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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.

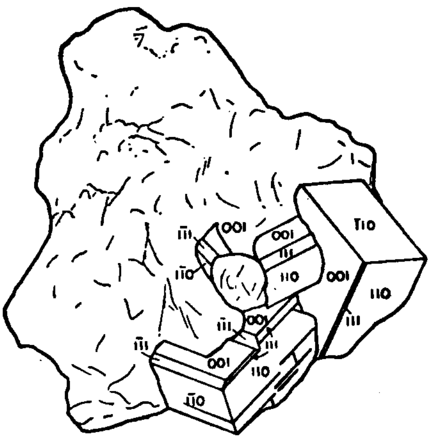


FIGURE 38.—Diagram illustrating crystal forms of inyoite shown in Plate I, *A*. The large crystal on the right was broken up, and glassy unaltered inyoite was obtained from its center. Nearly the entire specimen has altered to meyerhofferite.

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.

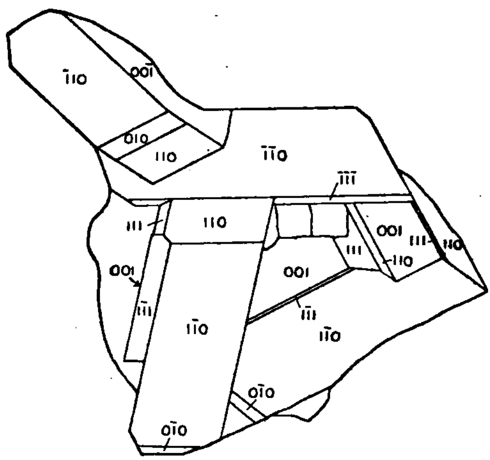
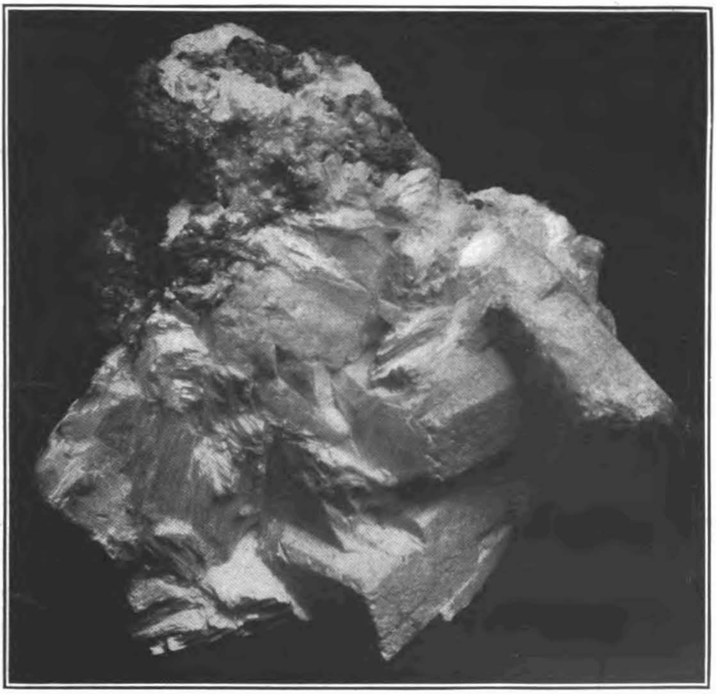


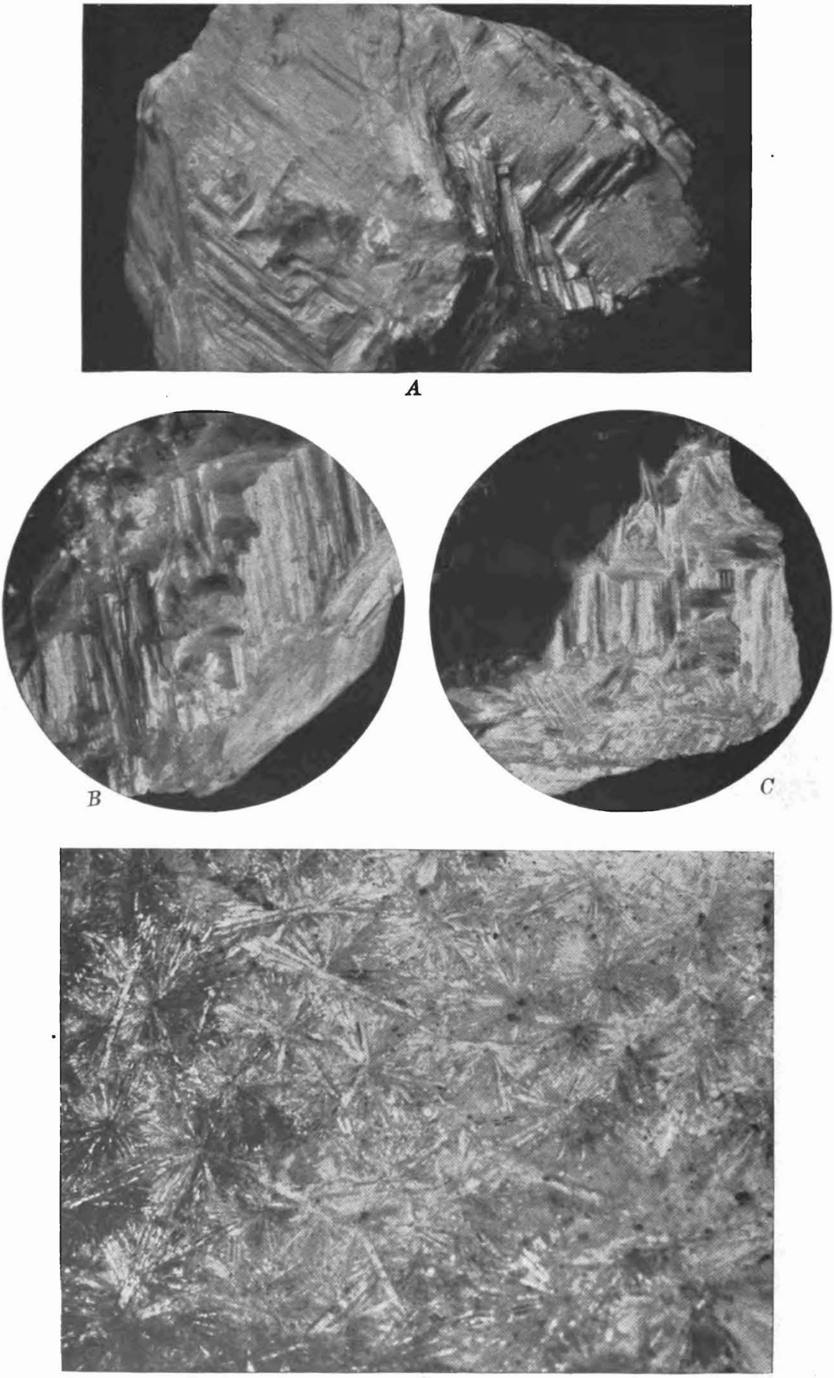
FIGURE 39.—Diagram illustrating crystal forms of inyoite shown in Plate I, *B*.

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:

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

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.

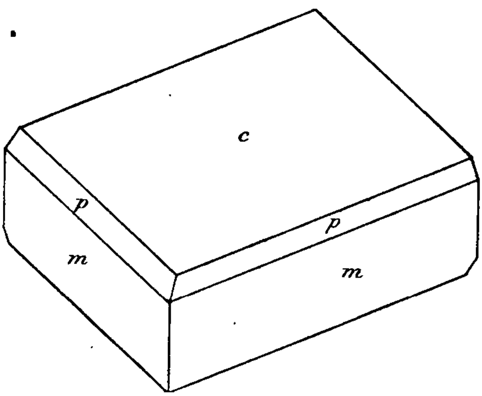


FIGURE 40.—Inyoite crystal. Forms: *c*{001}, *m*{110}, *p*{111}.

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
v	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	[ab] 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		φ 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

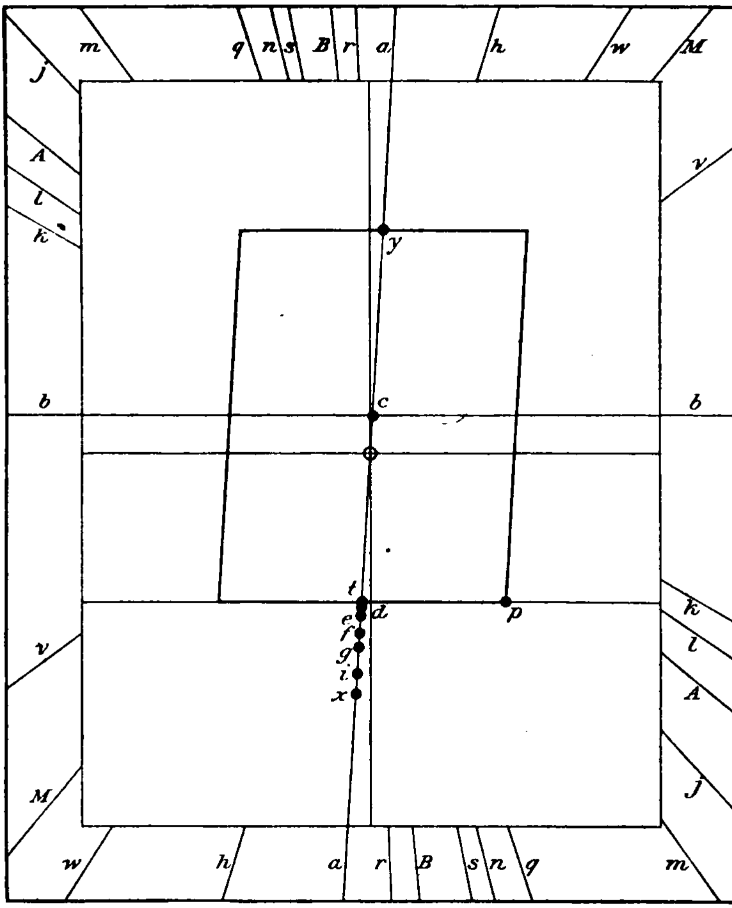


FIGURE 41.—Gnomonic projection of meyerhofferite forms. The form z{12. 0. 1}, not shown, falls outside of the projection.

unit pyramid $p\{111\}$ lies in such zones as $c\{001\}$, $p\{111\}$, $m\{110\}$, and $t\{101\}$, $p\{111\}$, $b\{010\}$.

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

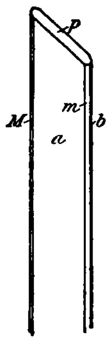


FIGURE 42.

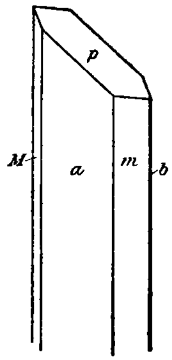


FIGURE 43.

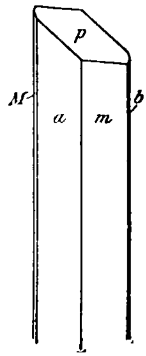


FIGURE 44.

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.

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.

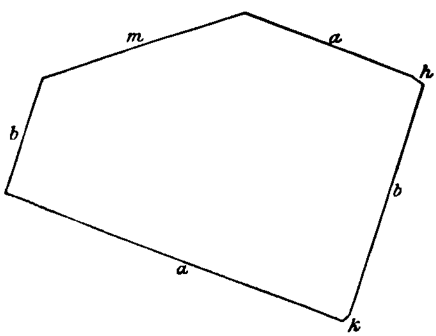


FIGURE 45.—Orthographic projection of crystal 17, meyerhofferite. Only the prism zone is shown on this crystal. Forms: $b\{010\}$, $a\{100\}$, $m\{110\}$, $k\{370\}$, $h\{3\bar{1}0\}$.

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.

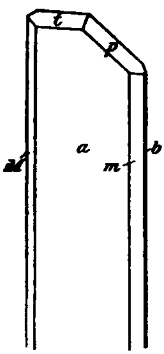


FIGURE 46.

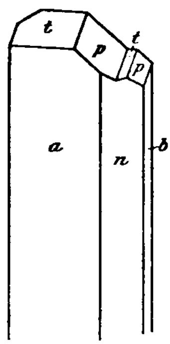


FIGURE 47.

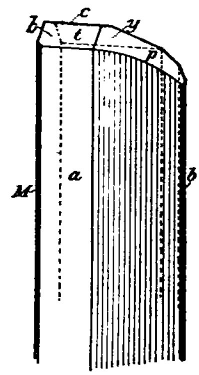


FIGURE 48.

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 $y\{\bar{1}01\}$ 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

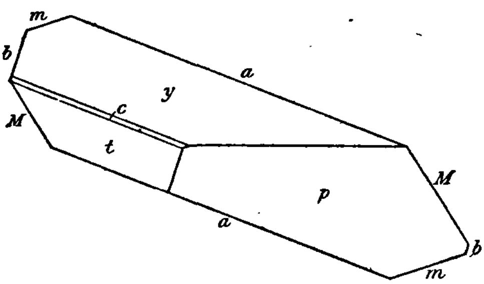


FIGURE 49.

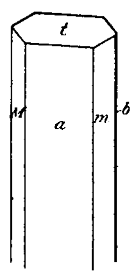


FIGURE 50.

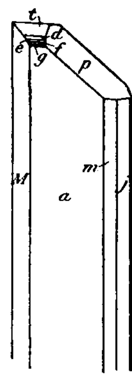


FIGURE 51.

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: $b\{010\}$, $j\{450\}$, $m\{110\}$, $a\{100\}$, $M\{1\bar{1}0\}$, $g\{504\}$, $f\{605\}$, $e\{706\}$, $d\{12.0.11\}$, $t\{101\}$, $p\{111\}$.

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.

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]

[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