# Origin of Martian meteorite Northeast Africa 053 with multiple lithologies

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1. Introduction
The Martian meteorite Northeast Africa (NEA) 053 (Fig. 1) is an unusual shergottite in which multiple lithologies with different grain sizes are juxtaposed with sharp contacts. Investigating the relationships between these lithologies and their petrogenesis provides insight into distinctive crystallization conditions in Martian magmas.
In this study, the two lithologies within a thin section were subdivided into Lithology A (coarse-grained) and Lithology B (fine-grained). We compared (i) mineral modal abundances, (ii) mineral chemistry, (iii) quantitative textural parameters derived from texture analyses, and (iv) equilibration temperature and oxygen fugacity estimates based on mineral compositions between Lithologies A and B, in order to evaluate the relationship and origin of the two lithologies.
2. Samples and methods
Overall textures were characterized using a polarizing microscope and back-scattered electron (BSE) images acquired by SEM. Element maps and quantitative analyses were obtained by EPMA. Texture analyses included calculation of mineral modes from element maps, estimation of crystallization environment and cooling history by crystal size distributions (CSD), and analysis of crystal spatial arrangements by spatial distribution patterns (SDP).
In addition, using pyroxene and Fe–Ti oxide compositions, we estimated (i) equilibrium temperatures during pyroxene-core crystallization, (ii) equilibrium temperatures during Fe–Ti oxide crystallization, and (iii) oxygen fugacity.
3. Results
3.1 Petrography and modal abundances of minerals
NEA 053 consists mainly of olivine, pyroxene, and maskelynite, with minor Fe–Ti oxides, spinel, and Ca-phosphates. In both lithologies, a small amount of poikilitic texture occurs in which pyroxene partially encloses olivine. Whole-section modal abundances are 12% olivine, 58% pyroxene, 26% maskelynite, and 4% for all other minerals combined. Pyroxene is the most abundant phase in both lithologies. Lithology A contains ~10% more olivine and ~10% less maskelynite than Lithology B.
3.2 Mineral chemistry
Olivine in Lithology A is more Mg-rich than that in Lithology B, indicating that Lithology A contains a larger proportion of more primitive olivine. In contrast, no large systematic differences were observed in the compositions of pyroxene and maskelynite between the lithologies. Pyroxene compositions show a trend closer to those of olivine-phyric shergottites than to previously reported pyroxene compositions in poikilitic shergottites.
3.3 Texture analyses
Cooling times estimated from CSD are nearly the same for olivine in Lithologies A and B, whereas pyroxene yields distinctly longer times in Lithology A than in Lithology B. In addition, the overall slopes of the CSD plots suggest accumulation of larger crystals in both lithologies, potentially due to processes such as crystal fractionation.
SDP results indicate that olivine is spatially heterogeneous and does not form a connected arrangement (touching framework). In contrast, pyroxene is more uniformly distributed and forms a touching framework.

 

3.4 Equilibrium temperatures and oxygen fugacity
Estimates using the QUILF program yield pyroxene-core crystallization temperatures of 1258–1283 ˚C for Lithology A and 1154–1208 ˚C for Lithology B, indicating slightly higher temperatures for Lithology A. Fe–Ti oxides yield 645 ˚C for Lithology A and 575–599 ˚C for Lithology B. Estimated oxygen fugacity is QFM +0.09 for Lithology A and QFM −0.36 to −1.52 for Lithology B. The Fe–Ti oxide temperatures are very low, suggesting possible effects of late-stage re-equilibration.
4. Relationship between the two lithologies and crystallization process
Mineral chemistry and texture analyses suggest that the two lithologies do not have fundamentally different origins, and are consistent with a scenario in which both formed through multi-stage crystallization with crystal fractionation in a single magma.
Olivine and spinel began crystallizing early, and minor poikilitic texture formed when pyroxene crystallization partially enclosed some olivine. Pyroxene then continued to grow and developed a touching framework, which likely constrained subsequent crystal segregation and growth. Finally, the remaining melt crystallized late, producing predominantly fine-grained crystals. This crystallization history may explain why NEA 053 shares characteristics with both poikilitic and olivine-phyric shergottites. The inferred crystallization sequence and model are summarized in Fig. 2.

Keywords: Martian meteorite, shergottite, crystallization process

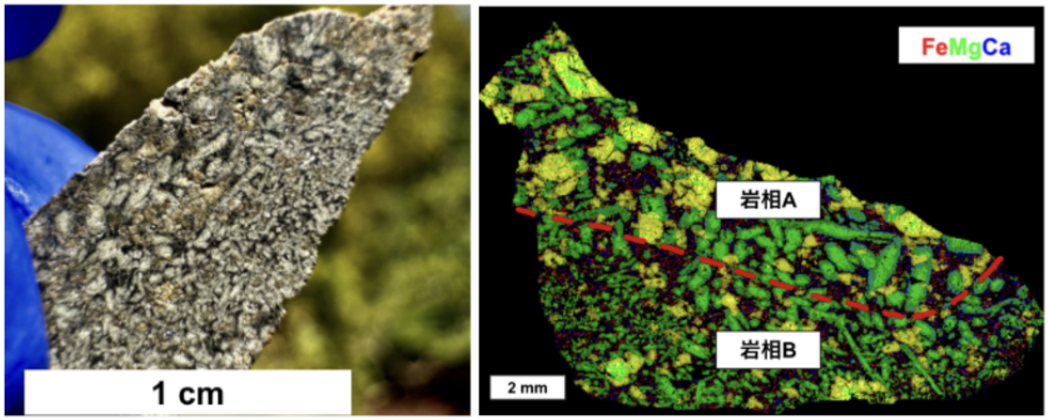


図1. 使用したNEA 053の試料の写真 (https://www.ebay.com より一部改変, 2026-01-01アクセス)
およびEPMAで取得したFeMgCa 元素マップ

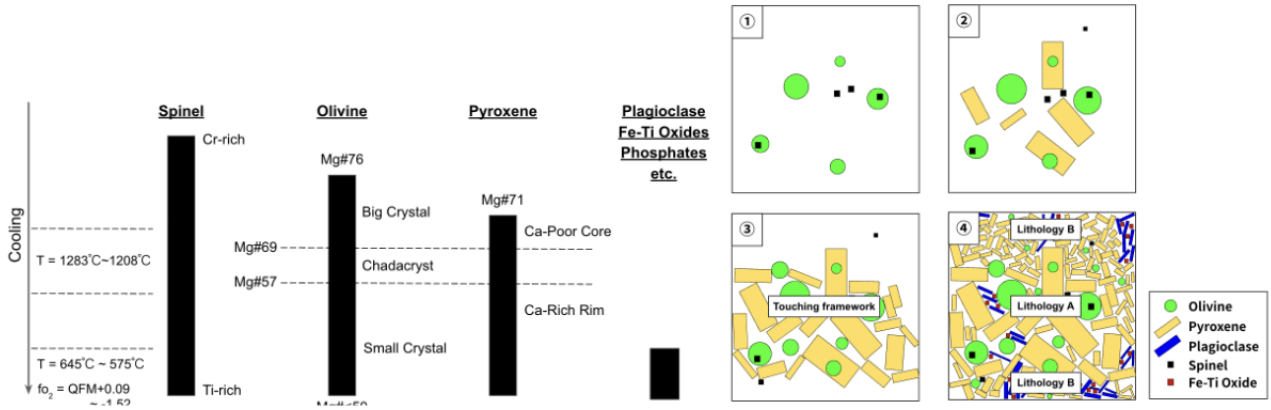


図2. NEA 053の推定された結晶化順序および結晶化モデル

 