CRYSTALLOGRAPHY OF COPIAPITE

By
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THIS joint work is the result of interrupted studies which commenced in 1934 when Palache measured a number of crystals of copiapite from Chile and found them to be triclinic with a well developed form-series. In this part of the work the senior author received some assistance from Berman and Wolfe, and also from Peacock, who critically examined the chosen setting in relation to the general problem of choosing triclinic elements from goniometric data, and later made a direct determination of the crystal lattice from single crystal *x*-ray photographs which were kindly prepared by Buerger.

About this time Ungemach's important monograph on the sulphate minerals of Chile (1935) was received. In this detailed work, which includes descriptions of four new minerals and single-circle measurements on five triclinic species, Ungemach also discovered the triclinic symmetry of copiapite and described a most elaborate development of forms. However, it was found that Ungemach had chosen an entirely different setting from the one adopted at Harvard, and that his elements and angles do not agree closely with ours when transformed to our setting. Although Ungemach had given much thought to the setting of copiapite he generously conceded the propriety of the Harvard setting when the results of the *x*-ray measurements were known;[1] however the differences in angles remained and no sufficient explanation for this was immediately apparent.

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[1] The results were transmitted personally to Ungemach in Strasbourg by Donnay, only a few days before Ungemach's untimely death on June 11, 1936. At that time Ungemach also bequeathed his large collection of measured crystals to Donnay, who in turn kindly placed the copiapite crystals at our disposal for further study.

In 1937-8, Berry undertook a study of the crystallography and crystal chemistry of copiapite during his first year of graduate study at Toronto. Peacock collaborated in this work which is described in an unpublished M.A. Thesis (Berry, 1938*a*), but only part of the work, that dealing with Ungemach's "pseudocopiapite" (Berry, 1938*b*), was published. Several abstracts of projected papers on copiapite and matters arising out of the study of that mineral have appeared: one announcing the "Harmonic-Arithmetic Rule" (Peacock, 1937); one giving the new geometrical and structural elements of copiapite (Peacock, 1939); and one on the variation of the composition and optical properties of the mineral (Berry, 1939).

During the past summer Palache returned to copiapite and, with Berry's Thesis and an angle-table by Peacock at hand, computed a complete angle-table for a projected volume of crystallographic tables, and a shorter presentation of the crystallography of the mineral for the second volume of the new *Dana*. When this was done it seemed proper that the previous scattered and interrupted work should be assembled in a single paper on the crystallography of this unusually interesting triclinic species. In the present account Palache is responsible for the measurements and calculations on the crystals from Chuquicamata (Table 1) and the formal angle-table (Table 4), while Peacock has prepared the rest of the paper with much assistance in the formal work by Berry. It is hoped that the results on the composition and optics of copiapite will be presented on another occasion.

EARLIER OBSERVATIONS

When distinctly crystallized, copiapite forms minute translucent yellow plates with perfect cleavage and pearly lustre on the plane of platy development. These plates are often rhombic in outline with principal optical directions practically coinciding with the normal to the plate and the diagonals of the rhomb. Copiapite was therefore considered to be orthorhombic by Bertrand (1881) and Des Cloizeaux (1881) and again by Posnjak & Merwin (1922).

On crystals showing small edge-faces Linck (1889) derived monoclinic elements:

$$a:b:c = 0.4791:1:0.9759;\ \beta = 108° 04'$$

and a series of forms most of which have complex symbols. Linck's

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elements are reproduced in Hintze
(1892, p. 964) gave slightly different
Goldschmidt (1913, p. 187); Schariz
Linck's measurements in an endeavou
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OBSERVATIONS ON CRYSTALS

Two-circle measurements. The tr
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The composite plot from half a
triclinic projection in which nearly all
lie at the nodes of an oblique eccen
which gives the *a*-axis shorter than th
slope to the front and to the right of th
angles gave the projection element
$x_0' = 0.2156, y_0' = 0.1078, \nu = 79° 34'$
elements:

$$p_0 : q_0 : r_0 = 1.0065 : 0.4002 : 1;\ \lambda = 83$$
$$a : b : c = 0.4058 : 1 : 0.4039;\ \alpha = 93$$

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elements are reproduced in Hintze (1930, p. 4,415), while Dana (1892, p. 964) gave slightly different values which were adopted by Goldschmidt (1913, p. 187); Scharizer (1913, p. 384) recomputed Linck's measurements in an endeavour to simplify the symbols, and these recomputed values are given by Doelter (1929, p. 556).

OBSERVATIONS ON CRYSTALS FROM CHUQUICAMATA

Two-circle measurements. The true triclinic symmetry of copiapite was discovered independently at Harvard and at Strasbourg (Alsace), where Ungemach made a thorough re-examination of the material which had been studied by Linck. Some correspondence can be found between Linck's angles and those of Ungemach and the present authors, but there is no doubt that Linck's unnatural crystallography is due to a misconception of the symmetry of copiapite, and that his results should be discarded as erroneous.

The crystals measured in 1934 by Palache were obtained from Chuquicamata, Chile. They are small, often somewhat elongated plates, bevelled by several zones of narrow facets. Of these zones two are particularly strong; they have an average interzonal angle of 77° 48½′ and they tend to give the plates their pseudorhombic appearance. Of these zones, the one with the generally longer edge was chosen as the $(hk0)$-zone, the other as the $(0kl)$-zone, with the plane of flattening and perfect cleavage as (010). These two zones could never be safely distinguished by inspection, and therefore a preliminary measurement with (010) as the pole-face (Berry, 1938*b*, p. 11) preceded the regular two-circle measurement with adjustment on the vertical crystal axis.

The composite plot from half a dozen crystals gave a typical triclinic projection in which nearly all the poles of the terminal faces lie at the nodes of an oblique eccentric net. In the one position which gives the a-axis shorter than the b-axis and makes the c-plane slope to the front and to the right of the a-plane, the mean measured angles gave the projection elements: $p_0' = 1.0353$, $q_0' = 0.4117$; $x_0' = 0.2156$, $y_0' = 0.1078$, $\nu = 79° 34'$ and hence the polar and linear elements:

$$p_0 : q_0 : r_0 = 1.0065 : 0.4002 : 1;\ \lambda = 83° 59',\ \mu = 76° 59\tfrac{1}{2}',\ \nu = 79° 34'$$

$$a : b : c = 0.4058 : 1 : 0.4039;\ \alpha = 93° 50',\ \beta = 102° 10',\ \gamma = 99° 21\tfrac{1}{2}'$$

TABLE 1

COPIAPITE: MEASURED AND CALCULATED ANGLES ON CRYSTALS FROM CHUQUICAMATA

Forms	Measured		Calculated					Obs.
	φ	ρ	φ	ρ	A	B	C	
(001)	63°11′	13°36′	63°26′	13°33′	76°59½′	83°59′	0°00′	5
(010)	0 00	90 00	0 00	90 00	79 34	0 00	83 59	14
(100)	79 34	90 00	79 34	90 00	0 00	79 34	76 59½	10
(110)	59 41	90 00	59 31½	90 00	20 02½	59 31½	76 29	3
$(1\bar{1}0)$	102 33	90 00	102 25	90 00	22 51	102 25	79 30½	8
$(2\bar{3}0)$	112 56	90 00	112 53½	90 00	33 19½	112 53½	81 14½	1
$(1\bar{2}0)$	122 08	90 00	121 59	90 00	42 25	121 59	82 58½	10
$(2\bar{5}0)$	129 45	90 00	129 34½	90 00	50 00½	129 34½	84 33½	1
$(1\bar{3}0)$	135 56	90 00	135 49	90 00	55 35½	135 49	85 55	2
$(1\bar{7}0)$	159 42	90 00	159 18	90 00	79 44	159 18	91 22½	2
(011)	22 35	29 17	22 32½	29 21½	74 31½	63 04½	20 54½	3
(021)	13 08	43 09	13 02	43 42½	74 01½	47 41½	36 17½	1
$(0\bar{1}1)$	144 28	20 36	144 39	20 26	81 32½	106 32½	22 33½	2
$(0\bar{2}1)$	162 40	36 46	163 14	36 46½	86 13	124 58½	40 59½	1
$(0\bar{3}1)$	169 33	49 37	169 10½	48 56	89 41½	137 46½	53 47½	1
(101)	76 15½	51 51½	76 32½	51 45	38 21	79 28	38 38½	2
$(\bar{1}02)$	−86 11	16 04	−87 15	16 22½	105 56	89 13½	28 56½	1
$(\bar{1}01)$	−96 08	38 47½	−95 40½	38 53½	128 44	93 33½	51 44½	6
$(\bar{2}01)$	−97 36	61 22	−98 21	61 29	151 24½	97 20	74 25	3
$(\bar{1}11)$	−67 27	40 53	−67 31½	40 58½	123 24	75 29	50 42½	6
$(\bar{1}\bar{1}1)$	−121 56	43 43	−121 28½	43 15½	129 46	110 58	56 46½	2
$(\bar{1}32)$	−26 22	34 18	−24 55½	34 51½	98 13½	58 47	36 43	1
(121)	44 54	60 18	47 48	59 01	43 12½	54 50½	46 03½	1
(131)	39 13	62 56	38 52½	63 02½	47 29	46 03½	50 53½	1
$(\bar{1}31)$	−34 22	54 55	−34 47	54 35½	109 38½	47 58½	57 35½	1
$(\bar{2}11)$	−87 05	61 06	−85 28	61 18	147 55½	86 01	73 05½	1
$(\bar{4}52)$	−68 16	62 52	−67 17½	63 08	138 19½	69 51½	72 21	1
$(\bar{2}31)$	−63 15	64 25	−62 00½	64 07½	134 49	65 01	72 25½	1
$(\bar{4}72)$	−57 28	64 58	−57 11½	65 13½	131 24½	60 32	72 26	2

The mean measured angles are summ
lated from these elements in Table 1.

Fig. 1 shows a crystal of copiapite fro
tinct elongation in the direction of the
somewhat irregular development of the be
was sketched and measured by Berman
used for the *x*-ray measurements by Peac
tive of the material which was analysed b
given later. Other crystals showed furthe
habit with occasional approach to the ps
crystal from Sierra Gorda shown in Fig.

X-ray measurements. The crystal sho
as for two-circle measurement, to rotate a
cobalt radiation, a rotation photograph
measurement of the *c*-period; a Weissenb
layer line gave the principal spacings, *d*(
angle ν (or γ^*) included by the normals t
a Weissenberg resolution of the first layer-
layer of the reciprocal lattice from which
α^*) and μ (or β^*) were calculated. By me
are now standard practice these quantitie
crystal lattice cell:

$a = 7.33,\ b = 18.15,\ c = 7.27$ kX; $\alpha = 93°51'$

The reciprocal lattice projection of
metrically similar to the gnomonic net of
procedure of choosing the single position
naming its elements is strictly analogous
sing the geometrical projection. It can
edges of the chosen lattice cell are the t
periods of the lattice, and that this cell is
single setting which conforms to the ru
obtuse.

The geometrical and structural axial
Chuquicamata compare as follows:

$a:b:c$	α	β	γ
0.4058 : 1 : 0.4039	93°50′	102°10′	99
0.4037 : 1 : 0.4005	93°51′	101°30′	99

TABLE 1

ASURED AND CALCULATED ANGLES
TALS FROM CHUQUICAMATA

Calculated					Obs.
φ	ρ	A	B	C	
63°26′	13°33′	76°59½′	83°59′	0°00′	5
0 00	90 00	79 34	0 00	83 59	14
79 34	90 00	0 00	79 34	76 59½	10
59 31½	90 00	20 02½	59 31½	76 29	3
102 25	90 00	22 51	102 25	79 30½	8
112 53½	90 00	33 19½	112 53½	81 14½	1
121 59	90 00	42 25	121 59	82 58½	10
129 34½	90 00	50 00½	129 34½	84 33½	1
135 49	90 00	55 35½	135 49	85 55	2
159 18	90 00	79 44	159 18	91 22½	2
22 32½	29 21½	74 31½	63 04½	20 54½	3
13 02	43 42½	74 01½	47 41½	36 17½	1
144 39	20 26	81 32½	106 32½	22 33½	2
163 14	36 46½	86 13	124 58½	40 59½	1
169 10½	48 56	89 41½	137 46½	53 47½	1
76 32½	51 45	38 21	79 28	38 38½	2
−87 15	16 22½	105 56	89 13½	28 56½	1
−95 40½	38 53½	128 44	93 33½	51 44½	6
−98 21	61 29	151 24½	97 20	74 25	3
−67 31½	40 58½	123 24	75 29	50 42½	6
−121 28½	43 15½	129 46	110 58	56 46½	2
−24 55½	34 51½	98 13½	58 47	36 43	1
47 48	59 01	43 12½	54 50½	46 03½	1
38 52½	63 02½	47 29	46 03½	50 53½	1
−34 47	54 35½	109 38½	47 58½	57 35½	1
−85 28	61 18	147 55½	86 01	73 05½	1
−67 17½	63 08	138 19½	69 51½	72 21	1
−62 00½	64 07½	134 49	65 01	72 25½	1
−57 11½	65 13½	131 24½	60 32	72 26	2

The mean measured angles are summarized with angles calculated from these elements in Table 1.

Fig. 1 shows a crystal of copiapite from Chuquicamata with distinct elongation in the direction of the chosen vertical axis and somewhat irregular development of the bevelling zones. This crystal was sketched and measured by Berman and it was subsequently used for the x-ray measurements by Peacock; it is also representative of the material which was analysed by Gonyer with the results given later. Other crystals showed further variations of the tabular habit with occasional approach to the pseudorhombic habit of the crystal from Sierra Gorda shown in Fig. 3.

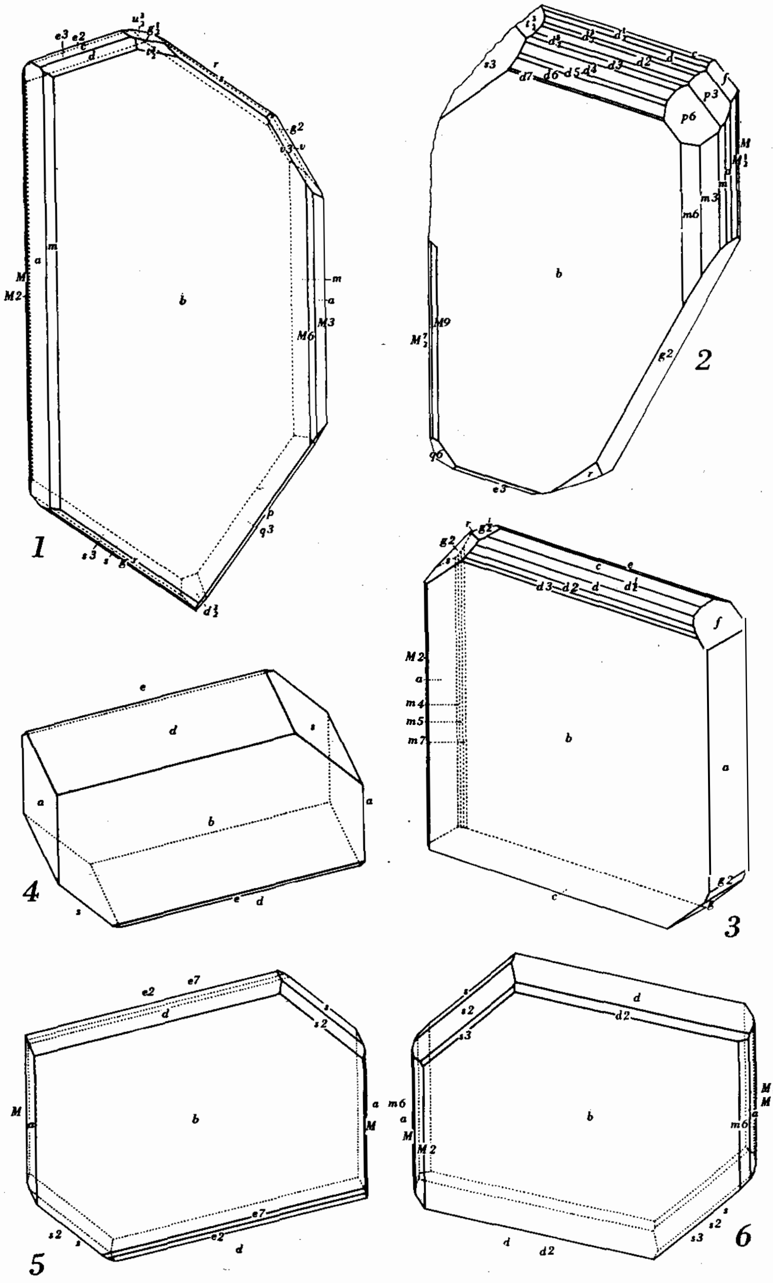
X-ray measurements. The crystal shown in Fig. 1 was adjusted, as for two-circle measurement, to rotate about the long axis. Using cobalt radiation, a rotation photograph was taken giving a direct measurement of the c-period; a Weissenberg resolution of the zero-layer line gave the principal spacings, $d(100)$ and $d(010)$, and the angle ν (or γ^*) included by the normals to these sets of planes; and a Weissenberg resolution of the first layer-line gave the offset of this layer of the reciprocal lattice from which the remaining angles λ (or α^*) and μ (or β^*) were calculated. By methods of calculation which are now standard practice these quantities give the elements of the crystal lattice cell:

$$a = 7.33,\ b = 18.15,\ c = 7.27\ \text{kX};\ \alpha = 93°51',\ \beta = 101°30',\ \gamma = 99°23'$$

The reciprocal lattice projection of the first layer-line is geometrically similar to the gnomonic net of the (hkl) planes, and the procedure of choosing the single position of the x-ray projection and naming its elements is strictly analogous to the procedure in discussing the geometrical projection. It can easily be shown that the edges of the chosen lattice cell are the three shortest non-coplanar periods of the lattice, and that this cell is set in the usually preferred single setting which conforms to the rules: $c < a < b$; α and β obtuse.

The geometrical and structural axial ratios of copiapite from Chuquicamata compare as follows:

$a : b : c$	α	β	γ	
0.4058 : 1 : 0.4039	93°50′	102°10′	99°21½′	(Gon., Palache)
0.4037 : 1 : 0.4005	93°51′	101°30′	99°23′	(X-ray, Peacock)



FIGS. 1-6.—Crystals of copiapite from Ch
material used for 2-circle measurement, x-ray mea
2, 3.—Sierra Gorda; two of Ungemach's crystals r
position. FIGS. 4, 5, 6.—Tierra Amarilla (pseudoc
crystals remeasured and redrawn in new position.
end of the c-axis is directed upward and the crystal
of $b(010)$; in Figs. 2, 3, 6, representing crystals whi
negative end of the c-axis, this end is directed upw
from the direction of $b(0\bar{1}0)$.

The substantial agreement shows that the
tural methods led to one and the same cry

Composition. On this material Berm
gravity 2.154 and Gonyer made the anal

TABLE 2

COPIAPITE: ANALYSIS (GONYER) AN

Analysis		Atoms in Ur		
FeO	0.44	Fe''	0.08	Oxyge
Al_2O_3	1.72	Al	0.41	
Fe_2O_3	27.28	Fe'''	4.18	
SO_3	39.83	S	6.09	
H_2O	29.92	H_2O	20.34	
Insol.	0.55			
	99.74			

The atomic content approaches X(OH
X is one oxygen equivalent of (Fe''', Al) a
fuller discussion of this and other analyse
for the projected paper on the composition

OBSERVATIONS ON CRYSTALS FRO

Ungemach's extensive work on copia
complex crystals from Sierra Gorda. A
with the plane of platy development a
("orientation ancienne") he finally chang
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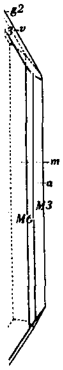
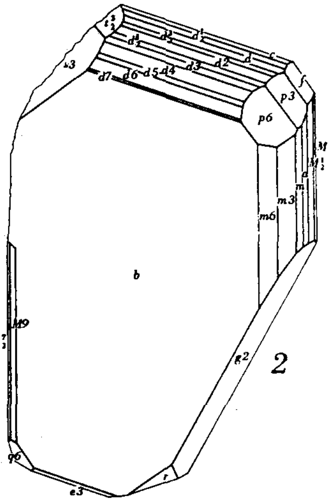
spect Ungemach's final setting resembles





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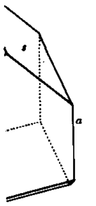

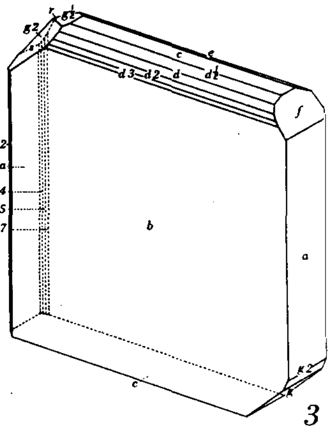

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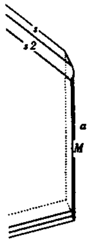

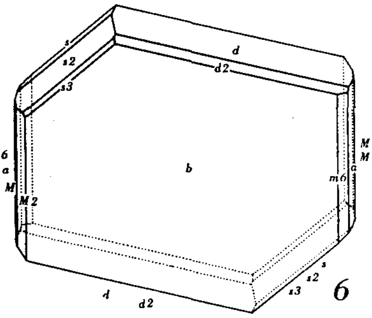

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The substantial agreement shows that the morphological and structural methods led to one and the same crystal lattice cell.

Composition. On this material Berman measured the specific gravity 2.154 and Gonyer made the analysis given in Table 2.

TABLE 2

COPIAPITE: ANALYSIS (GONYER) AND CELL CONTENT

Analysis		Atoms in Unit Cell					
FeO	0.44	Fe''	0.08	Oxygen	0.08	0.70	25.24
Al_2O_3	1.72	Al	0.41		0.62		
Fe_2O_3	27.28	Fe'''	4.18		6.27		
SO_3	39.83	S	6.09		18.27		
H_2O	29.92	H_2O	20.34				
Insol.	0.55						
	99.74						

The atomic content approaches $X(OH)_2Fe'''_4(SO_4)_6.nH_2O$ where X is one oxygen equivalent of (Fe''', Al) and *n* appears to be 19. A fuller discussion of this and other analyses of copiapite is reserved for the projected paper on the composition and optics of the mineral.

OBSERVATIONS ON CRYSTALS FROM SIERRA GORDA

Ungemach's extensive work on copiapite (1935) was done on complex crystals from Sierra Gorda. Adopting at first a setting with the plane of platy development and cleavage as the base ("orientation ancienne") he finally changed to a setting in which this plane is the side pinakoid ("notation définitive"). In this respect Ungemach's final setting resembles ours but otherwise it is

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FIGS. 1-6.—Crystals of copiapite from Chile. FIG. 1.—Chuquicamata; material used for 2-circle measurement, *x*-ray measurement, and analysis. FIGS. 2, 3.—Sierra Gorda; two of Ungemach's crystals remeasured and redrawn in new position. FIGS. 4, 5, 6.—Tierra Amarilla (pseudocopiapite); three of Ungemach's crystals remeasured and redrawn in new position. In Figs. 1, 4, 5 the positive end of the *c*-axis is directed upward and the crystals are viewed from the direction of *b*(010); in Figs. 2, 3, 6, representing crystals which are mainly developed at the negative end of the *c*-axis, this end is directed upward and the crystals are viewed from the direction of $b(0\bar{1}0)$.

radically different. Ungemach's preliminary setting is related to ours by the formula:

Ungemach (prelim.) to Authors: $\frac{1}{2}\frac{\bar{1}}{6}0/001/\frac{\bar{1}}{2}\frac{\bar{1}}{6}0$
Authors to Ungemach (prelim.): $10\bar{1}/\bar{3}0\bar{3}/010$

The final setting of Ungemach stands in no less complicated relation to ours, since it defines a 12-fold cell in the structural lattice (Fig. 7):

Ungemach (final) to Authors: $\frac{1}{2}0\frac{\bar{1}}{6}/\frac{\bar{1}}{2}\frac{\bar{1}}{2}0/\frac{\bar{1}}{2}0\frac{\bar{1}}{6}$
Authors to Ungemach (final): $10\bar{1}/\bar{1}21/\bar{3}0\bar{3}$

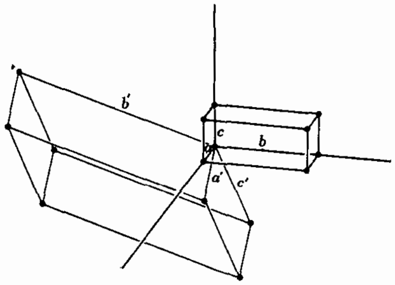

FIG. 7.—Crystal lattice of copiapite showing Ungemach's 12-fold morphological cell with $a'[10\bar{1}]$, $b'[\bar{1}21]$, $c'[\bar{3}0\bar{3}]$, in relation to the unit cell a, b, c, which conforms to the rules $c < a < b$, α and β obtuse.

The complexity of Ungemach's settings is indicated, as in other similar cases, by the weakness of the chosen vertical zone. The axes of weak zones correspond to relatively long lattice periods and if such axes are taken as crystal axes the geometrical elements are likely to define multiple and therefore unsuitable lattice cells. One must admire Ungemach's consummate skill with the single-circle goniometer, but his critical remarks about the two-circle instrument (1935, p. 99) are the less effective when we note that the use of this instrument leads one always to choose the strongest zone axis (usually the shortest lattice period) as the vertical axis, and thus to avoid the unfortunate settings that result from a feeble vertical zone.

The geometrical elements of Ungemach in his final setting:

$$a : b : c = 0.3010 : 1 : 0.7295;\ \alpha = 99°46',\ \beta = 90°30',\ \gamma = 104°21'$$

give the following comparison with the elements of Palache and Peacock when transformed to our setting:

$a : b : c$	α	β
0.4005 : 1 : 0.3971	93°58½′	102°08′
0.4058 : 1 : 0.4039	93°50′	102°10′
0.4037 : 1 : 0.4005	93°51′	101°30′

Ungemach noted 146 forms on copiapit
represented a number of the elaborat
skilful portrait drawings.

By combining Ungemach's geometri
length of the vertical axis, c = 7.27 kX
G = 2.134, both measured by Berry
Ungemach's collection, and using the res
the unit cell content, M = 1212.5, U
material from Sierra Gorda may be expr
the unit cell:

TABLE 3

COPIAPITE: ANALYSIS (UNGEMACH

Analysis			Atoms
Fe_2O_3	31.92	Fe‴	4.85
SO_3	38.89	S	5.89
H_2O	[29.19]	H_2O	19.66
	100.00		

Again the cell content can be expressed as
in which X is one oxygen equivalent of F

In view of the differences between
listed above, which correspond to angu
exceeding half a degree, Peacock meas
crystals which had kindly been made av
reflections obtained were only fair, prob
deterioration of the crystals brought abou
but it was possible to verify nearly all the
on these particular crystals. The measu
worth presenting since so many reflecti
somewhere between the angles calculated

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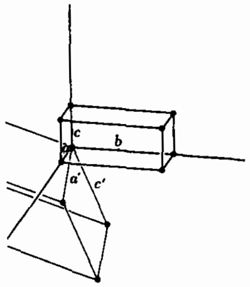
[2] In the warm dry atmosphere of the Mineral
University whole drawers of salts from Chile h
powder with loss of water of crystallization.

ch's preliminary setting is related to

.) to Authors: $\frac{1}{2}\frac{\bar{1}}{6}0/001/\overline{\frac{1}{2}\frac{1}{6}}0$
ach (prelim.): $10\bar{1}/\bar{3}0\bar{3}/010$

nach stands in no less complicated
s a 12-fold cell in the structural lattice

o Authors: $\frac{1}{2}0\frac{\bar{1}}{6}/\frac{\bar{1}}{2}\frac{\bar{1}}{2}0/\frac{\bar{1}}{2}0\frac{\bar{1}}{6}$
ach (final): $10\bar{1}/\bar{1}21/\bar{3}0\bar{3}$



iapite showing Ungemach's 12-fold morpho-
$0\bar{3}$], in relation to the unit cell *a*, *b*, *c*, which
and *β* obtuse.

h's settings is indicated, as in other
s of the chosen vertical zone. The
l to relatively long lattice periods and
tal axes the geometrical elements are
herefore unsuitable lattice cells. One
nsummate skill with the single-circle
narks about the two-circle instrument
tive when we note that the use of this
; to choose the strongest zone axis
eriod) as the vertical axis, and thus to
gs that result from a feeble vertical

of Ungemach in his final setting:
$\alpha = 99°46', \beta = 90°30', \gamma = 104°21'$
n with the elements of Palache and
our setting:

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a : *b* : *c*	*α*	*β*	*γ*	
0.4005 : 1 : 0.3971	93°58½'	102°08'	98°50'	Ungemach
0.4058 : 1 : 0.4039	93°50'	102°10'	99°21½'	Palache
0.4037 : 1 : 0.4005	93°51'	101°30'	99°23'	Peacock

Ungemach noted 146 forms on copiapite from Sierra Gorda, and represented a number of the elaborately developed crystals by skilful portrait drawings.

By combining Ungemach's geometrical cell with the absolute length of the vertical axis, $c = 7.27$ kX, and the specific gravity, $G = 2.134$, both measured by Berry on a typical crystal from Ungemach's collection, and using the resulting molecular weight of the unit cell content, $M = 1212.5$, Ungemach's analysis of his material from Sierra Gorda may be expressed in terms of atoms in the unit cell:

TABLE 3

COPIAPITE: ANALYSIS (UNGEMACH) AND CELL CONTENT

Analysis		Atoms in Unit Cell				
Fe_2O_3	31.92	Fe'''	4.85	Oxygen	7.27	24.94
SO_3	38.89	S	5.89		17.67	
H_2O	[29.19]	H_2O	19.66			
	100.00					

Again the cell content can be expressed as $X(OH)_2Fe'''_4(SO_4)_6.nH_2O$ in which X is one oxygen equivalent of Fe''' and *n* is apparently 19.

In view of the differences between the three sets of elements listed above, which correspond to angular differences sometimes exceeding half a degree, Peacock measured some of Ungemach's crystals which had kindly been made available by Donnay. The reflections obtained were only fair, probably due in part to some deterioration of the crystals brought about by atmospheric changes;[2] but it was possible to verify nearly all the forms noted by Ungemach on these particular crystals. The measurements, which are hardly worth presenting since so many reflections were poor, often fall somewhere between the angles calculated from Palache's and Unge-

---

[2] In the warm dry atmosphere of the Mineralogical Laboratories at Harvard University whole drawers of salts from Chile have unfortunately crumbled to powder with loss of water of crystallization.

mach's elements. It was not felt that these measurements should be given much weight in considering the question of the best geometrical elements for the mineral. Two of the remeasured crystals of Ungemach from Sierra Gorda are shown redrawn in our setting (Figs. 2, 3). Both crystals were more fully developed at the negative end of the c-axis which has therefore been directed upward while the broad face to the front is $b(0\bar{1}0)$.

OTHER OBSERVATIONS

In addition to normal copiapite, Ungemach distinguished an aberrant variety from Tierra Amarilla, Chile, which he named "pseudocopiapite." This material, which was said to have the same composition as normal copiapite, gave triclinic elements differing significantly from those of normal copiapite only in regard to the interaxial angles. Berry (1938*b*) remeasured fifteen crystals of Ungemach's pseudocopiapite and obtained elements which compare as follows with those of Ungemach transformed to our setting:

$a : b : c$	α	β	γ	
0.3938 : 1 : 0.3951	91°18½′	102°04′	98°59′	Ungemach
0.4007 : 1 : 0.4005	91°22′	102°22′	98°50′	Berry

Comparing these values with the previously given elements for normal copiapite one sees that there is now a significant difference only in the interaxial angles α. This difference might be due to an undetected difference in chemical composition which is allowed by variation in the terms X and n of the proposed general formula.

It remains to note some observations on very imperfect crystals of a cuprian copiapite from Chuquicamata, Chile, named *cuprocopiapite* by Bandy (1938). The material consists of tiny packs of minute weakly cohering nearly parallel green plates with the typical rhombic outline of copiapite. The broad face has a pearly lustre and even when freshly cleaved gives only a blurred signal. With the cleavage polar, trains of feeble reflections were obtained from the edges of the rhombic plates. From twelve pairs of measurements the average interzonal angle is 77° 42′, which is close to the interzonal angle [001] : [100] of copiapite, for which Ungemach gives 77° 48½′, Palache 77° 50′. In one of these zones a fair reflection is frequently seen at the mean polar distance B = 84° 13′ as compared to Palache's B = 83° 59′ for (001). In the other zone several signals

gave the mean angle B = 83° 22′ wh
the angle to (100) for which Palache
B = 80° 04½′. Thus the copper salt is
the crystals do not permit a determin

FORMAL CRYSTALLOGRA

Setting, elements, and angles. We
sent the geometrical crystallography
and graphical manner. The crystallo
well established, since it conforms to t
structural lattice in a widely used un
which was accepted for copiapite by

In regard to the choice of th
geometrical elements, we have consid
Palache's values, which agree best w
analysed material from Chuquicam
which accord best with his measureme
Sierra Gorda; (3) average values, whic
results into account. The difference
elements that have been derived for c
to the quality of the crystals which g
tions; probably of greater importance
in chemical composition which will
projected paper on composition and c
better to retain a set of values associ
sition rather than to submerge real v
Since Ungemach's measurements repre
of crystals, and his analysis indic
(X = Fe‴) without monovalent or
cided to adopt these values in our sett
calculated angles (hkl) : (010) also af
corresponding B-angles.

Table 4 gives the adopted element
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statistics and our observations. In a
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HER OBSERVATIONS

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ean polar distance B = 84° 13′ as compared
′ for (001). In the other zone several signals

gave the mean angle B = 83° 22′ which is only roughly similar to the angle to (100) for which Palache gives B = 79° 34′, Ungemach B = 80° 04½′. Thus the copper salt is close to copiapite in form, but the crystals do not permit a determination of the elements.

FORMAL CRYSTALLOGRAPHIC PRESENTATION

Setting, elements, and angles. We are now in a position to present the geometrical crystallography of copiapite in formal tabular and graphical manner. The crystallographic setting is, we believe, well established, since it conforms to the properly chosen cell of the structural lattice in a widely used unique conventional orientation which was accepted for copiapite by Ungemach.

In regard to the choice of the numerical values for the geometrical elements, we have considered several alternatives: (1) Palache's values, which agree best with the measurements on the analysed material from Chuquicamata; (2) Ungemach's values, which accord best with his measurements on analyzed material from Sierra Gorda; (3) average values, which might take Peacock's *x*-ray results into account. The differences between the several sets of elements that have been derived for copiapite may be due in part to the quality of the crystals which generally give only fair reflections; probably of greater importance is the considerable variation in chemical composition which will be further brought out in the projected paper on composition and optics. In that case it will be better to retain a set of values associated with a particular composition rather than to submerge real variation in a general average. Since Ungemach's measurements represent much the largest number of crystals, and his analysis indicates pure ferrian copiapite (X = Fe‴) without monovalent or divalent bases, we have decided to adopt these values in our setting. In this way Ungemach's calculated angles (*hkl*) : (010) also afforded a useful check on our corresponding B-angles.

Table 4 gives the adopted elements and calculated angles for the commoner forms of copiapite as indicated by Ungemach's frequency statistics and our observations. In addition to the standard two-circle angles, φ, ρ, and the interfacial angles to the axial planes, A, B, C, we give the interzonal angle Z which, together with B,

TABLE 4

COPIAPITE—$R(OH)_2Fe'''_4(SO_4)_6 20H_2O$*

Triclinic; pinakoidal—$\bar{1}$

$a : b : c = 0.4005 : 1 : 0.3971$; $\alpha = 93°58\frac{1}{2}'$, $\beta = 102°08'$, $\gamma = 98°50'$
$p_0 : q_0 : r_0 = 1.0010 : 0.3929 : 1$; $\lambda = 83°58'$, $\mu = 77°03\frac{1}{2}'$, $\nu = 80°04\frac{1}{2}'$
$p_0' = 1.0301$, $q_0' = 0.4043$, $x_0' = 0.2161$, $y_0' = 0.1081$

Forms		φ	ρ	A	B	C	Z
c	(001)	63°25½′	13°35′	77°03½′	83°58′	0°00′	77°48½′
b	(010)	0 00	90 00	80 04½	0 00	83 58	0 00
a	(100)	80 04½	90 00	0 00	80 04½	77 03½	0 00
m	(110)	60 10½	90 00	19 54	60 10½	76 26½	0 00
$M\frac{1}{2}$	$(2\bar{1}0)$	91 23½	90 00	11 19	91 23½	78 01½	0 00
M	$(1\bar{1}0)$	102 36	90 00	22 31½	102 36	79 30½	0 00
$M2$	$(1\bar{2}0)$	121 53	90 00	41 48½	121 53	82 56½	0 00
$M3$	$(1\bar{3}0)$	135 34½	90 00	55 30	135 34½	85 52½	0 00
$d\frac{1}{2}$	(012)	34 51½	20 42½	75 34½	73 08	10 50	77 48½
d	(011)	22 52	29 04½	74 44½	63 24	20 34	77 48½
$d2$	(021)	13 16	43 17	74 20	48 08½	35 49½	77 48½
$d3$	(031)	9 17½	53 14	74 42½	37 45½	46 12½	77 48½
e	$(0\bar{1}1)$	143 53	20 08	81 15½	106 09	22 11	77 48½
f	(101)	76 56	51 38½	38 28	79 47½	38 35½	39 05½
$g\frac{1}{2}$	$(\bar{1}02)$	−86 12	16 16½	105 47½	88 56	28 44½	106 14½
g	$(\bar{1}01)$	−94 58	38 43	128 32½	93 06½	51 29½	128 36½
$g2$	$(\bar{2}01)$	−97 45	61 21½	151 17	96 48	74 13½	151 08
$u\frac{3}{2}$	$(\bar{1}\bar{3}2)$	−153 37	33 14	108 56½	119 24½	44 45	106 14½
$p3$	(131)	39 24	62 43½	47 37	46 37½	50 29½	39 05½
$r\frac{1}{2}$	$(\bar{2}\bar{1}2)$	−108 47	40 09	129 34½	101 59	53 38	128 36½
r	$(\bar{1}\bar{1}1)$	−120 40½	42 52½	129 31	110 18½	56 26	128 36½
$r2$	$(\bar{1}\bar{2}1)$	−137 42½	49 53	127 11	124 27	62 41½	128 36½
s	$(\bar{1}11)$	−67 15	40 53½	123 26	75 20	50 36½	128 36½
$s2$	$(\bar{1}21)$	−47 12½	47 25	116 29½	59 59½	53 22	128 36½
$w3$	$(\bar{2}\bar{3}1)$	−128 50	66 45	143 32½	125 11	80 03	151 07½
$w6$	$(\bar{2}\bar{6}1)$	−145 50½	72 48	131 39	142 14	84 44	151 07½
$v3$	$(\bar{2}31)$	−61 57½	64 03	135 08½	64 59½	72 21½	151 07½

*Composition indicated by a large number of analyses.

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gives azimuth and distance from the
with Table 1 will show the differences
according to the two sets of elements.
how future measurements on analysed
alternative values.

Form-list and projection. To con
lography we give a complete list of the
a gnomonic projection of the whole fo
of the complicated relation between U
and the fact that Ungemach's form-l
Lévy" notation in the discarded settin
full list of forms in both notations. T
tance of the forms we have marked w
one of us while Ungemach's actual nu
after each of his symbols. From the
in Tables 1 and 4 the forms are classe
in the formal angle-table (Table 4), les
out distinguishing mark).

The form-list of copiapite presente
and tables forms can be denoted simpl
in drawings and projections briefer
letters, are convenient and generally
present a problem. In the case of we
puted setting, such as calcite (Palache,
to retaining and, if necessary, adding t
letters, drawing on Roman, Greek, a
case and capitals, and combining these
as single, double, or triple dots, to pro
distinct characters. But this procedur
and errors even in the hands of carefu
relatively little known copiapite, on
tional set of form-letters, and the pr
tically altered to a new one which we h
remain unchanged. An appropriate s
fore be used to denote the numerous c

The forms of copiapite all lie on a s
b' (Fig. 8). The transverse zone [*ac*

TABLE 4

—$R(OH)_2Fe'''_4(SO_4)_6 20H_2O$*

iclinic; pinakoidal—$\bar{1}$

3971; $\alpha = 93°58\frac{1}{2}'$, $\beta = 102°08'$, $\gamma = 98°50'$
9 : 1; $\lambda = 83°58'$, $\mu = 77°03\frac{1}{2}'$, $\nu = 80°04\frac{1}{2}'$
.4043, $x_0' = 0.2161$, $y_0' = 0.1081$

ρ	A	B	C	Z
13°35′	77°03½′	83°58′	0°00′	77°48½′
90 00	80 04½	0 00	83 58	0 00
90 00	0 00	80 04½	77 03½	0 00
90 00	19 54	60 10½	76 26½	0 00
90 00	11 19	91 23½	78 01½	0 00
90 00	22 31½	102 36	79 30½	0 00
90 00	41 48½	121 53	82 56½	0 00
90 00	55 30	135 34½	85 52½	0 00
20 42½	75 34½	73 08	10 50	77 48½
29 04½	74 44½	63 24	20 34	77 48½
43 17	74 20	48 08½	35 49½	77 48½
53 14	74 42½	37 45½	46 12½	77 48½
20 08	81 15½	106 09	22 11	77 48½
51 38½	38 28	79 47½	38 35½	39 05½
16 16½	105 47½	88 56	28 44½	106 14½
38 43	128 32½	93 06½	51 29½	128 36½
61 21½	151 17	96 48	74 13½	151 08
33 14	108 56½	119 24½	44 45	106 14½
62 43½	47 37	46 37½	50 29½	39 05½
40 09	129 34½	101 59	53 38	128 36½
42 52½	129 31	110 18½	56 26	128 36½
49 53	127 11	124 27	62 41½	128 36½
40 53½	123 26	75 20	50 36½	128 36½
47 25	116 29½	59 59½	53 22	128 36½
66 45	143 32½	125 11	80 03	151 07½
72 48	131 39	142 14	84 44	151 07½
64 03	135 08½	64 59½	72 21½	151 07½

by a large number of analyses.

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gives azimuth and distance from the normal to (010). Comparison with Table 1 will show the differences between corresponding angles according to the two sets of elements. It will be interesting to see how future measurements on analysed materials compare with these alternative values.

Form-list and projection. To conclude the descriptive crystallography we give a complete list of the observed forms (Table 5) and a gnomonic projection of the whole form-system (Fig. 9). In view of the complicated relation between Ungemach's notation and ours, and the fact that Ungemach's form-letters represent a "Millerized Lévy" notation in the discarded setting, it will be useful to give the full list of forms in both notations. To indicate the relative importance of the forms we have marked with x the forms noted by any one of us while Ungemach's actual number of observations is noted after each of his symbols. From the numbers of observations given in Tables 1 and 4 the forms are classed as common (**) and entered in the formal angle-table (Table 4), less common (*), and rare (without distinguishing mark).

The form-list of copiapite presented a special problem. In text and tables forms can be denoted simply by their Miller indices, but in drawings and projections briefer symbols, usually single italic letters, are convenient and generally used. Long form-lists always present a problem. In the case of well known species in an undisputed setting, such as calcite (Palache, 1943), there is no alternative to retaining and, if necessary, adding to the best current set of form-letters, drawing on Roman, Greek, and German alphabets, lower case and capitals, and combining these with additional symbols such as single, double, or triple dots, to produce the necessary number of distinct characters. But this procedure leads to practical difficulties and errors even in the hands of careful and scholarly workers. The relatively little known copiapite, on the other hand, has no traditional set of form-letters, and the previous setting has been drastically altered to a new one which we hope will recommend itself and remain unchanged. An appropriate set of new symbols may therefore be used to denote the numerous crystal forms.

The forms of copiapite all lie on a sheaf of zones meeting in *b* and *b*′ (Fig. 8). The transverse zone [*aca*′] cuts this sheaf into zone-segments which originate at their intersections with the zone [*aca′*] and terminate at *b* and *b′*. Conventional letters are given to the unit forms of the zone-segments as tabulated below.

Zone-Segment	Unit Form	Zone-Segment	Unit Form
(100)—(010)	*m*(110)	$(\bar{1}01)$—$(0\bar{1}0)$	*r*$(\bar{1}\bar{1}1)$
(100)—$(0\bar{1}0)$	*M*$(1\bar{1}0)$	$(\bar{1}01)$—(010)	*s*$(\bar{1}11)$
(001)—(010)	*d*(011)	$(\bar{1}02)$—(010)	*t*$(\bar{1}22)$
(001)—$(0\bar{1}0)$	*e*$(0\bar{1}1)$	$(\bar{1}02)$—$(0\bar{1}0)$	*u*$(\bar{1}\bar{2}2)$
(001)—(100)	*f*(101)	$(\bar{2}01)$—(010)	*v*$(\bar{2}11)$
(001)—$(\bar{1}00)$	*g*$(\bar{1}01)$	$(\bar{2}01)$—$(0\bar{1}0)$	*w*$(\bar{2}\bar{1}1)$
(101)—(010)	*p*(111)	(401)—(010)	*x*(411)
(101)—$(0\bar{1}0)$	*q*$(1\bar{1}1)$	(401)—$(0\bar{1}0)$	*y*$(4\bar{1}1)$
		$(\bar{5}01)$—(010)	*z*$(\bar{5}11)$

Any pole in a zone-segment, other than the end-poles and the units, are simply designated by the letter of the unit followed by a number which gives the gnomonic distance of the pole from the origin in terms of the unit gnomonic distance. For example, the pole (131) lies on the zone-segment *f*—*b* at a distance from the origin *f* which is three times the unit distance *f*-*p*. The form (131) therefore receives the symbol *p*3. Similarly (292) is lettered $p\frac{9}{2}$, (270

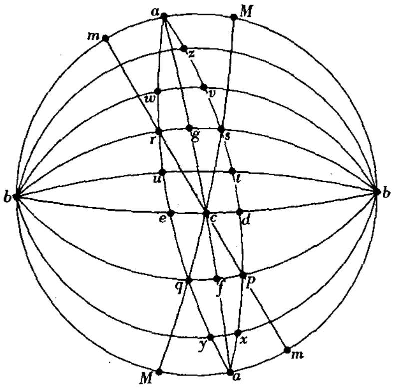
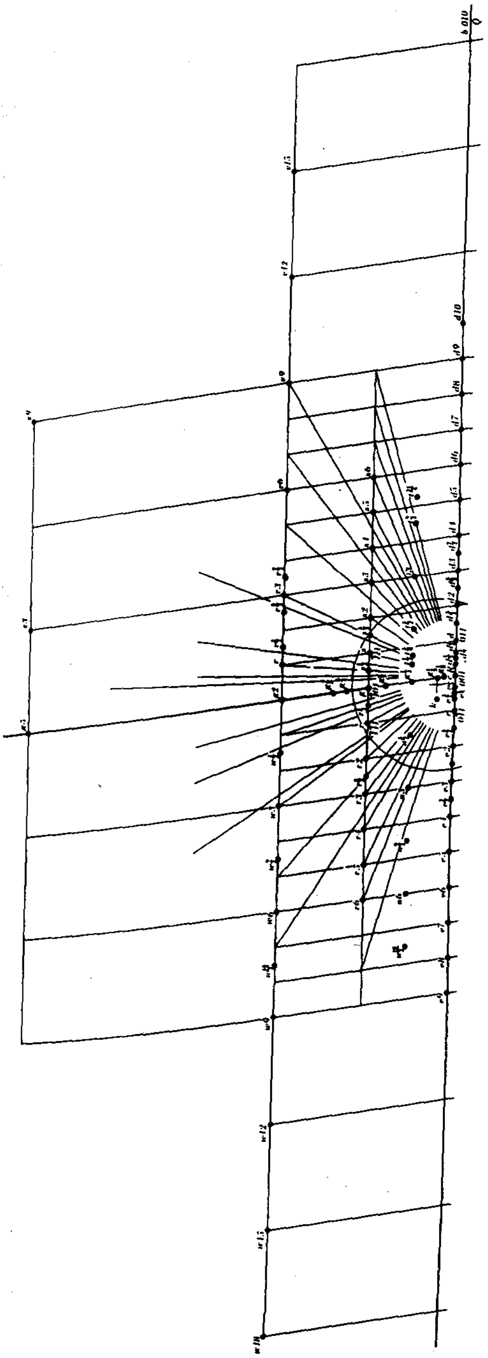


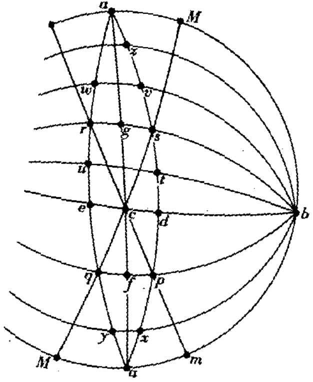
FIG. 8.—Stereographic projection of the principal zones of copiapite with the letters used to denote the forms in each zone-segment.



at their intersections with the zone [aca']
'. Conventional letters are given to the
nents as tabulated below.

Form	Zone-Segment	Unit Form
10)	$(\bar{1}01)$—$(0\bar{1}0)$	$r(\bar{1}\bar{1}1)$
$\bar{1}0)$	$(\bar{1}01)$—(010)	$s(\bar{1}11)$
11)	$(\bar{1}02)$—(010)	$t(\bar{1}22)$
$\bar{1}1)$	($\bar{1}$[illegible]2)—$(0\bar{1}0)$	$u(\bar{1}\bar{2}2)$
01)	$(\bar{2}01)$—(010)	$v(\bar{2}11)$
$\bar{0}1)$	$(\bar{2}01)$—$(0\bar{1}0)$	$w(\bar{2}\bar{1}1)$
11)	(401)—(010)	$x(411)$
$\bar{1}1)$	(401)—$(0\bar{1}0)$	$y(4\bar{1}1)$
	$(\bar{5}01)$—(010)	$z(\bar{5}11)$

gment, other than the end-poles and the
ed by the letter of the unit followed by a
gnomonic distance of the pole from the



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segment *f*—*b* at a distance from the origin
unit distance *f*-*p*. The form (131) there-
3. Similarly (292) is lettered $p_{\frac{9}{2}}$, $(2\bar{7}0)$

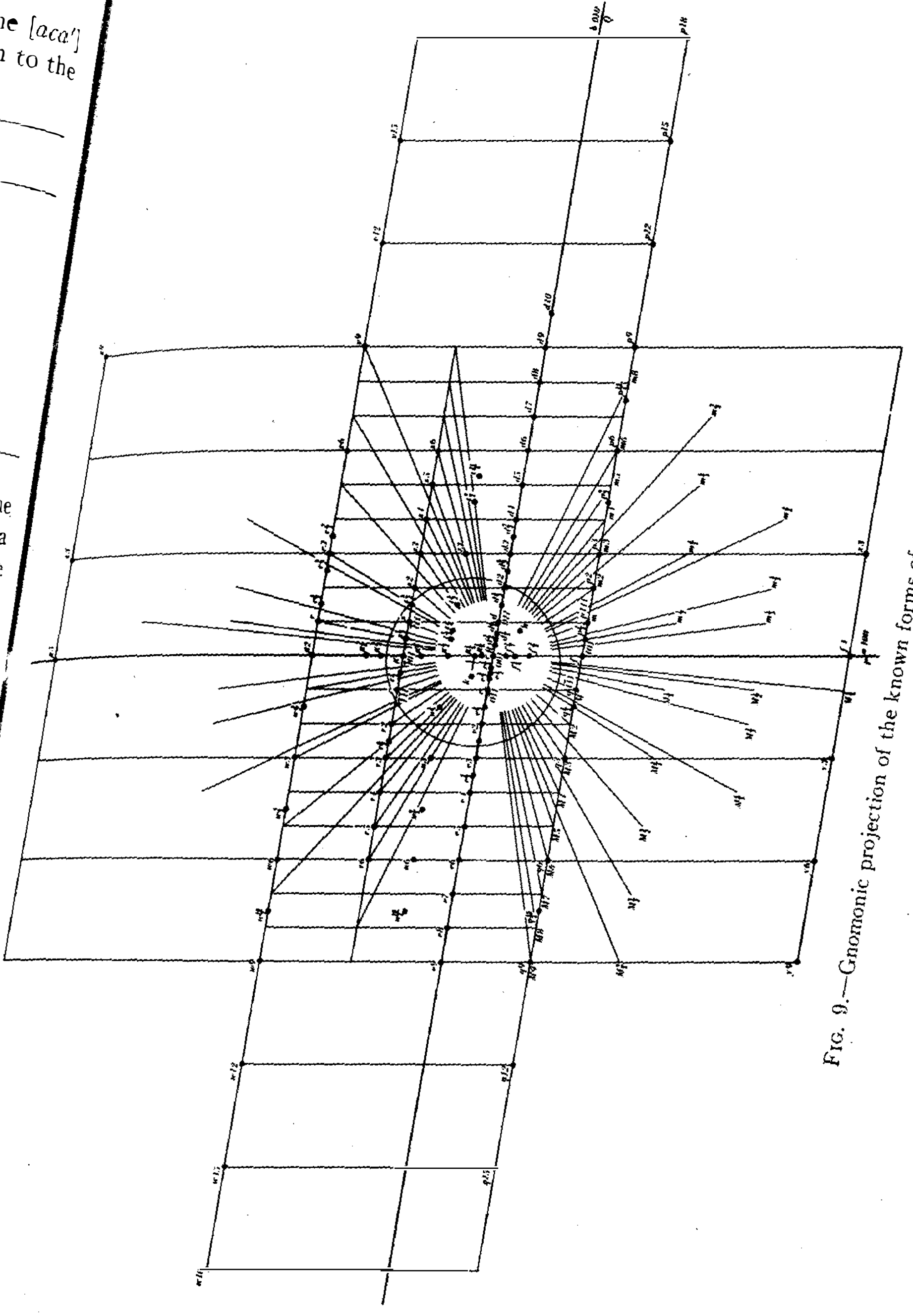

FIG. 9.—Gnomonic projection of the known forms of copiapite.

TABLE 5

COPIAPITE: OBSERVED FORMS

Authors		Obs.	Ungemach		Obs.	Authors		Obs.	Ungemach		Obs.
c	(001)**	x	δ_1	$(1\bar{1}3)$	28	$g\frac{5}{4}$	$(\bar{5}04)$*	–	$c\frac{1}{6}$	$(\bar{3}31)$	2
b	(010)**	x	g^1	(010)	2	$g\frac{7}{5}$	$(\bar{7}05)$	–	$c\frac{1}{4}$	$(\bar{2}21)$	1
a	(100)**	x	γ_1	$(\bar{1}13)$	30	$g2$	$(\bar{2}01)$**	x	c_1	$(\bar{1}11)$	21
$m8$	(180)	–	γ_{17}	$(\bar{1}.17.3)$	1	$g5$	$(\bar{5}01)$*	–	c^1	$(\bar{1}12)$	8
$m7$	(170)	x		$(\bar{1}.15.3)$	–	k	$(\overline{13}5)$	–	λ	$(1\bar{2}2)$	3
$m6$	(160)	x	γ_{13}	$(\bar{1}.13.3)$	2	h	(134)	–	$f\frac{5}{2}$	(115)	1
$m5$	(150)	x	γ_{11}	$(\bar{1}.11.3)$	2	$t\frac{1}{2}$	$(\bar{1}12)$	x		$(3\bar{1}3)$	–
$m4$	(140)	x	γ_9	$(\bar{1}93)$	2	$t\frac{3}{4}$	$(\bar{2}34)$	–	o^1	(101)	2
$m\frac{7}{2}$	(270)	–	γ_8	$(\bar{1}83)$	1	$t\frac{3}{2}$	$(\bar{1}32)$*	x	f_1	(111)	8
$m3$	(130)*	x	γ_7	$(\bar{1}73)$	6	$t3$	$(\bar{1}62)$*	–	f_3	(131)	5
$m\frac{5}{2}$	(250)	–	γ_6	$(\bar{1}63)$	1	$t\frac{9}{2}$	$(\bar{1}92)$	–	f_5	(151)	2
$m2$	(120)*	x	γ_5	$(\bar{1}53)$	6	$t\frac{21}{4}$	$(\bar{2}.21.4)$	–	f_6	(161)	1
$m\frac{3}{2}$	(230)*	–	γ_4	$(\bar{1}43)$	4	$u\frac{3}{4}$	$(\overline{23}4)$*	–	d_2	$(1\bar{2}1)$	4
$m\frac{4}{3}$	(340)	–	$\gamma\frac{11}{3}$	$(\bar{3}.11.9)$	2	$u\frac{3}{2}$	$(\overline{13}2)$**	–	d_3	$(1\bar{3}1)$	10
m	(110)**	x	γ_3	$(\bar{1}33)$	14	$u3$	$(\overline{16}2)$*	–	d_5	$(1\bar{5}1)$	5
$m\frac{2}{3}$	(320)	–	$\gamma\frac{7}{3}$	$(\bar{3}79)$	3	$u\frac{9}{2}$	$(\overline{19}2)$*	–	d_7	$(1\bar{7}1)$	8
$m\frac{1}{2}$	(210)*	–	γ_2	$(\bar{1}23)$	9	$u6$	$(\bar{1}.\overline{12}.2)$	–	d_9	$(1\bar{9}1)$	3
$m\frac{1}{3}$	(310)	–	$\gamma\frac{5}{3}$	$(\bar{3}59)$	3	$u\frac{15}{2}$	$(\bar{1}.\overline{15}.2)$	–	d_{11}	$(1.\overline{11}.1)$	3
$M\frac{1}{4}$	$(4\bar{1}0)$	–	$\gamma\frac{1}{2}$	$(\bar{2}16)$	3	$p\frac{1}{2}$	(212)	x		(016)	–
$M\frac{1}{3}$	$(3\bar{1}0)$*	–	$\gamma\frac{1}{3}$	$(\bar{3}19)$	6	p	(111)	x		(013)	–
$M\frac{1}{2}$	$(2\bar{1}0)$**	x	a^3	$(\bar{1}03)$	10	$p2$	(121)	x		(023)	–
$M\frac{2}{3}$	$(3\bar{2}0)$*	–	$\beta\frac{1}{3}$	$(\overline{31}9)$	5	$p3$	(131)**	x	i_1	(011)	10
M	$(1\bar{1}0)$**	x	β_1	$(\overline{11}3)$	24	$p\frac{9}{2}$	(292)	–	$i\frac{3}{2}$	(032)	1
$M\frac{4}{3}$	$(3\bar{4}0)$	–	$\beta\frac{5}{3}$	$(\overline{35}9)$	1	$p6$	(161)*	x	i_2	(021)	7
$M\frac{3}{2}$	$(2\bar{3}0)$*	x	β_2	$(\overline{12}3)$	5	$p\frac{15}{2}$	$(2.15.2)$	–	$i\frac{5}{2}$	(052)	2
$M2$	$(1\bar{2}0)$**	x	β_3	$(\overline{13}3)$	10	$p9$	(191)	–	i_3	(031)	3
$M\frac{5}{2}$	$(2\bar{5}0)$	x	β_4	$(\overline{14}3)$	2	$p12$	$(1.12.1)$	–	i_4	(041)	2
$M3$	$(1\bar{3}0)$**	x	β_5	$(\overline{15}3)$	10	$p15$	$(1.15.1)$	–	i_5	(051)	2
$M\frac{7}{2}$	$(2\bar{7}0)$	x		$(\overline{16}3)$	–	$p18$	$(1.18.1)$	–	i_6	(061)	2
$M4$	$(1\bar{4}0)$*	–	β_7	$(\overline{17}3)$	7	q	$(1\bar{1}1)$	–	$e\frac{1}{3}$	$(0\bar{1}3)$	1
$M\frac{9}{2}$	$(2\bar{9}0)$	–	β_8	$(\overline{18}3)$	1	$q\frac{3}{2}$	$(2\bar{3}2)$	–	$e\frac{1}{2}$	$(0\bar{1}2)$	1
$M5$	$(1\bar{5}0)$*	–	β_9	$(\overline{19}3)$	8	$q3$	$(1\bar{3}1)$*	x	e_1	$(0\bar{1}1)$	9
$M6$	$(1\bar{6}0)$	x	β_{11}	$(\bar{1}.\overline{11}.3)$	2	$q6$	$(1\bar{6}1)$*	x	e_2	$(0\bar{2}1)$	7
$M7$	$(1\bar{7}0)$	x	β_{13}	$(\bar{1}.\overline{13}.3)$	2	$q\frac{15}{2}$	$(2.\overline{15}.2)$	–	$e\frac{5}{2}$	$(0\bar{5}2)$	1
$M8$	$(1\bar{8}0)$	–	β_{15}	$(\bar{1}.\overline{15}.3)$	3	$q9$	$(1\bar{9}1)$	–	e_3	$(0\bar{3}1)$	2
$M9$	$(1\bar{9}0)$	–	β_{17}	$(\bar{1}.\overline{17}.3)$	1	$q12$	$(1.\overline{12}.1)$*	–	e_4	$(0\bar{4}1)$	4
$d\frac{1}{3}$	(013)*	–	$\delta\frac{1}{3}$	$(3\bar{1}9)$	6	$q15$	$(1.\overline{15}.1)$	–	e_5	$(0\bar{5}1)$	2
$d\frac{1}{2}$	(012)**	x	o^3	(103)	10	$r\frac{1}{2}$	$(\overline{21}2)$**	–	$\frac{3}{2}g$	$(2\bar{3}0)$	10

**Common forms. *Less common forms. Remaining forms rare.

TABLE 5.—*Con*

Authors		Obs.	Ungemach		Obs.	Au
$d\frac{2}{3}$	(023)	–	$\alpha\frac{1}{3}$	(319)	1	r
d	(011)**	x	α_1	(113)	19	$r2$
$d\frac{3}{2}$	(032)	x	α_2	(123)	1	$r\frac{5}{2}$
$d2$	(021)**	x	α_3	(133)	13	$r3$
$d\frac{5}{2}$	(052)	x	α_4	(143)	3	$r4$
$d3$	(031)**	x	α_5	(153)	11	$r5$
$d\frac{7}{2}$	(072)	–	α_6	(163)	1	$r6$
$d4$	(041)*	x	α_7	(173)	8	$s\frac{1}{2}$
$d5$	(051)*	x	α_9	(193)	4	s
$d6$	(061)	x	α_{11}	$(1.11.3)$	2	$s\frac{3}{2}$
$d7$	(071)*	x	α_{13}	$(1.13.3)$	4	$s2$
$d8$	(081)	–	α_{15}	$(1.15.3)$	1	$s3$
$d9$	(091)	–	α_{17}	$(1.17.3)$	1	$s4$
$d10$	$(0.10.1)$	–	α_{19}	$(1.19.3)$	2	$s5$
$e\frac{1}{3}$	$(0\bar{1}3)$*	–	$\delta\frac{5}{3}$	$(3\bar{5}9)$	7	$s6$
$e\frac{1}{2}$	$(0\bar{1}2)$*	–	δ_2	$(1\bar{2}3)$	7	$w\frac{3}{2}$
$e\frac{2}{3}$	$(0\bar{2}3)$*	–	$\delta\frac{7}{3}$	$(3\bar{7}9)$	4	$w3$
e	$(0\bar{1}1)$**	x	δ_3	$(1\bar{3}3)$	15	$w\frac{9}{2}$
$e\frac{3}{2}$	$(0\bar{3}2)$*	–	δ_4	$(1\bar{4}3)$	5	$w6$
$e2$	$(0\bar{2}1)$*	x	δ_5	$(1\bar{5}3)$	8	$w\frac{15}{2}$
$e\frac{5}{2}$	$(0\bar{5}2)$	–	δ_6	$(1\bar{6}3)$	3	$w9$
$e3$	$(0\bar{3}1)$*	x	δ_7	$(1\bar{7}3)$	4	$w12$
$e\frac{7}{2}$	$(0\bar{7}2)$	–	δ_8	$(1\bar{8}3)$	2	$w15$
$e4$	$(0\bar{4}1)$*	–	δ_9	$(1\bar{9}3)$	5	$w18$
$e5$	$(0\bar{5}1)$*	–	δ_{11}	$(1.\overline{11}.3)$	4	v
$e6$	$(0\bar{6}1)$	–	δ_{13}	$(1.\overline{13}.3)$	2	$v\frac{3}{2}$
$e7$	$(0\bar{7}1)$	–	δ_{15}	$(1.\overline{15}.3)$	3	$v\frac{5}{2}$
$e8$	$(0\bar{8}1)$	–	δ_{17}	$(1.\overline{17}.3)$	1	$v3$
$e9$	$(0\bar{9}1)$	–	δ_{19}	$(1.\overline{19}.3)$	1	$v\frac{7}{2}$
$f\frac{1}{7}$	(107)	–	d^2	$(1\bar{1}4)$	2	$v6$
$f\frac{1}{4}$	(104)*	–	$d\frac{5}{2}$	$(1\bar{1}5)$	7	$v9$
$f\frac{2}{5}$	(205)	–	$d\frac{7}{2}$	$(1\bar{1}7)$	2	$v12$
f	(101)**	x	p	(001)	17	$v15$
$f4$	(401)*	–	$c\frac{5}{2}$	$(\bar{1}15)$	4	$x3$
$g\frac{1}{8}$	$(\bar{1}08)$	–	$d\frac{7}{6}$	$(3\bar{3}7)$	3	$y3$
$g\frac{1}{5}$	$(\bar{1}05)$*	–	d^1	$(1\bar{1}2)$	9	$y6$
$g\frac{1}{2}$	$(\bar{1}02)$**	x	d_1	$(1\bar{1}1)$	18	$y9$
$g\frac{4}{5}$	$(\bar{4}05)$	–	$d\frac{1}{6}$	$(3\bar{3}1)$	1	$z9$
g	$(\bar{1}01)$**	x	m	$(1\bar{1}0)$	21	$z3$

**Common forms. *Less common forms.

TABLE 5

'E: OBSERVED FORMS

	Obs.	Authors		Obs.	Ungemach		Obs.
	28	$g_{\frac{5}{4}}$	$(\bar{5}04)$*	–	$c_{\frac{1}{6}}$	$(\bar{3}31)$	2
	2	$g_{\frac{7}{5}}$	$(\bar{7}05)$	–	$c_{\frac{1}{4}}$	$(\bar{2}21)$	1
	30	$g2$	$(\bar{2}01)$**	x	c_1	$(\bar{1}11)$	21
3)	1	$g5$	$(\bar{5}01)$*	–	c^1	$(\bar{1}12)$	8
3)	–	k	$(\bar{1}\bar{3}5)$	–	λ	$(1\bar{2}2)$	3
3)	2	h	(134)	–	$f_{\frac{5}{2}}$	(115)	1
3)	2	$t_{\frac{1}{2}}$	$(\bar{1}12)$	x		$(3\bar{1}3)$	–
	2	$t_{\frac{3}{4}}$	$(\bar{2}34)$	–	o^1	(101)	2
	1	$t_{\frac{3}{2}}$	$(\bar{1}32)$*	x	f_1	(111)	8
	6	$t3$	$(\bar{1}62)$*	–	f_3	(131)	5
	1	$t_{\frac{9}{2}}$	$(\bar{1}92)$	–	f_5	(151)	2
	6	$t_{\frac{21}{4}}$	$(\bar{2}.21.4)$	–	f_6	(161)	1
	4	$u_{\frac{3}{4}}$	$(\bar{2}\bar{3}4)$*	–	d_2	$(1\bar{2}1)$	4
))	2	$u_{\frac{3}{2}}$	$(\bar{1}\bar{3}2)$**	–	d_3	$(1\bar{3}1)$	10
	14	$u3$	$(\bar{1}\bar{6}2)$*	–	d_5	$(1\bar{5}1)$	5
	3	$u_{\frac{9}{2}}$	$(\bar{1}\bar{9}2)$*	–	d_7	$(1\bar{7}1)$	8
	9	$u6$	$(\bar{1}.\overline{12}.2)$	–	d_9	$(1\bar{9}1)$	3
	3	$u_{\frac{15}{2}}$	$(\bar{1}.\overline{15}.2)$	–	d_{11}	$(1.\overline{11}.1)$	3
	3	$p_{\frac{1}{2}}$	(212)	x		(016)	–
	6	p	(111)	x		(013)	–
	10	$p2$	(121)	x		(023)	–
	5	$p3$	(131)**	x	i_1	(011)	10
	24	$p_{\frac{9}{2}}$	(292)	–	$i_{\frac{3}{2}}$	(032)	1
	1	$p6$	(161)*	x	i_2	(021)	7
	5	$p_{\frac{15}{2}}$	$(2.15.2)$	–	$i_{\frac{5}{2}}$	(052)	2
	10	$p9$	(191)	–	i_3	(031)	3
	2	$p12$	$(1.12.1)$	–	i_4	(041)	2
	10	$p15$	$(1.15.1)$	–	i_5	(051)	2
	–	$p18$	$(1.18.1)$	–	i_6	(061)	2
	7	q	$(1\bar{1}1)$	–	$e_{\frac{1}{3}}$	$(0\bar{1}3)$	1
	1	$q_{\frac{3}{2}}$	$(2\bar{3}2)$	–	$e_{\frac{1}{2}}$	$(0\bar{1}2)$	1
	8	$q3$	$(1\bar{3}1)$*	x	e_1	$(0\bar{1}1)$	9
3)	2	$q6$	$(1\bar{6}1)$*	x	e_2	$(0\bar{2}1)$	7
3)	2	$q_{\frac{15}{2}}$	$(2.\overline{15}.2)$	–	$e_{\frac{5}{2}}$	$(0\bar{5}2)$	1
3)	3	$q9$	$(1\bar{9}1)$	–	e_3	$(0\bar{3}1)$	2
3)	1	$q12$	$(1.\overline{12}.1)$*	–	e_4	$(0\bar{4}1)$	4
	6	$q15$	$(1.\overline{15}.1)$	–	e_5	$(0\bar{5}1)$	2
	10	$r_{\frac{1}{2}}$	$(\bar{2}\bar{1}2)$**	–	$\frac{3}{2}g$	$(2\bar{3}0)$	10

mmon forms. Remaining forms rare.

TABLE 5.—*Continued*

Authors		Obs.	Ungemach		Obs.	Authors		Obs.	Ungemach		Obs.
$d_{\frac{2}{3}}$	(023)	–	$\alpha_{\frac{1}{3}}$	(319)	1	r	$(\bar{1}\bar{1}1)$**	x	${}_2g$	$(1\bar{2}0)$	17
d	(011)**	x	α_1	(113)	19	$r2$	$(\bar{1}\bar{2}1)$**	–	${}_3g$	$(1\bar{3}0)$	11
$d_{\frac{3}{2}}$	(032)	x	α_2	(123)	1	$r_{\frac{5}{2}}$	$(\bar{2}\bar{5}2)$	–	${}_{\frac{7}{2}}g$	$(2\bar{7}0)$	1
$d2$	(021)**	x	α_3	(133)	13	$r3$	$(\bar{1}\bar{3}1)$*	–	${}_4g$	$(1\bar{4}0)$	7
$d_{\frac{5}{2}}$	(052)	x	α_4	(143)	3	$r4$	$\bar{1}\bar{4}1)$*	–	${}_5g$	$(1\bar{5}0)$	7
$d3$	(031)**	x	α_5	(153)	11	$r5$	$(\bar{1}\bar{5}1)$	–	${}_6g$	$(1\bar{6}0)$	3
$d_{\frac{7}{2}}$	(072)	–	α_6	(163)	1	$r6$	$(\bar{1}\bar{6}1)$	–	${}_7g$	$(1\bar{7}0)$	1
$d4$	(041)*	x	α_7	(173)	8	$s_{\frac{1}{2}}$	$(\bar{2}12)$	–	${}_2h$	$(2\bar{1}0)$	3
$d5$	(051)*	x	α_9	(193)	4	s	$(\bar{1}11)$**	x	h^1	(100)	20
$d6$	(061)	x	α_{11}	$(1.11.3)$	2	$s_{\frac{3}{2}}$	$(\bar{2}32)$*	–	h_2	(210)	5
$d7$	(071)*	x	α_{13}	$(1.13.3)$	4	$s2$	$(\bar{1}21)$**	x	t	(110)	11
$d8$	(081)	–	α_{15}	$(1.15.3)$	1	$s3$	$(\bar{1}31)$*	x	g_2	(120)	9
$d9$	(091)	–	α_{17}	$(1.17.3)$	1	$s4$	$(\bar{1}41)$*	–	g_3	(130)	6
$d10$	$(0.10.1)$	–	α_{19}	$(1.19.3)$	2	$s5$	$(\bar{1}51)$*	–	g_4	(140)	4
$e_{\frac{1}{3}}$	$(0\bar{1}3)$*	–	$\delta_{\frac{5}{3}}$	$(3\bar{5}9)$	7	$s6$	$(\bar{1}61)$	–	g_5	(150)	1
$e_{\frac{1}{2}}$	$(0\bar{1}2)$*	–	δ_2	$(1\bar{2}3)$	7	$w_{\frac{3}{2}}$	$(\bar{4}\bar{3}2)$*	–	c_2	$(\bar{1}21)$	4
$e_{\frac{2}{3}}$	$(0\bar{2}3)$*	–	$\delta_{\frac{7}{3}}$	$(3\bar{7}9)$	4	$w3$	$(\bar{2}\bar{3}1)$**	–	c_3	$(\bar{1}31)$	10
e	$(0\bar{1}1)$**	x	δ_3	$(1\bar{3}3)$	15	$w_{\frac{9}{2}}$	$(\bar{4}\bar{9}2)$	–	c_4	$(\bar{1}41)$	2
$e_{\frac{3}{2}}$	$(0\bar{3}2)$*	–	δ_4	$(1\bar{4}3)$	5	$w6$	$(\bar{2}\bar{6}1)$**	–	c_5	$(\bar{1}51)$	11
$e2$	$(0\bar{2}1)$*	x	δ_5	$(1\bar{5}3)$	8	$w_{\frac{15}{2}}$	$(\bar{4}.\overline{15}.2)$	–	c_6	$(\bar{1}61)$	1
$e_{\frac{5}{2}}$	$(0\bar{5}2)$	–	δ_6	$(1\bar{6}3)$	3	$w9$	$(\bar{2}\bar{9}1)$*	–	c_7	$(\bar{1}71)$	6
$e3$	$(0\bar{3}1)$*	x	δ_7	$(1\bar{7}3)$	4	$w12$	$(\bar{2}.\overline{12}.1)$	–	c_9	$(\bar{1}91)$	3
$e_{\frac{7}{2}}$	$(0\bar{7}2)$	–	δ_8	$(1\bar{8}3)$	2	$w15$	$(\bar{2}.\overline{15}.1)$	–	c_{11}	$(\bar{1}.11.1)$	1
$e4$	$(0\bar{4}1)$*	–	δ_9	$(1\bar{9}3)$	5	$w18$	$(\bar{2}.\overline{18}.1)$	–	c_{13}	$(\bar{1}.13.1)$	2
$e5$	$(0\bar{5}1)$*	–	δ_{11}	$(1.\overline{11}.3)$	4	v	$(\bar{2}11)$	x		$(\bar{3}13)$	–
$e6$	$(0\bar{6}1)$	–	δ_{13}	$(1.\overline{13}.3)$	2	$v_{\frac{3}{2}}$	$(\bar{4}32)$*	–	a^1	$(\bar{1}01)$	5
$e7$	$(0\bar{7}1)$	–	δ_{15}	$(1.\overline{15}.3)$	3	$v_{\frac{5}{2}}$	$(\bar{4}52)$	x		$(\bar{3}\bar{2}3)$	–
$e8$	$(0\bar{8}1)$	–	δ_{17}	$(1.\overline{17}.3)$	1	$v3$	$(\bar{2}31)$**	x	b_1	$(\bar{1}\bar{1}1)$	9
$e9$	$(0\bar{9}1)$	–	δ_{19}	$(1.\overline{19}.3)$	1	$v_{\frac{7}{2}}$	$(\bar{4}72)$	x		$(\bar{3}\bar{4}3)$	–
$f_{\frac{1}{7}}$	(107)	–	d^2	$(1\bar{1}4)$	2	$v6$	$(\bar{2}61)$*	–	b_3	$(\bar{1}\bar{3}1)$	4
$f_{\frac{1}{4}}$	(104)*	–	$d_{\frac{5}{2}}$	$(1\bar{1}5)$	7	$v9$	$(\bar{2}91)$*	–	b_5	$(\bar{1}\bar{5}1)$	4
$f_{\frac{2}{5}}$	(205)	–	$d_{\frac{7}{2}}$	$(1\bar{1}7)$	2	$v12$	$(\bar{2}.12.1)$	–	b_7	$(\bar{1}\bar{7}1)$	1
f	(101)**	x	p	(001)	17	$v15$	$(\bar{2}.15.1)$	–	b_9	$(\bar{1}\bar{9}1)$	1
$f4$	(401)*	–	$c_{\frac{5}{2}}$	$(\bar{1}15)$	4	$x3$	(431)	–	ϑ	$(\bar{1}35)$	1
$g_{\frac{1}{8}}$	$(\bar{1}08)$	–	$d_{\frac{7}{6}}$	$(3\bar{3}7)$	3	$y3$	$(4\bar{3}1)$	–	$\beta_{\frac{5}{2}}$	$(\bar{1}\bar{1}5)$	2
$g_{\frac{1}{5}}$	$(\bar{1}05)$*	–	d^1	$(1\bar{1}2)$	9	$y6$	$(4\bar{6}1)$	–	η_3	$(\bar{1}\bar{3}5)$	1
$g_{\frac{1}{2}}$	$(\bar{1}02)$**	x	d_1	$(1\bar{1}1)$	18	$y9$	$(4\bar{9}1)$	–	η_5	$(\bar{1}\bar{5}5)$	1
$g_{\frac{4}{5}}$	$(\bar{4}05)$	–	$d_{\frac{1}{6}}$	$(3\bar{3}1)$	1	$z9$	$(\bar{5}31)$	–	a^2	$(\bar{1}02)$	1
g	$(\bar{1}01)$**	x	m	$(1\bar{1}0)$	21	$z3$	$(\bar{5}91)$	–	ϵ	$(\bar{1}\bar{2}2)$	1

**Common forms. *Less common forms. Remaining forms rare.

becomes $M\frac{1}{2}$, and so on. Only a few italic letters are used and the attached whole numbers or vulgar fractions are always written after the letter and on the same level. This gives a simple system which should present no typographic difficulty and could be adapted to other complex form-lists.

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MINERALS FROM THE HIGH
BEAVERDELL, BRI

By A. B. STAPLES, *Beave*
an
H. V. WARREN, *University of*

THE Highland-Bell Mine is now
Wallace Mountain, which is ne
Mining Division, about 23 miles ea
Columbia. The ore deposits of the
by Reinecke (1915) who mentions,
gyrite, tetrahedrite, and native sil
cussed the silver mineralization at
minerals and also argentite and p
concerned mainly with the silver
Mine, their modes of occurrence, ou
ties, and chemical compositions.
paragenetic relations elsewhere. T
R. B. Staples, Managing Director
permission to publish this paper, a
Vancouver, B.C., for the eleven ne
which many weighed only 0.25 to 0

The ore-bearing veins of the Hig
kettle Quartz Diorite (Jurassic), aro
Monzonite. The veins range from
thickness, with an average of about
numerous faults. The silver mine
tetrahedrite (freibergite), pyrargyr
native silver, all of which are desc
also given of the associated sphal
pyrite are found in abundance but c
widespread. Specular hematite, m
been found by the authors but they
ite (?) have been noted and fluorite

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[1] Descriptive mineralogy, abstracted b
authors, from a longer manuscript.