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The related layered minerals ganophyllite, bannisterite, and stilpnomelane¹

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Summary. Two monoclinic minerals formerly classified as ganophyllite have been differentiated on the basis of single-crystal X-ray data. True ganophyllite occurs at the Harstig mine, Pajsberg, Sweden (a , 16.60 ± 0.05 Å; b , 27.04 ± 0.08 Å; c , 50.34 ± 0.15 Å; β , $94^\circ 10' \pm 10'$; space group $A 2/a$), at the Benallt mine, Caernarvonshire, Wales, and in Aroostook County, Maine. Bannisterite, a new mineral, occurs at Franklin, New Jersey (a , 22.20 ± 0.07 Å; b , 16.32 ± 0.05 Å; c , 24.70 ± 0.08 Å; β , $94^\circ 20' \pm 10'$; space group $A 2/a$) and at the Benallt mine, Wales. Both minerals have similar pseudocells: a , 5.53 Å; b , 3.3 Å; c , 25 Å; β , 94° . The chemical analysis of ganophyllite from the Harstig mine, Sweden, is: SiO_2 , 39.67%; Al_2O_3 , 7.95%; Fe_2O_3 , 0.90%; MnO , 35.15%; CaO , 1.11%; MgO , 0.20%; PbO , 0.20%; K_2O , 2.70%; Na_2O , 2.18%; Li_2O , trace; H_2O , 9.79%; total, 99.85. The chemical analysis of bannisterite from Franklin Furnace, New Jersey, is: SiO_2 , 46.20%; Al_2O_3 , 4.74%; MnO , 23.02%; FeO , 6.40%; ZnO , 4.67%; CaO , 1.52%; MgO , 1.99%; Na_2O , 0.29%; K_2O , 1.21%; H_2O , 9.74%; total, 99.78.

Both ganophyllite and bannisterite show a structural resemblance to stilpnomelane from Deer Isle, Maine, in projection on selected zones. All three have a micaceous cleavage parallel to {001} in the orientations here taken. Stilpnomelane is triclinic, pseudotrigonal, and pseudomonoclinic. In the triclinic cell, $a = b$, 22.05 ± 0.06 Å; c , 17.70 ± 0.06 ; α , $124^\circ 49'$; β , $95^\circ 58'$; γ , $120^\circ 00'$ (angles $\pm 5'$). In the trigonal subcell, a' , 3.2 Å; c' , 36.4 . Small distorted trigonal subcells for ganophyllite have a' , 3.38 Å; c' , 37.7 , and for bannisterite have a' , 3.264 and c' , 37 Å.

GANOPHYLLITE, a complex manganese silicate, was first described from the Harstig mine, Pajsberg, Sweden, by Hamberg (1890). It has since been found at Franklin, New Jersey, at the Benallt mine in Wales and in the metamorphosed sedimentary manganese

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deposits of Aroostook County, Maine. A reported occurrence near San Jose, California, was disproven during the present study.

The first evidence that two different but closely related minerals have been confused under the name ganophyllite is found in the observations by Campbell Smith (1948) on the optical orientation and dehydration of crystals from the Benallt mine and from the Harstig mine. The crystals from Harstig are monoclinic with a micaceous cleavage on {001} in the orientation of Hamberg (1890). The optical orientation of

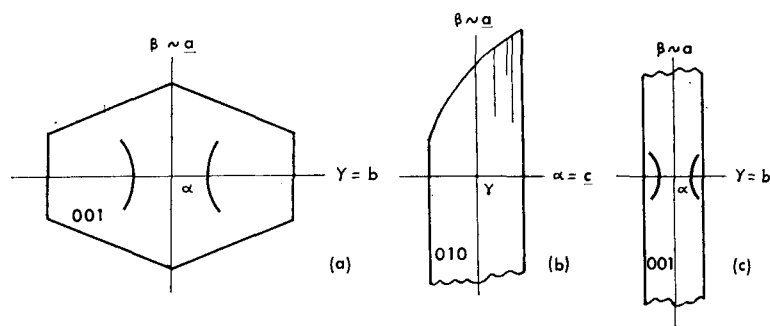


FIG. 1 *a*, Optical orientation in cleavage flake of Harstig ganophyllite; the *a*, *b*, and *c* axes of Hamberg (1890) and of the present study are parallel. *b*, lath-like crystal of Franklin ganophyllite resting on flat side, (010), showing trace of (001) cleavage. *c*, same, cleavage flake on (001).

the Harstig crystals (ganophyllite) found by Hamberg, and confirmed by Campbell Smith with the aid of X-ray single-crystal data, is shown in fig. 1. Campbell Smith observed that some of the crystals from the Benallt mine had the same optical orientation as the Harstig material, and that others had a different optical orientation as shown in fig. 2. On slight loss of water by heating or by desiccation, the two optical types were found by him to behave differently. In the Harstig material, the optic angle decreases to zero and then opens out in the plane at 90° to the original position. In the Benallt material with $\beta \parallel [010]$ the optic angle increases without change of orientation.

We have confirmed these observations, and have found that these two types of crystals also occur at Franklin, New Jersey. Study by X-ray single-crystal and powder methods together with a new chemical analysis of the Franklin material has established that two different minerals occur in the Benallt and Franklin specimens. These minerals are closely related to each other and to the complex iron silicate stilpnomelane. The name ganophyllite is here restricted to the original

material from Harstig, Sweden, and the name bannisterite is proposed for the new phase.

The established localities for ganophyllite are the Harstig mine in Sweden; Franklin, New Jersey; the Benallt mine, Caernarvonshire, Wales; and Aroostook County, Maine. The occurrence in the metamorphosed sedimentary manganese deposits in Maine was first recognized in 1952 by Charles Milton, U.S. Geological Survey.¹ Bannisterite

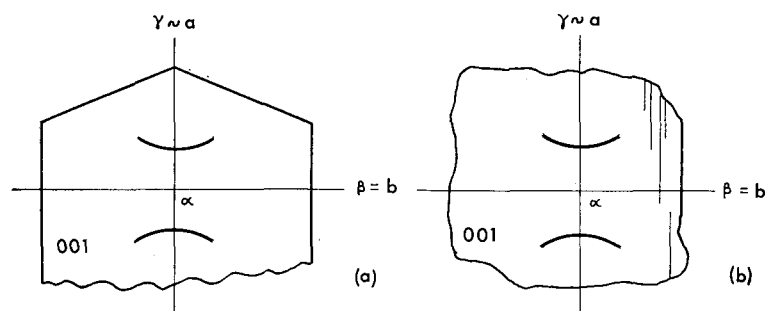


FIG. 2 *a*, Optical orientation in cleavage flake of Benallt bannisterite (from Campbell Smith, 1948). *b*, cleavage flake of Franklin bannisterite showing trace of the (010) cleavage.

occurs at the Benallt mine and at Franklin. This mineral also has been independently identified by R. Sadanaga, Y. Takeuchi, and T. Kato of the Mineralogical Institute, University of Tokyo, at the Ananai mine, Kochi, Japan.¹ These authors also recognized, by X-ray study, the separate identity of this mineral and ganophyllite.

Ganophyllite

X-ray data. Unit cell data for ganophyllite from Harstig, Sweden, and from Franklin, New Jersey, (the analysed sample of Larsen and Shannon, 1922) are compared with data for bannisterite from Franklin, New Jersey, and with stilpnomelane from Deer Isle, Maine, in table I. The data have been obtained by a combination of Weissenberg and precession camera techniques using various wave lengths of X-radiation: $\text{Mo-K}\alpha_{\text{av}} = 0.7107 \text{ \AA}$, $\text{Cu-K}\alpha_{\text{av}} = 1.5418 \text{ \AA}$, $\text{Cr-K}\alpha_{\text{av}} = 2.2909 \text{ \AA}$. Both ganophyllite and bannisterite have small monoclinic subcells, similar in projection on {010} with a , 5.5 \AA ; c , 25 \AA ; β , 94°. The $h0l$ patterns of ganophyllite and of bannisterite (fig. 3), and the $h\bar{2}h.l$ (fig. 3),

¹ Personal communication.

TABLE I. Unit cell data for ganophyllite, bannisterite, and stilpnomelane

	<i>Ganophyllite</i>		<i>Bannisterite</i>	<i>Stilpnomelane</i>	
	<i>Harstig Mine, Sweden</i> <i>Harvard No. 10118</i> <i>monoclinic</i>	<i>Franklin Furnace, N.J.</i> <i>Harvard No. 89837</i> <i>monoclinic</i>	<i>Franklin, N.J.</i> <i>Harvard No. 10857</i> <i>monoclinic</i>	<i>Deer Island, Maine</i> <i>Present study</i> <i>triclinic</i>	<i>Crystal Falls, Michigan</i> <i>Eggleton and Bailey, 1965</i> <i>triclinic</i>
<i>Symmetry</i>					
<i>a</i>	16.60 ± 0.05 Å	16.59 ± 0.05 Å	22.20 ± 0.07 Å	22.05 ± 0.06 Å	21.724 ± 0.004 Å
<i>b</i>	27.04 ± 0.08	27.08 ± 0.08	16.32 ± 0.05	22.05 ± 0.06	21.724 ± 0.004
<i>c</i>	50.34 ± 0.15	50.36 ± 0.15	24.70 ± 0.08	17.70 ± 0.06	17.740 ± 0.004
β	94° 10' ± 0° 10'	94° 10' ± 0° 10'	94° 20' ± 0° 10'	124° 49' ± 0° 05'	124.14 ± 0.015°
Vol.	22536 Å ³	22560 Å ³	8924 Å ³	95° 58' ± 0° 05'	95.86° ± 0.023°
Space group	<i>Aa</i> or <i>A2/a</i>	<i>Aa</i> or <i>A2/a</i>	<i>Aa</i> or <i>A2/a</i>	120° 00' ± 0° 05'	120.00° ± 0.02°
	<i>Monoclinic pseudocell</i>			Vol.	5117 Å ³
<i>a</i>	5.53 Å	5.53 Å	5.55 Å	<i>a</i> *	0.06262
<i>b</i>	13.52	13.54	3.264	<i>b</i> *	0.07586
<i>c</i>	25.17	25.17	24.70	<i>c</i> *	0.08237
β	94° 10'	94° 10'	94° 20'	α^*	43° 37'
Vol.	1878 Å	1880 Å ³	446 Å ³	β^*	56° 45'
	<i>Pseudo-space-group</i>			γ^*	46° 44'
	<i>Ia</i> or <i>I2/a</i>	<i>Ia</i> or <i>I2/a</i>	<i>A2, Am, or A2/m</i>	<i>Calculated angles, special relationships</i>	
	<i>Calculated angles</i>			$\alpha = \cos^{-1} -11b/24c$	
	$\beta = \cos^{-1} -2a/9c = 94^\circ 12'$	—	$\beta = \cos^{-1} -a/12c = 94^\circ 18'$	$\beta = \cos^{-1} -a/12c$	
				$\alpha^* = \cos^{-1} 2c^*/3b^*$	
				$\beta^* = \cos^{-1} 5c^*/12a^*$	

$2h.\bar{h}.l$, and hhl patterns of stilpnomelane are very similar, with only the weak superlattice reflections appearing different. More pronounced are the variations in the $0kl$ patterns of ganophyllite, of bannisterite, and of stilpnomelane, illustrated in fig. 4. The pattern differences are consequent to different numbers of trigonal subcells being packed

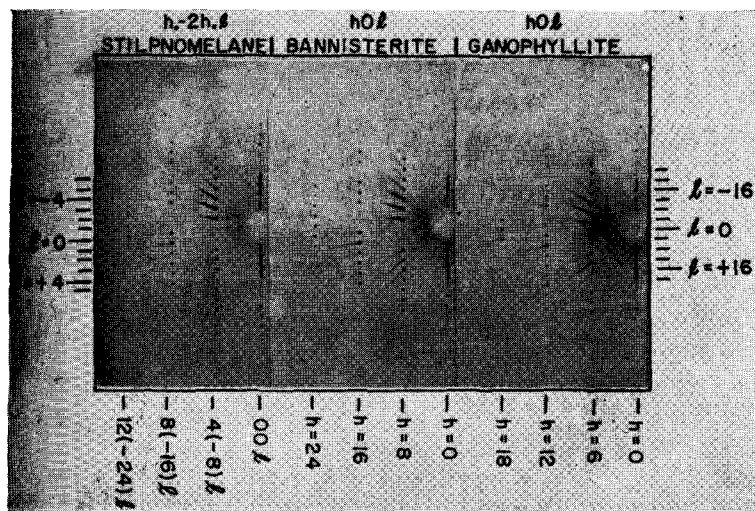


FIG. 3. The $h0l$ patterns of ganophyllite and of bannisterite and $h.\bar{2}h.l$ pattern of stilpnomelane (Buerger precession photographs). Note similarity of patterns for reflections corresponding to the subcell.

parallel to b in ganophyllite (8), b in bannisterite (5), and parallel to $b \sin \gamma$ (or $a \sin \gamma$) in stilpnomelane (6).

Ganophyllite has a micaceous cleavage parallel $\{001\}$ and secondary cleavages parallel $\{100\}$ and $\{010\}$. A modified layer structure, possibly a combination of a sheet and chain structure, is indicated. The very large repeat period of $c = 50 \text{ \AA}$ appears to represent the interstratification of four successive equal layers, alternately arranged, with basal spacing of 12.5 \AA . The basal spacing of these layers is not significantly changed by heating overnight at 120° C (d_{004} , 12.5 \AA) or by glycolating (d_{004} , 12.55 \AA) or by exposing to a humid atmosphere (d_{004} , 12.53 \AA). The body-centred pseudocell with a , 5.5 \AA ; b , 13.5 \AA ; c , 25 \AA ; β , 94° contains two layers, and the other two layers are related to these by an A -centring and an a -glide.

