MINERALOGY OF DHOFAR 309, 489 AND YAMATO-86032 AND VARIETIES OF LITHOLOGIES OF THE LUNAR FARSIDE CRUST. H. Takeda[1], T. Arai[2], A. Yamaguchi[2], M. Otuki[3] and T. Ishii[3], [1]Dept. Earth & Planet. Sci., Univ. of Tokyo and Chiba Inst. of Technology (Hongo, Tokyo 113-0033, Japan and takeda.hiroshi@it-chiba.ac.jp), [2]National Inst. of Polar Res.(1-9-10 Kaga, Itabashi, Tokyo 173-8515 Japan, tomoko@nipr.ac.jp), [3]Ocean. Res. Inst., Univ. of Tokyo (1-15-1 Minamidai, Nakano, Tokyo 164-8639, Japan, ishii@ori.u-tokyo.ac.jp).

Introduction: Magmatic evolution of the Moon [1] has been constructed by numerous researchers on the basis of nonrandom sampling of rock types. Now we have information from the farside crust. Dhofar 489 is a crystalline matrix anorthositic breccia including clasts of magnesian anorthosites and a spinel troctolite and is the most depleted in Th, FeO, and REE [2]. Remote sensing data suggest that the estimated concentrations of Th and FeO are consistent with the presence of such samples on the farside of the Moon. Korotev et al. [3] reported likely 15 stones from Dhofar with unique chemical compositions in the pair group [4], but mineralogy and petrology of such magnesian anorthosites have not been well documented. We have performed mineralogical and petrological studies of Dhofar 309 [5], a paired sample of the Dhofar 489 group to find a clast of the magnesian anorthosites.

^{39}Ar- ^{40}Ar, Rb-Sr, Sm-Nd, and Sm-isotopic studies by Nyquist et al. [6] characterized the chronology of Yamato (Y)-86032 and its precursors in the megaregolith. Low concentration of Th and Fe in the Y-86032 bulk meteorite supported earlier suggestions that Y-86032 comes probably from the lunar farside. We compared the clast-types of Y-86032, Dhofar 489 and 309, to discuss varieties of lithologies of the farside crust of the Moon, and to propose two models to give explanations for dichotomy of the Lunar Magma Ocean (LMO).

Samples and Methods: One polished thin section 11.5 × 6.5 mm in size of Dhofar 309 has been prepared from a slice 1.3 × 1.3 cm in size and was employed for mineralogical and petrographic studies. Elemental distribution maps of Si, Mg, Fe, Al, Ca, Ti and Cr were obtained by electron probe microanalysis (EPMA) at the Ocean Res. Inst. (ORI) of Univ. of Toyo and National Inst. of Polar Res. (NIPR).

Results: The Dhofar 309 sample was selected among 15 paired samples of the Dhofar 489 group, because Dhofar 309 is different in texture and mineral chemistry from the others found nearby.

Mineralogy and petrography of Dhofar 309. The first description of Dhofar 309 mentioned that the clast population is dominated by granulitic clasts of mainly anorthositic and troctolitic composition, and that fragments of possible pristine rocks and single mineral fragments are less common. We recognized two major clasts are embedded in a matrix of devitrified glass. One common clast type is a reddish orange colored angular fragment of crystalline rock with angular fragments of plagioclase. The lithic texture of this clast, rounded olivine crystals (0.01 × 0.02 to 0.1 × 0.05 mm in size) probably due to metamorphism, resembles those of some granulites, but elongated lath-shaped plagioclase crystals have more eucrite-like subophitic igneous texture. The largest crystalline clast 4.3 × 2.4 mm in size with a fragment of twinned plagioclase of 1.1 × 0.8 mm in size has uniform composition (An96.3-96.9), but plagioclase laths show minor zonings (An 95.0-96.6). The modal abundances in volume % of the minerals of this clast obtained from the mineral distribution map are: plagioclase 59, olivine 20, orthopyroxene 7.7, augite 1.7, and spinel 0.4 and others 12. The mineral assemblage of this clast is similar to that of spinel troctolite clast in Dhofar 489 [2].

The Fo contents of olivine (Fo83-86) are similar to those of the Dhofar 489 spinel troctolite. The variations of the Cr/(Cr+Al) atomic ratio of the spinel grains and the Fe/(Fe+Mg) ratio is more than those of the Dhofar 489. Minor pyroxene grains ($Ca_3Mg_{86}Fe_{11}$ to $Ca_9Mg_{78}Fe_{11}$) in the clast are found with olivine grains and as isolated crystals. High-Ca pyroxene crystals also occur in contact with low-Ca pyroxene crystals or as isolated crystals.

Magnesian anorthosite clasts in Dhofar 309. We found two clasts of subrounded clasts of the magnesian anorthosite as was found in Dhofar 489. The largest clast is 6.3 × 3.8 mm in size and includes several rounded olivine crystals (0.08-0.18 × 0.05 mm in size) and minor pyroxenes in large twinned grains of plagioclase. The An contents (96.0-96.6) and the Fo contents (76-79) are similar to those of Dhofar 489. The pyroxene compositions have minor ranges ($Ca_6Mg_{75}Fe_{18}$ to $Ca_8Mg_{73}Fe_{19}$). There are some smaller subrounded grains of plagioclase with the same chemical compositions in the glassy matrix. The matrix texture is uniform and is different from those of Dhofar 489.

Discussion: The comparisons of textures and mineral chemistry of Dhofar 309 and 489 suggest common components, although the matrix textures are very different. The first description of Dhofar 309 mentioned the presence of the abundant granulites in this meteorite, but its texture and the zonings [7] are different from those of typical granulites. The laths of plagioclase with minor zoning and the chemical compositions of minerals suggest that these angular clasts are fragments of a metamorphosed crystalline rock generated from an impact melt pool of a rock with bulk composition similar to those of spinel troctolite in Dhofar 489. If igneous rocks produced in an impact melt pool, such as 68416 [8], were annealed, mafic rich clasts in Dhofar 309 could be produced.

The Mg/(Mg+Fe) mol. % (*Mg* numbers=75-79) of olivine and pyroxene grains in the magnesian anorthosites in Dhofar 309 and 489 are similar and are higher than those of the Apollo ferroan anorthosites. Such materials were not recovered by the Apollo and Luna missions. This evidence supports the proposed pairing of Korotev et al. [3] and the existence of magnesian anorthosites in the lunar farside [2].

The differentiation trend deduced from the magnesian anorthosites extends up to Mg×100/(Mg+Fe) = 79. This is an important point and deserved some more consideration and comment in future, but we accept this model in this paper.

Remote sensing data indicate that the nearside and the farside of the Moon are substantially different in terms of inferred chemical compositions and rock lithologies [9]. Our discovery of magnesian anorthosites in Dhofar 489 from the lunar farside [2], supports an idea that the major rock type of the northern farside is magnesian anorthosite. Korotev et al. [10] studied lunar meteorites other than Dhofar 489 in relation to this problem.

More magnesian olivine in other lithologies is another important component representing the deeper crust or mantle, but they were now converted into some granulites, impact melt crystalline rocks found in Dhofar 309. If the magnesian anorthosites were crystallized from the farside LMO, we have to produce the Apollo ferroan anorthosites (FAN) in the nearside separately, or by some related processes.

Nyquist et al. [6] determined epsilon Nd of an anorthositic clast in Y-86032 and proposed that negative value is consistent with residence in a LREE-enriched environment as would be provided by an early plagioclase floatation crust on the LMO. Other possible explanations for the dichotomy in epsilon Nd values are advanced by introducing "magma sea" [6]. A major, accretionary, impact into a large volume of the Moon may have created a new magma sea, perhaps in the region now occupied by the nearside central highlands. Anorthosites which floated to the top of the nearside magma sea, would crystallize FAN with positive epsilon Nd as observed for nearside FAN's [6]. Although the farside origin is proposed for Y-86032, anorthositic clast with negative epsilon Nd has FAN-like mafic silicates. The differentiation trend of the farside LMO to produce FAN should be examined.

The Mg-suite rocks in the lunar differentiation trend has been proposed to come from the PKT region of the Moon [9]. Y-86032 contains fragments of plagioclases and mafic silicates including some inverted pigeonites, in the dark matrix (DG) of this fragmental breccia [6]. Mg-suite rocks with less KREEP components may have intruded into the crust around the boarder regions of the Moon.

Korotev et al. [3] proposed that Dhofar 489 et al. sample are from the farside, because they contain magnesian mafic silicates, and not because they are low in the KREEP components. But at the same time, he suggested that magnesian anorthosites are also distributed in the near-side. However, magnesian anorthosites of the nearside around the PKT should be contaminated by FAN and Mg-suite rocks by excavation of such materials by impacts from the nearby PKT region. Dhofar 489 does not conatin such contaminations.

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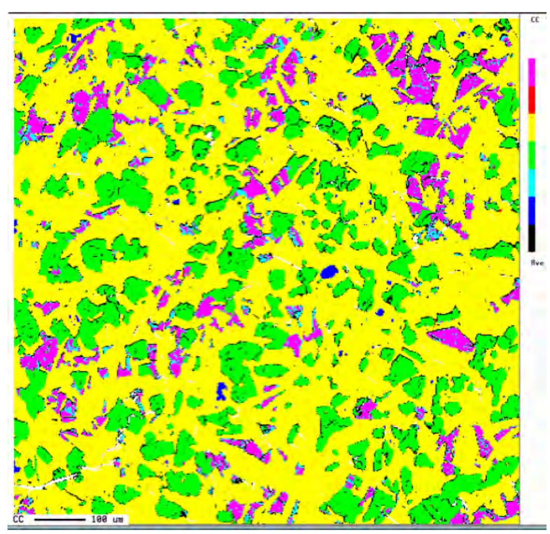

Fig. 1. Mineral distribution map of a crystalline clast in Dhofar 309. Yellow: plagioclase, green: olivine, pink: orthopyroxene, light blue: augite, and blue: spinel.