

*On Bassetite and Uranospathite, new species hitherto  
classified as Autunite.*

(With Plate VIII.)

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THE name autunite was originally given to the well-known mineral from Autun, but it would seem that no crystals of this material have been found that would afford measurements on the goniometer. As the result of optical examination Des Cloizeaux (2) concluded that the mineral was biaxial, and he observed further that the angle decreased when the specimen was heated (6); the extinction was apparently straight, and he therefore referred the crystals to the rhombic system; with the contact goniometer he found  $mm' = 90^\circ 43'$ . In the early part of last century some very beautiful crystals from Cornwall had been described and measured in England (4), and on crystallographic grounds were placed in the tetragonal system. The crystals occurred with torbernite, and the two minerals were not clearly distinguished by early writers (1). Des Cloizeaux assumed that the Autun mineral was identical with that from Cornwall, and he was indebted to Greg for an isolated specimen of the latter which afforded the measurements, published in 1858, on which the crystallography of the species has been based (3); he remarked, however, that the optic axial angle was greater than in the Autun mineral.

In 1879 Brezina (8) observed that small tabular crystals from Himmelsfürst mine in Saxony had an oblique extinction of  $4^\circ$ ; their optical properties were much confused by twinning, and the faces were not good enough for goniometric measurement. In accordance with the optics, Brezina considered the mineral to be oblique; he measured the plane angles of the tabular basal plane (001), which now became the pinakoid (010), and found  $\beta = 90^\circ 30'$ . The number of readings

obtained was not sufficient to give a reliable value for the ratio  $a:c$ , and the length of the  $b$  axis was, of course, unknown. Brezina therefore took Des Cloizeaux's measurements of the Cornish mineral, and retaining his fundamental angles, presented them as those of an oblique mineral with  $\beta = 90^\circ 30'$ .

The data for autunite are thus of a somewhat composite character, and a further examination of the material seemed desirable. The description of various specimens hitherto classed together as autunite forms the subject of this paper<sup>1</sup>; it will be seen that the Cornish material here described falls into groups which are headed *A* and *B* respectively. The relationship between these substances and the Autun mineral will be discussed at the close of the paper, the name bassetite being proposed for *A* and uranospathite for *B*.

#### MINERAL *A* (BASSETITE).

##### *Specimen No. 1.*<sup>2</sup>

The locality of this specimen is not recorded, but comparison with other material makes it fairly certain that it is from Cornwall. The crystals occur in fan-like groups of almost parallel tables, in cavities of a black gossany material into which project spikes of black limonite. They are tabular on  $b$  (010) and almost square in outline, being bounded by poorly developed faces of forms  $\{hk0\}$  and  $\{0kl\}$ ; in many cases the corners are modified by bright faces of  $\{111\}$  and  $\{\bar{1}01\}$  (text-fig. 1). Twinning is frequent, so that two or more individuals oriented approximately at  $90^\circ$  are united on  $b$ . The measurements given below were obtained on projecting corners of simple individuals.

The interference-figure is biaxial with a wide angle, the negative acute bisectrix being perpendicular to  $b$  (010); this, coupled with angle of  $90^\circ$  measured from the face  $\{\bar{1}01\}$  to  $b$ , supports the view that  $b$  is a plane of symmetry. The extinction is distinctly oblique and the crystals are therefore treated as belonging to the oblique system; there is no evidence of anorthic symmetry.

The almost square outline of the plane  $b$  (010), when bounded by the forms  $\{hk0\}$  and  $\{0kl\}$ , indicates pseudo-rhombic symmetry; when  $p$  (111) and  $x$  ( $\bar{1}01$ ) are present they modify the corners of  $b$  so that the outline is almost a regular octagon and the symmetry is then seen to be

<sup>1</sup> The author takes this opportunity of expressing his thanks to Dr. H. H. Thomas and Mr. W. F. P. McLintock for their advice in this work.

<sup>2</sup> No. L 1946, Museum of Practical Geology (Ludlam Collection).

pseudo-tetragonal. The deviations from true symmetry fall almost within the limits of error in reading, so that the angles  $\beta$  and  $90^\circ - \beta$  can only be separated with difficulty from a true angle of  $90^\circ$ . The oblique extinction fortunately affords a ready means of discrimination. Nineteen readings of the plane angle of the face  $b$  (i.e. the angle  $100:001$ ) showed that, with two doubtful exceptions, the axial plane lay within the acute angle between the axes  $a$  and  $c$ . The optical properties are thus consistent with the symmetry, and all the planes of the oblique crystal may be distinguished by their relation to the optic axial plane. The following measurements were made:—

Edges.	External plane angles between the edges of the face $b$ (010). (Measured under the microscope.)			Extinction angle on $b$ (010) to the edge $bm$ .	Goniometer readings.	
	$bm : bn$	$bm : bp_1$	$bn : bx$		$bp_1 = (010) : (111)$	$bx = (010) : (10\bar{1})$
No. of readings	19	9	5	14	15	9
Highest	89° 50'	44° 40'	45° 45'	4° 0'	76° 55'	91° 4'
Lowest	89 9	44 0	45 20	2 42	74 8	89 12
Mean	89 30	44 23	45 29	3 17	75 38	90 5
Calculated	*	*	45 38	—	*	—

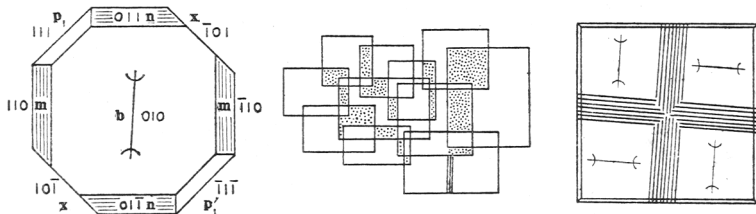
Oblique,  $a : b : c = 0.3615 : 1 : 0.3662$ ;  $\beta = 89^\circ 30'$ .

Forms:  $b$  {010},  $p_1$  {111},  $x$  {10 $\bar{1}$ },  $m$  {110},  $n$  {011}, and undetermined { $hk0$ } and { $0kl$ }.

Cleavages:  $b$  perfect,  $a$  and  $c$  moderate.

Refractive indices (by the immersion method):  $\gamma = 1.580$ ,  $\beta = 1.574$ .

Angle of extinction on  $b$  (010) with reference to the edge  $bm$ :  $3^\circ 17'$ .



Bassetite from Cornwall.

FIG. 1.—Simple crystal. FIG. 2.—‘Chessboard’ grouping of twinned and parallel crystals. FIG. 3.—Composite twin-crystal.

The measurements are not of high accuracy, but they possess interest

in that these crystals are intermediate in character between the scaly growths of specimen no. 2, and the stout crystals from Wheal Basset, described below. The latter differ in the presence of the form  $\{121\}$  instead of  $\{111\}$ , and the parameters assigned are not quite identical.

*Specimen No. 2.*<sup>1</sup>

This specimen, from Redruth, is typical of much Cornish material. The crystals are in cavities of a black gossan, forming flat groups composed of small square tables bounded by  $\{hk0\}$  and  $\{0kl\}$  (text-fig. 2 and Plate VIII, fig. 4). All the crystals lie in one plane, and the edges are approximately parallel; between crossed nicols, however, it can be seen that compensation frequently occurs between superposed lamellae, their axial planes being at right angles, so that the aggregate has a characteristic 'chessboard' appearance. The grouped crystals usually extinguish together with the exception of a few individuals whose extinction lies symmetrically on the other side of the edge.

The following determinations were made on these crystals: Extinction angle on  $b(010)$ , with reference to the edge  $bm$ ,  $3^{\circ} 49'$ . Refractive indices for sodium-light (determined by immersion in a mixed liquid),  $a = 1.580$ ,  $\beta = 1.574$ , these values being identical with those obtained for the last specimen. Specific gravity (determined by the flotation method), 3.10.

Twinning.—Small tables can sometimes be isolated, which show very well-marked supplementary twinning (text-fig. 3). These plates are divided into four quadrants by rather broad bands which remain dark when the nicols are rotated; the extinction is approximately parallel in all four divisions, but the axial planes in adjoining sectors are at right angles, and the isotropic bands evidently arise from compensation between the overlapping portions of adjacent crystals. It is a remarkable feature that these dividing bands are by no means normal to the edges of the plate, though they are themselves at right angles; their orientation is most simply expressed by the statement that they are very nearly parallel with the extinction. The following approximate angles were measured on twins of this type, between the edge of the plate and the trace of the combination-plane:  $85^{\circ} 0'$ ,  $84^{\circ} 35'$ ,  $85^{\circ} 20'$ ,  $86^{\circ} 20'$ , mean =  $85^{\circ} 19'$ . It is evident that the combination-plane is not a simple rational face. This question will be discussed further below.

Greg and Lettsom (4) remark that autunite was formerly obtained as

<sup>1</sup> No. L 1936, Museum of Practical Geology (Ludlam Collection).

bright yellow and nearly transparent crystals at South Wheal Basset, and that a specimen is in the British Museum; the measurements they publish were obtained from several small brilliant Cornish crystals, which exhibited the form  $\{121\}$  (oblique), a form also recorded by Des Cloizeaux. None of the specimens in the Museum of Practical Geology show this habit, but I am indebted to the Mineralogical Museum at Cambridge for facilities for measuring the very beautiful twinned crystal of this type which is described below; it will be observed that the results completely support the view that the symmetry is oblique, though the remarkable pseudosymmetry, coupled with twinning, will readily explain the earlier opinion that this substance was rhombic.

*Specimen No. 3.*<sup>1</sup>

The locality for this specimen is not recorded. It is a small isolated crystal about 1 mm. square and  $\frac{1}{2}$  mm. thick; with the exception of two small planes at one corner, the back of the crystal is a cleavage plane, which does not yield good readings. Between crossed nicols it transmits light of higher orders, but is divided into halves by a

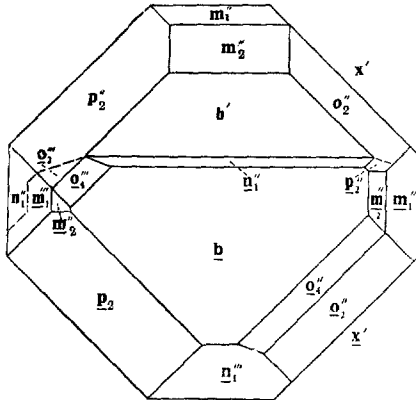


FIG. 4.—Twinned crystal of Bassetite. (For optical scheme see fig. 6.)

series of compensation bands which at once reveal the twinning. The faces give good readings, with a few exceptions, and the drawing (text-fig. 4) gives an almost exact representation of the appearance of the crystal.<sup>2</sup> The following table gives all the readings from both portions

<sup>1</sup> No. 1297, Mineralogical Museum, Cambridge (Brooke Collection).

<sup>2</sup> For convenience, the crystal is here viewed from the negative end of the *b*-axis.

of the twin. It was found that the measurements from the best faces were not suitable for direct calculation ; the parameters were therefore chosen so as to afford the best agreement between the observed and calculated angles.

Angle	$bm_1$	$bm_2$	$bn_1$	$bo_2$	$bo_4$	$bp_2$	$bx$
Readings observed	70° 34'	55° 12'	71° 21'	68° 47'	45° 23'	64° 0'	90° 13'
	70 40	55 12	70 56	68 43	45 26	63 59	89 57
	70 54	55 16	70 50			64 12	
	70 24	55 14				63 47	
Mean	70 38	55 13	70 53	68 45	45 24	63 59	90 5
Calculated	70 51	55 13	70 56	68 45	45 24	64 2	90 0

Angle	$o_2m_1$	$o_2n_1$	$p_2m_1$	$p_2n_1$	$m_1x$	$m_2o_2$	$m_2p_2$
Readings observed	42° 15'	42° 8'	41° 38'	41° 37'	48° 25'	39° 52'	39° 12'
			41 34		48 30		
			41 35		48 42		
			41 38				
Mean	42 15	42 8	41 36	41 37	48 32	39 52	39 12
Calculated	42 22	42 8	41 43	41 27	48 32	39 46	39 18

Oblique,  $a : b : c = 0.3473 : 1 : 0.3456$  ;  $\beta = 89^\circ 17'$ .

Forms:  $b$  {010},  $m_1$  {110},  $m_2$  {120},  $n_1$  {011},  $o_2$  {121},  $o_4$  {141},  $p_2$  {121},  $x$  {101}.

It may be convenient in this place to give a table (p. 227) showing the symbols assigned to the respective forms by various authors, including the forms determined on the specimens here described. A stereographic projection of the forms as stated in the last column is given in text-fig. 5.

Optical properties.—By the prism method, through the faces  $m_2''$  and  $m_2'''$  the value 1.580 was obtained for the refractive index, but the reading was not very satisfactory ; this value accords with that obtained for specimens 1 and 2 above. Extinction-angle on  $b$  with reference to

the edge  $bm$  approximately  $3^\circ$ . The axial angle of crystals similar to these was determined by Des Cloizeaux, who found  $2E = 110^\circ$ .

Greg (1858). Tetragonal.	Des Cloizeaux (1858). Rhombic.	Brezina (1879). Oblique.	A. F. H. Oblique.
$P$	$\left\{ \begin{array}{l} p \\ a^{\frac{1}{2}} \\ e^{\frac{1}{2}} \end{array} \right.$	$b$ 010	$b$ 010
$u$		$m$ 110	$m_1$ 110 $m_2$ 120
$l$		$q$ 011	$n_1$ 011 $p_1$ 111
	$\left. \begin{array}{l} \\ \\ \\ \end{array} \right\}$	$p$ 121	$p_2$ 121
		$\pi$ 12 $\bar{1}$	$o_2$ 12 $\bar{1}$
		$(a$ 100)	$o_4$ 14 $\bar{1}$
		$(c$ 001)	$(a$ 100)
$M$	$(m)$	$d$ 101	$(c$ 001)
			$x$ 10 $\bar{1}$

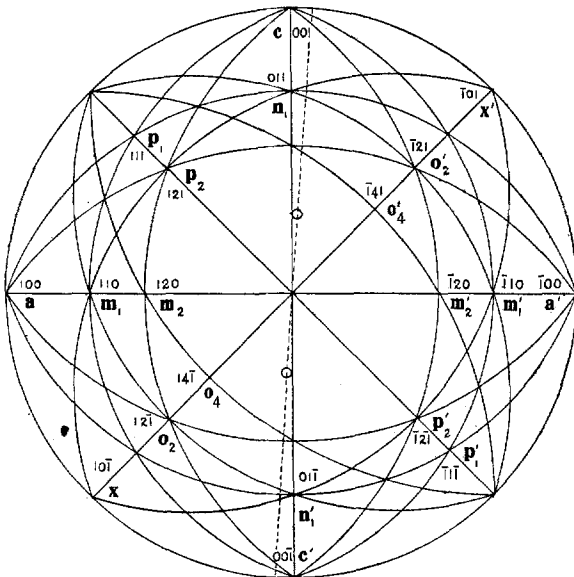


FIG. 5.—Stereographic projection of the crystal-forms of Bassetite.

Twin Law.—The relation between the two members is of special interest. Brauns (10) considered that the parallel extinction of some twins could only be explained by assuming parallel growth of the  $a$ -axis of one member with the  $c$ -axis of the other.

In the present crystal the faces  $b'$  and  $b''$  are parallel, while the faces  $m_1'' m_2'' b' n_1'' b' n_1'''$  are in zone; the zone  $[n_1'' b']$ , on the other hand, is inclined at about one degree to the zone  $[m_1''' m_2''' b' m_2'' m_1'']$ . The optical scheme (text-fig. 6) shows almost parallel extinction in the two members.

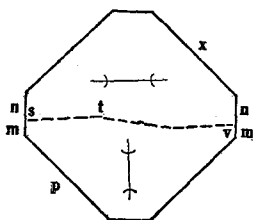


FIG. 6.—Bassetite: optical scheme of the crystal shown in fig. 4.

These data exclude the possibility of a rational twin-axis of low indices, even if rotation of  $90^\circ$  is admitted, and it must be assumed that the twin is a parallel growth of the axis  $a$  with the axis  $c$  of the second crystal.<sup>1</sup>

The following measurements were made between the principal zones by means of the two-circle goniometer:—

Zones.	Observed.	Calculated.
$[m_1''' b' m_1''] : [n_1'' b']$	$1^\circ 27'$	$1^\circ 26'$
$[n_1''' b' m_1''] : [m_1''' b' m_1'']$	89 22	89 17
$[n_1''' b' m_1''] : [n_1'' b']$	89 11	89 17
$[n_1''' b' m_1''] : [b' x']$	45 14	45 13
$[n_1''' b' m_1''] : [b' p_2']$	44 42	44 47

Also, for the angle  $x' : x'$ —Observed value,  $89^\circ 26'$ ; calculated,  $89^\circ 17'$ .

Combination-planes.—The trace of the junction between the two crystals is clearly visible on the faces  $n_1''$  and  $m_1'''$ , where it is shown as a broken line in the drawing. The face  $m_1'''$  of one crystal is brought against the face  $n_1''$  of the other and they meet in a slight angle. The line is stepped, being alternately parallel to the edge  $p_2 m_1'''$  and parallel to  $b$ . This suggests two combination-planes,  $b$  and  $m-n$ , for both these pairs of faces are approximately parallel.

Examination between crossed nicols permits the direction of the trace of the combination-plane to be determined as it crosses the face  $b$ . The view that  $m-n$  is a combination-plane at once leads to the expectation that the trace of the boundary will be a straight line parallel to the edges  $bm_2''$  and  $bn_1'''$ ; examination in polarized light shows that, on the contrary, the compensation band follows the line  $stv$  (text-fig. 6), which

<sup>1</sup> Examples of similar twins are given by O. Mügge, Fortschritte der Min., 1911, vol. i, p. 42.



is incommensurable and inclined to the edge  $bm$  in the same way as the similar lines in the twin of specimen 2 (text-fig. 3). The angle between the edge  $bm$  and  $st$  was measured as  $85^{\circ} 40'$ , a value which agrees fairly closely with the approximate mean value  $85^{\circ} 19'$  observed in specimen 2.

The general character of this combination plane recalls the 'rhombic section' in the felspar group. The parameters  $c$  and  $a$  differ slightly in value, and a closer fit between the two sides of the combination-plane may therefore be obtained by selecting an irrational line in the face  $b$  inclined to the axis  $a$  of one crystal ( $c$  of the other) so that the distance between successive molecules along that line is the same in both crystals.

With reference to the pericline twin of felspar, Evans remarks<sup>1</sup>: 'The intergrowth accordingly takes place in such a manner that the edges of the plane nets of molecules giving rise to the brachypinakoidal cleavage, which outcrop from the two component structures on the plane of composition, exactly coincide.' In the present case the outcrop of the  $c$  cleavage is brought into coincidence with that of the  $a$  cleavage of the second member. If  $\theta$  is the angle (measured in the same direction as the extinction) between the trace of the combination-plane and the  $c$ -axis of the crystal, and  $\beta'$  is the difference between  $\beta$  and  $90^{\circ}$ , then

$$\tan \theta = \frac{a-c}{a+c} \cot \beta'.$$

For the parameters given above,  $\beta' = 43'$ ,  $a-c = 0.0017$ ,  $a+c = 0.6929$ . The value of  $\theta$  is then  $11^{\circ} 19'$ . The value actually measured is about  $5^{\circ}$ , but the position of the section is so sensitive that this value would be obtained from the formula if the angle  $bn$  ( $= 70^{\circ} 56'$ ), which is assigned to the crystal above, were diminished to  $70^{\circ} 53'$ ; the latter value is almost equally consistent with the readings, and it may be recalled that Des Cloizeaux gives the value  $70^{\circ} 54'$ .

Chemical composition.—In 1875 Church (7) published analyses of the minerals from Cornwall and from Autun. He describes the former in the following words: 'The Cornish specimen occurred in thin isolated rhombic tables, translucent to sub-transparent, and was sulphur-yellow.' He concluded that the composition of the two was the same. In the absence of further description of the material it is difficult to be sure what mineral was analysed, and it is by no means certain that these, the only accurate analyses which appear to have been published for the Cornish material, were made on the mineral at present under discussion.

The mineral here described undoubtedly represents the Cornish

<sup>1</sup> J. W. Evans, *Mineralogical Magazine*, 1911, vol. xv, p. 393.

species, which was universally regarded as calcium uranyl phosphate. Although it belongs to the oblique system, the crystal measurements are so remarkably close to those of torbernite that it can be regarded with almost complete certainty as the isomorphous calcium salt, with the formula  $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot x \text{H}_2\text{O}$ , where  $x$  is probably eight.

#### MINERAL *B* (URANOSPATHITE).

##### *Specimen No. 4*<sup>1</sup>

This specimen, from Redruth, shows fan-like groups of crystals in black gossan, composed of thin yellow rectangular plates (Plate VIII, fig. 3), which superficially have some resemblance to those from specimen no. 1. Closer examination reveals, however, important differences; they are strongly striated parallel with the elongation, and often exhibit curious rows of peg-like inclusions which originate on a line parallel with the end of the crystal and are prolonged parallel with the sides in the direction of growth (see Plate VIII, fig. 5). The extinction is sensibly straight, and measurements with the microscope show that the angle between the edges cannot be distinguished from  $90^\circ$ . The crystals will therefore be treated as rhombic, the plane of perfect cleavage being taken as  $c$ .

The development is symmetrical and pseudo-tetragonal, the corners of the plates being often modified equally by edges approximately at  $45^\circ$ . The crystals have the appearance of having been re-dissolved, and the edges are rounded; no goniometric measurements could be obtained, and the length of the axis  $c$  is therefore unknown.

Rhombic,  $a : b : c = 1.0 : 1.0 : ?$

Cleavages:  $c$  perfect,  $a$  good,  $b$  (parallel with elongation) fibrous.

Specific gravity, by flotation, 2.50.

Optical properties.—The axial angle is wide, and the axial plane is parallel with the elongation, the negative acute bisectrix being normal to the perfect cleavage. The mean refractive index is somewhat below that of Canada balsam, a property which offers a ready means of recognizing the mineral in the slide (Plate VIII, fig. 1).

By immersion (Becke method), for sodium-light,  $\beta = 1.510$  and  $\gamma = 1.521$ . The axial angle for sodium-light was found to be  $2V = 69^\circ$ . The pleochroism is similar to that of bassetite, namely,  $\beta = \gamma$  deep yellow,  $a$  pale yellow.

<sup>1</sup> No. L1941, Museum of Practical Geology (Ludlam Collection).

Twinning is evidenced by the arrangement of groups of laths intersecting at right angles in the form of a cross, but the superposition of crystals at right angles is not common.

Chemical composition.—The remarkably low refractive index and specific gravity of this mineral at once distinguish it from the others here mentioned. Unfortunately, the material is so rare that it seems impossible to obtain sufficient for an analysis, nevertheless the physical properties afford some clue to its nature. The characteristic absorption-spectrum indicates that it is a uranyl compound, and this, coupled with the pseudo-tetragonal symmetry, suggests affinity with the uranite group. That it is a hydrated salt is evident from the behaviour in the desiccator, which recalls that of the Autun material.

#### PARALLEL GROWTHS OF MINERALS OF THE URANITE GROUP.

Parallel growths of zeunerite on trögerite are described by Goldschmidt (11); according to Gaubert (13) small crystals of barium chloride orientate themselves as they form upon flakes of torbernite. In the examination of the present material, two extremely well-defined cases of this kind were encountered; with our present knowledge of the uranite group it would be early to attempt to trace their significance, but they may perhaps be briefly recorded.

#### *Bassetite on Torbernite from Redruth.*<sup>1</sup>

Gossan in which the cavities have been coated with torbernite of the stout habit usually found in the Redruth specimens; on this is a layer of honey-yellow crystalline bassetite, which in places has a definite orientation with respect to the underlying crystals (text-fig. 7), while in other parts independent crystals are found of a stout lozenge-shaped habit. Under the microscope, the bassetite is seen to be built up of a series of lamellae in twin orientation, and the faces of zones *m* and *n* which bound the lozenge are in consequence heavily striated and irregular.

The top of a composite crystal is shown in text-fig. 7. The torbernite yielded measurements which identified the forms {001}, {111}, {101}. On the base the layer of bassetite is relatively thin, while it is doubtful whether any has been deposited on the {101} faces; the growth is evidently determined by the {111} faces of the torbernite, and possibly by the base. The face of contact between the two minerals is turbid,

<sup>1</sup> Specimen No. L 1901, Museum of Practical Geology (Ludlam Collection).

with numerous small cracks which probably represent an initial stage in which the torbernite was attacked by the calcium-bearing solution. In another, somewhat similar, specimen, considerable replacement of the torbernite has preceded the growth of the bassetite.

*Bassetite on Uranospathite.*<sup>1</sup>

A group detached from this specimen consists of a crystal of bassetite attached to a lath of uranospathite, so that the axial planes of the two are approximately parallel (text-fig. 8, and Plate VIII, figs. 1 and 2), the somewhat elongated *c*-axis edge of the bassetite being parallel with the striations of the uranospathite, while the two crystals are joined on the plane of perfect cleavage.

In both the above cases, as in those described by other observers, the cleavages of the minerals lie in parallel orientation.

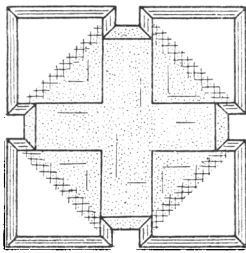


FIG. 7.—Parallel growth of Bassetite and Torbernite.

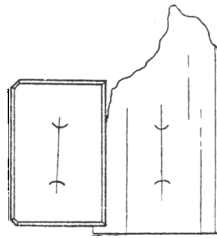


FIG. 8.—Parallel growth of Bassetite and Uranospathite.

RELATIONSHIP BETWEEN THE FOREGOING MINERALS.

The points of similarity between the substance *A* from Cornwall and that from Autun are no less remarkable than their differences. Both minerals are optically biaxial, negative, and possess about the same refractive indices, yet the axial angle in the Autun material is considerably the smaller. For the Autun mineral  $\beta = 1.575$  and  $\gamma = 1.577$  (Lévy and Lacroix, 9), whilst for the Cornish material  $\beta = 1.574$  and  $\gamma = 1.580$ . Again, the densities of both, though somewhat variable, are indistinguishable, for the minerals float together in the same region of a density column, at a value of 3.10. Thus far the observations seem to favour the theory that the low angle of the Autun material is due to twinning. If the crystals are built up, according to the law

<sup>1</sup> Specimen No. L 1946, Museum of Practical Geology (Ludlam Collection).

described above, of lamellæ oriented so that the  $a$ -axis is parallel with the  $c$ -axis, the optic axial angle would be reduced almost to zero, since the axial planes in this orientation lie at an angle of  $89^\circ$ ; if, on the other hand, the twinning takes place by rotation about the axes  $c$  or  $a$ , or about the normal to (101) or (10 $\bar{1}$ ), the angle between the axial planes is approximately either  $8^\circ$  or  $74^\circ$ . The axial angle derived from the first arrangement would seem to be too high, while the second would give rise to an axial plane bisecting the angle between the  $a$  and  $c$  cleavages. In the Autun material the plane is undoubtedly parallel to the cleavages, though an additional cleavage at  $45^\circ$  is occasionally to be observed.

Again, when the two minerals are placed over calcium chloride in the desiccator, it is found that the optic axial angle of the Autun material becomes zero; that of the Cornish crystals, on the other hand, remains high, whilst the extinction increases to about  $20^\circ$ , and the plates break up into four sectors with axial planes at right angles. The full description of the effects observed would be out of place here, but it is clear that the behaviour of the Autun material accords with rhombic symmetry, while that of the other is decidedly oblique. Such evidence, however, might still be explained as the result of sub-microscopic twinning, though the intimate and uniform structure required would be little different from that usually attributed to a crystal of higher symmetry.

Examination of the absorption-spectra of the minerals fortunately affords decisive evidence of their structural difference. If the two minerals are placed side by side opposite the slit of the micro-spectroscope it is at once evident that the system of five bands associated with the presence of the uranyl group is situated about 50 Angström units nearer the red in the spectrum of the Autun mineral, the difference being comparable with that of 10 Angström units observed by Rinne (12) between the spectra of torbernite and autunite. Here again, it is sufficient for the present purpose to remark that the difference exists; whatever its explanation, it is common to all good specimens of the two minerals, and it seems therefore impossible to include them in one species without extending the hypothesis of twinning to include an intimate molecular structure which, taken by itself, would be accepted readily as that of a rhombic crystal.

It seems clear, therefore, that no less than three distinct crystalline substances have been included under the name autunite; of these the Autun material has the best claim to the name, if only on the ground

that the word is derived from the type locality, Autun. It is unfortunate that the crystallographic data of the substance *A* should have been so closely identified with autunite, an error which is no doubt due to the rarity of the material. Although the chemical composition of the three minerals is possibly alike, apart from the water of crystallization, it does not seem possible to include them in one species as varieties of calco-uranite, for hydrates which differ crystallographically have hitherto been classed under separate names, in the groups with which they are isomorphous; the following names are therefore suggested for the substances classed under the headings *A* and *B* above:—

*A.*—*Bassetite*, after the Basset group of mines, one of the oldest and best localities for the mineral in Cornwall. Hydrated calcium uranyl phosphate. Oblique,  $a : b : c = 0.3473 : 1 : 0.3456$ ;  $\beta = 89^\circ 17'$ . Twinned by parallel growth of *a* and *c* axes so that the faces *b* are parallel, whilst the axis *a* of one individual is parallel to the axis *c* of the other. Cleavage, *b* perfect, also *a* and *c*.  $G = 3.10$ . Yellow, transparent. Optical properties: Biaxial,  $2E = 110^\circ$  (Des Cloizeaux). Negative, acute bisectrix normal to *b*. Axial plane within the acute angle between *a* and *c*, inclined  $4^\circ$  behind the *c*-axis.  $\beta = 1.574$ ,  $\gamma = 1.580$ . Pleochroic,  $\beta = \gamma$  deep yellow, *a* pale yellow. Soluble in acids. In the desiccator the extinction-angle increases to about  $20^\circ$ .

*B.*—*Uranospathite*, in allusion<sup>1</sup> to the elongated tabular habit of the typical specimens. A hydrated uranyl salt. Rhombic, pseudo-tetragonal,  $a : b : c = 1.0 : 1.0 : ?$ . In elongated tabular crystals. Twin-axis perpendicular to (110), in cruciform groups. Cleavage, *c* perfect, *a* good, *b*? fibrous.  $G = 2.50$ . Yellow to pale green. Optical properties: Biaxial,  $2V = 69^\circ$ . Negative acute bisectrix normal to *c*. Axial plane parallel to the elongation and to the fibrous cleavage.  $\gamma = 1.521$ ,  $\beta = 1.510$ . Pleochroic,  $\beta = \gamma$  deep yellow, *a* pale yellow. Soluble in acids. Becomes uniaxial in the desiccator.

The name autunite is retained for the Autun mineral, of which a comprehensive and detailed description has recently been published by Lacroix (14).

<sup>1</sup> From uranium and  $\sigma\pi\acute{\alpha}\theta\eta$ , a broad blade.

*Literature.*

The following list contains the papers to which reference is made in the text. In addition to these there are many notes reporting occurrences of the mineral, but it has not been thought advisable to attempt to collect them here.

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13. P. GAUBERT, 'Produits de déshydratation . . .' *Bull. Soc. franç. Min.*, 1904, vol. xxvii, p. 222.
14. A. LACROIX, 'Minéralogie de la France.' Paris, 1910, vol. iv, p. 543.

## EXPLANATION OF PLATE VIII.

Fig. 1.—Bassetite (in relief) in parallel growth on uranospathite, mounted in Canada balsam.  $\times 19$ .

Fig. 2.—The same, between crossed nicols.  $\times 19$ .

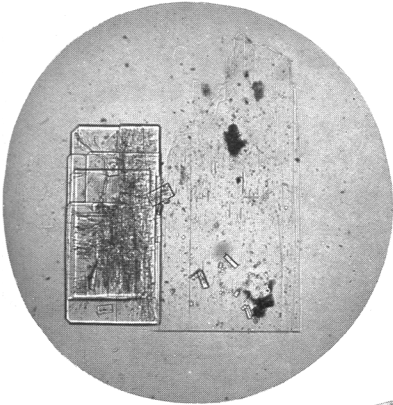
Fig. 3.—Uranospathite as transparent tabular crystals, in the cavities of black gossan.  $\times 4$ .

Fig. 4.—A 'chessboard' group of twinned crystals of bassetite (on the left) mounted by the side of a typical flake of autunite. The latter is also twinned, the composition plane being visible as a black diagonal line. Crossed nicols.  $\times 19$ .

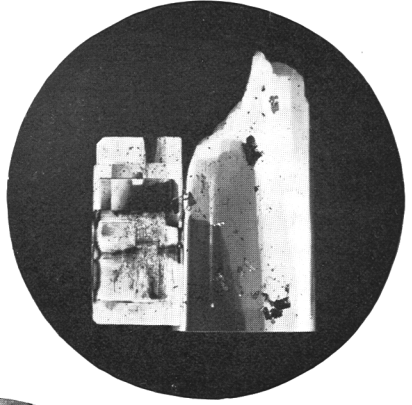
Fig. 5.—Uranospathite, a small terminated crystal. Crossed nicols.  $\times 33$ .

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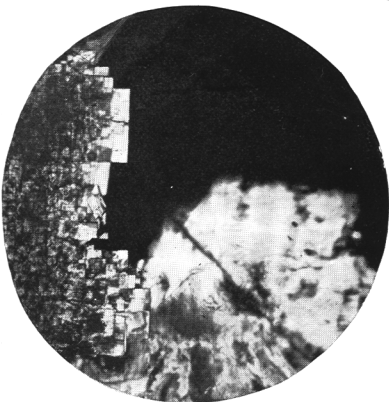
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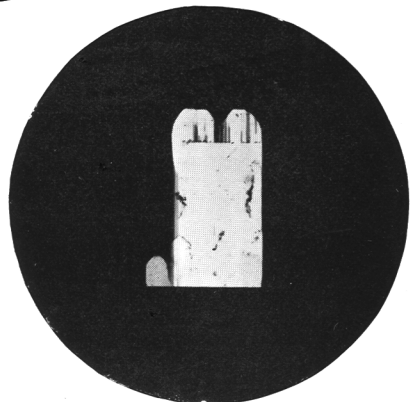
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