COMPARISONS OF MINERALOGY OF LUNAR METEORITES POSSIBLY FROM THE FARSIDE AND THE KAGUYA REMOTE SENSING DATA TO RECONSTRUCT THE EARIEST ANORTHOSITIC CRUST OF THE MOON. H. Takeda[1], H. Nagaoka[2], M. Ohtake[3], S. Kobayashi[4], A. Yamaguchi[5], T. Morota[6], Y. Karouji[3], J. Haruyma[3], M. Katou[3], T. Hiroi[7], L. E. Nyquist[8], [1]Dept. Earth & Planet. Sci., Univ. of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, and Chiba Inst. of Technology, Narashino, Chiba 275-0016, Japan (takeda.hiroshi@it-chiba.ac.jp), [2]Res. Inst. for Sci. and Engin., Waseda Univ., Shinjuku, Tokyo 169-8555, Japan. [3]JAXA Inst. of Space and Astron. Sci., Sagamihara, Kanagawa 229-8510, Japan, [4]National Inst. of Radiological Sci., Inage-ku, Chiba 263-8555, Japan, [5]National Inst. of Polar Res. (NIPR), Tachikawa, Tokyo 190-8518, Japan, [6]Graduate School of Environmental Studies, Nagoya Univ., Rigakukan 203-1, Furocho, Chigusa-ku, Nagoya city, Aichi 464-8601, Japan, [7]Dept. Geol. Sci., Brown Univ., Providence, RI 02912, USA, [8]KR111, NASA Johnson Space Center, Houston, TX 77058, USA.

Introduction: Ohtake et al. [1] observed by the Kaguya multiband imager and spectral profiler anorthosites composed of nearly pure anorthite (PAN) at numerous locations in the farside highlands. Based on the Th map made by the GRS group of the Kaguya mission, Kobayashi et al. [2] showed that the lowest Th region in the lunar farside occurs near the equatorial region and noted that the regions well correspond to the lunar highest region and the thickest crust region recently measured by Kaguya mission [3,4]. Such remote sensing data have been interpreted in terms of mineralogical studies of lunar meteorites of the Dhofar 489 group [5,6] (e.g., Dhofar 489, 908, and 307) and Yamato (Y-) 86032 [7], all possibly from the farside highlands. Although the presence of magnesian anorthosites in the Dhofar 489 group has been reported, we have not encountered large clast clearly identifiable as PAN.

In this study, we investigated mineralogy and textures of large clasts of nearly pure anorthosites recongnized in Dhofar 911 and the d2 clast in Dhofar 489 [8]. The d2 clast is the largest white anorthosite clast in Dhofar 489, but its mineralogy has not been investigated at that time. The low bulk FeO concentrations suggests that the d2 clast may be the pure anorthosite with very low abundance of mafic silicates. In conjunction with all data of the Dhofar 489 group including Dhofar 489, 908, 309 and 307, we propose a model of formation of the farside crust.

Samples and Methods: Samples Dhofar 911 and Dhofar 489 are proposed to be paired [5]. A chip of Dhofar 911 (0.41 g) from JAXA/ISAS was divided into two parts, one chip with a large white anorthositic clast for the PTS and the other small fragments for the reflectance spectroscopy. A part of the remainder of the d2 clast of Dhofar 489 was separated from the original mass from National Science Museum in Tokyo (NSMT) by Dr. Yoneda. The bulk chemical data of the d2 clast were analysed by Y. Karouji [6]. The polished thin section (PTS) of Dhofar 489, 2.7 × 4.4 mm^2 in size and PTS of Dhofar 911 prepared from the two Chips at NIPR were studied at Atmosphere and Ocean Res. Inst. (AORI), the Univ. of Tokyo and NIPR. Area analyses of plagioclase were performed with a JEOL 8900 EPMA at AORI. The reflectance spectra of the Dhofar 911 sample were measured at Brown Univ.

Results: Preliminary mineralogy of the d2 clast of Dhofar 489 has been reported by Nagaoka et al. [8]. The anorthosite clast in the PTS contains more than 99 vol. % of plagioclase. The petrological characteristic of the d2 clast is consistent with that of PAN (> 98 vol. %) found by the MI. A similar anorthositic clast was observed in the Dhofar 911 PTS, but the Mg/Fe ratios of the mafic silicates are not identical as given below.

Mineralogy of Dhofar 911. A large white anorthositic clast 2.4 × 1.8 mm in size is embedded in dark fine-grained crystalline matrix. Many much smaller plagioclase fragments are distributed in the matrix but their numbers are small. Angular fragments of orange-yellow olivine crystals up to 0.42×0.21mm are found only in the matrix. Although the textures are disturbed by networks of weathered products such as calcite produced at the hot desert in Oman, we can rcognize original crystalline texture with rounded boundaries and the albite twin texture within an ogriginal crystal of the anorthositic clast. The chemical composition of plagioclase is very uniform with An=96. One droplet-like round olivine crystal 0.067×0.040 mm is found at the marginal part of the anorthostitc clast. The Mg number(#)=Mg×100/(Mg+Fe) mol. % of this olivine is 82. This Mg number is little higher than that of the magnesian anorthosite in Dhofar 489 previously reported [6]. We looked for other mafic silicates by area analyses of the EPMA for a square with 200 micron edge with 20 micron intervals. Some mafic silicates were detected but mostly the diameter is so small that we could not obtain good analytical results.

Discussion: Comparison of two large anorthositic clasts in Dhofar 911 and the d2 clast in Dhofar 489 [8] revealed that the presence of nearly pure anorthosites, with very low concentrations of Th and FeO, as were expected from the remote sensing data on the farside of the Moon [6]. The Th map made by Kobayashi et al. [2] suggests that the pure anorthosite clasts might have been derived from the lowest Th regions (zone A and B) north of the equator of the farside.

The Mg numbers of such regions have been estimated from the meteorites, but a trial made by Ohtake et al.[9] on the basis of the Kaguya SP data is consistent with the higher values as we expected. However, the Mg numbers of olivines of the d2 clast obtained by Nagaoka et al. [8] is in the higher range of the FAN family. The Mg number of one olivine crystal in the anorthositic clast of Dhofar 911 is a little above the range of the magnesian anorthosite [6]. This range can be explained by the vertical variations of the mafic silicates within the thick crust of the anorthosite with the lowest Th region, the top layer being more magnesian than the bottom.

In order to deduce the origin of the low Th region and to propose a model of the crust formation, we have to take into account the presence of olivine-bearing anorthositic clasts found in Dhofar 489 group, especially Dhofar 307 and 309 [10]. Dhofar 307 PTS contains fine-grained magnesian granulitic clast (GR) similar to the ST clast in Dhofar 489 in mineral chemistry [6], and similar clasts with rapid growth features of the Dhofar 309, from an impact melt pool (IM clast). The range of the modal abundances in volume % of the minerals of these three clasts (ST, IM, GR) obtained from the mineral distribution map and mineral compositions are practically the same [10]. Based on the remote sensing data of Th [2], we assume magnesian anorthosites constitute major parts of the northern farside highland. Spinel troctolites are proposed to be present ca. 15 km beneath the magnesian anorthosite crust [6]. A large impact, which excavated a basin about 300 km in diameter, might have produced impact melts at the basin floor and crystallized IM-like clasts by rapid cooling. Granulites were produced by thermal metamorphism at the floor of a large basin or in deep ejecta. Smaller impacts within the basin produced breccias of these materials. Among a few large basins in the above lowest-Th region, the Dirichlet-Jackson (DJ) basin has many craters in the central region (e.g., Raimond, craters North of the highest point), where the Dhofar 307-type breccia might have been developed.

The lunar magma ocean (LMO) model initially proposed [11] is based on the FANs at all the highlands. Loper and Werner [12] proposed that lunar crustal asymmetries are the result of convective processes acting early in the Moon's history, during the LMO phase and after synchronous rotation was established. Buoyant anorthositic crystals were transported to the farside by a large-scale circulation, called "tilted convection". Crustal thickening near the equator resulted from the modification of tilted convection by the Coriolis force. The selective transport may have resulted in a nearside excess of incompatible elements, leading to the formation of the PKT.

Nyquist et al. [13] performed Sm-Nd and Ar-Ar studies of pristine ferroan anorthosites (FANs) of the returned Apollo samples and of Dhofar 908 and 489, and discussed implications for lunar crustal history. During the foregoing studies, we recognized that variations in pyroxene compositons of well known FANs such as 60025 and 67075 are larger than expected for pristine anorthosites from the LMO.

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Fig. 1. Photomicrograph of the anorhositic clast in Dhofar 911 lunar meteorite. Width: 3.3mm.