GRANULITIC LITHOLOGIES IN DHOFAR 307 LUNAR METEORITE AND MAGNESIAN, Th-POOR TERRANE OF THE NORTHERN FARSIDE CRUST.
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Introduction: The estimated low concentrations of Th and FeO by the remote sensing data [1] are consistent with the presence of the Dhofar-489-type lunar rocks [2] 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 reported mineralogical and petrological studies of Dhofar 309 [5], 908 [6], paired samples of the Dhofar 489 group to find a clast of the magnesian anorthosites. Now we performed a similar study on Dhofar 307 to find origin of the magnesian lithologies with olivine.

It has been mentioned that the feldspathic composition coupled with low Th concentration is not in itself good evidence of farside, and that Dhofar 489 et al. is highly magnesian, on the basis of Mg/Fe ratios inferred from the remote sensing data [3]. We compared the magnesian olivine-rich clast-types in Dhofar 489, 309, and 307 to discuss varieties of magnesian lithologies of the farside crust of the Moon.

Samples and Methods: One polished thin section of Dhofar 307 has been prepared from a chip and was employed for mineralogical and petrographic studies. Elemental distribution maps of Si, Mg, Fe, Al, Ca, Na 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 307 sample was selected among 15 paired samples of the Dhofar 489 group, because Dhofar 307 PTS contains magnesian granulitic clast (4.4 × 3.1 mm in size) similar to the spinel troctorite in Dhofar 489 in mineral chemistry. We will report only on this clast in this abstract.

Mineralogy and petrography of Dhofar 307. Dhofar 307 is different from Dhofar 309 in that impact melt rock fragments abundant in 309 is not present. The clast population is dominated by granulitic clasts of mainly anorthositic and troctolitic composition, and that fragments of large olivine are common in dark matrices. We recognized two major clasts are embedded in a matrix of devitrified glass and fragments of shocked plagioclase. One prominent clast is granulitic rock with a reddish orange colored olivine with subrounded shapes in granoblastic plagioclase, but the granoblastic texture is obliterated by shock effect. Another large clast is coarse-grained troctorite similar to the spinel troctolite found in Dhofar 489.

Magnesian granulitc clast. The lithic texture of this clast is granulitic with rounded olivine crystals (0.2 to 0.01 in the longest dimension) set in plagioclase matrices (An95-97). The sizes of the olivine are comparable to those of Dhofar 309 clast (0.1 × 0.05 to 0.01 × 0.02 mm in size). However, we could not observe rapid growth features of Dhofar 309 clast such as elongated lath-shaped plagioclase crystals with minor zonings (An 95.0-96.6) and fragments of twinned plagioclase of 1.1 × 0.8 mm in size with uniform composition (An96.3-96.9). The mineral assemblage of this clast is similar to that of spinel troctolite clast in Dhofar 489 [2].

The modal abundances in volume % of the minerals of this clast (Gr) obtained from the mineral distribution map are compared with those of the Dhofar 489 spinel troctorite (ST) and an impact melt clast (IM) in Dhofar 309:

Dhofar sample No.	307 Gr	309 IM	489 ST
plagioclase	60.5	59	72
olivine	23.7	20	25
orthopyroxene	0.9	7.7	2.2
augite	1.5	1.7,	0.5
spinel	0.1(Cr)	0.4	0.3
others(cracks etc.)	13.2	12.	-

The Fo contents of olivine (Fo84-86) are similar to those of the Dhofar 489 spinel troctolite (Fo84). The spinel grains in Dhofar 307 clast is fine chromite and the Mg-Al spinel found in the Dhofar 489 spinel troctorite and 309 were not found. Minor high-Ca pyroxene grains ($Ca_{46}Mg_{49}Fe_5$ to $Ca_{40}Mg_{50}Fe_9$) in the clast are found with olivine grains and as isolated crystals. Low-Ca pyroxene crystals ($Ca_2Mg_{85}Fe_{13}$ to $Ca_4Mg_{84}Fe_{13}$) also occur in contact with high-Ca pyroxene crystals or as isolated crystals.

The presence of large olivine fragments with Fo72-78 is related to the origin of granulites. These fragments are embedded in the dark devitrified glassy matrices and the sizes range from 1.0 × 0.8 to 0.3 × 0.2 mm in size. The large olivine fragments in the matrix may represent ejecta of the SPA basin of Arai et al. [6], where the impact penetrated into deeper olivine-rich mantle-type rock.

Discussion: The comparisons of textures and mineral chemistry of Dhofar 309 and 307 suggest common components, although the matrix textures are different. The laths of plagioclase with minor zoning and the chemical compositions of minerals in Dhofar 309 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. Although granoblastic textures of plagioclase of the Dhofar 307 clast were disturbed by the shock event, it is very typical granulite common in lunar meteorites. If the Dhofar 309-like clast is further annealed, granulitic rock will be produced.

The presence of Mg-Al spinel in both Dhofar 309 clast and 489 spinel troctolite suggested the common precursor, but small spinel grains in the Dhofar 307 clast may be converted to chromite during the metamorphism to produce granulitic textures.

With reference to the arguments for the farside origin of the Dhofar 489 group [3], low Th concentration is not in itself good evidence. The Dhofar 489 anorthosites contain more magnesian olivine than those of the ferroan anorhothites (FAN) of the Apollo samples. In addition, Dhofar 489 contains some deep seated rocks such as a spinel troctolite and their granulitic varieties. The impact which excavated and mixed the breccia components would have mixed the FAN lithologies of the near side with the magnesian anorthosites, because much of the crust of the nearside feldspathic highlands contains ferroan mafic silicate. The absence or very low abundance of FAN in the Dhofar 489-type feldspathic lunar meteorites rules out the possibility that the magnesian anothosites and FAN coexisted, when the Dhofar 489-type breccias were produced.

Nyquist et al. [7] argued that Y-86032, another lunar meteorite from the farside, was buried at a depth >~5 m for most of its history. This conclusion derives from the Sm-isotopic compostion coupled with noble gas data. Their conclusion is that most of the time Y-86032 was deeper than ~5 m, even if its recent excavation was from a depth less than ~5. The combination of surface-residence time, plus time on the surface would not be enough to acquire a signficant KREEP component. If we assume much deeper location, we will encounter the problems of the mixing magnesian and ferroan components as discussed above.

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 [1]. Our discovery of granulitic clasts and magnesian anorthosites in Dhofar 489, 309 and 307 from the lunar farside [2], produces some problems to support an idea that the major rock type of the northern farside is magnesian anorthosite, because Korotev et al.[3] thought that highly magnasian compositions are characteristic features of the farside anorthosites. More magnesian olivine in these lithologies discussed here may be another important component representing the the farside crust or mantle, but they were now converted into some granulites, impact melt crystalline rocks as were found in Dhofar 307 and 309. We may have to find a method to identify such lithologies by remote sensing methods.

The granulitic and troctoritic clasts include possible original spinel toctorite, impact melts and metamorphosed granulitic material. These clasts may have been produced in the same impact event of a large crater and excavated by another impact and incooperated into the Dhofar 489 site. It is important to find distribution of magnesian olivines around a large crater and to distinguish true magnesian anorthosites of the magma ocean origin by the Kaguya mission.

References: [1] Jolliff B. L. et al. (2000) *JGR. 105*, No.E2, 4197-4216. [2] Takeda H. et al. (2006) *Earth Planet. Sci. Lett., 247*, 171-184. [3] Korotev R. L. et al. (2006) *GCA*, *70*, 5935-5956. [4] Korotev R. L. (2006) *LPS XXVII*, Abstract #1402. [5] Takeda H. et al. (2007) *LPS XXVIII*, Abstract #1607. [6] Arai et al. (2007) *Meteoritics & Planet. Sci., 42, Suppl.,* A14. [7] Nyquist L. et al. (2006) *GCA*, *70*, 5990-6015. [8] NASA (1972) , *Apollo Preliminary Sci. Report*, NASA SP-315, p. 7-18.

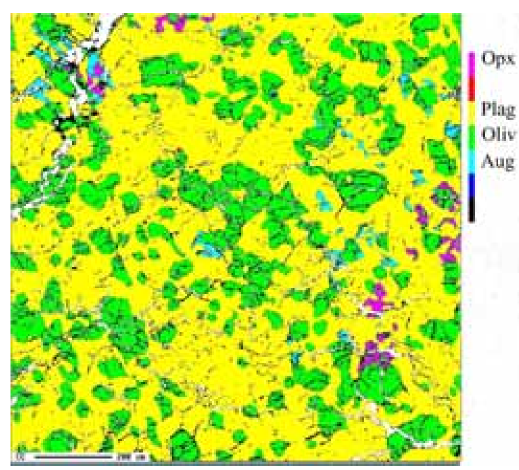

Fig. 1. Mineral distribution map of a crystalline clast in Dhofar 307. Yellow: plagioclase, green: olivine, pink: orthopyroxene, light blue: augite. Scale bar: 200 microns.