

*Augelite.*

By G. T. PRIOR, M.A., F.G.S., and L. J. SPENCER, B.A., F.G.S.

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**A**UGELITE was one of several aluminium phosphates from the iron mine of Westana, Skane, Sweden, described by C. W. Blomstrand in 1868 (*Öfv. Ak. Förh. Stockh.* XXV. 1868, p. 199). He states it to be a massive mineral with distinct cleavages in three directions, and names it augelite (*αυγη* lustre) on account of the strong pearly lustre on the cleavage surfaces. He determines its specific gravity as 2·77, and, as the result of his analyses, represents its chemical composition by the formula,  $2\text{Al}_2\text{O}_3 \cdot \text{P}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$ . Since this paper of Blomstrand, as far as we are aware, no further reference to augelite has been made, and, since hitherto distinct crystals of the mineral have not been found, its position as a definite species seems to have been regarded as somewhat doubtful, for we find that Dana, in the last edition of the *System of Mineralogy*, includes it in a rather unsatisfactory group of more or less doubtful species appended to evansite.

The crystals of augelite which supplied the material for the physical and chemical determinations given in the following paper, were found associated with the bournonite and octahedral pyrites from Machacamarca, Bolivia.<sup>1</sup> Almost all the bournonite specimens from this locality in the British Museum collection showed augelite, either filling cavities in the bournonite, or in isolated crystals upon, and lining crevices in, the quartzose matrix (consisting of angular quartz grains with interspersed iron pyrites) on which the bournonite was deposited. The crystals are of small size, the largest not measuring more than 6·5mm., and the majority not more than 3 to 4mm. along their greatest diameter. The crystallographic measurements were for the most part made on still smaller crystals found embedded in a yellow crumbling decomposition product from the pyrites and bournonite, which coated one side of a large specimen of bournonite.

<sup>1</sup> There seem to be at least three places called Machacamarca in Bolivia, two in Oruro, and one in Potosi.

*Crystalline Form.*

Monosymmetric.  $a : b : c = 1.6419 : 1 : 1.2708$ .  $\beta = 67^\circ 33\frac{1}{2}'$

$100 : 110 = 56^\circ 37'$ ;  $001 : 101 = 28^\circ 54\frac{1}{2}'$ ;  $001 : 011 = 49^\circ 35\frac{1}{2}'$ .

Observed Forms.— $c$  (001),  $m$  (110),  $x$  ( $\bar{1}01$ ),  $f$  (101),  $a$  (100),  $b$  (010),  $n$  (112),  $r$  (011),  $o$  ( $\bar{1}12$ ).

Doubtful forms—225, 334, 223, 665, 221, 530, 310 in the zones  $cm$  and  $mm$ .

Besides these there were other indefinite reflections in the zones  $cm$ ,  $mm$ ,  $xm$ ,  $ca$ .

	Calculated.	Measured.	Limits.	No. of Observations.
$ac$	$67^\circ 33\frac{1}{2}'$	$67^\circ 34'$	$67^\circ 24' - 67^\circ 39'$	3
$af$	$28^\circ 39\frac{1}{2}'$	$38^\circ 37'$	$38^\circ 31' - 38^\circ 43\frac{1}{2}'$	2
$cf$	$28^\circ 54\frac{1}{2}'$	$28^\circ 43'$	$28^\circ 30\frac{1}{2}' - 28^\circ 54'$	7
$cx$	$45^\circ 26\frac{1}{2}'$	$45^\circ 22'$	$44^\circ 36' - 46^\circ 4\frac{1}{2}'$	24
$xm$	$77^\circ 35\frac{1}{2}'$	$77^\circ 40'$	$77^\circ 29' - 78^\circ 6'$	19
$cn$	$31^\circ 7\frac{1}{2}'$	$31^\circ 9'$	$30^\circ 41\frac{1}{2}' - 31^\circ 19'$	9
* $mc$	—	$77^\circ 52\frac{1}{2}'$	$77^\circ 46' - 77^\circ 59'$	20
* $mm$	—	$66^\circ 46'$	$66^\circ 28' - 67^\circ 7'$	32
* $fm$	—	$64^\circ 33'$	$64^\circ 27' - 64^\circ 38'$	12
$fn$	$28^\circ 26'$	$28^\circ 24\frac{1}{2}'$	$28^\circ 15' - 28^\circ 30\frac{1}{2}'$	2
$fr$	$55^\circ 25\frac{1}{2}'$	$55^\circ 13'$	..	1
$an$	$54^\circ 53'$	$54^\circ 55'$	$54^\circ 36\frac{1}{2}' - 55^\circ 8\frac{1}{2}'$	4
$cr$	$49^\circ 35\frac{1}{2}'$	—	..	..
$c : 111$	$45^\circ 42\frac{3}{4}'$	—	..	..
$co$	$39^\circ 11\frac{1}{2}'$	$39^\circ 9\frac{1}{2}'$	..	2

DOUBTFUL FORMS.

225 : $c$	$26^\circ 20'$	$26^\circ 18'$	..	1
334 : $c$	$40^\circ 11\frac{1}{2}'$	$40^\circ 24'$	$39^\circ 0' - 40^\circ 56'$	3
665 : $c$	$50^\circ 37'$	$50^\circ 30'$	..	1
221 : $c$	$59^\circ 57\frac{1}{2}'$	$60^\circ$	..	1
530 : $m$	$14^\circ 18'$	$14^\circ 30'$	$14^\circ - 15^\circ$	2
310 : $m$	$29^\circ 47'$	$29^\circ 19'$	..	1

The basal plane is usually represented by one or more *vicinal faces* which lie in the zones  $cx$  and  $cm$ , and are generally the brightest faces, giving the best images. On account of these vicinal faces, the measurements from the prism plane varied from  $77^\circ 19\frac{1}{2}'$  to  $79^\circ 31'$  (number of observations 87). Within these limits they fell into five fairly well marked groups of which the means were  $77^\circ 29'$ ,  $77^\circ 45'$ ,  $77^\circ 52\frac{1}{2}'$ ,  $78^\circ 2'$ ,  $78^\circ 24'$ . The third of these measurements ( $77^\circ 52\frac{1}{2}'$ ) was taken as the true angle  $cm$ , for the calculated angles between other faces were found to be in closer agreement with the measured angles when this value, instead of any of the other four, was given to  $cm$ . The first two measurements

will then be due to vicinal faces in the zone  $cm$  at  $7\frac{1}{2}'$  and  $23\frac{1}{2}'$  from  $c$ , and the last two to vicinal faces in the zone  $cx$  at  $18\frac{1}{4}'$  and  $1^\circ 0\frac{1}{2}'$  from  $c$  (towards  $x$ ).

*Characters of the faces:—*

*c.* Smooth to deeply striated parallel to its intersections with  $x$  and  $m$ ; the vicinal faces in the zone  $cx$  are striated parallel to their intersections with  $x$ , and those in the zone  $cm$  to their intersections with  $m$ . The basal plane is often represented by only one of the vicinal faces, which is very smooth and bright, giving a single sharp image.

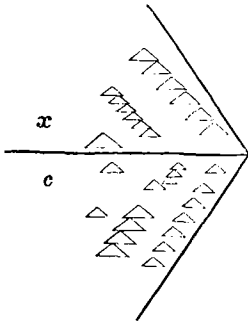


FIG. 1.

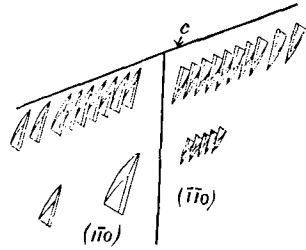


FIG. 2.

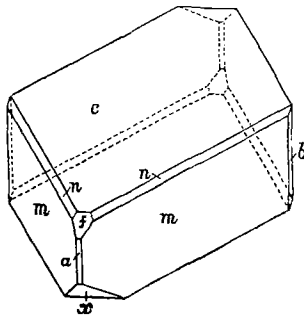


FIG. 3.

*x.* Usually rough and pitted; striated parallel to its intersections with  $c$  and  $m$ ; rarely smooth.

*m.* Smooth and bright; striated parallel to the prism edges, and sometimes very faintly parallel to its intersection with  $c$ ,

*f.* Small and bright.

*n*. Small narrow plane, which, with several indistinct planes (see list of doubtful forms above), truncates the edge *cm*.

*Habits* :—

(1.) The most common habit is tabular parallel to *c* (Fig. 3), with only the forms *c* and *m* prominent. The isolated crystals on the quartzose matrix usually assume this habit.

(2.) Thin triangular plates tabular parallel to *m*, with the edges bounded by *c*, *x*, and *m*.

(3.) Prismatic, with *c* and *x* equally developed, closely simulating rhombic crystals since the angles *cm* and *xm* are so nearly equal.

The crystals found embedded in the yellow decomposition product were of the two last habits.

*Etching* :—

Many of the crystals, especially those from the decomposition product, showed well marked etch-figures, and similar figures could be easily produced by heating crystals for a short time in hydrochloric acid. In Fig. 1 are shown the etchings on the *c* and *x* planes, and in Fig. 2 those on the prism planes. In their form they accord with the oblique symmetry of the crystals. As seen in the figure, they are generally arranged in lines parallel or nearly parallel to one, and one only, of the prism edges. This would seem to suggest a hemimorphic development of the crystals, and this idea receives some slight support from the fact that on one crystal the striations observed on the *x* plane were again only parallel to one of the prism edges. Hemimorphism was also suggested by the development of the form *n* on one or two crystals. No pyroelectricity on change of temperature, however, could be detected by means of Kundt's method.

*Physical Characters* :—

Colourless to white; transparent to translucent; streak white; lustre vitreous, inclining to pearly on the cleavage surfaces. Cleavage: *m* perfect; *x* less perfect, but good. Fracture uneven.

Hardness 4.5 to 5: brittle.

Density (weight of 1cc.) 2.696 at 22°C; material used 0.4166 gr.

Under the microscope, in some of the crystals, liquid cavities with bubbles were observed. No effect seemed to be produced on the bubbles on heating the crystals up to 54°C, so that the liquid was most probably water or an aqueous solution, and not carbonic acid.

*Determination of the Optical Constants :—*

The double refraction is positive. The plane of the optic axes is perpendicular to the plane of symmetry. The acute bisectrix makes with the vertical axis  $c'$  an angle of  $84^\circ$  approx. (in the acute angle  $\beta$ ), *i.e.* it makes an angle of  $11\frac{1}{2}^\circ$  with the normal to  $c$  and an angle of  $56^\circ$  with the normal to  $a$ .

The angle of extinction on  $m$  measures  $25^\circ$  to the prism edge.

Optical axial angle (sodium light) :—

$$2E_a = 84^\circ 42'. \quad 2H_a = 51^\circ 29'. \quad 2H_o = 132^\circ 12'.$$

From which  $2V = 50^\circ 49'$ .

These determinations were made with plates cut at right angles to the 1st and 2nd mean lines. The oil used was oil of anise ( $n = 1.5569$  as determined by means of the total reflectometer). No dispersion of the axes was observed.

Refractive Indices (sodium light) :—

$$\alpha = 1.5736, \quad \beta = 1.5759, \quad \gamma = 1.5877.$$

Double refraction,  $\gamma - \alpha = .0141$ .

$\alpha$  and  $\gamma$  were determined by means of a prism cut symmetrically about the plane of symmetry, and with the refracting edge parallel to the acute bisectrix.  $\beta$  was determined by calculation from the optic axial angles in oil in the two plates, and the index of refraction of the oil.

The value of  $2V$  calculated from the above values of  $\alpha$ ,  $\beta$ ,  $\gamma$ , is  $47^\circ 56'$ .

Measurements of the indices of refraction through the natural prism ( $m$ ) gave the two values  $1.5745$  and  $1.5889$ .

Owing to the small size of the transparent crystals, and the consequent difficulty in grinding down the plates and prisms by hand, the errors of orientation amounted in some cases to three or four degrees.

Experiment showed that the variation of the optical axial angle on change of temperature was scarcely appreciable. For a rise in temperature of  $100^\circ$  there appeared to be only a slight decrease in the angle of less than half a degree.

*Chemical Characters :—*

The mineral is infusible, and becomes opaque before the blowpipe. With cobalt nitrate it gives a blue colour. It yields much water in the closed tube. In fine powder it is slowly dissolved on digestion in hot concentrated hydrochloric acid.

Material for the quantitative analyses was carefully picked out under

the lens, and then separated as far as possible from quartz by means of methylene iodide. After the separation with methylene iodide the material was a second time picked out under the lens. It was found, however, to be impossible to completely remove the quartz from the angelite, for the very carefully selected material used in analysis I was found to contain 1·81 per cent. of silica, while the less carefully picked material used in the preliminary analysis II contained as much as 13·6 per cent. Blomstrand speaks of the difficulty of separating the quartz, and obtained in his analyses from 4 to 13 per cent. of silica. In the preliminary analysis II the water was determined by ignition, the phosphoric acid was separated by molybdate solution and reprecipitated by magnesia mixture, and the alumina was precipitated by ammonia and ammonium sulphide in the filtrate from the molybdate precipitate.

In analysis I the water was determined directly by absorption in a calcium chloride tube. A plug of sodium carbonate was placed in the mouth of the combustion tube in which the mineral was heated, to absorb any hydrofluoric acid which might be given off; but, on testing the sodium carbonate after the experiment, no fluorine was detected, and the increase in weight of the calcium chloride tube corresponded fairly closely with the loss in weight of the material. In this analysis the mineral was dissolved in hydrochloric acid, and the solution was divided into two portions, in one of which the alumina and the phosphoric acid were precipitated together by ammonia, while in the other the phosphoric acid was precipitated by molybdate solution, and finally weighed as pyrophosphate of magnesium.

The alumina was carefully tested for beryllium, but with negative results.

*Result of Analyses :—*

	I.	II.	III.	IV.
			(Blomstrand)	(Theory)
P <sub>2</sub> O <sub>5</sub>	34·60	35·33	35·04	35·50
Al <sub>2</sub> O <sub>3</sub>	51·40	50·28	49·15	51·00
CaO	0·11 <sup>1</sup>	0·90 <sup>1</sup>	1·09	—
H <sub>2</sub> O	13·77	13·93	12·85	13·50
Fe <sub>2</sub> O <sub>3</sub>	—	—	0·89	—
MnO	—	—	0·31	—
	<u>99·88</u>	<u>100·44</u>	<u>99·33</u>	<u>100·00</u>

<sup>1</sup> Most probably partly, if not wholly, derived from the reagents or from their action on the glass and porcelain vessels used in the analyses.

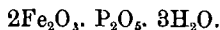
Weight of material used in analysis I = 0.8379 gr.

„ „ in analysis II = 0.8164 gr.

No water was given off below 360°.

Under III is given the mean of Blomstrand's four analyses of the mineral from Westaná, and under IV the theoretical numbers required by the formula  $2\text{Al}_2\text{O}_3 \cdot \text{P}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$ , or  $\text{AlPO}_4 \cdot \text{Al}(\text{OH})_3$ .

The orthorhombic dufrenite has the analogous formula—



The result of the analyses of the mineral from Machacamarca, together with the determination of the specific gravity and the observation of the three cleavage surfaces, showed that angelite was the only mineral to which it could be referred. Any doubt as to the absolute identity of the mineral from Bolivia with that from Sweden was at once set at rest when, through the kindness of Prof. Blomstrand, the Museum became possessed of a small specimen of the original angelite from Westaná; for the angles between the three cleavage surfaces were found by measurement to be, within a few minutes ( $mm = 66^\circ 52'$ ,  $mv = 77^\circ 33'$ ), the same as those between the corresponding faces on our crystals, and prism cleavage flakes from both minerals showed under the microscope with a  $\frac{1}{2}$  immersion the same optical character, viz. the emergence of an optic axis just beyond the edge of the field.

Judging from the Museum specimens, angelite appears to be by no means a rare mineral at Machacamarca. That it has been so long overlooked may perhaps be accounted for by its having been mistaken for other minerals. Thus Sandberger (*Neues Jahrb.*, 1886, (1), p. 89) speaks of bournonite from this locality associated with barytes. We have found no barytes on any of the bournonite specimens from Machacamarca in the Museum collection, and it is just possible that the barytes to which Sandberger refers was really angelite, for the habit of the two minerals is somewhat similar.

Besides the angelite, on specimens from Machacamarca in the Museum collection we have noted the following minerals:—

*Bournonite*.—Grooved prisms with the forms  $a b m c e n o u y \Omega^1$ . The faces in the zone  $n o u [11\bar{1}]$  are sometimes large. The crystals are usually bright, but sometimes coated with melaconite, and at times much altered.

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<sup>1</sup> The letters are those used in Dana's Mineralogy.

*Iron Pyrites*.—Symmetrically developed octahedra, usually very bright, but sometimes with a thin, dull, black coating (melaconite?). One large isolated crystal is an icositetrahedron  $\beta$  {322} with small {111} planes. Another crystal shows the forms  $n$  {211} and  $p$  {221} besides the large octahedral faces.

*Zinkenite*.—Interlacing acicular crystals on the bournonite. A few needles are sometimes enclosed in the augelite. Sandberger (*loc. cit.*) notes the occurrence of guejarite on bournonite from Machacamamarca. We have been unable to detect this rare mineral on our specimens: the acicular crystals on the bournonite on analysis always proved to be zinkenite.

Zinkenite, bournonite, pyrites, argentiferous galena, and tetrahedrite are mentioned by Damour<sup>1</sup> as occurring at Machacamamarca.

*Mispickel*.—A few minute prisms on the pyrites, terminated by a very low pyramid and brachydome approximating to the basal plane.

*Quartz*.—Minute crystals covering the surface of the quartzose matrix on which the bournonite occurs.

*Chalcedony*.—Stained with oxide of iron.

*Bleinierite*.—Pseudomorphous after zinkenite.

*Chalcanthite*.—In the decomposition product from the bournonite.

*Melaconite*.—Thin dusty layer on the bournonite.

*Anglesite*.—In thin flakes, coating the bournonite crystals and lining crevices in them.

*Blende*.—Very rough, irregular, black crystals.

*Copper Pyrites*.—Massive.

We have given the above brief account of the mineral occurrences at Machacamamarca since there appear to be very few references to the subject. Dana (*Mineralogy*, 6th Ed., p. 128) mentions Machacamamarca as a locality for bournonite, and Domeyko (*Mineralogía*, 3rd Ed., p. 235) gives an analysis and short description of the mineral from this locality; but these, together with the two quoted above, are the only references we have been able to find respecting minerals from Machacamamarca.

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<sup>1</sup> F. de Castlenau, *Expédition dans les parties centrales de l'Amérique du Sud*, 1850-1. Vol. v. pp. 438-440.