On the identity of Neocolemanite with Colemanite.

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THE beautiful crystals of colemanite from the Death Valley, Inyo County, and from the Calico district, San Bernardino County, California, were described almost simultaneously in the autumn of 1884 by several different observers.[1] The most complete examination we owe to Jackson, who identified forty-two forms and determined the axial ratios which are usually accepted for the mineral, namely, $a:b:c = 0{\cdot}774843:1:0{\cdot}540998:\beta = 110^\circ\ 9'\ 15''$. Very similar values for these constants were adopted by Hiortdahl and by vom Rath.

In 1902 Eakle[2] published a full account of the measurements made by him with the two-circle goniometer on a number of good crystals, some of which had already been examined by Jackson. In order to render two-circle methods more intelligible to his readers he appended to his description of the crystals an account of the principles underlying this mode of treatment, with full examples of the necessary calculations. As the result of this work, thirteen new forms were added to the list, making fifty-five in all, and the values of the position-angles ϕ and ρ were tabulated for forty-seven of these. The crystals were set up with the zone-axis of the prism-zone, [100,010], parallel to the axis of the vertical circle, and the following axial ratios[3] were adopted, $a:b:c = 0{\cdot}7768:1:0{\cdot}5430$; $\beta = 110^\circ\ 7'$.

In 1911 Eakle[4] described a borate from Lang, Los Angeles County,

[1] A. W. Jackson, Bull. Calif. Acad. Sciences, 1885, No. 2, pp. 2–36, and 1886, No. 4, 358–365; T. Hiortdahl, Zeits. Kryst. Min., 1885, vol. x, pp. 25–31; C. Bodewig and G. vom Rath, ibid., pp. 179–186; A. Arzruni, ibid., 272–276.

[2] A. S. Eakle, Univ. Calif. Publ. Bull. Dept. Geol., 1902, vol. iii, pp. 31–49.

[3] All the angles of colemanite quoted in this paper have been computed from these constants.

[4] A. S. Eakle, 'Neocolemanite, a variety of colemanite, and howlite from Lang, Los Angeles County, California,' Univ. Calif. Publ. Bull. Dept. Geol., 1911, vol. vi, pp. 179–189.

California, of which he says: 'The borate is known as colemanite, and in its chemical composition and general physical properties it agrees with the colemanite from the Death Valley and Calico district, but in its optical and crystallographic properties it is somewhat different, so the name *neocolemanite* is proposed to distinguish it as a variety of colemanite.'

It would appear, however, that Eakle's measurements are capable of a different interpretation to that put upon them by him, and it is the object of this communication to show that by a change in the orientation adopted for the crystals the properties of neocolemanite can be brought into complete harmony with those of colemanite. In order to demon-

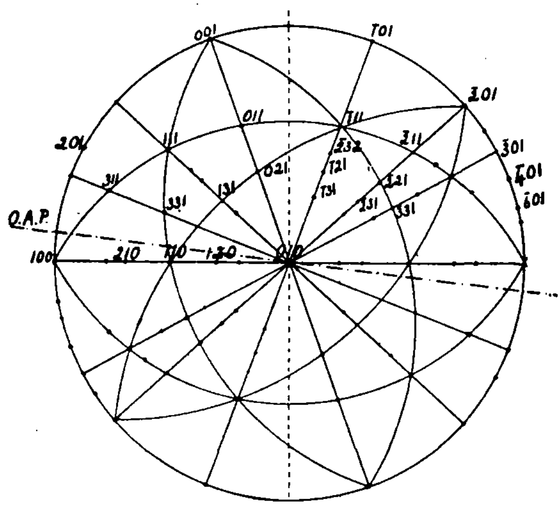

FIG. 1.—Stereogram of Colemanite.

strate this identity it will be necessary to give first a brief description of the crystallography of colemanite and of neocolemanite, and then to proceed to a comparison of the two.

Colemanite.

The poles of a number of the fifty-five forms observed on this mineral are marked on the accompanying stereogram (fig. 1), and the corresponding indices are inscribed against one pole of each of the forms of common occurrence, as well as of one form {331} which is but rarely met with. The projection has been made on the plane of symmetry, as this position is best adapted for exhibiting the interesting zonal relations of the substance.

It will be observed in the first place that the faces (001) and $(\bar{1}01)$ are about equally inclined to the vertical axis, and that the angles (010): (011) = 62° 59′ and (010):(021) = 44° 26½′ are approximately the same as $(010):(\bar{1}11)$ = 63° 4½′ and $(010):(\bar{1}21)$ = 44° 33′. This relation was observed and commented on by all previous workers and led to the suggestion that the crystals might be referred to a set of nearly rectangular axes.

Another relation, which appears, however, to have escaped attention hitherto, is the similarity of the angles (001):(100) = 69° 53′ and $(001):(\bar{2}01)$ = 68° 25′, coupled with the approximate equality of the angles measured in the two zones [010, 100] and $[010, \bar{2}01]$. Thus we

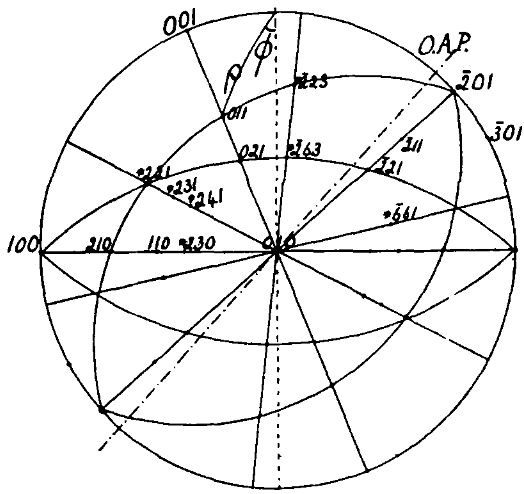

FIG. 2.—Stereogram of Neocolemanite.

have (010):(110) = 53° 53½′ and (010):(210) = 69° 58′, while (010): $(\bar{2}21)$ = 54° 9′ and $(010):(\bar{2}11)$ = 70° 8½′. This similarity suggests another possible arrangement of nearly rectangular axes, $(40\bar{1})$ being taken as (100), but owing to the resulting complexity of the indices such a selection offers no advantages. Further, it will be noticed that while the face (201) is present there are no other forms developed in the zone [010, 201]..

The mineral has an excellent cleavage parallel to the plane of symmetry, (010), and also possesses a less perfect, but distinct, cleavage parallel to (001). The plane of the optic axes is perpendicular to the plane of symmetry and makes an angle of approximately 84° with the vertical axis in the obtuse axial angle, its trace, shown by a broken line in fig. 1, being coincident with the acute bisectrix.

Neocolemanite.

On the crystals from Lang, Los Angeles County, Eakle observed eighteen forms, of which eleven were identified with known forms of colemanite, but seven were described as new. The positions of the whole of these forms are shown on the stereogram[1] (fig. 2), the indices of the seven new ones being prefixed by an asterisk.

If now we compare the development of these crystals with those of colemanite we notice at once certain very characteristic differences. In the first place the zone [201,010], which, as we have seen, is not developed in colemanite, is well represented in neocolemanite by the three new forms {221}, {231}, and {241}. Another new zone contains the forms {$\bar{2}$23} and {$\bar{2}$63}. On the other hand, the important zones [010,101] and [010,$\bar{1}$01] of colemanite are unrepresented in neocolemanite.

Ten good crystals were measured by Eakle on the two-circle goniometer, and the angles he observed are quoted in the following table (table I), together with the calculated angles given by him in 1902 for the eleven known forms.

On comparing the two sets of values it will be seen that a moderate degree of concordance prevails except in the case of the faces (001), (011), and (021). For (001) the value of ρ is considerably too great, while both ϕ and ρ lie well outside the limits of experimental error for the other two forms. On this point Eakle writes as follows: 'It was evident from the first crystal measured that the angles ϕ and ρ for the clinodomes and base were greater than those for colemanite, indicating that the vertical axis was longer and the forms steeper. This variation was constant for all crystals, and the lowest values of ϕ and ρ were higher than the greatest values for the corresponding faces on colemanite.' This discrepancy led Eakle to assign to neocolemanite the axial ratios, $a:b:c = 0{\cdot}7771:1:0{\cdot}5492$; $\beta = 111^\circ\ 40'$; and if these constants are adopted, the calculated values of ϕ and ρ agree very closely indeed with those determined by measurement.

[1] The stereograms, figs. 1 and 2, are on the same scale and have been reduced from accurate projections 20 cm. in diameter. Since the plane of projection is the plane of symmetry, each dot may be taken to represent two faces, one in the northern hemisphere and one vertically below it in the southern.

Table I.

Form.	Neocolemanite.		Colemanite.	
	Measured.		Calculated.	
	φ	ρ	φ	ρ
001	90° 00′	21° 40′	90° 00′	20° 07′
010	0 00	90 00	0 00	90 00
100	89 58	90 00	90 00	90 00
110	54 09	90 00	53 53	90 00
210	70 08	90 00	69 58	90 00
230	42 41	90 00	—	—
021	19 58	49 22	18 38	48 54
011	35 53	34 07	34 00	33 13
$\bar{3}01$	$\overline{90}$ 00	62 00	$\overline{90}$ 00	61 49
$\bar{2}01$	$\overline{90}$ 00	48 15	$\overline{90}$ 00	48 18
241	41 10	71 09	—	—
231	49 20	68 25	—	—
221	60 12	65 43	—	—
$\bar{6}61$	$\overline{51}$ 32	79 39	—	—
$\bar{2}21$	$\overline{45}$ 52	57 31	$\overline{45}$ 56	57 22
$\bar{2}23$	$\overline{16}$ 47	20 50	—	—
$\bar{2}63$	5 24	47 47	—	—
$\bar{2}11$	$\overline{63}$ 59	51 21	$\overline{64}$ 11	51 16

Another important difference between the two substances is the position of the plane of the optic axes, which in neocolemanite is inclined at an angle of about 42° to the vertical axis in the acute axial angle. With these exceptions the properties of neocolemanite agree with those of colemanite, and Eakle concludes his account of the former mineral with the remark: 'The analysis of the mineral shows that it does not differ from colemanite in composition, so the indicated morphotropy in the vertical direction is not due to a chemical replacement or change. The variety is simply an allotropic modification of colemanite brought about by a possible difference in the mode of crystallization.'

Identity of Neocolemanite and Colemanite.

That a mineral so beautifully crystallized and so definite in composition as colemanite should exist in two forms, at once so similar in many respects and so different in others, appeared to the writer a phenomenon worthy of some attention, for it seemed not impossible that a change in the orientation of the crystals might perhaps bring the properties of the two substances into harmony. This idea had evidently been present to Eakle, for he says: 'If the neocolemanite is reversed in position so that all the positive forms become negative and vice versa, then the readings would correspond closer to those for forms on colemanite . . . .' He rightly concludes, however, that this suggestion cannot be entertained, for he adds: 'the two minerals have a similar basal cleavage, and it was by this cleavage that the crystals were oriented.'

In offering an alternative explanation we must, therefore, bear in mind that there can be no doubt as to the correct identification of the zone [010, 001] in the two minerals, and we have accordingly to face the difficulty presented by the great discrepancies in the values of the angles ϕ and ρ for the faces (011) and (021). This difficulty is, however, more apparent than real, and depends on the circumstance that the two-circle measurements given by Eakle, though perfectly accurate in themselves, do not exhibit the important zonal relations of the crystals, but indeed only too effectually conceal them! Taking, on the one hand, the measured angles ϕ and ρ observed on neocolemanite, and, on the other hand, the axial ratios of colemanite adopted by Eakle, we will calculate the angles (010):(011) and (010):(021) for both minerals. The result is as follows:

Neocolemanite, $(010):(011) = 62^\circ\ 58'$; $(010):(021) = 44^\circ\ 30'$.

Colemanite, $(010):(011) = 62^\circ\ 59'$; $(010):(021) = 44^\circ\ 26\frac{1}{2}'$.

The agreement is excellent, and disposes of the view that there is any abnormal angular development in this zone.

Further, since the neocolemanite angle $(001):(100) = 68^\circ\ 20'$ is very near to the colemanite angle $(001):(\bar{2}01) = 68^\circ\ 25'$, the idea suggests itself that an explanation of the anomalous properties of the former substance is to be sought in the great similarity of the two zones of colemanite [010, 100] and [010, $\bar{2}$01]. This similarity has already been remarked upon above, and it is obvious that it may readily become a dangerous source of confusion.

To test this view, let us begin with a crystal of neocolemanite in the position of fig. 2, and let us rotate it through 180° about the normal to the (001) face. When this is done the face (100) (neocolemanite) comes into the position occupied by the face ($\bar{2}$01) (colemanite); (010) and (0$\bar{1}$0) change places, while the forms {210}, {110}, and {230} become coincident with {$\bar{2}$11}, {$\bar{2}$21}, and {$\bar{2}$31} respectively. At the same time, the forms {221}, {231}, and {241} (neocolemanite) fall into the positions occupied by {$\bar{1}$11}, {$\bar{2}$32}, and {$\bar{1}$21} (colemanite); {$\bar{2}$23} and {$\bar{2}$63} become {111} and {131}; {$\bar{2}$11} and {$\bar{2}$21} become {210} and {110}; the face (301) becomes (60$\bar{1}$); and finally {$\bar{6}$61} becomes {331}.

This identity can be convincingly demonstrated by means of the two stereograms, for if a copy of fig. 2 be made on tracing paper and the paper be then reversed, back to front, and applied to fig. 1, so that the poles of (001) are coincident, the truth of the above statements can easily be verified. Further, it will be seen that the new orientation brings the optic axial plane of neocolemanite into coincidence with that of colemanite, an inclination to the vertical of 42° in the acute axial angle of neocolemanite being the equivalent of an inclination of 83° 47′ to the vertical axis in the obtuse axial angle of colemanite.

Table II.

Neocolemanite.				Colemanite.				
		Angle on 010.	Angle on 001.	Angle on 010.	Angle on 001.			
b	010	—	90° 00′	—	90° 00′	010	*b*	common
c	001	90° 00′	—	90° 00′	—	001	*c*	,,
κ	011	62 58	27 2	62 59	27 1	011	*κ*	,,
a	021	44 30	45 30	44 26½	45 33½	021	*a*	,,
h	$\bar{2}01$	90 00	69 55	90 00	69 53	100	*a*	,,
o	$\bar{2}11$	69 58	71 11	69 58	71 9	210	*t*	,,
v	$\bar{2}21$	54 2	73 52	53 53½	73 52	110	*m*	,,
*𝔴	$\bar{2}23$	70 5½	33 50	70 2	33 49	111	*β*	,,
*𝔟	$\bar{2}63$	42 30	53 21	42 32	53 18½	131	*ω*	frequent
*𝔞	221	63 4	47 39	63 4½	47 34	$\bar{1}11$	*y*	common
*𝔯	231	52 42	53 3	52 42	52 59½	$\bar{2}32$	*r*	frequent
*𝔢	241	44 34	57 58½	44 33	57 56	$\bar{1}21$	*d*	common
a	100	89 58	68 20	90 00	68 25	$\bar{2}01$	*h*	,,
t	210	70 8	69 41	70 8½	69 45½	$\bar{2}11$	*o*	,,
m	110	54 9	72 85	54 9	72 39	$\bar{2}21$	*v*	,,
*𝔩	230	42 41	75 30	42 42	75 33	$\bar{2}31$	*ϵ*	frequent
*𝔮	$66\bar{1}$	52 16	83 15½	52 25½	83 37	$\bar{3}31$	*q*	rare
W	$80\bar{1}$	90 00	96 20	90 00	96 24½	$\bar{6}01$	*U*	frequent

* Indicates the new forms.

To further demonstrate the correctness of this explanation, the angles which all the faces of neocolemanite make with the two cleavage-planes (010) and (001) have been calculated from the observed values of ϕ and ρ published by Eakle; and these have been tabulated for comparison with the angles made with the same two cleavage-planes, by those faces of colemanite with which the neocolemanite faces become coincident when the crystals of the latter mineral are rotated about the normal to (001) in the manner described above. The results of these calculations are given in table II, in which are arranged: (i) the letters and indices assigned to the forms of neocolemanite, together with the angles made by the faces of these forms with the planes (010) and (001) respectively; (ii) the letters, indices, and angles of the forms of colemanite with which the neocolemanite forms are identical; (iii) a statement as to the relative frequency of occurrence of the various forms of colemanite taken from the writings of Eakle and Jackson.

A glance at the table shows an extraordinary degree of concordance between the two sets of figures. In but three instances does the divergence exceed 5′, and the most pronounced discrepancy occurs, as it happens, in the case of the form *q* (colemanite), the only one of the whole eighteen which is of rare occurrence, and for which the tabulated values of ϕ and ρ represent but one observation. With this exception, the new forms of neocolemanite are seen to be planes of common occurrence on colemanite and to exhibit identical angular relations—an indirect but valuable testimony to the accuracy of Eakle's goniometric observations.

Conclusions.

The results of this investigation may then be briefly summarized as follows:

1. The crystallographic and optical properties of neocolemanite can be brought into harmony with those of colemanite by a change in the orientation of the crystals.

2. This is brought about by rotating the neocolemanite crystals through 180° about the normal to the cleavage-plane (001).

3. This rotation brings the new forms $\{221\}$, $\{231\}$, $\{241\}$, $\{\bar{2}23\}$, $\{\bar{2}63\}$, $\{66\bar{1}\}$, and $\{230\}$ into coincidence with well-known forms of colemanite $\{\bar{1}11\}$, $\{\bar{2}32\}$, $\{\bar{1}21\}$, $\{111\}$, $\{131\}$, $\{\bar{3}31\}$, and $\{\bar{2}31\}$.

4. At the same time the optic axial planes also become coincident.

5. The name neocolemanite and the special axial ratios assigned to it are therefore unnecessary.