Microstructure of olivine in basalt recovered from shock experiment and a comparison with olivine in Martian meteorites

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Martian meteorites are known to contain brown colored olivine (brown olivine) whose color is induced by iron nano-particles (Fe-nps) formed by a shock event. Brown olivine is only reported in Martian meteorites. Several previous studies discussed its formation processes (e.g., Treiman et al., 2007) although it is still in controversy. The formation processes and formation conditions of brown olivine should be quantitatively studied because they are important for understanding impact events and origins of Martian meteorites. In this study, we performed shock-recovery experiments to constrain the formation processes and formation conditions of brown olivine. In previous studies of shock-recovery experiments focusing on olivine, olivine single phase was chosen. However, rocks similar to Martian meteorites should be used as starting materials to compare shock effects on olivine. Therefore, we used olivine-phyric basalt from Kita-Matsuura, Nagasaki as a target sample. Due to the presence of Fe-rich olivine (~Fo69), this basalt is similar to Martian meteorites, particularly olivine-phyric shergottites.
The experiments were conducted using a single stage propellant gun at NIMS. The basalt chips were cut as circular disks of 1 mm thick and packed in tightly sealed stainless containers. Stainless flyers of 3 mm thick and tungsten flyer of 2 mm thick were used for ~40 GPa and 50 GPa shock, respectively. We performed four shots and actual shock pressures calculated with the flyer velocity just before the impact were 22.2, 28.7, 39.5 and 48.5 GPa. Polished thin sections (PTSs) of the recovered samples were observed by optical and scanning electron microscopy (SEM). Thin film section for TEM observation was cut off from PTS by FIB. Regarding olivine darkening, we checked the presence of Fe-np because it is difficult to judge whether olivine is darkened or not by optical microscopy because part of olivine was originally colored due to alteration.
In our observation, plagioclase shocked at 22.2 GPa showed wavy extinction while that in basalt shocked over 28.7 GPa was completely maskelynitized. Pyroxene and olivine show only wavy extinction and weak mosaicism even in basalt shocked at 48.5 GPa. Although shock melt veins formed in basalt were subjected to over 28.7 GPa, no high-pressure phases were found. Interestingly, olivine shocked at 39.5 GPa and 48.5 GPa exhibited lamellar textures similar to planar deformation features and widths of lamellae were ~0.25 and ~ 1 μm, respectively. Observation of these lamellae by TEM revealed that the lamellae corresponded to defect-rich areas. However, Fe-nps were not found even in these areas.
Our previous study revealed that brown olivine areas were composed of lamellae in Northwest Africa 1950 (Takenouchi et al., 2015). The lamellar texture observed in this study is similar to its texture, however, contains no Fe-nps and showed no characteristic features of brown olivine. Mikouchi et al. (2011) reported that the shock recovery experiments of olivine powder at 40 GPa produced Fe-nps in olivine. It is indicated that not only high-pressure but also high-temperature is needed to produce Fe-nps because powdered sample is likely to be experienced higher temperature during experiment due to its higher porosity compared to basalt. As a result, our experiments suggests that olivine darkening is occurred by formation of defect-rich lamellar texture by high-pressure followed by diffusion of iron forming nano-particles at high temperature.
The lamellar texture has a potential to be an indicator of shock pressure because the widths of lamellae change depending on the shock pressure. The lamellar width in olivine in Martian meteorites is about ~2 μm, which is similar to those in the recovered sample shocked at 48.5 GPa. On the other hand, a number

density of lamellae is higher in Martian meteorites, indicating that the shock temperature may control the number density. Thus, the lamellar texture could be an indicator of shock pressure and temperature.

Keywords: Shock-recovery experiment, Martian meteorite, Olivine