Mineralogy and isotopic age of KREEP-rich lunar meteorite NWA 4485

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Lunar volcanism occurs dominantly on the nearside of the Moon, especially in and around the Procellarum KREEP Terrane (PKT). Since erupted mare basalts largely resurfaced the PKT, the underlying and mostly predated KREEP-related magmatism are not well understood. Due to their small number and mass of the KREEP basalts, their petrogenesis are still matter of debate. Here, we conduct mineralogical, petrologic, and isotopic studies of KREEP-rich lunar meteorite NWA 4485 to provide further constraints on KREEP magmatism.

A polished thin section and a thick section of NWA 4485 were studied. Mineralogical analyses were performed with JEOL JXA8200 electron microprobe at National Institute of Polar Research (NIPR). U-Pb, and Pb-Pb isochron age dating of zircon and baddeleyite were conducted by the SHRIMP II at NIPR.

NWA 4485 is a polymict breccia, including mm-sized lithic clasts with variable texture and modal abundance, isolated mineral fragments, and glasses. Mineral fragments are pyroxene, olivine, plagioclase, ilmenite, chromite, merrilite, apatite, baddeleyite, zircon, k-feldspar, silica, Fe-metal, and FeS. Fragments of K-feldspar and silica intergrowth are widely distributed in the matrix. Despite the distinct textures and modal abundances, most of the lithic clasts have similar mineralogical compositions and constituent minerals. Among the clasts, intersertal clasts with coarse grain sizes (several hundred microns across) is the least affected by shock deformation. They consist of Na-rich plagioclase, Mg-rich pyroxene, ilmenite, K-feldspar, merrilite, apatite, zircon, baddelyite, and Si-rich glass. Symplectic intergrowth of K-feldspar, Si-rich glass and ilmenite is present in the mesostases. Pyroxenes in some clasts show chemical zonings from orthpyroxene cores to magnesian pigeonite, and further to magnesian augite, while those in the others are co-existing pigeonite and augite, without extensive zoning. Magnesian pigeonites predominate with augite as exsolution lamella of up to a few micron in thickness. Modal abundance of one clast with is a large grain of ilmenite (700 micron across): 38 vol% plagioclase, 32 vol% pyroxenes, 22 vol% ilmenite, 6 vol% phosphates, and others.

The initial crystallization of Mg-rich orthopyroxene, followed by pigeonite and augite found in the the intersertal clasts is typical of Apollo 15/17 KREEP basalts and Apollo 14 LKFM basalts. The presence of Na-rich plagioclase, phosphates, Zr-bearing minerals, K-feldspar, Si, K-rich glass also indicate a derivation from a KREEP-rich magma. Glass spherules rich in K_2O and P_2O_5 are in line with a KREEP-rich provenance of this meteorite. The large euhedral ilmenite grains with a few wt% MgO in the intersertal KREEP basalt clasts imply that ilmenites likely crystallize in an early stage, probably with plagioclase. The pyroxene exsolution lamellae of a few microns thick far exceeds those in typical Apollo mare basalts. The KREEP basalts may have been cooled in a hyperabyssal setting, and/or equilibrated, covered by hot ejecta blanket.

The Several distinct isochron ages were determined for both zircon and baddeleyite. The Pb-Pb age of zircons in the intersertal clasts is 4172 +/- 5 Ma. The averaged Pb-Pb age of the largest zircon fragments (100 x 150 micron) is 4224 +/- 17 Ma, while smaller zircon fragment yields an old age of 4.35 Ga. The Pb-Pb age for the fragments of baddeleyite (20 x 30 micron) is 3940 +/- 20 Ma. Some of these younger ages may have been modified by shock effect, but the results indicate that the KREEP basalt magmatism occurs prior to 3.9 Ga. These ages are compatible with those of the Apollo KREEP basalts and KREEP-related rocks. Assumed all the ages represent the timing of crystallization from a magma, the KREEP volcanism in the source region of NWA 4485 occurred for as long as 0.4 billion years.