The shock recovery experiments of CI chondrites

Toru Nakahashi[1], Masaaki Miyahara[1], Akira Yamaguchi[2], Takamichi Kobayashi[3], Hitoshi Yusa[3], and Naotaka Tomioka[4]
[1]*Hiroshima University*, [2]*National Institute of Polar Research (NIPR)*, [3]*National Institute for Materials Science (NIMS)*, [4] *Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC).*

About 80% of the asteroids in the main belt are C-type, and their spectra are similar to CI-CM chondrites. CM chondrites are found much more frequently on Earth than CI chondrites. However, this is probably due to a sampling bias that makes CI chondrites brittle and easily weathered, making them difficult to recover on the ground. The bulk composition of CI chondrites matches well with the elemental composition of the solar photosphere, suggesting that the majority of C-type asteroids are composed of CI chondrites. The C-type asteroid Ryugu has many boulders on its surface (Tachibana et al., 2022). The boulders have a layered structure that is likely evidence of shock metamorphism. These external features indicate that Ryugu is a ruble-pile type object that has been repeatedly impacted, destroyed, and reaccumulated. The petrological, mineralogical, and geochemical characteristics of Ryugu grains most closely resemble a CI chondrite (Ito et al., 2022; Nakamura et al., 2023; Yokoyama et al., 2023).

Impact phenomena not only modify the external features of asteroids, but also induce thermal metamorphism. Thermal metamorphism in the parent bodies of carbonaceous chondrites is important because of i) aqueous alteration after melting of ice accreted to the parent bodies, ii) dehydration of hydrous minerals, iii) increase in maturity of organic materials. The evaluation of the shock pressure and temperature (degree of shock metamorphism) of a meteorite is made by comparison with samples recovered from shock experiments of samples with comparable characteristics. However, shock recovery experiments have not been performed on a CI chondrite because of its rarity and the high volatile content causing explosive dispersion by post-shock heating.

A typical shock recovery experiment requires about 500 mg of sample per experiment, but experiments that consume large amounts of valuable CI chondrites are not feasible. However, we have developed a technique that allows shock recovery experiments to be performed with small amounts of sample. As a result, we have been able to perform a shock experiment using only about 70 mg of sample at a time and recover the samples without explosive dispersion after shock compression. In this study, we conduct the shock recovery experiments of CI chondrites by using the developed technique to establish a shock classification scale dedicated to a CI chondrite. A single-stage propellant gun installed at NIMS was used for the shock experiments. Shock recovery experiments were performed using the Orgueil CI and Y 980115 CY chondrites as starting materials. CY chondrite is similar to CI chondrite, but a bit thermally metamorphosed (King et al., 2019). The shock pressure applied to the samples was estimated by impedance matching method to be in the range of 5–30 GPa, although this is tentative due to the lack of Hugoniot data for a CI chondrite. All impacted samples were successfully recovered. The microstructural observation and chemical composition analysis of the recovered samples were performed by FE-SEM and TEM/STEM-EDS.

Orgueil CI and Y 980115 CY chondrites as starting materials are composed almost entirely of matrix, including phyllosilicates (saponite and serpentinite), oxides (magnetite and hematite), and sulfides. Significant textures associated with shock metamorphism are not observed in the starting materials. Subparallel cracking, preferential orientation of oxides and sulfides, dispersion of aggregated magnetite grains, and shock-induced melting were observed in Orgueil and Y 980115 after the shock experiments. In the shocked samples of Orgueil, the aggregated magnetite grains were stretched at 5 GPa, and individual grains of aggregated magnetite were dispersed at 10 GPa. At 20 GPa, cracks develop nearly parallel to each other. Melting occurs at 20 GPa and 30 GPa, as quenched crystals of magnetite and silicate glass are seen in some of the matrix. Melting occurs along cracks or in puddles. In the shocked samples of Y 980115, dispersion of aggregated magnetite grains and preferential orientation of oxide and sulfide were observed at 10 GPa. Melting occurred in a portion of the matrix at 20 GPa and 30 GPa. The number density of subparallel cracks in the Orgueil and Y 980115 starting materials and in the experimental shock recovery samples was measured using image analysis software. As a result, the number density of cracks in the starting material was close to 0, while the number density of cracks in the shocked samples tended to increase with increasing shock pressure. We plan to use the dispersion degree of aggregated magnetite grains, the melting of a matrix, and dehydration degree of phyllosilicates as well as the number density of subparallel cracks to establish the shock classification scale for CI chondrites.

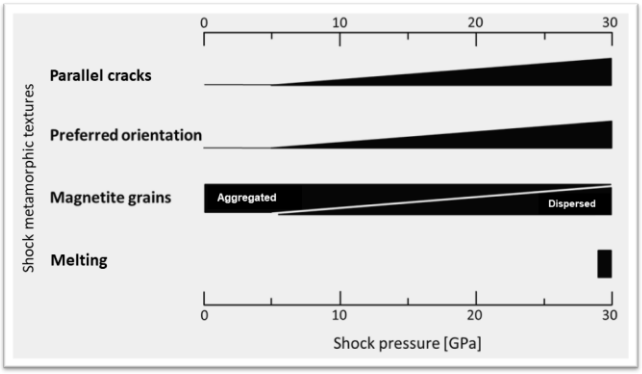

Figure 1. A schematic diagram showing a relationship between shock pressure and shock metamorphic textures based on experimentally shocked Orgueil CI carbonaceous chondrite.

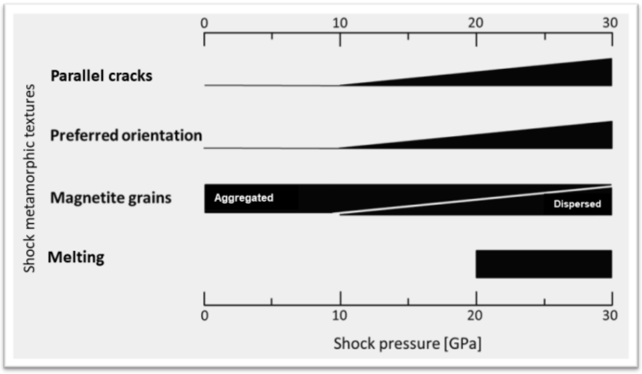

Figure 2. A schematic diagram showing a relationship between shock pressure and shock metamorphic textures based on experimentally shocked Y 980115 CY carbonaceous chondrite.

References

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