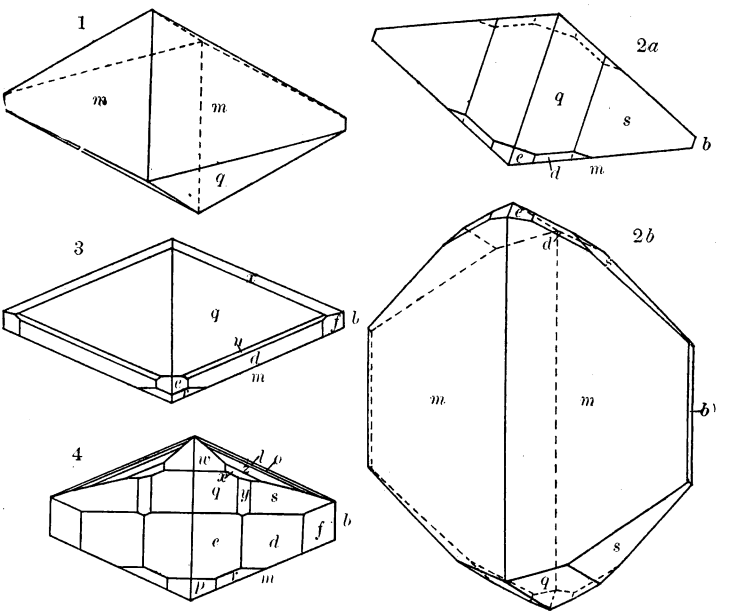
ART. XXXIX.—*Kröhnkite, Natrochalcite (a new mineral), and other Sulphates from Chile;* by CHARLES PALACHE and C. H. WARREN.

THE minerals briefly described in this paper* were sent to the Harvard Mineralogical Laboratory for identification by the Foote Mineral Co. of Philadelphia, whose manager, when the scientific interest of the material was pointed out, at once



placed at our disposition all of the material in his possession with generous permission to use whatever was necessary for the investigation.

The collection comes from the mining district of Chuquicamata in the Province of Antofagasta, Chile. It was obtained from exhausted copper veins and includes the following species: kröhnkite, natrochalcite (a new mineral), blödite, brochantite, atacamite, chalcanthite, copiatite, botryogen, sideronatrite, halite and gypsum.

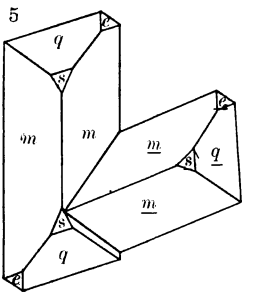
Kröhnkite.

Kröhnkite is the most abundant mineral in the collection and appears in three distinct habits, as follows:

* A more extended crystallographic description of this material will appear hortly in Zeitschrift für Krystallographie.

Phase a.—Clusters of octahedroid crystals of the type of figure 1 but mostly in twin groups, the crystals firmly aggregated to a highly cellular mass, largely infilled with an earthy yellow iron sulphate which may be copiapite. These crystals reach a diameter of 1·5^{cm} and are of a dull greenish blue color with smooth but lusterless faces.

Phase b.—Single crystals and fibrous or acicular aggregates of pale blue color, implanted on the white quartzose vein material. The crystals are slender prisms with the forms of figure 1 but with the prism largely developed and its planes much curved and facetted through the presence of steep vicinal pyramids. Single crystals reach a length of 4^{cm}.



Phase c.—Solid crusts up to 2^{cm} in thickness of deep vitriol blue color, the crystals composing the mass often large and either short or long prismatic, with the forms of figure 2. In cavities on the surfaces of such crusts is a second generation of prismatic crystals of pale blue color, beautifully crystallized and showing the complex combinations of figures 3 and 4. Twin crystals of the type shown in figure 5 are also found on this deep blue material.

The position adopted for the crystals differs from that given by Dana, front and back being interchanged. The axial ratio calculated from measurements on a number of crystals is

$$\dot{a} : \bar{b} : \dot{c} = 0{\cdot}5229 : 1 : 0{\cdot}4357 \quad \beta = 56^\circ\ 17'\ 20''$$

The observed forms are as follows:—a(100), b(010), m(110), h(120), k(130), e(011), d(021), f(031), t ($\bar{1}01$), u($\bar{3}02$), v($\bar{3}01$), p(111), r(121), q($\bar{1}11$), s($\bar{1}21$), w($\bar{2}11$), x($\bar{2}21$), z($\bar{3}31$), i($\bar{5}51$), o($\bar{1}\bar{0}{\cdot}10{\cdot}1$), y($\bar{2}32$), n($\bar{1}32$).

(Tables of measured and calculated angles and combinations will be found in the paper cited above.)

Twinning.—The twin plane is the base, (001). Twins are either contact or interpenetrating, the latter resembling parallel growths owing to peculiarities of angles and distortion.

Cleavage.—Cleavage is perfect and easy parallel to *b*(010) and good but not so easily produced parallel to *c*(011). No trace of a prism cleavage as recorded by Darapsky could be detected. Hardness is a little less than 3, just scratched by the finger nail. Specific gravity is 2·061 (Warren), determined in absolute alcohol and calculated for water at 4°C.

Optical Characters, determined by H. E. Merwin.—The principal indices of refraction, determined by means of the refractometer, are : $\alpha = 1{\cdot}5437$, $\beta = 1{\cdot}5775$, $\gamma = 1{\cdot}6013$ for sodium light. $2V_{na}$ calculated from the refractive indices is 78° 36′; from observation of the acute optic angle in oil 78°42′.

The plane of the optic axes is in the plane of symmetry, with the acute bisectrix for yellow (ether-axis *a*) inclined 48° 45′ to the crystallographic axis *c* in the obtuse angle β. The dispersion, as determined by the colored hyperbolas of interference figures, is inclined. The acute bisectrix for blue is nearer *c* than the bisectrix for red. The optic axes also are slightly dispersed, more for blue than for red, as indicated by broader color fringes on the hyperbola emerging nearly perpendicular to *c*.

Chemical Composition, with analysis by C. H. Warren.—Analysis of the very pure material available confirms the composition of the mineral as given by earlier writers.

$$CuSO_4.Na_2SO_4 + 2H_2O.$$

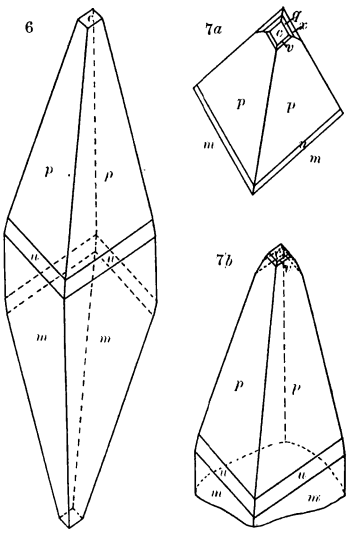
Most of the water is given off below 150°. Small additional amounts continue to come off up to 350°, when dehydration is complete. The residue may be brought to complete fusion without further decomposition, yielding a bright green enamel.

	Per cent.	Mol. Ratio.		Theory.
CuO	23·25	·292	·98	23·49
Na_2O	18·89	·304	1·02	18·39
SO_3	47·60	·595	2·00	47·44
H_2O	10·72	·595	2·00	10·68
Atacamite	trace			
	100·46			100·00

Paragenesis.—Kröhnkite is the most abundant sulphate in these specimens and the first to be formed. Atacamite alone of the few associated minerals may be older, thin crusts of it sometimes lying between the kröhnkite and the vein matrix. Crystals of kröhnkite also show occasional inclusions of copiapite, brochantite and atacamite; none of the other minerals mentioned above as occurring in the collection is found with kröhnkite.

Natrochalcite, a new mineral.

Bright emerald-green crystals of what proves to be a new hydrous double sulphate of copper and sodium were found on several specimens. The crystals are either isolated or in closely adhering crusts upon the white vein matrix; in one specimen they are embedded in chalcanthite and doubly terminated crystals were obtained by carefully breaking away the enclosing blue vitriol. The mineral is monoclinic with a striking pyramidal habit, shown in figure 6; the crystals attain a length of about 1^{cm} and are generally attached to the matrix in such a way that portions of both prism and pyramid are developed;



an oscillatory striation parallel to intersection edge of these forms, due to the development of steeper pyramids between them, is generally well marked. A small basal pinacoid and the other faces shown in figure 7, but of minute size, are generally present. The faces proved to be of good quality in most cases and the measurement of six crystals, mostly very small and one of them doubly terminated, yielded satisfactory data for calculation of the elements. For this purpose 45 faces of seven forms were available.

$$p_0 = \cdot 8526 \qquad q_0 = 1\cdot 065 \qquad \mu = 61^\circ\ 17'\ 30''$$

from which was calculated

$$\dot{a} : \bar{b} : \dot{c} = 1\cdot 423 : 1 : 1\cdot 214 \qquad \beta = 61^\circ\ 17'\ 30''$$

The table contains the forms found, the angles calculated from the elements and the observed angles with their range of variation. It will be seen that the calculated and observed angles show a very satisfactory agreement.

Natrochalcite.—Table of Angles.

		Calculated.		Measured.		Limits.		No. of faces
		ϕ	ρ	ϕ	ρ	ϕ	ρ	
c	001	90°00′	28°42′	90°00′	28°41′	.....	28°39′ 23°42′	3
b	010	00 00	90 00	00 00	90 00	.....	.....	4
m	110	38 41	90 00	38 41	90 00	38°40′–38°43′	.....	12
p	111	51 23	62 47	51 23	62 47	51 15–51 31	62°45–62 50	11
v	112	59 35	50 10	59 35	50 09	59 28–59 44	50 07–59 12	3
u	221	45 45	73 58	45 55	73 39	45 41–46 01	73 14–74 11	5
w	331	43 34	78 45	43 35	78 55	.....	.....	1
q	$\bar{1}11$	$\bar{1}\bar{9}$ 16	52 08	$\bar{1}\bar{9}$ 16	52 08	19 12–19 20	52 06–52 10	7
x	$\bar{2}21$	$\bar{2}\bar{9}$ 54	70 21	$\bar{2}\bar{9}$ 56	70 17	29 50–30 04	70 13–70 21	5

The habit of the crystals is always dominated by the forms chosen as prism and pyramid, *m* and *p*; all other forms are developed with but small faces and often without the full number of their faces.

Cleavage.—Cleavage is perfect and easy parallel to the base, (001). Hardness 4·5, scratching fluorite easily and not scratched by it. Specific gravity 2·33, determined by Warren.

Optical Characters determined by H. E. Merwin.—The principal indices of refraction, determined by means of the reflectometer, and the optic angle for sodium light, are as follows: $\alpha = 1{\cdot}6491, \beta = 1{\cdot}6555, \gamma = 1{\cdot}7143$. $2V_{na}$, calculated from the refractive indices, 36° 52′; by observation of obtuse optic angle in oil, 36° 48′.

The plane of the optic axes is in the plane of symmetry, the acute bisectrix for yellow being inclined to the crystallographic axis $\dot{c}$ 12° in the acute angle β. The acute bisectrix is the axis *c*; the mineral is therefore optically positive. Dispersion of the optic axes is strong, the acute optic angle for the strongest blue rays transmitted by cobalt glass being 3° greater than the corresponding angle for yellow. There is also a slight inclined dispersion of the acute bisectrix, that for blue lying nearer $\dot{c}$ than that for red.

Chemical Composition.—The composition of the mineral may be expressed by the formula

$$Na_2SO_4.Cu_4(OH)_2(SO_4)_2 + 2H_2O.$$

The water is given off gradually on continued heating above 150°. The mineral decomposes and gives off SO_3 between 350° and incipient redness. Before the blowpipe it decrepitates and fuses very easily (about 1) to a black bead. Gives off acid water in closed tube, fusing to a dark enamel. It is very slowly dissolved by water and easily by acids.

The analysis which follows was made on less than one gram of material and is not wholly satisfactory to Dr. Warren, the analyst; lack of available substance, however, except at the expense of one of the two remaining specimens, made it seem well to publish it as it stands, subject to revision later should more of the mineral be discovered.

	Per cent.	Mol. Ratio.		Theory.
CuO	41·95	·528	4·00	42·08
Na_2O	8·44	·136	1·03	8·24
SO_3	42·10	·526	4·00	42·51
H_2O	7·70	·427	3·23	7·17
Insoluble res.	·70			
Cl from atacamite	·05			
	100·94			100·00

Paragenesis.—Natrochalcite does not occur with kröhnkite in these specimens, but takes its place, bearing the same age relations to atacamite and brochantite which occur sparingly with it. As above mentioned, it is embedded in chalcanthite in one specimen.

Blödite.—Blödite was identified by the following analysis. It is a massive granular form of the mineral, white where not stained blue by chalcanthite or pale green by finely divided atacamite. It showed no trace of crystalline form. In one specimen it was accompanied by halite and kröhnkite.

Composition, analysis by C. H. Warren:

	Per cent.	Mol. Ratio.		Theory.
MgO	12·00	·300	1·00	11·48
Na_2O	18·20	·296	0·98	18·56
SO_3	47·49	·593	1·98	47·90
H_2O	21·60	1·20	4·00	21·56
Insol.-atacamite and quartz,	·50			
	99·70			100·00

leading to the usual formula, $MgSO_4.Na_2SO_4+4H_2O$.

Of the remaining minerals listed on the first page as occurring in this material there is little to note of special interest. Brochantite is sparingly present in acicular crystals implanted on or surrounded by kröhnkite. Atacamite is in green and deep blue-black crystals of ordinary prismatic and tabular habits; also in crystals elongated parallel to the brachyaxis with nearly equal development of the forms *m*, *e*, *r* and *n*. Chalcanthite is in the form of granular crusts, copiapite and botryogen in granular masses of no distinct form and sideronatrite in yellow needles. Halite in small cubes was present on one specimen of blödite and gypsum is shown in a coarse granular form saturated with finely divided hematite and also in aborescent crystallizations of snow-white color, closely resembling cave-formations of calcite.

Cambridge, June, 1908.