UNGEMACHITE AND CLINO-UNGEMACHITE: NEW MINERALS FROM CHILE

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ABSTRACT

Ungemachite. System and lattice, hexagonal—*R;* class, rhombohedral—$\bar{3}$; $a:c=1:2.2966$; $\alpha=62°51\frac{1}{2}'$; 32 forms. Habit, thick tabular {0003}{111}. Space group C_{3i}^2—$R\bar{3}$. Hexagonal cell dimensions: $a_0=10.84\pm0.02$ Å, $c_0=24.82\pm0.05$ Å; $a_0:c_0=1:2.290$. Rhombohedral cell dimensions: $a_{rh}=10.37$ Å; $\alpha=62°59\frac{1}{2}'$. $V_{rh}=842$ cubic Å; $M_{rh}=1167$; contains $Na_8(K, Fe''')_4(OH)_2(SO_4)_6\cdot 10H_2O$. Cleavage {0003}{111}, perfect and easy. Brittle; fracture irregular, with glassy luster. Hardness, $2\frac{1}{2}$. Density, 2.287 ± 0.003. Colorless to yellowish; transparent. Uniaxial, negative. Indices of refraction (Na): $\omega=1.502\pm0.002$, $\epsilon=1.449\pm0.002$. Soluble in weak HCl. Analysis: Na_2O 21.61, K_2O 11.35, Fe_2O_3 7.69, SO_3 40.23, H_2O 16.69, N_2O_5 trace, insol. 2.07 = 99.64. Composition, $Na_4(K, Fe''')_2(OH)(SO_4)_3\cdot 5H_2O$. Occurs with sideronatrite in massive altered iron sulphates at Chuquicamata, Chile. Named in memory of Henri Léon Ungemach [1880–1936] of Strasbourg.

Clino-ungemachite. System and lattice, monoclinic—*F;* $a:b:c=1.6327:1:1.7308$; $\beta=110°40'$; 24 forms; the simple lattice is pseudo-rhombohedral, like that of ungemachite but definitely different. Visibly indistinguishable from ungemachite. Remaining properties not determinable for lack of material.

INTRODUCTION

In 1935 one of us (Bandy) spent four months in northern Chile collecting minerals for the United States National Museum and the Mineralogical Museum of Harvard University. The visit proved highly productive, yielding over a ton of material which consists mainly of specimens of the many natural salts of copper and iron for which the rainless region of Chile is famous. A number of well-known species are represented in the collection, also some rare species and a few that are certainly new. The collection was divided between the interested institutions and rapidly studied, first in Washington and later in Cambridge, in collaboration with the resident mineralogists.

The present paper concerns a pair of the new minerals which were studied in the Harvard Laboratory under the direction of Professor Charles Palache. In this work we were assisted in various ways by Doctor Berman, Doctor West and Mr. Gonyer, and especially by Professor Palache, who took a large part in the morphological study.

The two new species are much alike, consequently they were not at once distinguished; furthermore, their general properties appeared to agree with those given for an artificial salt identified with the mineral loweite—$Na_2SO_4\cdot MgSO_4\cdot 2\frac{1}{2}H_2O$. When the analysis of the more abundant substance gave a composition unlike that of any known salt it was

clear that we were dealing with a new mineral species. For this mineral, which is rhombohedral, we propose the name *ungemachite*, in memory of Henri Léon Ungemach [1880–1936] of Strasbourg, whose life-long devotion to crystal morphology has enriched the literature of descriptive mineralogy with many detailed studies, almost the last of which was an outstanding contribution (1935 A) on the natural sulphates of Chile. The rarer of the two new minerals appears to differ from ungemachite mainly in its symmetry, which is monoclinic; it is therefore named *clino-ungemachite*.[1]

Geometrical Relations in the Hexagonal System

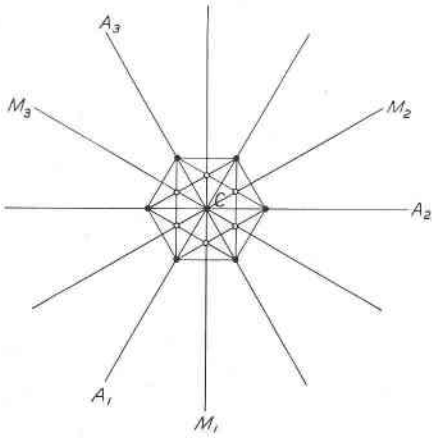
Goldschmidt's treatment of the hexagonal system, involving the alternative settings G_1 and G_2, has given rise to ambiguities which have led to wide-spread difficulty and confusion.[2] In working out the morphology of ungemachite it was found that these ambiguities disappeared if only the G_1 setting is used and certain simple changes are made in the orientation of the polar axes and prime meridian. The resulting presentation is then completely consistent and in entire agreement with that used in the standard works of reference.

The hexagonal system, in the wide sense, comprises all crystals with a hexagonal or rhombohedral lattice. The rhombohedral lattice is a "centered" hexagonal lattice obtained by systematically adding two lattice points on a long body- diagonal of each hexagonal cell, as shown in the plan (Fig. 1) and the inclined view (Fig. 3). In accordance with accepted convention the hexagonal (Bravais) axes $A_1\ A_2\ A_3\ C$ and the rhombohedral (Miller) axes $M_1\ M_2\ M_3$ take the directions shown. If we denote the simple (primitive) hexagonal lattice as hexagonal—P and the centered (rhombohedral) hexagonal lattice as hexagonal—R, and add the axial ratio $a:c$, which is common to both, the mode of the lattice and its geometrical form are completely defined.

The plan (Fig. 2) and inclined view (Fig. 4) show the corresponding reciprocal (polar) lattice in proper relative positions. The reciprocal rhombohedral lattice is obtained from the reciprocal hexagonal lattice by systematically omitting two points out of every three, as shown. The hexagonal polar axes $P_1\ P_2\ R$ (normals to the faces of the direct hexagonal lattice cell) and the rhombohedral polar axes $H\ K\ L$ (normals to the faces of the direct rhombohedral lattice cell) take the directions indicated; and again the lattice is correctly defined by a symbol indicating the lattice mode and the common polar axial ratio $p_0:r_0$.

[1] The word is purposely hyphenated to break the succession of vowels.

[2] These have been pointed out again by Parsons (1937).



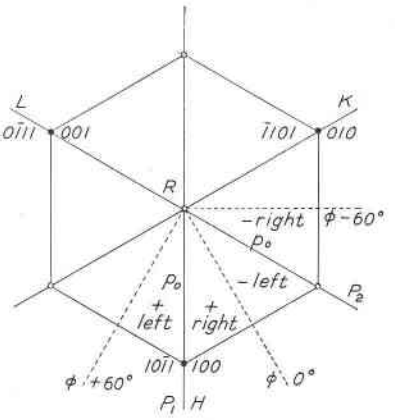
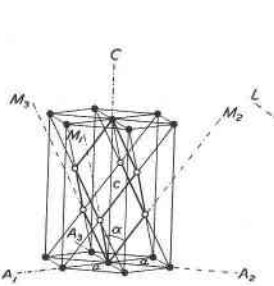


FIG. 1 (left). The direct hexagonal lattice in plan, showing the directions of the linear hexagonal (Bravais) axes $A_1\,A_2\,A_3\,C$ and the linear rhombohedral (Miller) axes $M_1\,M_2\,M_3$. The filled points are the points of the simple hexagonal lattice; the blank points are the additional points of the rhombohedral lattice.

FIG. 2 (right). The reciprocal hexagonal lattice in plan, showing the directions of the reciprocal hexagonal axes $P_1\,P_2\,R$, the reciprocal rhombohedral axes $H\,K\,L$, and the recommended position of the prime meridian ($\phi=0°$). The plane of the figure is the plane of the first layer of the hexagonal reciprocal lattice (the plane of the gnomonic projection). The filled points are rhombohedral reciprocal lattice points ($h+i+l=3n$); the blank points are hexagonal reciprocal lattice points ($h+i+l\neq 3n$) which vanish in the rhombohedral lattice.



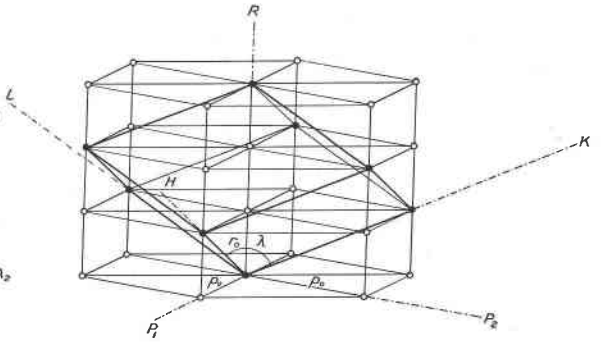


FIG. 3 (left). Inclined view corresponding to Fig. 1, showing also the axial lengths a, c, of the direct hexagonal-rhombohedral lattice and the axial angle α of the rhombohedral lattice.

FIG. 4 (right). Inclined view corresponding to Fig. 2, showing also the axial lengths p_0, r_0 of the reciprocal hexagonal-rhombohedral lattice and the axial angle λ of the reciprocal rhombohedral lattice. Figures 1–4 represent the lattice of ungemachite.

Alternatively the rhombohedral lattice may be defined by the direct rhombohedral axial angle, $M_1 : M_2 = \alpha$ (Fig. 3), or by the reciprocal rhombohedral axial angle, $H : K = \lambda$ (Fig. 4). The four equivalent geometrical elements are related to the fundamental angle $\rho = (0001) : (10\bar{1}1)$ by the equations:

$$p_0 : r_0 = \tan \rho : 1$$
$$\sin \tfrac{1}{2}\lambda = \tfrac{1}{2}\sqrt{3}.\ \sin \rho$$
$$a : c = 1 : \tfrac{1}{2}\sqrt{3}.\ \tan \rho$$
$$\tan \tfrac{1}{2}\alpha = \sqrt{3}.\ \cos \rho$$

A rhombohedral lattice plane is correctly denoted by the Bravais symbol $(h\ k\ \bar{\imath}\ l)$ where $h\ k\ l$ are the co-ordinates of the corresponding reciprocal lattice point on the polar axes $P_1\ P_2\ R$ and $i = h + k$. The hexagonal reciprocal lattice points which vanish in the rhombohedral reciprocal lattice are those whose co-ordinates are such that $h + i + l$ is not divisible by three; therefore it is clearly necessary to denote rhombohedral crystal planes by symbols that satisfy the law[3] $h + i + l = 3n$. Rhombohedral lattice planes may also be denoted by the Miller symbol $(h\ k\ l)$, where $h\ k\ l$ are the co-ordinates of the corresponding reciprocal lattice point on the polar axes $H\ K\ L$; and since the rhombohedral lattice is a primitive lattice the Miller indices are not subject to any extinction law. The indices $h\ k\ l$ (Bravais) and $h\ k\ l$ (Miller) are related by the transformation formula:[4]

Bravais to Miller: $\frac{2}{3}\frac{1}{3}\frac{1}{3}/\frac{\bar{1}}{3}\frac{1}{3}\frac{1}{3}/\frac{\bar{1}}{3}\frac{\bar{2}}{3}\frac{1}{3}$
Miller to Bravais: $1\bar{1}0/01\bar{1}/111$

When the hexagonal projection axes $P_1'\ P_2'$ are drawn parallel to the hexagonal polar axes $P_1\ P_2$ on the plane of the gnomonic projection (the plane of the first layer of the reciprocal hexagonal lattice), then the co-ordinates $p_1 p_2$ of any face-pole in the double sextant enclosed by the positive Bravais axes $A_1\ A_2$ are related to the corresponding Bravais and Miller indices as follows:

$$p_1 = h/l;\ p_2 = k/l \text{ (Bravais)}$$

$$p_1 = (h-k)/(h+k+l);\ p_2 = (k-l)/(h+k+l) \text{ (Miller)}$$

The Miller indices may be read directly from the gnomonic projection by a simple method given by Barker (1922, p. 80).

Finally, if we place the prime meridian midway between the positive axes $P_1\ P_2$ then the face-poles with $\phi = 0°$ to $+60°$ represent positive

[3] This is Ungemach's (1935 B) convenient form of the law governing the four-index symbols of rhombohedral planes.

[4] Written in the correct fractional form, as suggested by J. D. H. Donnay.

forms and face-poles with $\phi = 0°$ to $-60°$ represent negative forms, in accord with accepted convention. The positive and negative sextants divide into right and left half-sextants, permitting the maximum differentiation required in the lowest symmetry classes of the hexagonal system.

The treatment outlined is essentially the G_1 treatment of Goldschmidt with necessary changes in the positions of the axes P_1 P_2 (P_1' P_2') and the prime meridian, arising from a clear recognition of the fact that the elements, symbols and angles must be interconsistent in the polar and linear presentations.

Ungemachite

Morphology. The crystals of ungemachite occur singly or in groups of parallel individuals, associated with sideronatrite in friable massive altered iron sulphates from Chuquicamata, Chile. The single crystals are mostly less than 1 mm. in size, colorless or yellowish, distinctly rhombohedral in habit with a large base and numerous narrow faces developed on all the free sides. The crystals are easily brought into accurate adjustment by polar setting of the excellent basal reflection, the truncating faces falling mainly into three radial zones clearly revealing a three-fold, but not a six-fold symmetry axis. The symmetry class was determined from the relations of the third order terminal planes on both the upper and lower sides of single crystals. In several cases such planes were repeated only by the three-fold axis and an inversion center. This minimum symmetry was found sufficiently often to determine the class as rhombohedral—$\bar{3}$, in which the general form is the rhombohedron of the third order.

The gnomonic projection of the observed forms of ungemachite (Fig. 5) clearly shows that the lattice is rhombohedral. This may be seen in a qualitative way in the complete dissimilarity of adjacent vertical zones of first order forms; more definitely the rhombohedral character of the lattice is shown by the fact that the majority of the hexagonal face-symbols (Table 1) conform to the rhombohedral centering law: $h+i+l=3n$. The symbols of only four out of the thirty-two forms, namely $c\{0003\}$, $m\{30\bar{3}0\}$, $J\{0.3.\bar{3}.12\}$, $L\{03\bar{3}9\}$, must be written in the multiple form to meet the rhombohedral requirement.

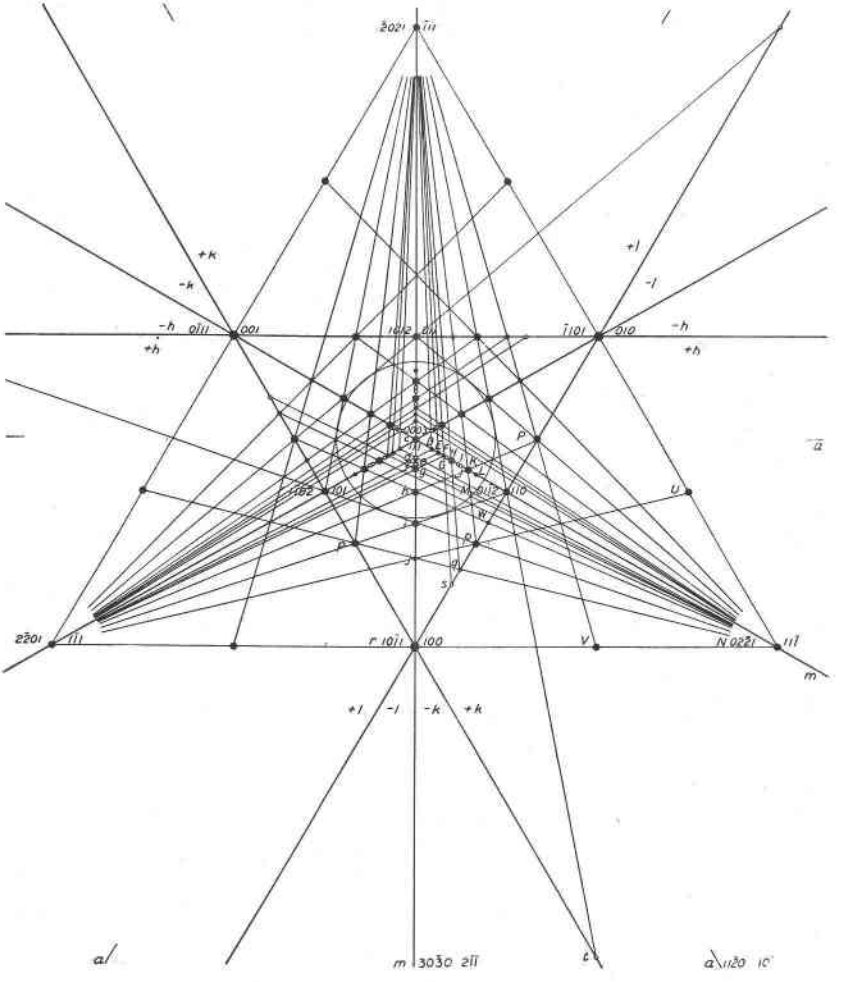


FIG. 5. Ungemachite. Gnomonic projection of the observed forms. The regions separated by the zone line (100)—(010), (010)—(001), (001)—(100) are appropriately marked $+h$, $-h$, $+k$, $-k$, $+l$, $-l$, to facilitate reading the Miller indices from the projection.

TABLE 1. UNGEMACHITE: FORMS AND ANGLES
Hexagonal—R; Rhombohedral—$\bar{3}$

$a:c=1:2.2966$; $\alpha=62°51\frac{1}{2}'$. $p_0:r_0=2.6519:1$; $\lambda=108°15\frac{1}{2}'$

Forms	Bravais	Miller	No. of Faces	Measured				Calculated	
				Range		Mean			
				ϕ	ρ	ϕ	ρ	ϕ	ρ
Basal pinakoid:									
c	0003	111	14	—	—	—	0°00′	—	0°00′
Hexagonal prism of the first order:									
m	$30\bar{3}0$	$2\bar{1}\bar{1}$	4	—	—	30°00′	90 00	30°00′	90 00
Hexagonal prism of the second order:									
a	$11\bar{2}0$	$10\bar{1}$	16	—	—	0 00	90 00	0 00	90 00
Positive rhombohedrons of the first order:									
b	$1.0.\bar{1}.13$	544	1	—	—	30 00	11 30	30 00	11 32
d	$2.0.\bar{2}.23$	977	1	—	—	30 00	12 56	30 00	12 59½
e	$1.0.\bar{1}.10$	433	2	—	—	30 00	14 49	30 00	14 51
f	$2.0.\bar{2}.17$	755	1	—	—	30 00	17 10	30 00	17 19½
g	$10\bar{1}7$	322	15	—	17′	30 00	20 45½	30 00	20 45
k	$4.0.\bar{4}.19$	955	1	—	—	30 00	29 25	30 00	29 10½
h	$10\bar{1}4$	211	19	—	15	30 00	33 31	30 00	33 32½
i	$20\bar{2}5$	311	7	—	15	30 00	46 45	30 00	46 41½
j	$40\bar{4}7$	511	3	—	—	30 00	56 40	30 00	56 34½
r	$10\bar{1}1$	100	28	—	24	30 00	69 21	30 00	69 20½
Negative rhombohedrons of the first order:									
D	$0.1.\bar{1}.11$	443	5	—	23	−30 00	13 33½	−30 00	13 33½
E	$01\bar{1}8$	332	3	—	37	−30 00	18 26	−30 00	18 20½
F	$0.2.\bar{2}.13$	553	2	—	—	−30 00	22 05	−30 00	22 11½
G	$0.4.\bar{4}.23$	995	1	—	—	−30 00	24 50	−30 00	24 45½
H	$01\bar{1}5$	221	7	—	10	−30 00	27 55	−30 00	27 56½
I	$0.4.\bar{4}.17$	773	1	—	—	−30 00	32 00	−30 00	31 58
J	$0.3.\bar{3}.12$	552	1	—	—	−30 00	33 17	−30 00	33 32½
K	$02\bar{2}7$	331	8	—	10	−30 00	37 05	−30 00	37 09
L	$03\bar{3}9$	441	4	—	26	−30 00	41 41	−30 00	41 28½
M	$01\bar{1}2$	110	27	—	51	−30 00	52 53	−30 00	52 58½
N	$02\bar{2}1$	$11\bar{1}$	16	—	23	−30 00	79 19	−30 00	79 19½
Right rhombohedron of the second order:									
p	$11\bar{2}3$	210	21	—	17	0 00	56 50½	0 00	56 51
Left rhombohedron of the second order:									
P	$2\bar{1}\bar{1}3$	201	13	—	20	60 00	56 51	60 00	56 51

TABLE 1.—(*Continued*)

Forms	Bravais	Miller	No. of Faces	Measured				Calculated	
				Range		Mean			
				ϕ	ρ	ϕ	ρ	ϕ	ρ
Positive right rhombohedrons of the third order:									
q	$21\bar{3}4$	310	3	6	7	10 51	60 20	10 53½	60 18½
s	$31\bar{4}5$	410	1	—	—	16 06	62 31	16 06	62 23½
t	$21\bar{3}1$	$20\bar{1}$	2	18	6	10 45	81 57	10 53½	81 53
Negative right rhombohedron of the third order:									
U	$\bar{1}3\bar{2}2$	$12\bar{1}$	8	18	11	−49 05	74 06	−49 06½	74 05½
Negative left rhombohedrons of the third order:									
V	$12\bar{3}2$	$21\bar{1}$	6	15	12	−10 51	74 08	−10 53½	74 05½
W	$12\bar{3}5$	320	2	24	7	−10 40	54 35	−10 53½	54 31½

The unit rhombohedron $\{10\bar{1}1\}$ $\{100\}$ was chosen to correspond to the unit cell of the structural lattice. The geometrical form of the lattice being known, criteria were apparent in the gnomonic projection which would have led to the same choice had they been clearly recognized. The most direct is afforded by the characteristic interrupted Bravais symbol series in the main radial zone $[c\ m]$, of which more will be said on another occasion. Two further indications can be obtained by analogy with the usual distribution of forms on a simple lattice. In such cases the axial zones, $[a\ b]$, $[b\ c]$, $[c\ a]$, are normally the strongest zones while the radial zone-bundles through the poles of the planes of the unit pyramidal form are the strongest that can be drawn. In the rhombohedral lattice, which is a simple lattice, the axial zones are those joining the upper three poles of the primitive rhombohedron and forming an equilateral triangle whose center is at the center of the projection; the poles of the unit form $\{11\bar{1}\}$ lie at the apices of the inverted circumscribed equilateral triangle whose sides are twice as long as those of the primitive triangle. Inspection of the projection (Fig. 5) shows that with these criteria we would choose $r\{10\bar{1}1\}\{100\}$ as the unit rhombohedron since the zones through the three poles of r, each with ten face-points, are the strongest of their kind. Independently we would select $N\{02\bar{2}1\}\{11\bar{1}\}$ as the unit "pyramidal" form since its poles are the nodes of the strongest zone-bundles through first order rhombohedral face-points.

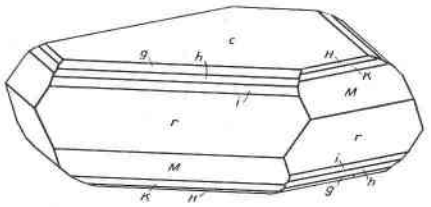
With this choice of primitive rhombohedron the mean measurements on the common forms lead to the reciprocal (polar) elements:

$$p_0 : r_0 = 2.6519 : 1;\ \lambda = 108°15\tfrac{1}{2}',$$

giving the direct (linear) elements:

$$a:c = 1:2.2966;\ \alpha = 62°51\tfrac{1}{2}'.$$

Table 1 gives a summary of the measurements on eleven crystals of ungemachite together with the two-circle angles calculated from the above elements. The generally excellent agreement between the mean measured and calculated angles show that the crystals approach geometrical perfection with unusual closeness.



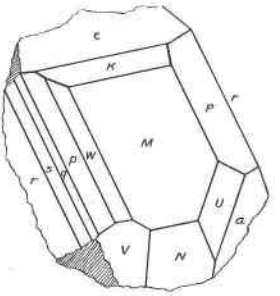


FIG. 6 (left). Ungemachite. Crystal of usual habit.
FIG. 7 (right). Ungemachite. Crystal fragment showing unusual development of third order rhombohedral planes.

The crystals of ungemachite are very uniform in habit (Fig. 6); they are usually bounded by a large base and complex series of positive and negative rhombohedrons of the first order, accompanied by a short prism of the second order and the right and left rhombohedrons of the second order. Strong development of rhombohedrons of the third order was observed only on one crystal fragment (Fig. 7), which is based on a sketch and measurements by Professor Palache. The most important forms are *r c M;* next in importance are *p h N a g P K U H i V;* the rare forms are *D m L j E q e F t W;* the accessory forms, each seen but once, are *b d f k G I J s.*

Elements and Content of the Structural Cell. The following *x*-ray photographs with copper radiation were made on a small crystal of ungemachite: basal Laue; rotation about the three-fold axis; zero-layer and second-layer Weissenberg about the three-fold axis. The Laue photograph clearly showed the symmetry of the three-fold axis and the absence of vertical symmetry planes, in keeping with the rhombohedral class. The rotation photograph showed eleven serviceable layer lines giving a good value for the principal lattice period, c_0. The zero-layer Weissenberg photograph showed the trigonal symmetry with very weak reflections from the first, third, fifth and seventh orders and strong reflections from the second, fourth and sixth orders of $(11\bar{2}0)$ which were used for determining a_0.

Reciprocal lattice projections of the Weissenberg photographs showed only the points of the rhombohedral lattice ($h+i+l=3n$, hexagonal notation). As there are only two space groups in the rhombohedral class (hexagonal tetartohedry of the second kind—Schoenflies), the hexagonal space group $C_{3i}^1-C\bar{3}$, and the rhombohedral space group $C_{3i}^2-R\bar{3}$, the space group of ungemachite is definitely determined as $C_{3i}^2-R\bar{3}$. It is interesting to note that the morphology alone, which clearly reveals the rhombohedral lattice, also gives the space group in the present favorable case.

The elements of the hexagonal (triple) cell are:

$$a_0=10.84\pm0.02 \text{ Å}, \; c_0=24.82\pm0.05 \text{ Å}; \; a_0:c_0=1:2.290.$$

The ratio of the cell edges agrees well with the morphological ratio, $a:c=1:2.2966$. The calculated elements of the rhombohedral (simple) cell are:

$$a_{rh}=10.37 \text{ Å}; \; \alpha=62°59\tfrac{1}{2}'$$

in which the rhombohedral axial angle compares closely with the morphologically determined angle, $\alpha=62°51\frac{1}{2}'$. The volume of the rhombohedral cell is:

$$V_{rh}=842 \text{ cubic Å}$$

The density of ungemachite, measured by flotation, is:

$$d=2.287\pm0.003$$

The molecular weight of the rhombohedral cell is therefore:

$$M_{rh}=1167$$

TABLE 2. UNGEMACHITE: ANALYSIS AND CELL CONTENT

$M_{rh}=1167$

	1	2	3	4		
Na_2O	21.61	22.15	21.6	Na	8.34	
K_2O	11.35	11.63	12.3	K	2.88	4.03
Fe_2O_3	7.69	7.88	7.0	Fe'''	1.15	
SO_3	40.23	41.23	41.8	S	6.01	
H_2O	16.69	17.11	17.3	H	22.18	
N_2O_5	trace	—	—	O	36.28	
Insoluble	2.07	—	—		—	
	99.64	100.00	100.0			

A sample of ungemachite was prepared by Dr. Berman and analyzed by Mr. Gonyer, with the result given in Table 2, in which column 1 gives the reported percentage weights, column 2 the percentage weights reduced to 100 per cent after deducting the insoluble portion, column 4

the number of each kind of atom in the unit cell, as obtained from the determined molecular weight of the cell. Column 3 gives the percentage weights corresponding to the deduced cell formula, K:Fe''' being taken as 3:1. The close approach to whole numbers in the last column is satisfactory. The unit cell of ungemachite therefore contains:[5]

$$Na_3\,(K,\,Fe''')_4\,(OH)_2\,(SO_4)_6\cdot 10H_2O, \text{ or}$$
$$2[Na_4\,(K,\,Fe''')_2\,(OH)(SO_4)_3\cdot 5H_2O]$$

in which K:Fe''' is about 3:1. To be sure that ferric oxide is not derived from the very slight amount of impurity contained in the sample, a minute crystal fragment, which appeared water-clear and quite free from foreign substance under the microscope, was tested for ferric iron; the result was strongly positive.

The composition of ungemachite does not compare with that of any sulphate described in Groth (1908) or Mellor (1922); in a system of mineralogy it will therefore appear with the basic hydrous alkali sulphates without close relatives.

Physical and Optical Properties. Ungemachite has a perfect and easy basal cleavage. The hardness is $2\frac{1}{2}$. The crystals are brittle, breaking with an irregular fracture showing a glassy luster. The mineral is uniaxial, optically negative with strong double refraction: $\omega(\text{Na}) = 1.502 \pm 0.002$, $\epsilon(\text{Na}) = 1.449 \pm 0.002$. Except for slight turgid inclusions the crystals dissolve completely in weak HCl.

Clino-ungemachite

Among the crystals selected for measurement were a few that were outwardly indistinguishable from ungemachite but gave gnomonic projections of a distorted trigonal character. The distortion was such that the three poles corresponding to the upper faces of the rhombohedron $r\{100\}$ of ungemachite formed an isosceles triangle, two of the poles having a polar distance $2\frac{1}{2}°$ greater than the third, which lay sensibly at the same angle as in ungemachite. Furthermore a feeble zone was found whose axis was inclined a degree or so to the vertical. Several crystals of this sort were found, each showing precisely the same amount of departure from the rhombohedral form, an amount many times greater than the greatest variation in the measured angles of ungemachite.

[5] In a summary of the properties of ungemachite and clino-ungemachite (1936) the cell formula is in error, (SO_3) being written instead of (SO_4); this error was corrected in a second notice (1937). The erroneous formula has unfortunately been repeated by Spencer (1937 A, 1937 B).

As pointed out by Dr. Berman, the structural equivalence of K and Fe''' implied by this formula is improbable; this would be avoided by writing the cell content as:

$$Na_8K_3Fe'''(OH)_2(SO_4)_6\cdot 10\ H_2O.$$

TABLE 3. CLINO-UNGEMACHITE: FORMS AND ANGLES
Monoclinic—*F*; Prismatic—2/*m*

$a:b:c=1.6327:1:1.7308$; $\beta=110°40'$
$r_2:p_2:q_2=0.6175:0.6546:1$; $\mu=69°20'$

Forms	No. of Faces	Measured		Calculated	
		ϕ_2	ρ_2	ϕ_2	ρ_2
c 001	4	69°20′	90°00′	69°20′	90°00′
b 010	1	— —	0 00	— —	0 00
a 100	6	0 00	90 00	0 00	90 00
m 110	2	0 01	33 10	0 00	33 12½
d 012	2	69 18½	50 52	69 20	51 00
e 011	2	69 17½	31 43½	69 20	31 42
f 101	2	33 21	90 00	33 30½	90 00
g $\bar{1}02$	3	100 43	90 00	100 43	90 00
h $\bar{1}01$	2	127 05	90 00	127 05	90 00
k 113	1	52 56	65 20	52 57	65 16½
p 111	5	33 28	46 18½	33 30½	46 18
l 331	1	14 23	36 50	14 49	36 57½
n $\bar{1}13$	1	90 08	60 00	90 01½	60 01
o $\bar{1}11$	4	127 05	35 55½	127 05	35 54½
q $\bar{3}31$	1	161 49	31 31	161 41½	31 30½
r $\bar{3}15$	2	106 48	71 36½	106 50	71 40
s 131	2	33 23½	19 14½	33 30½	19 13½
t $\bar{1}0.1.10$	1	127 02	81 58	127 05	82 08½
u $\bar{3}13$	1	127 06	65 22	127 05	65 17
v $\bar{1}31$	1	127 02	13 26	127 05	13 34½
w 533	1	23 45	55 06	23 49	55 03
x 211	1	20 08	58 17	20 43½	58 31
y $\bar{3}11$	1	161 37	61 30	161 41½	61 28
z 811	1	6 10	79 42	6 03	79 40

Professor Palache examined such a projection and saw that it represented a tilted monoclinic crystal which could be placed in a possible crystallographic position by setting the slightly inclined vertical axis upright. Two monoclinic crystals were then measured and projected with reference to the two-fold symmetry axis, which corresponds to the edge $(100)/(111)=[0\bar{1}1]$ of the pseudo-rhombohedron. It was then found

that a preferable setting would be obtained by swinging the pseudo-rhombohedron forward about the two-fold symmetry axis until the upper front face stood vertically, the pseudo-rhombohedral faces (100), (010), (001), (111), receiving, in simplest terms, the monoclinic symbols (100), ($\bar{1}$11), ($\bar{1}\bar{1}$1), (001), respectively. In this setting the elements, forms and angles of clino-ungemachite are those given in Table 3 and represented graphically in Fig. 8.

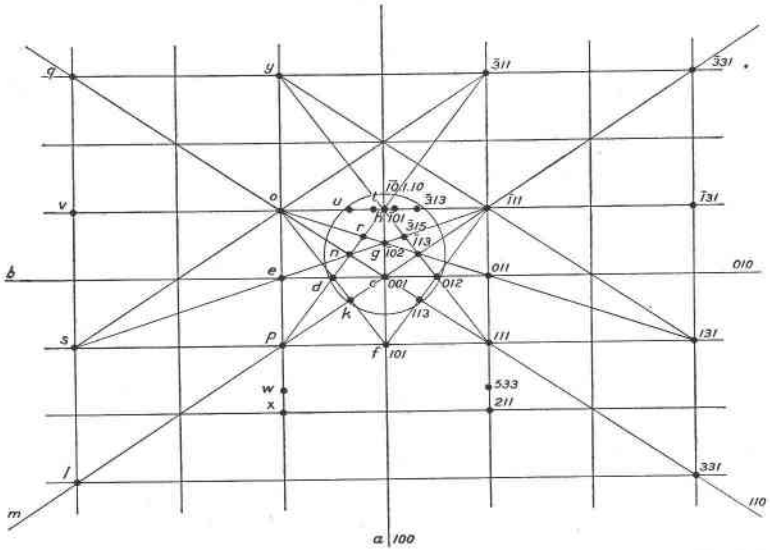


FIG. 8. Clino-ungemachite. Gnomonic projection of the observed forms showing the characteristic absence of planes due to all-face-centering of the lattice.

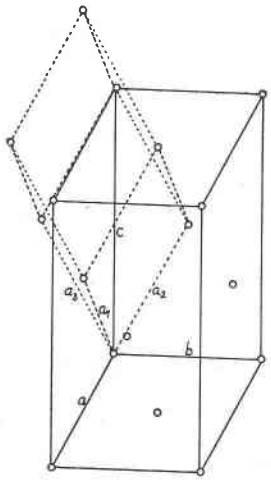
Later study of the geometrical relations of ungemachite and clino-ungemachite showed that the chosen setting of clino-ungemachite results in an all-face-centered monoclinic lattice cell, as shown in Fig. 9. The reversible transformations, with reference to the pseudo-rhombohedral lattice as the simple crystal lattice, are:

Pseudo-rhombohedral to monoclinic: $2\bar{1}\bar{1}/01\bar{1}/011$
Monoclinic to pseudo-rhombohedral $\frac{1}{2}0\frac{1}{2}/0\frac{1}{2}\frac{1}{2}/0\frac{\bar{1}}{2}\frac{1}{2}$

It is clear that the equivalence of planes given in the previous paragraph is in reality:

Pseudo-rhombohedral		Monoclinic
(100)	=	(200)
(010)	=	($\bar{1}$11)
(001)	=	($\bar{1}\bar{1}$1)
(111)	=	(002)

and that the monoclinic symbols should conform to the *F*-lattice centering law: *h*, *k*, *l*, all odd or all even. Table 3, in which the indices are retained in their simplest form, shows that the symbols of the majority of the general planes do conform to the above condition. Figure 8 likewise shows the systematic omission of points which do not meet the *F*-condition, more clearly in the outer field of the projection where the first layer reciprocal lattice pattern is unobscured by gnomonic points which properly belong to higher reciprocal lattice levels.



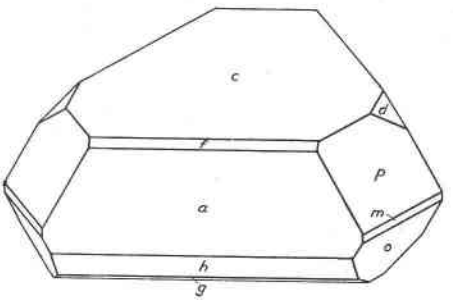


FIG. 9 (left). Clino-ungemachite. Morphological lattice showing the pseudo-rhombohedral simple cell (axes a_1 a_2 a_3) in relation to the all-face-centered monoclinic cell (axes *a b c*).

FIG. 10 (right). Clino-ungemachite. Typical pseudo-rhombohedral crystal.

Since an all-face-centered monoclinic lattice can always be referred to a one-face-centered monoclinic cell, the effect of such a transformation was considered in the present case. It was found, however, that a change either to the *A*-cell or to the *C*-cell resulted in a setting of the crystal which concealed the striking resemblance to a crystal of ungemachite. The *F*-lattice cell is therefore retained.

As in the case of ungemachite the agreement between calculated and measured angles is very good, even in the case of the single observations. Of the twenty-four forms on clino-ungemachite, seventeen correspond to observed forms on ungemachite; the common forms on clino-ungemachite are also important forms on ungemachite, and thus a typical monoclinic crystal (Fig. 10) looks much like an average rhombohedral crystal tilted forward in the described manner.

In Table 4 are given the symbols and angles for some of the principal corresponding faces on the two species. The differences in the corresponding angles range from half a minute between *cr* on ungemachite and *ca* on clino-ungemachite to 4°46½′ between *cM* and *ch*, clearly proving the crystallographic individuality of the monoclinic species.

TABLE 4. UNGEMACHITE AND CLINO-UNGEMACHITE: CORRESPONDING SYMBOLS AND ANGLES

Ungemachite	Clino-ungemachite
$c(111)$: $h(211) = 33°32\frac{1}{2}'$	$c(001)$: $f(101) = 35°49\frac{1}{2}'$
: $r(100) = 69\ 20\frac{1}{2}$	: $a(100) = 69\ 20$
: $H(122) = 27\ 56\frac{1}{2}$	: $g(\bar{1}02) = 31\ 23$
: $M(011) = 52\ 58\frac{1}{2}$	: $h(\bar{1}01) = 57\ 45$
: $M(110) = 52\ 58\frac{1}{2}$	: $p(111) = 54\ 06\frac{1}{2}$
: $N(11\bar{1}) = 79\ 19\frac{1}{2}$	: $m(110) = 78\ 51\frac{1}{2}$
: $r(010) = 69\ 20\frac{1}{2}$	: $o(\bar{1}11) = 71\ 45\frac{1}{2}$

In all, only six minute crystals of clino-ungemachite were detected; and of these only one remained after some unsuccessful attempts were made to obtain some of their physical and optical properties. There was, therefore, no possibility of analyzing the substance, and the description necessarily remains incomplete. At the same time it seems desirable to place these observations on record so that the mineral may be recognized and more fully described if it should be found again in larger amounts.

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