

## THE ANTHOPHYLLITE AND CUMMINGTONITE-GRUNERITE SERIES

A. N. WINCHELL, *University of Wisconsin,  
Madison, Wisconsin.*

Since the publication of a second study of the amphiboles,<sup>1</sup> about seven years ago, much new information of importance has become available. One of the most important contributions is to be credited to Sundius,<sup>2</sup> who analyzed and measured the optical properties of carefully chosen samples of cummingtonite and grunerite and derived the relationships between optical properties and composition much more accurately than had previously been possible. In a later study<sup>3</sup> Sundius discussed the chemical relations of stable forms in the anthophyllite, cummingtonite and actinolite series of amphiboles, and concluded that anthophyllites and cummingtonites are not dimorphous, since he considered that anthophyllites contain less than 40 per cent of ferrous iron, while cummingtonites (and grunerites) contain 40 per cent or more. Bowen and Schairer<sup>4</sup> reported the results of a study of a remarkably pure iron grunerite and showed graphically the relations between optical properties and composition in natural amphiboles of the cummingtonite-grunerite series as well as in artificial fluor-amphiboles of similar composition.

Warren,<sup>5</sup> Sundius,<sup>6</sup> Tilley and Flett,<sup>7</sup> Simpson,<sup>8</sup> Tilley,<sup>9</sup> Rao,<sup>10</sup> Eskola,<sup>11</sup> and Wayland<sup>12</sup> have described certain samples of cummingtonite

<sup>1</sup> Winchell, A. N., Further studies in the amphibole group: *Am. Mineral.*, vol. **16**, pp. 250-266, 1931.

<sup>2</sup> Sundius, N., The optical properties of manganese-poor grunerites and cummingtonites compared with those of manganeseiferous members: *Am. Jour. Sci.*, vol. **21**, pp. 330-344, 1931.

<sup>3</sup> Sundius, N., Ueber die Mischungslucken zwischen Anthophyllit-Gedrit, Cummingtonit-Grunerit und Tremolit-Aktinolith: *Zeits. Krist.*, B(M.P.M.), vol. **43**, pp. 422-440, 1933.

<sup>4</sup> Bowen, N. L., and Schairer, J. F., Grunerite from Rockport, Massachusetts, and a series of synthetic fluoramphiboles: *Am. Mineral.*, vol. **20**, pp. 543-551, 1935.

<sup>5</sup> Warren, H. V., *Mineral. Mag.*, vol. **22**, p. 477, 1931.

<sup>6</sup> Sundius, N., *Geol. För Förh. Stockholm*, vol. **56**, p. 98, 1934.

<sup>7</sup> Tilley, C. E., and Flett, J. S., *Min. Abst.*, vol. **4**, p. 402, 1931.

<sup>8</sup> Simpson, E. S., *Jour. Roy. Soc. W. Australia*, vol. **18**, p. 61, 1931-32.

<sup>9</sup> Tilley, C. E., *Mineral. Mag.*, vol. **24**, p. 181, 1935.

<sup>10</sup> Rao, B. Rama, *Mysore Geol. Dept.*, **15**, 1934.

<sup>11</sup> Eskola, P., *C. R. Geol. Soc. Finlande*, vol. **9**, p. 475, 1936.

<sup>12</sup> Wayland, R. C., *Am. Mineral.*, vol. **21**, p. 607, 1936.

and grunerite, and Henderson,<sup>13</sup> Simpson,<sup>14</sup> Orlov,<sup>15</sup> Ignatiev,<sup>16</sup> Sundius,<sup>17</sup> and Eskola<sup>18</sup> have described samples of anthophyllite and gedrite. Also, under the name "amosite," Peacock<sup>19</sup> described in 1928 samples of asbestos from South Africa, which he classified as orthorhombic amphiboles.

At the time of the previous study, data were insufficient to permit a graph showing in the anthophyllite series the variation in the optic angle, and the curve for  $N_m$  was merely a suggestion. New data made it possible for Sundius to draw curves for  $N_m$  and the optic angle from 0 to about 40 per cent of the iron end-member. At present the data of Peacock permit the extension of the curves for  $N_o$  and  $N_p$ , and the specific gravity to the pure iron end-member by extrapolation only beyond 90 per cent, as shown in Fig. 1.

In the cummingtonite-grunerite series Simpson<sup>8</sup> described a "ferruginous kupfferite" with only 23 numerical per cent of the  $H_2Fe_7Si_8O_{24}$  end-member and an extinction angle of  $15^\circ$ . He has very generously sent to the writer a portion of the material that served for the analysis. A study of this material by Reginald G. Comer, using the double variation method of Emmons, has shown that it consists of two minerals, one having parallel extinction and the other having a maximum extinction angle of  $18^\circ$  in the vertical zone. The second mineral is decidedly uncommon and forms at most about ten per cent of the whole. Therefore, the analysis represents approximately the composition of an orthorhombic mineral, and the composition of the monoclinic mineral is unknown. This orthorhombic mineral has two cleavages (or partings) parallel with the elongation, but they are parallel and normal to the optic plane and must therefore be pinacoidal in position. After careful search, the poorly developed prismatic cleavages were found also, at an angle of about  $125^\circ$  with each other and bisected by the optic plane. This orthorhombic amphibole is clearly an anthophyllite; it has the following optical properties as measured on two crystal fragments:

$Z \wedge c = 0^\circ$ ,  $(+)2V = 79\frac{1}{2}^\circ$ ,  $N_o = 1.6462$ ,  $N_m = 1.6345$ ,  $N_p = 1.6268$  (calc.);  $N_o - N_p = 0.0194$  (D line).

$Z \wedge c = 0^\circ$ ,  $(+)2V = 81^\circ$ ,  $N_o = 1.6462$ ,  $N_m = 1.6345$ ,  $N_p = 1.6265$  (calc.);  $N_o - N_p = 0.0197$  (D line).

The dispersion ( $F-C$ ) is 0.0083 for  $N_o$  (and also for  $N_m$ ) on the first crystal, and 0.0086 on the second crystal.

<sup>13</sup> Henderson, E. P., *Am. Mineral.*, vol. 16, p. 563, 1931.

<sup>14</sup> Simpson, E. S., *Jour. Roy. Soc. W. Australia*, vol. 17, p. 137, 1931.

<sup>15</sup> Orlov, A., *Cent. Min.*, p. 269, 1932.

<sup>16</sup> Ignatiev, N. A., *Min. Abst.*, vol. 6, p. 419, 1937.

<sup>17</sup> Sundius, N., *Zeits. Krist.*, B(M.P.M.) vol. 43, p. 422, 1933.

<sup>18</sup> Eskola, P., *C. R. Geol. Soc. Finlande*, vol. 9, p. 475, 1936.

<sup>19</sup> Peacock, M. A., *Am. Mineral.*, vol. 13, p. 241, 1928.

These properties are almost exactly those of an anthophyllite with 23 numerical per cent of  $H_2Fe_7Si_8O_{24}$ , as shown in Fig. 1.

The monoclinic mineral likewise has two cleavages (or partings) parallel with the elongation, but they are parallel and normal to the optic plane and must therefore be pinacoidal (100 and 010), just as in the orthorhombic mineral. Only by careful search were the prismatic

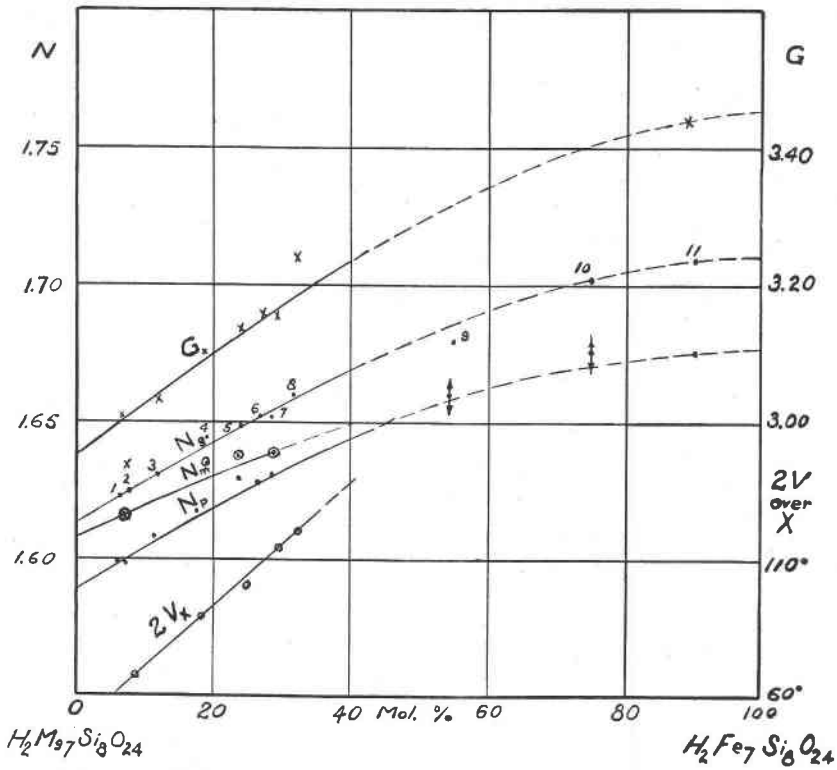


FIG. 1. Variations in composition and properties in the anthophyllite series.

cleavages found, because they are so inferior to the pinacoidal. They are so poorly developed that their position is somewhat uncertain, but they seem to be symmetrically placed about the optic plane at about the amphibole angle. The optic properties of this mineral are:

$Z \wedge c = 18^\circ$ , (+)  $2V = 78^\circ$ ,  $N_o = 1.6508$ ,  $N_m = 1.6358$ ,  $N_p = 1.6261$  (calc.);  $N_o - N_p = 0.0247$  (D line).

Unless actinolite can be optically positive (a condition thus far unknown), these properties indicate that the monoclinic amphibole belongs

at 1a in Fig. 2, and therefore is in the cummingtonite series with about 30 numerical per cent of the  $H_2Fe_7Si_8O_{24}$  end-member.

The extinction angle ( $15^\circ$ ) reported by Simpson seemed impossible until the discovery by Bowen and Schairer<sup>4</sup> that in fluor-amphiboles the

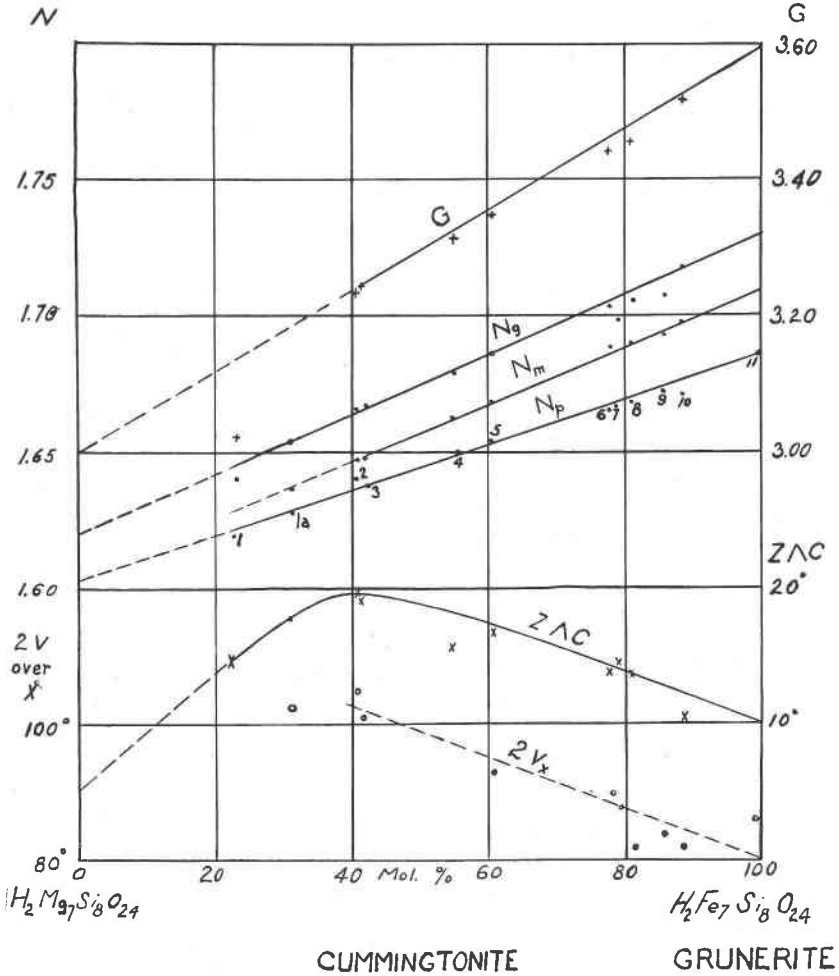


FIG. 2. Variations in composition and properties in the cummingtonite-grunerite series.

extinction angle passes through a maximum at about forty numerical per cent  $F_2Fe_7Si_8O_{22}$ . If the extinction angle curve remains about parallel in the two series of amphiboles, natural (hydroxy-) amphibole of this series, containing no iron, would have an extinction angle of about  $5^\circ$ , and this is the value that is derived by extrapolation in Fig. 2.

Perhaps the most important conclusion to be derived from these studies is that the anthophyllite and cummingtonite series actually illustrate a case of isodimorphism, since the cummingtonite series extends beyond 60 numerical per cent of  $H_2Mg_7Si_8O_{24}$  and the anthophyllite series extends at least to about 90 numerical per cent of  $H_2Fe_7Si_8O_{24}$ .

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## REFERENCES FOR FIG. 1

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2. "Valleite," Kongsberg, Norway. Sundius, N.: *loc. cit.*
3. Miask, Russia. Kunitz, W.: *loc. cit.*
4. Franklin, N. C., Penfield, S. L.: *Am. Jour. Sci.*, vol. 40, p. 394, 1890, and Bowen, N. L.: *Jour. Wash. Acad. Sci.*, vol. 10, p. 411, 1920.
5. Kongsberg, Norway. Sundius, N.: *loc. cit.*
6. Kjerneverud. Kunitz, W.: *loc. cit.*
7. Falun, Sweden. Johannsen, K.: *Zeits. Krist.*, vol. 73, p. 31, 1930.
8. (Source?). Sundius, N.: *loc. cit.* Is it possible that the value given for  $N_p$  (1.6454) is actually  $N_m$ ?
9. "Amosite," Kalkfontein, S. Africa. Peacock, M. A.: *Am. Mineral.*, vol. 13, p. 241, 1928. This contains 7.02  $Al_2O_3$  and 10.84 CaO; the lime doubtless lowers the indices of refraction somewhat. The lower index is an average of  $N_m$  and  $N_p$ .
10. "Amosite," Penge, Transvaal. Peacock, M. A.: *loc. cit.* The lower index is an average of  $N_m$  and  $N_p$ .
11. "Ferroanthophyllite," Jakobeny, Bukowina. Orlov, A.: *Cent. Min.*, p. 269, 1932. This contains 10.66 MnO, 2.31 CaO, 2.34  $Al_2O_3$  and 6.32  $Fe_2O_3$ . It seems probable that the MnO and  $Fe_2O_3$  may about balance each other in their effects on the indices.

## REFERENCES FOR FIG. 2

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- 1a. The same, as measured at the University of Wisconsin by R. G. Comer.
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3. Cummingtonite, Robbersgruvan, Sweden. Sundius, N. (2): *Geol. För. Förh. Stockholm*, vol. 46, p. 154, 1924.
4. Cummingtonite, Silvergruvan, Sweden. Sundius, N. (2): *loc. cit.*
5. Grunerite, Michigamme, Mich. Sundius, N. (1): *loc. cit.*
6. Grunerite, Cummington, Mass. Sundius, N. (1): *loc. cit.*
7. "Cummingtonite," Krivoi Rog, Russia. Polovinkina: *N. J. Min.*, A, I, p. 39, 1927.
8. "Silvbergite," Silvberg, Sweden. Sundius, N. (2): *loc. cit.*
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11. Grunerite, Rockport, Mass. Bowen, N. L., and Schairer, J. F.: *Am. Mineral.*, vol. 20, p. 543, 1935.