A newly found unique shergottite Asuka 12325: comparison in petrology and shock metamorphism with other poikilitic shergottites

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Introduction: Martian meteorites are key samples to elucidate the Martian volcanic activity because they are the only Martian rock we can directly analyze on the Earth. However, we cannot conclude which craters Martian meteorites were originated from, which resulted in a weak connection between Mars (the Martian surface) and Martian meteorites. Shock metamorphism recorded on Martian meteorites provides us shock parameters such as pressure, temperature and durations. Using such parameters, we can estimate the conditions of collisional events and then constrain source craters of Martian meteorites. Therefore, to investigate shock metamorphism on Martian meteorites and to reveal above shock parameters are important to link Martian meteorites to Mars.

In this study, we reported petrological observation results of a newly found Martian meteorite based on its igneous and shock textures, and compared them with the other Martian meteorites to widen insights into both igneous and collisional events on Mars.

Sample: In this study, we observed Asuka 12325 (hereafter A 12325), which was recovered in 2012 by Belgium-Japan joint expedition in the Nansen Ice field in the south of the Sør Rondane Mountains. Its original total weight is ~28 g. While its petrological and geochemical data were preliminary reported by [1,2], respectively, we conducted further petrological observation and discussed its petrogenesis and collisional event.

A 12325 is the first poikilitic shergottite showing depleted rare earth element (REE) patterns [1,2]. Its modal composition is as follows: olivine (57.1 vol.%), pyroxene (28.1 vol.%), feldspar (10.7 vol.%) and accessory minerals (phosphate, chromite and ulvöspinel). Chemical composition of rock-forming minerals are olivine phenocrysts (Fo61-69), olivine in non-poikilitic areas (Fo50-60), pyroxene oikocrysts (En39Wo41-En36Wo32) and feldspar (An29Or1-An26Or3). Note that the compositional variation of feldspar becomes narrower than that reported in [1]. This is because we rejected the most Ca-rich data which was affected by adjacent Ca-rich pyroxene during measurement resulting in small enrichment of Mg and Fe within a stoichiometry. Preliminary reported Sm-Nd and Lu-Hf crystallization age were 390 and 270 Ma, respectively, and initial ε143Nd and ε176Hf values indicated A 12325 was derived from completely different sources from the other Martian meteorites [2].

Method: We studied a polished thin section of A12325 (51-1) loaned from NIPR. Observation of the thin section was performed by optical microscopy and field emission scanning microscopy (FE-SEM; JEOL JSM-7100F) at NIPR. For phase identification and crystal orientation investigation, we used electron backscattered diffraction (EBSD) analyzed by A Ztec EBSD system (Oxford Instruments). Moreover, micro-Raman spectroscopy (JASCO NRS-1000) was also adopted for phase identification using 532.12 nm green laser and laser power of 2.5 mW.

Results: As we previously reported in [1], A 12325 showed a poikilitic texture with relatively small pyroxene oikocrysts compared with the other poikilitic shergottites. Pyroxene oikocrysts in A 12325 exhibited Mg-

![BSE+Orientation image](image)

Fig. 1 BSE image with EBSD orientation map and EDS chemical map of the same region. In EDS map, Mg, Ca and Fe are represented by red, green and blue, respectively. Pyroxene oikocryst single crystal is indicated by red and black lines. There are Ca-poor rims around Ca-rich area in the oikocryst. Some feldspar converted to maskelynite showing no EBSD solution (black area at the center bottom of upper image).
rich core (orthopyroxene) and Ca-rich rim (augite) similar to other poikilitic shergottite formed from evolved magma. However, the rims of pyroxene oikocryst in A 12325 became Ca-poor again (pigeonite) at the end of the rim, which was not reported in the other shergottites. According to our EBSD analysis, the Ca-poor rim, Ca-poor core and Ca-rich belt between them certainly composed a single crystal (Fig. 1).

Regarding shock textures, parts of feldspars transformed to maskelynite regardless of a distance from shock melts and there was no compositional differences between feldspar and maskelynite. In shock melt veins, we found high-pressure phases of phosphate (tuite) and feldspar (lingunite+jadeite similar to that in [3]) (Fig. 2) in addition to previously reported ringwoodite and majorites. Some high-pressure phase of feldspar shows EBSD patterns well-fitted by jadeite, their Raman peaks were similar to that of tissintite (Fig. 2). Some majorite grains (~3 µm) shows oscillatory zonings.

**Discussion:** The Ca-poor rims around Ca-rich areas in pyroxene oikocrysts were not reported so far. However, there is a possibility that this feature is a common feature in poikilitic shergottite. This is because slightly iron enrichment in the Ca-poor rim compared with the core [1] is similar trend to that of pyroxene in non-poikilitic area in other shergottites indicating that the Ca-poor rim could form by overgrowth from intercumulus melt. Alternatively, it is also possible that the Ca-poor rim is a unique feature of A 12325 since this meteorite has rapider accumulation/cooling rates [1], lower Ca contents and unique REE/isotopic compositions [2]. In either case, we need reanalysis of other shergottites focusing on pyroxene oikocrysts.

Recently, several studies certificated that feldspar transformed to maskelynite by weak shock pressures with high temperature around shock veins [4, 5]. In contrast, since the shock temperature far from shock veins could be negligible, the coexistence of crystalline feldspar and maskelynite throughout A 12325 indicated that shock pressure partly exceeded the pressure for maskelynitization due to local pressure increase such as shock wave refraction. Therefore, the initial peak shock pressure of A12325 may be around 26-31 GPa and decreased to 16-22 GPa during formation of high-pressure minerals in the shock melt veins [1]. In spite of similar Fe-rich composition of olivine and pyroxene in A 12325 to those of LEW 88516 (intermediate) and RBT 04261 (enriched), smaller pyroxene oikocryst in A 12325 may indicate crystallization at shallower part or within a smaller igneous body compared with the other poikilitic shergottites. Furthermore, shallower part origin and the weakest shock metamorphism in depleted poikilitic shergottite compared with the other poikilitic shergottites may indicate a small scale impact event or its distant origin from an impact point. In contrast, the deeper origin and stronger shock metamorphism in “intermediate” poikilitic shergottites [e.g. 6] may indicate that their ejection event was larger scale compared with those of depleted (A12325) and enriched (RBT 04261) poikilitic shergottites. Revealing shock conditions including initial depths and shock durations will help to describe Martian rock ejection events and constrain their source craters.


![Fig. 2](a) BSE image inside a shock vein (b) EBSD patterns obtained at a blue point in (a). (c) Raman spectra obtained from red points in (a) and other point (not shown). Maj: majorite, Rgt: ringwoodite, Jd: jadeite, Tis: tissintite and Lg: lingunite.

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