Lattice strain analyses for the L6 ordinary chondrites by the X-ray diffraction method

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Introduction

The measurement of the extraterrestrial materials by the X-ray diffraction method is useful for characterizing the powders (e.g., Howard et al., 2010) and polished thins sections (Imae and Nakamuta, 2018; Imae et al., 2019), sub-millimeter grains (Imae and Kimura, 2019), and ~50 μm-sized grains (Nakamuta et al., 2006, Nakamura et al., 2001; Jenkins et al. 2019). Imae et al. (2019) found the positive correlation between the shock stage defined by Stöffler et al. (1991; 2018) and the full width at half maximum (FWHM) for olivine 130 indices of 11 L6 chondrites. It suggests the lattice strains in olivines. However, since the olivine 130 is one of the slip planes for shock (e.g., Müller and Hornemann, 1969), more general examination using a lot of indices of olivines may be needed. Moreover, the lattice strain is an essential parameter for quantifying the shock effects of stony meteorites. Uchizono et al. (1999) applied the strain analytical method explored by Williamson and Hall (1953) to the shock recovery experiments using forsterites. Then, Nakamuta et al. (2006) determined the maximum lattice strains of olivines in equilibrated ordinary chondrites using the Gandolfi camera, and estimated the shock pressures using the calibration curve by Uchizono et al. (1999). In the present study, the averaged lattice strains of olivines and orthoenstatites were determined using a similar analytical method from the measurements of polished thin sections (PTSs) for 14 L6 chondrites the in-plane rotation method (Imae and Nakamuta, 2018), newly trying to propose the shock barometer.

Experiments

Samples

The measured PTSs were Y-74035 (,96-3, S1, 1.0 cm^2), A-881806 (,121-1, S1, 1.8 cm^2), Y-793569 (,61-1, S1, 1.3 cm^2), A-87010 (,91-1, S3, 0.8 cm^2), Y-86010 (,51-1, S3, 0.6 cm^2), Y-86007 (,51-1, S3, 0.8 cm^2), ALH-769 (,98-2, S3, 2.0 cm^2), Y-791771 (,51-1, S4, 1.3 cm^2), A-881091 (,31-1, S4, 1.8 cm^2), Mangui (S4-5, 1.6 cm^2), NWA 7984 (S5, 1.6 cm^2), Tenham (,51-3, S6, 1.7 cm^2), NWA 4719 (S6, 0.9 cm^2), and Sahara 98222 (S6, 1.8 cm^2), the parentheses show PTS number, shock stage, and surface area, respectively.

Measurements

The X-ray diffractometer installed at National Institute of Polar Research (SmartLab, Rigaku) was used for the study, on the condition of tube current 40 mA, tube voltage 40 kV, length limiting slit of 5 mm, divergence angle (1/6)º, 3-75º of the scanned twice Bragg angle, 100 rpm of the in-plane rotation rate for PTS, BB optics, silicon semiconductor detector (D/tex Ultra 250), and removal of Cu Kβ by Ni-filter.

Analyses

The data analyses were carried out under the software of PDXL with PDF (powder diffraction data) data sets of olivine (Fa18, 01-088-1993), orthoenstatite (Fs20, 01-071-1162), and plagioclase (Ab76, 00-041-1480). After the repeated trial and error to avoid the overlapping the peaks both in the same phase and in different phases, the focused indices were four of 130, 211, 222, and 322 for olivines, and five of 610, 511, 421, 631, 12 12 for orthoenstatites. To plot between the tangent of Bragg angle and integral breadth (Williamson-Hall plot, or WH plot) (Williamson and Hall, 1953), profile fittings were carefully carried out using the software of PDXL (Rigaku).

Results

Olivines

The WH plots for olivines of 14 L6 chondrites showed relatively good correlation factors more than 0.9 for 11 samples (but remain three samples 0.76, 0.68, 0.74). Each slope of the least-squares gives the lattice strain, and it was plotted for the shock stage according to the definition by Stöffler et al. (1991; 2018).

Orthoenstatites

The WH plots for orthoenstatites only showed an excellent correlation of more than 0.85 for 8, but four samples intermediate correlation of 0.77-0.82 and two samples (Y-791771 and NWA 4719) were absent from relationship. The lattice strains were obtained from 12 samples showed correlations, and they were plotted for the shock stage.

Plagioclase

There is a clear trend between FWHM and integrated intensity of plagioclase $\bar{2}01$ shows; when the shock stage from S1 increases, the FWHM first increases (S3), the intensity secondary decreases with the decreasing FWHM (S4-S5), and finally both FWHM and intensity are toward to zero (S6).

Discussion

The lattice strains for olivines are positively correlated with the shock stages, however, scattered. When the strains for each shock stage were averaged, then the positive correlation becomes clear. Also, the trend is nearly consistent with the maximum strains of olivines experimentally determined by Uchizono et al. (1999). The reason for the scattered data of strains among the same shock stage may be due to specific factors for each sample, such as annealing after the shock. The lattice strains for orthopyroxenes decrease for the S6 chondrites, suggesting a significant amount of breakdown to clinoenstatites during the high-pressure stage by the intense shock. The maskelynitization of plagioclase may help the interpretation for the shock effects on olivines and orthenstatites. In summary, the combed data of shock effects for olivine, orthoenstatite, and plagioclase becomes suitable barometer estimating the shock pressure of the L6 chondrites.

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