

## 158. A Preliminary Note on a New Mineral, Indialite, Polymorphic with Cordierite

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(Comm. by S. TSUBOI, M.J.A., Oct. 12, 1954)

The present paper is concerned with the finding of a new hexagonal mineral from Bokaro coalfield, India,  $(\text{Mg}, \text{Fe}^{+2})_2 \text{Al}_4\text{Si}_5\text{O}_{18}$  in composition, polymorphic with cordierite. This mineral has hitherto been identified as cordierite; but, as will be seen, it is a distinct species, to which the name "indialite" is proposed.

### Previous Synthetic Investigations on Polymorphs of $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$

G. A. Rankin and H. E. Merwin (1918) synthesized two crystalline compounds with composition  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ , which they called " *$\alpha$ - and  $\mu$ -forms of ternary compound*" or " *$\alpha$ - and  $\mu$ -ternary compound*". It was considered by them that the  $\alpha$ -form is probably identical with natural cordierite.

H. S. Yoder, Jr. (1952) synthesized the  $\alpha$ -form by a hydrothermal method at temperatures above  $830^\circ\text{C}$ , while he obtained similar crystals having slightly higher refractive indices by the same method at temperatures below  $830^\circ\text{C}$ . He, considering that there is no significant difference in X-ray pattern between the two kinds he obtained, concluded that they both are identical with cordierite. Shortly later M. D. Karkhanavala and F. A. Hummel (1953), asserting that the latter represents a new form of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ , named it " *$\beta$ -form*". Further they remarked that the  $\mu$ -form is iso-structural with  $\beta$ -spodumene, and so is decidedly different from natural cordierite.

Thus, of three forms,  $\alpha$ ,  $\beta$ , and  $\mu$ , of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  which have been considered to exist, the  $\alpha$ -form (possibly the  $\beta$ -form too) has generally been believed to be identical with cordierite.

### Hexagonal Symmetry of the $\alpha$ - and $\beta$ -Forms

Our attention was drawn to the fact that the  $\alpha$ -form differs from natural cordierite in optical angle. According to the original description by Rankin and Merwin, the former is uniaxial negative, while the latter is biaxial, both negative and positive, usually with a large optical angle. We examined, by means of the Philips Geiger counter X-ray spectrometer, a sample of the  $\alpha$ -form obtained by devitrifying glass of that composition at temperatures around  $1200^\circ\text{C}$ ,

and found that its powder pattern is different from that of natural cordierite, as is shown in Fig. 1. The most distinctive is the pattern in the range of  $2\theta$  between  $29^\circ$  and  $30^\circ$  for  $\text{CuK}\alpha$  radiation. There

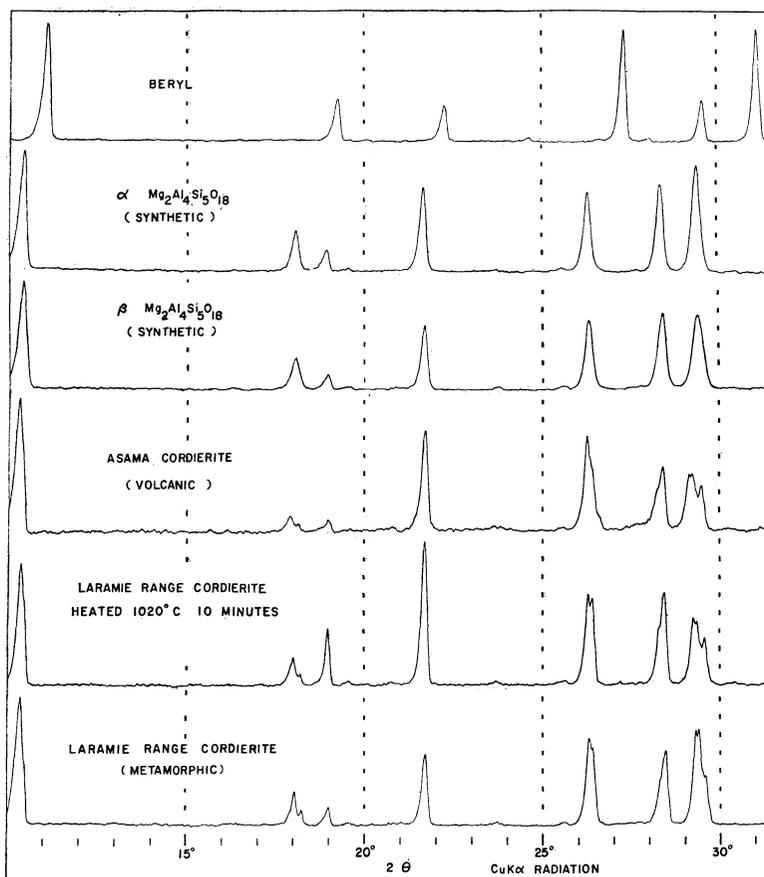


Fig. 1. X-ray spectrograms of beryl, indialites ( $\alpha$ - and  $\beta$ - $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ), and cordierites

is only one peak in this range in the  $\alpha$ -form, while there are, in the same range, at least three peaks, which are closely spaced but clearly distinguishable from one another, in natural cordierite.

The powder data of the  $\alpha$ -form can be perfectly indexed on the basis of a hexagonal unit cell with dimensions:  $a=9.782\text{ \AA}$  and  $c=9.365\text{ \AA}$ . This fact, taken in conjunction with the optically uniaxial character, indicates that the  $\alpha$ -form has hexagonal symmetry.

The hexagonal symmetry of  $\alpha$ - $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  is confirmed also from an examination of the so-called "synthetic iron-cordierite",  $\text{Fe}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ , the iron analogue of the  $\alpha$ - $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ . Drs. J. F. Schairer and H. S. Yoder, Jr. of the Geophysical Laboratory, Car-

negie Institution of Washington, kindly provided us with an X-ray spectrogram of "iron-cordierite" which was synthesized by J. F. Schairer and K. Yagi (1952) in the course of their study of the ternary system  $\text{FeO-Al}_2\text{O}_3\text{-SiO}_2$ . We found that the spectrogram is very similar to that of the  $\alpha$ -form of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ , and that it can be indexed on the basis of a hexagonal unit cell with dimensions:  $a=9.860 \text{ \AA}$  and  $c=9.285 \text{ \AA}$ . If the true symmetry of  $\alpha\text{-Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  were lower than hexagonal one, and if the shape of the unit cell coincided accidentally with that of the hexagonal one, probably the shape of the unit cell of the iron analogue would not coincide with that of a hexagonal one.

Then we have sufficient reasons to believe that  $\alpha\text{-Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  is truly hexagonal in symmetry. Then,  $\alpha\text{-Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  is a form, distinct from cordierite which is rhombic (or possibly monoclinic) and pseudohexagonal.

Dr. F. R. Boyd of the Geophysical Laboratory kindly synthesized for us what appears to be the  $\beta$ -form of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  by the hydrothermal method at  $775^\circ\text{C}$  and under a vapour pressure of 2000 bars. Its powder pattern is very similar to that of the  $\alpha$ -form as shown in Fig. 1, and can be indexed on the basis of a hexagonal unit cell with dimensions:  $a=9.792 \text{ \AA}$  and  $c=9.349 \text{ \AA}$ . Thus, the  $\beta$ -form is, as the  $\alpha$ -form, also probably hexagonal, and is distinct from cordierite.

Several investigators reported the formation of "synthetic magnesium cordierite" with variable optical angles, such as  $8^\circ$ ,  $30^\circ$ , and even  $82^\circ$  in dry processes. We investigated this problem and came to the conclusion that most of those "cordierites", if not all, probably belong to the  $\alpha$ -form showing optical anomaly. Then the most reliable diagnostic character for the identification of the hexagonal forms is not the optical angle but the X-ray spectrogram. Twin-like optical structure, sometimes observed between crossed nicols, of synthetic "cordierites" may actually be a kind of optical anomaly.

As is shown in Fig. 1, the X-ray spectrograms of the  $\alpha$ - and  $\beta$ -forms show a general resemblance to those of natural cordierite and also of beryl. The  $\alpha$ - and  $\beta$ -forms are probably iso-structural with beryl. The structure of natural cordierite is derived by slight deformations from those of the  $\alpha$ - and  $\beta$ -forms. The existence of such crystals as are structurally intermediate between the hexagonal forms and natural cordierite is not impossible, though we have not found an example of such.

#### Occurrence of the $\alpha$ -Form in Nature

Does the  $\alpha$ - or  $\beta$ -form of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  occur in nature? If it

does, it is expected from rocks subjected to a process similar to synthetic experiments. In this respect, the "cordierite" from the fused sediments (so-called para-lava) in Bokaro coalfield, India, was considered to be promising to be the  $\alpha$ -form. The rocks were found in 1916 by L. L. Fermor and are believed to have been produced by the fusion of sedimentary rocks owing to the burning of the underlying coal seams (Fermor, 1924). According to a personal communication from Dr. A. P. Subramaniam of the Geological Survey of India, the burning was due to some natural cause. Crystals of "cordierite" in the rocks were recently described in detail by V. Venkatesh (1952 and 1954). Dr. M. S. Krishnan and Mr. V. Venkatesh of the Geological Survey of India kindly sent us two specimens of the fused sediments.

We found that the "cordierite" in the rocks is not true cordierite, but is the  $\alpha$ -form, just as we had expected. It is hexagonal as is shown in Table I, and it is not the  $\beta$ -form because it does not show any decrease in refractive indices on heating at 1000°C. Its unit cell dimensions are:  $a=9.812\text{ \AA}$  and  $c=9.351\text{ \AA}$ . Some crystals

Table I

Powder diffraction data of the  $\alpha$ -form from Bokaro coalfield, India

Indices $N, l$	Intensity	$2\theta$ obs.	$2\theta$ calc.
1, 0	100	10.42	10.41
3, 0	18	18.05	18.08
1, 2	54	21.68	21.69
—	18	25.63*	
3, 2	43	26.31	26.31
—	18	27.80*	
4, 2	25	28.38	28.36
7, 1	54	29.38	29.38
7, 2	21	33.81	33.83
0, 4	14	38.47	38.47
12, 4	11	54.14	54.15

\* Due to impurity

Note: Filtered Cu radiation is used.  $N=h^2+k^2+hk$ . $a=9.812\text{ \AA}$ ,  $c=9.351\text{ \AA}$ . (Specimen No. 23/951)

are optically uniaxial negative, while others are biaxial, probably owing to optical anomaly (Specimen No. 23/951). If we assume that the unit cell dimensions and the refractive indices of the  $\alpha$ -form vary linearly with progressive replacement of Mg by  $\text{Fe}^{+2}$ , the  $\text{Fe}^{+2}:\text{Mg}$  ratio of the sample from India is computed to be about 3:7. Thus, the  $\alpha$ -form has been ascertained to occur in nature as a mineral in the proper sense of the word. We propose to call this new mineral "indialite" after India where it was found.

### Nomenclature of Polymorphs of $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$

A. Miyashiro, T. Iiyama, M. Yamasaki, and T. Miyashiro found previously that there probably exist two polymorphic forms in natural cordierite (unpublished). Now that so many polymorphs of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$  are known to exist, it is desirable to establish a clear nomenclature. In the original nomenclature by Rankin and Merwin, the names " $\alpha$ - and  $\mu$ -forms of ternary compound" were used merely for distinguishing the two forms from each other. Introduction of such terms as " $\alpha$ -,  $\beta$ - and  $\mu$ -cordierites" by some later writers has brought an unfortunate confusion in nomenclature. Now that these forms have been proved to be different from cordierite, and probably not to be in high-low inversion relation with cordierite,<sup>1)</sup> it is undesirable to call them with the name "cordierite". We here propose to use prefixes,  $\alpha$ ,  $\beta$ , and  $\mu$  only as those for chemical names, such as " $\alpha$ -,  $\beta$ - and  $\mu$ - $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ " or " $\alpha$ -,  $\beta$ - and  $\mu$ -forms of  $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ", following the original usage by Rankin and Merwin. We propose to restrict the use of the mineralogical name "*cordierite*" to the two rhombic (possibly monoclinic), pseudo-hexagonal forms represented by natural cordierite, and to use the mineralogical name "*indialite*" for the two hexagonal forms ( $\alpha$ - and  $\beta$ -forms). When necessary, the  $\alpha$ -form should be called "*high-indialite*", while the  $\beta$ -form "*low-indialite*", as they are connected by high-low inversion relation.

### Acknowledgements

We are greatly indebted to Dr. J. F. Schairer, Dr. H. S. Yoder, Jr., and Dr. F. R. Boyd, of the Geophysical Laboratory, for many informations and synthesis of the so-called  $\beta$ -form for us. We owe to Dr. M. S. Krishnan, Mr. V. Venkatesh, and Dr. A. P. Subramaniam, of the Geological Survey of India, for samples of the parala and informations on it. Mr. K. Sugiura of Tokyo Institute of Technology supplied a sample of the  $\alpha$ -form he had synthesized. Dr. S. Tsuboi, Dr. H. Kuno, and other members of the Geological and Mineralogical Institutes of Tokyo University gave us kind advice and criticism. Dr. M. Fleischer of the U. S. Geological Survey also gave us kind advice. However, the writers alone are responsible for all the contents of this paper.

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1) These hexagonal forms are probably metastable in any range of temperatures as will be discussed in a late paper.

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