hettstedt, nebst Bemerkungen über die chemische Zusammensetzung des Melilith: Zeitschr. Kryst. Min., vol. 41, p. 226, 1906.

hand, he states that melilites may be treated as having the general composition $R''R'''_2Si_2O_8.nR''_2SiO_4$. Zambonini also states that Bodlaender's theory, according to which melilites are composed of $R''SiO_3$ and $R''Al_2O_4$, agrees well with the facts.

Busz and Rüsberg,[1] in a recent paper, gave analyses of two samples of artificial melilite crystals, and, having found that Vogt's theory does not fit their analyses, they suggested that melilite is a mixture of either (1) gehlenite and $R''_3Si_2O_7$, or (2) the three components $3RO''.R'''_2O_3.2SiO_2$ (gehlenite), Ca_2SiO_4, and $CaSiO_3$.

Clarke[2] has recently suggested that gehlenites are mixtures of $2CaO.Al_2O_3.SiO_2$ and $9CaO.Al_2O_3.6SiO_2$.

Several other theories have been proposed, but, as admitted by their originators, they are not entirely satisfactory for explaining all the observed facts and need not be repeated here.

It seems to the writer that, with the exception of Vogt's, all the proposed theories are mainly attempts to express the composition of a given melilite by the summation of a number of compounds whose only reason for existence is that they are rational and theoretically possible chemical compounds. They show no relationship either among themselves or to the melilites in form or in properties. What resemblance is there between melilite and $CaSiO_3$ or Ca_2SiO_4, or for that matter why should the metasilicate and orthosilicate of lime be grouped together in isomorphous mixture when the properties of their known forms are so different?

If it is admitted that melilite represents an isomorphous mixture of a certain number of end products, then the problem is solved when these end members are identified. But these end members must satisfy the requirements of isomorphism; they must be related chemically, they must have a similar crystal form, they must form mixtures with the same crystal forms as the end members themselves, and all natural occurrences of melilite must be capable of being expressed quantitatively as mixtures of these end members.

All the proposed theories fail to meet these requirements, although Vogt's theory comes nearest to the truth. The essence of his theory is correct, but the foundations are not correct—the composition of his end members was not correctly expressed.

CHARACTERISTICS OF THE MELILITE GROUP.

The melilite group is well defined and includes the minerals known under the names melilite, gehlenite, and fuggerite. They are tetragonal, and when in distinct crystals form short, square prisms and

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[1] Busz, K., and Rusberg, F. W., Mineralogisch-chemische Untersuchungen am Olivin- und Melilithkristallen in Hochofenschlacken: Centralbl. Mineralogie, 1913, p. 625.

[2] Clarke, F. W., The constitution of the natural silicates: U. S. Geol. Survey Bull. 588, pp. 31-34, 1914.

tabular forms (especially the artificial products). The cleavage is parallel to the base and the prism. The hardness is from 5 to 6, the density 2.9 to 3.1, the refractive index between 1.60 and 1.67, and the double refraction low. Some crystals are positive and others negative. Chemically the minerals are silicates of lime and alumina with smaller and varying amounts of magnesia, alkalies (especially soda), iron, etc. They readily gelatinize with acids.

The properties of the minerals of the melilite group, as outlined above, are characteristic and also fairly uniform. It follows, therefore, that the properties of the end members are probably similar among themselves and similar to those given above for the members of the group. In fact, the properties of the mixtures, as given above for the melilites (and gehlenites), are so nearly constant that the properties of the end members may be almost determined from the properties of their mixtures. One of the end members must have a density of about 2.9, another of about 3.1; the refractive index of one must be about 1.60, of another 1.67; one must be negative, another positive. The properties of the end members as proposed herein are consistent with the properties of their mixtures (melilites, gehlenites).

NEW THEORY.

PRIMARY COMPOUNDS.

NATURAL ANHYDROUS CALCIUM-ALUMINUM SILICATES.

A review of the literature shows that the anhydrous calcium-aluminum silicates occurring in nature are few in number. They are given below, with their crystal symmetry.

Anhydrous calcium-aluminum silicates occurring in nature.

Name.	Formula.	Crystal symmetry.
Anorthite	$CaO.Al_2O_3.2SiO_2$	Triclinic.
Didymolite	$2CaO.3Al_2O_3.9SiO_2$	Monoclinic.
Grossularite	$3CaO.Al_2O_3.3SiO_2$	Isometric.
Sarcolite	$3CaO.Al_2O_3.3SiO_2$	Tetragonal.
Velardeñite	$2CaO.Al_2O_3.SiO_2$	Tetragonal.
Melilite	(?)	Tetragonal.
Gehlenite	(?)	Tetragonal.

Sphenoclase, considered a doubtful species with the formula $6CaO.Al_2O_3.6SiO_2$, has been shown by V. M. Goldschmidt[1] to be a rock composed chiefly of pyroxene and grossularite.

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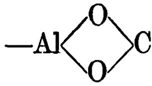
[1] Goldschmidt, V. M., Ueber den sogenannten Sphenoklas: Centralbl. Mineralogie, 1911, pp. 35-36.

Meionite, supposed to be $4CaO.3Al_2O_3.6SiO_2$, has been shown by Borgström[1] to have the composition $CaCO_3.3CaAl_2Si_2O_8$.

To the above list of minerals is added åkermanite, a tetragonal silicate of lime and magnesia, which has the crystal form of melilite, and whose physical and optical properties are also very similar to those of melilite.

Sarcolite and velardeñite are the only tetragonal minerals listed above whose composition is definitely known. A few trials soon showed that all the suitably described members of the melilite and gehlenite group can be satisfactorily explained as isomorphous mixtures of the primary compounds, sarcolite ($3CaO.Al_2O_3.3SiO_2$), a theoretical soda-sarcolite ($3Na_2O.Al_2O_3.3SiO_2$), velardeñite ($2CaO.Al_2O_3.SiO_2$), and åkermanite ($4MgO.8CaO.9SiO_2$). Sarcolite and åkermanite occur in nature in a pure state as distinct mineral species, and velardeñite forms 80 per cent of a mineral occurring at Velardeña, Mexico, åkermanite forming the remaining 20 per cent. The physical and optical properties of these minerals are known and well defined and the important ones are grouped together on page 117.

The chemical composition of these tetragonal primary compounds, if expressed by empirical formulas, does not show a close relationship, but their formulas may be written in such a way as to suggest that a possibility of relationship exists, as shown by the formulas given below. No contention is made that these formulas structurally express the composition of the individual minerals; they are given only to show that a possible chemical relation exists between the minerals above named, which, in isomorphous mixture, comprise the minerals of the melilite group. Inasmuch as no aluminum is present in åkermanite, it is necessary to consider that the aluminum in sarcolite and velardeñite plays the part of a base and not an acid. In the formulas given below the univalent group (AlO_2Ca), or  $-\mathrm{Al}\genfrac{<}{>}{0pt}{}{\mathrm{O}}{\mathrm{O}}\mathrm{Ca}$, is the only base in velardeñite. Two forms for sarcolite are given to show better the relationship of sarcolite to velardeñite and to åkermanite, respectively. The sarcolite 1 formula is more closely related to that of velardeñite than the sarcolite 2 formula, but in turn the formula of sarcolite 2 is more closely related to that of åkermanite than the formula of sarcolite 1.

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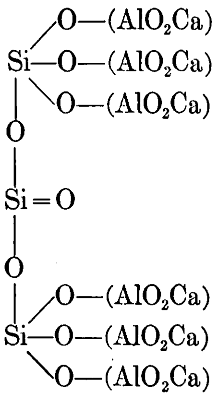
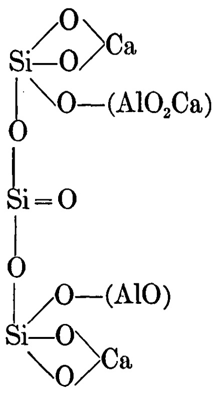
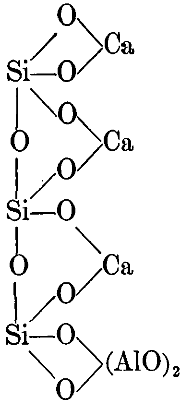
[1] Borgström, L. H., Zeitschr. Kryst. Min., vol. 54, p. 238, 1914.



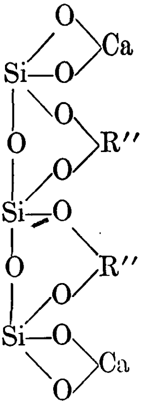
Velardeñite.



Sarcolite 1.



Sarcolite 2.



Åkermanite. R″=(Ca, Mg) in the ratio of 1:2.

SARCOLITE.

Sarcolite ($3CaO.Al_2O_3.3SiO_2$) is a rare mineral found in the ejected masses of Monte Somma, Vesuvius. The properties of the mineral are defined as follows by Zambonini.[1] Tetragonal, hemihedral, $c=0.8861$; density 2.92 (2.936 Breithaupt, 2.932 Rammelsberg); uniaxial, positive, for sodium light $\omega=1.6035$, $\epsilon=1.6147$, $\epsilon-\omega=0.0112$.

Three analyses of sarcolite are available and are given below. Of these, the one by Scacchi seems to be of less value than the other two. A small amount of soda is given in all three analyses. It doubtless replaces lime (CaO) but has been considered in this paper as belonging to a theoretical soda sarcolite, $3Na_2O.Al_3O_2.3SiO_2$. It would make no difference for comparative purposes whether the soda were reduced to its equivalence of lime or whether, as is done in this paper, it were kept by itself as belonging to a distinct compound.

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[1] Zambonini, F., Mineralogia Vesuviana, p. 247, 1910. Zambonini states that the optical properties given by Pauly (Centralbl. Mineralogie, 1906, p. 266) for sarcolite were in reality determined on some other mineral. Pauly gives $\omega=1.6404$, $\epsilon=1.6566$, for sodium light

The agreement of the analyses of sarcolite with the values calculated from its formula is shown below.

Comparison of analyses of sarcolite with calculated composition.

	Scacchi.[a]	Rammelsberg.[b]	Pauly.[c]	Calculated for $3CaO.Al_2O_3.3SiO_2$.
SiO_2	42.11	40.51	39.34	40.08
Al_2O_3	24.50	21.54	21.63	22.65
CaO	32.43	32.36	33.70	37.27
Na_2O	2.93	3.30	4.43	
K_2O		1.20		
MgO			.36	
	101.97	98.91	99.46	100.00

[a] Scacchi, A., Quadri Crystallographia, p. 66, Naples, 1842.

[b] Rammelsberg, C., Ueber die chemische Zusamensetzung einiger seltenen Mineralien des Vesuvs: Poggendorff's Annalen, vol. 109, p. 570, 1860.

[c] Pauly, A., Zur mikroskopischen Charakterisierung des Sarkolith: Centralbl. Mineralogie, 1906, p. 266.

The sarcolite from Vesuvius analyzed by Scacchi is composed of an isomorphous mixture of 7.2 per cent of soda sarcolite and 92.8 per cent of sarcolite. Calculated composition of this mixture is shown below.

Comparison of analysis of sarcolite by Scacchi with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	42.11	41.29	39.96	−1.33
Al_2O_3	24.50	24.03	22.58	−1.45
CaO	32.43	31.80	34.58	+2.78
Na_2O	2.93	2.88	2.88	.00
	101.97	100.00	100.00	

The differences are considerable and indicate that the analysis is not very exact or, more probably, that the sample analyzed was not pure and homogeneous.

The sarcolite from Vesuvius analyzed by Rammelsberg is composed of an isomorphous mixture of 10.5 per cent of soda sarcolite and 89.5 per cent of sarcolite. The analysis agrees fairly well with the calculated composition, as shown below.

Comparison of analysis of sarcolite by Rammelsberg with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	40.51	41.12	39.92	−1.20
Al_2O_3	21.54	21.87	22.56	+.69
CaO	32.36	32.85	33.36	+.51
Na_2O	3.30	4.16	4.16	.00
K_2O	1.20	....	....	....
	98.91	100.00	100.00	....

The sarcolite from Vesuvius analyzed by Pauly is composed of an isomorphous mixture of 2.6 per cent of åkermanite, 11.2 per cent of soda sarcolite, and 86.2 per cent of sarcolite. The agreement of the analysis with the calculated composition is good. A small admixture of åkermanite is introduced to account for the small amount of magnesia in the analysis.

Comparison of analysis of sarcolite by Pauly with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	39.34	39.56	40.09	+0.53
Al_2O_3	21.63	21.75	21.96	+.21
CaO	33.70	33.88	33.14	−.74
Na_2O [a]	4.43	4.45	4.45	.00
MgO	.36	.36	.36	.00
	99.46	100.00	100.00	....

[a] Trace of K_2O.

SODA SARCOLITE.

As stated under sarcolite, a soda sarcolite ($3Na_2O.Al_2O_3.3SiO_2$), corresponding in formula to sarcolite, has been assumed to be present in the sarcolites analyzed and also in nearly all the natural occurrences of the melilites and gehlenites. Its amount is never large, the maximum being 12.2 per cent in a melilite from Vesuvius analyzed by Damour. Most of the analyses show amounts less than 10 per cent. The reference of the soda to a compound of the sarcolite type is justified because sarcolite is the only naturally occurring end member of the melilite group containing soda. If no independent soda compound were assumed, an arbitrary assignment of the soda to either CaO or MgO would have to be made. The properties of soda sarcolite are not known, but its molecular weight (469) is so close to that of sarcolite (451) that their properties are doubtless very similar

ÅKERMANITE.

Åkermanite ($4MgO.8CaO.9SiO_2$), as a mineral, was identified by Zambonini[1] at Vesuvius. Its properties, as given by him, are as follows: Tetragonal, cleavages, 001 and 110; density, 3.12 (3.05 Freda); uniaxial, positive; for sodium light, $\omega=1.6332$, $\epsilon=1.639$, $\epsilon-\omega=0.006$.

The two analyses reproduced in the subjoined table fully substantiate the formula $4MgO.8CaO.9SiO_2$. As shown below, the samples analyzed contained small amounts of the isomorphic mineral sarcolite, and if this is allowed for, the agreement with the formula is still closer.

Comparison of analyses of åkermanite with calculated composition.

	Analyses.[a]		Calculated for 4MgO. 8CaO. $9SiO_2$.
	Freda.	Zambonini.	
SiO_2	46.70	46.55	47.08
Al_2O_3	1.09	.96	....
CaO	39.62	39.30	38.93
MgO	13.38	13.30	13.99
FeO	....	.12	....
	100.79	100.23	100.00

[a] Zambonini, F., Mineralogia Vesuviana, p. 255, 1910.

The åkermanite from Vesuvius analyzed by Freda is composed of an isomorphous mixture of 95.4 per cent of åkermanite and 4.6 per cent of sarcolite. The analysis agrees closely with the calculated composition.

Comparison of analysis of åkermanite by Freda with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	46.70	46.47	46.76	+0.29
Al_2O_3	1.09	.96	1.04	+ .08
CaO	39.62	39.23	38.86	− .37
MgO	13.38	13.34	13.34	.00
	100.79	100.00	100.00	....

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[1] Zambonini, F., Mineralogia Vesuviana, p. 255, 1910.

The åkermanite from Vesuvius analyzed by Zambonini is composed of an isomorphous mixture of 94.9 per cent of åkermanite and 5.1 per cent of sarcolite. This analysis also shows only slight differences from the calculated composition.

Comparison of analysis of åkermanite by Zambonini with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	46.55	46.33	46.72	+0.39
Al_2O_3	.96	1.08	1.16	+ .08
CaO	39.30	39.31	38.84	− .47
MgO	13.30	13.28	13.28	.00
FeO	.12	....	....	....
	100.23	100.00	100.00	....

The suggestion of Shepherd, Rankin, and Wright[1] that the correct formula for pure åkermanite is $3CaO.2SiO_2$ is not in agreement with the facts.

VELARDEÑITE.

The properties of velardeñite ($2CaO.Al_2O_3.SiO_2$), the third mineral species and primary compound which occurs in isomorphous mixture in the members of the melilite group, have already been described on page 107.

SUMMARY OF PROPERTIES OF PRIMARY COMPOUNDS.

For comparison and convenience, the properties of the primary compounds used in the following discussion of the isomorphous mixtures of two or more of the primary compounds are summarized in the following table:

Summary of properties of tetragonal primary compounds.

	Sarcolite.	Åkermanite.	Velardeñite.
Density	2.92	3.12	3.04
Optical sign	Positive.	Positive.	Negative.
ω	1.6035	1.6332	1.667
ϵ	1.6147	1.639	1.658
Birefringence	.0112	.006	.009

---

[1] Shepherd, E. S., and Rankin, G. A., Preliminary report on the ternary system $CaO-Al_2O_3-SiO_2$; a study of the constitution of Portland cement clinker, with optical study by F. E. Wright: Jour. Ind. and Eng. Chemistry, vol. 3, p. 224, 1911.

ISOMORPHOUS MIXTURES OF TWO OR MORE OF THE PRIMARY COMPOUNDS.

In the following pages all the reliable analyses of minerals of the melilite group (including gehlenite) have been tested to see whether their composition can be expressed as mixtures of the four primary compounds just given. It may be said, in advance, that with the exception of the iron-rich melilites from Capo di Bove and the one from Colorado, all the samples analyzed agree very well with the interpretation here given.

The literature previous to 1892 has not been searched, as the analyses given by Dana[1] have (with some exceptions) been taken. To these are added the analyses that have been published since 1892. Of the melilite analyses given by Dana only those by Damour could be utilized. Von Kobell's analysis, published in 1832, was omitted, as the original paper was not available and no proof could be had as to the purity of the sample analyzed. The last melilite analysis given by Dana was made by Schulze on a small amount of material, which was, moreover, contaminated with olivine, whence the high percentage of MgO+FeO.

It has also been necessary to disregard several of the gehlenite analyses. Dana's Nos. 4 and 5, published by Kühn[2] in 1846, have to be omitted, as reference to the original article showed that Kühn treated his material with very dilute acid to remove calcium carbonate and furthermore did not determine the state of oxidation of the iron. The figures for iron represent arbitrary assumptions. The two analyses by Janovsky[3] (Dana's Nos. 6 and 7) were both made on impure material, and No. 7 especially (not No. 6, as given by Dana) contained considerable mixed vesuvianite. No. 6 is stated to have contained vesuvianite but was considered much purer than No. 7.

It was decided to omit all analyses of artificial melilites, as these were for the most part accidentally formed and did not represent pure products. It would be difficult to determine the purity of some of the artificial melilites whose analyses have been published, and any assumptions as to the composition of the impurity would be so uncertain that the results derived from a consideration of analyses of artificial melilite would be of no value.

The comparison of the analyses of the natural minerals with the calculated composition has been simplified by combining several bases and then recalculating the original analyses to 100.00 per cent. Water and other foreign matter have been simply omitted.

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[1] Dana, E. S., System of mineralogy, 6th ed., pp. 475, 476, 1892.

[2] Kühn, O. B., Mineralanalysen; 4, Gehlenit: Annalen d. Chemie und Pharmacie (Wöhler und Liebig), Bd. 59, p. 371, 1846.

[3] Zepharovich, V., Mineralogische Mittheilungen: 2, Gehlenit von Oravicza: Akad. Wiss. Wien Sitzungsber., Bd. 69, Abth. 1, p. 26, 1874.

Ferric iron, as Fe_2O_3, has been recalculated to alumina (Al_2O_3). Ferric iron exists in large amount in the melilite from Capo di Bove, near Rome. In fact, the analyses of the brown melilite, the variety richest in Fe_2O_3, show a higher actual percentage of Fe_2O_3 than of Al_2O_3, but considered molecularly the iron does not exceed the Al_2O_3. In the analyses showing the greatest amount of iron the ratio of Fe_2O_3 to Al_2O_3 is almost exactly 1 : 1. Another primary component, namely, an iron-calcium silicate, should possibly have been introduced, but the number of components would then have become five and the expression of the interpretation would have been complicated considerably. The Fe_2O_3 has therefore been recalculated and combined with the Al_2O_3.

As Fe_2O_3 has not been determined to exist in notable quantity in any of the pure end members, it would furthermore be impossible to decide to which of the three end-member minerals it should be assigned. The compound $3CaO.Al_2O_3.3SiO_2$ (sarcolite) is polymorphous, for the formula represents that of grossularite as well as that of sarcolite. Now an iron-calcium garnet, $3CaO.Fe_2O_3.3SiO_2$, andradite, is a common mineral, and the ferric iron in melilites would naturally then be ascribed to the presence of a ferric iron sarcolite, $3CaO.Fe_2O_3.3SiO_2$. A recent paper by Scrivenor[1] describes an iron-calcium garnet which was "quickly and completely decomposed when reduced to powder and heated with hydrochloric acid, silica being liberated." The garnet was isotropic and showed very clearly the form of the rhombic dodecahedron. Crystals of sarcolite resemble those of the isometric system, and, as sarcolite is tetragonal, basal cleavage pieces would be isotropic. Could a ferric iron sarcolite ($3CaO.Fe_2O_3.3SiO_2$) have been present?

The remaining bases which in the recalculated analyses are to be added to other bases are few in number. K_2O naturally goes with Na_2O, and FeO and MnO have been added to MgO, CaO therefore standing by itself and not receiving any increment in the form of replacing bases. It is doubtful if much difference in the ratios would have been found if the FeO+MnO had been added to CaO. In silicates, however, it seems as if CaO on the one hand and FeO+MnO+MgO on the other hand exist as separate groups which do not replace each other.

The recalculated and reduced analyses may represent the original analyses inaccurately in that the combination of bases may not be correct; in that the omission of the water as such may be wrong, for the water may, in part at least, belong to an associated hydrous mineral; and in that the reduction to 100.00 per cent distributes an error in the determination of a single constituent over the whole analysis.

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[1] Scrivenor, J. B., A calcium-iron garnet from China: Mineralog. Mag., vol. 17, p. 51, 1913.

The fact, however, that the following comparisons show a very close agreement indicates that perhaps these inaccuracies are not great.

The gehlenite from Velardeña[1] analyzed by Allen (quoted by Wright) is composed of an isomorphous mixture of 20 per cent of åkermanite, 0.7 per cent of soda sarcolite, and 79.3 per cent of velardeñite.

Comparison of gehlenite analysis by Allen with calculated composition[a] *of isomorphous mixture.*

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	26.33	26.99	27.10	+0.11
Al_2O_3	27.82	29.43	29.65	+ .22
CaO	39.55	40.50	40.17	− .33
Na_2O	.21	.29	.29	.00
MgO	2.44	2.79	2.79	.00
TiO_2	.03			
Fe_2O_3	1.43			
K_2O	.10			
FeO	.50			
MnO	.01			
H_2O	1.85			
	100.27	100.00	100.00	

[a] The reduced analysis and the calculated composition differ slightly from the values given on p. 107 simply because there the soda was combined with the lime, whereas here it is treated separately.

The gehlenite from Monzoni analyzed by Rammelsberg[2] is composed of an isomorphous mixture of 36.2 per cent of åkermanite and 63.8 per cent of velardeñite.

Comparison of gehlenite analysis by Rammelsberg with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	29.78	30.81	31.04	+0.23
Al_2O_3	22.02	24.91	23.73	−1.18
CaO	37.90	39.21	40.16	+ .95
MgO	3.88	5.07	5.07	.00
Fe_2O_3	3.22			
FeO	1.63			
MnO	.19			
Ignition by difference	1.38			
	100.00	100.00	100.00	

---

[1] This is the mineral called velardeñite. See p. 106.

[2] Dana, E. S., System of mineralogy, 6th ed., p. 476, 1892.

The gehlenite from Monzoni, analyzed by Lemberg,[1] is composed of an isomorphous mixture of 28.7 per cent of åkermanite, 15.7 per cent of sarcolite, and 55.6 per cent of velardeñite.

Comparison of gehlenite analysis by Lemberg with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	30. 01	31. 88	32. 00	+0. 12
Al_2O_3	21. 33	25. 08	24. 24	− . 84
CaO	36. 74	39. 03	39. 75	+ . 72
MgO	3. 77	4. 01	4. 01	. 00
Fe_2O_3	3. 56			
Ignition	4. 72			
	100. 13	100. 00	100. 00	

The gehlenite from Monzoni analyzed by Damour[1] is composed of an isomorphous mixture of 16.4 per cent of åkermanite, 0.8 per cent of soda sarcolite, 38.1 per cent of sarcolite, and 44.7 per cent of velardeñite.

Comparison of analysis of gehlenite by Damour with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	31. 60	32. 97	33. 09	+0. 12
Al_2O_3	19. 80	24. 64	25. 42	+ . 78
CaO	38. 11	39. 76	38. 86	− . 90
Na_2O	. 33	. 34	. 34	. 00
MgO	2. 20	2. 29	2. 29	. 00
Fe_2O_3	5. 97			
H_2O	1. 53			
	99. 54	100. 00	100. 00	

The melilite from Colorado analyzed by Schaller[2] is composed of an isomorphous mixture of 41.3 per cent of åkermanite, 8.7 per cent of soda sarcolite, and 50 per cent of sarcolite.

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[1] Dana, E. S., op. cit., p. 476.

[2] Larsen, E. S., and Hunter, J. F., Melilite and other minerals from Gunnison County, Colo.: Washington Acad. Sci. Jour., vol. 4, p. 473, 1914.

Comparison of analysis of melilite by Schaller with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	42.07	44.56	42.85	+1.71
Al_2O_3	10.30	11.25	13.22	−1.97
CaO	35.41	34.98	34.72	+ .26
Na_2O	3.24	3.43	3.43	.00
MgO	4.15	5.78	5.78	.00
TiO_2	.20			
Fe_2O_3	.50			
FeO	2.18			
MnO	.16			
P_2O_5	.82			
CO_2	.90			
H_2O	.47			
K_2O	Trace.			
	100.40	100.00	100.00	

The melilite from Vesuvius analyzed by Damour[1] is composed of an isomorphous mixture of 42.5 per cent of åkermanite, 12.2 per cent of soda sarcolite, 34 per cent of sarcolite, and 11.3 per cent of velardeñite.

Comparison of analysis of melilite by Damour with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	40.69	42.11	40.77	−1.34
Al_2O_3	10.88	14.19	14.57	+ .38
CaO	31.81	32.92	33.88	+ .96
Na_2O	4.43	4.83	4.83	.00
MgO	5.75	5.95	5.95	.00
Fe_2O_3	4.43			
K_2O	.36			
	98.35	100.00	100.00	

The melilite from Capo di Bove analyzed by Bodlaender is composed of an isomorphous mixture of 42.5 per cent of åkermanite, 9.8 per cent of soda sarcolite, 41.2 per cent of sarcolite, and 6.5 per cent of velardeñite.

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[1] Dana, E. S., op. cit., p. 476.

Comparison of analysis of melilite by Bodlaender with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	41.09	41.63	41.67	+0.04
Al_2O_3	10.93	13.28	13.89	+ .61
CaO	34.78	35.24	34.59	− .65
Na_2O	3.40	3.90	3.90	.00
MgO	5.87	5.95	5.95	.00
Fe_2O_3	3.40			
K_2O	.68			
H_2O	.24			
	100.39	100.00	100.00	

The yellow melilite from Capo di Bove analyzed by Damour[1] is composed of an isomorphous mixture of 49 per cent of åkermanite, 7.8 per cent of soda sarcolite, 33.7 per cent of sarcolite, and 9.5 per cent of velardeñite.

Comparison of analysis of yellow melilite by Damour with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	39.27	41.77	41.67	−0.10
Al_2O_3	6.42	13.75	12.86	− .89
CaO	32.47	34.54	35.53	+ .99
Na_2O	1.95	3.09	3.09	.00
MgO	6.44	6.85	6.85	.00
Fe_2O_3	10.17			
K_2O	1.46			
	98.18	100.00	100.00	

The yellow melilite from Capo di Bove analyzed by Zambonini[2] is composed of an isomorphous mixture of 49.5 per cent of åkermanite, 8.3 per cent of soda sarcolite, 32.4 per cent of sarcolite, and 9.8 per cent of velardeñite.

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[1] Dana, E. S., op. cit., p. 476.

[2] Zambonini, F., Ueber eine krystallisierte Schlacke der Seigerhütte bei Hettstedt, nebst Bemerkungen über die chemische Zusammensetzung des Melilith: Zeitschr. Kryst. Min., vol. 41, p. 266, 1906.

Comparison of analysis of yellow melilite by Zambonini with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	40.14	41.93	41.63	−0.30
Al_2O_3	6.47	13.40	12.80	−.60
CaO	32.98	34.45	35.35	+.90
Na_2O	2.18	3.30	3.30	.00
MgO	6.33	6.92	6.92	.00
Fe_2O_3	9.95	....	....	....
FeO	.53	....	....	....
K_2O	1.49	....	....	....
H_2O	.27	....	....	....
TiO_2,MnO	Trace.	....	....	....
	100.34	100.00	100.00	....

The brown melilite from Capo di Bove analyzed by Damour[1] is composed of an isomorphous mixture of 50.3 per cent of åkermanite, 8.2 per cent of soda sarcolite, 26.5 per cent of sarcolite, and 15 per cent of velardeñite.

Comparison of analysis of brown melilite by Damour with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	38.34	40.26	40.73	+0.47
Al_2O_3	8.61	15.77	13.37	−2.40
CaO	32.05	33.65	35.58	+1.93
Na_2O	2.12	3.28	3.28	.00
MgO	6.71	7.04	7.04	.00
Fe_2O_3	10.02	....	....	....
K_2O	1.51	....	....	....
	99.36	100.00	100.00	....

The brown melilite from Capo di Bove analyzed by Zambonini[2] is composed of an isomorphous mixture of 47.9 per cent of åkermanite, 8.3 per cent of soda sarcolite, 28 per cent of sarcolite, and 15.8 per cent of velardeñite.

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[1] Dana, E. S., op. cit., p. 476.

[2] Zambonini, F., op. cit., p. 266.

Comparison of analysis of brown melilite by Zambonini with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	39. 20	40. 93	40. 42	−0. 51
Al_2O_3	7. 56	15. 47	14. 05	−1. 42
CaO	32. 18	33. 60	35. 53	+1. 93
Na_2O	2. 21	3. 31	3. 31	. 00
MgO	6. 41	6. 69	6. 69	. 00
Fe_2O_3	11. 34			
K_2O	1. 45			
H_2O	. 21			
TiO_2,MnO	Trace.			
	100. 56	100. 00	100. 00	

The main difference between the calculated composition and the reduced analyses shown in the last two tables is that in the calculated composition Al_2O_3 is too low and CaO too high. The two analyses of brown melilite from Capo di Bove both show a large amount of Fe_2O_3 and no FeO. It seems possible that a part of the iron in these melilites may exist as FeO but had become oxidized, possibly by fine grinding, so that the determination of Fe_2O_3 as given in the analysis is too high. A readjustment on such a basis would give results agreeing much closer with the calculated composition than the actual analysis does.

The fuggerite from Monzoni analyzed by E. Mayr[1] is composed of an isomorphous mixture of 35.3 per cent of åkermanite, 5.2 per cent of soda sarcolite, 16 per cent of sarcolite, and 43.5 per cent of velardeñite.

Comparison of analysis of fuggerite with calculated composition of isomorphous mixture.

	Original analysis.	Analysis reduced.	Calculated.	Difference.
SiO_2	34. 04	34. 45	34. 59	+0. 14
Al_2O_3	17. 97	20. 45	20. 93	+ . 48
CaO	37. 65	38. 10	37. 48	− . 62
Na_2O	2. 04	2. 06	2. 06	. 00
MgO	4. 89	4. 94	4. 94	. 00
Fe_2O_3	3. 49			
Insoluble	. 12			
K_2O, MnO	Trace.			
	100. 20	100. 00	100. 00	

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[1] Weinschenk, E., Fuggerit, ein neues Mineral aus dem Fassathal: Zeitschr. Kryst. Min., vol. 27, p. 577, 1896.

COMPOSITION OF THE MIXTURES.

In order to show more clearly the relations of the minerals whose composition has been discussed on the previous pages, the 17 mineral analyses have been plotted on a triangular plan with the three minerals åkermanite, sarcolite, and velardeñite as the three apices (fig. 89). The percentages of sarcolite and soda sarcolite have been added together, a procedure justified by the nearly equal molecular weight of the two compounds. (Compare p. 115.)

The mineral compositions as plotted on figure 89 are summarized below, with the same numbering as used in the diagram.

Summary of mineral composition of members of the melilite group, graphically shown in figure 89.

No.	Mineral.	Locality.	Author.	Åkermanite.	Sarcolite.	Velardeñite.
1	Sarcolite	Vesuvius	Scacchi	0	100	0
2	.....do	.....do	Rammelsberg	0	100	0
3	.....do	.....do	Pauly	2.6	97.4	0
4	Åkermanite	.....do	Freda	95.4	4.6	0
5	.....do	.....do	Zambonini	94.9	5.1	0
6	Gehlenite (velardeñite).	Velardeña, Mexico.	Wright	20.0	.7	79.3
7	Gehlenite	Vesuvius	Rammelsberg	36.2	.0	63.8
8	.....do	.....do	Lemberg	28.7	15.7	55.6
9	.....do	.....do	Damour	16.4	38.9	44.7
10	Melilite	.....do	.....do	42.5	46.2	11.3
11	.....do	Capo di Bove, Italy.	Bodlaender	42.5	51.0	6.5
12	Yellow melilite	.....do	Damour	49.0	41.5	9.5
13	.....do	.....do	Zambonini	49.5	40.7	9.8
14	Brown melilite	.....do	Damour	50.3	34.7	15.0
15	.....do	.....do	Zambonini	47.9	36.3	15.8
16	Melilite	Colorado	Larsen and Hunter.	41.3	58.7	0
17	Fuggerite	Fassathal	Weinschenk	35.3	21.2	43.5

The "gehlenites" have a varying composition, as is clearly shown in figure 89, and do not all correspond to the simple formula $3CaO.Al_2O_3.2SiO_2$, as has been advocated. Together with those of velardeñite and fuggerite, however, their symbols lie in the velardeñite portion of the triangle, and, like velardeñite, all the "gehlenites" are optically negative. They represent isomorphous mixtures of the three minerals, in which the negative velardeñite occurs in greater amount than either of the other two. The properties of fuggerite as given by Weinschenk are not accurately in accord with those of the other gehlenites, and the fact that the symbol of a double salt with properties differing from those of velardeñite, åkermanite, or sarcolite falls in this part of the diagram may explain the unusual properties shown by fuggerite.

Now, if, as has been suggested by the chemical composition, melilite is essentially an isomorphous mixture of åkermanite and sarcolite (all the melilites contain over 80 per cent of åkermanite and sarcolite), both of which are optically positive, then the melilites should likewise be positive. In fact melilites are mostly negative, though occasionally a positive one is seen. Melilites which are almost isotropic have also been described.

The plotted analyses of melilite are confined to a small portion of the triangular field (fig. 89), although out of seven analyses only three localities are included. The melilite from Colorado is apparently the simplest in composition, for it is composed of only two end members, sarcolite and åkermanite. It is to be noted, however, that the agreement of the analysis with the calculated composition, as given on page 122, is not very close. Over 84 per cent of the other melilites consist of sarcolite and åkermanite. Now, both these two minerals are optically positive, whereas melilite is generally negative, although positive varieties are known.

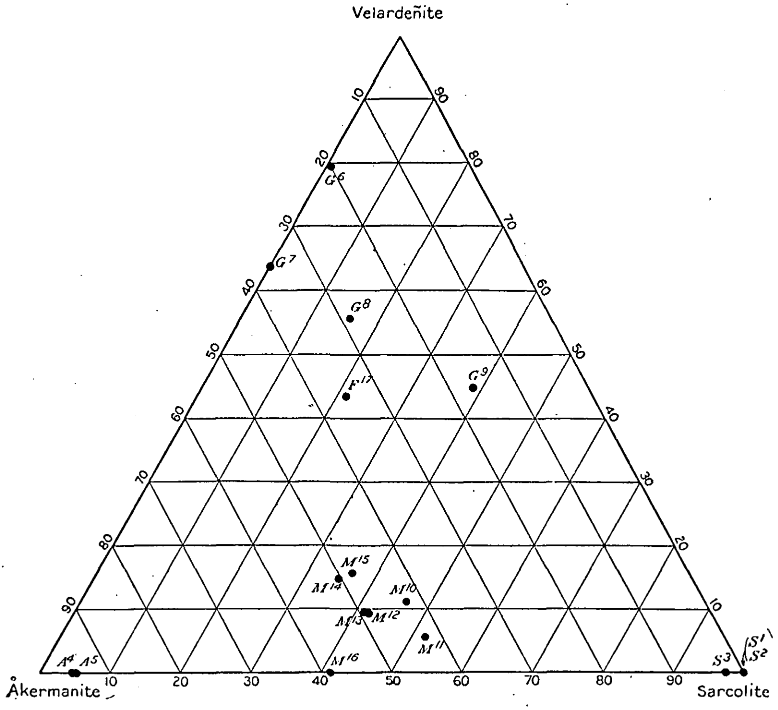

FIGURE 89.—Triangular representation of the chemical composition of minerals of the melilite group, including åkermanite (*A*), sarcolite (*S*), velardeñite (G^6), melilite (*M*), gehlenite (G^7 to G^9), and fuggerite (*F*).

Two explanations suggest themselves to explain the apparent discrepancy. One is that an isomorphous mixture of two optically positive substances is not necessarily of the same sign throughout, for the sign depends on the relative values of the refractive indices. For positive minerals, ϵ is greater than ω, but for negative minerals it is less. If the refractive indices of all isomorphous mixtures of sarcolite and åkermanite are linear functions of their composition, then negative melilite can not be such a simple isomorphous mixture. On the other hand, if the indices are not linear functions of the composition, then negative melilites may be isomorphous mixtures of two positive minerals, the refractive indices changing with the composition, as shown in figure 90. If some such relation held good, then most melilites would be negative, a smaller number would be positive, and a very small number would be isotropic. With relations as shown in figure 90, there are two mixtures (about 14 per cent and 79 per cent of åkermanite) which are isotropic.

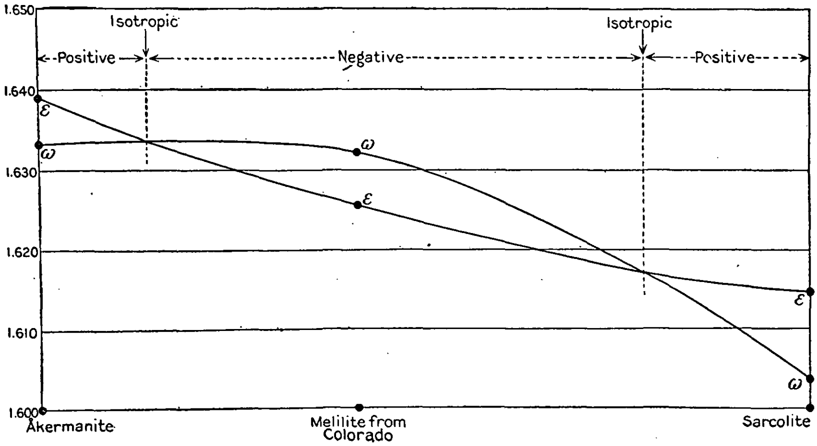

FIGURE 90.—Diagram showing hypothetical relation of refractive indices to composition of mixtures of åkermanite and sarcolite.

A second explanation, however, deserves careful consideration, although at present its possibility can only be suggested. It is dependent on the existence of a double compound of åkermanite and sarcolite which would be optically negative, and the melilites would consist essentially of this double compound with smaller amounts of åkermanite, sarcolite, and velardeñite in solid solution.

The concentration of the symbols representing the melilite analyses in a small portion of the field (fig. 89) is in a way somewhat suggestive of the existence of a double compound.

THE COMPOSITION OF CEBOLLITE.

Cebollite, an alteration product of melilite, was found near Cebolla Creek, Gunnison County, Colo., and as described by Larsen[1] forms compact masses of a fibrous character. The mineral is probably orthorhombic, biaxial, positive, $\alpha = 1.595 \pm 0.003$, $\beta = 1.60$, $\gamma = 1.628 \pm 0.005$. It resembles the zeolites in its properties and composition. Hardness = 5, specific gravity = 2.96.

The mineral gelatinizes with acids and gives off water when heated in a closed tube. An analysis of a sample containing as little as possible of the associated insoluble diopside and garnet gave the following results:

Analysis and ratios of cebollite.

	Analysis.	Insoluble deducted.	Ratios.		
Insoluble[a]	18.05	....			
Soluble in HCl:					
SiO	27.06	33.02	0.550		3.26 or 3×1.09
Al_2O_3	11.49	14.02	.137	.158	0.94 or 1×0.94
Fe_2O_3	2.81	3.43	.021		
CaO	29.27	35.72	.638	.799	4.74 or 5×0.95
FeO	.17	.21	.003		
MgO	3.84	4.69	.117		
Na_2O	2.10	2.57	.041		
H_2O+	5.13	6.26	.348		2.06 or 2×1.03
H_2O-	.00	....			
TiO_2, K_2O	Trace.	....			
	99.92	99.92			

[a] Diopside and garnet.

The formula derived from the analysis is $3SiO_2.Al_2O_3.5R''O.2H_2O$, in which R'' is chiefly Ca with smaller amounts of Mg and Na_2. The ratio of $Na_2O : MgO + FeO : CaO$ is 1 : 3 : 16. Considering all the R''O as CaO, the formula, $Si_3Al_2Ca_5H_4O_{16}$, may be written in two ways—$(SiO_4)_3.Ca_5.[Al(OH)_2]_2$ or $(SiO_4)_3.(CaOH)_4.Ca.Al_2$.

The powdered mineral, treated with water, does not show an alkaline reaction with phenolphthalein, and if for certain minerals such a reaction indicates the presence of the CaOH group, as is suggested on page 154, the second of the formulas above given

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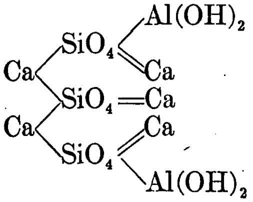
[1] Larsen, E. S., and Schaller, W. T., Cebollite, a new mineral; Washington Acad. Sci. Jour., vol. 4, p. 480, 1914.

becomes untenable, and the formula of cebollite is consequently $(SiO_4)_3.Ca_5.[Al(OH)_2]_2$, which can be written structurally as follows:



The cebollite seems to belong to the zeolite group, although the presence of several per cent of magnesium is unusual.

THE CRYSTALLOGRAPHY OF THAUMASITE.

Several specimens of thaumasite from the well-known locality at West Paterson, N. J., showed well-developed crystals which reached a maximum length of about 5 millimeters. The crystals are hexagonal and consist of the prism m{10$\bar{1}$0} and the base c{0001}. They show gradations from a short prismatic habit (fig. 91) to a long prismatic habit (fig. 92). Although well-formed single crystals are not rare, many of them are composed of one or more large units, to which several smaller crystals are attached. These smaller crystals are either in parallel position or deviate slightly from strict parallelism, as is shown in figure 93, which represents such a group as it appeared under the microscope. The crystals are striated vertically.

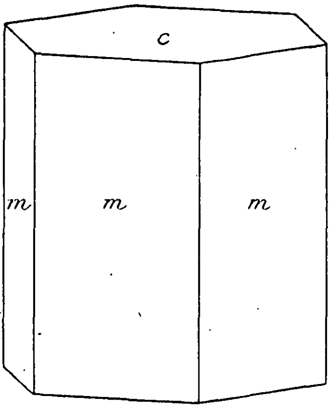


FIGURE 91.

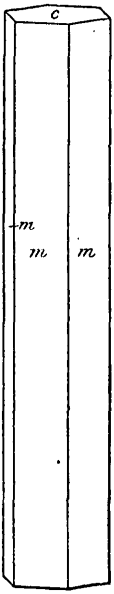


FIGURE 92.

FIGURE 91.—Short prismatic crystal of thaumasite.
FIGURE 92.—Long prismatic crystal of thaumasite.

A single terminated crystal was found and measured. It is shown in ideal development in figure 94. The forms present are m, c, and p{10$\bar{1}$1}. The ρ angles of the pyramid faces, of which only four could be measured, are 53°30′, 51°30′, 50°15′, and 50°45′; average 51°30′, from which the c axis is calculated to be 1.09.

The prism faces, although striated and built up of several faces, not all of which were in parallel position, were bright and gave good reflections. Their interfacial angle seldom measured more than a degree different from 60°. The base is always dull and gave no reflection. The pyramid faces were likewise dull and could be measured only by means of maximum illumination.

The same crystal which showed the faces of *p* also had a minute face whose ρ angle was 31°40′. On a different crystal a face was measured whose ρ angle was 31°41′ and on a third crystal two faces gave ρ angles of 31°45′ and 31°53′. The ϕ angles varied so much for these different faces that the position of the form could not be determined, although the faces measured may not belong to a definite form, yet it would seem remarkable to find faces on three different crystals which would give the same ρ angle.

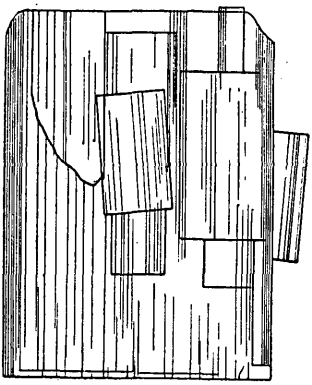


FIGURE 93.

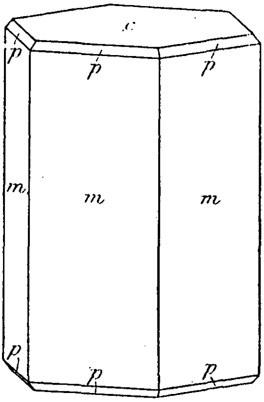


FIGURE 94.

FIGURE 93.—Compound crystal of thaumasite, with attached smaller crystals, as seen under the microscope.

FIGURE 94.—Terminated crystal of thaumasite. Forms: $m\{10\bar{1}0\}$, $c\{0001\}$, $p\{10\bar{1}1\}$.

Qualitative tests on a small sample of the selected crystals showed that they were thaumasite.

THE CHEMICAL COMPOSITION OF TREMOLITE.

In a recent paper Allen and Clement[1] have suggested that the water in tremolite is "not chemically combined, although the mineral in the powdered state is not completely dehydrated under 900°. It is to be regarded as dissolved water, and tremolite as a solid solution. * * * Diopside and tremolite seem to give off their water continuously, but not indefinitely, with rising temperatures, though it is quite possible the curves represent cases of false equilibria."

According to their view, then, the mineral tremolite, as found in nature, represents a chemical compound + water. The water present would not be a necessary inherent part of the mineral, and the true composition of the mineral would be shown by the analysis with the water excluded. This conclusion the authors reached as a result of finding that "the water in all the specimens is lost gradually as the temperature rises, without any sudden change of properties or loss of homogeneity. It can not, therefore, be chemically combined, even though it is given off so very slowly at a temperature of 900°."

It seems probable, however, that a different explanation may be offered from that which contends that the water in tremolite is dissolved and not a true part of the mineral. A similar conclusion was reached by Coblentz[2] as a result of experiments based on the absorption spectrum of water in minerals. He said: "From the present data it is evident that the water in tremolite is not present in the same condition as in other substances containing water in solid solution or dissolved water. * * * From the present data it appears that in tremolite the water is constitutional, with possible OH groups, the small band at 2.95 μ being complex, as in the other hydroxides just cited [brucite, diaspore, bauxite, göthite]. This is, of course, contrary to the vapor-pressure experiments; but it is the most satisfactory conclusion to be drawn from the present experiments."

The zeolites have often been cited as examples of minerals in which the water is not chemically combined, but Beutell and Blaschke[3] have recently contended that the water in stilbite is chemically combined, and they further question whether it has been proved that for any hydrosilicate the water is dissolved or absorbed.

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[1] Allen, E. T., and Clement, J. K., The rôle of water in tremolite and certain other minerals: Am. Jour. Sci., 4th ser., vol. 26, p. 101, 1908.

[2] Coblentz, W. W., The rôle of water in minerals: Franklin Inst. Jour., vol. 172, p. 334, 1911.

[3] Beutell, A., and Blaschke, K., Das Wasser im Desmin ist chemisch gebunden: Centralbl. Mineralogie, 1915, pp. 4-11; Ist die Existenz krystallisierter Hydrosilicate mit gelöstem oder absorbiertem Wasser erwiesen? : Idem, pp. 195-200.

Together with their experimental data, Allen and Clement give five analyses of tremolite which have not heretofore been accorded the attention they deserve, for not only were the samples carefully selected and purified, but the analytical work was done by a skilled analyst of the highest grade. The five analyses of tremolite are reproduced below.

Analyses of tremolite.

[E. T. Allen, analyst.]

	1 Ham Island, Alaska.	2 Ossining, N. Y.	3 Gouverneur, N. Y.	4 Russell, N. Y.	5 Edwards, N. Y.
SiO_2	58.59	57.35	56.92	56.36	58.24
TiO_2	....	.07	.10	.06	.04
Al_2O_3	.10	1.21	1.65	1.88	.60
Fe_2O_3	....	.11	.36	.61	.43
FeO	....	.23	None.	1.01	None.
MnO	....	.01	....	.04	1.28
MgO	24.78	23.87	23.81	22.97	25.16
CaO	13.95	14.02	12.51	12.82	10.85
Na_2O	.12	.42	1.22	.94	.82
K_2O	.10	.19	.60	.74	.19
H_2O	2.31	2.21	2.01	1.72	2.50
F	None.	.11	1.03	1.23	.24
	99.95	99.80	100.21	100.38	100.35
$O=F_2$	.00	.05	.43	.53	.10
	99.95	99.75	99.78	99.85	100.25

Assuming that fluorine and hydroxyl replace each other and adding together the percentages of water (H_2O, equivalent to 2OH) and one-half the percentages of fluorine (since F is equivalent to OH, F_2 becomes equivalent to 2OH or H_2O), we obtain the following percentages of water plus fluorine for the five tremolite analyses: 2.31, 2.27, 2.53, 2.34, 2.62. These figures surely denote a constant quantity for a mineral which is a member of a large isomorphous group.

The ratios were calculated from the analyses just given. Titanium as TiO_2 is combined with silica (SiO_2), Fe_2O_3 with Al_2O_3, MnO with FeO, K_2O with Na_2O, and F_2 with H_2O.

Ratios of tremolite analyses.

	1	2	3	4	5
SiO_2	0.971	0.952	0.945	0.936	0.967
MgO	.615	.592	.591	.570	.624
CaO	.249	.250	.223	.229	.193
H_2O	.128	.126	.139	.128	.145
Al_2O_3	.001	.013	.018	.022	.009
FeO	....	.003	....	.014	.018
Na_2O	.003	.009	.026	.023	.015

If all these bases are combined on an assumption of equal valence—that is, $RO = MgO + CaO + H_2O + FeO + \frac{1}{3}Al_2O_3$—the following results are obtained:

Comparison of ratios of total bases to silica in tremolite.

	1	2	3	4	5
RO	0.995	0.984	0.985	0.971	0.998
SiO_2	.971	.952	.945	.936	.967
$\frac{RO}{SiO_2}$	1.02	1.03	1.04	1.04	1.03
$RO - H_2O$	.867	.858	.846	.843	.853
$\frac{RO - H_2O}{SiO_2}$	.89	.90	.89	.90	.88

This table shows conclusively that if all the MgO, CaO, Al_2O_3, Fe_2O_3, FeO, MnO, Na_2O, K_2O, H_2O, and F_2 are considered as forming the base of the chemical compound of which SiO_2 ($+TiO_2$) is the acid, then the ratio of base to acid is 1 : 1, as it should be in tremolite. That the ratio of the bases is very slightly above 1 is doubtless due to the fact that the summation of the bases includes a maximum number of ten constituents. The chance of foreign material (dust, impurities in reagents, etc.) being added during the analysis is very much greater for these ten bases than for the single acid (SiO_2).

From the above table it can also be seen that if water (plus fluorine) is excluded from consideration, then the ratio of the bases to the acid, $\frac{RO - H_2O,}{SiO_2}$ falls short of unity.

The same results can be shown by arbitrarily changing the ratio of silica (SiO_2) to 8.00 and recalculating the bases accordingly, as shown below:

Recalculated ratios of tremolite analyses.

	1	2	3	4	5
SiO_2	8.00	8.00	8.00	8.00	8.00
MgO	5.07	4.97	5.00	4.87	5.16
CaO	2.05	2.10	1.89	1.96	1.60
MO [a]	.02	.13	.27	.38	.30
H_2O [b]	1.07	1.06	1.18	1.09	1.20

[a] Includes FeO, MnO, Na_2O, K_2O, $\frac{1}{3}(Al_2O_3)$, $\frac{1}{3}(Fe_2O_3.)$

[b] Includes fluorine as (F_2).

Obviously the ratios of MgO + CaO + MO do not suffice to satisfy the eight parts of silica, and without the water the composition of the mineral is incomplete, unless so complex and improbable a formula as $7RO.8SiO_2$ or $9RO.10SiO_2$ is assumed for tremolite.

The constituents of MO can be so distributed between MgO and CaO, which they obviously replace, as to make the ratios of SiO_2: MgO : CaO : H_2O come very close to 8 : 5 : 2 : 1 and it is suggested that the formula for tremolite is $8SiO_2.5MgO.2CaO.H_2O$ and not $3MgO.CaO.4SiO_2$, as given in the textbooks.

From the chemical side, it seems at least doubtful whether the conclusion of Allen and Clement is correct, and the writer suggests, in accordance with the conclusions of other authors (earlier cited), that the water in tremolite may be different from "dissolved water."

NEW OCCURRENCES OF SOME RARE MINERALS.

It seems advisable to put on record the identifications of some rare minerals which have been sent to the Geological Survey within the last few years.

A specimen of massive guanajuatite was sent by Mr. John E. Erickson from Salmon, Idaho. No mention of any other locality than the original one at Guanajuato, Mexico, could be found in the literature, so that the Idaho occurrence would make the second locality for this rare bismuth selenide.

Well-crystallized jarosite, in hexagonal scales reaching a diameter of 1 millimeter, was found in the Shattuck-Arizona copper mine at Bisbee, Ariz, and were sent in by Mr. Philip D. Wilson, of Bisbee. The brilliant crystals lie on massive iron oxide (hematite) and show only the base $c\{0001\}$ and the rhombohedron $r\{10\bar{1}1\}$. The angle $c : r$ was measured as 53° 19′, but the measurements were poor and not very reliable. Most of the crystals are uniaxial, negative; several of them show, in basal section, a division into six biaxial sectors (compare fig. 88) with the axial plane parallel to the edge *cr*. The measured angle 53° 19′, between that of jarosite (55° 16′) and natrojarosite[1] (51° 53′), suggested that the mineral from Bisbee might lie chemically between jarosite and natrojarosite, but qualitative tests showed that although a little soda was present potash was the predominant alkali.

Some rock specimens, sent in by Mr. George W. Davies, of Topaz, Cal., are thickly coated with brilliant yellow to orange greenockite.

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[1] Compare table given by Hillebrand, W. F., and Penfield, S. L., Some additions to the alunite-jarosite group of minerals: U. S. Geol. Survey Bull. 262, p. 40, 1905.

GIGANTIC CRYSTALS OF SPODUMENE.

The occurrence of gigantic crystals of spodumene in the Black Hills of South Dakota has been known for some time and has been several times referred to in the literature. Blake,[1] as early as 1885, wrote: "One crystal which extends horizontally parallel with a drift is 36 feet in length in a straight line, and is from 1 to 3 feet in thickness. * * * Crystals from 5 to 20 feet long are numerous and incline in all directions." Hess[2] mentions a crystal that measured "42 feet in length, with a cross section of approximately 3 by 6 feet. Part was decayed and useless, but about 37 tons of spodumene was mined from it."

Ziegler[3] describes, in part, the immense size of the spodumene crystals as follows:

> The crystals are often of enormous size. In the Etta mine, where they are best exposed both in the open cut and in the tunnel, they frequently attain a diameter of 3 to 4 feet and a length of 30. The largest "log" so far found was 42 feet long and of 5 feet 4 inches maximum diameter. This one log alone would yield 90 tons of spodumene.

Two photographs of such gigantic crystals are shown in Plate V. The upper picture, taken by Mr. S. C. Smith at the Etta mine, near Keystone, in 1904, shows the largest "log," as these crystals are called, which had been uncovered up to that time of which Mr. Smith had any record. The length of the exposed portion, calculated from the photograph, is 47 feet. In Plate V, *B*, two molds of such large crystals are shown. The length of each of these molds, measured by the writer in 1904, was 40 feet, and the thickness varied from 2½ to 3 feet. In another part of the mine was seen a spodumene log whose exposed length was 25 feet and whose diameter was from 3 to 3½ feet.

These spodumene logs rarely contain any other mineral included as impurity. On a few crystals small amounts of quartz were seen, and more rarely minute amounts of cassiterite or strüverite occur embedded in the spodumene or form small veins therein. The spodumene cleaves readily and as mined is broken up into blocks about a foot in diameter. A layer of some alteration product, several inches thick, coats many of the crystals. It has been estimated that 25 tons of waste rock have to be removed in the extraction of 1 ton of spodumene.

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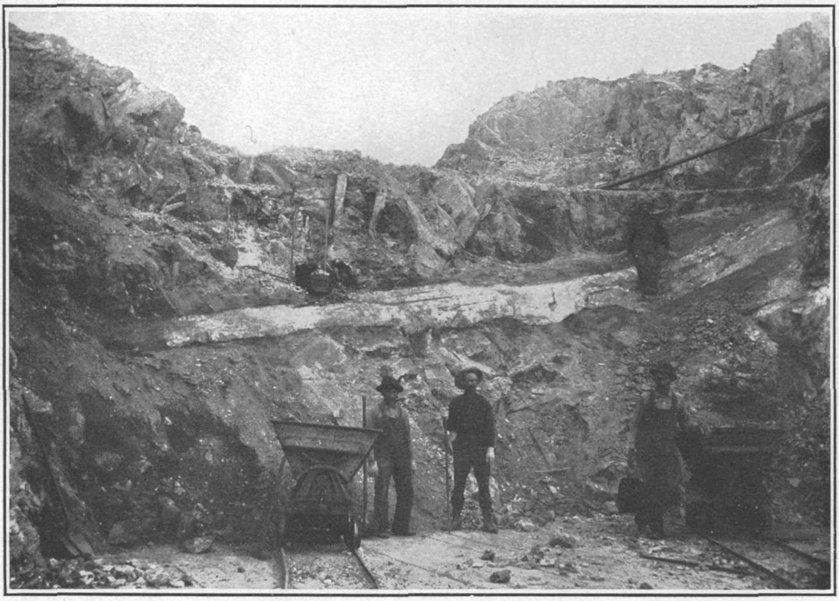
[1] Blake, W. P., Spodumene crystals of gigantic size: Am. Jour. Sci., 3d ser., vol. 29, p. 71, 1880.

[2] Hess, F. L., Lithium: U. S. Geol. Survey Mineral Resources, 1909, Part II, pp. 649-653, 1911.

[3] Ziegler, V., The mineral resources of the Harney Peak pegmatites—II; Min. and Sci. Press, vol. 108, p. 654, Apr. 18, 1914.



A. LARGEST CRYSTAL MINED UP TO 1904.

Photograph furnished by S. C. Smith.

B. MOLDS OF TWO IMMENSE CRYSTALS.

GIGANTIC CRYSTALS OF SPODUMENE, ETTA MINE, BLACK HILLS, S. DAK.

THE PROBABLE IDENTITY OF MARIPOSITE AND ALURGITE.

A comparison of the two analyses of mariposite made by Hillebrand[1] with Penfield's analysis[2] of alurgite shows that the two minerals are probably identical, as can be seen by the following table:

Comparison of analyses of mariposite and alurgite.

	Alurgite (Penfield).	Mariposite (Hillebrand).	
		White.	Green.
SiO_2	53.22	56.79	55.35
TiO_2	....	[a].18	.18
Al_2O_3	21.19	[a] 25.11	25.62
Fe_2O_3	1.22	[b].63	.63
Cr_2O_3	.87	None.	.18
FeO	....	[b].92	.92
MnO	.18	....	....
MgO	6.02	3.29	3.25
CaO	....	.07	.07
Na_2O	.34	[c].17	[c].12
K_2O	11.20	8.92	9.29
H_2O	5.75	4.72	4.52
	99.99	[d] 100.80	100.13

[a] The $Al_2O_3+TiO_2$ is given by Hillebrand as 25.29 per cent.

[b] The total iron oxides are given by Hillebrand as 1.59. The ferrous and ferric oxides were not separately determined. As the total sum of $FeO+Fe_2O_3$ in the green mariposite is 1.55 per cent, or nearly the same as in the white mariposite, the values for FeO and Fe_2O_3 in the white are taken from those given for the green.

[c] Includes Li_2O.

[d] The summation in Hillebrand's publication is 100.84.

A better comparison can be made by omitting the TiO_2, adding molecularly the Fe_2O_3, Cr_2O_3, and Mn_2O_3 to the Al_2O_3, the FeO, MnO, and CaO to the MgO, and the Na_2O to the K_2O, and then reducing the analyses to 100 per cent.

Recalculated analyses of mariposite and alurgite.

	Alurgite.	White mariposite.	Green mariposite.
SiO_2	53.58	56.76	55.74
Al_2O_3	22.69	25.49	26.32
MgO	6.16	3.85	3.84
K_2O	11.78	9.18	9.54
H_2O	5.79	4.72	4.56
	100.00	100.00	100.00

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[1] Hillebrand, W. F., Mineralogical notes: U. S. Geol. Survey Bull. 167, p. 74, 1900.

[2] Penfield, S. L., On some minerals from the manganese mines of St. Marcel, in Piedmont, Italy: Am. Jour. Sci., 3d ser., vol. 46, p. 288, 1893.

The ratios calculated from these analyses, with SiO_2 taken arbitrarily as 12.00, are as follows:

Ratios of analyses of alurgite and mariposite.

	Alurgite.	White mariposite.	Green mariposite.
SiO_2	12.00	12.00	12.00
Al_2O_3	2.99	3.18	3.34
MgO	2.08	1.21	1.23
K_2O	1.69	1.24	1.31
H_2O	4.38	3.34	3.29

In alurgite the ratios become simple if the water (H_2O) and potash (K_2O) are taken together, for then the ratios yield the formula $12SiO_2.3Al_2O_3.2MgO.6(H_2,K_2)O$. The ratios of the green mariposite, which show greater divergence from the alurgite formula than the ratios of the white mariposite, indicate that the mariposite micas represent a solid solution of which one end member is represented by alurgite but of whose other end member no representative has as yet been found. The trend of the ratios would indicate some such formula as $12SiO_2.4Al_2O_3.K_2O.3H_2O$ for the second end member.

The physical and optical properties of these minerals, so far as determined, show a close relation, as is indicated by the following comparison:

Comparison of properties of alurgite and mariposite.

	Alurgite.	Mariposite.
Density	2.835–2.849	2.787, 2.817.
Pleochroism	Not very marked	Not perceptible.
Birefringence	Rather strong	Brilliant polarization colors, like talc.
Optical sign	Negative	Negative.
Axial angle (2*E*)	Biaxial and uniaxial (due to twinning) $2E=0°-57°$.	Uniaxial.
Mean index	1.594	1.63.

The name alurgite was proposed (in 1865) three years before the name mariposite (in 1868). Moreover, the first analysis of alurgite was published (in 1893) a few years before those of mariposite (1895). The name alurgite therefore clearly has priority.

THE AMBLYGONITE GROUP OF MINERALS—FREMONTITE (=NATRAMBLYGONITE).

It has long been recognized that both a fluophosphate and a hydroxyphosphate of aluminum and lithium have been placed together under the name of amblygonite. Descloizeaux separated the two species in his Manuel de minéralogie, but Dana, in the sixth edition of the System of mineralogy, grouped them together under the common name amblygonite, although he clearly stated the difference in their properties.

A consistent, systematic treatment of mineral species necessitates the separation of what is called amblygonite into two distinct species, and Penfield's analyses [1] sufficiently indicate the existence of both a fluo-compound and a hydroxy-compound with many intermediate mixtures.

A few years ago the writer [2] described a new mineral which was in fact the soda equivalent of amblygonite, and in order to emphasize this point the new mineral was named natramblygonite. This name, however, being half Greek and half Latin, is objectionable. (Compare the section "Nomenclature" in Dana's System of mineralogy, 6th edition, page xliii, No. 11.) A further objection to the name is found in the fact that in German it becomes "Natronamblygonit," a word that also means a "sodic amblygonite," which is not the intended meaning of "natramblygonite." A still further objection to the name is voiced by Gonnard,[3] who justly states that the mineral should have been called natromontebrasite, inasmuch as the water, considered as hydroxyl, is present in nearly twice the amount of the fluorine.

In view of these facts, it is considered best to withdraw the name natramblygonite and to substitute for it the name fremontite, after Fremont County, Colo., in which the mineral was found.

Fremontite, then, is a hydrophosphate of aluminum and sodium, with the formula $Na(AlOH)PO_4$. The only published analysis of fremontite shows a partial replacement of the sodium by lithium and of the hydroxyl by fluorine.

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[1] Dana, E. S., System of mineralogy, 6th ed., p. 782, 1892.

[2] Schaller, W. T., Natramblygonite, a new mineral: Am. Jour. Sci., 4th ser., vol. 31, p. 48, 1911.

[3] Gonnard, F., Soc. fraç. minéralogie bull., vol. 36, p. 120, 1913.

The amblygonite group consists of the following definite species, which very rarely occur in a pure state but whose mixture has been found at numerous localities:

Amblygonite, $Li(AlF)PO_4$ or $Li_2O.Al_2O_3.P_2O_5.F_2$.[1]
Montebrasite, $Li(AlOH)PO_4$ or $Li_2O.Al_2O_3.P_2O_5.H_2O$.
Fremontite, $Na(AlOH)PO_4$ or $Na_2O.Al_2O_3.P_2O_5.H_2O$.
Durangite,[2] $Na(AlF)AsO_4$ or $Na_2O.Al_2O_3.As_2O_5.F_2$.[1]

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[1] Minus 1 atom of oxygen.

[2] The crystallographic relations of durangite with amblygonite are not yet clear.

THE CRYSTALLOGRAPHY OF FREMONTITE.

The original material of fremontite did not show any crystal form, and its crystallographic relation to amblygonite could only be inferred. The optical properties did not indicate any variance from the symmetry of amblygonite.

With zealous interest Mr. J. D. Endicott, of Canon City, Colo., continued development of the pegmatite in which the fremontite was found and procured a number of large crystals of that mineral. The best ones seen are in the collection of the late Mr. A. F. Holden, of Cleveland, Ohio, now in Harvard University, and through the kindness of Mr. Holden the writer was permitted to study and describe the crystals.

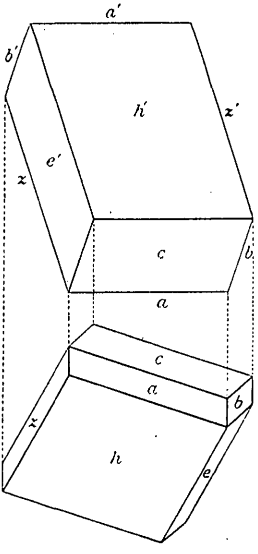

FIGURE 95.—Crystal of fremontite. Forms: $c\{001\}$, $b\{010\}$, $a\{100\}$, $z\{1\bar{2}0\}$, $h\{\bar{1}01\}$, $e\{0\bar{2}1\}$.

The smallest crystal is completely developed and is described below. Two specimens of pegmatite contain larger crystals built up of several individuals in parallel position. Both of the larger crystals are similar in combination and habit to the smaller one and are therefore not further described.

The small crystal is thick tabular in habit and is shown in projection in figure 95. The dimensions of the crystal are 35 by 28 by 13 millimeters. The faces are all dull and uneven, and the edges are considerably rounded. In appearance the crystal resembles kaolinized orthoclase, though its high density (3.05) compared with that of feldspar is noted at once. A closer inspection of the crystal form likewise shows a difference from that of feldspar. The color is grayish white; on the two larger crystals it is reddish in places. Two cleavages are readily identified; the one better developed is parallel to the base $c\{001\}$, and the other one is parallel to the orthopinacoid $a\{100\}$. Cleavage planes were not present, but their orientation could readily be definitely determined by the direction of their traces. These were well developed as parallel lines on the faces of $h\{\bar{1}01\}$, $e\{0\bar{2}1\}$ and $z\{1\bar{2}0\}$.

The angular values of the crystal could be only approximately obtained with the contact goniometer. These measurements, by which the crystal was correctly oriented, are given in the following table. Various other orientations were temporarily chosen, but only with the one adopted were the measured angles of fremontite in accord with those of amblygonite. The angular constants of amblygonite are taken for those of fremontite, pending the measurement of better crystals which would yield more accurate values. These constants are $a : b : c = 0.7334 : 1 : 0.7633$; $\alpha = 108°31$, $\beta = 97°48'$; $\gamma = 106°27'$.

Measured and calculated angles for fremontite.

	Measured.	Calculated.
	°	° ′
$c : a = (001) : (100)$	76	75 30
$a : h = (100) : (\bar{1}01)$	51	51 16
$h : e = (101) : (0\bar{2}1)$	69	67 51
$e : z = (0\bar{2}1) : (1\bar{2}0)$	44	45 53
$z : h = (1\bar{2}0) : (\bar{1}01)$	68	66 16
$a : b = (100) : (010)$	68	69 36
$c : b = (001) : (010)$	68	67 38
$b : e = (010) : (0\bar{2}1)$	37–40	37 42
$b : z = (010) : (1\bar{2}0)$	39	38 17

A comparison of the forms observed on the two minerals is as follows:

Amblygonite.	Fremontite.
$c\{001\}$	$c\{001\}$
......	$b\{010\}$
$a\{100\}$	$a\{100\}$
$m\{110\}$	......
$m\{110\}$	......
$z\{120$	$\{120\}$
$e\{021\}$	$e\{021\}$
$l\{101\}$	......
$h\{101\}$	$h\{101\}$

THE CHEMICAL COMPOSITION OF NEPHELITE.

The chemical composition of nephelite has long been a much discussed problem among mineralogists. One general theory endeavors to harmonize the analytical figures with the calculated values by the assumption of a number of complex formulas. The very complexity of these formulas is sufficient to cast doubt on their correctness. Another view is that the groups SiO_4 and Si_3O_8 can replace each other, in an isomorphous sense, so that by the presence of sufficient Si_3O_8, replacing SiO_4, the analytical figures obtained can readily be accounted for. Foote and Bradley[1] have proposed still another explanation, namely, that as a substance on crystallizing may form a "solid homogeneous solution with foreign matter," the mineral nephelite consists of a pure compound, probably $NaAlSiO_4$, with a varying amount of dissolved silica. Such an interpretation certainly is suggestive, but before it can be accepted for nephelite it must be proved that the compound $NaAlSiO_4$ can dissolve silica. Furthermore, the fact that chemically the "dissolved silica" acts in an entirely different way from any known modification of silica must be satisfactorily accounted for.

The composition of nephelite can be readily explained without assuming complex formulas and without calling on the hypothesis of "dissolved silica." The mineral albite has the formula $AlNaSi_3O_8$, and the corresponding isomorphous mineral anorthite has the formula $AlCa_{\frac{1}{2}}SiO_4$. The soda anorthite, $AlNaSiO_4$, has been prepared artificially, and Washington and Wright[2] have assumed its presence to the extent of 5.58 per cent in a feldspar (anemousite) consisting essentially of albite and anorthite in isomorphous mixture.

In the feldspars just named there are two types of compounds—$AlR'SiO_4$ and $AlR'Si_3O_8$—and their isomorphous relation, as earlier developed by Clarke,[3] led to a simple interpretation of the composition of nephelite. These compounds occur in several modifications, which are isomorphous. This relation can be best shown schematically.

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[1] Foote, H. W., and Bradley, W. M., On solid solution in minerals, with special reference to nephelite: Am. Jour. Sci., 4th ser., vol. 31, p. 25, 1911.

[2] Washington, H. S., and Wright, F. E., A feldspar from Linosa and the existence of soda anorthite (carnegieite): Am. Jour. Sci., 4th ser., vol. 29, p. 52, 1910.

[3] Clarke, F. W., The constitution of the silicates: U. S. Geol. Survey Bull. 125, 1895.

Modifications of compounds $AlR'SiO_4$ and $AlR'Si_3O_8$.

Compound.	Hexagonal.	Monoclinic.	Triclinic.
$AlNaSiO_4$	Essential component of nephelite; artificially prepared.		Artificially prepared; naturally only in mixture (carnegieite).
$AlKSiO_4$	Kaliophilite		
$AlCa_{1/2}SiO_4$	Present in small amounts in the calcic varieties of nephelite.	Celsian is the corresponding barium salt.	Anorthite.
$AlNaSi_3O_8$	Naturally only in mixture in nephelite.	Barbierite	Albite.
$AlKSi_3O_8$		Orthoclase	Microcline.
$AlCa_{1/2}Si_3O_8$			

The mineral nephelite is then an isomorphous mixture of the compounds crystallizing in the hexagonal modification, which are $AlNaSiO_4$ (essential component), $AlKSiO_4$ (kaliophilite), and $AlNaSi_3O_8$ (best known in its triclinic form as albite).

To show that the explanation offered is in agreement with the analyses of nephelite it will suffice to quote two analyses, one by Foote and Bradley and one by Morozewicz (No. V in paper of Foote and Bradley). These have been chosen for the reason that they are among the best analyses and show a minimum amount of other bases, such as CaO and Fe_2O_3.

The nephelite analyzed by Foote and Bradley consists, as calculated from their ratios, of the following compounds in the proportions indicated: 60 parts or 19.0 per cent of $KAlSiO_4$, 245 parts or 70.4 per cent of $NaAlSiO_4$, and 21 parts or 10.6 per cent of $NaAlSi_3O_8$. The comparison of the analysis with the figures calculated from this composition is very close, as is shown below.

Comparison of analysis of nephelite by Foote and Bradley with calculated values.

	Analysis.	Calculated.
SiO_2	44.46	44.45
Al_2O_3	33.11	33.37
Fe_2O_3	.96	
K_2O	5.61	5.66
Na_2O	16.32	16.52
H_2O	.38	
	100.84	100.00

The analysis made by Morozewicz yields the following composition: 62 parts or 19.7 per cent of $KAlSiO_4$, 259 parts or 74.7 per cent of $NaAlSiO_4$, and 11 parts or 5.6 per cent of $NaAlSi_3O_8$. As in the other case, the comparison of the analysis with the values calculated from this composition shows a very close agreement.

Comparison of analysis of nephelite by Morozewicz with calculated values.

	Analysis.	Calculated.
SiO_2	42.71	43.04
TiO_2	.04	....
Al_2O_3	33.83	34.20
Fe_2O_3	.40	
K_2O	5.86	5.89
CaO	.32	16.87
Na_2O	16.46	
H_2O	.18	....
Impurities	.06	....
	99.86	100.00

The figures prove that the composition of the mineral nephelite is best explained by assuming an isomorphous relation of SiO_4 and Si_3O_8.

The remarkable fact that the compound $KAlSiO_4$ is always present in nephelite to the extent of about 20 per cent has not yet received any adequate explanation.

LARGE CRYSTALS OF BLOEDITE.

Some bloedite recently found by Mr. Hoyt S. Gale, of the Geological Survey, is remarkable for the large size of the crystals. An extensive deposit of soda forms a crust on Soda Lake, in Carrizo Plain, San Luis Obispo County, Cal. This deposit has been described by Arnold and Johnson,[1] who give a detailed analysis of the saline crust that shows it to be nearly pure sodium sulphate with 1.66 per cent of MgO. In the black mud below this crust were found the isolated crystals of bloedite, a hydrous magnesium sodium sulphate with 12 per cent of MgO.

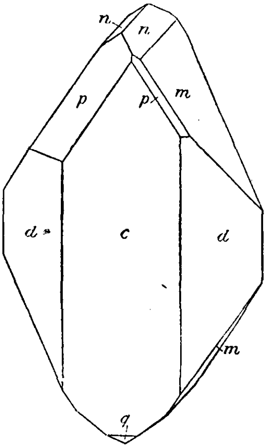

FIGURE 96.—Crystal of bloedite from Carrizo Plain, Cal. Forms: *c*{001}, *d*{011}, *m*{110}, *n*{210}, *q*{$\bar{2}01$}, *p*{111}. The crystal is drawn with the base *c*{001} vertical.

The larger crystals have a dark, almost black appearance when the superficial covering of gray mud is removed, though the smaller crystals are nearly colorless, the black appearance being due to impurities. In places the larger crystals are likewise nearly colorless and translucent and in small pieces transparent. The clear and glassy fragments which do not show any cleavage greatly resemble quartz fragments.

The largest crystal at present on hand measures 16.5 by 10.5 by 3.5 centimeters and weighs 652 grams. The crystals are flattened somewhat parallel to the base and show the following forms:

Large: *c*{001}, *d*{011}, *m*{110}.
Medium: *n*{210}, *p*{111}.
Small: *q*{$\bar{2}01$}, *s*{$\bar{2}11$}, *u*{$\bar{1}11$}, *x*{$\bar{1}21$}.

The measurements were made with a contact goniometer and gave the following results:

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[1] Arnold, Ralph, and Johnson, H. R., Sodium sulphate in Soda Lake, Carrizo Plain, San Luis Obispo County, Cal.: U. S. Geol. Survey Bull. 380, pp. 369–371, 1909.

Measurements of bloedite crystals.

Form.	Measured.	Calculated.	
	°	°	′
$m(110):p(111)$	47	46	42
$c(011):q(\bar{2}01)$	50	50	06
$c(001):p(111)$	36	36	55
$n(210):n'''(2\bar{1}0)$	68	67	06
$m(110):m'''(1\bar{1}0)$	105	105	58
$d(011):d(0\bar{1}1)$	67	66	46
$c(001):s(\bar{2}11)$	55	55	16½
$c(001):u(\bar{1}11)$	43	42	05

The form $x(\bar{1}21)$ was determined by zonal relations.

A peculiarity noted on almost all the crystals examined is that the pair of faces of the pyramid $p\{111\}$ are very unequally developed, as shown in figure 96. In order to show better the relative development of the faces, the drawing was made with the *a* and *c* axes interchanged, so that the basal pinacoid $c\{001\}$ is shown in vertical position.

The analysis made on selected pure material gave the following values:

Analysis of bloedite from California.

H_2O	21.37
MgO	11.93
Na_2O	18.26
SO_3	48.11
	99.67

These values are close to those that are required by the formula $Na_2Mg(SO_4)_2.4H_2O$.

ALUNITE FROM MARYSVALE, UTAH.

The occurrence of alunite near Marysvale, Utah, has been fully described by Butler and Gale.[1] On some of the more coarsely crystalline alunite small cavities were noted in which were found crystals showing the base $c\{0001\}$ and the rhombohedron $r\{10\bar{1}1\}$, both developed as large faces whose edges were in part truncated by narrow faces of $s\{02\bar{2}1\}$.

An analysis of a selected clear-pink, translucent, coarsely granular crystalline specimen gave the results shown below in column 1, whereas an analysis of the very compact fine-granular alunite rock (column 2), which has a decided porcelain-like appearance, showed that it was much impurer than the better-crystallized granular material.

Analyses of alunite from Marysvale, Utah.

	1. Coarse granular variety.	2. Compact fine-grained rock.	Calculated composition.
Al_2O_3	37.18	34.40	36.97
Fe_2O_3	Trace.	Trace.	...
K_2O	10.46	9.71	11.36
Na_2O	.33	.56	...
SO_3	38.34	36.54	38.63
P_2O_5	.58	.50	...
H_2O-	.09	.11	...
H_2O+	12.90	13.08	13.04
SiO_2	.22	5.28	...
	100.10	100.18	100.00

The first analysis, made on pure material, agrees well with the composition of the mineral as calculated from the formula $3Al_2O_3.K_2O.4SO_3.6H_2O$.

Laboratory experiments showed that the powdered mineral, when ignited, gives off all its water and three-quarters of its sulphuric acid. The remaining quarter is combined with the potassium as potassium sulphate and may be dissolved out with water. The residue consists of aluminum oxide plus the impurities, such as silica, which were present in the sample. The maximum amount of alumina found in the water leach of several experiments was 0.25 per cent. It is prob-

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[1] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysville, Utah: U. S. Geol. Survey Bull. 511, 1912.

able that a small amount of potassium sulphate was volatilized by the heat. The following results were obtained by igniting the powdered alunite and subsequent leaching with water:

	Per cent.
Volatilized (H_2O, 13; SO_3, 29; K_2SO_4(?), 2)	44
Insoluble residue (Al_2O_3)	37
Water-soluble residue (K_2SO_4)	18
	99

It follows that about 92 per cent of the total potassium sulphate in the mineral was obtained in a water-soluble form by this treatment. A higher percentage can doubtless be obtained by regulating the heat, as it is believed that in the experiments some of the potassium sulphate was volatilized.

According to these experiments about 32 per cent of the ignited alunite consists of available potassium sulphate which can be extracted and recovered by simple water leaching and evaporation. The remaining 68 per cent consists of alumina (Al_2O_3) plus the impurities of the mineral sample.

THE COMPOSITION AND RELATIONS OF CUSTERITE.

OCCURRENCE AND ASSOCIATION.

Custerite has been described by Umpleby [1] as occurring in a contact zone of granite porphyry with Mississippian limestone, 3½ miles southwest of Mackay, Custer County, Idaho. The zone is worked for copper, and the ore minerals, principally chalcopyrite and its oxidation products, are intimately associated with garnet, diopside, magnetite, fluorite, and other contact minerals in bodies that are nearly coincident in extent with original limestone inclusions. In some of these inclusions none of the original limestone remains, though locally its bedded structure is preserved in the garnet-diopside rock, but in others a core of unaltered blue limestone grades outward through pale-blue, partly recrystallized limestone into white marble and on into a zone made up principally of garnet, diopside, and magnetite. The custerite was collected between the garnet-diopside and marble zones which fringe one of these inclusions.

PHYSICAL AND OPTICAL PROPERTIES.

The results of microscopic study indicate that custerite is monoclinic. Two cleavages were noted, one parallel to the base and the other parallel to a prism. The hardness is 5 to 6, the density 2.91. The crystals show lamellar twinning like albite. As determined by Umpleby and Larsen, the refractive indices are, for sodium light, $\alpha = 1.586 \pm 0.005$, $\beta = 1.589 \pm 0.005$, $\gamma = 1.598 \pm 0.005$.

Fuller description of the optical relation is given in the paper cited, in which the microscopic characterization of custerite is summarized as follows:

> Custerite is characterized microscopically by its moderate index of refraction, low birefringence, polysynthetic twinning, maximum extinction angle of twin lamellæ of 6°–7°, positive optical character, distinct dispersion of the optic axes with $\rho < v$, and three cleavages which intersect at high angles. There is no known mineral species from which it may not be readily distinguished optically. Its birefringence and twinning suggest albite, but its refringence is much higher. Its relief, lack of color, and cleavage in thin section might at first glance lead to its being mistaken for a colorless pyroxene, but its refringence and birefringence are lower, and its extinction angle is less than in all pyroxenes except ægirite. It resembles hillebrandite in index of refraction and birefringence, but that mineral is orthorhombic, optically negative, and occurs in fibrous forms. In relief and birefringence also it resembles eudialyte, which, however, is uniaxial and occurs in association with soda minerals.

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[1] Umpleby, J. B., Schaller, W. T., and Larsen, E. S., Custerite, a new contact-metamorphic mineral: Am. Jour. Sci., 4th ser., vol. 36, p. 385, 1913.

It is believed that custerite is a mineral of rare occurrence, for its optical properties are so distinctive that it would scarcely have been overlooked. In the hand specimen, however, it is so unpromising in appearance that thin sections of it may never have been cut. The mineral should be looked for in fluorine-bearing contact zones, apparently in the border phases of the metamorphism.

CHEMICAL PROPERTIES.

PYROGNOSTICS.

When heated gently in a closed tube, custerite turns a transitory yellow and phosphoresces with a golden-yellow light. As seen in a darkened room, the color of the glow is like that of a deep-colored golden beryl. On increasing the heat the phosphorescence is destroyed and water is given off. The mineral does not decrepitate. A white ring, due to the fluorine, is obtained by heating the mineral at a temperature sufficient to melt the glass tube. In the blowpipe flame custerite fuses with difficulty to an opaque white enamel.

The mineral is very readily decomposed by acids, gelatinous silica separating so quickly when the powdered mineral is treated with HCl as to form a stiff coherent mass. The separated gelatinous silica floats around in an excess of acid, the solution itself not gelatinizing on further boiling. Custerite therefore does not "gelatinize" like natrolite.

QUANTITATIVE COMPOSITION.

The chemical analysis showed that water, fluorine, silica, and lime were the essential constituents, the small amounts of iron and magnesium present being probably due to magnetite and diopside, respectively. Fairly pure, fresh material, suitable for analysis, was available only in portions of 0.25 to 0.75 gram.

The analytical results obtained are shown in the following table:

Analyses and ratios of custerite.

	1	2	Average.	Ratios.
SiO_2	32. 13	32. 20	32. 17	0. 536
CaO	55. 11	....	55. 11	. 984
H_2O	5. 53	5. 06	5. 30	. 294
F	8. 12	....	8. 12	. 427
MgO	1. 19	1. 19	1. 19	. 030
Magnetite	. 85	1. 14	1. 00	....
			102. 89	
			$O=F_2-3.42$	
			99. 47	

These results were verified by a partial analysis (water not being determined) of a different, somewhat less pure portion of the same specimen of custerite. The results obtained are: SiO_2, 33.46; CaO, 53.93; F, 7.29; MgO, 1.41; magnetite, 2.13. Alkalies were not determined on any of the samples because of paucity of material. Some of the whiter, chalky-looking material gave less water than the fresh material, several different samples yielding from 2 to 3 per cent H_2O instead of the 5 or 6 per cent given in the above analyses. Whether this represents an alteration of the custerite or a much impurer sample could not be determined on the scanty material available.

INTERPRETATION OF ANALYSIS.

The ratios derived from the above analytical figures can be interpreted by considering either that the small amount of magnesia belongs to the custerite or that it represents admixed diopside. These alternatives are shown in the table below.

Interpretation of ratios of custerite analysis.

	Ratios.	Combining CaO+MgO.	Deducting diopside.	Combining water and fluorine.
SiO_2	0.536	2.00	2.00	2.00
CaO	.984	3.78	4.01	4.01
MgO	.030			
H_2O	.294	1.10	1.24	2.14 H_2O or 4.27 F
F	.427	1.59	1.79	

The formula derived for custerite is Ca_2SiHFO_4, with some of the fluorine replaced by water (hydroxyl). The composition may also be expressed as a mixture of the two compounds $2SiO_2.4CaO.2H_2O$ and $2SiO_2.4CaO.4F$, with the first one slightly in excess. The relation of the fluorine to water (hydroxyl) can be much better shown in the empirical formula, according to which the ratios reduce to $Ca_4Si_2O_6(OH,F)_4$ with the ratio of hydroxyl (OH) to fluorine (F) as 2.48 : 1.79, or nearly 4 : 3.

No water was given off when custerite was heated to 110°, indicating that the water is an inherent part of the mineral. The temperature at which the water does go off was not determined, but the observation was repeatedly made that the phosphorescence phenomenon displayed itself and was destroyed by heat before the water was given off. Some powdered custerite, placed in a watch glass with several cubic centimeters of water, immediately gives a deep-red color with a few drops of phenolphthalein. This reaction was described by Clarke,[1] who has suggested that it is indicative of the presence of the univalent group CaOH. As the ratio of OH to F is

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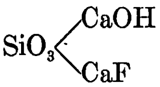
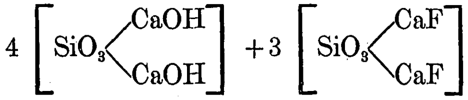
[1] Clarke, F. W., The alkaline reaction of some natural silicates: U. S. Geol. Survey Bull. 167, p. 156, 1900.

approximately 1 : 1, the formula of custerite may be structurally interpreted as a metasilicate, as follows:



The ratio of hydroxyl (OH) to fluorine (F) being not exactly 1 : 1 but more nearly 4 : 3, custerite may be more accurately considered as an isomorphous mixture of the following compounds, in the ratio indicated.



RELATION TO OTHER MINERALS.

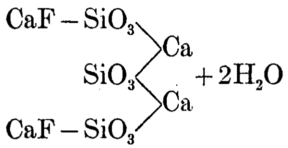
There are only three minerals known to which custerite is related in composition. These are zeophyllite, cuspidine, and hillebrandite. The relation in composition can be best shown by directly comparing their analyses:

Comparison of composition of custerite with that of related minerals.

	Custerite.	Zeophyllite.	Cuspidine.		Hillebrandite.
			Franklin Furnace.	Vesuvius.	
SiO_2	32.17	38.84	32.36	32.80	32.59
CaO	55.11	44.32	61.37	61.12	57.76
H_2O	5.30	8.98	....	....	9.36
F	8.12	8.23	9.05	9.88	....
Rest	2.19	2.62	1.46	.42	.53
	102.89	102.99	104.24	104.22	100.24
Deduct $O=F_2$	−3.42	−3.47	−3.81	−3.98	
	99.47	99.52	100.43	100.24	

Zeophyllite is the only one of the three minerals which contains both water and fluorine. The proportions of silica and lime are different from those in custerite, though structurally its formula may be written in a somewhat similar way. The mineral is described as rhombohedral, the crystals being composed of a uniaxial center surrounded by a biaxial border. On being heated the mineral becomes uniformly and permanently uniaxial. In crystal form and physical and optical properties there is no relation between zeophyllite and the other minerals chemically related to custerite. In its paragenesis zeophyllite is also totally different from custerite, being a zeolite-like mineral found in basalt with natrolite, calcite, apophyllite, analcite, etc. A specimen of zeophyllite obtained through the kindness of Dr. Koechlin, of the Vienna Hof-Museum, was tested for its alkaline reaction and found to give only a very faint pink color with phenolphthalein.

The dual optical character of zeophyllite suggests strongly that it is polymorphous. Possibly the uniaxial compound is the zeolite-like mineral, bearing no relation to custerite, cuspidine, or hillebrandite. The biaxial compound, not found as such in nature, may possibly represent a compound similar in properties to custerite, cuspidine, and hillebrandite. Its formula, $Ca_4Si_3H_4F_2O_{11}$, can be written as that of custerite plus one part of metasilicic acid, thus: $Ca_4Si_2H_2F_2O_8$ (custerite) $+ H_2SiO_3$, but what significance, if any, is to be attached to this fact is not known. The formula of zeophyllite can be interpreted structurally in a way analogous to that of custerite:



which would explain the fact that zeophyllite does not give a strong alkaline reaction with phenolphthalein but which seems inconsistent with the fact that less than 1 per cent of the water is given off at 110°. Other structural interpretations are of course possible.

Cuspidine, found originally at Vesuvius, has recently been noted at Franklin Furnace, N. J., by Palache. At Vesuvius it was found as well-developed crystals in druses associated with augite, hornblende, biotite, garnet, sarcolite, haüyne, and calcite (derived from altered cuspidine). Granular aggregates resembling a fine-grained diabase, composed of cuspidine with augite and biotite, were also noted. Attention may also be called to the "cuspidine-like mineral"[1] found with green magnesia mica and white sodalite and occurring in rhombic prisms, apparently different from cuspidine. The composition of this material is not known, though Zambonini [2] considers it identical with humite.

The density of the Franklin Furnace cuspidine is given as 2.965–2.989, and that of the Vesuvius cuspidine, as determined by Zambonini, as 2.962; the average being 2.97. The formula derived by Zambonini, $Ca_2(CaF)_2Si_2O_7$, is in perfect accord with his own analysis and with Warren's analysis of the Franklin Furnace material. The presence of only 0.57 per cent of water (not determined according

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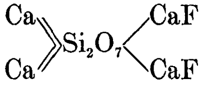
[1] Rath, G. von, Zeitschr. Kryst. Min., vol. 8, p. 45, 1884.

[2] Zambonini, F., Appendice alla Mineralogia Vesuviana: Accad. Sci. Napoli Atti, vol. 12, p. 44, 1912.

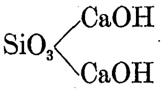
to Warren's analysis) would suffice to bring the ratio of [F + (OH)]: SiO_2 to 1.00 : 1.00 instead of 1.00 : 0.88, as calculated from his analysis. Structurally the formula of cuspidine can be interpreted as



$$\begin{matrix}\mathrm{Ca} & & \mathrm{CaF}\\ & \rangle\mathrm{Si_2O_7}\langle & \\ \mathrm{Ca} & & \mathrm{CaF}\end{matrix}$$

which does not show any direct relation to that of custerite.

Hillebrandite is genetically similar to custerite, being one of the products of contact metamorphism of limestone. A sample of hillebrandite kindly furnished for study by Dr. F. E. Wright yielded 0.77 per cent of water at 110° and 9.64 per cent on ignition (calculated 9.45 per cent). The strong alkaline reaction with phenolphthalein as described by Wright was confirmed and suggests the presence of the CaOH group. From these results the composition of hillebrandite can be readily interpreted as a metasilicate with the following structural formula:



$$\mathrm{SiO_3}\langle\begin{matrix}\mathrm{CaOH}\\ \mathrm{CaOH}\end{matrix}$$

This formula is identical in type with that of custerite and suggests at once that custerite is an isomorphous mixture of hillebrandite and a theoretic fluo-hillebrandite, in which all the hydroxyl is replaced by fluorine. This conception is simple and rational but is opposed by other considerations.

As cuspidine has been found at two widely separated localities, the inference may be justified that in the presence of much fluorine and little or no water a mineral of the cuspidine formula, $3CaO.2SiO_2CaF_2$, would always form instead of a fluo-hillebrandite with the formula $2CaO.2SiO_2.2CaF_2$. In other words, fluo-hillebrandite seems to be unstable under the metamorphic conditions prevailing, though this inference rests solely on the fact that at the only two localities where a calcium fluo-silicate occurs a compound of different type (cuspidine) was formed. It seems likely, therefore, that, in view of the isomorphous replacement of fluorine and hydroxyl, the isomorphous series of which hillebrandite is the hydroxyl end consists of the two end members $(CaOH)_2SiO_3$ and $(CaF)(CaOH)SiO_3$ and not of the theoretic end members $(CaOH)_2SiO_3$ and $(CaF)_2SiO_3$.

The symmetry of hillebrandite and custerite is apparently different, though some of the properties of hillebrandite could not be as definitely determined as those of custerite. Hillebrandite is fibrous and orthorhombic, whereas custerite is granular and monoclinic, with a close approach to orthorhombic symmetry, as is indicated by the nearly rectangular cleavages and low extinction angle. The custerite and hillebrandite compounds may both be dimorphous, only the two nonisomorphous end members of the four possible compounds being known.

The status of the relations of these minerals, so far as can be judged by the available evidence, seems to be somewhat as is given below.

Cuspidine: $Ca_4Si_2F_2O_7$.

Theoretic fluo-hillebrandite: $Ca_4Si_2F_4O_6$. Unstable, nonexistent.

Custerite: $Ca_4Si_2F_2(OH)_2O_6$. Dimorphous; orthorhombic form isomorphous with hillebrandite (not known) and monoclinic.

Hillebrandite: $Ca_4Si_2(OH)_4O_6$. Dimorphous; monoclinic form isomorphous with custerite (not known) and orthorhombic.

Zeophyllite: $Ca_4Si_3H_4F_2O_{11}$. Dimorphous; the known form not related to the above-named minerals.

The close chemical relation of these four minerals can be shown by writing their formulas so as to keep intact the common compound, $Ca_4Si_2F_2O_7$.

Cuspidine.....$Ca_4Si_2F_2O_7$.
Custerite......$Ca_4Si_2F_2O_7.H_2O$ (or cuspidine plus water).
Hillebrandite.$Ca_4Si_2(OH)_2O_7.H_2O$.
Zeophyllite....$Ca_4Si_2F_2O_7.H_2O.SiO_2$ (or cuspidine plus water and silica).

These relations suggest the existence of a hydroxy-cuspidine, $Ca_4Si_2(OH)_2O_7$, and the derivability of custerite and zeophyllite (or a polymorphic form of the zeophyllite compound) from cuspidine by the actual addition of water and silica.

The essential properties of the four minerals considered in the preceding paragraphs are briefly tabulated below for future reference.

Properties of custerite and related minerals.

	Custerite.	Zeophyllite.	Cuspidine.	Hillebrandite.
Composition	$Ca_4Si_2H_2F_2O_8$	$Ca_4Si_3H_4F_2O_{11}$	$Ca_4Si_2F_2O_7$	$Ca_4Si_2H_4O_{10}$.
Symmetry	Monoclinic	Rhombohedral.	Monoclinic	Orthorhombic.
Cleavage	Two, basal and prismatic.	One, basal	One, basal	Prismatic (?).
Hardness	5–6	3	5–6	5–6.
Density	2. 96	2. 75	2. 97	2. 69.
Fusibility	Difficult	Very easy	Difficult	Difficult.
Axial plane	Normal to basal cleavage.	Normal to cleavage.	{010}, normal to cleavage.	Parallel to cleavage.
Index γ	1. 598	1. 565	1. 602[a]	1. 612.
Index β	1. 589		1. 595[a]	
Index α	1. 586	1. 560	1. 590[a]	1. 605.
Birefringence	0. 011	0. 005	0. 012[a]	0. 007.
2E	105°	0–27½°	110°	60–80°.
Dispersion	Strong, $\rho>v$	$\rho<v$	Crossed, very distinct, $\rho>v$.	$\rho<v$.
Sign	Positive	Negative	Positive[a]	Negative.
Extinction	6½°		5°	0°.
Twinning	Prominent, polysynthetic.		Twinning plane (100).	
Elongation				Z.

[a] Data kindly furnished by Esper S. Larsen, measured on the Vesuvius mineral.

THE COMPOSITION OF HODGKINSONITE.

OCCURRENCE AND ASSOCIATIONS.

The occurrence of hodgkinsonite at Franklin Furnace, N. J., is described by Palache[1] as follows:

> Hodgkinsonite is a hydrous silicate of zinc and manganese crystallizing in the monoclinic system. It occurs in seams in massive granular ore of the typical willemite-franklinite mixture; the seams are generally very thin with but a film of the mineral which is always associated with white barite and not uncommonly with plates of native copper. Locally the film thickens to a narrow vein, and then the new mineral may show individuals up to 2 centimeters across, sharply angular in form and apparently with crystal faces but in reality determined in their outline wholly by the older platy barite which incloses them. The clear pink color and brilliant cleavage of hodgkinsonite together with the snow-white barite make such specimens both striking and attractive in appearance.

The crystals so far obtained have occupied cavities in the thicker veins and show evidence of solution, the faces being generally faceted and dull. The largest crystal seen measures about 1 centimeter in length. In the cavities hodgkinsonite is accompanied by black rhombohedral crystals of pyrochroite and scalenohedral crystals of calcite, both later in age and partly incrusting it. The hodgkinsonite crystals are implanted directly on willemite or franklinite, and in one specimen on manganese garnet. The association and mode of occurrence both indicate a pneumatolytic origin for the new mineral.

CRYSTALLOGRAPHY.

Hodgkinsonite was determined by Palache to be monoclinic with normal symmetry. The highly perfect cleavage, normal to the symmetry plane, has been taken as the basal pinacoid. In other directions the fracture is conchoidal. The habit of the crystals is acute pyramidal. The axial ratio[2] is $a : b : c = 1.538 : 1 : 1.1075$, $\beta = 84° 35'$. The forms determined are $c\{001\}$, $m\{110\}$, $l\{210\}$, $s\{011\}$, $o\{021\}$, $v\{\bar{4}03\}$, $w\{\bar{2}01\}$, $t\{\bar{4}01\}$, $p\{111\}$, $r\{221\}$, $n\{\bar{3}11\}$.

CHEMICAL PROPERTIES.

PYROGNOSTICS.

The mineral decrepitates when held in the blowpipe flame, wherein it fuses readily and quietly to a brown enamel. When heated in a closed tube it decrepitates strongly, splitting up into numerous thin

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[1] Palache, Charles, and Schaller, W. T., Hodgkinsonite, a new mineral from Franklin Furnace, N. J.: Washington Acad. Sci. Jour., vol. 3, p. 474, 1913.

[2] Palache, Charles, Supplementary note on the crystal form of hodgkinsonite: Washington Acad. Sci. Jour., vol. 4, p. 154, 1914.

cleavage scales which on further heating yield water and become brown in color. The mineral is readily soluble in acid, yielding gelatinous silica.

QUANTITATIVE COMPOSITION.

The chemical analyses of hodgkinsonite were made on carefully selected cleavage fragments of a clear pink color and gave the following results. Quarter-gram samples were used, as the total amount of available material was only somewhat over a gram.

Analyses and ratios of hodgkinsonite.

	1	2	3	Average.	Ratios.	
SiO_2	19.92	19.89	19.77	19.86	0.331	1.02
MnO	20.39	20.97	....	20.68	.291	2.98
ZnO	52.93	(a)	....	52.93	.653	
CaO	.99	.88	....	.93	.017	
MgO	.04	....	....	.04	.001	
H_2O	....	....	[b] 5.77	5.77	.321	.99
					100.21	

[a] A duplicate determination of ZnO, of which a small amount was lost, gave 51.38 per cent.

[b] Determined directly by fusing the mineral with sodium carbonate and collecting the water in a calcium chloride tube. A determination of the loss on ignition, corrected for oxidation of the manganese, gave 4.68 per cent.

A doubtful trace of lead was encountered, but iron and chlorine were absent. No water was given off by the mineral at 110°.

The ratios yield the formula $3RO.SiO_2.H_2O$, in which R is chiefly zinc and manganese. If the manganese, calcium, and magnesium are arbitrarily taken together, then the ratio of $MnO + CaO + MgO$ to ZnO is 309 to 653, or 1 : 2.11, or nearly 1 : 2. The formula may then be written $MnO.2ZnO.SiO_2.H_2O$, which may, as the water is all constitutional, be interpreted as $Mn.(ZnOH)_2.SiO_4$.

CRYSTALS OF PISANITE FROM DUCKTOWN, TENNESSEE.

Some specimens of pisanite from Ducktown, Tenn., were sent to the writer for crystallographic study by Prof. F. R. Van Horn, of Cleveland, Ohio, who has recently[1] given a full description of the occurrence and composition of the mineral. Several crystals were detached from the specimens and measured with the following result:

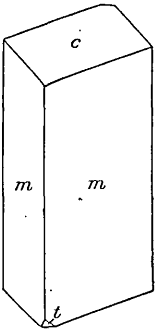

FIGURE 97.

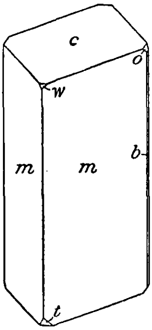

FIGURE 98.

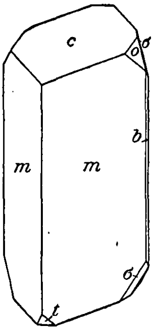

FIGURE 99.

FIGURE 97.—Crystal 1, pisanite from Ducktown, Tenn. Forms: m{110}, c{001}, t{$\bar{1}$01}.

FIGURE 98.—Crystal 2, pisanite from Ducktown, Tenn. Forms: b{010}, m{110}, c{001}, o{011}, w{103}, t{$\bar{1}$01}.

FIGURE 99.—Crystal 3, pisanite from Ducktown, Tenn. Forms: b{010}, m{110}, c{001}, o{011}, t{$\bar{1}$01}, σ{$\bar{1}$21}.

Forms determined:

b{010}, very narrow, figures 98 and 99.
c{001}, large, figures 97, 98, 99. Cleavage.
m{110}, large, dominant form, figures 97, 98, 99.
o{011}, small, figures 98 and 99.
w{103}, minute, figure 98.
t{$\bar{1}$01}, minute but larger than w, figures 97, 98, 99.
σ{$\bar{1}$21}, minute, figure 99.

Average measured and calculated angles of pisanite from Ducktown, Tenn.

	Measured.				Calculated.			
	φ		ρ		φ		ρ	
	°	′	°	′	°	′	°	′
b{010}	0	17	90	00	0	00	90	00
c{001}	89	23	15	54	90	00	15	11
m{110}	41	34	90	00	41	36	90	00
o{011}	9	35	57	19	10	07	57	04
w{103}	88	27	36	29	90	00	35	48
t{$\bar{1}$01}	89	21	47	06	90	00	47	09
σ{$\bar{1}$21}	18	33	72	06	19	32	72	46

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[1] Van Horn, F. R., Notes on a new occurrence of pisanite and arsenopyrite, and some large staurolite crystals from the Ducktown district, Tenn.: Am. Jour. Sci., 4th ser., vol. 37, p. 40, 1914.

THE REFRACTIVE INDICES OF STRENGITE.

The only published figures for the refractive indices of strengite, $Fe_2O_3.P_2O_5.4H_2O$, which could be found are those given by Schroeder van der Kolk.[1] His figures are $1.81+0.03$, which can be stated, as Lacroix[2] did, in the form $\alpha=1.81$, $\gamma=1.84$. Determination of these values for a manganese strengite from California gave $\alpha=1.70$–1.71, $\gamma=1.72$–1.73. Lacroix[3] determined the mean index of similar material (which he called angelardite) as approximately 1.70. It therefore seemed necessary to redetermine the refractive indices of typical strengite in order to bring the conflicting determinations in accord.

Professor Ledroit, of Mainz, very kindly presented several specimens of the mineral from the Eleonore mine, on the Dunsberg, near Giessen. The strengite forms small spherulites associated with beraunite (eleonorite), cacoxenite, etc. Crushed fragments of these spherulites were used for determining the minimum and maximum refractive indices. The oil-immersion method was used, and the results obtained are as follows:

α (normal elongation of fibers)$=1.71$.
γ (parallel elongation of fibers)$=1.735$.
$\gamma-\alpha=0.025$.

The figures given by Schroeder van der Kolk are therefore wrong, and it seems most probable that his figure 1.81 was miscopied for 1.71.

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[1] Tabellen zur mikroskopischen Bestimmung der Mineralien, p. 54, 1906.

[2] Lacroix, A., Minéralogie de la France, vol. 4, p. 475, 1910.

[3] Idem, p. 523.

THE CALCULATION OF A MINERAL FORMULA.

In the calculation of the ratios of a mineral analysis, it is customary to select arbitrarily one of the constituents as unity or some multiple of unity and on this basis to calculate the ratios of the other constituents. As an example the analysis of pearceite from the Veta Rica mine, Sierra Mojada, Coahuila, Mexico, as recently given[1] by Van Horn and Cook, is reproduced below.

Analysis and ratios of pearceite.

	Analysis.	Ratios.		
S	17.46	0.5444	10.80	11
As	7.56	.1008	2.00	2
Ag	59.22	[a].2744	7.886	8
Cu	15.65	[b].1231		
Sb	.00	....		
	99.89			

[a] Considered as Ag_2. [b] Considered as Cu_2.

The ratios are sufficiently close to 11 : 2 : 8 to show that these are the correct values. The true ratios are very much closer to 11 : 2 : 8 than those given by Van Horn and Cook, as will be shown below.

The first column from the ratios given above is reproduced below (1) with the figures for silver and copper combined, and all the figures multiplied by 100 for convenience. By taking the lowest number as unity it is readily seen that the approximate ratio is 5½ : 1 : 4. On dividing the first value by 2 times 5½ (these numbers are doubled to avoid fractions) the second by 2 times 1 and the third by 2 times 4, the results under (2) are obtained. These numbers should be nearly the same. Their average is 4.986. Dividing now the ratios obtained from the analysis by this average we obtain the figures given under (3), which are much closer to 11, 2, and 8 respectively than those given by Van Horn and Cook.

	(1)	(2)	(3)
S	$54.44 \div (2\times 5\frac{1}{2})$	$=4.949$	10.92
As	$10.08 \div (2\times 1)$	$=5.040$	2.02
Ag_2+Cu_2	$39.75 \div (2\times 4)$	$=4.969$	7.97
		Average$=4.986$	

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[1] Van Horn, F. R., and Cook, C. W., A new occurrence of pearceite: Am. Jour. Sci., 4th ser., vol. 31, p. 518, 1911.

Ratios like those given above under (3), which vary considerably from the whole numbers they approximate, should not be compared as they stand. The figures should be reduced to multiples of approximate unity, which can then be directly compared, as the following table shows. In the last column only two decimals are expressed. If the third decimal is below 5, it is neglected. If it is 5 or above, the second decimal is increased 1.

S	$10.92=11\times0.993=11\times0.99$
As	$2.02=2\times1.01=2\times1.01$
Ag_2+Cu_2	$7.97=8\times0.996=8\times1.00$

These figures show that the ratios deduced from the pearceite analysis are in fact very close to the whole numbers 11 : 2 : 8, a fact that is not brought out by the ratios 10.80 : 2.00 : 7.886 given by Van Horn and Cook, which were obtained by arbitrarily assigning a whole number to one of the values. The form of the last set of ratios given above expresses most accurately the relations calculated from the analysis.