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DISORDERED ORTHOPYROXENE IN METEORITES

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ABSTRACT

Disordered orthorhombic pyroxene, which was first found in meteorites by Brown and Smith (1963), and later by Pollack and Ruble (1964), has now been found in all the enstatite achondrites except Shallowater. It has also been found in the Stannern(eucrite), Abee(enstatite chondrite) and Hugoton(olivine-bronzite chondrite).

INTRODUCTION

This paper contains the data on the occurrence of disordered orthorhombic pyroxene published earlier (Pollack and Ruble, 1964) as well as results from 22 additional stony meteorites. The same techniques employed before were used in studying the new samples.

ENSTATITE ACHONDRITES

Although no optical means has been found for always distinguishing between the ordered and disordered enstatites, there are some differences between the two which can be used to select grains which are most likely to be ordered or disordered. The comments below are based on observation of less than 0.25 g samples of each of the enstatite achondrites and therefore may not be truly representative of these meteorites. Most orthopyroxene crystal fragments from enstatite achondrites (and all other meteorites studied) longer than about 0.2 mm and transparent are either 100% ordered or close to it, however, not all fragments which are not transparent are disordered.

Generally, the disordered grains have numerous cracks perpendicular to the longest dimension, which is usually the *c* axis. Those pyroxene fragments which are not transparent are usually milky white, cloudy, or rust stained although a few appear gray. In the Bustee sample the gray portion is diopside while in the Peña Blanca and Khor Temiki the gray pieces are disordered enstatite. Only disordered enstatite has been detected in the Aubres and Bustee.[1] When viewed with reflected light under a microscope, the fragments of these achondrites appear white until they are crushed to about 0.1 mm; then they become transparent to varying degrees but usually retain a somewhat cloudy appearance. Aside from the Bishopville and Shallowater, from which no single crystals of disordered enstatite have been isolated, it was more difficult to isolate single crystals of disordered enstatite from the Pesyanoe than from any of the other enstatite achondrites. This is because the disordered grains are

[1] Although I have not found ordered enstatite in the Bustee, Dr. Geake, of Manchester, has informed me in a private communication that Dr. R. S. Mackenzie has.

more transparent and less shattered than those of the other achondrites in this class. One fragment of Pesyanoe with a longest dimension of about 0.1 mm turned out to be a split crystal one part of which was ordered and the other disordered.

Most of the orthopyroxene fragments used in this study were oriented along the longest dimension, the *c* axis, and then single crystal Weissenberg patterns of the (*hk*0), (*hk*1) and (*hk*2) nets were obtained. Some crystals produced patterns where all reflections (*hk*1) *h* even, and (*hk*2) *h* odd are more diffuse than the other (*hkl*) spots. Other crystal patterns showed the same diffuse reflections and in addition showed extra weak spots.

In our earlier paper, the extra spots were interpreted as an enlarged *a* axis. Since that work, we have been able to obtain some crystals of twinned clinoenstatite and prepare Weissenberg photographs from them. A comparison of these photographs with those of disordered enstatite from the Norton County meteorite shows all the extra spots are in positions identical to strong spots on the clinoenstatite[1] patterns and, therefore, are due to thin lamallae of twinned clinoenstatite and not a superlattice. On the Aubres and Cumberland Falls patterns even the sharper spots are somewhat diffuse. However, for the Pesyanoe, Bustee, Khor Temiki, Peña Blanca, Mt. Egerton, Stannern and Hugoton there is a high degree of contrast between the relative sharpness of the sharper and the diffuse spots. Table I lists the type of disordered pattern found in the meteorites examined to date.

TABLE I. METEORITES IN WHICH DISORDERED ORTHOPYROXENE HAS BEEN DETECTED AND THE TYPE OF SINGLE-CRYSTAL PATTERN THE DISORDERED ORTHOPYROXENE PRODUCED

(*Indicates ordered orthopyroxene also present.)

Type of Single-Crystal Pattern					
Diffuse and Sharp Spots Only		Diffuse and Sharp Plus Clino-ens. Spots		No Macroscopic Disordered Crystals Found	
Aubres	(Ae)	*Bustee	(Ae)	*Bishopville	(Ae)
*Cumberland Falls	(Ae)	*Khor Temiki	(Ae)	Abee	(Ce)
*Pesyanoe	(Ae)	*Norton Co.	(Ae)		
Stannern	(Ap)	*Peña Blanca	(Ae)		
Hugoton	(Cb)	Mt. Egerton	?		

[1] Clinoenstatite has been found in three of the enstatite achondrites. It was described in Norton county enstatite by Beck and La Paz (1951) and in Norton County, Peña Blanca and Cumberland Falls by Reid (1965).

Although single crystal photographs show the variations described above, Debye-Scherrer photographs of powdered disordered enstatite crystals from Aubre, Bustee, Cumberland Falls, Khor Temiki, Norton County and Peña Blanca appear to be almost identical. All the powder patterns made from Pesyanoe and Bishopville were from mixtures of ordered and disordered enstatites or wholly ordered samples.

Other Stony Meteorites

Disordered orthopyroxene has also been found in the Abee and Hugoton chondrites, the Stannern achondrite and Mt. Egerton. Five crystals selected from the Abee all gave x-ray patterns which showed that they

Table II. Meteorites in which Disordered Orthopyroxene has not been Detected (All Contain Ordered Orthopyroxene)

Achondrites		Chondrites		Other
Ibbenbuhren	(Ah)	Khairpur	(Ce)	Bondoc
Johnstown	(Ah)	St. Marks	(Ce)	
Manegaon	(Ah)	Gnadenfrei	(Cb)	
Shalka	(Ah)	Richardton	(Cb)	
Tatahouine	(Ah)	Selma	(Cb)	
Kapoeta	(Ap)	Weston	(Cb)	
Shallowater	(Ae)	Bjurbole	(Ch)	
		Knyahina	(Ch)	
		Modoc	(Ch)	

(Ae) enstatite achondrite (Ce) enstatite chondrite
(Ah) hypersthene achondrite (Cb) olivine-bronzite chondrite
(Ap) pyroxene plagioclase (Ch) olivine-hypersthene chondrite
(classification after Mason, 1962, and Prior and Hey, 1953)

were highly split, and so the identification of disordered enstatite in the Abee is based on its powder pattern. Single crystals of disordered enstatite have been found in the other three meteorites. The lattice parameters of two crystals from each meteorite were measured and gave reproducible results. However, the estimation of the molecular fraction $FeSiO_3$ was not the same for the three dimensions of each crystal measured. Using the curves of Hess (1952), the molecular fraction of $FeSiO_3$ was estimated to be zero for Mt. Egerton,[1] 15–22% for Hugoton and 45–55% for the Stannern.

Table II lists the meteorites in which only ordered orthopyroxene has been detected. Debye-Scherrer patterns have been obtained from several

[1] Reid (1965) has analyzed several enstatite grains from Mt. Egerton using a microprobe and found the iron content to be below the minimum detection limit of 0.3%.

samples of each meteorite and single-crystal patterns have been obtained of crystals from most of the achondrites in Table II.

Discussion

With the possible exception of Mt. Egerton (of which little is known), the disordered orthopyroxenes were detected only in the brecciated meteorites, though not in all of them. In the meteorite class in which samples from all members have been examined, the enstatite achondrites, disordered enstatite was found in the eight which Mason (1962) describes as brecciated and not observed in the Shallowater which he calls unbrecciated. This suggests that the disordering of the enstatite occurred at the same time as the brecciation. If this is true, then it is surprising that no disordered orthopyroxene was detected in any of the five hypersthene achondrites which have been examined. Possibly the deformation or deformations which caused the brecciation of the enstatite achondrites was more intense than that which affected the hypersthene achondrites. The presence of iron in the pyroxene apparently does not prevent disordering since disordered orthopyroxene containing iron has been found in the Hugoton and Stannern.

Synthetic disordered orthorhombic enstatite has been prepared by M. L. Keith (Brown and Smith, 1963) by heating MgO, SiO_2, and a B_2O_3 flux to 1450° C. and quenching. However, Reid (1965) has pointed out that the presence of both ordered and disordered enstatite in the same sample, the large grain size and lack of zoning all argue against a rapid cooling rate for the enstatite achondrites.

A detailed study of the effects of high shock pressures on orthopyroxene should reveal whether the presence of disordered orthopyroxene can be explained on the basis of deformation alone or if some more complex theory is required.

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