# Petrology, mineralogy and geochemistry of olivine-phyric shergottites.

*Kei Kawai[1], Ryosuke Sakai[1], Ryoichi Nakada[2], Fumito Shiraishi[1], Mizuho Koike[1]

1. Hiroshima University, 2. Japan Agency for Marine-Earth Science and Technology

Olivine-phyric shergottites are characterized by olivine megacrysts and a fine-grained matrix, recording a sequence of igneous processes, including the evolution of Martian mantle-derived magmas and crystallization within magma chambers [1]. In this study, we conduct petrological, mineralogical, and geochemical analyses of an olivine-phyric shergottite, Amgala 001, to understand its crystallization sequence in the Martian interior and to discuss the magmatic activity. For comparison, other olivine-phyric shergottites, Northwest Africa (NWA) 1195, NWA 2626, and Tissint are also examined.
Polished mounts of Amgala 001 and three other samples were briefly observed using a scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS; JEOL JSM-6390A) at Hiroshima University (HU). Detailed mineralogy were observed using a field emission SEM-EDS combined with a focused ion beam (FIB) system (Thermo Fisher Scientific Helios G4 UC) and a transmission electron microscopy (TEM; JEOL JEM-F200) at the Natural Science Center for Basic Research and Development (N-BARD), HU. Major element compositions of individual minerals were analyzed using an electron probe microanalyzer (EPMA; JEOL JXA-iSP 100) at N-BARD, HU. Rare earth element (REE) abundances of whole-rock sample of Amgala 001 were determined by an inductively coupled plasma mass spectrometry (ICP-MS) at the Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Major element compositions of the same whole rock sample were determined using an inductively coupled plasma optical emission spectroscopy (ICP-OES) at HU.
The whole-rock analysis of Amgala 001 shows a flat REE pattern with the La/Yb ratio of 1.09, indicating the meteorite is classified as enriched shergottite. The SEM-EDS and EPMA analyses reveal that most olivine crystals in Amlaga 001 exhibit a well-developed positive zoning, with Mg-rich cores (average Mg# = 71) and Fe-rich rims (average Mg# = 51). The Mg# value of coexisting melt is calculated as 56, using an $Fe^{2+}$–Mg partition coefficient between olivine and the Martian magma [2]. This value is much lower than the analyzed whole-rock Mg content (Mg# = 56.4), indicating that the bulk compositions of Amgala 001 reflect the olivine accumulation.
Elemental mapping of an olivine grain in Amgala 001 reveals oscillatory phosphorus (P) band zoning toward the Fe-rich rim. The submicron-scale analyses using scanning transmission electron microscopy (STEM) and EDS demonstrate that the P-band zoning is not associated with mineral inclusions, but instead reflects chemical heterogeneities within olivine crystals. This P-band zoning is interpreted to record rapid crystal growth of olivine [3, 4].
Crystallization pressure of the pyroxene can be estimated based on their Ti and Al contents and an experimentally derived model by [5] as 0.93 GPa, corresponding to the lower crust of Mars. At this depth, cores of olivine megacrysts, pyroxene, and Fe-Ti-Al oxides crystallized in a magma chamber. Subsequently, plagioclase crystallized within the magma chamber or during the magma ascent. The occurrence of P-band zoning at the center of the olivine grain indicates that the glomerocrystic olivine accumulated within a second-stage magma chamber under shallower and lower-temperature conditions. These crystals were finally entrained during magma ascent and erupted onto the Martian surface.

References:

[1] Aucamp et al. (2023), Meteorit. Planet. Sci., 58, 1654–1676.
[2] Filiberto and Dasgupta (2011), Earth Planet. Sci. Lett., 304, 527–537.
[3] Mari et al. (2020), Meteorit. Planet. Sci., 55, 1057–1072.

[4] Eckley et al. (2024), Geochim. Cosmochim. Acta, 373, 197–210.
[5] Filiberto et al. (2010), Meteorit. Planet. Sci., 45, 1258–1270.

Keywords: Martian meteorites, olivine-phyric shergottites, Magmatic processes, Phosphorus zoning, Amgala 001

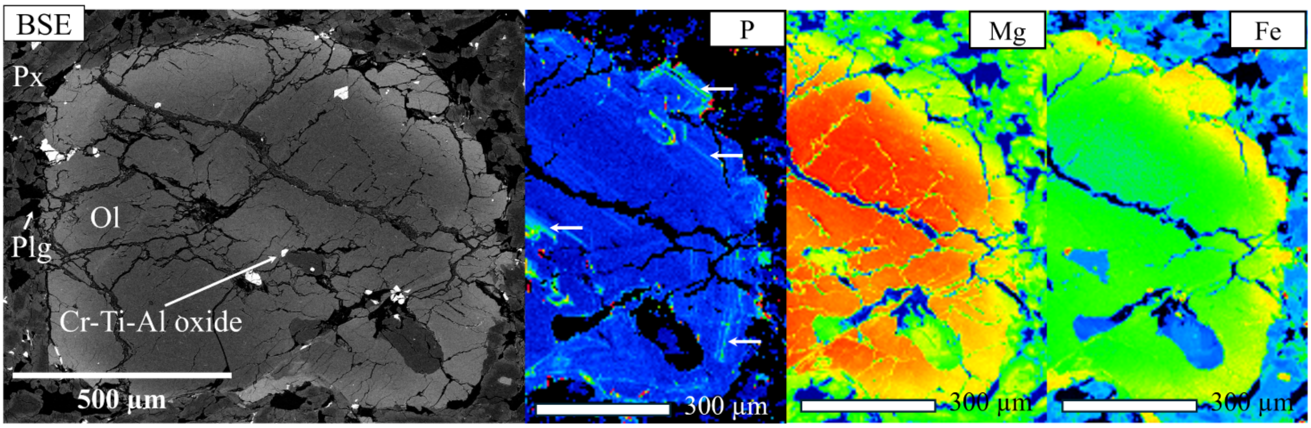

Figure 1. Large-sized olivine in Amgala 001: BSE image and Kα X-ray elemental heat maps. P Kα map after masking pixels with high Ca Kα intensities.