Crystallization of poikilitic shergottites as deduced from textural and mineral compositional diversities of seven samples.

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Introduction: Shergottites are young (mostly 160-570 Ma crystallization ages) igneous rocks of Martian magma, which comprise nearly 90% of Martian meteorites [e.g., 1]. Shergottites are generally classified into three subgroups based on their petrological characteristics: basaltic (diabasic), olivine-phyric and poikilitic, reflecting distinct crystallization processes of Martian magma. It is also known that shergottites originated from three distinct mantle reservoirs regardless of petrological grouping [e.g., 1-4]. Among three shergottite petrological groups, poikilitic shergottites are characterized by remarkable textures that well reflect their crystallization conditions. Poikilitic shergottites consist of a poikilitic region where pyroxene oikocrysts (usually reaching several mm in size) surround olivine chadacrysts and an interstitial non-poikilitic region where olivine, pyroxene and maskelynite (shock transformed plagioclase glass) are present. The poikilitic texture is considered to have formed in a magma reservoir at depth, while the non-poikilitic texture was formed by rapid cooling near the surface when oikocryst-bearing magma was transported to a shallower region [e.g., 3]. The recent discovery of many samples of poikilitic shergottites mostly from African deserts has revealed that there are significant petrological and compositional variations within this group. However, the factors to cause these differences as well as their final crystallization process near the surface are not well discussed. Therefore, in this study, we analyzed seven poikilitic shergottites, especially newly found samples, to compare their textures and mineral compositions. Using such data, we examine the magmatic crystallization process of poikilitic shergottites, especially crystallization of non-poikilitic regions, by applying crystal size distribution (CSD) analysis of non-poikilitic olivine crystals. We also calculated a heat transfer in the igneous body where oikocryst-bearing magma of poikilitic shergottites intruded near the Martian surface to estimate the size of the body and to discuss Martian crustal structures near the surface in general.

Samples and methods: We studied thin sections of NWA 14127, ALH 77005, NWA 4468, NWA 13366, NWA 13369, NWA 12241 and NWA 13227. Among them, NWA 14127, NWA 13227 and NWA 4468 are enriched samples and ALH 77005, NWA 12241, NWA13366 and NWA13369 are intermediate samples in terms of geochemical characteristics. Elemental maps were obtained using a JEOL JXA-8900 electron probe microanalyzer (EPMA) at the University of Tokyo (15 kV acceleration voltage and 80 nA beam current). The elemental maps were then used for quantitative analysis to decide the analysis points of olivine, pyroxene, maskelynite and spinel minerals in both poikilitic and non-poikilitic regions. For olivine, pyroxene and spinel, the quantitative analysis was set up at acceleration voltage of 15 kV and beam current of 12 nA and for maskelynite, acceleration voltage of 15 kV and beam current of 6 nA (beam diameter: 5 μm). To estimate the solidification time of the intrusive magma, CSD analysis was performed on olivine crystals in non-poikilitic region. We used ImageJ to measure the crystal size and number of olivine crystals. Here, the crystal growth rate of olivine was assumed to be ~$3.1\mathrm{x}10^{-8}$ mm/s [5].

Results: The seven poikilitic shergottites studied show variation in the abundance of poikilitic and non-poikilitic areas. The abundance of poikilitic regions is relatively higher for ALH 77005 and NWA 12241 at ~50 %, whereas the abundance of poikilitic regions for NWA13227 and NWA14127 are lower at only ~30%. It is also clear that there is a large textural variation in the proportion of maskelynite in non-poikilitic regions, with NWA 13227 and NWA 14127 accounting for ~40 %, whereas ALH 77005 and NWA 12241 accounting for ~10 %. The mineral compositions of the pyroxene oikocrysts of seven poikilitic shergottites do not show significant differences for the analyzed samples. The core is about $\mathrm{En}_{69\pm8}\mathrm{Wo}_{12\pm7}$ and the rim is about $\mathrm{En}_{51\pm5}\mathrm{Wo}_{35\pm5}$. As for mineral composition of olivine, NWA 13227 and NWA 14127 have larger compositional ranges ($\mathrm{Fo}_{71\text{-}39}$) than those of other samples ($\mathrm{Fo}_{82\text{-}58}$), suggesting that they may have been formed under the condition of faster cooling of magma. Regarding the maskelynite composition, NWA 13227, NWA 14127 and NWA 4468 have relatively large compositional ranges of $\mathrm{An}_{65\text{-}35}\mathrm{Or}_{0\text{-}10}$, suggesting faster cooling rate, whereas ALH 77005 and NWA 12241 have a narrower compositional range of $\mathrm{An}_{65\text{-}45}\mathrm{Or}_{1\text{-}3}$ that may have been formed at slow cooling rates. The CSD analysis result shows that the solidification time of seven poikilitic shergottites range from *ca*. 40 to 130 days. There is a negative correlation between the solidification time of the magma and the modal abundance of maskelynite in the non-poikilitic regions (Fig. 1). Because plagioclase crystallized after olivine and pyroxene, this may reflect the accumulation degree of olivine and pyroxene.

Discussion and Conclusion: Mineralogy of seven poikilitic shergottites has revealed that there is more variation in petrological texture and mineral compositions in this group than previously known [e.g., 4, 6]. Especially, the number of poikilitic shergottites with lesser amounts of poikilitic regions (such as NWA 14127 or NWA 13227) has increased. We consider that the degree of crystal accumulation (pyroxene oikocryst and olivine) is an important factor that causes differences in petrological textures. In addition, a cooling rate of magma is related to the degree of crystal accumulation and makes differences in mineral compositions. Considering the differences in cooling rates and degrees of crystal accumulation, a model to consider a temperature gradient upon an intrusion of magma into a country rock was provided to assume the final crystallization of non-poikilitic areas of poikilitic shergottites near the Martian surface (Fig. 1). Assuming that such country rocks were universally present on Mars, samples with small degrees of accumulation and short solidification time, such as NWA13227 and NWA14127, would have been formed by rapid cooling of intrusive magma near the country rock. On the other hand, samples with a larger abundance of cumulus phases and a longer time of solidification, such as ALH 77005 and NWA 12241, are considered that they were formed under slower cooling condition near the center of the intrusive magma. The other samples formed at the intermediate regions of the intrusive body. To constrain the intrusive body size of poikilitic shergottites, we estimate the thermal evolution of the intruding magma from the thermal diffusion equation. Under the condition that thermal diffusion coefficient of both intrusive magma and country rock is 10^{-6} m^2/s, initial country rock temperature is 0 °C, initial intrusive magma temperature is 1200 °C and solidification temperature of the intrusive magma is 1000 °C, we calculated that the size of intrusion where the center area was solidified in ~127 days (ALH 77005 solidification time) was ~13 m (Fig. 2) [7]. Because we studied both enriched and intermediate poikilitic shergottites and obtained similar results for both geochemical groups, it is suggested that ~13 m size of intrusive bodies of poikilitic textures are universally present near the surface of Mars, regardless of the source magma from different mantle sources.

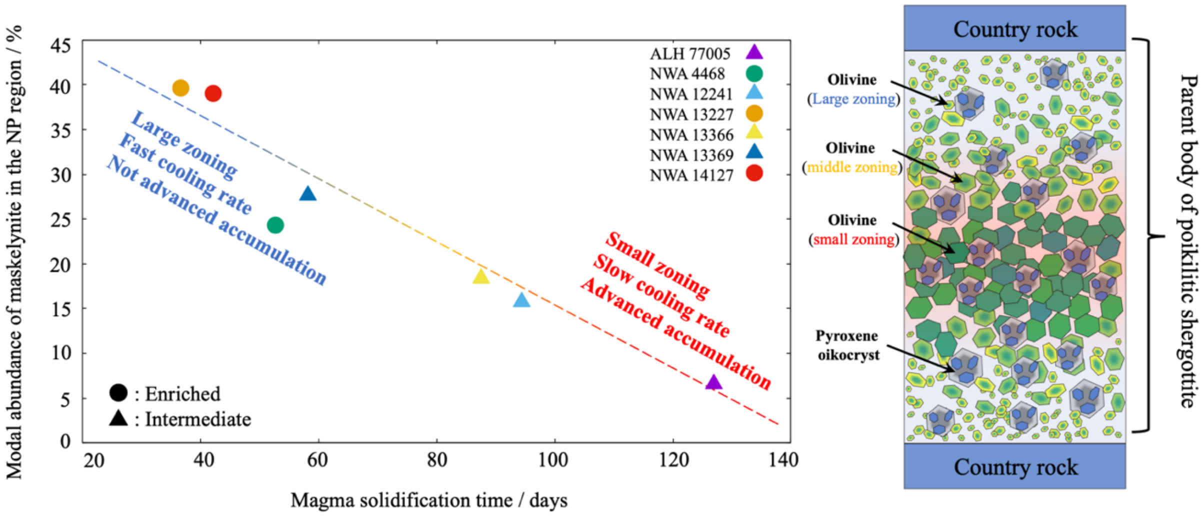

Fig. 1. Left. CSD analysis results showing a relationship between accumulation and crystallization time. Right. A schematic illustration showing a stratigraphy of an igneous body of poikilitic shergottites when they were solidified near the Martian surface to form non-poikilitic regions.

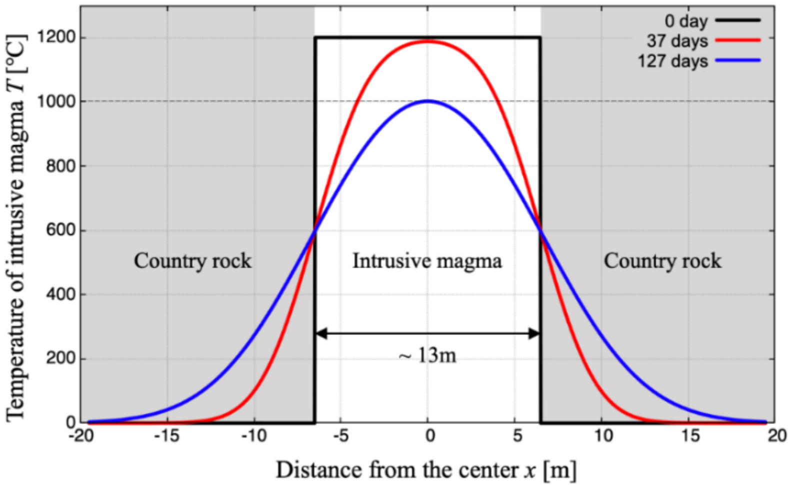

Fig. 2. Thermal evolution of intrusive magma assuming the formation of non-poikilitic regions of poikilitic shergottites. We assumed initial temperature of magma is 1200 ℃ and solidified at 1000 ℃. The obtained result shows that the size of this body is ~13 m in size.

References

[1] Udry A. et al. (2019) *Jour. Geophys. Res. Planets*, *125*, e2020JE006523. [2] Howarth G. H. et al. (2014) *Meteorit. Planet. Sci.*, *49*, 1812-1830. [3] Howarth G. H. et al. (2017) *Meteorit. Planet. Sci.*, *52*, 391-409. [4] Rahib R. R. et al. (2019) *Geochim. Cosmochim. Acta*, *266*, 463-496. [5] Sarbadhikari A. B. et al. (2009) *Geochim. Cosmochim. Acta*, 73, 2190-2214. [6] Mikouchi T. and Kurihara T. (2008) *Polar Sci.*, *2*, 175-194. [7] Philpotts R. A. & Ague J. J. (2009) *Principles of Igneous and Metamorphic Petrology*: Cambridge University Press.