

## CORDIERITE

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Repeated attempts at the University of Wisconsin to obtain a reasonable correlation of composition and optic properties in cordierite on the basis of published data have been unsuccessful, but H. Shibata<sup>1</sup> of the University of Tokyo has solved the problem with the aid of new data on iron-rich cordierite from Japanese pegmatites.

As a basis for some theoretical discussion it may be worth while to present the results of an independent study of the data, although they confirm Shibata's results in general; but Shibata based his correlation on the molecular ratio of  $\text{FeO} + 2\text{Fe}_2\text{O}_3 + \text{Na}_2\text{O}$  to  $\text{MgO} + \text{FeO} + 2\text{Fe}_2\text{O}_3 + \text{Na}_2\text{O}$ ; and the writer prefers to use the molecular ratio between  $\text{FeO} + 2\text{Fe}_2\text{O}_3 + \text{MnO}$  and  $\text{MgO} + \text{FeO} + 2\text{Fe}_2\text{O}_3 + \text{MnO}$ . Manganese is not common and never abundant in cordierite, but it resembles iron so closely, both in its chemical nature and its effects on optical properties, that it should be included with it. Analyses of cordierite do not show that ferric iron replaces alumina, because some analyses have been made on impure material or by inaccurate methods, and the tenor of ferric iron is always low. On the other hand the ferric iron may represent iron which was ferrous at the time of formation of the mineral; but in any case its influence on the optic properties is similar to that of an equivalent tenor of ferrous iron. Shibata includes soda with iron in his calculations, although he suggests that it plays an entirely different role in the crystal, namely, the same role as that of alkalis in beryl. It is true that one sample<sup>2</sup> of cordierite is reported to have properties such that it fits the diagram better when soda is included with iron, but the writer regards this as the result of chance, especially in view of the fact that soda has effects on physical properties in all other minerals very different from those of iron.

The relations between composition (excluding sodium and including manganese with iron) and physical properties are shown in Fig. 1. Artificial  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  is negative<sup>3</sup> and uniaxial, or nearly so, with  $N_g = N_m = 1.528$  and  $N_p = 1.524$ . This has been considered to be artificial pure magnesian cordierite, but the diagram (Fig. 1) suggests that it is a differ-

<sup>1</sup> Shibata, H., Graphic intergrowth of cordierite and quartz in pegmatites from Sasago and Dosi, Province of Kai, Japan: *Jap. Jour. Geol. Geog.*, vol. 13, p. 205, 1936.

<sup>2</sup> Cordierite from Haddam, Conn., analyzed by M. Dittrich and studied by L. Oppenheimer: *N. J. Min.*, I, p. 175, 1915.

<sup>3</sup> Rankin, G. A., and Merwin H. E., *Am. Jour. Sci.*, vol. 215, p. 301, 1918. Also Greig, J. W., *Am. Jour. Sci.*, vol. 13, p. 41, 1927.

ent phase, since the magnesian end member of natural cordierite would almost certainly be positive (although Shibata sketches a sharp reversal of the  $2V$  curve to a uniaxial negative end member). Of course it is also possible that natural magnesian cordierite differs from the artificial com-

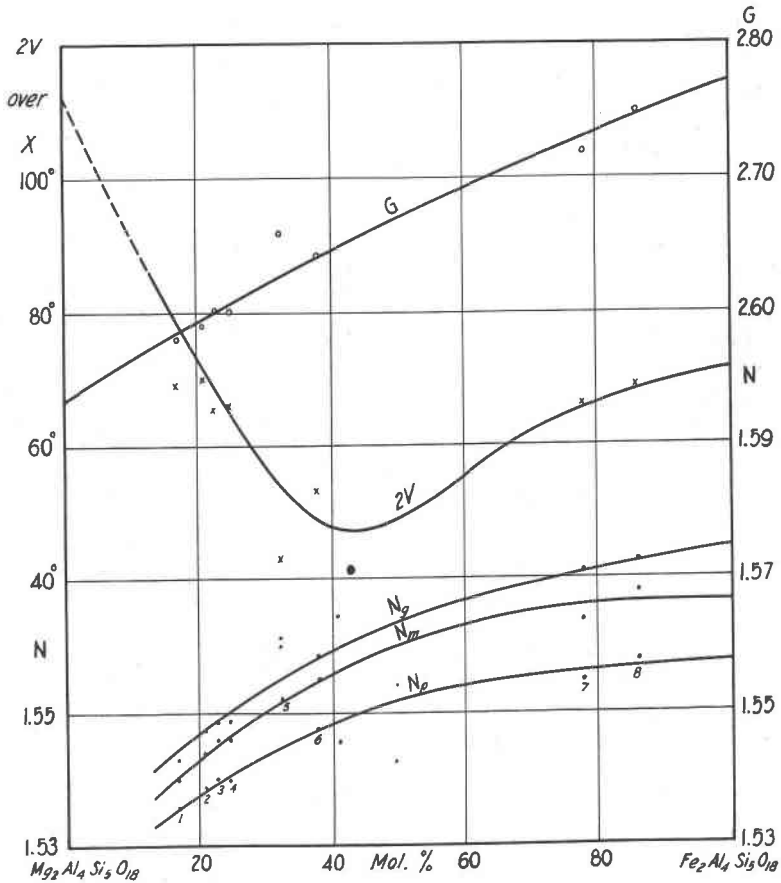


FIG. 1. Variations in composition and physical properties in cordierite.

pound chemically—for example, by the presence of water—enough to change the optic sign. In any case, Tsuboi<sup>4</sup> supplies evidence that natural cordierite in a single rock varies in optic angle from positive, near  $0^\circ$ , to negative and nearly uniaxial, though most of the grains are of very large optic angle, near  $90^\circ$ , of both optic signs! From the diagram (Fig. 1) the pure magnesian cordierite might be uniaxial positive, and cordierite with about 40 per cent iron might be of small optic angle. But it seems

<sup>4</sup> Tsuboi, *S. Jap. Jour. Geol. Geog.*, vol. 13, p. 337, 1936.

probable that some other factor (besides Fe+Mn) has a considerable influence on the optic angle.

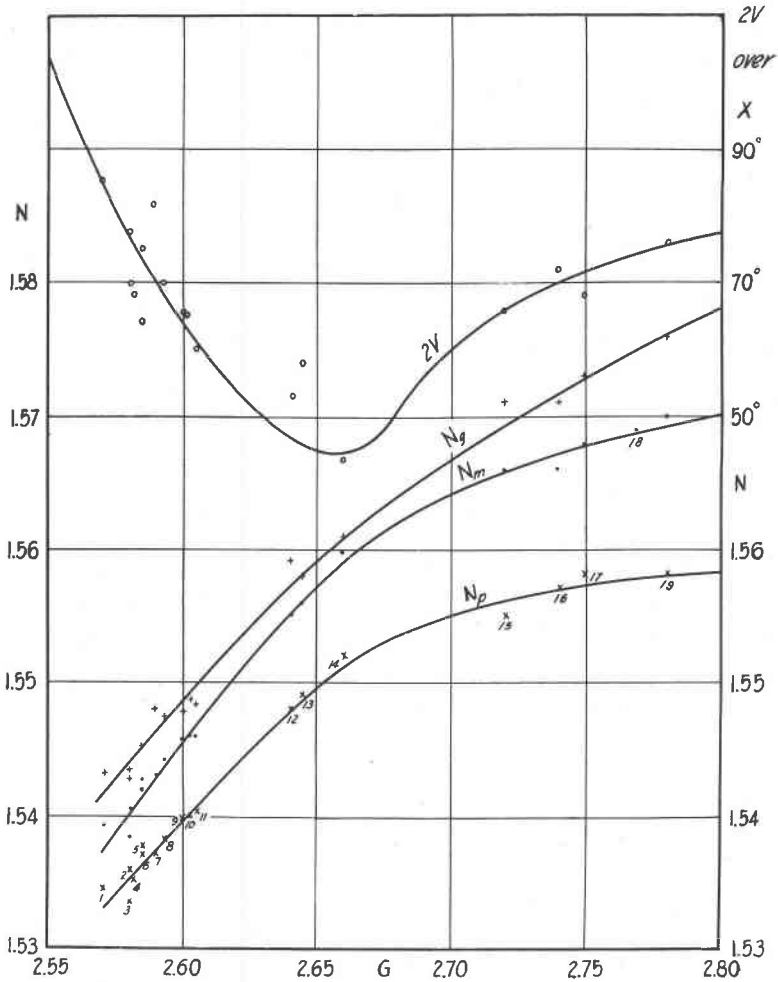


FIG. 2. Relations between specific gravity and optic properties in cordierite.

Shibata called attention to the fact that the specific gravity curve is nearly a straight line; assuming it to be actually straight, he used it as the basis of a second diagram of the optic properties. The writer has repeated this work and obtained a result quite similar to Shibata's diagram; it is shown in Fig. 2. This diagram is significant for at least two reasons. First, as compared with Fig. 1, more than twice as many samples

of cordierite are available for use in it, and this results in fixing more completely and more accurately the course of the curves for the optic properties. Second, there is clearly a closer correlation of optic properties with measured specific gravities than with chemical analyses. This is another reason why the curves of optic properties can be drawn more accurately.

An explanation of these conditions is not difficult. Professor R. C. Emmons in the Mineral Laboratories of the University of Wisconsin has found repeatedly that the indices of refraction of cordierite vary considerably, not only in different crystals from a single rock, but even in various parts of a single crystal. The observations reported by Tsuboi<sup>5</sup> are further evidence of the variability in the optic properties. There is no reason to doubt that these variations in optic properties are largely or wholly the result of variations in composition. Accordingly, a chemical analysis of cordierite separated from some rock, which must ordinarily be made on an aggregate of scores or even hundreds of small crystals or crystal fragments, represents the average composition of the aggregate, whereas the measurements of the optic properties, made on some part of one crystal, may differ notably from average values. On the other hand, the specific gravity may be determined from the same crystal used for the optical measures. It is therefore to be expected that there will be a closer correlation between specific gravity and optic properties than between chemical composition and optic properties.

Of course it is true that the closer correlation may be due to other causes. For example, the specific gravity depends upon all the chemical variations, and not only on those used in the diagram. But this does not seem to be important, since the other variations in composition are of types that have minor effects on the optic properties in other minerals.

The lack of correlation between chemical composition and optic properties is illustrated by the fact that there are almost as many (seven) samples of cordierite which have been analyzed and measured optically that can not be used in the diagram as the number (eight) used in preparing it. Of course this condition explains the fact that previous attempts to find a correlation have not succeeded.

An examination of Fig. 2 reveals some points of special interest. Thus, the curve for  $N_m$  approaches closest to that for  $N_g$  at about  $G. = 2.654$ , just as it should to correspond with an optic angle of about  $40^\circ$  about X; likewise it is about halfway between  $N_g$  and  $N_p$  at  $G. = 2.568$ , which corresponds with  $2V = 90^\circ$ . This diagram makes it very improbable that the optic angle can be  $0^\circ$  about X (with  $N_m = N_g$ ) at  $G. = 2.55$ , which is near

<sup>5</sup> Tsuboi: *Op. cit.*

the value for pure  $Mg_2Al_4Si_5O_{18}$ . But the optic angle seems to be widely variable for a single value of the refractive index, if the results of Tsuboi are accurate: he reported finding a nearly uniaxial positive cordierite having  $N_m = 1.560$ ! Can this be due to a variation in the tenor of water?

## REFERENCES FOR FIG. 1

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