CONSTRAINTS ON LUNAR KREEP MAGMATISM: A VARIETY OF KREEP BASALT DERIVATIVES IN LUNAR METEORITE NWA 4485. T. Arai[1,2], K. Misawa[2], T. Tomiyama[2], M. Yoshitake[2], and A.J. Irving[3]. The University Museum, [1]The University of Tokyo, Hongo, Tokyo 113-0033, Japan (tomoko@um.u-tokyo.ac.jp), [2]Antarctic Meteorite Research Center, National Institute of Polar Research, Kaga, Tokyo 173-8515, Japan, [3]University of Washington, Seattle, USA.

Introduction: Lunar volcanism occurs dominantly on the nearside of the Moon, especially in and around the Procellarum KREEP Terrane (PKT) [1]. The local enrichment of incompatible trace elements in the PKT is considered to be linked with a magma ocean differentiates, and also to be a major heat source for the long-lived lunar volcanism. Since erupted mare basalts largely cover the surface of the PKT, the underlying and mostly predated magmatic activities in the region are not well understood. Products of non-mare magmatism include KREEP basalts, high-Al basalts, very high-K basalts as well as Mg-rich and Alkali-rich rocks. Due to the smaller number and mass of these samples than those of mare basalts, their petrogenesis are still matter of debate. Here, we conduct mineralogical and petrological studies of KREEP-rich lunar meteorite NWA 4485 [2-4] to provide further constraints on KREEP magmatism.

Sample and method: A polished thin section and a thic section of NWA 4485 were studied. Mineralogical analyses were performed with JEOL JXA8200 electron microprobe at National Institute of Polar Research.

Results: NWA 4485 is a polymict breccia, including mm-sized lithic clasts with variable texture and modal abundance, isolated mineral fragments, and glasses. Fractures across the samples are filled with terrestrial calcite. Mineral fragments are pyroxene, olivine, plagioclase, ilmenite, chromite, merrilite, apatite, baddeleyite, zircon, k-feldspar, silica, Fe-metal, and FeS. Pyroxene fragments generally show a few micron to 5 micron thick exsolution lamellae (Fig. 1a). The breccia matrix consists of heterogeneous glass including degraded mineral fragments. Some matrix glasses are vesiculated. Fragments of K-feldspar and silica intergrowth are widely distributed in the matrix. Glass spherules of a few tens to 300 micron in diameter are present, but not abundant relative to those in typical regolith breccias. Besides some Al-rich glasses (22-24 wt% Al_2O_3), most of homogeneous glasses have similar composition to each other: 1.2-1.8 TiO_2, 10-12 wt % FeO, 15-16 wt% Al_2O_3, 47-50 wt%, SiO_2, 8-11 wt%, MgO, 0.5-0.7 wt% Na_2O, 0.2-0.4 wt% P_2O_5, 0.1-0.7 wt% K_2O. Divitrified glass clasts of ~1 cm across contain ilmenite, zircon, baddelyite, and phosphates with dominant plagioclase and pyroxene. Despite the distinct textures and modal abundances, most of the lithic clasts have similar mineralogical compositions and constituent minerals.

Intersertal clasts: Several clasts with coarse grain sizes (several hundred microns across) are present. Their modal abundances are variable among clasts because the clast size (mostly < 1mm across) is not large enough to represent the occurrence of the coarse-grained rock. They consist of plagioclase, 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 of some clasts. Plagioclase grains show extensive core-rim zoning ($An_{76-85}Ab_{14-26}Or_{1-2}$ in one clast and $An_{70-79}Ab_{18-23}Or_{2-12}$). 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 (Fig. 2). The Fe/(Fe+Mg)[=Fe#])value mostly ranges from 0.25 to 0.61, but rarely up to 0.75. Orthopyroxene cores include ~1.0 wt% Al_2O_3, while magnesian pigeonite and augite have 1.0−2.5 wt% Al_2O_3. Discrete orthopyroxene and augite grains occur, but are rare. Magnesian pigeonite predominate with augite as exsolution lamella of up to a few micron in thickness. Large grain of ilmenite (700 micron across) is found in one clast (Fig. 1b). Modal abundance of this clast is: 38 vol% plagioclase, 32 vol% pyroxenes, 22 vol% ilmenite, 6 vol% phosphates, and others. The ilmenite contains up to 2.5 wt% MgO.

Intergranular clast: A subrounded-shaped clast (Fi.g 1c) dominantly consists of fasicular grains (up to a few hundred micron across) of pyroxene (43 vol%) and plagioclase (53 vol%) with ilmenite (4 vol%), phosphates (0.6 vol%) and silica minerals. Some pyroxene grains overgrow on plagioclase grains. Chemical zonings are present both in plagioclase ($An_{81-93}Ab_{6-16}Or_{1-3}$) and pyroxene (Fe#=0.39-0.61).

Granulitic clasts: They generally consist of subrounded pigeonite and augite up to several tens micron, enclosed in plagioclase with trace ilmenite, K-feldspar and Si-rich glass. The pyroxene Fe# values are 0.33-0.47. The plagioclase shows clast to clast compositional variations ($An_{82-86}Ab_{13-16}Or_{1-2}$, $An_{90-95}Ab_{0-10}$). Modal abundance of plagioclase is 50-70 vol%. Pigeonite cores are overgrown by augite rim. The both pyroxenes exhibit exolution lamellae of sub-micron scale. Some clasts consist of olivine (Fo_{79-80}) without pyroxene.

Feldspathic breccia clast: This clast is texturally and modally heterogeneous within a 1×1.5 cm sized clast (Fig. 1d). It is probably a recrystallized clast-laden impact melt breccia. The size of the plagioclase range from <100 micron to 1 cmm across. The modal abundance is 69 vol% plagioclase, 19 vol% pigeonite, 10 vol% augite, 1 vol% ilmenite with K-feldspar, chromite, baddelyite, and phosphates. The plagioclase shows a grain-to-grain compositional variation ($An_{75-95}Ab_{5-11}Or_{0-14}$). Pigeonite and augite occur both as discrete grains and core-rim relations (Fig. 2). The both display exolution lamellae of sub-micron to a few micron thick. Ilmenite grains including 2.7-3.7 wt % MgO of a few hundred micron across crystallize with large plagioclase grains.

Discussions:

The clasts presented above all have common constituent minerals and mineralogical composition. They consist of Na-rich plagioclase and moderately Mg-rich pyroxene. 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 [5, 6] and Apollo 14 LKFM basalts [7], The compositions of orthopyroxene and pigeonite in NWA 4485 are slightly Fe-rich than the those of Apollo KREEP basalts. The presence of 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.

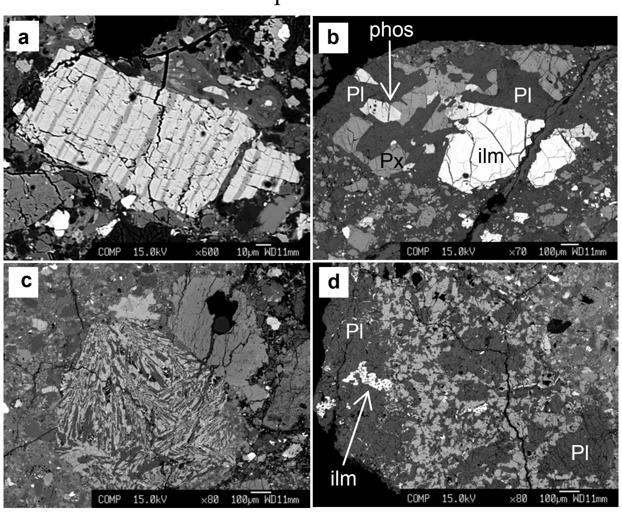

Fig. 1. Back-scattered electron images. (a) Pyroxene fragment with coarse exsolution lamellae: augite lamellae in host pigeonite, (b) Intersertal KREEP basalt clast, (c) Intergranular clast, and (d) Feldspathic breccia clast. Pl: plagioclase, Px: pyroxene, ilm: ilmenite, and phos: phosphate.

The early crystallization of orthopyroxene unlike the case of mare basalts can be explained by a unique crystallization sequence. As observed in the Apollo KREEP basalts, plagioclase is a liquidus phase and thus the melt which become depleted in Ca subsequently crystallize Ca-poor orthopyroxene [5-7]. 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 absence of Fe enrichment in the pyroxene zoning may be resulted from the early precipitation of ilmenite.

The pyroxene exsolution lamellae of a few micron thick far exceeds those in typical Apollo mare basalts [8]. The presence of such thick exsolution lamellae indicate that the KREEP basalt clasts are cooled more slowly than typical mare basalts, but hardly plutonic, because of the preserved chemical zoning. The KREEP basalts may have been cooled in a hyperabyssal setting, and/or equilibrated, covered by hot ejecta blanket.

Y983885 includes a moderately equilibrated intersertal KREEP basalt clast, which is remarkably similar in the clast of Fig. 1b [11]. However, a pairing with Y983885 is less likely because of the lower bulk-Th content (2.37 ppm) [12].

Remote sensing studies reveal that some of the KREEP basalts formed after the mare basalt eruption [9, 10]. Isotopic age dating of the KREEP basalt clasts will constrain the timing of the KREEP magmatic activity.

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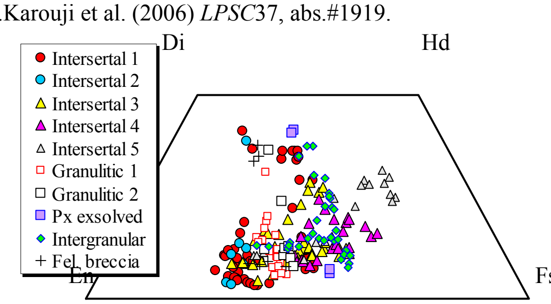

Fig. 2. Pyroxene compositions of lithic clasts.