On crossite from Anglesey.

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Introduction.

THE occurrence of a member of the glaucophane group of minerals in Anglesey has been known since 1888, in which year Blake[1] reported the presence of a blue amphibole in a schist exposed in the neighbourhood of the Anglesey Column, west of the Menai Bridge. In the course of his paper Blake made general remarks on the petrography of the schist and on its field relations. He dwelt at some length on the question of the identity of the blue amphibole which is its most notable constituent, describing its columnar habit and pleochroism, and recording an extinction angle of 15° with the axis of elongation (*c*). By comparison with a description of glaucophane due to Rosenbusch, Blake concluded that the blue amphibole from the Anglesey rock is a normal glaucophane, although its extinction angle as recorded by him is considerably in excess of the 4° to 6° mentioned by Rosenbusch. The associated minerals he identified as epidote, rutile (?), quartz, a felspar (?), and some calcite (the marks of interrogation are his own).

The chemistry of the glaucophane-schist was subsequently studied by Washington,[2] who gave a short description of the rock analysed. He stated that the glaucophane-schists 'are seen to be composed of a rather pale, prismatic glaucophane, with the normal pleochroism, rather less [amounts of] pale epidote, and small amounts of magnetite, quartz, mica and titanite'. He also noted the absence of calcite. He regarded the rock as having been derived from a diorite or possibly from a gabbro, but was uncertain whether the development of glaucophane-schist in Anglesey was due to regional or to thermal metamorphism.

Greenly, in his classical work,[3] added little to Blake's description of the schist or of its blue amphibole, which latter he, like Blake, considered to belong to glaucophane proper. Greenly's main contribution lay in his investigation of the field relations of the glaucophane-schists,

[1] J. F. Blake, Geol. Mag., 1888, dec. 3, vol. 5, pp. 125–127.

[2] H. S. Washington, Amer. Journ. Sci., 1901, ser. 4, vol. 11, pp. 42, 43.

[3] E. Greenly, The geology of Anglesey. Mem. Geol. Surv. Great Britain, 1919, pp. 115–118. [M.A. 1-328.]

which he clearly distinguished as being products of regional metamorphism.

The identification of the blue amphibole from the schists of the Monument Hill does not appear to have been questioned, and no further communications on the subject have appeared to date. A chemical analysis of the blue amphibole was obviously required, but, since the fineness of grain of the schists which contain it render difficult a reasonably pure separation of the mineral, it is not surprising that no such analysis has previously been recorded. Recently, however, the methods of separating minerals from crushed rocks have been considerably improved, notably by the introduction of the use of the centrifuge in association with heavy liquids. Using this technique, it has been found possible to separate the blue amphibole in a very nearly pure state.

Petrography of the 'glaucophane'-schist.

The material investigated was collected from the foot of the crag on the south-eastern face of the Monument Hill, on the north side of the Holyhead road, near the village of Llanfairpwllgwyngyll, and some one and a half miles west of the Menai Bridge.

In the hand-specimen it is a blue-grey rock showing a nemablastic schistosity, with very subsidiary sericitic material intersecting the texture in thin and impersistent films. In thin slice it is seen to correspond closely to the material described by Blake and by Greenly, showing a strongly developed alinement of slender prisms of the blue amphibole and of prismatic to granular epidote, with occasional granular sphene. Also conforming to the schistose fabric are occasional thin layers of quartz and albite mosaic, the latter mineral occasionally twinned on the albite law and sometimes building small sub-porphyritic knots or augen about which the nemablastic fabric is disturbed. A pale green chlorite which is present in small quantities is not recognizably pseudomorphous after any mineral, but is intersected by sharply bounded prisms of the blue amphibole which may have grown in part at the expense of the chlorite. Rutile and calcite referred to by Blake (loc. cit.) have not been observed in the thin slices, nor has been the sericitic material observed in the hand-specimen. Spongy haematite, showing red in thin plates, occurs sporadically in the rock.

Physical properties of the blue amphibole.

The habit of the blue amphibole corresponds to the description given by Blake (loc. cit.), the forms (110) and (010) being clearly defined while the terminations are indefinite. It is moderately pleochroic in thin section, with α pale neutral tint, β pale grey-violet, and γ sky-blue, the absorption being $\alpha < \beta < \gamma$. The refractive indices for sodium (D) light are α 1·649, β 1·656, and γ 1·657. The optic axial plane is parallel to (010) with $\beta = b$, the maximum measured extinction angle $\gamma : c$ being 11°. The optic axial 2V is variable about 17°, with $Bx_a = \alpha$.

As a powder the mineral is medium grey-blue in colour; its specific gravity (determined by dispersing the powder in a liquid of matching density and confirming the stability of the suspension with the centrifuge) is 3·206 (uncorrected value determined at room temperature about 15° C.).

While perhaps 90% by volume of the blue amphibole content of the 'glaucophane'-schist corresponds to the foregoing description, occasional cores of blue amphibole show stronger coloration with α pale neutral tint, β grey-green, and γ greenish-blue, a formula which suggests a more riebeckitic amphibole than that which it accompanies and which is the subject of this study.

The sample prepared for analysis contained not more than 1 % of epidote as its only impurity. The more strongly coloured amphibole detected in the examination of thin sections had apparently differed sufficiently in specific gravity from the more abundant variety to be completely removed during the separation process.

Constitution and affinities of the blue amphibole.

The chemical analysis of the blue amphibole is tabulated under 1, table I, and is restated in terms of 'atomic' proportions, adjusted to the conventional basis of 24(O,OH) per unit cell, under 1, table II. The analysis confirms the close relationship of the mineral to the alkali-amphiboles of the glaucophane-riebeckite series.

Analysed glaucophanes agree in showing a uniformly *low* value for the atomic ratio of ferric iron to aluminium, while in the same mineral the ratio of ferrous iron to magnesium varies from fractional values up to a maximum of about unity. In the riebeckites, on the other hand, both of these ratios have high values. The blue amphibole of the Anglesey 'glaucophane'-schist occupies an intermediate position in that the appropriate value for both of these ratios is near to unity, the proportion for aluminium substituted for silicon in the amphibole structure being ignored for the purpose of this comparison. The approximately equivalent proportion of ferric iron to aluminium, and of ferrous iron to magnesium, is a character shared with analysed crossites from Berkeley, California, and elsewhere. Analyses of Berkeley material by Palache[1] (the type

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[1] C. Palache, Bull. Dept. Geol. Univ. California, 1894, vol. 1, pp. 181–192. [Min. Mag. 11–35.]

material) and by Kunitz[1] are quoted for comparison under A and B respectively in tables I and II.

TABLE I. Chemical analyses of crossite.

	1.	A.	B.
SiO_2	50·41	55·02	54·72
TiO_2	1·66	—	—
Al_2O_3	7·82	4·75	8·27
Fe_2O_3	8·73	10·91	7·03
FeO	10·81	9·46	11·82
MnO	0·14	trace	0·36
MgO	7·39	9·30	7·26
CaO	3·99	2·38	1·58
Na_2O	7·04	7·62	6·31
K_2O	0·57	0·27	0·40
$H_2O+105°$ C.	1·17	—	1·96
$H_2O-105°$ C.	0·10	—	—
	99·83	99·71	99·71
Sp. gr.	3·206	3·126–3·16	3·184

1. From crossite-epidote-quartz-albite-schist at base of crag south-east of the Anglesey Monument, Llanfairpwllgwyngyll, Anglesey. Analyst, N. Holgate.

A. From albite-crossite-schist, Berkeley, California. Analyst, W. S. T. Smith (Palache, 1894).

B. From crossite-mica-schist, Berkeley, California. Analyst, W. Kunitz (Kunitz, 1930, p. 244).

TABLE II. Analyses of crossite, recalculated as atomic proportions.

	1.			A.			B.		
Si	7·443		8·000	7·439		8·000	7·825		8·000
Al	1·357	0·557 0·800	4·936	0·756	0·561 0·195	4·262	1·396	0·175 1·221	4·994
Ti	0·185			—			—		
Fe‴	0·974			1·114			0·760		
Fe″	1·331			1·066			1·418		
Mg	1·637			1·887			1·552		
Mn	0·009			—			0·043		
Ca	0·632		2·747	0·346		2·384	0·244		2·071
Na	2·007			1·991			1·754		
K	0·108			0·047			0·073		
H	1·155		1·155	—		—	1·877		1·877

1. Blue amphibole (crossite), Anglesey, new analysis.
$(H)_{1\cdot155}(Na,K,Ca)_{2\cdot747}(Mg,Fe'',Fe''',Al,Ti,Mn)_{4\cdot936}(Si,Al)_8O_{24}$.

A. Crossite, Berkeley, Palache, 1894.
$(Na,K,Ca)_{2\cdot384}(Mg,Fe'',Fe''',Al)_{4\cdot262}(Si,Al)_8O_{22}$.

B. Crossite, Berkeley, Kunitz, 1930.
$(H)_{1\cdot877}(Na,K,Ca)_{2\cdot071}(Mg,Fe'',Fe''',Al,Mn)_{4\cdot994}(Si,Al)_8O_{24}$.

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[1] W. Kunitz, Neues Jahrb. Min., Abt. A., 1930, vol. 60, pp. 198, 244. [M.A. 4–200.]

The close similarity of the Anglesey material to these named crossites, on the basis of chemical composition, is well shown by a comparison in detail. While members of the glaucophane-riebeckite series proper do not bear any considerable content of lime, the Anglesey mineral, in agreement with the Berkeley crossites though in greater degree, carries lime in such proportions as to take a significant part in the constitution of the mineral. Unless, therefore, this unusually high lime content is regarded as sufficiently important to constitute a diagnostic character, in which case a new mineral name would be called for, the Anglesey blue amphibole, hitherto regarded as a true glaucophane, should be recognized as an outlying member of the crossite group of the alkali-amphiboles. Its assignment to crossite rather than to glaucophane is in agreement with Sundius's[1] (p. 17) proposal based on the atomic ratio of ferric iron to that part of aluminium occupying positions of six-coordination in the amphibole structure. According to this criterion, Kunitz's crossite (analysis quoted under B, tables 1 and 2) is rather to be referred to glaucophane.

The recalculated analysis of the present material corresponds closely to the general formula for the alkali-amphiboles proposed by Kunitz (loc. cit.) and by Warren.[2] The recalculation shows aluminium proxying for silicon in very nearly the same proportion as does calcium appear in the unit cell. This would support the suggestion due to Winchell[3] that there is present in these minerals a lime-bearing hornblende molecule.

The determination of combined water ('+105° C.') was made by the Penfield tube method, and hence may be in part responsible for the low value of hydroxyl shown in the recalculated analysis. Yet the apparatus used and the procedure followed in the determination might have been expected to achieve a nearly complete expulsion of the combined water of the sample, and its subsequent weighing. An alternative possibility, that the permissible total hydroxyl content is to a considerable degree substituted by halogens, has not been investigated.

A consideration of the physical properties of the Anglesey blue amphibole gives further support to the conclusion reached on chemical grounds. Kunitz (loc. cit.), in his tabulation of the 'glaucophane series', records specific gravities which vary from 3·085 for a glaucophane from the Matterhorn to 3·382 for riebeckite from Pike's Peak, Colorado. The

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[1] N. Sundius, Årsbok Sveriges Geol. Undersök., 1946, vol. 40, no. 4. (Avh. Upps., Ser. C., no. 480.) [M.A. **10**–70.]

[2] B. E. Warren, Zeits. Krist., 1930, vol. 72, pp. 493–517. [M.A. **4**–278.]

[3] A. N. Winchell, Elements of optical mineralogy. Pt. II, New York, 1933, p. 259. [M.A. **5**–337.]

Anglesey crossite with its specific gravity of 3·206 lies slightly above the value (3·184) determined by Kunitz for a crossite from Berkeley.

The refractive indices of the Anglesey crossite similarly accord well with those recorded for the Berkeley crossites, the values for the former lying between the respective values determined by Palache and by Kunitz. The birefringence of the Anglesey mineral is somewhat low by comparison.

The optical orientation of the crossites appears to be less useful as a diagnostic character, since there is some lack of unanimity on this matter as between described crossites. The Anglesey mineral has its optic axial plane parallel to (010) and the obtuse bisectrix γ near to the crystallographic axis c. The original crossite described by Palache (loc. cit.) is given as having its optic axial plane also parallel to (010), but has its optic symmetry axis α near to c; the optic sign is not given (Kunitz, loc. cit., p. 198, appears to have misquoted Palache's determinations). According to Louderback,[1] the optic orientation of another crossite from the Berkeley area has its optic axial plane normal to (010) with great dispersion of the optical axial plane about b. Murgoci,[2] following Brouwer,[3] states that crossite is characterized by having the optic axial plane normal to (010). Sundius (loc. cit., p. 17) states that while those members of the glaucophane-riebeckite series with the ratio Fe'''/Al for positions of octahedral coordination less than unity are characterized by the orientation of the optic axial plane parallel to (010), the members (crossites, riebeckites) for which the ratio exceeds unity, while tending to have the optic axial plane normal to (010), do not invariably show this character. While it is not yet clear to what extent this lack of agreement as to the optic orientation of the crossites is the result of compositional differences, the latter may well be the operative factor. Willems[4] concludes that the presence of Ca in the constitution of the blue amphiboles has some influence in determining their individual optical properties. It is possible that the rather high proportion of calcium in the constitution of the Anglesey crossite is responsible for its apparently abnormal optical orientation.

Conclusion.

A more detailed study of the Anglesey 'glaucophane' than has previously been attempted shows that in chemical constitution and in

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[1] G. D. Louderback, Bull. Dept. Geol. Univ. California, 1909, vol. 5, p. 360.

[2] G. Murgoci, Compt. Rend. Acad. Sci. Paris, 1922, vol. 175, pp. 426–429. [M.A. 2-221.]

[3] H. A. Brouwer, Bull. Soc. Franç. Min., 1913, vol. 36, pp. 272–275.

[4] H. W. V. Willems, Proc. K. Akad. Wetenschap. Amsterdam, 1937, vol. 40, pp. 720–724. [M.A. 7-250.]

optical properties it has more in common with the crossites than with any other of the amphiboles of the glaucophane-riebeckite series. Although the chemical analysis reveals some 4 % of lime, it is believed that the mineral is best described as a crossite, especially as all analysed crossites show some degree of 'contamination' of this kind.

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