Art. V.—*The Crystallography of Hydromagnesite;* by Austin F. Rogers.

Although hydromagnesite, hydrous basic magnesium carbonate, [$Mg_4(OH)_2(CO_3)_3.3H_2O$], was described nearly a century ago,[1] its crystal system still remains in doubt. The first work on the morphological side was by J. D. Dana,[2] who assigned it to the monoclinic system with $\beta = 82°\text{-}83°$. Tschermak,[3] however, decided that it crystallized in the orthorhombic system. E. S. Dana[4] referred it to the monoclinic system with $\beta = 90°$. Weinschenk[5] also concluded that it must be monoclinic, but a few years later, Brugnatelli[6] reversed this decision and placed it in the orthorhombic system. More recently Rogers[7] expressed the opinion that it is monoclinic.

While a few authors of treatises and text-books have followed the Danas and Weinschenk in assigning hydromagnesite to the monoclinic system, most of them have given the system as orthorhombic. Apparently, some authorities classify hydromagnesite in the orthorhombic system because β is recorded as 90°. Now β, the angle between the a-axis and the c-axis, is not necessarily an oblique angle. In the monoclinic minerals polybasite, pyrostilpnite, chondrodite, clinohumite, biotite, and xanthophyllite, β is 90°. These minerals are assigned to the monoclinic system because they have the symmetry of the prismatic class ($A_2.P.C$), and except in the case of polybasite the determination is checked by optical tests, especially by the oblique extinction in sections parallel to (010).

The crystal system of hydromagnesite, as the writer will show presently, is monoclinic. But as a matter of fact, the angle β in hydromagnesite is not 90°. Apparent single crystals such as those illustrated by figs. 1-4 are in reality twins with (100) as twinning-plane (as shown in fig. 1*a*). This fact accounts for the assignment of β as

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[1] Wachtmeister, *Ak. H. Stockholm,* **18**, 1827.
[2] System of Mineralogy, 4th ed. p. 456, 1854.
[3] Min. u. petr. Mitth., 1871, p. 113.
[4] System of Mineralogy, 6th ed., p. 304, 1892.
[5] Zs. Kryst., vol. 27, p. 570, 1897.
[6] Abstract in Zs. Kryst. vol. **41**, p. 257, 1906.
[7] Introduction to the Study of Minerals and Rocks, 2nd ed. N. Y., 1921.

90° by E. S. Dana, but why the mineral was placed in the monoclinic system is not clear in the absence of optical data.

A new Locality for Euhedral Hydromagnesite.

A discovery by the writer some time ago of distinctly crystallized hydromagnesite in Alameda County, California, furnishes the geometrical and optical data of this article. The locality is on the southern slope of a hill called Sugarloaf Butte, which is two miles south of the summit of Cedar Mountain and about 16 miles southeast of the town of Livermore, California. Here the hydromagnesite is found in narrow veins in serpentine. The veins have a central space with snow-white crusts from 2 to 10 mm. thick on each side. On the free surface of these crusts, minute euhedral crystals of hydromagnesite are developed.

Fig. 1.

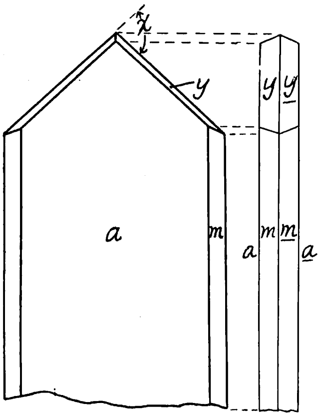
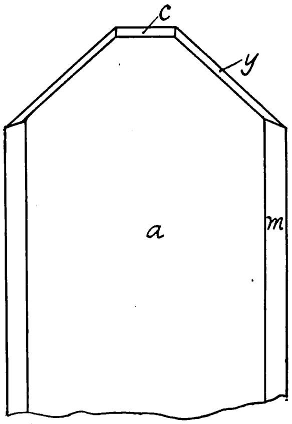


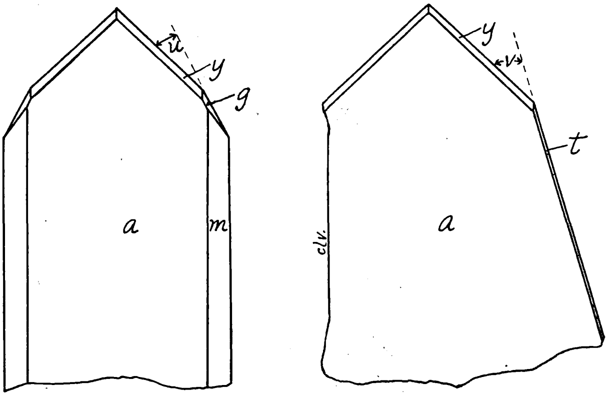
Fig. 2.



Figs. 1, 1a.—Common type of Hydromagnesite crystal with side elevation showing the twin structure; $a = (100)$, $m = (110)$, $y = (011)$.
Fig. 2.—Less common type of Hydromagnesite crystal; $c = (001)$.

Most of the crystals are 0.3 to 0.5 mm. long and from 0.01 to 0.05 mm. thick, but occasionally they reach a length of about 1 mm. Examined on the stage of a polarizing microscope the crystals appear as shown in figs. 1-4. They are tabular in habit with *a* (100) as the dominant form and are more or less elongated in the direction of the *c*-axis. The prominent beveled edge is the *m* (110) face and the terminal face invariably present is the *y* (011) face (Dana = 121). The common type of crystal which consists of these three forms alone is shown in front elevation and side elevation in figs. 1 and 1*a*. Doubly-terminated crystals are exceedingly rare; they are so small that the forms cannot be identified. In addition to the three forms mentioned, three others have been determined. In fig. 2 the form truncating the *y* : *y* edge is *c* (001). In fig. 3, the *g*-face is (021), and fig. 4 shows *t* (041). These faces cannot be measured directly on account of the thinness of the crystal, but the plane angles of figs. 1-4 may be measured on the stage of a polarizing microscope. The angle *x* in fig. 1 was found

FIG. 3. FIG. 4.



FIGS. 3, 4.—Rare types of Hydromagnesite crystals; *g* = (021), *t* = (041)

FIG. 5.

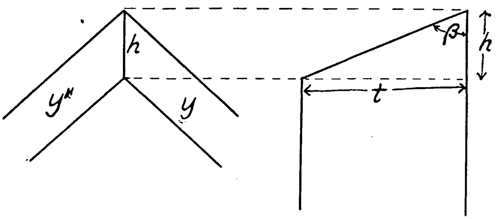


FIG. 5.—Front elevation and side elevation of a portion of a Hydromagnesite crystal.

to be 85° 54′; the calculated value is 85° 50′. This is twice the angle *zl* in the stereographic projection of fig. 6, which was calculated by solving the angle *cay* of the right-angled spherical triangle *cya,* having given the sides *ay* and *cy.* The angle *u* in fig. 3 was found to be 19° 30′, the calculated value being 18° 49′. The angle *v* in fig 4 was found to be 33° 20′, the calculated value being 32° 2′. The angles *u* and *v* were calculated by means of the tangent relations of the angles *zl, zn,* and *zr* in fig. 6.

Fig. 6.

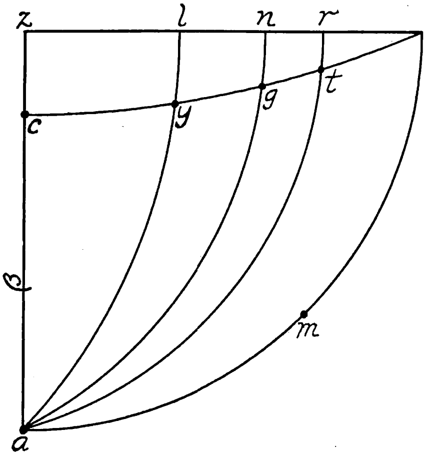


Fig. 6.—Stereographic projection of upper front octant of a Hydromagnesite crystal.

To further prove the identity of our crystals with those described by Dana, an indirect method of measuring the angle between the *c*-axis and the edge *y* : *y′* was devised. In fig. 5, which represents a front elevation and a side elevation of a portion of a hydromagnesite crystal, *t* represents the thickness of the crystal, *h* the trace of the edge *y* : *y′* on a vertical line and *β* the angle between the edge *y* : *y′* and the *c*-axis (vertical line). The distance *h,* measured by means of a micrometer eye-piece, was found to be 0.01 mm., the thickness *t* was found to be 0.023 mm. (determined by observing the interference color and calculation in the formula $\Delta = t\ (n_1\text{-}n_2)$, $n_1\text{-}n_2$ for the (100) section being 0.019). The angle *β*, *h*, and t are connected by the equation: cot. $\beta = h/t$. The value of β was found to be 66° 30′, which checks well with the value for this angle 65° 52′, determined by solving the right-angled spherical triangle *cya* of fig. 6, from the values *ay* (71° 50′) and *cy* (40° 20′) given by E. S. Dana.

This indirect measurement with the direct measurement of the angle x of fig. 1 proves conclusively that the terminal form of our crystals is Dana's y face. There seems to be a remarkable uniformity in the crystal habit and common forms of hydromagnesite from various localities.

Determination of the Geometrical Constants of Hydromagnesite.—Since the writer's work proves that hydromagnesite is monoclinic and since the crystals are invariably twinned, there is no necessity of taking β to be 90°. It is therefore necessary to recalculate the geometrical constants. The interfacial angles given by E. S. Dana[8] may be used in lieu of more accurately determined ones. Dana's y face is taken as (011) instead of (121), while a (100) and m (110) remain the same. The transformation scheme of Dana's indices to those of the writer and *vice versa* is as follows:

Dana	
$p \cdot q \cdot r$	$p\text{-}r \cdot \frac{q}{2} \cdot r$
	Rogers
$h+l .\ 2k\ .\ l$	$h\ .\ k\ .\ l$

The fundamental angles given by E. S. Dana are mm''' $(110 : 1\bar{1}0) = 92°\ 8'$; ay $(100 : 121) = 71°\ 0'$; yy''' $(121 : 1\bar{2}1) = 80°\ 40'$. If we take the symbols of the writer the three fundamental angles become *am* $(100 : 110) = 46°\ 4'$; *ay* $(100 : 011) = 71°\ 50'$, and *cy* $(001 : 011) = 40°\ 20'$. In the right-angled spherical triangle *cya* (fig. 6) we have two sides *ay* and *cy*; solving for the third side *ac* by Napier's rule, we obtain 65° 52′, which is the acute angle β between the a- and c- axes. The axial ratio $a : b : c$ is obtained by solving the following equations: $c/b = \tan(001 : 011)/\sin\ \beta$ and $a/b =$

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[8] System of Mineralogy, 6th ed., p. 304, 1892.

tan (100 :110)/sin β. The following values were obtained: $a : b : c = 1.1374 : 1 : 0.9304$; $\beta = 65° 52'$. Forms present: *a* (100), *m* (110), *c* (001), *y* (011), *g* (021), *t* (041).

Twinning.—When crystals of hydromagnesite are examined in a casual way there is no sign of twinning (see figs. 1-4, for example). But when thin sections cut parallel to (010) are examined every crystal is found to be made up of two or more individual crystals twinned on the (100) face as shown in fig. 7. Polysynthetic twinning is common. Twinning is also apparent in crushed fragments on account of the (010) cleavage. (See *e, f, g, h,* fig. 10.) A side elevation of a twin crystal is shown in ideal development in fig. 1*a*.

FIG. 7.

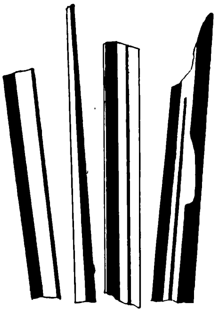

FIG. 7.—Twinned Hydromagnesite crystals, cut parallel to (010), between crossed nicols.

Optical Properties.—Crystals of hydromagnesite such as fig. 1 have parallel extinction with the slower ray in the direction of the *b* axis. The index of refraction for this direction is 1.545 ± .001, which was determined by means of immersion liquids with known indices of refraction, a cell with a saturated solution of potassium bichromate 1 cm. thick being used as a substitute for sodium light in a dark room. As this was found to be the maximum of all values obtained it is the value for n_γ and so $b = \gamma$ and $n_\gamma = 1.545 \pm .001$. The other value of n of crystals parallel to (100) is 1.526 ± .001. As the crystals are monoclinic, the direction of the *c*-axis is not an optic ellipsoid axis, but it may be designated thus: $n_c = 1.526 \pm .001$. The optical orientation of a hydromagnesite crystal is shown in fig. 8. The value n_c is a more important one in determinative work than n_α and n_β, which are obtained with considerable difficulty. The values for n_α and n_β were found to be respectively: 1.523 ± .003 and 1.527 ± .003. The principal indices of refraction, then, are: $n_\alpha = 1.523 \pm .003$, $n_\beta = 1.527 \pm .003$, and $n_\gamma = 1.545 \pm .001$.[9]

Fig. 8.

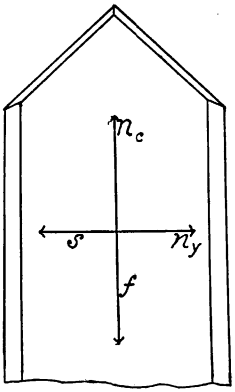

Fig. 8.—Optical orientation of Hydromagnesite crystals.

Since n_β is closer to n_α than it is to n_γ, hydromagnesite is optically positive.

Since $b = \gamma$, α and β are in the plane parallel to (010). Their position may be determined by extinction angles in sections cut parallel to (010). Thin sections of the hydromagnesite crusts, kindly prepared for me by the late W. G. Cooper, formerly assistant in mineralogy at Stanford University, fortunately contained plates cut parallel to (010). These showed polysynthetic twins (tw. pl. = 100) (fig. 7) and in some spots the extinction angles of adjacent twin lamellae were found to be approximately equal, which means that the plates are cut normal to the (100) plane. The maximum of the equal values of extinction angles were determined by means of a sensitive gypsum plate as follows:

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[9] Larsen's (U. S. Geol. Surv., Bull. 697, p. 89, 1921) values are: $n_\alpha = 1.527 \pm .003$; $n_\beta = 1.530 \pm .003$; $n_\gamma = 1.540 \pm .003$. This illustrates the fact that unless considerable care is taken the minimum index obtained may be too high and the maximum one, too low.

Average of 10 angles on one side (varying from 42° 16′ to 43° 28′) = 42° 46′.

Average of 10 angles on the other side (varying from 42° 8′ to 43° 44′) =43° 9′.

Average of these two values = 42° 51′.

Twinned crystals with free ends similar to those of fig. 7 examined with a mica plate show that α is situated between the crystallographic axes a and c. The optical orientation, then, is: $\beta \wedge c = -42° 51'$; $\alpha \wedge c = +47° 9'$; $\gamma = b$. This is shown in fig. 9, which is a diagrammatic representation of a twinned crystal projected on the (010) plane.

Fig. 9.

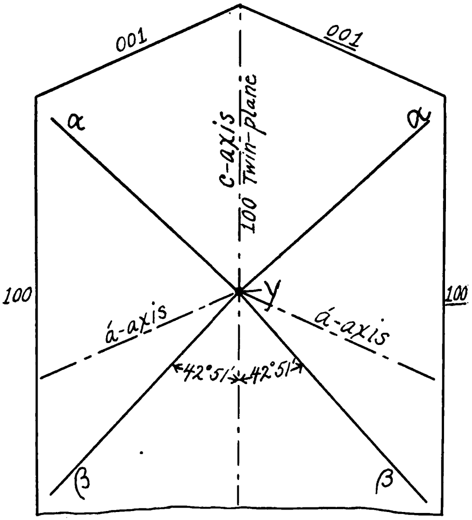

Fig. 9.—Optical orientation of Hydromagnesite. (Section parallel to 010.)

Cleavage and Parting.—Broken crystals of hydromagnesite often show straight edges parallel to the c-axis, which indicates that there is perfect cleavage parallel to (010) as is the case of many other monoclinic minerals. These are shown at a and b in fig. 10. Fragments of hydromagnesite which have been crushed also show narrow plates with parallel extinction as indicated at *c* and *d* (fig. 10). Small and thoroughly crushed crystals show fragments such as *e, f, g,* and *h,* which show polysynthetic twinning, and as the interference colors are uniform these must be cleavage flakes parallel to (010).

Weinschenk describes (100) cleavage in hydromagnesite, but this is probably parting caused by twinning. There is often an abrupt change in the interference colors of broken crystals which is due to a portion of a crystal being broken off parallel to (100) as shown in *i* and *j* (fig. 10).

Fig. 10.

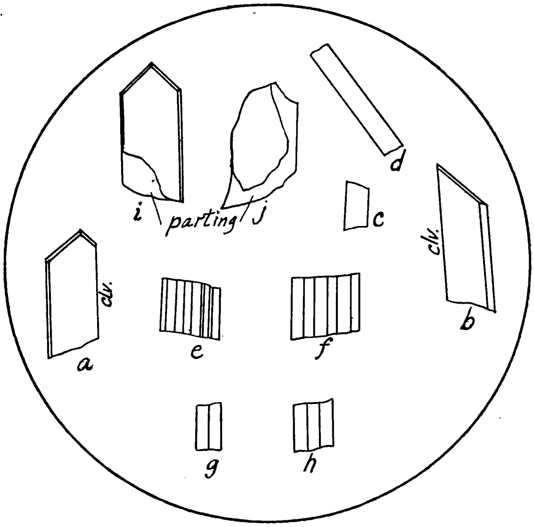

Fig. 10.—Crushed fragments and broken crystals of Hydromagnesite, showing cleavage parallel to (010) and parting parallel to (100).

Hardness.—The hardness of the hydromagnesite crusts is about 3.5.

Specific gravity.—The specific gravity of the hydromagnesite was found to be 2.152. This determination was made on 1.9 g. of material by means of a chemical balance.

Chemical Analysis of Hydromagnesite.—A chemical analysis of a carefully selected sample of the hydromagnesite gave Mr. K. S. Boynton the following results:

		Theory for $4MgO.3CO_2.4H_2O$.
MgO	44.16	44.14
CaO	0.20	
Al_2O_3	*nil*	
Fe_2O_3	*nil*	
CO_2	35.16	36.13
H_2O	20.30	19.72
Insol.	0.05	
Total	99.87	99.99+

Other Occurrences of Hydromagnesite in California.

While by no means a common mineral, hydromagnesite is occasionally found in the serpentine outcrops of the Coast Ranges of California. The following occurrences have come under my notice.

Arroyo Mocho.—On the Arroyo Mocho, about 20 miles southeast of Livermore, hydromagnesite occurs in serpentine in seams like those of the Sugarloaf occurrence. just described except that calcite and aragonite are associates. In thin sections under crossed nicols the mineral shows polysynthetic twinning.

Calaveras Valley.—In the lower end of Calaveras Valley, Santa Clara County, hydromagnesite was found in large masses in serpentine by Mr. Sydney F. Adams. The mineral is apparently amorphous, but under the polarizing microscope it proves to be a crystalline aggregate with optical properties like those of hydromagnesite as nearly as may be ascertained. At this locality the writer has collected small (1 cm.) nodules of hydromagnesite in the serpentine.

Alum Rock Canyon.—In a serpentine outcrop near the lower end of Alum Rock Canyon, which is about five miles west of the city of San Jose, more or less spherical nodules of hydromagnesite 2 to 4 cm. in diameter are found. In thin sections these prove to be crystalline with a fine aggregate structure.

Searsville Lake.—Near Searsville Lake, which is about 8 miles west of Stanford University, hydromagnesite occurs in small white patches in serpentine.

San Benito County.—The writer has collected hydromagnesite in seams in the serpentine near the benitoite mine in San Benito County which is about 25 miles north of Coalinga. In cavities of the seams minute crystals like Figs. 1 and 2 were identified.

Sulphur Creek.—In the region of Sulphur Creek, Colusa County, hydromagnesite as a chalk-like product of the decomposition of serpentine is an abundant mineral according to Kramm.[10] A photograph of a specimen is shown and a chemical analysis of the mineral is given to prove its identity with hydromagnesite.

Summary.

An occurrence of exceptionally fine hydromagnesite in Alameda County, California, proves that this mineral crystallizes in the monoclinic system. The newly calculated geometrical constants are: $a : b : c = 1.1374 : 1 : 0.9034$; $\beta = 65° 52'$. Forms present: *a* (100), *m* (110), *c* (001), *y* (011), *g* (021), *t* (041). The crystals are invariably twinned, the twin-plane being (100).

The optical constants are: $n_\alpha = 1.523 \pm .003$; $n_\beta = 1.527 \pm .003$; $n_\gamma = 1.545 \pm .001$. Optical character, positive. Optical orientation: $b = \gamma$; $c \wedge \alpha = +47° \ 9'$; $c \wedge \beta = -42° \ 51'$.

Other occurrences of hydromagnesite in the serpentines of the Coast Ranges of California are mentioned.

Stanford University,
March 5, 1923.

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[10] Proc. Am. Phil. Soc., vol. 49, p. 344, 1910.