CRYSTALLOGRAPHY OF ULEXITE

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HISTORICAL

Ulexite has been known since about 1840, but only as the fine fibers known as "cotton-ball," or more recently as massive prismatic aggregates, but never in definite crystals. Accordingly, little has been known of its crystal character. Hintze[1] states that it is possibly monoclinic, but says that nothing definite is known of its crystallography. The suggestion of monoclinic symmetry is based on the work of Buttgenbach,[2] who studied minute flakes under the microscope. The flakes were sometimes bounded by edges making angles of 45° and 70° with their elongation. Assuming these edges to represent faces normal to the flakes, he suggested that the mineral may occur in crystals which are platy parallel to (010), and bounded by a monoclinic combination of (100) (101) ($\bar{1}03$). Other flakes were nearly rectangular in outline, and suggested orthorhombic symmetry. He determined extinction as always parallel to the elongation, which was positive. This agrees with Des Cloizeaux,[3] who considered the extinction as nearly or exactly parallel to elongation. Larsen and Berman[4] made the following determinations of optical properties: Biaxial positive; indices, $\alpha=1.491$, $\beta=1.504$, $\gamma=1.520$; $X=b$; $Y\wedge c=23°-0°$; $2V$ moderate. They give the specific gravity as 1.65 and hardness = 1, (erroneous, because determined on "cotton-ball"). Foshag[5] found massive fibrous material at Lang, California, and gives an analysis of it. Schaller,[6] with similar material from the Kramer district of California, determined indices in close agreement with Larsen and Berman. He found Y to be approximately parallel to the elongation, the angle $Y\wedge c$ variable, and about 20°. Elongation was usually negative, though occasionally positive. His material showed universal and intimate polysynthetic twinning parallel to the elongation. Specific gravity of this massive material is 1.963, a much more accurate value than could be ob-

[1] Hintze, Carl, *Handbuch der Mineralogie.* Erst. Band, Viert. Abt., erste Hälfte, 156–167.

[2] Buttgenbach, H., The borate deposits of Salinas Grandes, Argentina: *Ann. Soc. Geol. Belgique,* **28,** mem. 99 (1900–1901).

[3] Des Cloizeaux, A., *Manuel de Minéralogie,* **2,** 10 (1874).

[4] Larsen, Esper S., and Berman, Harry, The Microscopic Determination of the Nonopaque Minerals: *U.S.G.S., Bull.* **848,** 99 (1934).

[5] Foshag, W. F., The origin of the colemanite deposits of California: *Econ. Geol.* **16,** 204 (1921).

[6] Schaller, W. T., Borate minerals from the Kramer district, Mohave desert, California: *U.S.G.S., Prof. Paper* **158–I,** 139 (1930).

tained from the "cotton-ball." Many reliable chemical analyses have fixed the chemical composition as $NaCaB_5O_9 \cdot 8H_2O$.

Occurrence

The writer recently had the good fortune to discover measurable crystals of ulexite, and to work out their crystallography. Identification of the mineral was by means of indices of refraction, which agreed closely with published values, and by a confirmatory chemical analysis.

The material studied was collected from the waste dump of the new shaft of the Suckow Borax Mine, in the Kramer district, San Bernardino County, California. It consists of three or four small hand specimens, which were taken because of their leached and crystalline appearance. Close examination showed them to be made up largely of white or transparent ulexite in a matrix of clay and borax. Exposure to the elements had resulted in the weathering away of some of this matrix, partially exposing the crystals to view. The ulexite occurs as massive aggregates of crystalline grains, sub-parallel or divergent, with occasional regions in which the individuals are more or less completely separated, and irregularly distributed in the matrix. Some of these separate crystals are more or less completely terminated and can be readily detached for study. Other crystals were obtained by careful leaching and washing away of the matrix, many of the individuals thus separated being excellent for crystallographic measurement. There is a frequent tendency, especially in the case of the larger ones, for these crystals to be partially hollow, due to the inclusion, and subsequent dissolving away, of small grains of borax. In such crystals, terminal faces are absent, or appear as narrow faces surrounding the pitted ends.

Most of the crystals are only a fraction of a millimeter in length, although they may reach a maximum of 5–6 millimeters. The larger crystals are usually incomplete, or with no terminal faces, but a large proportion of the smaller individuals are well formed. In general, they are rather slender, elongated, with six or eight faces in the prism zone, and with from three to six terminal faces. About half of the crystals studied were flattened parallel to (100), and the others were more or less equidimensional or diamond shaped in the direction of elongation.

It is interesting to note that the ulexite crystals in the hand specimen appear to remain clear and glassy for an indefinite period, but that crystals isolated and mounted for study become roughened and whitened in the course of a month or so, even when kept in a stoppered vial. This behavior is disappointing, as such crystals soon become unmeasurable, and so are not available for re-examination.

Physical and Optical Properties

Ulexite in crystals is transparent and colorless, with vitreous luster. It is brittle, with a hardness just over 2.5, since it scratches halite with difficulty. The specific gravity, as determine on a pure fragment by both Dr. Harry Berman and the writer, on the torsion micro-balance,[7] is $1.955 \pm .001$. This checks very closely with Schaller's value of 1.963 on massive material, and with the calculated value of 2.001 from x-ray data. There are two good cleavages and one poor one in the prism zone, and a direction of easy fracture nearly perpendicular to it. One very perfect cleavage is parallel to (010), and was oriented by splitting a measured crystal with a needle, and determining the position of the cleavage face with respect to known crystallographic directions. Another cleavage, not quite so good, is parallel to $(1\bar{1}0)$, and was located in the same way. The third cleavage in the prism zone, parallel to (110) was determined under the miscroscope only, and was not observed on the goniometer. It is rather poor. The cross fracture shows on nearly every prism fragment, but is too uneven to be considered a cleavage.

Twinning is rare in the separate crystals, but rather common in the aggregates. It is quite varied, a number of twin planes being measured. The following are fairly well determined: (010), (100); less positively $(3\bar{4}0)$ or $(2\bar{3}0)$; in addition a number of planes were observed apparently bearing no very simple relationship to the axes, but approaching in position such faces as $(\bar{2}31)$, (011), or $(0\bar{7}1)$.

Optically, the biaxial positive character and recorded indices of refraction are confirmed. Elongation is positive, and the maximum extinction angle from the prism is $21\frac{1}{2}°$. The optical orientation of the mineral was determined on the universal stage, and checked for the writer by Dr. James Gilluly. $2V = 73° \pm 1°$; $Y \wedge c = 21\frac{1}{2}°$. The stereogram of this orientation is shown in Fig. 1.

An analysis of selected material from the Suckow locality as compared with the theoretical values, and with analyses by Foshag and Schaller, is given below.

	1	2	3	4
CaO	13.85	13.92	14.14	14.06
Na_2O	7.65	7.78	7.06	7.09
B_2O_3	42.95	43.07	43.12	42.94
H_2O	35.55	35.34	35.68	35.54
insol.	—	—	—	0.10

(1) Theoretical; (2) Suckow, F. A. Conyer; (3) Lang, W. F. Foshag; (4) Kramer, W. T. Schaller.

[7] Berman, Harry, A torsion micro-balance for the determination of specific gravities of minerals: *Am. Mineral.*, **24**, 434–440 (1939).

Crystallography

Ulexite is triclinic, probably holohedral, occurring ordinarily in prisms elongated parallel to *c*. Usually only unit forms are present, but one or two crystals were observed showing more complex faces. Thirty-nine crystals were measured, and more examined under the binocular. No visibly twinned crystals were seen among those measured or examined,

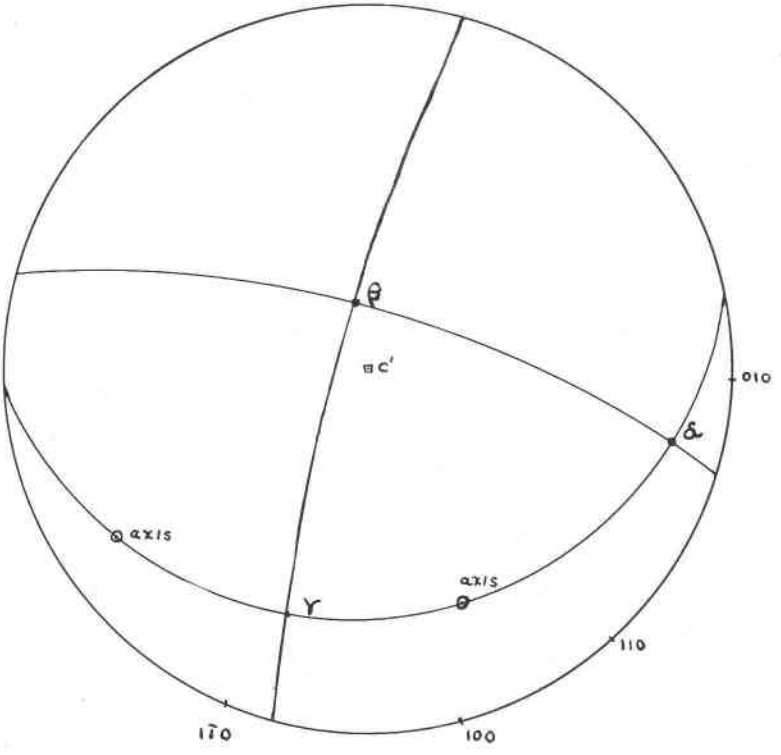

Fig. 1

although twinning was noted in the massive material. No doubly terminated crystals were observed, but of those measured, 23 were upper terminations, and 16 were lower, and there was no appreciable difference in the percentage frequency of terminal faces on the two ends.

Orientation

Orientation of the crystals was determined from the gnomonic projection by using the normal setting for triclinic crystals advocated by Peacock,[8] in which (001) lies to the right and forward of the center, and a is shorter than b. It so happens that in this setting the positive pyra-

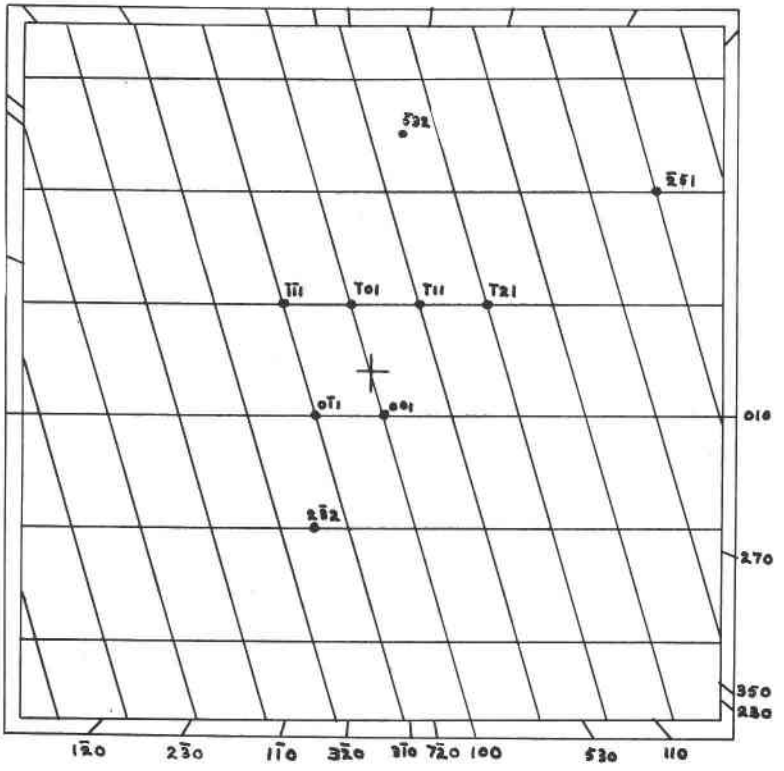

FIG. 2

mids are absent, but the position is analogous to the revised setting of meyerhofferite described by Palache[9] which has the dominant faces in the rear octants.

[8] Peacock, M. A., On the crystallography of axinite and the normal setting of triclinic minerals: *Am. Mineral.*, **22,** 592–593 (1937).

[9] Palache, Charles, Crystallography of meyerhofferite: *Am. Mineral.*, **23,** 644–648 (1938).

Forms

The forms present are as follows, those within the brackets are uncommon: c (001), b (010), a (100), m (110), M ($1\bar{1}0$), s ($0\bar{1}1$), o ($\bar{1}01$), t ($\bar{1}11$), p ($1\bar{1}1$), d ($\bar{1}21$) [z, ($2\bar{3}2$) x ($\bar{5}32$) q ($\bar{2}51$), l (270) h (350), k (230), r (530) L ($7\bar{2}0$), N ($3\bar{1}0$), R ($3\bar{2}0$), K ($2\bar{3}0$), H ($1\bar{2}0$)].
Figure 2 shows the gnomonic projection of these forms.

Calculation of elements

The axial ratio is: $a:b:c=0.6855:1:0.5191$.
The axial angles are: $\alpha=90°16'$; $\beta=109°08'$; $\gamma=105°07$.
These elements were derived from the average measurements of ϕ and ρ for eight commonly appearing forms. For these averages, only faces giving good signals were used, but many other readings, with poorer signals, agree very closely with them. X-ray oscillation photographs were taken about the axis of elongation, and showed no plane of symmetry, thus confirming the triclinic character of the mineral. The length of the vertical edge of a possible unit cell was measured directly from the spacing of the layer lines in the photographs. The other dimensions were calculated from the x-ray data using the morphologic axial angles. The values are as follows: $a_0=8.71$Å, $b_0=12.72$Å, $c_0=6.69$Å. Recalculated to $b=1$ these values give $a:b:c=0.6856:1:0.5256$, which agree very closely with the crystallographic measurements. The unit cell apparently contains two molecules, as the density calculated on this basis, is 2.001, agreeing very closely with the observed value of 1.955.

Description of Forms

In general, the larger terminal faces are ($\bar{1}1\bar{1}$) and ($0\bar{1}1$), with (001) ($\bar{1}01$) and ($\bar{1}11$) quite small, so that the crystals have a distinctly oblique end, and a monoclinic aspect. In the prism zone, (100) is nearly always dominant, and frequently has a somewhat irregular surface. The prisms (110) and ($1\bar{1}0$) are about equally well developed, narrower than (100) and nearly always smooth and glassy. (010) is generally quite subordinate, and practically always the narrowest face in the zone, sometimes appearing only as a line-face. This combination produces the characteristic lathlike appearance of many crystals, which are ordinarily rather slender. There are sometimes variations from these proportions, so that the crystals become more nearly equidimensional prisms, but the length is always at least 2 to 3 times the next longest dimension, and frequently much more. Some of the commoner types of terminations are shown in the drawings (Figs. 3–5). No one type is predominant among the crystals studied. The wide variation in terminal combinations is shown in the table on page 760, which includes 27 completely terminated crystals.

In the prism zone, all but four crystals show only the two pinacoids and unit prisms and in the terminal zone, only two crystals show any but the unit forms or ($\bar{1}21$). Crystal #7 shows the usual prismatic faces, but two uncommon terminals, ($2\bar{3}2$) and ($\bar{2}51$). (001) ($\bar{1}\bar{1}1$) and ($0\bar{1}1$) are small, ($2\bar{3}2$) is large and gives a good signal. ($\bar{2}51$) is rather large, but rough, and gives no definite signal. Its position was determined by maximum illumination,

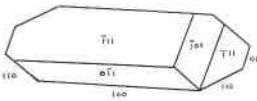

FIG. 3

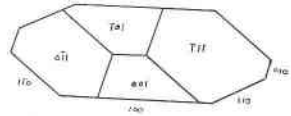

FIG. 4

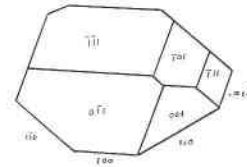

FIG.5

TABLE 1

Form		*c*	*s*	*p*	*o*	*t*	*d*	*z*	*q*	Total crystals
Type	1	x	x	x	x	–	–	–	–	5
	2	x	x	–	x	x	–	–	–	4
	3	–	x	x	x	–	–	–	–	3
	4	–	x	x	x	x	–	–	–	3
	5	–	x	x	–	–	x	–	–	2
	6	x	x	x	x	x	–	–	–	2
	7	x	–	x	–	x	–	–	–	2
	8	x	x	x	–	–	x	–	–	1
	9	x	x	x	–	–	–	x	x	1
	10	x	–	x	x	x	–	–	–	1
	11	x	x	–	x	–	x	–	–	1
	12	–	x	x	–	x	–	–	–	1
	13	x	x	x	x	x	x	–	–	1

and it may perhaps be an interference surface, not a true crystal face. Crystal #24 shows an unusual combination of prism faces in addition to the ordinary. These are as follows: (530), ($3\bar{5}0$), ($7\bar{2}0$), ($2\bar{3}0$), ($\bar{3}20$), all narrow with poor signals; ($3\bar{2}0$) narrow but fair signal; (130), ($7\bar{2}0$) average of poor double signals; ($1\bar{2}0$) best of poor triple signal. They may be considered as very doubtful forms. This same crystal also has an unusual combination of terminal faces. They are (001) and ($0\bar{1}1$), both small, with ($\bar{5}32$), a large face with good signal, not observed on any other crystal. Poorly developed, narrow faces in the prism zone also occur on three other crystals. Crystal #1, ($3\bar{1}0$). #15 (230), #34 (530). (230) and (350) do not occur on the same crystal and probably represent poor positions for the same form. The same is true for ($7\bar{2}0$) and ($3\bar{1}0$).

It might be interesting to see how the forms and cleavage as observed might fit in with Buttgenbach's microscopic determinations. For instance, his monoclinic form might be duplicated by assuming a cleavage flake on ($1\bar{1}0$) bounded by $\bar{1}21$, with the ρ angle near 45°, and ($0\bar{1}1$), with ρ near 20°. The cleavage lines in the section would then be the (010) cleavage. The other might well be a cleavage flake bounded by the prism faces and the nearly horizontal cross fracture.

TABLE 2. ANGLE TABLE

For reference, the complete angle table for ulexite calculated in the conventional form, is given below.

Triclinic Pinacoidal $C_i^1-P\,\bar{1}$

$a:b:c=0.6855:1:0.5191$

$\alpha=90°16'\quad \beta=109°08'\quad \gamma=105°07'$

$p_0:q_0:r_0\quad 0.7852:0.5080:1$

$\lambda=84°20\frac{1}{2}'\quad \mu=70°05\frac{1}{2}'\quad \nu=73°53\frac{1}{2}'$

$p_0'=0.8351\quad q_0'=0.5403\quad x_0'=0.3466\quad y_0'=0.1048$

Form	ϕ	ρ	A	B	C
c (001)	73°10′	19°54½′	70°05½′	84°20½′	0°00′
b (010)	0°00′	90°00′	73°53½′	0°00′	84°20½′
a (100)	73°53½′	90°00′	0°00′	73°53½′	70°05½′
l (270)	20°42′	90°00′	53°11½′	20°42′	78°18′
h (350)	35°19′	90°00′	38°34½′	35°19′	74°24′
k (230)	37°35′	90°00′	36°18½′	37°35′	73°53′
m (110)	46°05½′	90°00′	27°48′	46°05½′	72°21′
r (530)	55°12½′	90°00′	18°41′	55°12½′	71°20′
L ($7\bar{2}0$)	84°28½′	90°00′	9°13½′	84°28½′	70°28′
N ($3\bar{1}0$)	86°19′	90°00′	12°25½′	86°19′	70°43′
R ($3\bar{2}0$)	99°05′	90°00′	25°11½′	99°05′	72°10′
M ($1\bar{1}0$)	111°02′	90°00′	37°08½′	111°02′	74°23′
K ($2\bar{3}0$)	125°48′	90°00′	51°52½′	125°48′	78°04′
H ($1\bar{2}0$)	136°37′	90°00′	62°43½′	136°37′	81°15′
s ($0\bar{1}1$)	141°29½′	29°06′	79°19′	112°22½′	28°09′
o ($\bar{1}01$)	−105°35′	25°19′	115°15′	96°33′	45°13½′
t ($\bar{1}11$)	− 47°47½′	31°36′	105°58½′	69°23′	45°09½′
p ($\bar{1}\bar{1}1$)	−145°41′	38°57′	118°59′	121°17′	55°38′
d ($\bar{1}21$)	− 25°32½′	46°35′	96°50½′	49°03′	52°29½′
z ($2\bar{3}2$)	112°52′	51°16′	52°40′	107°39′	37°33½′
x ($\bar{5}32$)	− 78°34′	59°25½′	139°46′	80°10′	77°16½′
q ($\bar{2}51$)	− 28°14′	69°23½′	101°36½′	34°27′	74°27½′

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