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Estimation of shock pressure experienced by ordinary chondrites with an X-ray diffraction method

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Shock metamorphism is pervasively recognized in meteorites, and it is an important subject to estimate the degree of shock experienced by each meteorite. Stoffler et al. (1991) classified meteorites based on the degree of shock that was recorded as shock textures on olivine. However, the classification of Stoffler et al. (1991) is qualitative one. In this study, we determined apparent strains of olivine crystals in ordinary chondrites by an X-ray powder diffraction method and estimated shock pressures experienced by each meteorite.

We analyzed six ordinary chondrites, which are listed in Table 1 together with the results of this study. The polished thin sections of the six meteorites were observed under a microscope with a polarized light. Chemical compositions of olivines were analyzed by an EPMA equipped with a wavelength dispersive spectrometer. Olivine grains of about 50 micron meter in size, being confirmed to be homogeneous in their chemical compositions by EPMA, were taken out of the polished thin sections. Their X-ray powder diffraction patterns were obtained by a Gandolfi camera. The position and the integral breadth of each X-ray reflection were precisely determined by applying a profile-fitting technique with a pseudo-Voigt type shape function. Apparent strains of olivine crystals were determined by the method shown by Wilson (1962).

An example of the X-ray diffraction pattern of an olivine grain (50 micron meter in size) is shown in Fig. 1. As shown in Fig. 1, a clear X-ray diffraction pattern can be obtained even from a very small crystal by using a Gandolfi camera.

The X-ray line broadening can be related to the apparent strain in a crystal by the equation, B = 4e tan(theta), where e and B are respectively the apparent strain and the broadening due to the strain and theta is the half of the angle between incident and diffraction beams (Wilson, 1962). Fig. 2 shows the plot of B vs. tan(theta) for olivine grains from the Bruderheim (assigned to S4 shock stage) and the Great Bend (S1 shock stage) chondrites. The olivine from the Bruderheim chondrite (S4) is plotted on the diagram along the line having a greater slope than that for the olivine from the Great Bend chondrite (S1). The results suggest that the former is strained more than the latter and that the apparent strain measured by an X-ray method corresponds well to the shock stage determined by the method of Stoffler et al. (1991).

For each meteorite, the apparent strains of four to six olivine grains were determined. The maximum value of the apparent strains for each meteorite is shown in Fig. 3 as a thin solid line parallel to the shock pressure-axis. The lengths of the lines show the ranges of shock pressures that are estimated for the shock stages to which each meteorite is assigned (Stoffler et al., 1991). Uchizono et al. (1999) experimentally showed that the apparent strain of a olivine crystal increases with the increase of shock pressure experienced by it. By assuming a linear relation between the apparent strain and shock pressure, we can draw two lines on the diagram of Fig. 3, which restrict the shock pressure experienced by each meteorite. The line drawn through solid circles in Fig. 3 shows the linear relation between the apparent strain and shock pressure that has the maximum slope among the lines showing the linear relation and restricts the shock pressure at the lower-pressure side for each meteorite. The other line drawn through solid squares has the minimum slope and restricts the shock pressure at the higher-pressure side. The thick solid lines drawn for each meteorite in Fig. 3 show the shock pressure ranges restricted by the maximum and minimum slope lines. The shock pressures estimated for each meteorite like this are also summarized in Table 1.

References: Stoffler et al. (1991) G.C.A. 55, 3845-3867; Uchizono et al. (1999) Mineral. J. 21, 15-23; Wilson, A.J.C. (1962) X-ray Optics, John Wiley & Sons Inc., New York.

Table 1. Meteorites of this study and their estimated shock pressure.

Meteorites	Chemical Group	Shock Stage*	Estimated Shock Pressure (GPa)
Great Bend	H6	S1	2.8 ± 0.2
Y-790752	LL6	S2	5.5 ± 0.5
Mulga(north)	H6	S2	9.2 ± 0.8
Dhurmsala	LL6	S3	13.2 ± 1.2
Ohuma	L5	S3	18.2 ± 1.8
Bruderheim	L6	S4	22.2 ± 2.2

*: estimated based on Stöffler et al. (1991).

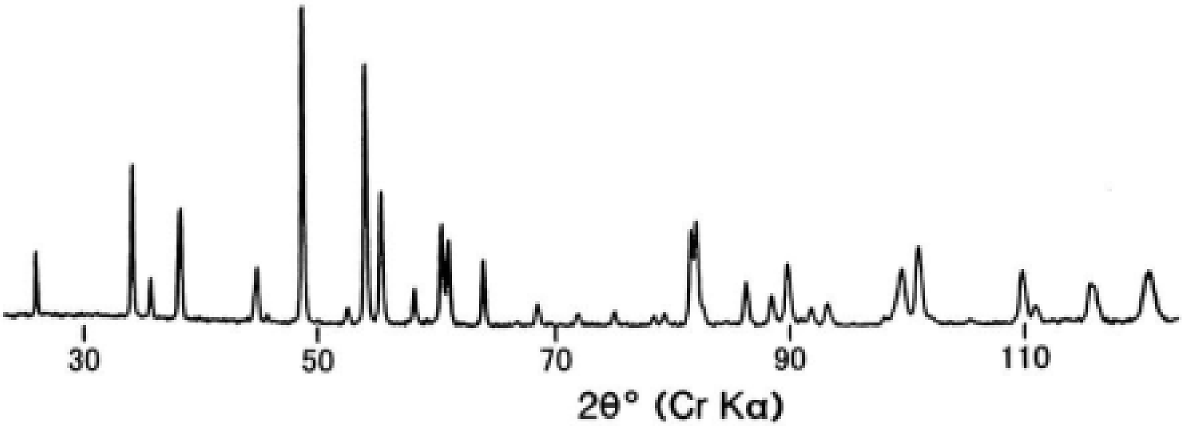

Fig. 1. X-ray diffraction pattern of an olivine grain (50 μm) taken by a Gandolfi camera.

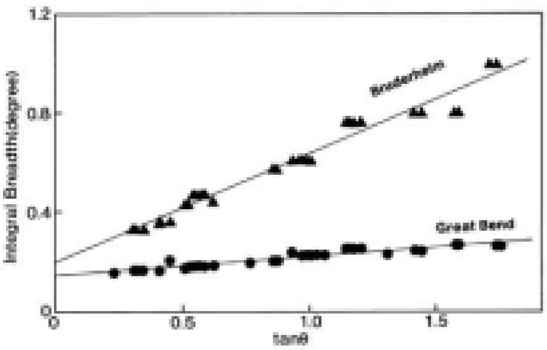

Fig. 2. Plot of integral breadth vs. tan θ for olivin grains from Bruderheim (S4) and Great Bend (S1) chondrites.

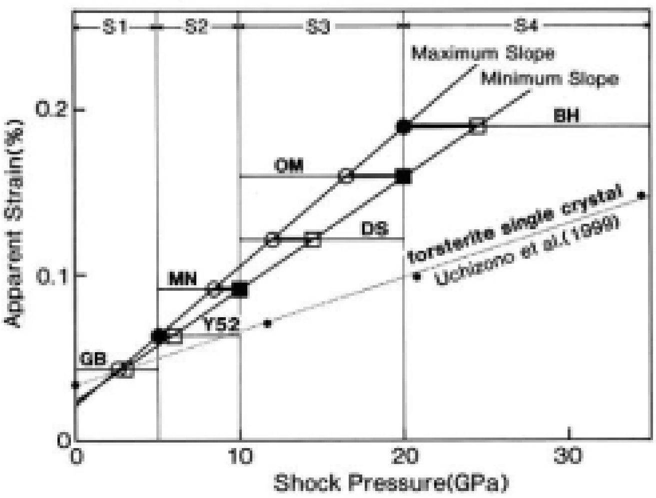

Fig. 3. Relation between the maximum value of the apparent strain for each meteorite and shock pressure. GB: Great Bend; Y52: Y-790752; MN: Mulga(north); DS: Dhurmsala; OM: Ohuma; BH: Bruderheim.