Mineral Chemistry and Reflectance Spectra for the Anorthosite Clast in Lunar Meteorite Dhofar 489 with Reference to Lunar Farside Crust. H. Nagaoka[1], H. Takeda[2], Y. Karouji[3], M. Ohtake[4], A. Yamaguchi[5], S. Yoneda[6], N. Hasebe[1], [1]Research Institute for Science and Engineering, Waseda University, Shinjuku, Tokyo 169-8555, Japan (hiroshi-nagaoka@asagi.waseda.jp), [2]Department of Earth & Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan, [3]Lunar and Planetary Exploration Program Group, Japan Aerospace Exploration Agency (JAXA), Sagamihara, Kanagawa, 229-8510, Japan, [4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (JAXA), Sagamihara, Kanagawa 229-8510, Japan, [5]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan, [6]National Museum of Nature and Science (NMNS), Shinjuku, Tokyo 169-0073, Japan.

Introduction:

Dhofar 489 is a 34.4 g lunar rock found in the hot desert of Oman. This rock is a feldspathic breccia including feldspathic lithologies embedded in a much finer-grained, dark crystalline matrix [1]. Takeda et al. [1] reported the mineralogy and chemical compositions summarized as follows; (1) the molar 100 × Mg/(Mg+Fe) (Mg numbers = 70-78) of olivine and pyroxene grains coexisting with plagioclase in the anorthositic clasts are higher than those of the Apollo ferroan anorthosite. (2) Dhofar 489 is the most depleted in Th, FeO, and REE among the feldspathic lunar meteorites [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. (3) Among the anorthosite clasts in Dhofar 489, the d2 clast is the largest white anorthosite clast, which has the chemical composition of lower FeO (0.46 %) and Th (0.0118 ppm). The low FeO concentration suggests that the d2 clast is an anorthosite clast with very low abundance of mafic silicates. The d2 clast has not been investigated with an electron microprobe analysis, although the chemical composition of the d2 clast has been determined by neutron-induced prompt gamma-ray analysis (PGA) and inductively coupled plasma mass spectrometry (ICP-MS) [1].

In this work, we investigated the d2 clast in Dhofar 489 derived from the farside of the Moon [1] with both an electron microprobe analysis and reflectance spectroscopic techniques, and characterize the d2 clast.

Sample and Methods:

A Dhofar 489 chip (a3) containing the d2 clast (Fig. 1) was obtained from National Museum of Nature and Science (NMNS). The chemical composition of the d2 clast [1] was obtained from the adjacent part of the d2 clast (Fig. 1). The polished thin section (PTS) of Dhofar 489, 2.7 × 4.4 mm^2 in size (Fig. 2), was made at National Institute of Polar Research (NIPR) from the chip sample (Fig. 1), and was employed for mineralogical, petrographical and reflectance spectroscopic studies.

The PTS was examined with a petrographic microscope. The elemental X-ray maps (Fig. 3) and backscattered electron (BSE) images were collected with the HITACHI S-3000N scanning electron microscope (SEM) at Waseda University. Quantitative mineral compositions in the PTS were analyzed with the JEOL JXA-8900 electron probe micro-analysis (EPMA) at Atmosphere and Ocean Res. Inst., Univ. of Tokyo (AORI), with well-characterized oxide and silicate standards at 15 kV, 1.2×10^{-8} A.

The reflectance spectra of Dhofar 489 d2 clast (the cutting surface of the chip sample for the PTS) were measured at Japan Aerospace Exploration Agency (JAXA).

Results and Discussion:

Figure 4 shows the absorption depth of the reflectance spectrum of the d2 clast in Dhofar 489. This figure shows strong absorptions of orthopyroxene (opx) (900 and 950 nm) and a weak absorption of plagioclase (1250 nm). Furthermore, the absorption top of opx shifts to the high wavelength band by the absorptions of olivine (1000 and 1050 nm).

The d2 clast is embedded in a much finer-grained, dark crystalline matrix (Fig. 2). Angular, orange colored olivine fragments are present in the crystalline matrix. The mineral compositions of these olivine fragments (MgO = 35.7-48.0 %, FeO = 11.4-23.8 %, Fo73-88) are more magnesian than those of other feldspathic lunar meteorites. The individual crystals of olivine grains range from 10 um to 100 um across in the crystalline matrix. Pyroxenes are lower in abundances and smaller in grain sizes compared with olivine fragments. The An values of plagioclase in the crystalline matrix show small in range (An96-97). The bulk composition of the crystalline matrix in this work shows the anorthositic composition with lower FeO and MgO concentrations (Al_2O_3 mean = 33.0 %, FeO mean = 1.5 %, MgO mean = 3.0 %). These data of the crystalline matrix are consistent with the previous report [1].

The d2 clast was intersected in half by the impact melt vein which has a similar bulk composition as the matrix. The larger clast was named to be the anorthosite clast 1 and another clast was named to be the anorthosite clast 2. These two anorthosite clasts occupy by 65.5 vol. % of this PTS (Figs. 2 and 3). The anorthosite clast 1 (2.8×3.0 mm^2) is composed of 99.2 vol. % plagioclase and 0.8 vol. % mafic silicates, while the anorthosite clast 2 (2.1×2.5 mm^2) is composed of 99.8 vol. % plagioclase and 0.2 vol. % mafic silicates. Both of these clasts composed mostly of plagioclase (FeO mean = 0.16 %, MgO mean = 0.14 %) with very low mafic silicates. These plagioclase clasts present original crystallization texture with twinning. In the d2 clast, the mafic silicates are very rare (< 1 vol. %), and small in the grain sizes (< 30 um). We are planning to perform more detailed analysis of the mineral compositions of the mafic silicates to compare the results with the chemical composition of the d2 clast [1].

We found the large anorthosite clasts having a high abundance of plagioclase (> 99 vol. % plagioclase) in Dhofar 489 that is a feldspathic breccia derived from the farside of the Moon [1]. The global distribution of the rocks that have a high abundance of plagioclase (nearly 100 vol. % plagioclase) has been observed by the Multiband Imager (MI) on board the first Japan's large-scaled lunar explorer, Kaguya. These rocks are defined as the purest anorthosite (PAN) [3]. The global PAN rocks probably formed by the crystallization and segregation of plagioclase inside lunar magma ocean [3]. However most of the Apollo FAN contain small amount of mafic silicates, and mineralogy of such high plagioclase abundant rocks are not known [e.g. 4]. The petrogenesis of PAN is interesting in the study of lunar magma ocean. The presence of the large anorthosite clast having a high abundance of plagioclase such as the d2 clast and the low FeO content in Dhofar 489, imply that this rock has a relationship with PAN.

Summary:

In this work, we have investigated the d2 clast in Dhofar 489 by means of mineralogy, petrography and reflectance spectroscopy. The d2 clast is composed of mostly plagioclase (> 99 vol. %) with very low mafic silicates. The presence of such a large anorthosite clast having a high abundance of plagioclase and the low FeO content in Dhofar 489, imply that this rock has a relationship with PAN.

Acknowledgements:

EPMA was supported by AORI. This work was in part supported by Research Fellowships of the Japan Society for the Promotion of Science for Young Scientists.

References:

[1] Takeda H. et al. (2006) *EPSL*, 247, 171-184. [2] Korotev R. L. et al. (2003) *GCA*, 67, 4895-4923. [3] Ohtake M. et al. (2009) *Nature*, 461, 236. [4] Heiken et al. 1991. *Lunar Sourcebook*. Cambridge, Cambridge University. Press.

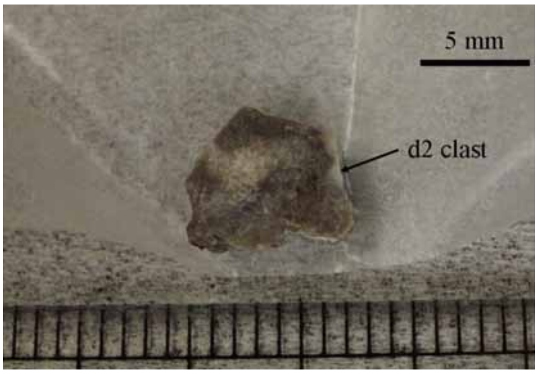

Figure 1. Chip sample of Dhofar 489 (a3). The d2 clast is a white large anorthosite clast.

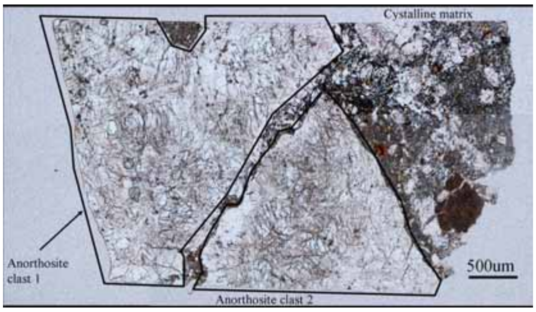

Figure 2. Photomicrograph of polished thin section of the d2 clast in Dhofar 489.

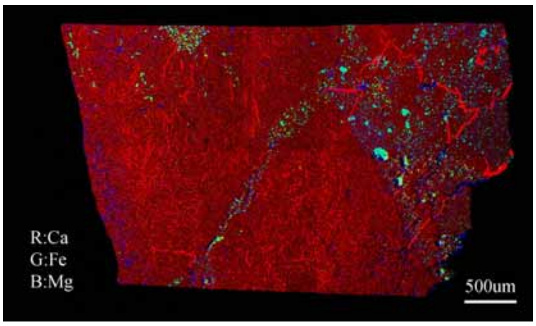

Figure 3. Combined X-ray elemental map of the PTS, red represents Ca, green represents Fe, blue represents Mg.

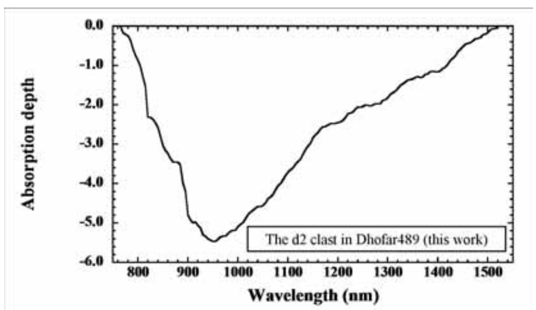

Figure 4. The absorption depth of the reflectance spectrum of the d2 clast in Dhofar 489 (750 nm-1550 nm).