論文の内容の要旨

Collisional events on Mars as described by shock P-T histories of shergottites Martian meteorites with brown olivine

(黒色カンラン石を含むシャーゴッタイト火星隕石の衝撃温度圧力履歴から読み解く火星上での天体衝突現象)

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Heavily shocked Martian meteorites are known to contain brown colored olivine so-called “brown olivine”. The presence of brown olivine affects the remote sensing data such as lowering of albedo, in particular disappearance of 1 μm absorption which is characteristic for olivine, and changing of magnetic susceptibility (Pieters et al. 2008). Therefore, revealing their origins and formation conditions are essential to correctly interpret the remote sensing data and could be applied for describing shock events on Mars.

Brown olivine in the NWA 2737 chassignite has been well-investigated for a decade because NWA 2737 is distinct form the other chassignites. The studies of brown olivine in NWA 2737 revealed that the presence of iron metal nanoparticles in olivine induces the brown coloration (+ lowering of albedo) and changing of the magnetic susceptibility (e.g., Treiman et al., 2007; Van de Moortèle et al., 2007a). The formation conditions and processes of such iron nanoparticles have been considered based on NWA 2737 and their conditions are adopted to an indicator for shock stage classification (Fritz et al., 2017). On the other hand, brown olivine is present in shergottites as well. The formation conditions of brown olivine in shergottites could be different from those in

NWA 2737 because the shock history of NWA 2737 is complex due to multiple shock events (e.g. Treiman et al. 2007; Bogard and Garrison, 2008). Formation conditions of brown olivine based on the complex shock history in NWA 2737 are not suitable for a shock indicator for all meteorites and they should be better revealed based on shergottites instead of NWA 2737 chassignite.

In this study, I observed 13 shergottites, 1 chassignite, 1 lunar meteorite and 1 L chondrite. According to the observations of these meteorites, brown olivine in shergottites is heterogeneously darkened and darkened areas certainly contain iron metal nanoparticles. In TEM observation, the iron nanoparticles are present within domain-like areas of olivine and no SiO-rich phases are observed around iron metal. Fe-XANES analysis reveals that brown olivine contains non-negligible Fe^{3+} compared with colorless olivine, indicating that iron nanoparticles are formed by a disproportionation reaction. Brown olivine is composed of bundle of lamellae and often accompanied by thin (<10 μm) melt veins indicating local temperature increase (1480-1600 ^{o}C) and formation of lamellae during darkening. Brown olivine shows additional double Raman peaks around 640-690 cm^{-1}, which is characteristic for brown olivine. In some shergottites, olivine around shock melt veins/pockets is partly darkened and shows similar features to those of brown olivine. These observations support that brown olivine is formed under conditions similar to those around shock melt veins/pockets, and suggest the relationships between olivine darkening and transformation of olivine to its high-pressure phases. However, no iron nanoparticles are generally observed in high-pressure minerals such as ringwoodite and no high-pressure phases are survived in meteorites with brown olivine. Therefore, back-transformation of olivine is another essential factor for the formation of iron nano-particles in a shock event.

In this study, shock recovery experiments are also performed in order to reveal shock pressures of shergottites and conditions for olivine darkening. According to the experiments, planar deformation features (PDFs) of olivine are formed over 37 GPa in shock pressure and its fine-texture will be a good indicator for estimating shock pressure (bands of dislocation for 37-49 GPa; amorphization for 50-60 GPa). Based on the shock experiments and observations of Martian meteorites, the shock pressure of shergottites with brown olivine and those without brown olivine is in the range of 50-60 and 37-49 GPa, respectively. The shock duration of shergottites with brown olivine is constrained by the formation of a thin melt vein within brown olivine and calculated as <40 ms, which is not so different from those of shergottites without brown olivine. The most different point in the shock histories between shergottites with/without brown olivine is post shock heating. Components of shock melt veins (vesicles, quench crystals, etc.) and absence of high-pressure phases in shergottites with brown olivine indicate that they have high post shock temperature (>900 ^{o}C) while the post shock temperature is low (<600 ^{o}C) in shergottites without brown olivine. Therefore, the presence of brown olivine could be an indicator for the meteorites which experienced transformation of olivine and back-transformation of the high-pressure phase due to high-pressure (50-60 GPa) and high post shock temperature (>900 ^{o}C).

Comparison of the shock events on Mars with those of L chondrites reveals that the shock event on Mars is induced by small projectiles because the shock durations are significantly short in Martian meteorites (10-40 ms for Martian meteorites, ~4 sec for L chondrites estimated by Ohtani et al., 2004) while the shock pressures are not different in the order of magnitude (37-60 GPa for Martian meteorites and 18-23 GPa for L chondrite). In spite of higher shock pressure of Martian meteorites, they contain less amounts of high-pressure minerals compared with L chondrite, which indicates that the presence of high-pressure minerals is not an appropriate shock indicator as pointed out by Fritz et al. (2017). When I assume the shock histories of Martian meteorite as described above, the combination of the shock history and a numerical model for rock ejection from Mars suggests that Martian meteorites are derived from relatively small craters (2-8 km in diameters) as suggested by Tornabene et al. (2006)