Chemical Characteristics of lunar meteorites, Yamato 86032 and Dhofar 489. Y. Karouji[1] M.Ebihara[1,2] and A. Yamaguchi[2], [1]Graduate School of Science, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan, [2]National Institute of Polar Research, Itabashi, Tokyo 173-8515, Japan.

Introduction:

Yamato (Y) 86032 is a lunar meteorite which was found on Antarctica in 1986. This meteorite was classified into feldspathic lunar highland breccia [1, 2]. One ferroan anorthosite clast of Y86032 has a very old Ar-Ar age of ~4.35-4.4 Ga [3]. This meteorite is composed of at least three lithologies, white and light feldspathic lithology, dark-gray matrix (hereafter DG) and black impact melt veins (B) [4]. Dhofar (Dho) 489 is a lunar meteorite recently found in Oman in 2002, and was classified into feldspathic crystalline matrix breccia [5]. This lunar meteorite also has an old Ar-Ar age of ~4.27 Ga [6].

In this study, we determined major, minor and trace elements compositions of Y86032 and Dho489 by using several analytical methods and aimed to characterize these meteorites chemically as well as petrographically in comparison with those for other lunar highland meteorites and lunar rocks retuned by the Apollo mission.

Samples and analytical methods:

We analyzed three fragments of Y86032; Y86032,34 (81.9mg), Y86032,36 (92.8mg) and Y86032,131 (238.6mg) (values in parentheses indicate weight of samples allocated to us). Both ,34 and ,36 are black impact melt (B) and ,131 is dark-gray lithology (DG) [4]. For Dho489, we analyzed four fragments; Dho489a, b, c and d. Dho489a (143.5mg) and Dho489b (31.0mg) are bulk materials, Dho489c (36.0mg) is pure anorthosite material, and Dho489d (9.2mg) is matrix fragment. Samples were first analyzed by neutron-induced prompt gamma-ray analysis (PGA), for which lump samples were used. Following PGA, instrumental neutron activation analysis (INAA) was performed. Except for Dho489d, lumps were ground in a clean agate mortar and some aliquants were used in INAA. We also used inductively coupled plasma mass spectrometry (ICP-MS) for the determination of rare earth elements (REEs), Th and U.

Results and Discussion:

Table 1 shows major, minor and trace element composition of the two lunar highland meteorites analyzed in this study. Our data of three fragments of Y86032 are mostly consistent with those of Palme et al. (1991) [7] except for such elements as Na, Al, V, Cr, Mn and heavy-REEs (HREEs), indicating that this meteorite is heterogeneous in chemical composition in a scale of g-size. The chemical composition of Y86032 is almost indistinguishable from those of other lunar highland meteorites except for incompatible elements, which are systematically lower in Y86032. Compared with other lunar highland meteorite, Dho489 is characterized by even lower concentrations of Sc, V, Cr, Mn, Co, Ni and REEs (e.g., [7]) and much higher mg# (atom Mg/(Mg + Fe)).

Texture and mineralogy of mafic components in anorthosite of lunar highland meteorites are complex, and, in most cases, modified by regolith processes and shock and thermal metamorphisms, being evidenced by the presence of glassy materials and granulitic breccias. Nevertheless, lunar highland meteorites follow relatively simple chemical trends in terms of some major elements [7]. Figure 1 shows a TiO_2 versus Al_2O_3 correlation for lunar highland meteorites and rocks. In this figure, indivisual values for Y86032 and Dho489 are shown, while average compositions of the other lunar highland meteorites are plotted. We have calculated such average values from the following sources and other references cited therein: Jolliff et al. (1991) [8], Koeberl et al. (1989, 1990)[9, 10], Korotev et al. (1996) [11], Palme et al. (1991) [7] and Warren and Kallemeyn (1991) [12]. As shown in Fig. 1, lunar meteorites, except for Dho489, show a trend with negative slope, which is not overlapped with that for Apollo 16 highland rocks.

Figure 2 shows chondrite-normalized REE abundance patterns for lunar highland meteorites analyzed in this study. The REE pattern of Y86032,34 (B) is very similar to the pattern of ,131 (DG), with ,36 (B) being slightly enriched in HREE. The REE abundance of Dho489 is much lower than those of other lunar highland meteorites including Y86032. A U/Th ratio of Dho489 is much higher than those of other lunar highland meteorites, and must have been increased by weathering in the hot desert. Similarly, negative anomaly of Ce seen in the REE abundance patterns of Y86032 and Dho489 could have been caused by weathering in cold and hot deserts. Dho489a and Dho489b represent bulk samples of this meteorite and their REE abundance patterns are similar to each other. Their REE abundances are the lowest among those of other lunar highland meteorites. Considering this fact and that other incompatible element abundances are similarly lower in Dho489 compared with those of other lunar highland meteorites, Dho489 must have come from a site with long distance from Mare Imbrium, highly probably from the far-side of the moon. However, the source region of Y86032 whose REE abundance is not so low as that for Dho489 needs not necessarily be the far-side of the moon.

References:

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Acknowledgements:
We thank H. Takeda for valuable discussion.

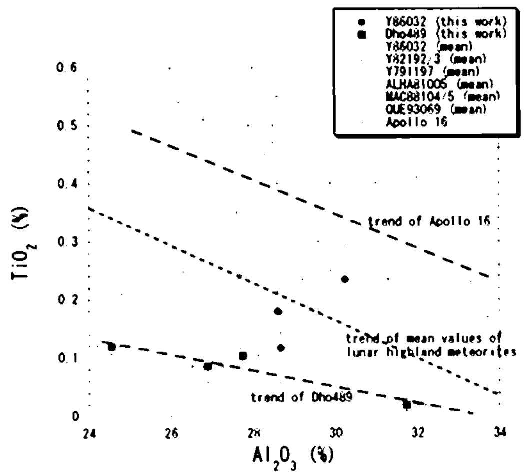

Fig.1 TiO_2 vs. Al_2O_3 for Lunar highland meteorites and Apollo 16 rocks.

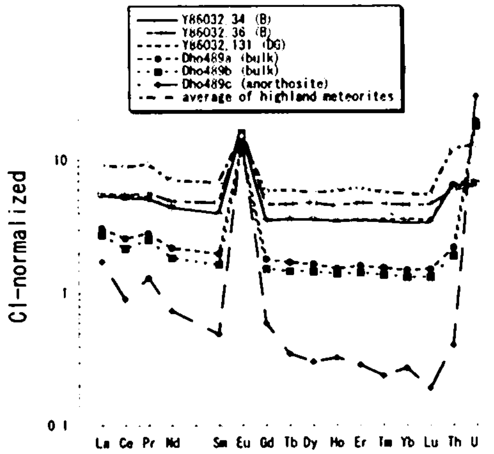

Fig.2 Chondrite-normalized REE abundance patterns for lunar highland meteorites.

Table 1 Chemical composition of Y86032 and Dho489.

		Yamato 86032						Dhofar 489							
		.34 (B)		.36 (B)		.131 (DG)		a (bulk)		b (bulk)		c (anorthosite)		d (matrix)	
			error		error		error		error		error		error		error
Na	%	0.344	0.003	0.397	0.004	0.373	0.004	0.275	0.001	0.267	0.001	0.356	0.001	0.307	0.001
Mg	%	3.79	0.37	3.36	0.36	3.34	0.33	3.93	0.28	3.37	0.41	1.43	0.18	5.25	0.58
Al	%	15.2	0.5	15.1	0.5	16.0	0.6	14.7	0.2	13.0	0.2	16.8	0.3	14.2	0.2
Si	%	21.3	0.7	20.8	1.0	20.6	0.6	20.3	0.4	20.5	0.6	19.9	0.6	20.8	1.0
K	%	0.0367	0.0097	0.0107	0.0075	0.0401	0.0155	0.0300	0.0098	0.0589	0.0210	0.0232	0.0180		
Ca	%	11.0	0.8	11.0	0.8	11.3	0.8	11.2	0.7	10.3	0.8	13.2	1.0	10.4	0.9
Sc	ppm	8.56	0.02	10.32	0.03	10.34	0.03	4.77	0.02	4.02	0.03	0.71	0.01	4.94	0.03
Ti	%	0.070	0.036	0.108	0.022	0.140	0.034	0.0622	0.0044	0.0720	0.0084	0.0115	0.0066	0.0514	0.0169
V	ppm	35.1	4.9	18.5	3.0	38.8	3.9	14.1	2.7	5.59	2.43				
Cr	%	0.0648	0.0003	0.0605	0.0003	0.0752	0.0003	0.0441	0.0002	0.0386	0.0003	0.0055	0.0001	0.0470	0.0003
Mn	%	0.0527	0.0022	0.0529	0.0022	0.0586	0.0022	0.0366	0.0015	0.0291	0.0020	0.0088	0.0009	0.0356	0.0026
Fe	%	3.43	0.02	3.46	0.02	3.89	0.02	2.55	0.02	2.20	0.02	0.36	0.01	2.56	0.03
Co	ppm	16.2	0.2	14.0	0.1	16.3	0.2	10.1	0.1	8.8	0.2	1.6	0.1	10.4	0.2
Ni	ppm	130	10	110	10	115	12	57.3	7.0						
Ga	ppm	3.65	0.69	2.86	0.64										
Ba	ppm	41.0	0.6	48.2	0.3	44.8	1.1	28.4	0.6	25.4	0.4	219	2		
La	ppm	1.28	0.02	1.34	0.03	1.30	0.02	0.727	0.023	0.645	0.012	0.405	0.010	0.659	0.053
Ce	ppm	3.15	0.01	3.26	0.04	3.25	0.06	1.56	0.03	1.31	0.02	0.545	0.010		
Pr	ppm	0.456	0.007	0.509	0.012	0.464	0.008	0.251	0.006	0.224	0.006	0.116	0.004		
Nd	ppm	1.99	0.02	2.21	0.05	2.00	0.03	0.986	0.029	0.831	0.023	0.333	0.016		
Sm	ppm	0.586	0.012	0.708	0.015	0.584	0.014	0.291	0.009	0.241	0.013	0.072	0.010	0.328	0.009
Eu	ppm	0.894	0.008	0.988	0.012	0.928	0.008	0.718	0.019	0.668	0.011	0.802	0.015	0.743	0.041
Gd	ppm	0.692	0.012	0.915	0.012	0.702	0.013	0.353	0.010	0.300	0.020	0.117	0.010	1.28	0.72
Tb	ppm	0.129	0.003	0.168	0.005	0.129	0.003	0.0613	0.0027	0.0525	0.0031	0.0126	0.0008		
Dy	ppm	0.870	0.008	1.16	0.01	0.873	0.020	0.400	0.017	0.351	0.012	0.074	0.003		
Ho	ppm	0.194	0.002	0.253	0.005	0.194	0.004	0.0857	0.0049	0.0781	0.0027	0.0184	0.0011		
Er	ppm	0.559	0.007	0.760	0.007	0.570	0.010	0.254	0.010	0.225	0.012	0.046	0.002		
Tm	ppm	0.0827	0.0012	0.113	0.002	0.0847	0.0016	0.0371	0.0015	0.0327	0.0016	0.0057	0.0005		
Yb	ppm	0.547	0.008	0.747	0.005	0.589	0.012	0.241	0.012	0.214	0.003	0.045	0.003		
Lu	ppm	0.0813	0.0011	0.111	0.003	0.0844	0.0025	0.0360	0.0007	0.0315	0.0022	0.0046	0.0004		
Hf	ppm	0.454	0.032	0.408	0.027	0.400	0.043	0.173	0.020						
Th	ppm	0.185	0.003	0.171	0.006	0.191	0.004	0.0634	0.0021	0.0551	0.0030	0.0118	0.0009		
U	ppm	0.0530	0.0024	0.0518	0.0016	0.0564	0.0026	0.156	0.004	0.143	0.006	0.241	0.011		

Errors are due to counting statistic (1σ) in γ-ray counting except for Ba, REE, Th, and U, whose errors indicate standard deviation (1σ: n= 5) in ICP-MS.