American Mineralogist, Volume 106, pages 1470–1479, 2021

Quantitative determination of the shock stage of L6 ordinary chondrites using X-ray diffraction

Naoya Imae[1,2,*] and Makoto Kimura[1]

[1]National Institute of Polar Research, 10-3 Midori-cho, Tachikawa-shi, Tokyo 190-8518, Japan
[2]SOKENDAI, 10-3 Midori-cho, Tachikawa-shi, Tokyo 190-8518, Japan

Abstract

The shock stages of 14 L6 ordinary chondrites are estimated using the random X-ray diffraction patterns of polished thin section samples and the in-plane rotation method. The mean lattice strains and grain size factors for olivine and orthopyroxene are determined from the analyses based on the Williamson–Hall plots, which depict the tangent Bragg angle and integral breadth β. The lattice strain in olivine, ε^{Ol}, is distributed from ~0.05% to ~0.25%, while that in orthopyroxene, ε^{Opx}, is distributed from ~0.1 to ~0.4%, where we selected the isolated peaks of olivine and orthopyroxene. The olivine peaks have Miller indices of (130), (211), (222), and (322), while the orthopyroxene peaks have Miller indices of (610), (511), (421), (631), and (12.1.2). The intercept for integral breadth β_0^{Ol} and β_0^{Opx} for the Williamson–Hall plots correlates with the grain size of the constituent minerals. The grain size is proportional to the inverse of β_0 since the β intercept increases with the shock stage. Introducing a new parameter, $-\varepsilon/\log \beta_0$ for olivine (0.04–0.16) and orthopyroxene (0.07–0.32) reveals a clear relationship between them: $-\varepsilon^{Opx}/\log \beta_0^{Opx} = -0.01 + 2.0\,(-\varepsilon^{Ol}/\log \beta_0^{Ol})$ ($R > 0.9$). In addition, the isolated peak of plagioclase ($\bar{2}01$) systematically changes as the shock stage increases, suggesting the progress of amorphization (maskelynitization). Another parameter, $(I/\mathrm{FWHM})_{\mathrm{Pl}(\bar{2}01)}$ reveals additional relationships: $-\varepsilon^{Ol}/\log \beta_0^{Ol} = 0.14(\pm 0.01) - 5.2 \times 10^{-5}\,(\pm 5.7 \times 10^{-6}) \times (I/\mathrm{FWHM})_{\mathrm{Pl}(\bar{2}01)}$, and $-\varepsilon^{Opx}/\log \beta_0^{Opx} = 0.25(\pm 0.04) - 8.9 \times 10^{-5}\,(\pm 2.6 \times 10^{-5}) \times 10^{-5} \times (I/\mathrm{FWHM})_{\mathrm{Pl}(\bar{2}01)}$. These three parameters systematically change with the shock stage, suggesting that they are suitable shock barometers. The present method is useful to evaluate the shock stage of L6 chondrites and potentially enables quantitative shock stage classification for stony meteorites.

Keywords: Olivine, orthopyroxene, ordinary chondrites, X-ray diffraction, lattice strain, shock metamorphism