Shock conditions for shergottites: A comparison between Asuka 12325 and other shergottites

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Most Martian meteorites, in particular shergottites, show severe shock metamorphism, such as shock melting, complete maskelynitization of plagioclase, transformation to high-pressure phases and its back-transformation. Recently, weakly shocked shergottites (Northwest Africa (NWA) 8159 and NWA 10416) whose plagioclase is still crystalline were reported (Sharp et al. 2019; Walton et al. 2016) and we also found that Asuka 12325 (A 12325) retained birefringent plagioclase (Takenouchi et al. 2019, 2020). Such weakly shocked shergottites are rare and may have recorded specific shock conditions when shergottites were ejected from Mars. For example, NWA 8159 experienced longer shock duration (~100 ms) compared with Tissint or Zagami (Sharp et al. 2019). Revealing such differences in shock conditions between severely and weakly shocked shergottites is important to constrain shock conditions for shergottites' ejection. Therefore, in this study, we compare shock metamorphism of A 12325 with that of other shergottites and discuss the shock conditions of shergottites.
A 12325 is a poikilitic shergottite with "depleted" rare earth element pattern and general descriptions are found in Debaille et al. (2019) and Takenouchi et al. (2019). Poikilitic shergottites, in particular "intermediate" ones, commonly contain maskelynite and their shock pressures were estimated ~55 GPa (e.g., Takenouchi et al. 2018), while their shock durations are poorly constrained yet. In contrast to such poikilitic shergottites, almost of all plagioclase in A 12325 are only partly isotropic indicating its shock pressure below 26-31 GPa (Takenouchi et al. 2019), which is slightly weaker than that of Tissint (Walton et al. 2014). A shock vein in A 12325 is occupied mainly by ringwoodite (<1 μm in size) and chemically zoned majorite (~3 μm in size), which is different from shock melt veins in "intermediate" poikilitic shergottites containing abundant voids and quenched low-pressure minerals. Even in the center of the thickest vein (220 μm in width), majorite and ringwoodite are present. Ringwoodite also occurs at the rim of the host olivine adjacent to the shock melt vein. The ringwoodite rim around a 110 μm-thick shock vein is composed of a 20 μm-thick homogeneous (microcrystalline) region and a ~15 μm-thick lamella-rich region.
If we assume cooling by 1-dimensional thermal conduction (Carlsow and Jaeger 1959) with an initial temperature gradient from 2573 K to 2023 K within the vein and from 2023 K to 273 K in surrounding areas, we can reproduce the ringwoodite formation around the 110 μm-thick shock vein by calculating its growth rate (Ohtani et al. 2004), although differences such as Fe contents in ringwoodite were not taken into consideration. Then, when we calculated the cooling of the 220 μm-thick shock vein in the same way, we obtained that the cooling of the vein center from 2573 K to 2200 K and to 2000 K took 9.2 ms and 21 ms, respectively. In order to form ringwoodite at the center of the thickest shock vein, high-pressure about 13-16 GPa must have been retained when the vein temperature reached its solidus temperature. Therefore, if we adopt 2000-2200 K for solidus temperature at 13-16 GPa (Agee et al. 1995), the shock duration may be longer than at least >9.1-21 ms. The shock duration of 9-21 ms is almost the same or a little longer compared with those of Tissint and Zagami, but shorter than that of NWA 8159. This result indicates that shergottites with similar shock pressure tend to experience similar shock duration regardless of its primary igneous texture, and possibly, shock pressure and duration may be correlated among rocks that have escaped from Mars. If this is the case, "intermediate" shergottites may have experienced the shortest shock duration owing to its highest shock pressure. In addition to their high post-shock temperature, such short shock duration may contribute to the absence of high-pressure

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minerals in those severely shocked shergottites.

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