

# CRYSTALLIZED VARISCITE FROM UTAH.

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## INTRODUCTION.

The material on which the following descriptions are based was collected near Lucin, Utah, by Mr. Douglas B. Sterrett, of the United States Geological Survey. A part of the material consists of well crystallized variscite, a condition so unusual for this mineral that it was at first thought to be a new species. The detailed study has shown, however, that the mineral is identical with variscite, and the quantity of material was sufficient to determine all the chief properties of the mineral. Mr. Sterrett brought out a striking property of this mineral by heating a fragment of it before the blowpipe. At a low temperature the vivid green color was readily changed to a deep lavender. The chemical study of the mineral was extended in order to find out if possible the cause of this change, and the various properties of the lavender-colored variscite were studied, as well as those of the green mineral in order, if possible, to correlate the two. The author wishes to express his thanks to Mr. Sterrett for permission to describe this very interesting mineral and for his generosity in furnishing the material needed. The specimens described in this paper are the property of the United States National Museum. (Cat. No. S6993.)

## OCCURRENCE AND GEM QUALITY.

The following notes on the occurrence of the variscite near Lucin, Utah, and of the kind and quality of the gem stones have been taken from the manuscript report on the "Production of precious stones in the United States for 1910," by Douglas B. Sterrett.

The variscite deposits, about 5 miles northwest of Lucin, Utah, are in the northern part of an irregular-shaped hill, called Uthlite Hill. Uthlite Hill is about a mile long in a northwest-southeast direction and about one-half mile wide. It has an elevation of about 5,000 feet above sea level, and rises over 300 feet above the mesas

and gentle slopes at its base and about 500 feet above the railroad at Lucin. Four claims have been located, and these are, in order from northwest to southeast, Utah Gem, Greenback Lode, Utahlite, and Protection Lode. The variscite deposits are in and around small rocky summits standing above the rest of the hill. These summits have cavities and small caverns in them, resembling those made by wave action. They were probably formed on one of the shore lines of the former Lake Bonneville. The work done at the time of examination consisted of an open cut 50 feet long and 2 to 5 feet deep, with several prospect pits.

The rock in which the variscite occurs and which forms the crest of the hill is cherty or chalcedonic quartz which contains inclusions of nodules and streaks of limestone. The limestone inclusions range up to a foot thick and in places are several feet long. The character of most of the rock is that of a hard breccia cemented together by silica. This breccia forms rough rocky ledges and knobs rising from a few feet to 25 feet above the hill slopes. Three of these knobs contain large quantities of variscite.

The variscite occurs in balls, nodules, and irregular masses in the chert. Veins of variscite are not common, but some with a northeast strike and northwest dip were seen on the Utah Gem claim. The nodules and balls of variscite range in size from a fraction of an inch to several inches across, and some of the segregations of variscite inclosing matrix are a foot across. The variscite fills fractured and brecciated zones in the rock, some of which it replaces and some of which it incloses. The replacements are generally rounded concretionary masses, often with a banded concentric structure. The fragments of some of the brecciated rock, especially white quartz, that have been inclosed by and cemented with variscite have remained angular and sharp. Some of the concretionary forms appear to grade from green variscite cores into the inclosing yellow, brown, gray, and white phosphatic and cherty minerals. There is considerable chalky mineral filling cavities in the variscite-bearing rock and coating the nodules and masses of variscite. A quantity of variscite pebbles and cobbles have been found in the open cut in the loose detritus below the main outcrop on the Utahlite claim. These pebbles probably owe their rounded form largely to the nodular shape of the variscite in the original rock, but also probably to some extent to water action on a former lake shore. The pebbles are coated with a white chalky substance, and have to be broken into before the presence or quality of the variscite can be determined.

Both the variscite and the matrix minerals possess various shades of color, several of which are sometimes present in a single specimen. The different colors combined with the various markings and patterns due to the structure of the mineral and brecciation of the matrix

furnish a large range in the types of stones that can be cut from the variscite. The variscite ranges in color from a very pale green through different shades to a bright grass green. The matrix is either white, gray, yellow, brown, or nearly black.

The gems that can be cut from the variscite from the Edison and Bird mine range from large pure stones with light to dark green color through those with small quantities of matrix, to those in which the matrix predominates. The dark and bright green variscite is obtained in pieces that will cut into pure stones measuring more than an inch across, and paler-colored mineral will yield even larger pure stones. Some of the bright-green variscite is partly translucent and thin pieces and small pebbles display their color well in the partially transmitted light. This is especially true of the coarser-grained, finely crystalline variscite. Specimens of matrix are obtained that will yield slabs 6 inches across, some of which show quite remarkable patterns and colors. One block of matrix found at this mine measures 4 to 6 inches in diameter and weighs several pounds. The whole mass is composed of variscite mottled with brown and white matrix. The pattern is the typical turtleback and the markings are coarser in some parts of the specimen than in others. The markings are due to rounded patches or nodules of pale to bright green variscite, some of which are surrounded by rims of white or gray, and all filled with purplish-brown matrix. The brown matrix occurs only as an inter-nodular filling and the seams are rarely over a millimeter thick. Occasional larger patches of matrix occur where several seams meet around the variscite nodules. The rounded masses of variscite vary from a fraction of a millimeter to a centimeter in diameter. Other smaller pieces of mottled variscite have been found along with specimens of brown, gray, and white matrix, with practically the same texture. Some pieces of mottled matrix contain little if any variscite, but would itself cut into stones with the turtleback markings.

Among other types of variscite matrix is that with bright grass-green variscite mottled with patches and cloudlike masses of lighter green material, or vice versa. Such matrix may contain seams and spots of white, gray, or yellowish mineral through it. A white quartz breccia, cemented and filled in with bright green variscite, is also a pleasing stone when cut, but is more difficult to polish because of the difference in hardness of the two minerals. The quartz occurs in sharp, angular fragments, which are in excess of the variscite in some specimens, but generally less prominent.

The variscite and variscite-matrix from this locality would yield very beautiful gems for the so-called barbaric jewelry. It is susceptible to nearly every form of cutting used with opaque gems, but on account of its comparative softness is not adapted to rough wear. For pendants, brooches, pins, belt stones, etc., it is well suited.

The especially bright colors of some of the variscite from this locality are rarely found in that from other places and the variety of markings shown by the matrix is probably equal to any other material found.

#### GENERAL DESCRIPTION.

The material available for study consists of nodular aggregates of variscite, irregular in shape and of various dimensions. The deep green aggregates of crystallized mineral consist of tabular crystals, a few of which reach a millimeter in length. Their breadth is about half their length, and their thickness varies from about one-fourth of a millimeter to very thin plates. The coarser aggregates of variscite consist of well-developed crystals (shown in pl. 33, upper figure), which are often nearly complete. The finer-grained material does not show such distinct crystals, while the very fine-grained compact mineral has more the appearance of a crypto-crystalline mass. Several small cavities in the coarse material were lined with projecting crystals, which furnished good material for crystallographical study. A view of such a cavity, enlarged six times, is shown in plate 33, lower figure. The crystals are transparent and pale green when viewed under the microscope.

#### OPTICAL PROPERTIES.

##### ORIENTATION AND PLEOCHROISM.

The crystallographical orientation of the variscite crystals was so chosen that the large flat face became the brachypinacoid  $b$  (010), and the striations on this face were placed vertically. Variscite being orthorhombic, these facts are sufficient to definitely orient the crystals, so that the optical relations can be readily comprehended. The basal pinacoid,  $c$  (001), was not observed on these crystals, and the macropinacoid,  $a$  (100), is a rare form, seldom larger than a narrow face between the unit prisms  $m$  and  $m'''$ .

The optical relations were ascertained by studying the flat crystals, and also by means of two thin sections of the granular aggregate, which were carefully prepared without being subjected to any heat. If a section of the granular variscite be made in the ordinary manner, it will be found that the heat employed in the operation is sufficient to cause the green color of the mineral to change to the deep lavender, with consequent changes in the various physical properties of the mineral.

The extinction is parallel in all sections, and the mineral behaves optically in strict concordance with the orthorhombic symmetry of the crystals.

The axial plane is parallel to the flat face  $b$  (010), the acute bisectrix is normal to the base  $c$  (001), the obtuse bisectrix then being normal to  $a$  (100). The mineral is positive, so that the acute bisec-

trix, identical in direction with the crystallographical axis  $c$ , is the axis of minimum velocity of light. The optical relationship can, therefore, be expressed in the conventional form as follows:

$$a = X = a$$

$$b = Y = b$$

$$c = Z = c$$

The axial angle is large;  $2E$  was measured as about  $113^\circ$ . Dispersion was not marked and its kind could not be determined.

Viewed in transmitted light under the microscope the crystals are colorless if very thin, or pale green if somewhat thicker. The coloring pigment is not uniformly distributed, but is generally arranged in irregular cloudlike areas. In a few cases the coloring seemed to bear in its distribution some relation to the shape of the crystal, and in these cases the color was most intense near the edges of the crystals.

The pleochroism is distinct but slight, and its relation to the crystal directions is shown in the following scheme:

$$a (X) = \text{colorless.}$$

$$b (Y) = \text{pale green.}$$

$$c (Z) = \text{pale green.}$$

The weakness of the pleochroism is in striking contrast to that of the heated lavender-colored material in which, as described further on, the pleochroism is strong.

#### REFRACTIVE INDICES.

The indices of refraction were measured by the method of oil immersion for  $\gamma$  and  $\alpha$ . The values found are  $\gamma = 1.577$  and  $\alpha = 1.547$ . Therefore  $\gamma - \alpha = 0.030$ , which is very close to the average value (0.032) found by actual determination of the birefringence. This birefringence was measured accurately on the flat brachypinacoid, and the average value obtained is 0.032. The value was measured on 11 crystals with the following results:

*Birefringence ( $\gamma - \alpha$ ) measured on  $b$  (010).*

Crystal No.	Thickness in milli- meters.	Birefrin- gence.
1.....	0.055	0.034
2.....	.041	.029
3.....	.042	.035
4.....	.070	.027
5.....	.051	.031
6.....	.051	.037
7.....	.066	.029
8.....	.055	.034
9.....	.042	.030
10.....	.053	.030
11.....	.047	.034
Average.....	.....	.032

As the value 0.032 is more accurate than the value 0.030, obtained by measuring the indices directly, the values of  $\gamma$  and  $\alpha$  are each changed one unit so as to bring their difference in accord with the more accurately determined value of the birefringence. The values of  $\gamma$  and  $\alpha$  are therefore taken as 1.578 and 1.546, respectively.

The value for  $\beta$  was found by measuring the difference of refraction ( $\beta - \alpha$ ) in basal sections of the mineral. A thin section of the crystalline aggregate furnished basal and brachypinacoid sections of the same thickness, so that the value ( $\beta - \alpha$ ) could be determined by noting the interference colors (blue first order) on the basal sections and comparing them with the colors on sections showing the maximum birefringence. The value ( $\beta - \alpha$ ) was thus found to be 0.010. Therefore  $\beta = 1.556$ .

A section of a crystal that seemed to be nearly parallel to  $a$  (100), showed a very large axial angle and a difference of refraction of about 0.020, which, for a section parallel to  $a$  (100), should be 0.022.

Summarizing the optical properties as determined, we have:

Axial plane  $\parallel b$  (010).  $Bx_a \perp c$  (001). Positive.

$\alpha = 1.546$ ,  $\beta = 1.556$ ,  $\gamma = 1.578$

$(\gamma - \alpha) = 0.032$ ,  $(\gamma - \beta) = 0.022$ ,  $(\beta - \alpha) = 0.010$ .

$n = \frac{\alpha + \beta + \gamma}{3} = 1.560$ .

#### STRUCTURE OF CRYSTALS.

An additional feature of considerable interest is the structure of these crystals. Although the material is well crystallized and the individual crystals sharply bounded by plane and brilliant surfaces, the interior of the crystals is in most cases crowded with a mass of small particles of the same material irregularly bounded and not in parallel position with the crystal itself.

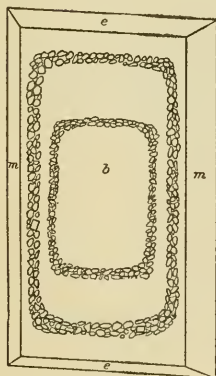


FIG. 1.—VARISCITE CRYSTAL, SHOWING REGULAR GROUPING OF SMALL PARTICLES— $b$  {010},  $m$  {110},  $e$  {012}. THE BRACHYPINACOID  $b$  {010} IS DRAWN IN FRONT.

In some crystals these particles are entirely absent; in others they are sparsely scattered through the crystal. Still others contain a vast number of these particles, generally aggregated close together. These aggregates are either irregular in shape and occupy the center of the crystal or else they are arranged in a regular fashion patterned after the shape of the crystal itself. Such a regular grouping of these particles is shown in figure 1, which illustrates also the tabular habit of the variscite crystals.

In figure 1 the brachypinacoid  $b$  (010) is drawn in front, in order to better show the mode of distribution of the particles. These particles are generally irregular in their shape,

though occasionally a rectangular one can be noted among the mass. The particles still manifest themselves in the dehydrated lavender crystals and show no difference, except in their orientation and shape, from the rest of the crystal.

PROPERTIES OF DEHYDRATED LAVENDER VARISCITE.

The very remarkable color change undergone by the mineral on dehydration at a relatively low temperature (below  $160^{\circ}$ ) also markedly affects the optical properties. The most striking change is in the pleochroism. The green crystals of variscite are only faintly pleochroic (colorless to pale green), whereas the lavender ones are strongly pleochroic with intense shades.

The optical orientation of these lavender colored crystals could not be determined, though numerous attempts were made, both on loose crystals and on thin sections of the granular aggregate. The birefringence of the mineral has become so low that no definite effects could be obtained when tests for axial angles were made. Both basal and brachypinacoidal sections seemed to show the emergence of a bisectrix with a very large axial angle, though, as stated, the results were inconclusive. It could, however, be easily seen that the optical orientation was changed. In the green crystals, viewed on the flat face,  $b$  (010), the vertical axis is a direction of minimum velocity, but on the lavender crystals this same direction is one of maximum velocity. Similarly on basal sections, the  $b$  axis is a direction of minimum velocity for the green crystals, whereas on the lavender ones the  $b$  axis is a direction of maximum velocity.

The pleochroism of the lavender crystals is strong and very striking. All the colors are combinations of red and blue, and therefore rather hard to describe accurately. On crystals that are not too thin the colors are very intense and beautiful. The brachypinacoidal sections are strongly pleochroic, whereas basal sections hardly show any difference in shade in different directions. The colors may be described as follows:

$a$  axis = lavender.

$b$  axis = pinkish lavender.

$c$  axis = violet.

The color effects given above are such as were noted on crystals that had been gradually heated up to  $160^{\circ}$  C. If the green crystals be suddenly heated to a high temperature, as, for instance, by putting them on a piece of platinum foil and suddenly heating them in the hot flame of a Bunsen burner, the results are different. The crystals are then considerably cracked and on brachypinacoidal sections the optical orientation is like that of the green crystals, namely, the  $c$  axis

of the crystal corresponds to a direction of minimum velocity. Moreover, the pleochroism is interchanged, so that now:

*a* axis = violet.

*c* axis = lavender.

The changes in the indices of refraction and the birefringence undergone by the green variscite crystals on changing to the lavender phase are also very marked. The mean refractive index has dropped from 1.560 to about 1.448 and the birefringence from 0.032 to 0.003 or possibly even less. The birefringence does not exceed 0.003 in any section and is much less in most cases. The approximate values of the indices, determined by oil immersion, are as follows:

$$\alpha = 1.447, \beta = 1.448, \gamma = 1.450$$
$$\gamma - \alpha = 0.003.$$

This decrease in the values of the refractive indices and the birefringence is accompanied by the loss of water of the mineral, and it is a fact worth emphasizing that the loss of water, without destroying the optical possibilities of the mineral, decreases both these values.

When the lavender crystals are heated with water on the steam bath (not over 100° C.) for several days, they gradually lose their lavender color and become a dirty grayish white and are then non-pleochroic. A sample, treated in this way for about a week, was then air dried for several days and the loss on ignition (= water absorbed) determined. This amount was found to be 2.05 per cent. The ignited crystals had again become deep lavender in color. It therefore seemed possible by appropriate treatment to change the dehydrated lavender crystals back to their original vivid green color. With this view in mind, some of the lavender crystals were treated with hot water for several days until they became grayish white in color and then sealed in a glass bomb with a little water and heated for several hours at a higher temperature. The glass bomb was first heated for four hours at 170° C., the next day for the same time at 190° C., and the third day for a similar length of time at 225° C. Unfortunately it was not possible to heat the tube at these temperatures continuously, as should probably have been done. After three days' heating, as just described, the grayish white crystals had become very pale greenish yellow, but when the crystals were removed from the tube and the loss on ignition determined after they had been air dried for several days the result was disappointing. A loss of only 1.12 per cent was found, so that the crystals had absorbed less water in the glass bomb treatment than by simply treating with hot water.

The crystals from the glass bomb were very light brown or nearly colorless when viewed under the microscope. Pleochroism was distinct, though very slight. Parallel to the *c* axis, a direction of maxi-



imum velocity (unlike the green crystals), light brown; parallel to the  $a$  axis, a light brown with a decided greenish-yellow tint. The birefringence is about 0.006, the interference colors on the thicker crystals reaching into first-order yellow. The areas of "irregular aggregates" (shown in fig. 1) are stronger colored and indefinite in character. They somewhat resemble the kaolinization effects seen in rock slides.

#### RELATION TO ANALOGOUS MINERALS.

A brief comparison of the optical properties of variscite, as given, with those of the analogous minerals scorodite, strengite, and phosphosiderite, shows some close relationships as well as some marked differences.

The optical properties of variscite given by Lacroix<sup>1</sup> are not entirely in accord with those given in this paper, but this is due to the fact that Lacroix's material was fibrous and not in distinct crystals. He gives the axial plane as parallel to  $b$  (010), with negative acute bisectrix normal to  $a$  (100), whereas the positive acute bisectrix is normal to  $c$  (001). The value of  $2E$  is given as about  $96^\circ$  and the mean index as 1.579, which is a little higher than the value 1.560 found on the Utah crystals, but is almost identical with the maximum index found thereon, namely ( $\gamma$ ) 1.578. The birefringence is stated to be a little higher than that of quartz, but the birefringence observed by Lacroix was probably not the maximum, which reached a value of 0.032 in the crystals from Utah. It is not known to what extent, if any, the chromium and vanadium present in the green crystals from Utah influence the optical values.

The comparison of the chief optical properties of the different analogous minerals can be most conveniently shown in tabular form. The orientation of the variscite is so chosen that the axial plane is  $b$  (010), but it is possible, as shown beyond, to so orient the crystals that the axial plane is  $a$  (100), analogous to that of scorodite and strengite.

#### Comparison of optical relations.

Mineral.	Axial plane.	Opt. sign.	$Bx_a$	$2E$ .	Mean index.	Birefringence.
Variscite.....	$b$ (010)	+	$\perp$ (001)	$113^\circ$	1.560	0.03
Scorodite.....	$a$ (100)	+	$\perp$ (001)	$130^\circ$	.....	.03
Strengite.....	$a$ (100)	+	$\perp$ (001)	$60^\circ$	1.825	.03
Phosphosiderite..	$b$ (010)	+	$\perp$ (001)	$126^\circ$	1.73	.....

In adopting the orientation for variscite as given in this paper, namely, with the optic axial plane parallel to  $b$  (010), an interesting condition obtains for the isomorphous mixtures of variscite ( $AlPO_4 \cdot 2H_2O$ ) and strengite ( $FePO_4 \cdot 2H_2O$ ), for in the latter mineral the optic axial plane is parallel to  $a$  (100). Such an isomorphous

<sup>1</sup> Lacroix, A. Mineralogie de France, vol. 4, 1910, p. 479.

mixture is represented by the mineral barrandite, of which two analyses are on record and in both of which the iron phosphate predominates, so that barrandite, instead of being a distinct mineral species is, in reality, only an aluminous strengite.<sup>1</sup> Now, in strengite the axial plane is  $a$  (100) and  $2E$  equals  $60^\circ$ , whereas in variscite the axial plane is  $b$  (010) and  $2E$  is nearly twice as large. The isomorphous admixture of a small amount of variscite in strengite would therefore tend to decrease the axial angle of strengite, and for a certain amount of variscite the axial angle becomes zero. A still greater amount of variscite in the mixture will give an increasing axial angle, but with the axial plane now parallel to  $b$  (010) as in pure variscite. Since the axial angle of strengite is much smaller than that of variscite, an isomorphous mixture with an axial angle of nearly  $0^\circ$  should contain more strengite than variscite.<sup>2</sup> Both the analyses of barrandite show an excess of the strengite molecule, in one in the ratio 4 : 3 and in the second 5 : 2. In that of the last ratio, it therefore becomes highly significant to note that Lacroix in describing<sup>3</sup> barrandite says that the optic axes are very close together, so that the value of  $2E$  is very small. In the analysis of barrandite given by Lacroix the ratio of  $Fe_2O_3$  to  $Al_2O_3$  is about as  $2\frac{1}{2} : 1$ . An approximate calculation of the value of the axial angle of such an isomorphous mixture shows that it should be very small and approximately  $10^\circ$ .

On the other hand, it must be stated that the density and mean refractive index of barrandite, as given by Lacroix, are not consistent with the values calculated from those of variscite and strengite, as is shown by the following table:

*Comparison of values for barrandite.*

Mineral.	Density.	Mean refractive index.
Variscite.....	2.54	1.560
Strengite.....	2.87	1.825
Barrandite* found.....	2.59	1.575
Barrandite* calculated.....	2.78	1.749

\* Barrandite consists of 5 parts strengite and 2 parts variscite.

The wide discrepancies in the found and calculated values of the density and refractive index, respectively, are not in accord with the idea of the isomorphous character of barrandite as developed for the optical orientation.

<sup>1</sup> Compare the "Conclusions" of the paper "A study of the rutile group," in Bulletin 509, U. S. Geological Survey, entitled, "Mineralogical Notes, Series 2."

<sup>2</sup> It is interesting to note that should an isomorphous mixture of variscite and strengite be found (without definite crystals) in such proportions that the axial angle is  $0^\circ$ , the discoverer would be very likely to consider the find as a distinct new species, as it would be strictly uniaxial, while both variscite and strengite are biaxial.

<sup>3</sup> Lacroix, A. Mineralogie de la France, vol. 4, 1910, p. 486.

## CRYSTALLOGRAPHY.

## INTRODUCTION.

The flat crystals are orthorhombic in their symmetry and simple in their combination. The large tabular face is taken as the brachypinacoid and the chief forms noted, as shown in figure 2, are:  $b$  (010),  $m$  (110), and  $e$  (012). In addition to these forms the macropinacoid  $a$  (100) is sometimes present as a narrow face. Occasionally the crystals are much longer and the prism faces more developed in comparison with the macropinacoid. The common habit of the crystals is as shown in figure 2. A better idea of the shape of the crystals can be had from figure 1, on page 418, which shows a variscite crystal so drawn as to bring the brachypinacoid  $b$  (010) in front. The rectangular, tabular shape of the crystals, due to the large development of the brachypinacoid, is there well shown.

Several other forms are present on these crystals, but they could not be determined. On crushing some of the coarsely crystallized aggregate and examining it under the microscope one occasionally sees an acutely terminated crystal which has the corners replaced by small faces, probably those of the unit pyramid.

In orienting the crystals of variscite three positions are available, depending on which pinacoid the broad face is referred to. This broad face is generally slightly striated vertically. In conformity with the analogous mineral scorodite, the striations are taken as parallel to the  $c$  axis. Striated crystals of scorodite have been described by several authors. Thus, Kokscharow<sup>1</sup> states that the form (010) is strongly striated vertically. Zimányi<sup>2</sup> describes scorodite crystals on which the prism  $d$  (120) is vertically striated, and Lacroix<sup>3</sup> mentions vertical striations on (120) and the two pinacoids (100) and (010). He also describes scorodite crystals slightly flattened parallel to either  $a$  (100) or  $b$  (010) and states further that a rare phase of strengite is formed by plates flattened parallel to  $a$  (100).

The possibilities of the three available orientations will be discussed after the measurements of the variscite crystals are given.

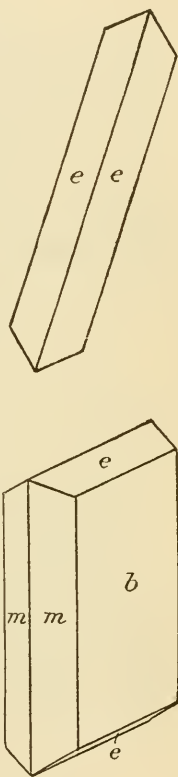


FIG. 2.—VARISCITE CRYSTAL  $b$  {010},  $m$  {110},  $e$  {012}.

<sup>1</sup> Kokscharow, N. Mineralogie Russlands, vol. 6, 1870, p. 309.

<sup>2</sup> Zimányi, K. Beiträge zur Mineralogie der Komitate Gümör und Aban-Torna. Föld. Közl., vol. 35, 1905, p. 545.

<sup>3</sup> Lacroix, A. Mineralogie de la France, vol. 4, 1910, p. 472.

## CALCULATION OF ELEMENTS.

Variscite being orthorhombic, only two angular values are necessary for a determination of the crystallographical elements.

The fundamental values of variscite are:

$$b \wedge m = (010):(110) = 48^\circ 10'$$

$$b \wedge e = (010):(012) = 61^\circ 17'$$

From these values the axial ratio is calculated and found to be:

$$a:b:c = 0.8952 : 1 : 1.0957$$

The measurements from which the fundamental values for variscite were obtained are as follows: In the measurements of the angle (010):(110) it is possible to obtain eight values on each crystal, namely, (010 : 110), (010 :  $\bar{1}10$ ), ( $0\bar{1}0$  :  $1\bar{1}0$ ), ( $0\bar{1}0$  :  $\bar{1}\bar{1}0$ ),  $\frac{1}{2}(110 : \bar{1}10)$ ,  $\frac{1}{2}(1\bar{1}0 : \bar{1}\bar{1}0)$ ,  $90^\circ - \frac{1}{2}(110 : 1\bar{1}0)$ ,  $90^\circ - \frac{1}{2}(\bar{1}10 : \bar{1}\bar{1}0)$ . In the following table only such ones of these possible eight values are given where the reflections from the faces were fairly good and distinct:

*Measurements of angle  $b \wedge m = (010) : (110)$ .*

Crystal No. ....	1	2	4	5	6	7
	° /	° /	° /	° /	° /	° /
	48 28	48 26	48 19	48 02	48 07	46 59
	47 34	48 11	48 44	48 13	48 12	49 07
	48 42	48 33	47 56	.....	48 14	48 04
	47 21	47 51	48 22	.....	48 19	.....
	47 55	48 18	48 10	.....	.....	.....
	48 08	48 14	.....	.....	.....	.....
Average.....	48 01	48 14	48 18	48 08	48 13	48 03
Average of 26 measurements = $48^\circ 10'$ .						

For the faces of  $e$  (012) the number of possible measurements was not so large as the crystals measured were broken off at the lower end.

*Measurements of angle  $b \wedge e = (010) : (012)$ .*

	° /		° /
Crystal No. 2.....	{61 21	Crystal No. 6.....	{61 31
	{61 15		{61 10
Crystal No. 3.....	{61 22	Crystal No. 7.....	{61 26
	{61 08		{61 10
Crystal No. 4.....	{61 28	Crystal No. 8.....	{61 14
Crystal No. 5.....	{61 19		{61 01
Average of 12 measurements = $61^\circ 17'$ .			

The only crystallographical study hitherto made of variscite is the work of Chester<sup>1</sup> on the Arkansas mineral. He found some

<sup>1</sup> Chester, Albert H. Note on the crystallization of variscite. Amer. Journ. Sci., 3 ser., vol. 15, 1878, p. 207.

minute crystals with the forms  $b$  (010),  $a$  (100),  $m$  (110), and  $c$  (001). Of these,  $b$ ,  $m$ , and  $c$  were well developed. The angle  $m \wedge m''$  (110:1 $\bar{1}$ 0) is given as  $65^\circ 54'$ , but it has not been possible to correlate this angle with any simple form for the variscite-scorodite group.

The following table gives the coordinate angles for the forms of variscite. The table is adapted for measuring the crystals by the two-circle method, but, of course, it also gives the necessary interfacial angles.

*Variscite.*

$a=0.8952, c=1.0957, p_0=1.2240, q_0=1.0957$					
No.	Letter.	Symbol.		$\phi$	$\rho$
		<i>Gdt.</i>	<i>Miller.</i>	° ' "	° ' "
1	$b$	$0 \infty$	010	0 00	90 00
2	$a$	$\infty 0$	100	90 00	90 00
3	$m$	$\infty$	110	48 10	90 00
4	$e$	$0\frac{1}{2}$	012	0 00	28 43

The three possible orientations for the variscite crystals will now be given and their relation to the orientation of the analogous minerals scorodite, strengite, and phosphosiderite studied.

FIRST ORIENTATION.

The first orientation is the one chosen for the mineral, as it best shows the relation of variscite to the other minerals and at the same time yields the simplest indices for the crystal forms of variscite. In the comparisons, two orientations are given for phosphosiderite, both of which are different from the accepted position of that mineral. The first, phosphosiderite (1), is the one suggested by Bruhns and Busz<sup>1</sup> and the second, phosphosiderite (2), is obtained by interchanging the  $a$  and  $c$  axes in the generally adopted position and then doubling the new  $a$  axis.

The close relation between the angles of variscite and the other minerals of analogous composition can be seen in the table below:

*Comparison of angles (first orientation).*

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				(1)	(2)
$b \wedge m = (010) : (110)$	48 10	49 07	49 08	50 33	48 45
$b \wedge e = (010) : (012)$	61 17	64 30	63 50	64 52	61 57

A comparison of the axial ratio also shows clearly the similarity in values and at the same time shows the very close agreement of

<sup>1</sup> Zeit. Kryst. Min., vol. 17, 1890, p. 555. Also given in Dana's System of Mineralogy, 6th ed., 1892, p. 823.

variscite with phosphosiderite (2) and their greater difference from the values of the other minerals.

*Comparison of axial ratios (first orientation).*

Mineral.	a axis.	c axis.
Scorodite.....	0.8658	0.9541
Strengite.....	.8652	.9827
Variscite.....	.8952	1.0957
Phosphosiderite (1).....	.8229	.9381
Phosphosiderite (2).....	.8772	1.0660

It is to be particularly noted that the agreement of values is much closer for variscite and phosphosiderite (second position) than for variscite and scorodite or strengite. This fact led to the suggestion that perhaps the mineral here described was not variscite but a new mineral bearing the same relation to true variscite that phosphosiderite is supposed to bear to strengite. The analysis, however, shows that the crystallized variscite from Utah agrees well with the formula  $Al_2O_3 \cdot P_2O_5 \cdot 4H_2O$ . A careful study of the relations of phosphosiderite to strengite, considered with the close crystallographic values of phosphosiderite and variscite, lead to the conclusion that phosphosiderite and strengite are identical notwithstanding the apparent differences in the optical properties.

SECOND ORIENTATION.

In the second possible orientation the large face is made the macro-pinacoid  $a$  (100). As the optical axial plane of variscite is parallel to this large face, such an orientation would bring variscite into optical conformity with scorodite and strengite. It then becomes necessary, however, in order to retain the crystallographical analogy, to give to the prism  $m$  the symbol (340). The dome  $e$  then becomes (102) and the close angular agreement of the minerals in this position can be seen by the following table:

*Comparison of angles (second orientation).*

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				(1)	(2)
$b \wedge m = (100):(340)$	48 10	49 11	49 05	47 39	49 28
$b \wedge e = (100):(102)$	61 17	61 02	60 24	60 19	58 43

On the basis of the above angular values the following comparison of the axial ratios is made:

*Comparison of axial ratios (second orientation).*

Mineral.	a axis.	c axis.
Variscite.....	0.8379	0.9181
Scorodite.....	.8658	.9541
Strengite.....	.8652	.9827
Phosphosiderite (1).....	.8229	.9351
Phosphosiderite (2).....	.8772	1.0660

The agreement in values is much closer than for the first orientation, but the prism form loses its simple indices. It must be said, however, that this orientation has much to commend it and may perhaps be chosen in the future as the best one for the mineral, especially when the properties of strengite and barrandite are better defined than they are at present.

THIRD ORIENTATION.

A third orientation is still possible, namely, by considering the large face as the basal pinacoid. Though the angular values derived from this orientation show a close agreement, such a habit is entirely at variance with that of all the other minerals of this group, and the choice of orientation must be left to the first or second one.

By making the large face the basal pinacoid and taking *m* as (101) and *e* as (021), the following comparison is obtained:

*Comparison of angles (third orientation).*

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				(1)	(2)
$b \wedge m = (001):(101)$	48 10	47 47	48 38	48 45	50 33
$b \wedge e = (001):(021)$	61 17	62 20	63 02	61 57	64 52

From these values the following axial ratios are obtained:

*Comparison of axial ratios (third orientation).*

Mineral.	a axis.	c axis.
Variscite.....	0.8170	0.9126
Scorodite.....	.8658	.9541
Strengite.....	.8652	.9827
Phosphosiderite (1).....	.8229	.9351
Phosphosiderite (2).....	.8772	1.0660

## TWIN CRYSTAL.

A twin crystal was observed under the microscope among the crushed aggregate. The twinning plane is (102) (first orientation) as the inclination of the twinned part of the complex to the untwinned part was measured as  $31^\circ$  and the angle (001):(102) is calculated as  $31^\circ 28'$ . Similar twins were noted on phosphosiderite, again showing the striking crystallographical closeness of variscite with phosphosiderite, and emphasizing the probable identity of phosphosiderite with strengite.

## RELATION TO ANALOGOUS MINERALS.

It may be stated that the angular values for the minerals of this group are so close in three different directions that one must be very careful that the correct position has been chosen. This should always be verified optically if at all possible, as on poor crystals it would be difficult to distinguish with certainty some of the angles. This similarity in angular values can be well shown by the following table:

*Comparison of angles showing similarity.*

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				(1)	(2)
	° /	° /	° /	° /	° /
(100):(340)	50 03	49 11	49 05	47 39	49 28
(010):(110)	48 10	49 07	49 08	50 33	48 45
(001):(101)	50 45	47 47	48 38	48 45	50 33
(010):(012)	61 17	64 30	63 50	64 52	61 57
(001):(021)	65 28	62 20	63 02	61 57	64 52
(100):(102)	58 32	61 02	60 24	60 19	58 43

It is possible that the mineral vilateite,<sup>1</sup> the violet crystals of Des Cloizeaux's hureaulite, belong to this group. The crystals are described as monoclinic, but the angular differences from orthorhombic symmetry are slight, and Lacroix states that optically the mineral behaves somewhat like an orthorhombic substance. The similarity in axial ratios to scorodite, etc., can be seen in the following table. For vilateite, half the  $a$  axis, as given by Lacroix, has been taken.

*Comparison of axial ratios.*

Mineral.	$a$ axis.	$c$ axis.	$\beta$ .
Vilateite.....	0.8479	0.8886	89 27
Variscite <sup>2</sup> .....	.8379	.9181	90 00
Scorodite.....	.8678	.9583	90 00
Strengite.....	.8652	.9827	90 00
Phosphosiderite (1).....	.8229	.9381	90 00

<sup>1</sup> Lacroix, A. *Mineralogie de la France*, vol. 4, 1910, p. 477.

<sup>2</sup> Second orientation.



## CHEMICAL COMPOSITION.

## GENERAL PROPERTIES.

The mineral is infusible before the blowpipe, but readily changes its color in a striking way. The deep emerald green changes to a deep lavender and the crystals take on a much more brilliant luster. As quantitative analyses showed, all the water of the mineral is given off during the change of color and the lavender variscite is anhydrous. Chester<sup>1</sup> mentions a similar change in color for the variscite from Arkansas, but his results seem to have been generally overlooked. In describing the properties of the crystallized variscite Chester says:

The colors observed are deep emerald green. \* \* \* Before the blowpipe it becomes opaque, friable, and of a deep purple when hot, lighter purple when cold. In the glass tube yields much water and changes in color as above.

The density of the green mineral was found to be 2.54.

The powdered mineral is insoluble in boiling hydrochloric acid, but after dehydration and change in color it readily dissolves in acids. The striking color changes observed in the mineral suggested testing especially for such rarer elements as had a strong chromatic effect. It was found that chromium and vanadium were present in small amounts, and a trace of iron was also determined.

## CHEMICAL ANALYSIS.

The results of the quantitative analysis and the ratios deduced therefrom are here given.

*Analysis and ratios of crystallized variscite from Lucin, Utah.*

Analysis.		Ratios.	
H <sub>2</sub> O .....	22.68	1.260	4.00
P <sub>2</sub> O <sub>5</sub> .....	44.73	.315	1.00
V <sub>2</sub> O <sub>5</sub> .....	.32	.002	} 1.02
Cr <sub>2</sub> O <sub>3</sub> .....	.18	.001	
Fe <sub>2</sub> O <sub>3</sub> .....	.06	.....	
Al <sub>2</sub> O <sub>3</sub> .....	32.40	.318	
Ni, Co, Cu, } .....	None.		
Mn, As, } .....			
Ca, Mg, } .....			
	100.37		

The ratios agree very well with the formula Al<sub>2</sub>O<sub>3</sub>.P<sub>2</sub>O<sub>5</sub>.4H<sub>2</sub>O, thus comparing with strengite (Fe<sub>2</sub>O<sub>3</sub>.P<sub>2</sub>O<sub>5</sub>.4H<sub>2</sub>O) and not with phosphosiderite (Fe<sub>2</sub>O<sub>3</sub>.P<sub>2</sub>O<sub>5</sub>.3½H<sub>2</sub>O) even though the crystals of variscite are much closer in angular values to those of phosphosiderite than to those of strengite.

<sup>1</sup> Chester, Albert H. On the identity of the so-called peganite of Arkansas with the variscite of Breithaupt and Callainite of Damour. Amer. Journ. Sci., 3 ser., vol. 13, 1877, p. 295.

The results obtained as to loss of water at different temperatures are as follows:

*Loss of water on heating.*

Temperature °C.	Color of powdered sample.	Total percentage of loss due to water.
110° (first day).....	Pale green.....	
115° (second day).....	Pale green.....	5.09
110° (third day).....	Light gray*.....	9.67
140°.....	Pale lavender.....	12.48
160°.....	Lavender.....	19.81
	Deep lavender.....	22.50

\*The color called light gray is very difficult to define. The mineral powder had lost its original green color but did not show any decided lavender shade. Perhaps the combination of some lavender and some green gave the resultant effect here called gray.

The vanadium and chromium were determined on a 4-gram portion of the mineral, the method used being that described by Hillebrand.<sup>1</sup> After the chromium had been determined colorimetrically, the correction necessary to apply to the vanadium determination was found by titrating a hot sulphuric acid solution of sodium chromate containing the same amount of chromium oxide ( $\text{Cr}_2\text{O}_3$ ), as was present in the sample of variscite analyzed. Qualitative tests with ferricyanide showed that there was no ferrous iron in the solution of the mineral which had been heated to 160° C. Therefore, it was possible to determine the state of oxidation of the vanadium. For this purpose a gram of the mineral was heated to 160° C, which completely dehydrated it and changed its green color to the intense lavender. The powdered mineral was then dissolved in sulphuric acid and titrated with permanganate. The amount consumed was equivalent to 0.45 per cent vanadium oxide ( $\text{V}_2\text{O}_5$ ) and, corrected for the chromium present, gave a value of 0.41 per cent vanadium oxide ( $\text{V}_2\text{O}_5$ ). This is higher than the value obtained on the 4-gram sample (0.32 per cent) but the lower result is taken as being the most accurate. It may be here stated that a cold solution of bichromate in sulphuric acid will consume a small but appreciable amount of permanganate which has to be determined and allowed for in such instances as the present one. The ferric iron was determined colorimetrically using potassium sulphocyanide.

An adequate explanation of the remarkable color change and accompanying changes in physical and optical properties has not been found.

EXPLANATION OF PLATE 33.

Upper figure.—Nodule of variscite from Lucin, Utah. Shows the usual compact phase on the left and the crystalline aggregate on the right. Natural size.

Lower figure.—Crystallized variscite from Lucin, Utah. Shows a cavity in the crystalline aggregate with the tabular crystals. Enlarged 6 diameters.

Described on page 416.

<sup>1</sup> Hillebrand, W. F. The analysis of silicate and carbonate rocks. Bull. 422, U. S. Geol. Survey, 1910.



CRYSTALLIZED VARISCITE FROM UTAH.

FOR EXPLANATION OF PLATE SEE PAGE 430.

