PLATE 15

Colemanite pseudomorphous after inyoite from Death Valley, California

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COLEMANITE PSEUDOMORPHOUS AFTER INYOITE FROM DEATH VALLEY, CALIFORNIA

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The frontispiece of this number is a photograph of an interesting specimen presented to the geology department of Stanford University by the late Mr. C. A. Waring of the California State Mining Bureau. This, and a similar specimen in the department museum collected by Mr. H. P. Knight, are from the Biddy McCarty mine of the Pacific Coast Borax Company in Death Valley, Inyo County, California. The specimen shown in the photograph was labeled in the field "colemanite after calcite," while the other specimen was labeled "rare form of calcium borate."

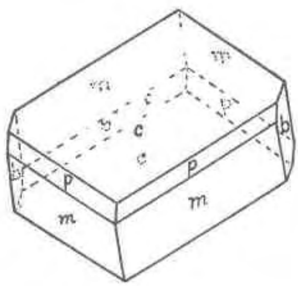

FIG. 1. Form of original inyoite.

CRYSTAL FORM

The material of both specimens proves to be colemanite, but the original mineral was inyoite, a hydrous calcium borate recently described by Schaller[1] from the same region. The crystals, on close examination, prove to be monoclinic instead of hexagonal as at first supposed. The forms present are: *c* (001), *m* (110), *b* (010), and *p* (111). The habit is tabular parallel to *c* (001) as represented in Fig. 1. The following inter-

[1] *U. S. Geol. Survey, Bull.* **610**, 37, 1916.

facial angles, (each the average of ten values with the limits stated) were measured with a contact goniometer:

Angle	Limits	Average	Schaller's Value
$m : m$ (110 : 1$\bar{1}$0)	$77\frac{2}{3}°–79\frac{1}{2}°$	78° 21′	79° 45′
m : c (110 : 001)	71 –72	71 36	69 20
b : c (010 : 001)	$88\frac{2}{3}$ –$90\frac{1}{2}$	89 34	90 0
a : c (edge 110/1$\bar{1}$0 : 001)	$63\frac{1}{3}$ –$65\frac{5}{6}$	64 31	62 37
$m : p$ (110 : 111)	37 –39	37 57	36 15
$c : p$ (001 : 111)	$32\frac{2}{3}$ –35	33 54	33 5

These measurements clearly prove that the form is that of inyoite, but it is believed that the average angles given are closer to the truth than those given by Schaller, in spite of the fact that the crystals are pseudomorphs. The crystals are very sharp and well defined, and the faces for the most part are fairly smooth.

Graphic Determination of Geometrical Constants of Inyoite

The measured angles will furnish on calculation the geometric constants to the fourth or fifth decimal place, but as the angles are only approximate, a better method is to determine these constants graphically. For this purpose the gnomonic projection is well suited. Figure 2 shows the procedure. The Penfield sheets for stereographic projection may be employed, as scale No. 2 of these sheets (shown at the bottom of Fig. 2) gives directly tangents of angles.

The projection is made on a plane perpendicular to the [100 : 110 : 010] zone, so that the center of the circle is the projection of the c-axis. The b-axis is projected along the line Bz and the a-axis (foreshortened) along the line Az. The pinacoid b (010) is projected at infinity in the direction of the radius zB. One-half the (110 : 1$\bar{1}$0) angle is laid off on the divided circle to the right. The point V is thus established. The unit prism m is projected at infinity. It is indicated by drawing a radius thru V. Next the point c (projection of 001) is located by plotting the tangent of the complement of the angle, 64° 31′ (β) from z along the zone line Az. Thru c the zone line Mcp is drawn parallel to zV. This line contains the point p, not yet located. Angles along a zone line may be plotted by finding what is called the *angle point of the zone.*

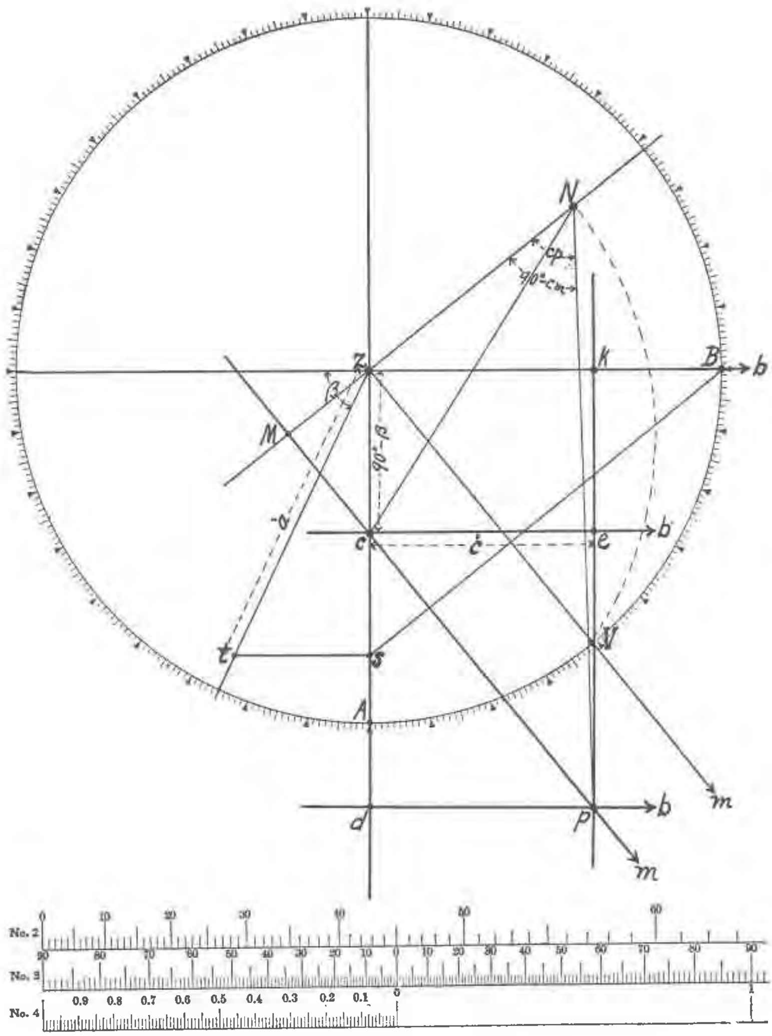

FIG. 2. Graphic determination of constants of inyoite.

With radius MV and center at M an arc of a circle is drawn, which cuts the line thru M and z at N, the angle point of the zone. Nz in stereographic degrees (scale No. 3) is the complement of Mz in gnomonic degrees (scale no. 2). The angle cNp equal to cp (33° 54′) is laid off and thus the point p (projection of 111) is determined. It was found that the angle MNc gave a point on the line zd not quite coincident with the point on the same line established by the complement of the angle β (001 : 100), so that c (001) was taken half way between the two points and in this way an average value of β was obtained.

The zone line pk is next drawn, parallel to Az, and thus e, the projection of a possible face (011), is determined by the intersection of pk with the zone line thru c parallel to Bz. Similarly a zone line pd parallel to Bz thru the point p establishes d, the projection of a possible face (101).

A line thru B perpendicular to Vz determines the distance zs, which is the foreshortened unit length of the a-axis. The true value of a is found by drawing a line from z at an angle of 65° (graphically determined β) from the line Bz. A perpendicular to the left from s determines the point t and the distance zt is axis $\grave{a}$, in terms of the radius of the circle (use scale No. 4). The unit length of the c-axis is the distance ce in terms of the radius.

The writer,[2] in an article published in 1907, treated the gnomonic projection from a graphical standpoint, but the method of finding the value of the $\grave{a}$-axis (in the monoclinic system) indicated above is simpler than the one given in that paper.

The graphically determined geometrical constants thus found for inyoite are $\grave{a} : b : \grave{c} = 0.90 : 1 : 0.63$; $\beta = 65°$. These values should replace those given by Schaller, which are expressed in four decimal places, altho the angular measurements are confessedly approximate values, obtained by means of the contact goniometer and each the average of from four to six measurements given only to degrees. This use of graphic methods to determine geometrical constants from approximate measurements has not to my knowledge been emphasized before.

Identification of Pseudomorphous Mineral

Chemical Tests. The mineral now constituting the specimens in question gives qualitative tests for the borate radical and for

[2] *School Mines Quart.*, **29**, 24–33, 1907.

calcium.[3] It is soluble in hydrochloric acid with the separation of boric acid. The mineral also gives water when heated in the closed tube. These chemical tests, however, do not differentiate colemanite from the other hydrous calcium borates: meyerhofferite, $Ca_2B_6O_{11}.7H_2O$, inyoite, $Ca_2B_6O_{11}.13H_2O$, and priceite,[4] $Ca_5B_{12}O_{23}.9H_2O$.

Crystal Form.—A few small crystals were found. They prove to be monoclinic with good cleavage parallel to the symmetry-plane (010). The forms are *m* (110) and *y* ($\bar{1}$11), with interfacial angles very close to those of colemanite. This habit, tho very simple, seems to be a new one for this mineral.

Optical Tests.—Now, even the crystal form and chemical composition taken together are not always sufficient to determine a mineral, for there is the possibility of paramorphism[5] as the writer has recently shown in the case of the silica minerals.[6] Some physical property needs to be determined, in addition to the crystal form and chemical composition. Of all the physical properties, the most satisfactory ones for minerals that transmit light are optical properties, and of these the indices of refraction are the most fundamental. Crushed fragments of the mineral have the following indices of refraction:[7] $n_1(n_\gamma) = 1.615 \pm 0.001$, $n_2 n_\beta = 1.595 \pm 0.001$. These indices are greater than those of the other three calcium borates, and prove conclusively that the mineral in question is colemanite.

Alteration of Inyoite to Colemanite.—The formation of colemanite at the expense of inyoite involves merely dehydration. The alteration of inyoite to meyerhofferite, $Ca_2B_6O_{11}.7H_2O$, described by Schaller[8] from the same region is a similar change. Of the three hydrates of $Ca_2B_6O_{11}$, colemanite, the pentahydrate, seems likely to be the most stable under atmospheric conditions in arid regions, such as Death Valley.

[3] As calcium is precipitated when the acid solution is made alkaline with ammonium hydroxid, the best test for calcium is to precipitate it as $CaSO_4.2H_2O$ with dilute sulfuric acid in the presence of 50 per cent. ethyl alcohol. This also furnishes the best test for calcium in phosphates.

[4] Larsen (*Am. Min.* **2**, 1, 1917) has shown that priceite is a distinct mineral.

[5] A paramorph is a pseudomorph of one polymorphous form of a substance after another. Polymorphism seems to be a general phenomenon of nature.

[6] Silica in the form of tridymite from Tuolumne County, California, proved to be cristobalite paramorphs after tridymite. *Am. J. Sci.* [4], **45**, 222, 1918.

[7] The fragments are cleavage plates parallel to (010), so that the minimum value of the index of refraction (n_α) is not obtained.

[8] *Place cited.*