Mineralogy of Yamato 983885 Lunar Polymict Breccia with Alkali-rich and Mg-rich Rocks.

T. Arai[1], M. Otsuki[2], T. Ishii[2], T. Mikouchi[3], and M. Miyamoto[3], [1]Lunar Exploration Technology Office, Japan Aerospace Exploration Agency (JAXA), 2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan. arai.tomoko@jaxa.jp, [2]Ocean Research Institute, University of Tokyo, Minamidai, Nakano, Tokyo, Japan, [3]Dept. of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan.

INTRODUCTION: Yamato (Y) 983885 is a lunar meteorite recently found in Antarctica. Kaiden and Kojima [1] reported preliminary results for the petrography and oxygen isotopic composition, and verified the lunar origin. This rock is a polymict regolith breccia with a variety of crustal components, such as alkali-rich rocks, Mg-rich rocks, and mare basalts. We studied this new lunar meteorite with mineralogical technique to understand the petrogenesis and source region on the Moon.

SAMPLE and METHOD: A polished thin section (PTS) Y983885, 59-2 is provided by the National Institute of Polar Research (NIPR). Chemical compositions of minerals and glasses were studied by JEOL 733 and 8900 electron microprobes at Ocean Research Institute, the University of Tokyo, and Field Emission SEM at Department of Earth and Planetary Science, the University of Tokyo.

RESULTS: This rock is a polymict regolith breccia with various types of rock clasts, isolated mineral fragments, and glass spherule, embedded in the dark glassy matrix. Compared to several large clasts larger than 0.5mm across, most of isolated mineral fragments are smaller than 100 µm in size. These mineral fragments are plagioclase, pyroxene and olivine with minor silica mineral, ilmenite, chromite, metallic Fe, and troilite. Feldspathic impact glass spherules of 50-500 µm in diameter are found. Some glasses are devitrified and include plagioclase and pyroxene crystals. Others are fairly homogeneous and the compositional variation between spherules are SiO_2= 45-49 wt.% and Al_2O_3= 21-27 wt.%, FeO=5-9 wt.%, MgO= 4-8 wt.%. No pyroclastic glass is recognized. Lithic clasts include an alkali gabbronorite (GN), a Mg-rich norite and a Mg-rich troctolite, a granulite, a high-aluminum (HA) basalt and a very low Ti (VLT) basalt. Modal abundance of each clast is given in table1. Petrography and mineralogy of each clast are presented as follows:

Alkali Gabbronorite: This clast is 0.8 x 0.4 mm in size with relatively coarse-grained igneous texture. It consists of ternary plagioclase, Ca-rich pyroxene, ilmenite, REE-rich whitlockite, Si,Al,K-rich glass, Ba-rich potassium feldspar, trace of zircon (Fig. 1). Although the plagioclase grains show shock-induced undulatory extinction, the primary igneous texture is well preserved without granulation. The plagioclase show extensive chemical zoning from core (An= 95.9) to rim (An= 72.4), and one grain co-crystallizing with Si,Al,K-rich glass is extreme enriched in sodium (An=71.3-63.1). Pyroxene consists of both low-Ca and high-Ca pyroxenes as shown in Fig. 2. One pyroxene (px 1 in Fig. 2) has a chemical zoning from Mg-rich augite core (Wo37Fs17En46, Mg#= 72) to Fe-rich augite rim (Wo21Fs47En33, Mg#= 48), while another pyroxene grain (px 3) shows co-existing pigeonite (Wo11Fs38En51, Mg#= 57) and augite (Wo32Fs24En44, Mg#= 65). Pyroxene exsolution is rarely found. Si,Al,K-rich glass is compositionally heterogeneous (SiO_2= 76.4 - 80.1 wt.%, K_2O = 5.14 - 6.46 wt.%, Al_2O_3 = 10.7 - 12.7 wt.%). Si, Al, K-rich glass is a residual product of late-stage crystallization with the extreme Na-rich plagioclase rim, Fe-rich augite rim and ilmenite. The residual glass is also found as droplets (about 10µm in diameter) within whitolockite, indicating immiscibility of silica-rich melt with phosphate-rich phase.

Norite: The clast is 0.4 x 0.3 mm in size, with granoblastic texture and composed of Ca-rich plagioclase (An= 91-94), low-Ca pyroxene (Wo5-7Fs21-23En74-70, Mg#= 75-77 in Fig. 2), and Mg-rich olivine (Fo= 74). The granoblastic texture and homogeneous mineral composition show that the clast is fairly equilibrated.

Troctolite: The clast is 2 x 1.8 mm in size, with granoblastic texture. It includes Ca-rich plagioclase (An=95-97), Mg-rich olivine (Fo= 70), low-Ca pyroxene (Wo3-11Fs24-26En73-63, Mg#= 71-75), Ti, Al-bearing chromite (Chr64Ulv10Her26), ilmenite, apatite, troilite and FeNi metal (both kamacite and taenite). Sub-rounded equigranular olivine crystals are surrounded by pyroxene crystal, indicating "olivine-resorption". This clast is moderately shocked and plagioclase show undulatory extinction and is partly intruded by dark glassy matrix. With slight variation of the pyroxene composition (Fig. 2), chemical compositions of all the minerals are fairly homogeneous. The granoblastic texture and homogeneity of the mineral composition indicate that the clast is well equilibrated by slow cooling.

Granulite: Round, polygonal, olivine crystals with 30-200 µm in diameter are included in a 0.6 x 0.7 mm plagioclase crystal. Chemical compositions of olivine (Fo= 70) and host plagioclase (An= 96) are homogeneous. The modal abundance (Table 1) shows that the precursor of this granulite clast is ferroan anorthosite.

High-Al Basalt: This clast, 1.2 x 0.7 mm in size, shows fine-grained basaltic (ophytic) texture with mostly plagioclase (An= 91-97), olivine (Fo= 66-70), pigeonite (Wo11Fs53En36, Mg#=70), augite (Wo33Fs22En45, Mg#= 68), FeNi metal, troilite and apatite.

Very-Low-Ti Basalt: This clast, 0.5 x 0.5mm in size, consists of pyroxene, plagioclase (An=96), silica mineral and dark mesostasis with break-down of silica, fayalite and ilmenite. Pyroxene crystals show extensive chemical zoning as shown in Fig. 2.

DISCUSSION:

Compared to known alkali-rich rocks dominantly from Apollo 12 and 14 samples [2,3,4,5,6], the alkali gabbronorite in this rock shows several unique features; well-preserved primary igneous texture, extensive chemical zonings both in plagioclase and pyroxene within the small clast less than 1 mm, lack of detectable pyroxene exsolution and the presence of Si, Al, K-rich residual glass. These nature all support its pristinity. They also indicate that the clast formed under relatively rapid cooling, and probably of extrusive derivation, unlike other known alkali-rich rocks. Considering this feature, the clast is more similar to KREEP basalt. Though it lacks the pyroxene zoning trend from Mg-rich orthopyroxene to Fe-rich augite in typical KREEP basalt [7], this might be due to poor representativeness by the small fragment size. While the petrogenesis of alkali-rich rock is still under debate, alkali-rich rocks have been proposed to form from pluton of KREEP basalt magma [2], or Mg-rich magma that assimilated urKREEP [4]. The presence of the Mg-rich norite and troctolite clasts and alkali-rich clast intermediate between alkali gabbronorite and KREEP basalt supports the above proposed petrogenesis.

The high-Al basalt in the rock is similar to group 4 of [8]. The presence of apatite (0.4 vol. %) is consistent with proposed KREEP-assimilation petrogenesis [8].

Pristine Alkali-rich and Mg-rich rocks have not been reported in lunar meteorites to date with exception of apatite-rich anorthositic troctolite [9]. The apatite-rich clast of [9] belongs to ferroan anorthosite and quite distinct from the Y983885 alkali gabbronorite. Thus, Y983885 is not paired with any known lunar meteorites.

Alkali-rich rock and high-Al basalt rich in K are dominantly found in Apollo 12 and 14 samples [e.g. 2-6, 8-11]. Apollo 14 sites, known as Fra Mauro Formation, are unique among other Apollo sites because the bedrock consists of indulated polymict breccia, which probably represents material entrained by impacts related to the Imbrium event [12]. Remote-sensing data indicates that the northwestern hemisphere (Apollo12 - Apollo14 region) of the lunar near-side is exceptionally enriched in the incompatible trace elements, such as KREEP. The presence of alkali-rich rock and high-Al basalt implies that Y983885 is probably originated from the northwestern hemisphere of the lunar near-side.

SUMMARY: Y983885 is a polymict regolith breccia with various rock clasts. The alkali-rich clast intermediate between alkali gabbronorite and KREEP basalt is an unprecedented rock type. The presence of alkali-rich rock and high-Al basalt suggests that Y983885 is derived from the northwestern hemisphere on the near-side of the Moon.

References: [1] Kaiden H. and Kojima H. (2002) LPS XXXIII, CD-ROM #1958. [2] James et al. (1987) PLPSC 17th, E314-330. [3] Warren P. H. et al. (1981) PLPSC, 12B, 21-40. [4] Warren P. H. et al. (1983a) PLPSC 13th, A615-630. [5] Warren P. H. et al. (1983b) PLPSC 14th, B151-164. [6] Lindstrom M.M. (1984) PLPSC 15th, C50-62. [7] Ryder et al. (1977) PLPSC 8th, 655-658. [8] Dickinson T. et al. (1985) PLPSC 15th, C365-374. [9] Goodrich et al. (1985) PLPSC 15th, C405-414. [10] Shervais et al. (1983) B177-B192. [11] Shervais et al. (1985) PLPSC, 16th, D3-D18. [12] Taylor et al. (1983) *EPSL*, 66, 33-47.

Table 1 Modal mineralogy of each clast in Y983885

	Alkali GN	Norite	Troctolite	Granulite	HA basalt	VLT basalt
Plagioclase	64.1	48.8	59.6	91	75.4	42.5
Pyroxene	20	40.4	15.5	-	21.5	53.4
Olivine	-	10.8	23.4^{+}	9	-	Tr
Ilmenite	2.1	-	-	-	-	Tr
Chromite	-	-	Tr	-	-	-
K-feldspar	Tr	-	-	-	-	-
Silica	-	-	-	-	-	4.1
SiAlK glass	11	-	-	-	-	-
FeS	-	-	Tr	-	1.9	-
FeNi	-	-	1.5	-	0.8	-
Whitlockite	2.8	-	-	-	-	-
Apatite	-	-	Tr	-	0.4	-

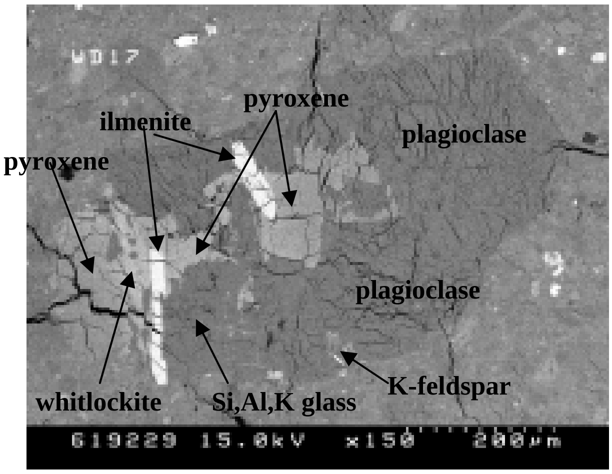

Fig.1 BSE image of Alkali gabbronorite (field of view is 0.8 mm)

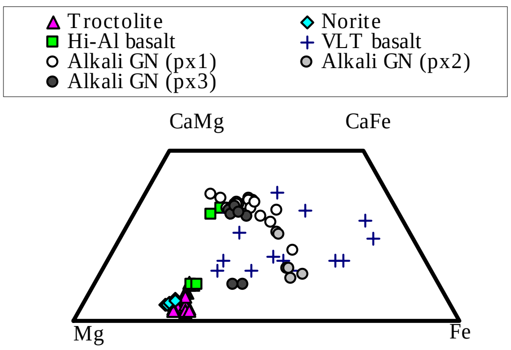

Fig. 2 Pyroxene compositions from each clast