Ganophyllite from the Benallt mine, Rhiw, Carnarvonshire.

(With Plate XXI.)

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GANOPHYLLITE was first detected in the Benallt mine as small fibrous patches varying in colour from pale pink to brown, in the thin vein cutting ore in the Ty Canol incline from which the manganese-rich chlorite, pennantite, was described.[1] These were identified by X-ray photographs. It had previously been found at the neighbouring Nant mine by Sir Arthur Russell[2] in 1911.

During my visit with Dr. A. W. Groves to the Benallt manganese mine in June, 1945, glistening brown flakes of the mineral were found at several places, associated with calcite, on fracture surfaces in the manganese ore. The best specimen obtained at that time was found in Stope 73 by Mr. Pickering (B.M. 1945,109), and another fine specimen was collected later in the year by Mr. T. J. A. Wills, the mine manager, at Peg 31 on the 60-foot level (B.M. 1945,131).

On all the specimens obtained the ganophyllite occurs as very small six-sided flakes, cinnamon-brown in colour, and with a brilliant lustre which ranges from pearly to metallic or micaceous. None of the flakes exceeds 1 mm. in longest dimension.[3] They have a perfect mica-like cleavage. The crystals are biaxial, optically negative, with 2E varying in measured flakes from 30 to 40°, and the acute bisectrix is at right angles to the perfect cleavage. Refractive indices, on several specimens, measured by the immersion method in sodium-light, are for β between 1·610 and 1·612. Estimates of birefringence based on universal-stage

[1] W. Campbell Smith, F. A. Bannister, and M. H. Hey, Min. Mag., 1946, vol. 27, p. 218.

[2] A. Russell, Min. Mag., 1946, vol. 27, p. 234.

[3] A specimen obtained earlier and given me by Mr. Wills had flakes up to 4 mm. across, but it is not known from which part of the mine this was obtained. The ganophyllite is associated with white calcite which fluoresces pink in ultra-violet light. (B.M. 1945,108.)

measurements of retardation and the microscope method of measuring thickness gave $\gamma-\alpha$ 0·040±0·003, $\gamma-\beta$ 0·001.

The pleochroism observed in thin sections is: α', perpendicular to the cleavage, straw-yellow; β and γ' parallel to the cleavage, colourless.[1] The cleavage flakes show no perceptible pleochroism.

Qualitative chemical tests established the presence of much manganese and of water given off at a low temperature in the closed tube. No further chemical work was done as the amount of available material was small. An approximate value for the specific gravity is 2·8. The identification with ganophyllite is confirmed by X-ray photographs, the evidence from which is discussed below.

Ganophyllite was first described from the Harstig mine, Pajsberg, Sweden, by A. Hamberg in 1890.[2] On crystals, which were up to an inch in length but presented very poor faces for measurement, Hamberg found a prism angle (110):(1$\bar{1}$0) of 44° 49′. A basal cleavage flake of one of these prismatic crystals thus shows pairs of edges making plane angles of about 44° and 136°, and the symmetry plane (010) bisects the obtuse angles (136°). The perfect micaceous cleavage was taken as the base, *c* (001) (text-fig. 1*a*).

Hamberg gave as the value for the optic axial angle, $2E_{Na}$ 41° 53′, negative. He measured the refractive indices, β and γ, by means of a 30° prism of which the perfect cleavage formed one face, but the second face was so poorly polished that it was necessary to attach a cover-glass to it with Canada balsam to improve the light transmission. The values he obtained by this method, β 1·7287, γ 1·7298, were shown by Larsen and Shannon[3] to be quite incorrect and they redetermined them by the immersion method as α 1·573, β 1·603, γ 1·604. The optical orientation is given by Hamberg (loc. cit., p. 586) as: 'the plane of the optic axes is perpendicular to the symmetry plane and perpendicular to the base. . . . The acute bisectrix is perpendicular to the base.' Thus his setting of the optical orientation is therefore $\alpha = c$, $\beta = a$, $\gamma = b$ (text-fig. 1*a*′).

E. S. Larsen in 'The microscopic determination of the nonopaque minerals' (1921, p. 267, and 2nd edit., 1934, p. 167) has given a different orientation, '$X \wedge c$ = small. $Y = b$', and this has been followed by W. E. Ford in Dana's 'Textbook of mineralogy' (4th edit., 1932, p. 641),

[1] A similar absorption scheme is recorded for a mineral taken to be a mica in one of the specimens carrying banalsite from Benallt described in 1944 (Min. Mag., vol. 27, p. 40).

[2] A. Hamberg, Geol. För. Förh. Stockholm, 1890, vol. 12, pp. 586–598.

[3] E. S. Larsen and E. V. Shannon, Ganophyllite from Franklin Furnace, New Jersey. Amer. Min., 1924, vol. 9, p. 239. [M.A. 3–216.]

who gives the characters as: 'Optically −. Ax. pl. || (010). X nearly || c axis.'

Our observations and particularly the series of X-ray photographs taken by Dr. Bannister confirm the correctness of Hamberg's statement for the Harstig ganophyllite that the optic axial plane is perpendicular to the plane of symmetry (010), but the statement by Larsen that the orientation of the optic axial plane is parallel to (010) is of particular interest as we find in specimens from different parts of the Benallt mine examples of both orientations. This discovery is due to Dr. Bannister, who found for the first of several specimens from Benallt of which he took X-ray photographs that the optic axial plane was parallel to the plane of symmetry. Other specimens agreed with the Harstig ganophyllite in having the axial plane perpendicular to the plane of symmetry, but we subsequently found a second specimen with the parallel orientation. In every case Dr. Bannister's observations are confirmed by our optical measurements on flakes of the several specimens.

Our confirmation of Hamberg's orientation for the Harstig ganophyllite is based on the following observations on a specimen in the British Museum collection (80037). As mentioned above, the cleavage flakes are bounded by edges making plane angles of about 44° and 136°, and the plane (010) in Hamberg's setting bisects the obtuse angle of 136°. The plane of the optic axis is at right angles to the trace of this (010) plane.

The existence of a plane of symmetry in this position is confirmed by a Laue photograph taken by Dr. Bannister of a flake from the Harstig ganophyllite set with the plane bisecting the 136° angle between the bounding edges vertical (pl. XXI, fig. 1), the optic axial plane being horizontal. The flake in this position rotated about the third mean line (β), which is taken by Hamberg as parallel to the a-axis, gives a layer-line spacing of 5·6 Å. Rotated about the obtuse bisectrix (γ), parallel to the b-axis, the layer-line spacing is 13·5 Å. These spacings give a ratio $b/a = 2{\cdot}41$, which agrees sufficiently well with the axial ratios obtained by Hamberg $a:b = 0{\cdot}4130:1$, from which $b/a = 2{\cdot}42$. It has not yet been possible to determine the angle β from X-ray measurements. The value of the c (001) spacing for ganophyllite from Harstig is 12·5 Å. and has been derived from reflections on the zero layer-line of rotation photographs of flakes rotated about the a and b axes.

Returning now to the Benallt specimens, we find the mica-like flakes are bounded by edges of which two opposite pairs make angles of about

132°, and for the best specimen, from the 60-foot level (B.M. 1945,131), and several others we find the plane of the optic axes at right angles to the plane bisecting this obtuse angle. Assuming the angle of 132° to correspond with 136° measured on flakes of the Harstig ganophyllite we have the same orientation as given by Hamberg, namely, Ax. pl. $\perp$(010), $\gamma = b$. This is confirmed for B.M. 1945,131 by a rotation photograph about the third mean line (β) which gives the same, a-axis, spacing as for the Harstig ganophyllite.

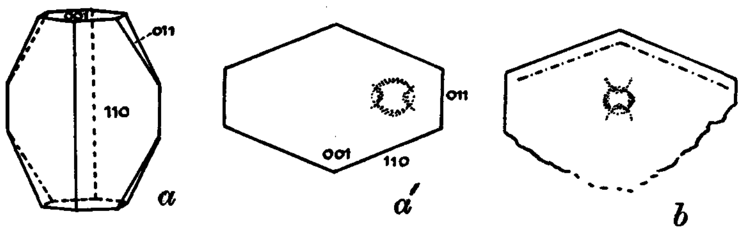

FIG. 1. (a) and (a') Tracings of Hamberg's figures of ganophyllite from the Harstig mine, Pajsberg, Sweden (loc. cit., pl. 13, figs. 8 and 9).
(b) Reduced from a tracing of a photomicrograph from the Benallt mine of the ganophyllite showing the abnormal position of the optic axial plane, parallel to (010).

A different orientation, however, was found when X-ray photographs were taken of the flakes from another specimen (B.M. 1944,36) collected by Dr. Groves in 1944 from no. 5 ore-body in the Benallt mine. The bounding edges of these flakes are poorly developed, but the position of the plane of symmetry was established by a Laue photograph and was found to be *parallel* to the optic axial plane. Moreover, a rotation photograph taken with the third mean line vertical gave a spacing of 13·5 Å., corresponding to b for the Harstig ganophyllite, while a rotation photograph with the positive obtuse bisectrix vertical gives the a-axis spacing of 5·6 Å. Thus for this specimen the orientation is $\beta = b$, $\gamma = a$, which is the orientation given by Larsen. The optic axial angles observed in flakes of this specimen vary considerably, some flakes being nearly uniaxial, but values up to 27° for 2E were measured, and the flake selected by Dr. Bannister was one with a clearly defined axial angle. His determination of the 'parallel' orientation was subsequently confirmed by examination of other flakes and of several crystals measured in a thin section cut across the specimen B.M. 1944,36 in which the ganophyllite occurs in thin veins traversing the ore. Text-fig. 1b is a tracing from a photomicrograph of one such section. Lines of inclusions, parallel to the prism faces m and m''', are at a plane angle of about 136°. The optic axial plane lies *in* the plane bisecting this angle.

One other specimen (B.M. 1945,110, from Stope 84) was found with the 'parallel' orientation of the optic axial plane. The orientation could not be definitely verified in thin flakes many of which are composite, but it was established by a rotation photograph, taken by Dr. Bannister. The flake rotated about the third mean line (β) gives the spacing found for the Harstig mineral rotated about the Bx_o (γ), which is parallel to the b-axis. The optic axial angle in flakes from this specimen is very variable, angles of 2E from 20 to 35° being observed.

The only other notable difference in the optical properties of specimens with the two different orientations is that thin sections of the specimen B.M. 1944,36 cut across the flakes show vibrations parallel to the cleavage light ochraceous buff, whereas those perpendicular to the cleavage are nearly colourless. This gives the absorption scheme $\gamma' > \alpha$, whereas for the 'normal' ganophyllite it is $\alpha > \beta = \gamma$ (p. 344). The evidence for this pleochroism seems quite definite in thin sections, but has not been confirmed by observations on flakes of the mineral.

Within the limits of errors of the immersion method as applied to thin flakes of the mineral (which are notoriously bad subjects for this method) no considerable difference in the values of β and γ has been found between flakes from specimens with the two different orientations.

For specimens with 'normal' orientation values for β in Na-light obtained at room-temperatures between 17 and 19° C. were:

Flakes with 2E 44°, β_{Na} 1·6099. (B.M. 1945,108.)
,, ,, 2E 40°±1°, β_{Na} near and greater than 1·605. (BM. 1945,109.)
,, ,, 2E 30°, β_{Na} 1·6099; also another reading just less than 1·6097. (B.M. 1945,131.)
γ is only slightly greater than β (see p. 344).

Similar measurements on specimens with 'parallel' orientation gave:

Flakes with 2E 17° at 19° C. gave γ_{Na} 1·6098 and β slightly less, but another determination gave γ_{Na} 1·6109. (B.M. 1944,36.)
Flakes with 2E 35° at 17° C. β and γ near 1·6120, $\beta <$ 1·6123. (B.M. 1945,110.)
A single measurement of $\gamma - \alpha$ was obtained on a thick flake and gave $\gamma - \alpha =$ 0·038±0·001. (B.M. 1944,36.)

Change of optical orientation on dehydration.

Hamberg in his original work on ganophyllite had shown that the mineral readily lost water when heated and that if sufficient time were allowed most of the water was re-absorbed if the mineral was left exposed to moist air. It was this behaviour of the water in ganophyllite which led Hamberg to describe it as a mangan-zeolite.

Knowing of this property of the mineral it seemed probable that the variation in 2V and perhaps also the presence of two types of ganophyllite with differing optical orientation would be found to be related

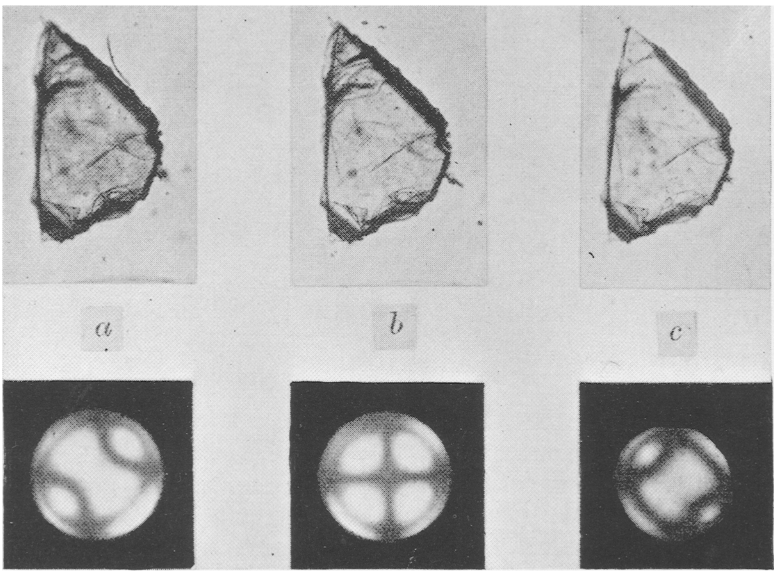

FIG. 2. Ganophyllite from Benallt mine. Change of optical orientation on heating. (*a*) Unheated. (*b*) Heated to about 50° C. for one hour. (*c*) Heated to about 105° C. for half an hour. The upper pictures show the flake seen in parallel light, and below are the corresponding optic pictures in polarized convergent light. The magnification of the flake is × 46. Length of longest edge 0·6 mm.

to the water content of the mineral in the same way as the optic axial angles and orientation of some zeolites alters when water is driven off by heating as shown by the work of F. Rinne and others.

Experiments to test this idea made on a purely qualitative scale confirmed that the optic axial angle and the optical orientation change when flakes of ganophyllite are heated and change back to the original value and position as the flakes are cooled in moist air; moreover, flakes from specimens of the two different orientations behave differently.

A flake of the ganophyllite with 'normal' orientation (B.M. 1945,131) heated in the open at about 50° C. for an hour became uniaxial. Heated further in an air oven between 95 and 105° C. for 45 minutes the optic eyes had opened out to 35° (2E) in the plane of symmetry, at right angles to their original position. The effect is shown in text-fig. 2.

On repeating the experiment with a flake with 'parallel' orientation (B.M. 1945,36) the optic axial angle increases in the plane of symmetry to about 30° (2E).

Flakes of the two types after heating have the same optical orientation and approximately the same value of 2E.

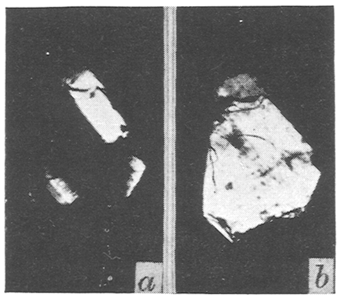

FIG. 3. The same flake (as in fig. 2) photographed in parallel polarized light at two stages during cooling. (*a*) The flake is seen when over most of its surface it is uniaxial and appears dark between crossed nicols, but in some lamellae it is still birefringent. (*b*) The same flake photographed after standing in moist air overnight: birefringence is uniform over the whole plate.

Tests at higher temperatures were made on ganophyllite from the Harstig mine. In an air oven heated to 320° C. a flake near the centre of the oven became quite opaque after an hour's heating (probably less), while a flake nearer the oven door heated probably to round about 250° C. showed the phenomenon described above, the optic eyes having opened out in the plane of symmetry to 2E 44°.

That these changes are due to loss of water is confirmed by placing flakes in a desiccator charged with concentrated H_2SO_4 under which conditions flakes of 'normal' ganophyllite become practically uniaxial within 24 hours, but the opening out in the plane at right angles was not clearly observed until the fifth day of the test.

The heated flakes on cooling in moist air slowly regain their original optical properties, just as they regain their water as Hamberg showed. It was, however, several times observed that in some parts of the flakes the recovery of the original orientation was delayed and lagged behind the other parts of the flakes. An example may be given of a flake from

B.M. 1945,131 heated for 30 minutes to 105° C. and allowed to cool. In the main part of the flake 2E fell from 44° to about 25° in 85 minutes' cooling. On further cooling for half an hour it was noticed that in one or two lamellae, bounded by edges parallel to the trace of (010), the optic eyes had ceased to close in while the rest of the flake was by now nearly uniaxial. The effect between crossed nicols in parallel light is illustrated in text-fig. 3. During the next two hours the optic eyes over the main part of the plate had opened out to 2E 20° in the plane perpendicular to the plane of symmetry, but in the lamellae the optic axial plane was still parallel to the plane of symmetry and 2E 12°. After standing overnight the whole flake had resumed its original condition. Similar lag in recovery was observed in several flakes both from Benallt and Harstig. Where the lag is in progress the effect between crossed nicols in parallel light is as of twin lamellae with edges parallel to (010).

It has not been possible with the apparatus at present available to determine the refractive indices of the flakes at various stages during these heating experiments. Attempts to determine the refractive index of flakes dried in a desiccator over concentrated H_2SO_4 show that for ganophyllite with normal orientation (B.M. 1945,131) β and γ for sodium-light are near 1·6085 (comparing with β 1·6099 for untreated material). β and γ both decrease as water is lost, γ decreasing more rapidly than β. A decrease of γ also is indicated by measurements on flakes from B.M. 1945,131 dried in a desiccator for 72 hours during which time 2E had increased from 17 to 24°.

If these determinations can be relied upon sufficiently they indicate that something other than, or more than, a difference of water content is responsible for the different optical orientation of the two types found at the Benallt mine.

In concluding this paper I must add that I am greatly indebted and very grateful to Dr. F. A. Bannister for his help, and also to Mr. D. L. Williams, assistant experimental officer in the Department, who has assisted in the heating experiments and taken the photographs.

Note on ganophyllite from Franklin Furnace, New Jersey.

It seems likely that ganophyllite from Franklin Furnace, New Jersey, where it was first recorded by Palache in 1910,[1] shows two different optical orientations. Our observations, both optical and X-ray, on a cleavage flaked from a thin blade-like crystal (similar in habit to those

[1] C. Palache, Amer. Journ. Sci., 1910, ser. 4, vol. 29, p. 187.

described by Larsen and Shannon) on a specimen of rhodonite from Franklin Furnace in the British Museum collection shows that the optical orientation is the same as for ganophyllite from Harstig, namely, axial plane perpendicular to the perfect cleavage and perpendicular to the plane of symmetry. The acute bisectrix (α) is perpendicular to the perfect cleavage which is parallel to the flat face of the blade; β is parallel to the direction of elongation. A Laue and a rotation photograph (about β) of the same flake (taken by Dr. Bannister) show unmistakably that the plane of symmetry is perpendicular to the optic axial plane, and that the cleavage face, parallel to the face of the blade-like crystals, is c (001). Thus we find, as for Harstig ganophyllite, $\alpha = c$, $\beta = a$, $\gamma = b$.

The blade-like crystals from Franklin Furnace described first as a probably new hydrated manganese silicate by Larsen and Shannon (1922)[1] and subsequently identified (1924)[2] as ganophyllite differ from the crystal examined by us. They record a micaceous cleavage, taken to be (001) and a second, perfect cleavage parallel to (100). Y (i.e. β) is nearly parallel to the length of the blades, X (i.e. α) is nearly perpendicular to the thin edge of the blade, and Z (i.e. γ) nearly perpendicular to the flat face. Moreover, sections perpendicular to Z (i.e. γ), and therefore parallel to the flat face, show twinning with composition-plane perpendicular to the face and parallel to the length and give symmetrical extinction of about 2°. Since elsewhere Larsen has given the orientation as '$X \wedge c$ = small. $Y = b$', it appears that if this orientation applies to Larsen and Shannon's ganophyllite from Franklin Furnace the flat face of the blades is (100), and the thin edge (001).

[1] E. S. Larsen and E. V. Shannon, Amer. Min., 1922, vol. 7, p. 152. [M.A. 2-472.]
[2] Ibid., 1924, vol. 9, pp. 238-240. [M.A. 3-216.]

EXPLANATION OF PLATE XXI.

FIG. 1. Laue photograph of a flake of ganophyllite (B.M. 80037) from the Harstig mine, Pajsberg, Sweden, set with the plane bisecting the prism angle (m:m''' = 44°) vertical. The optic axial plane is horizontal. A vertical plane of symmetry is clearly seen. Crystal-film distance 3 cm. Tungsten target. (Same size.)

FIG. 2. Thin section from a specimen from no. 5 ore-body, Benallt mine (B.M. 1944,36) showing a crystal of ganophyllite bounded by edges of two prism faces making a plane angle of about 136°. The optic axial plane in this section as figured here is vertical. (×95.)

The cost of the three plates (XIX–XXI) in this issue of the Magazine (no. 201) is met by the Miers Memorial Fund.

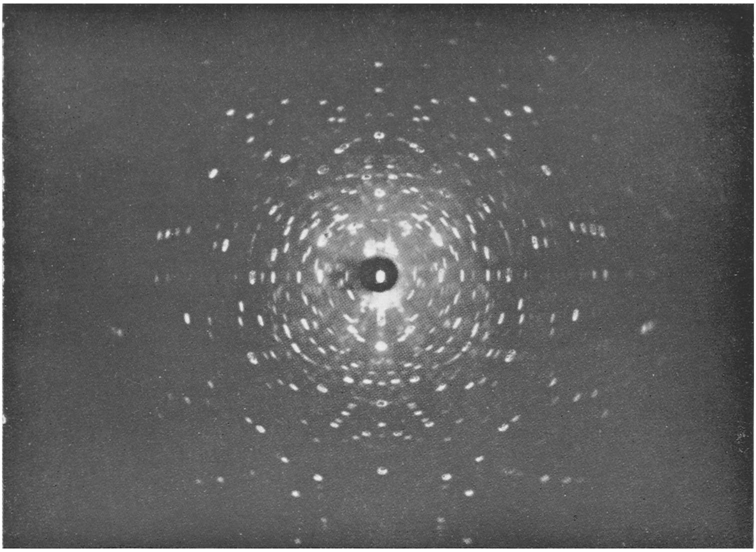

FIG. 1.

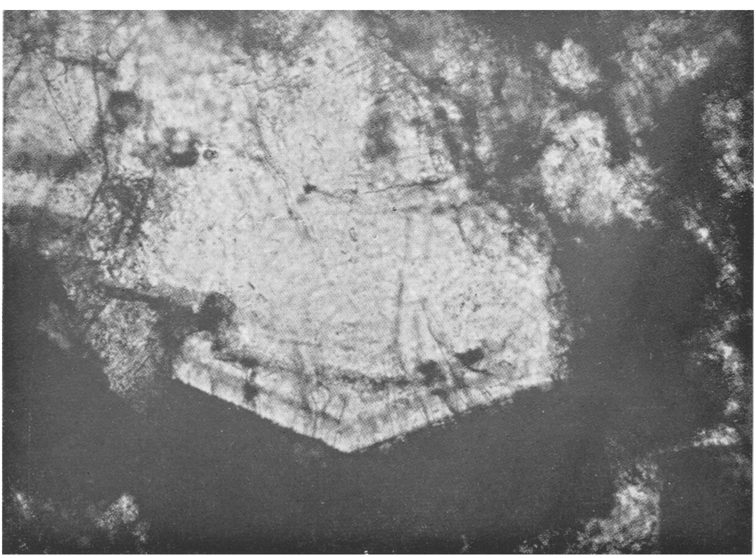

FIG. 2.

W. CAMPBELL SMITH: GANOPHYLLITE.