

## A THIRD STUDY OF CHLORITE

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In a first study of the chlorite system, published about ten years ago,<sup>1</sup> the chief purpose of the writer was to show that it is possible to find a definite relationship between variations in composition and variations in optic properties in the system; to do this it was necessary to understand the mode of variation in composition (and this requires a knowledge of the end-member molecules), and to use a graphic method of correlation, involving four molecules.

In a second study of chlorite published about eight years ago,<sup>2</sup> the correlation of variations in optic properties with variations in composition was revised in the light of the new data supplied by Orcel.<sup>3</sup>

At the present time the correlation needs revision once again for two reasons, first, because there are considerable additional data now available, and, second, because the diagram should be based on such numbers of molecules as will make the centerpoint of the square which represents 50 parts of the molecule at one corner plus 50 parts of that at the opposite corner, also represent, *as its equal*, 50 parts of the molecule at an adjoining corner plus 50 parts of that at its opposite corner.

To show the real increase in data it is only necessary to point out that, if only those analyses be considered which are accompanied by optic data known to be on the same material and which can be calculated into Tschermak's molecules (assuming  $\text{Fe}_2\text{O}_3 = \text{FeO}$ ) with a maximum discrepancy of 3.0 per cent of  $\text{SiO}_2$ , there were only seven such analyses available for the first study, and only twenty-seven for the second study, while there are forty at present. Illustrating the point in a different way, in the first publication there were used eight analyses with more than 30 per cent iron molecules, in the second publication there were only six such analyses used, and in this case there are fourteen.

In order to present a diagram mathematically correct it is only necessary to use  $2[\text{H}_4(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_9]$  at the left side and  $3[\text{H}_4(\text{Mg}, \text{Fe})_2\text{Al}_2\text{SiO}_9]$  at the right side {instead of  $\text{H}_4(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_9$  and  $\text{H}_4(\text{Mg}, \text{Fe})_2\text{Al}_2\text{SiO}_9$ }, as shown in Fig. 1. It is gratifying to find that the new data require very little change in the diagram, which differs only slightly from that published eight years ago, aside from the change due to different units at the corners of the square.

It is important to note that no claim of high accuracy is made for the

<sup>1</sup> Winchell, A. N., *Am. Jour. Sci.*, vol. **XI**, 1926, pp. 238-300.

<sup>2</sup> Winchell, A. N., *Am. Mineral.*, vol. **XIII**, 1928, pp. 161-170.

<sup>3</sup> Orcel, J., *Bull. Soc. Min. Fr.*, vol. **L**, 1927, pp. 75-456.

diagram. It is only the best representation of existing data that the writer has been able to devise. However, it seems clear that it is approximately correct since new data lead to practically no changes.

All the chlorites on the diagram have been plotted on the basis of the chemical analyses. The diagram gives their optic properties closely with the following exceptions.

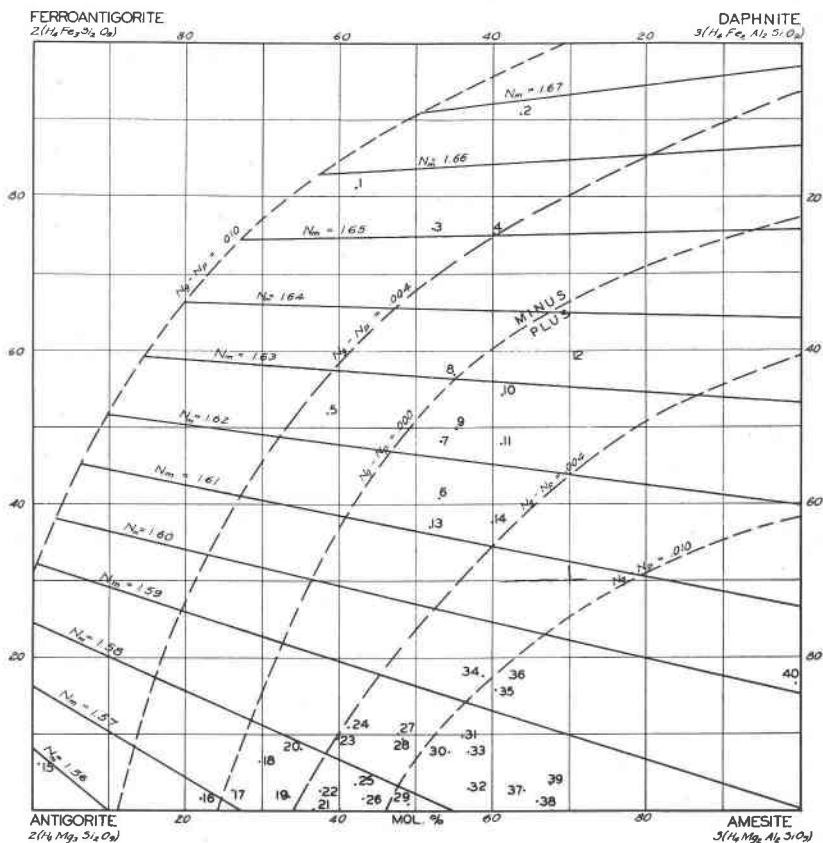


FIG. 1. Variations in composition and optic properties in the chlorite system.

The mean index of refraction is shown within  $\pm 0.01$  except in No. 1 (which is described as variable in index), No. 3 (which has  $N_m$  0.014 too high, perhaps due to the presence of 10.56 per cent of  $Fe_2O_3$ ), No. 8 (which has  $N_m$  0.013 too high), No. 11 (which has  $N_m$  0.062 too high perhaps due to 17.95 per cent of  $Fe_2O_3$ ), No. 12 (which has been measured twice with conflicting results), No. 17 (which has  $N_m$  0.021 too low per-

haps due to 1.85 per cent of  $K_2O$ ) and No. 37 (which has  $N_m$  0.022 too low perhaps because of 14.00 per cent of  $H_2O$ ).

The optic sign is correct in all cases except No. 11.

The birefringence is correct within  $\pm 0.004$  except in No. 3 (which has  $N_g - N_p$  0.007 too high perhaps because of 10.56 per cent of  $Fe_2O_3$ ), No. 11 (which has  $N_g - N_p$  0.012 too high perhaps because of 17.95 per cent of  $Fe_2O_3$ ), and No. 24 (which has  $N_g - N_p$  0.006 too high).

As to the assumptions on which the diagram is based, it seems unnecessary to discuss further the theory of the constitution of chlorite—recent *x*-ray studies of chlorite seem to have demonstrated the validity of the theory of Tschermak. However, the writer's theory as to the variability of the state of oxidation of the iron without destruction of the crystal structure needs further study. Barnes<sup>4</sup> has demonstrated the possibilities of such variations in amphiboles and has shown the effects on the optic properties of these variations when produced artificially. Dschang<sup>5</sup> has made similar experiments on chalcodite and ripidolite with the following results:

CHALCODITE, FROM BARENSTEIN, RADAUTAL, HARZ

	Before heating	After heating to redness
FeO=	10.15	0.835
Fe <sub>2</sub> O <sub>3</sub>	31.16	42.66
$N_g = N_m =$	1.701	1.726

RIPIDOLITE<sup>6</sup> FROM WALLIS, SWITZERLAND

	Before heating	After heating to redness
FeO=	28.07	3.16
Fe <sub>2</sub> O <sub>3</sub> =	2.42	30.0
$N_p =$	1.637	1.674
	Isotropic	Negative

Similar results (not accompanied by analyses) were obtained on peninite by Klein<sup>7</sup> forty years ago.

It is quite in harmony with these results to find that natural chlorites containing important quantities of ferric iron (which is assumed to be, and calculated as, ferrous iron oxidized to ferric, in nature) have higher refractive indices than appropriate for their composition. It was found by Klein that oxidation may change the optic sign from plus to minus, and that it increases the birefringence. All these effects can be found in

<sup>4</sup> Barnes, V. E., *Am. Mineral.*, vol. **XV**, 1930, p. 393.

<sup>5</sup> Pauling, L., *Proc. Nat. Acad. Sci.*, vol. **XVI**, 1930, p. 578; Mauguin, C., *C. R.*, **1928**, 186, p. 1852 and 187, p. 303; *Bull. Soc. Fr. Min.*, vol. **LIII**, 1930, p. 279; McMurchy, R. C., *Zeit. Krist.*, vol. **LXXXVIII**, 1934, p. 420.

<sup>6</sup> A complete analysis (before heating) was made by Dschang, *op. cit.*, p. 429.

<sup>7</sup> Klein, C., *N. J. Min.*, **1895**, II, pp. 119-132.

the natural chlorites rich in ferric iron oxidized from ferrous iron. For example, the thuringite from Evisa, Corsica, (#44) has 10.56 Fe<sub>2</sub>O<sub>3</sub> and N<sub>m</sub>=1.665 with N<sub>g</sub>-N<sub>p</sub>=.012, while its position on the diagram calls for N<sub>m</sub>=1.65 with N<sub>g</sub>-N<sub>p</sub>=.005. Again, the thuringite from Messina, Transvaal (#45) has 17.95 Fe<sub>2</sub>O<sub>3</sub> with N<sub>m</sub>=1.685, N<sub>g</sub>-N<sub>p</sub>=0.015, and negative sign, while the diagram calls for N<sub>m</sub>=1.621, N<sub>g</sub>-N<sub>p</sub>=.003 and positive sign.

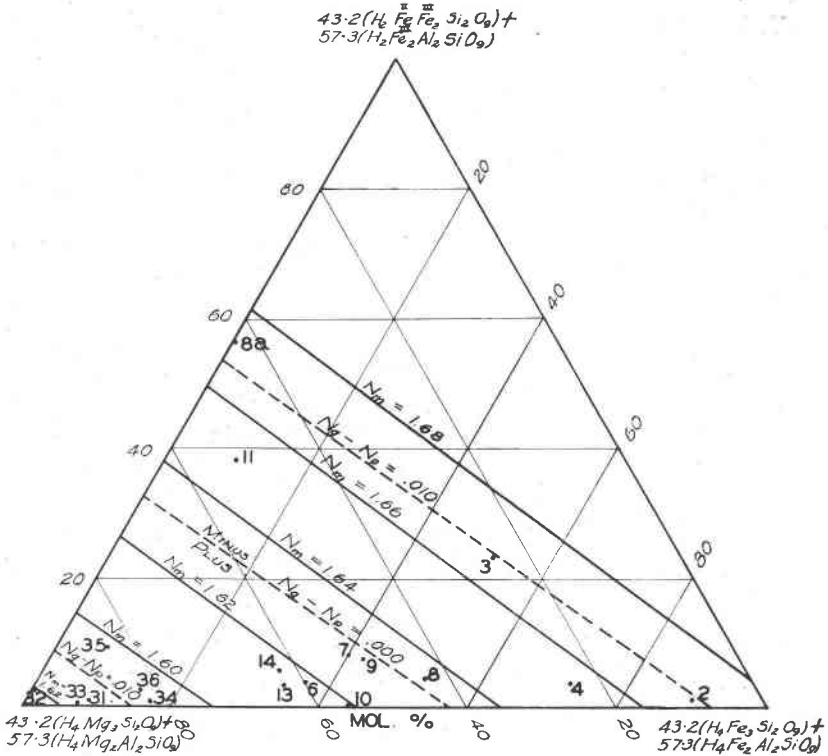


FIG. 2. Effects of oxidation of ferrous iron on the optic properties of certain chlorites.

It has been found possible to show the effects of oxidation of ferrous iron in chlorites diagrammatically—see Fig. 2. The base line of this figure corresponds with a line from a point on the base line of Fig. 1 representing about 57% of 3(H<sub>4</sub>Mg<sub>2</sub>Al<sub>2</sub>SiO<sub>9</sub>) to a point on the top line of Fig. 1 representing the same percentage of 3(H<sub>4</sub>Fe<sub>2</sub>Al<sub>2</sub>SiO<sub>9</sub>). The formulas at the lower left corner contain no iron and therefore take no part in the oxidation, which may affect the formulas at the lower right corner from

0 to 100 per cent. Accordingly, Dschang's<sup>8</sup> ripidolite unoxidized, belongs near the middle of the base line at 8; the same mineral, after oxidation, is found near the middle of the upper left line at 8a: it is evident that it has moved in a direction parallel with the upper right border. The same change has raised the refringence from 1.637 to 1.674 and the birefringence from zero to an unmeasured amount (from the diagram, about .011). Similarly, the oxidation of ferrous iron in No. 45 may be inferred to have raised the index from about 1.62 to about 1.65 (the measured value, 1.685, is inconsistent for an unknown reason) and changed the sign from plus to minus.

Diagrams for other percentages of the aluminous molecules of Fig. 1 can be prepared when sufficient data are available. It is probable from present scanty evidence that they will be similar to Fig. 2.

Dschang<sup>9</sup> attempts to explain the composition of iron-rich chlorites ("leptochlorites" of Tschermak) by assuming the presence of an end-member molecule, rich in silica, which he writes as follows:  $H_8Mg_4Si_5O_{18}$ . It is very generally agreed that one end-member molecule of the chlorite system is antigorite (or "serpentine") having the formula,  $H_4Mg_3Si_2O_9$ , or  $H_8Mg_6Si_4O_{18}$ . Dschang's proposed molecule differs from this by substituting one ion of Si for two ions of Mg. Now Mg ions have a radius of 0.75 and Si ions a radius of only about half as much, 0.40. Mg ions are surrounded by six oxygens and Si ions are surrounded by four oxygens in silica and all known silicates. Therefore a replacement of Mg by Si seems very improbable.

On very insufficient data a diagram (Fig. 3) has been prepared to show the effects of chromium on the optic properties of chlorites. In order to reduce this to three components it is necessary to assume the absence of iron. The samples used contain 1.5 to 6.5% of iron oxides. In the diagram the chlorite from Deer Park (#16) has an index which is too high for the diagram (1.59 instead of 1.575); this may be due to dehydration, as the analysis indicates a deficiency of 2.7% of  $H_2O$ . The sample from Sweden (#16a) contains 13.5% excess  $SiO_2$ ; is it possible that so much quartz was present as an impurity in the sample? Chlorites containing chromium in any important amount are easily recognized by their lavender or violet color. The diagram shows plainly that as Cr replaces Al the index rises slowly, but the chief effect is a tendency to change the optic sign to minus, unless it is already minus, as in chlorites with very little alumina. As in the amesite-antigorite series, this is accomplished by decreasing

<sup>8</sup> Dschang, G. L., *Chem. Erde*, vol. VI, 1931, p. 416.

<sup>9</sup> Dschang, G. L., *Chem. Erde*, vol. VI, 1931, p. 434.

the birefringence of amesite (with + sign) to zero, and then increasing it to about .005 (with - sign).

The chief subdivisions of the chlorite system should be defined in terms of the end-member molecules as used in Figs. 1 and 2. In the past, variety names have been used without adequate definition. Even though

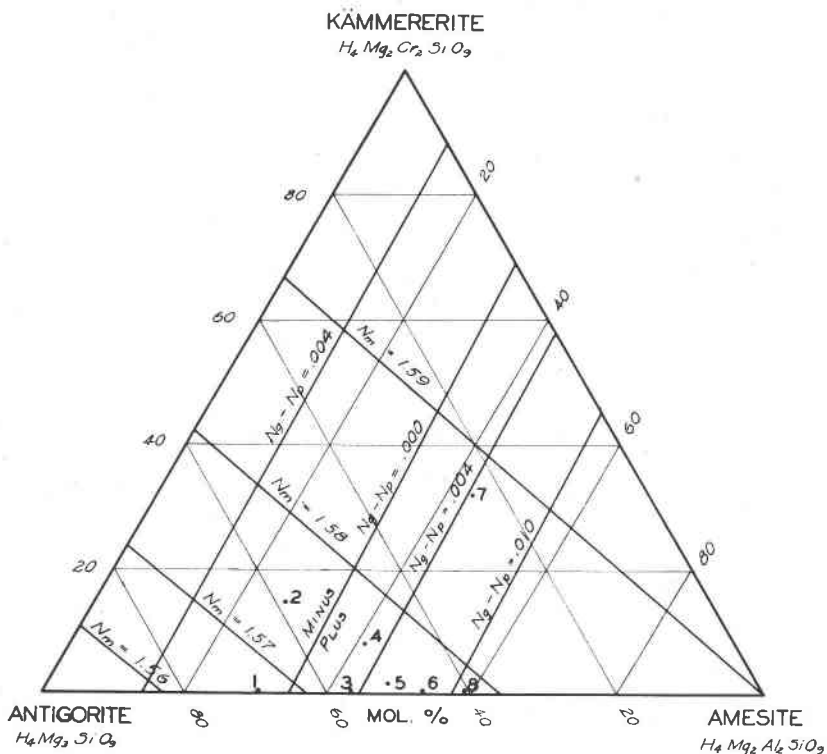


FIG. 3. Variations in composition and optic properties in the antigorite-amesite-kammererite system.

it involves some change in usage as compared with the definitions<sup>10</sup> suggested ten years ago, it seems desirable to define the varieties as indicated in the following table.

This table includes two names (rumpfite and brunsvigite) not previously used. These types are not very common, but there is no doubt of their existence. Accurate definitions may be useful.

<sup>10</sup> Winchell, A. N., *Am. Jour. Sci.*, vol. XI, 1926, p. 294.

## CHEMICAL CLASSIFICATION OF THE CHLORITE SYSTEM

Names	% $(3At+3Dn)$	% $(2Ant+2FeAnt)$	% $(2FeAnt+3Dn)$	% $(2Ant+3At)$
Antigorite	0-20	100-80	0-20	100-80
Jenkinsite	0-20	100-80	20-40	80-60
Penninite	20-40	80-60	0-20	100-80
Delessite	20-40	80-60	20-40	80-60
Clinochlore	40-60	60-40	0-20	100-80
Rumpfite	40-60	60-40	20-40	80-60
Diabantite	40-60	60-40	40-60	60-40
Brunsvigite	40-60	60-40	60-80	20-40
Corundophilite	60-80	40-20	0-20	100-80
Prochlorite	60-80	40-20	20-40	80-60
Ripidolite	60-80	40-20	40-60	60-40
Aphrosiderite	60-80	40-20	60-80	40-20
Thuringite	60-80	40-20	80-100	20-0
Amesite	80-100	20-0	0-20	100-80
Daphnite	80-100	20-0	80-100	20-0

For convenience in petrographic work a classification based on optic properties may be useful. As modified by the two new terms just suggested, it is as follows:

## OPTIC CLASSIFICATION OF THE CHLORITE SYSTEM

Names	Sign	$N_m$	$N_g-N_p$
Antigorite	-	1.55-1.58	0.004-0.010
Jenkinsite	-	1.58-1.61	0.004-0.010
-Penninite	-	1.56-1.59	0.000-0.004
Delessite	-	1.59-1.61	0.000-0.004
Diabantite	-	1.61-1.63	0.000-0.004
Aphrosiderite	-	1.63-1.65	0.000-0.004
Daphnite	-	1.65-1.67	0.000-0.004
Brunsvigite	-	1.63-1.65	0.004-0.010
Thuringite	-	1.65-1.68	0.004-0.010
+Penninite	+	1.57-1.61	0.000-0.004
Rumpfite	+	1.61-1.63	0.000-0.004
Ripidolite	+	1.63-1.65	0.000-0.004
Clinochlore	+	1.57-1.59	0.004-0.010
Prochlorite	+	1.59-1.62	0.004-0.010
Amesite	+	1.58-1.61	0.010-0.015+

These two classifications of chlorite are only roughly equivalent. The relations between them are shown in Fig. 4.

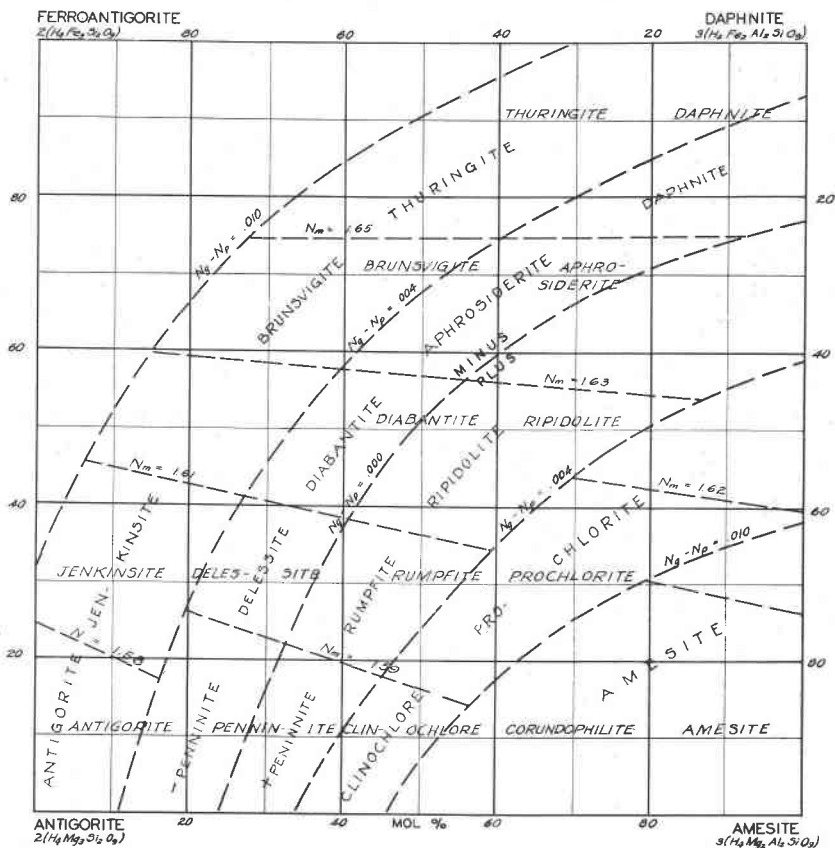


FIG. 4. Chemical and optical classifications of the chlorite system.

REFERENCES AND OPTIC DATA FOR FIGS. 1 AND 2

1. "Thuringite," Creede, Colo. Larsen, E. S. and Steiger, G.: *Jour. Wash. Acad. Sci.*, vol. VII, 1917, p. 7. (-)  $2V$ =moderate.  $N_m=1.637$  (variable),  $N_o-N_p=.01 \pm$ .
2. "Bavalite," Bas-Vallon, France. Orcel, J.: *Bull. Soc. Fr. Min.*, vol. L, 1925, pp. 245-248; Orcel's analysis 128, (-)  $2V$ =very small.  $N_o=N_m=1.667$  (calc. from  $N_o-N_p$ ),  $N_p=1.658$ ,  $N_o-N_p=.009$ .
3. "Thuringite," Evisa, Corsica. Orcel, J.: *Op. cit.*, pp. 254-262; Orcel's analysis 25. (-)  $2V=?$   $N_o=N_m=1.665$ ,  $N_p=1.653$ ,  $N_o-N_p=.012$ .
4. "Aphrosiderite," Weilburg, Nassau. Orcel, J.: *Op. cit.*, pp. 250-262; Orcel's analysis 123, (-)  $2V=?$   $N_o=N_m=1.651$ ,  $N_p=1.648$ ;  $N_o-N_p=.003-.004$ .
5. "Diabantite," Westfield, Mass. Shannon, E. V.: *U. S. Nat. Mus. Proc.*, vol. LVII, 1920, p. 397. (-)  $2V=0^\circ$ ,  $\pm N=1.62 \pm$ .
6. "Ripidolite," Isère, France. Orcel, J.: *Op. cit.*, pp. 229-231; Orcel's analysis 95. (+)  $2V$ =very small.  $N_o=1.620$ ,  $N_m=N_p=1.616$ ,  $N_o-N_p=.004$ .
7. "Ripidolite," Masoala, Madagascar. Orcel, J.: *Op. cit.*, pp. 237-239; Orcel's analysis 82. (+)  $2V=?$   $N_o=1.634$ ,  $N_m=N_p=1.633$ ,  $N_o-N_p=.001$ .



8. "Ripidolite," Wallis, Switzerland. Dschang, G. L.: *Chem. Erde*, vol. VI, 1931, p. 416. Isotropic with  $N = 1.637$ ;  $8a$ , same after oxidation:  $(-)$   $2V = ?$ ,  $N_p = 1.674$ .
9. "Ripidolite," Laifour, Ardennes, France. Orcel, J.: *Op. cit.*, pp. 232-237; Orcel's analysis 81.  $(+)$   $2V = 0^\circ \pm$ ,  $N_o = 1.638$ ,  $N_m = N_p = 1.637$ ,  $N_o - N_p = .001$ .
10. Chlorite, Shoshone Co., Idaho. Shannon, E. V.: *U. S. Nat. Mus., Bull.* 131, 1926, p. 378.  $(+)$   $2V = 0^\circ \pm$ ,  $N_o = 1.635$ ,  $N_m = N_p = 1.630$ ,  $N_o - N_p = .005$ .
11. "Thuringite," Messina, Transvaal. Orcel, J.: *Op. cit.*, pp. 262-266. Orcel's analysis 9.  $(-)$   $2V = 0^\circ \pm$ ,  $N_o = N_m = 1.685$ ,  $N_p = 1.670$ ,  $N_o - N_p = .015$ . These data do not check the diagram, perhaps due in part to the presence of 17.95 Fe<sub>2</sub>O<sub>3</sub>.
12. "Aphrosiderite," Field, Brit. Col. Larsen, E. S. and Steiger, G.: *Jour. Wash. Acad. Sci.*, vol. VII, 1917, p. 6.  $N_m = 1.623$ ,  $N_o - N_p =$  very low. Optics also by Orcel: *Op. cit.*, pp. 360 and 415.  $(+)$   $2V = ?$ ,  $N_o = 1.610$ ,  $N_m = N_p = 1.606$ ,  $N_o - N_p = .004$ .
13. "Ripidolite," Androta, Madagascar. Orcel, J.: *Op. cit.*, pp. 227-229. Orcel's analysis 93.  $(+)$   $2V = 0^\circ$ .  $N_o = 1.621$ ,  $N_m = N_p = 1.618$ ,  $N_o - N_p = .003$ .
14. "Prochlorite," Waterworks tunnel, D. C. Analysis by F. W. Clark and E. A. Schneider, *U. S. Geol. Surv., Bull.* 78, 1891, p. 19. Optic data by E. S. Larsen (*U. S. Geol. Surv., Bull.* 679, 1920, p. 123):  $(+)$   $2V =$  small,  $N_m = 1.605$ ,  $N_o - N_p =$  weak. Optic data also by E. V. Shannon: *U. S. Nat. Mus., Proc.* LVIII, 1920, p. 475:  $(+)$   $2V = 0^\circ \pm$ ,  $N_o = 1.610$ ,  $N_m = N_p = 1.606$ ,  $N_o - N_p = .006$ .
15. "Antigorite," Muruhatten, Sweden. Du Rietz, T.: *Geol. För. Förh. Stockholm*, vol. LVII, 1935, p. 133.  $N_o = 1.570 \pm .002$ ,  $N_p = 1.564$ ;  $N_o - N_p = .006 - .009$ .
16. "Colerainite," Nottingham, Pa. Shannon, E. V. and Wherry, E. T.: *Jour. Wash. Acad. Sci.*, vol. XII, 1922, p. 239.  $(-)$   $2E = 30^\circ$ ,  $N_o = N_m = 1.560$ ,  $N_p = 1.555$ ,  $N_o - N_p = .005$ .
17. "Pennine," Recess, Ireland. Hutchinson, A. and Smith, W. C.: *Mineral. Mag.*, vol. XVI, 1912, p. 264.  $(+)$   $2V = 0^\circ \pm$ ,  $N_m = 1.551$ .
18. "Pennine," locality? Dschang, G. L.: *Chem. Erde*, vol. VI, 1931, p. 416.  $(+)$   $2V = ?$ , " $N_o = ?$   $N_m = 1.567$ ,  $N_p = 1.5655$ ," [but record probably should be:  $N_o = 1.567$ ,  $N_m = N_p = 1.5655$ —A. N. W.]
19. "Leuchtenbergite," No. Korea. Sato, S.: *Jour. Shanghai Sci. Inst.*, vol. I, 1933, p. 17.  $(+)$   $2V = 0^\circ$ , " $N_o = N_m = 1.575$ ,  $N_p = 1.571$ ,  $N_o - N_p = .004$ ," but record should be:  $N_o = 1.575$ ,  $N_m = N_p = 1.571$ , since the mineral is positive.
20. "Leuchtenbergite, Urals. Dschang, G. L.: *Chem. Erde*, vol. VI, 1931, p. 416.  $(+)$   $2V = 0^\circ \pm$ , " $N_o = ?$ ,  $N_m = 1.5760$ ,  $N_p = 1.5705$ ," [but record probably should be:  $N_o = 1.576$ ,  $N_m = N_p = 1.5705$ —A. N. W.]
21. "Leuchtenbergite," Phillipsburg, Mont. Shannon, E. V. (and Ross, C. S.): *Am. Mineral.*, VIII, 1923, p. 8.  $(+)$   $2V = 6^\circ - 14^\circ$ ,  $N_o = 1.575$ ,  $N_m = N_p = 1.572$ ,  $N_o - N_p = .003$ .
22. "Clinochlore," Togoland. Orcel, J.: *Op. cit.*, pp. 267-271; Orcel's analysis 272.  $(+)$   $2V = 0^\circ \pm$ ,  $N_o = 1.576$ ,  $N_m = N_p = 1.571$ ,  $N_o - N_p = .0053$ .
23. "Clinochlore," West Town, Pa. Dschang, G. L.: *Chem. Erde.*, vol. VI, 1931, p. 416.  $(+)$   $2V = 0^\circ \pm$ , " $N_m = 1.5755$ ,  $N_p = 1.5715$ ," [but record probably should be:  $N_o = 1.5755$ ,  $N_m = N_p = 1.5715$ —A. N. W.]
24. "Chlinochlore," Besofotra, Madagascar. Orcel, J.: *Op. cit.*, pp. 266-267. Orcel's analysis 170.  $(+)$   $2V = 0^\circ \pm$ ,  $N_o = 1.594$ ,  $N_m = N_p = 1.584$ ,  $N_o - N_p = .010$ .
25. Chlorite, Mt. Ampanobe, Madagascar. Lacroix, A.: *Mineral. Madagascar*, vol. II, p. 544. Optics by J. Orcel: *Op. cit.*, p. 414.  $(+)$   $2V = 0^\circ \pm$ ,  $N_o = 1.588$ ,  $N_m = N_p = 1.578$ ,  $N_o - N_p = .010$ .
26. "Leuchtenbergite," Korea. Kinosaki, Y.: *Bull. Mineral. Survey Chosen*, vol. VII, 1932, No. 1; *Min. Abst.*, vol. V, p. 421.  $(+)$   $2V =$  small,  $N_o = 1.576$ ,  $N_m = N_p = 1.5715$ ,  $N_o - N_p = .0045$ .

27. "Prochlorite," Modena, Italy, Gallitelli, P.: *Min. Abst.*, vol. IV, 1930, p. 470.  $N = 1.58$ .
28. "Prochlorite," Ambatofinandrahana, Orcel, J.: *Op. cit.*, pp. 199–202; Orcel's analysis 71. (+)  $2V = 29^\circ$ ,  $N_g = 1.5989$ ,  $N_m = 1.5887$ ,  $N_p = 1.5580$ ,  $N_g - N_p = .0109$ .
29. "Leuchtenbergite," Midongy, Madagascar. Orcel, J.: *Op. cit.*, pp. 196–199; Orcel's analysis 47. (+)  $2V = 18^\circ - 19^\circ$ ,  $N_g = 1.5904$ ,  $N_m = 1.5754$ ,  $N_p = 1.5749$ ,  $N_g - N_p = .015$ .
30. "Grochauite," Kaslinski, Urals. St. Pavlovitch: *Min. Abst.*, vol. V, 1933, p. 215.  $N_g = 1.597$ ,  $N_m = 1.593$ ,  $N_p = 1.587$ ,  $N_g - N_p = 0.010$ . [ $N_m$  probably too high, since the mineral is probably positive with small optic angle—A. N. W.]
31. "Prochlorite," Madison Co. N. C. Orcel, J.: *Op. cit.*, pp. 207–208 and 415. (+)  $2V = 0^\circ \pm$ ,  $N_g = 1.596$ ,  $N_m = N_p = 1.588$ ,  $N_g - N_p = .008$ .
32. "Sheridanite," Miles City, Mont. Shannon, E. V. and Wherry, E. T.: *Jour. Wash. Acad. Sci.*, vol. XII, 1922, p. 329. (+)  $2E = \text{small}$ ,  $N_g = 1.589$ ,  $N_m = N_p = 1.576$ ,  $N_g - N_p = .013$ .
33. "Prochlorite," Madison Co., N. C. Orcel, J.: *Op. cit.*, pp. 205–206. Orcel's analysis 57. (+)  $2V = 19^\circ$ ,  $N_g = 1.600$ ,  $N_m = ?$ ,  $N_p = 1.588$ ,  $N_g - N_p = .012$ .
34. "Prochlorite," Rainbow Camp, Transvaal. Orcel, J.: *Op. cit.*, pp. 214–216. Orcel's analysis 68. (+)  $2V = \text{small}$ ,  $N_g = 1.602$ ,  $N_m = N_p = 1.593$ ,  $N_g - N_p = .009$ .
35. "Clinochlore," Achmatowsk. Dschang, G. L.: *Chem. Erde.*, vol. VI, 1931, p. 416. (+)  $2V = ?$ , " $N_g = ?$ ,  $N_m = 1.5975$ ,  $N_p = 1.588$ ," [but the record probably should be:  $N_g = 1.5975$ ,  $N_m = N_p = 1.588$ ,  $N_g - N_p = .0095$ —A. N. W.]
36. "Grochauite," Antohidrano, Madagascar. Orcel, J.: *Op. cit.*, pp. 217–220. Orcel's analysis 67. Optics given on p. 217: (+)  $2E = 40^\circ$ ,  $N_g = 1.606$ ,  $N_m = N_p = 1.594$ ,  $N_g - N_p = .012$ . Optics given on p. 415.  $N_g = 1.596$ ,  $N_m = N_p = 1.584$ ,  $N_g - N_p = .012$ .
37. "Colerainite," Brinton's Quarry, Pa., Shannon, E. V. and Wherry, E. T.: *Jour. Wash. Acad. Sci.*, vol. XII, 1922, p. 239. (+)  $2V = 0^\circ$ ,  $N_g = 1.576$ ,  $N_m = N_p = 1.562$ ,  $N_g - N_p = .014$ .
38. "Sheridanite," Sheridan Co., Wyo. Wolff, J. E.: *Am. Jour. Sci.*, vol. XXXIV, 1912, p. 475. (+)  $2E = 26^\circ - 50^\circ$ ,  $N_g = 1.589$ ,  $N_m = 1.580 - 1.581$ ,  $N_p = 1.580$ ,  $N_g - N_p = .009$ .
39. "Sheridanite," Comberousse, France. Orcel, J.: *Op. cit.*, pp. 189–195. Orcel's analysis 31. (+)  $2E = 20^\circ \pm$ ,  $N_g = 1.586$ ,  $N_m = 1.580$ ,  $N_p = 1.578$ ; also, on p. 414,  $N_g = 1.588$ ,  $N_m = 1.581$ ,  $N_p = 1.580$ ,  $N_g - N_p = .008$ .
40. "Amesite," Chester, Mass. Shannon, E. V.: *Am. Jour. Sci.*, vol. XLIX, 1920, p. 96. (+)  $2V = 0^\circ \pm$ ,  $N_g = 1.612$ ,  $N_m = N_p = 1.597$ ,  $N_g - N_p = .015$ .

REFERENCES AND OPTIC DATA FOR FIG. 3

1. = 16 of preceding list.
2. Chlorite, Deer Park, Wyo. Shannon, E. V.: *U. S. Nat. Mus. Proc.*, vol. LVIII, 1920, p. 378. (–)  $2V = 0^\circ \pm$ ,  $N_g = N_m = 1.590$ ,  $N_p = 1.587$ ,  $N_g - N_p = .003$ .
3. = 19 of preceding list.
4. Chlorite, Togoland, Orcel, J.: *Op. cit.*, pp. 267–271. Orcel's analysis 271. (+)  $2V = 0^\circ \pm$ ,  $N_g = 1.584$ ,  $N_m = N_p = 1.579$ ,  $N_g - N_p = .005$ .
5. = 22 of preceding list.
6. = 26 of preceding list.
7. "Kämmererite," Säkok Ruopsok, Sweden. Du Rietz, T.: *Geol. För. Förh. Stockholm*, vol. LVII, 1935, p. 133. (+)  $2V = \text{small}$ ,  $N_g = 1.590$ ,  $N_m = ?$ ,  $N_p = 1.586$ ,  $N_g - N_p = .004$ .
8. = 29 of preceding list.
9. = 38 of preceding list.