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CONSORTIUM REPORTS OF LUNAR METEORITE YAMATO-793274

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Abstract: Yamato (Y)-793274 is a fragmental breccia with some regolith components and is rich in pyroxene fragments. Chemical variation of pyroxenes in Y-793274 can be interpreted in terms of chemical zoning similar to those found in a rare basaltic clast in Apollo 16 breccia, 60019. Some pyroxene fragments show thin exsolution lamellae. The most magnesian gabbroic clast found consists of nearly homogeneous olivine, plagioclase, and pigeonite with fine exsolution. Plagioclase fragments show much wider variation in An contents than other lunar meteorites. All these data indicate that Y-793274 is a regolith breccia with components suggestive of mare origin (or non-highland). The mare components are not always surficial basalts, and may be a coarse-grained rock similar to the basaltic clast with chemically zoned pyroxenes in 60019, which is different from the mare basalt samples collected by the Apollo missions.

1. Introduction

All five lunar meteorites, ALHA81005, Y-791197, Y-82192, Y-82193 and Y-86032 we studied up to this consortium study were breccias from the lunar highlands (*e.g.*, WARREN *et al.*, 1989; TAKEDA *et al.*, 1990a). Among these breccias, small components of mare basalts have been recognized (*e.g.*, TREIMAN and DRAKE, 1983; LINDSTROM *et al.*, 1986), but our attention was directed to highland specimen, which will tell us more crustal evolution of the Moon. Two allocations from two different areas of lunar meteorite Y-86032 have been made for our consortium study. Three preliminary reports (TAKEDA *et al.*, 1989; KOEBERL *et al.*, 1989; EUGSTER *et al.*, 1989) and several individual reports (KOEBERL *et al.*, 1990; WANG and LIPSCHUTZ, 1990; WARREN *et al.*, 1989) have been published on these samples. The results indicated that Y-86032 is a feldspathic fragmental breccia with little regolith component and with low solar wind gases and KREEP component. The noble gas abundances, cosmic ray exposure ages and terrestrial ages (EUGSTER *et al.*, 1989) suggested that Y-86032 is paired with Y-82192 and Y-82193, which is consistent with their mineralogical and petrographic data (TAKEDA *et al.*, 1989). The U-Pb isotopic characteristics of Y-86032 (TATSUMOTO, 1990) and other results (KURAT *et al.*, 1990) have been reported at the 15th Symposium of Antarctic meteorites.

Very low concentrations of KREEP components, such as REE, U, Th, and volatile siderophile elements in the Y-86032 group have been interpreted as evidence that they were derived from a site far from Mare Imbrium, where KREEP components are abundant (WARREN *et al.*, 1989; KOEBERL *et al.*, 1989), namely, the lunar farside regions or lunar rims. Granulitic clasts, which were known to be present in the lunar farside (LINDSTROM and LINDSTROM, 1986) have been found in these anorthositic fragmental breccias, but mare basalt components have been rare (TAKEDA *et al.*, 1989, 1990a).

Y-793274, which is the fourth lunar meteorite in the Yamato meteorite collection (YANAI and KOJIMA, 1987a, b) weighs only 8.66 g and was classified as an anorthositic regolith breccia. The samples of Y-793274 were separated on February 22, 1990 and allocated to small numbers of the consortium members for the maximum usage of the small sample. The pyroxene compositions are distributed within a restricted region of the pyroxene quadrilateral. There is a sharp cut at the magnesian side and data extend more to the Fe-rich side (YANAI and KOJIMA, 1987a, b). This pyroxene diagram implies that Y-793274 is distinct from any other lunar meteorites, and the PTS microphotograph of this meteorite in the Photographic Catalog (YANAI and KOJIMA, 1987a, b) shows abundant mafic silicate fragments not common in lunar highland rocks. Meanwhile, WARREN and KALLEMEYN (1989), DELANEY (1989) and DELANEY and SUTTON (1990) identified EET87521 as a lunar breccia dominated by mare basalt. Comparisons with their data indicated Y-793274 may also have more mare components than ALHA81005 or Y-791197. Our preliminary reports (EUGSTER, 1990; FUKUOKA, 1990; KURAT *et al.*, 1990; LINDSTROM and MARTINEZ, 1990; TAKEDA *et al.*, 1990b) confirmed that Y-793274 is indeed rich in mare basalts similar to these found in highland fragmental breccias (TAKEDA *et al.*, 1987).

2. Sample Allocation and Experimental Methods

The sample of Y-793274 weighed 8.411 g before this processing and had a saw cut surface at the left side of the entire sample seen in the B-view (Photo 321 of YANAI and KOJIMA, 1987b). About one third of the sample adjacent to and parallel to the cut surface was chipped. Two large fragments 1.4×1.2 cm in size (sub-sample number ,10 weight 2.125 g) and 0.5×0.8 cm (,61 0.172 g) were produced (Fig. 1), leaving 5.945 g of the original sample. On both sides of the two fragments, there is a large grayish clast (G1) 0.3×0.2 cm in size. Lithic and mineral fragments including this clast and a much smaller clast of this type (G2) and white feldspathic ones are set in a much smaller comminuted angular fragments rimmed with glassy interstitial materials between the fragments, which include dark yellowish to pinkish and brownish pyroxenes and white plagioclase. The amounts of mafic fragments exceed that of plagioclase. A part of G1 (,93) was allocated to the Instrumental Neutron Activation Analysis (INAA) study (Table 1).

The larger chip (,10) was further subdivided into more than ten fragments. One fragment containing clast G2 (,81 0.022 g) and matrix sample (,84 0.032 g) with numerous mafic and anorthositic fragments were allocated to another INAA study. A sample of collected small chips (,65 0.075 g) was allocated to an exposure age study, and another similar sample of matrix was allocated to a noble gas study (,85 0.028 g). The remainder of the large chip (,10 1.266 g) was further subdivided into several chips and allocated for terrestrial and cosmic-ray exposure age determination (,66 *a.*

b.

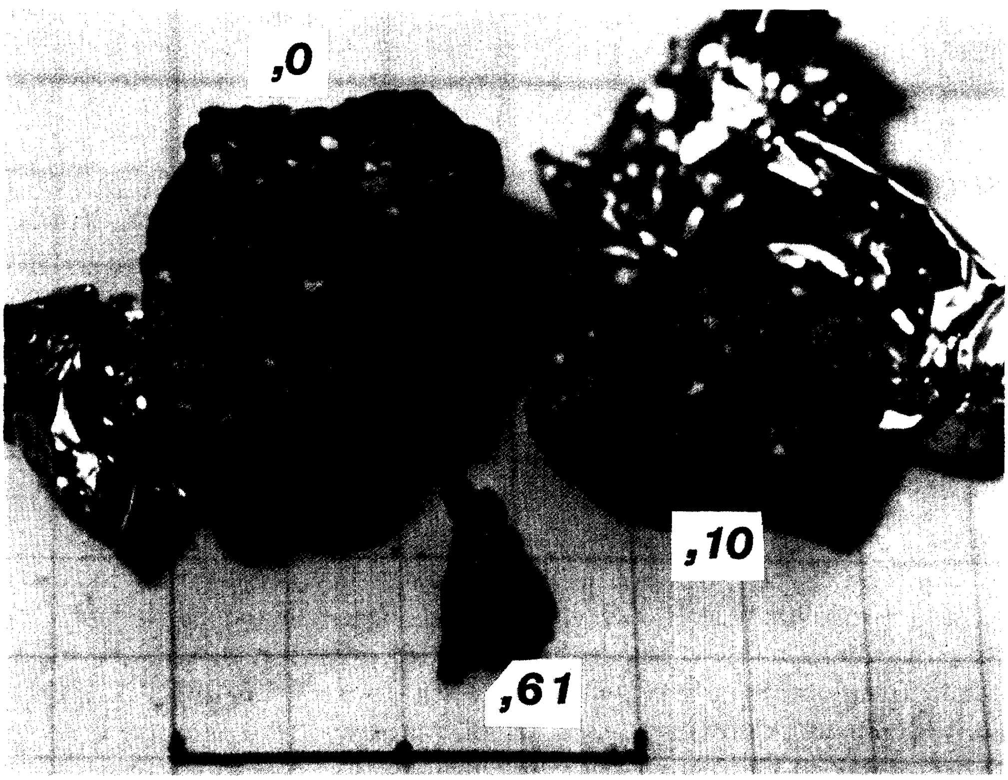


Fig. 1. *a*: *Photograph of Y-793274 main mass, covered by a dusty-gray fusion crust and weighs 5.9 g (remainder). Many white (anorthosite) and yellowish-brown (pyroxene) clasts are seen in the gray matrix. Scale bar (vertical) is 1 cm.*

b: *Photograph of fragments of Y-793274 allocated to this consortium study. Scale bar is 2 cm.*

Table 1. Sample allocation of Y-793274,0 (8.622 g) for this consortium study.

Total	,10	2.125 g chip 1.4×1.2 cm	
T. FUKUOKA	,83	0.009 dif. clast	Major, trace elements
	,96	0.020 matrices	
C. KOEBERL	,93	0.031 G1	Halogens and other trace elements
	,94	0.050 matrix	
P. H. WARREN	,81	0.022 clast G2	INAA and petrology
	,82	0.040 matrix	
O. EUGSTER	,66	0.048 interior	Terrestrial and Kr^{81} exposure age
D. STÖFFLER	,95	0.018 interior chips	Petrography, chemistry
I. KANEOKA	,97	0.018 clasts	^{40}Ar-^{39}Ar chronology
	,85	0.028 matrix	
K. NISHIIZUMI	,65	0.075 interior	Cosmic-ray exposure and terrestrial age
M. TATSUMOTO	,86	0.042 clast-rich	U-Th-Pb chronology
	,92	0.016 clast G1	
	,84	0.032 matrix	
M. E. LIPSCHUTZ	,62	0.132 interior chip	Volatile trace elements
R. N. CLAYTON	,88	0.027 whole rock	Oxygen isotopes
N. TAKAOKA	,63	0.058 whole rock	Noble gas isotopes
H. TAKEDA	,91–2	PTS	Mineralogy,
	,98	0.010 matrix	TEM of matrix
Remainder	,10	0.543 ,0 5.945 g	
kept for future studies	,92	G1; ,64 Brown Px; ,21 0.377; ,87 PTS of G2 5 mg	

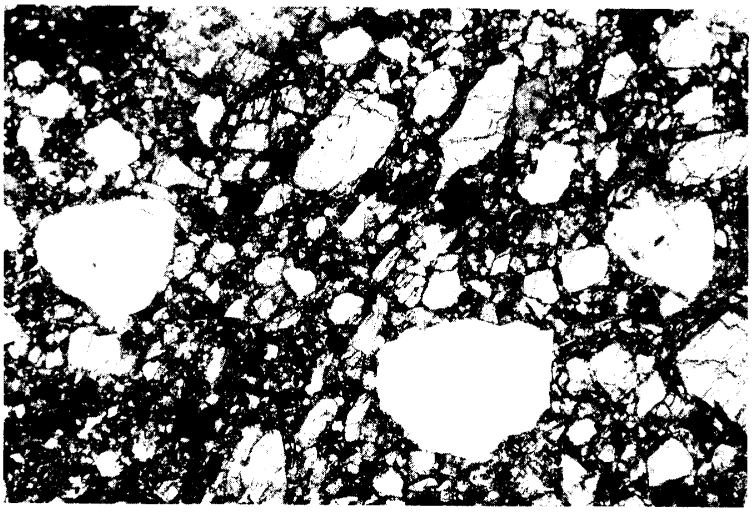
0.048 g), Radiochemical Neutron Activation Analysis (RNAA) (,62 0.132 g) and the U-Pb systematics (,84 matrix-rich and ,86 0.042 g clast-rich) (Table 1). A chip contrary part of G2 was used for PTS preparation. Several chips were used for mineralogical studies and a PTS was prepared from the sawn sample (,91).

3. Results

Microscopic observations of a PTS (,91-1) described previously and a new one (,91-2) show that this fragmental breccia is richer in angular mafic minerals than plagioclase (Fig. 2a). Clast-laden glassy breccias and a small number of glass spherules and glassy fragments are also present. This observation indicates that Y-793274 is a regolith breccia. One large clast, which should be part of a G1-like clast (a clast similar to G1) includes fragments of pyroxene, olivine and plagioclase in a white (transparent) maskelynite-like glassy matrix (Fig. 2b). A swirly glass produced by impact is present at a corner of the clast. One gabbroic clast consists of rounded olivine in plagioclase and pyroxene (Fig. 2c). No lithic clasts of apparent plutonic origin were recognized in the PTS. Inverted pigeonite or pyroxenes with coarse exsolution lamellae indicative of lunar crustal rocks were not found.

The chemical compositions of pyroxene fragments analyzed by electron microprobe (Fig. 3) distribute in the same manner as previously reported (YANAI and KOJIMA, 1987b). Each pyroxene grain show variation in chemical composition (Fig. 3). By combining zoning trends of all fragments measured, we find that their varia-

a.



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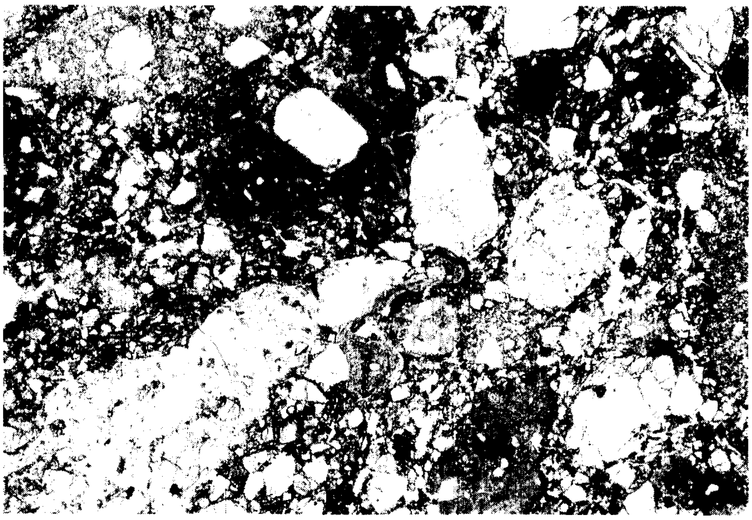

c.

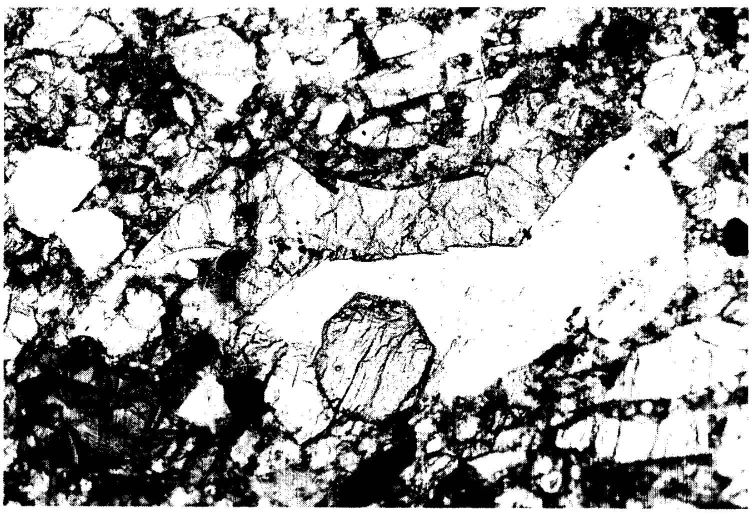

Fig. 2. Photomicrographs of Y-793274,91–2.
a: Overall view of a fragment-rich part of Y-793274. Width is 3.3 mm.
b: Part of G1-like clast (lower left). Width is 3.3 mm.
c: Gabbroic clast with olivine, pyroxene with fine exsolution lamellae and plagioclase. Width is 1.3 mm.

tion covers the entire range, except for the Mg-rich fragments. The most Mg-rich trend is similar to an exsolution trend, but lamellae widths are very thin. Some grains

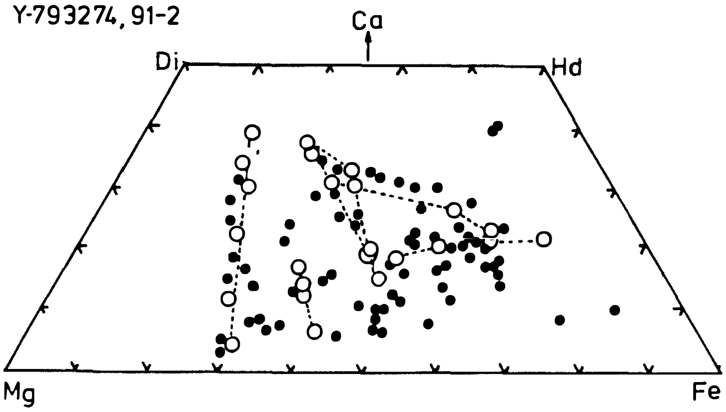

Fig. 3. Pyroxene quadrilateral of Y-793274,91-2. Solid circles are individual measurements; open circles with dotted lines represent zoning trends within one crystal fragment.

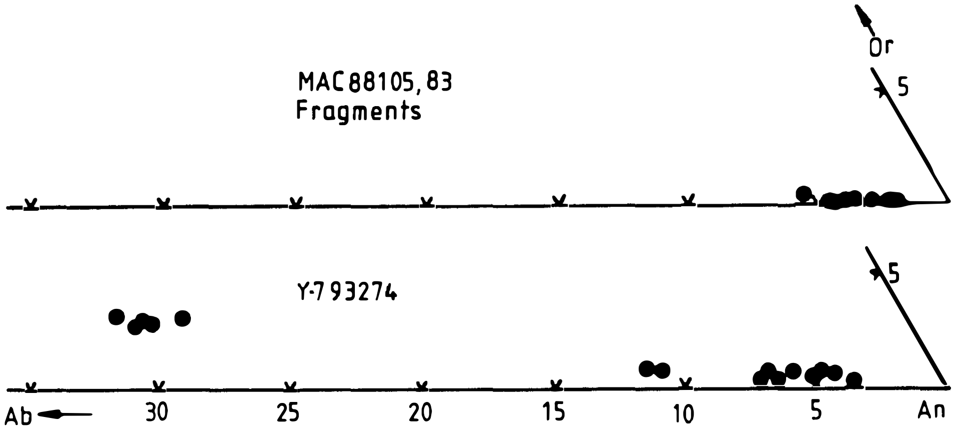

Fig. 4. Chemical compositions of Y-793274 plagioclase fragments in the matrix plotted in a part of the An-Ab-Or diagram together with those of highland one MAC88105.

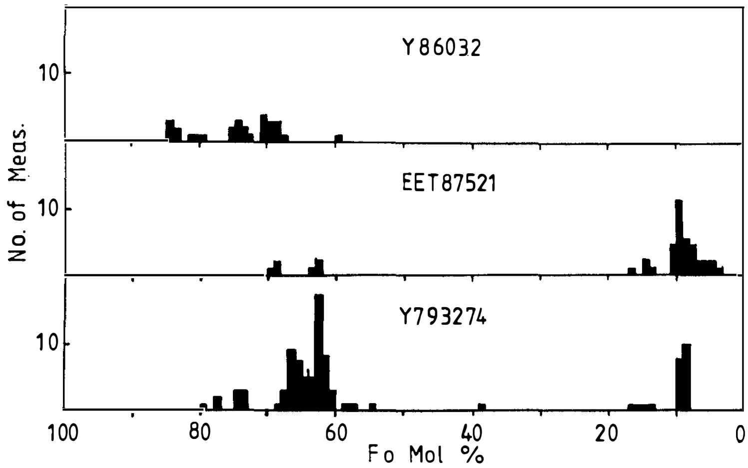

Fig. 5. Histogram of Fo content distribution of olivine fragments in Y-793274 and related rocks.

show fine lamellae-like texture suggestive of exsolution with nearly constant Mg/Fe. The results suggest that the pyroxene chemical variation is not due to the presence of many types of crustal rocks as seen in other lunar meteorites (TAKEDA *et al.*, 1990b), and that the trend may represent zoned pyroxenes such as those reported for rare mare rock clasts found in Apollo 16 breccias and Luna 16 (TAKEDA *et al.*, 1987), and lunar mare meteorites (WARREN and KALLEMEYN, 1989; DELANEY and SUTTON, 1990; WARREN *et al.*, 1990; YANAI, 1990a, b). The original rock may be coarse-grained.

The chemical compositions of plagioclase fragments range from An 98 to 88 (Fig. 4). Some fragments are chemically zoned within the above range. Rare fragments have extremely Ab-rich composition for lunar plagioclase, with $An_{67}Ab_{30}Or_3$ and $An_{54}Ab_{44}Or_2$. The olivine compositions vary from Fo 8 to 80 (Fig. 5). The presence of large grains of silica mineral, fayalite, hedenbergite and Na-rich plagioclase suggests fractionation within a possible intrusion. Data of EET 87521 and MAC 88105 are after TAKEDA (private commun., 1990). Minor ilmenite is present within the G1 clast.

4. Discussion

In spite of presence of large plagioclase-rich clasts and large plagioclase fragments, almost all the pyroxene fragments in Y-793274 show chemical zoning or fine exsolution lamellae indicative of rapidly cooled rocks. Clast-laden vitric breccias, clast-laden breccias with fine-grained matrix and fine-grained impact melt-like basalts are other components of larger clasts. These features may be the reason why this breccia has been classified as anorthositic regolith breccia. Two other factors are that the largest gray plagioclase-rich clasts are white maskelynite-like glassy fragmental breccias with mafic silicates of non-highland origin, and that the original mare-type rocks were very coarse grained and relatively plagioclase-rich.

Types of mare components in regolith or fragmental breccias provided us with more useful information than their relative amounts of mare components in the anorthositic highland breccias. ALHA81005 and Y-791197 included only small amount of VLT (Very Low Titanium) basalts previously known only in Apollo 17 and Luna 24 samples (*e.g.*, TREIMAN and DRAKE, 1983; LINDSTROM *et al.*, 1986; TAKEDA *et al.*, 1986). Although EET87521 contained higher amounts of mare components, non-mare breccias are still present. Asuka-31 and Y-793169 are crystalline rocks (unbrecciated) and thus are the first lunar mare meteorites in a true sense (YANAI, 1990a, b).

Although bulk chemical compositions of EET87521, Asuka-31 and Y-793169 plot in the VLT basalt region in a diagram of TiO_2 *versus* Mg/(Mg+Fe) (YANAI, 1990a), their pyroxene chemical trends are not identical to those of the previously reported VLT basalts. The bulk chemistry of Y-793274 (FUKUOKA, 1990; LINDSTROM and MARTINAZ, 1990) is in the VLT region, but the pyroxene chemical trend extends towards the Mg-rich side. We (TAKEDA *et al.*, 1990b) pointed out the similarity of a pyroxene chemical trend of Y-793274 to the trend of basalt clasts (Ba-2) found in Apollo 16 anorthositic fragmental breccia 60019 (TAKEDA *et al.*, 1987). The bulk chemistry of Ba-2 has not been reported except for that obtained by the model abundance. The Ba-2 clast is coarse-grained and the zoning trend extends from Mg-rich to Fe-rich side. The Ba-2 clast may not be VLT basalt, because of the presence of minor ilmenite. The mare components are very rare in the Apollo 16 samples but such basalts are also known in the Luna 16 samples.

Occurrence of both Ba-2 and the VLT basalt mostly in lunar highland breccias and lunar meteorites, suggest a possibility that original basalt of Y-793274 is a highland basalt. The possibility of older age of Y-793274 reported first by TATSUMOTO (1990) is very important information on this problem, and further study is deeply awaited. The high concentration of trapped noble gases (EUGSTER, 1990) indicates that Y-793274 is a mature regolith breccia.

In summary, (1) Chemical variation of pyroxenes in Y-793274 can be interpreted in terms of chemical zoning similar to those found in a rare basaltic clast (Ba-2) found in lunar highland fragmental breccia 60019 (TAKEDA *et al.*, 1987) and meteoritic lunar mare materials. (2) Some pyroxene fragments show thin exsolution lamellae. (3) The most magnesian gabbroic clast found consists of nearly homogeneous olivine, plagioclase, and pigeonite with fine exsolution. (4) Y-793274 is a fragmental breccia with minor regolith components and is rich in pyroxenes suggestive of mare origin (or non-highland). (5) The mare components are not quickly cooled surficial rocks, but may be coarse-grained rocks from thick lava flows of differentiated materials.

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