Proc. NIPR Symp. Antarct. Meteorites, 2, 3–14, 1989

PRELIMINARY REPORT ON THE YAMATO-86032 LUNAR METEORITE: I. RECOVERY, SAMPLE DESCRIPTIONS, MINERALOGY AND PETROGRAPHY

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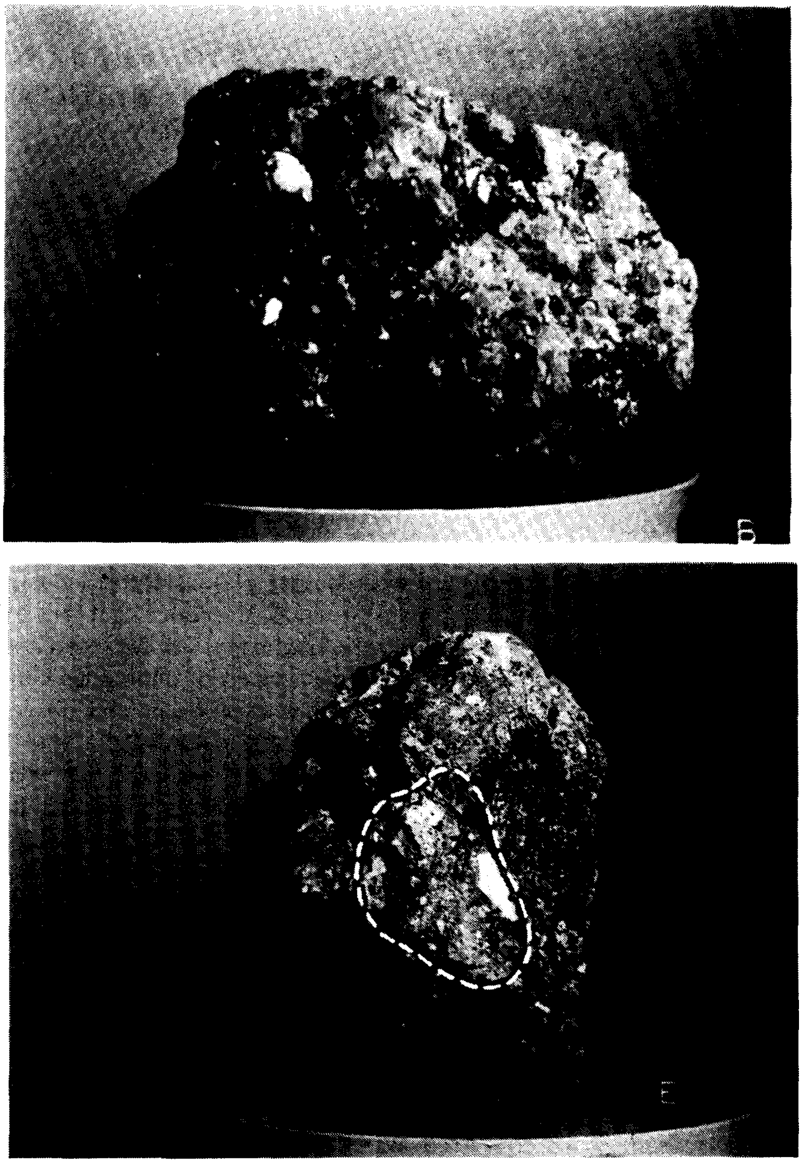
Abstract: A preliminary consortium examination of the largest lunar meteorite (Y-86032) recovered from the Yamato Mountains revealed that it is a feldspathic breccia, but rather resembles feldspathic fragmental breccias than regolith breccias. Y-86032 is a rugged grayish stone penetrated by numerous compact clast-laden impact melt glassy veins. Distributions of pyroxene and plagioclase chemical compositions are similar to those of Y-82192 and Y-82193, and clast-laden glassy veins and granulitic breccias are abundant. A large light clast in the first consortium sample is another feldspathic fragmental breccia similar to that found in Y-82192.

1. Introduction

Yamato-86032 is the largest lunar meteorite ever recovered and weighs 648.43 g (Fig. 1a). A preliminary examination by YANAI *et al.* (1987) showed that it is an anorthositic (regolith) breccia similar to the Yamato-82192 and 82193 lunar meteorites. Y-86032 is the fifth lunar meteorite identified in the Yamato meteorite collection. It was recovered from the area where Y-82192 and Y-82193 (Y-82192/3) were recovered by the 27th Japanese Antarctic Research Expedition Party (NISHIO *et al.*, 1987).

The purpose of the third lunar meteorite consortium study is to continue our efforts to characterize lunar meteorites to find possible pairing of several specimens recovered to date and candidates of craters where the meteorites were derived from. The origin of lunar highlands especially of the farside and the formation processes of lunar crust from a magma ocean will then be investigated on the basis of the data obtained by our group. Because of the large size of the Y-86032 sample, new scopes of researches will be possible. To find variability of clast types and matrices within the large breccia and origin of the glass veins is another important subject of this consortium study on Y-86032. It is also hoped to confirm the proposed pairing with the Y-

* See members of the group in Table 1.



a.

b.

Fig. 1. Photographs of lunar meteorite Y-86032. (a) B side. (b) E side. The chipped portion is indicated. Edge of the cube is 1 cm.

82192/3 lunar meteorites.

Among the research proposals for our consortium group, those accepted by NIPR for a preliminary examination are listed in a separate table (Table 1).

2. Recovery of Y-86032

The inland traverse party of the 27th Japanese Antarctic Research Expedition (JARE-27) led by Dr. F. NISHIO visited the Yamato Mountains region in the 1986–87 austral summer season, and search and collection of meteorites were carried out in the Meteorite Ice Field (NISHIO *et al.*, 1987). During the glaciological survery, Y-86032 was found and collected at the neighbouring site of Y-82192 and Y-82193 (KATSUSHIMA *et al.*, 1985).

Table 1. List of the consortium members.

1.	NISHIO, F., KOJIMA, H. and YANAI, K. (NIPR): Recovery, processing and characterization.
2.	KUSHIRO, I. and HARAMURA, H. (Univ. Tokyo): Bulk chemistry and petrology.
3.	LINDSTROM, M. M. *et al.* (NASA/JSC): Geochemistry, INAA.
4.	MCKAY, D. S. *et al.* (NASA/JSC): Regolith study.
5.	KOEBERL, C. *et al.* (Univ. Vienna): Halogens and other trace elements.
6.	EUGSTER, O. (Univ. Bern): Exposure ages, terrestrial ages, noble gases.
7.	LIPSCHUTZ, M. E. (Purdue Univ.): Volatile trace elements by RNAA.
8.	WARREN, P. H. and KALLEMEYN, G. W. (UCLA): Compositional, petrographic studies by INAA.
9.	TAKEDA, H. *et al.* (Univ. Tokyo): Mineralogy.
10.	CLAYTON, R. N. and MAYEDA, T. (Univ. Chicago): Oxygen isotopes.
11.	MASUDA, A. *et al.* (Univ. Tokyo): Geochronology and REE.
12.	NISHIIZUMI, K. and ARNOLD, J. R. (UCSD): Cosmic-ray exposure histories.
13.	FUKUOKA, T. *et al.* (Gakushuin Univ.): Trace element chemistry.
14.	TAKAOKA, N. (Yamagata Univ.): Noble gas analyses.
15.	TATSUMOTO, M. *et al.* (USGS Denver): Pb chronology.
16.	KANEOKA, I. (Univ. Tokyo): Ar-Ar chronology.
17.	NAGATA, T. and FUNAKI, M. (NIPR): Magnetic properties.
18.	STÖFFLER, D. *et al.* (Inst. Planet., Univ. Münster): Shock metamorphism.
19.	WÄNKE, H. and BEGEMANN, F. (Max-Planck-Inst.): Multi-element chemistry.
20.	PILLINGER, C. T. and GRADY, M. M. (Open Univ.): Carbon and nitrogen.
21.	NAGAO, I. (Okayama Univ.): Kr exposure age.
22.	TANAKA, T. (Japan Geol. Survey): Ce isotopes.
23.	NYQUIST, L. E. *et al.* (NASA/JSC): Rb-Sr and Sm-Nd isotopic studies.
24.	XIE, X. *et al.* (Inst. Geochem., Academia Sinica).
25.	MCFADDEN L. *et al.* (UCSD): Reflectance spectroscopy.

The glaciological party stayed about one month, in the southern part of the bare ice area extending from the Minami Yamato Nunataks in the Meteorite Ice Field. They resurveyed the triangulation chain installed in 1983 to measure ice flow and strain rates, and measured the ice thickness by radio-echo sounding to depict a topographic map of the bare ice area. During the glaciological survey, the search for meteorites was not systematically organized, but conducted by careful observations of the bare ice surface with the naked eye mostly while driving snow vehicles at all times by all members of the traverse party.

Y-86032 was found on the bare ice surface in the neighbouring location of Y-82192/3 collected in the austral summer of 1982–83 as shown in Fig. 2. It was recognized as a lunar meteorite when it was recovered in the field on December 9, 1986 by Dr. F. NISHIO who also noticed that this meteorite was similar to Y-82192/3 (F. NISHIO, pers. commun., 1987). This finding was also confirmed by Dr. A. GRAHAM, who was a visiting scientist at the NIPR at the time of sample processing.

Y-86032 is the fifth lunar meteorite identified in the Yamato meteorite collection and the locations of lunar meteorites are shown in Fig. 2. The location of Y-86032 is very close to that of Y-82192/3 within a several kilometers on the bare ice surface, but is more than 30 km far from the location of lunar meteorites of Y-791197 and Y-793274.

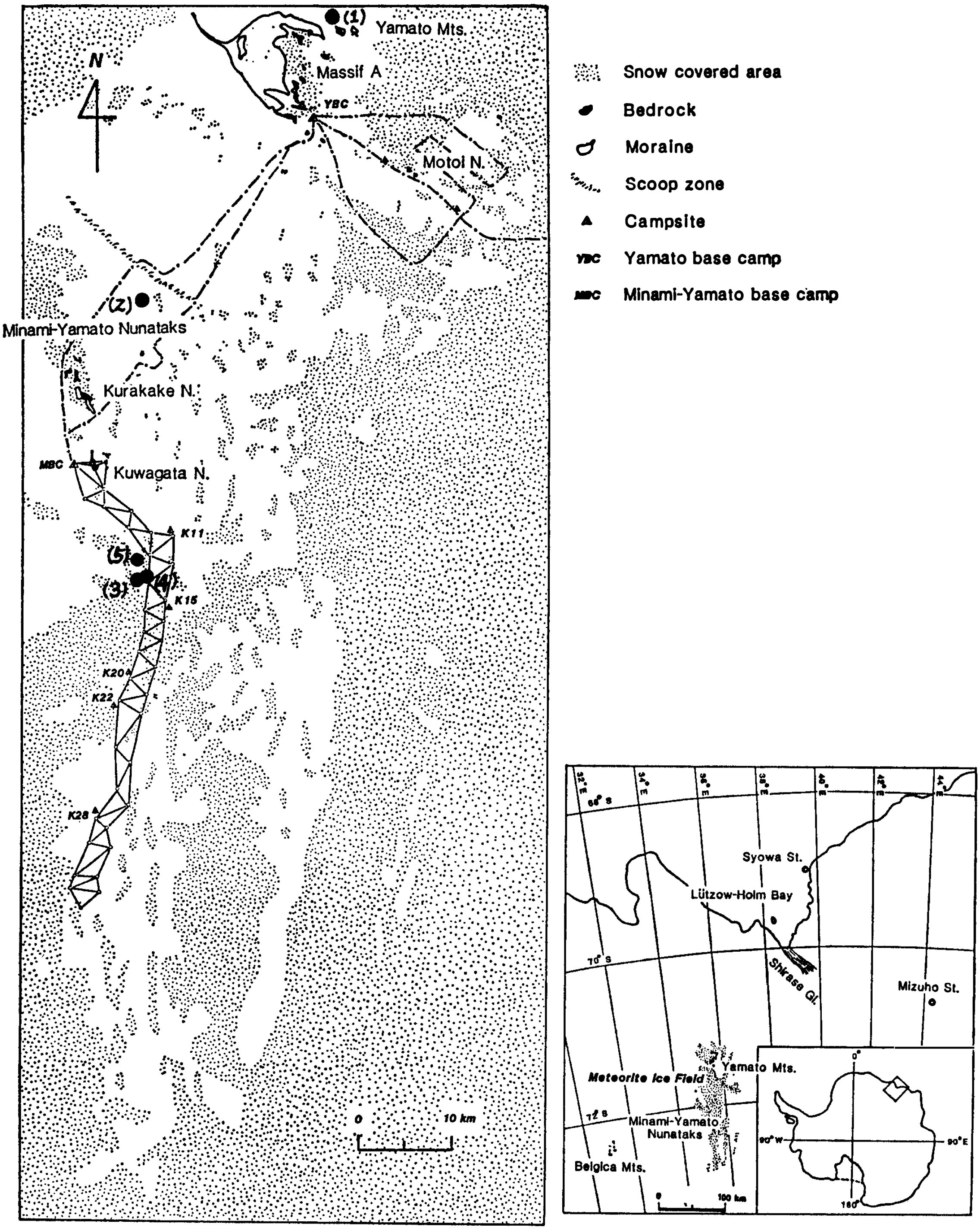


Fig. 2. Location map of lunar meteorite findings. Solid circles: location of lunar meteorite finding. Solid line: triangulation chain. (1) Y-791197, (2) Y-793274, (3) Y-82192, (4) Y-82193, (5) Y-86032.

3. Physical Description

Physical descriptions of each side of Y-86032 are given in Photographic Catalog (YANAI *et al.*, 1987). It has the typical appearance of lunar meteorites, such as white to gray clasts set in light gray more comminuted matrix (Fig. 1a). It is characterized by the presence of numerous impact melt veins and deep narrow cavities. The S and T views show such features. Impact melts characterized by a compact gray glassy appearance without clasts are seen at the upper right and lower left corners of the T view. A part of the fusion crust with a smooth curved surface is visible together with a number of large white clasts on the W and N views. The yellow-brown coating is visible in the N view.

A typical fresh breccia matrix has been observed in the middle left side on the E view (Fig. 1b). This portion shows a smooth slightly weathered surface, where fragments of white clasts up to 5×3 mm are seen. Adjacent to this area, a large grayish white (light) clast with fine-grained compact texture 1.0×0.5 cm in size is embedded in a gray fine-grained compact impact melt extending 6.0 cm along the top-to-bottom right portion of the E side. Samples for the first allocation were chipped off from this portion, including a large part of the large light clast. About 2 cm towards the right side the surface is rugged and the fractured-matrix with fine clasts (less than 1 mm in diameter) show subparallel fractures and deep narrow voids.

4. Processing and Descriptions of Samples

These first consortium samples consist of three large fragments, two of which include a part of the large light clast, and many small fragments containing small white clasts. The large light clast is enclosed by matrix and one side of the clast is bordered by a dark glass vein. The small chips are almost entirely dark to medium gray matrix and occasionally contain small white clasts. Except for a few chips they have no visible glass veins. Three fragments (collectively designated ,71, 1.191 g), one including a large light clast, were allocated to the U.S. investigators.

The first sample (,20) chipped off from the main mass for the consortium study consists of three large chips (,52, ,53, ,61) and weighs 6.898 g. Small fragments have

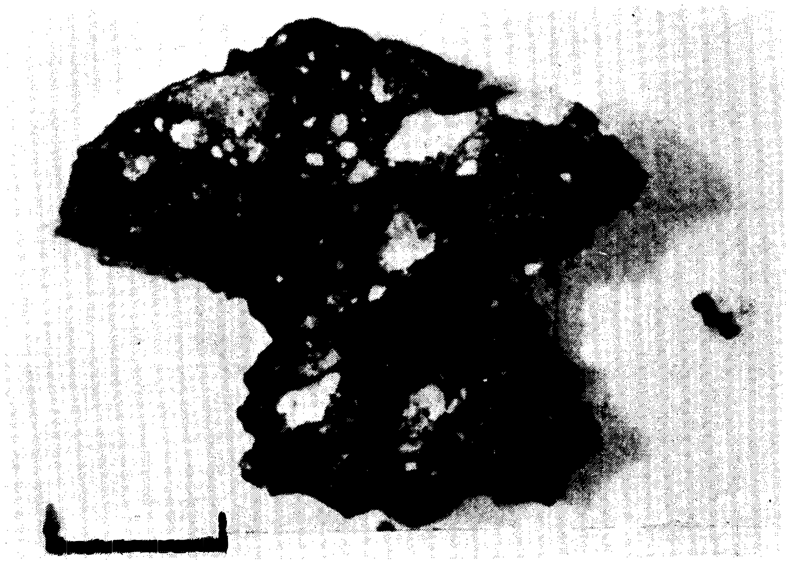


Fig. 3. Photograph of a chip (,57) distributed for the second consortium allocation. Bar width is 0.5 cm.

been produced by the second chipping, and the total weight for the first allocation is about 10 g. The largest chip (,52, 3.273 g) includes a part of the light clast 8×4 mm in size. This sample (,52) is kept at NIPR for future studies. Another portion of this clast still remains in the original main mass. The second large chip (,53) includes three large white clasts up to 3×2 mm in size and a portion of the matrix which may be a part of the weathered surface. This specimen was divided into two chips and one (,54, 1.033 g) was allocated to petrographic, mineralogical and geochemical studies

Table 2. Generic relationship of sample (0) prepared for the consortium study.

Sub-No.	Weight (g)	Remarks	Investigator*
20	6.898	(Subdivided)	
51	2.136	PTS	
56	0.788	Bulk chem.	2
61	1.063	(Subdivided)	
62	0.110	(Subdivided)	
63	0.224 (matrix)	Noble gas	14
70	0.163 (interior)	Stable isotopes	20
71	1.191	(Subdivided)	
81	0.170 (fragments)		
84	0.309 (impact melt)	Halogens	5
85	0.315 (bulk)	Halogens trace elements	5
86	0.420 (bulk)	Noble gases	6
87	0.376	Magnetic study	17
88	0.113	Trace elements etc.	19
89	0.143	Petrography, shock effects	18
90	0.028	*ibid.*	18
109	0.013 (glass)	INAA	13

Parents	Sample No.	Weight (g)	Remarks	Investigator*
20	52	3.273		
	53	3.033		
	82	0.336 (clast)		
	83	0.182	PTS	
	91	0.074		
53	54	1.033	Geochemistry	21
	55	0.215 (exterior)	Exposure ages	12
61	93	0.022	INAA	8
	95	0.175 (clast)	REE	11
	97	0.008 (clast)	PTS	
	98	0.310 (matrix)	REE	11
	99	0.048 (matrix)	Noble gases	16
	106	0.008 (clast)	INAA	13
	107	0.003 (clast)	PTS	13
62	64	0.100 (clast+matrix)	INAA	
	65	0.010 (clast)	PTS	
	71	1.191	U.S. splits	
82	92	0.143 (clast)	Noble gases	16
	108	0.071 (clast)	Noble gases	14

* See number in Table 1.

(XIE). Another exterior chip (,55, 0.215 g) was allocated for the exposure age study (NISHIIZUMI).

About one-third of the third large sample (,61) weighing 1.063 g is the light clast (feldspathic fragmental breccia). A PTS (,97) of the light clast was made from this fragment. A fragment of this light clast (,95) was allocated to a REE study (MASUDA). Matrix portions (,98) were also allocated to the REE study (MASUDA), and noble gas study (,99, KANEOKA), which is located at the back-side of the light clast. The sample (,61) includes three other small clasts; a chalky white anorthositic clast (,93) was allocated to an INAA study (WARREN) and one white clast (,106) to another INAA study (FUKUOKA).

Another fragment of the light clast (,82, 0.336 g) was divided into two, and a 0.143 g sample (,92) was allocated to noble gas studies (KANEOKA); and 0.071 g sample (,108) to another such study (TAKAOKA).

A sample including also this light clast (,71), which consists of three fragments A, B and C (,72, ,73, ,74), was allocated to the U.S. members. Many other clean fragments were picked up for the remaining studies listed in Table 2. A sample (,56) including fragments of all portions of the entire chips without fusion crust, totaling 0.788 g, was allocated to the bulk chemical analysis (KUSHIRO and HARAMURA).

A sample of fragment of grayish breccia matrix (,63, 0.224 g) was allocated for an additional noble gas study (TAKAOKA). A 0.100 g fragment (,64) of clast and matrix was allocated to the INAA study (FUKUOKA) for identification of the clast type and 0.010 g sample (,65) is saved for the PTS.

A 1.191 g split of Y-86032 (,71) was received at the NASA-JSC Meteorite Processing Laboratory for processing and distribution to U.S. investigators. The sample consisted of three chips, all of which were matrix material containing some clasts and free of fusion crust. The matrix is light to dark gray, medium-grained and fairly uniform. Clasts include anorthosites and anorthositic breccias. LINDSTROM/LIPSCHUTZ received matrix (,75, ,76), two clasts (,101, ,103) and a glass vein (,102) for INAA/RNAA. TATSUMOTO was allocated with matrix (,77, 0.160 g) for radiogenic isotope studies. WARREN received matrix (,78, 0.285 g) and two clasts (,104, 0.008 g; ,105, 0.005 g) for INAA. CLAYTON was allocated with matrix (,79, 0.154 g) for oxygen isotope studies. D. MCKAY was given the matrix residues (,80, 0.175 g) from the three fragments for regolith studies.

Another large fragment (Fig. 3) far from the location of the first chips has been chipped for the second allocation.

5. Thin Section Description

Y-86032 is a feldspathic lunar highland breccia consisting of lithic and mineral clasts set in fine-grained matrix of comminuted minerals. The PTS (Y-86032,51-1) of the representative portion as is given in the Photographic Catalog (YANAI *et al.*, 1987) shows some characteristics of regolith breccias of the lunar highland, but also resembles feldspathic fragmental breccias (MCKAY *et al.*, 1986). The regolith components such as glass spheres and agglutinates are smaller than in ALH81005 (RYDER and OSTERTAG, 1983; WARREN *et al.*, 1983) and Y-791197 (LINDSTROM *et al.*, 1986). It may be a very immature regolith breccia or a part of megaregolith.

The glassy materials are present in vitric clasts, matrices and as veins. The matrix glasses are not as abundant as in ALH81005 and Y-791197, but portions of the matrices are penetrated by brown clast-laden glassy veins with flow textures. These features are similar to Y-82192/3. The glass matrix may be devitrified crystalline materials on micron scale detectable by TEM.

The mineral fragments consist of plagioclases, pyroxenes, and olivines. The mafic silicates components are more abundant than in Y-791197 (OSTERTAG *et al.*, 1986). Lithic clasts include many impact melt clasts, light feldspathic clasts, and granulitic breccias consisting of plagioclase, olivine, and pyroxene. Granulitic clasts and clast-laden vitric (devitrified) breccias are dominant.

The most characteristic feature of Y-86032 is a clast-laden impact melt vein penetrating the breccia. The shapes of clasts facing the vein tend to be modified and show smooth curved surfaces. Granulite, the most abundant clast lithology in ALHA81005, is also common in Y-86032. This lunar meteorite has been described as regolith breccia but it resembles feldspathic fragmental breccias of the Apollo 16 lunar highland (LINDSTROM and SALPAS, 1983), in that it contains very few glassy regolith components.

Y-86032,50-1 is a PTS of a general breccia portion as described above (,51-1), but the matrix is not as crystalline as was reported previously for Y-82192/3 (YANAI *et al.*, 1984). This PTS includes a few large lithic clasts and fragments of crystalline to partly shock-melted plagioclases, and vitric clasts. The clasts vary in size, with the largest clast 2×0.8 mm in size.

Thin section Y-86032,83-1 is a PTS of a part of the large light clast, which is a

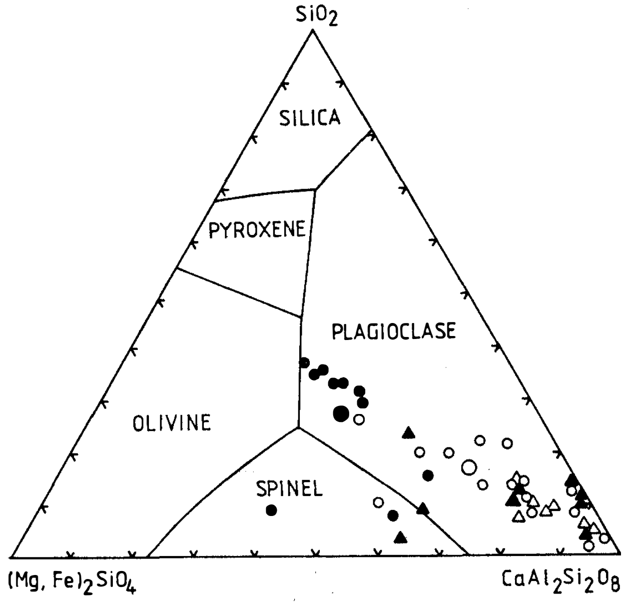


Fig. 4. Compositions of matrix glasses in Y-82192 anorthositic breccia clast (open triangles) and Y-86032 plotted in the silica-olivine-anorthite pseudo-ternary system. Solid triangles: Y-86032 light anorthositic breccia clast; open circles: bulk matrix; and solid circles: clast-laden glassy vein. Large symbols are average compositions.

light-colored anorthositic fragmental breccia similar to one (BB clast) found in Y-82192 (TAKEDA *et al.*, 1987). The clast is a fine-grained light brown anorthositic breccia containing some plagioclase fragments. The clasts are set in light brown matrix of fine comminuted anorthosites and light-colored glassy materials. It contains a few fine-grained rounded mafic minerals. The clast is surrounded by dark clast-rich matrix and one side of the clast is bounded by still darker fragment-laden glass, which is a part of the impact glass vein seen on the E surface. The clast is bleached at this boundary. The other sides of the clast are surrounded by dark clast-rich matrix, which represents the matrix portion of the entire breccia. This portion contains more fragments of mafic silicates than other lunar meteorites. The amount of matrix glass in the light clast is smaller than the host matrix and the bulk chemical composition of the matrix glass obtained by a broad beam analysis of EPMA is more feldspathic than the matrix of Y-82192 (Fig. 4).

6. Mineralogy and Petrography

The compositions of small fragments of pyroxene in the Y-86032 matrix plotted in the pyroxene quadrilateral (Fig. 5) are distributed within the Mg-rich field of the lunar crustal rocks (RYDER and NORMAN, 1978a, b). This pattern is close to that of 60016 (TAKEDA *et al.*, 1979). Y-86032 contains only minor regolith components such as glass spherule and agglutinates. Mare basalt components have not been confirmed.

The compositions of plagioclase fragments are similar to those of the other lunar meteorites. The An mol% ranges from 87 to 99, but the most abundant range is between 95 and 98 with maximum population at 96.5. The distribution of the An mol% of plagioclase in the light clast compared to that of the entire PTS shows that the compositional variation is small. The Fa mol% of olivine fragments ranges from 15 to 40.

The compositions of the glassy matrix within the light anorthositic breccia clast, the impact melt glasses, and bulk matrices, plotted in the silica-olivine-anorthite diagram (Fig. 4), show that the composition of the matrix of the light anorthositic

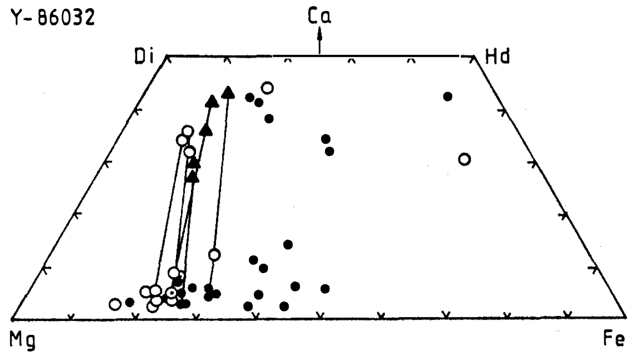


Fig. 5. Pyroxene quadrilateral of Y-86032. Solid circles are compositions of individual fragments of pyroxenes in the matrix. Open circles are those of lithic clasts. Tie-lines connect the host and exsolved lamella-augite pairs.

breccia clast is more anorthitic than the bulk matrix, and is similar to that of the Y-82192 (BB) anorthositic breccia clast (TAKEDA *et al.*, 1987). The composition of the dark clast-laden glassy vein is rich in mafic components and silica. Such veins penetrate the breccia matrices.

The distribution of pyroxene compositions in the pyroxene quadrilateral (Fig. 5) is similar to those of Y-82192 and Y-82193 and to Apollo 16 regolith breccia 60016 (TAKEDA *et al.*, 1979), and feldspathic fragmental breccia 67016,111 (TAKEDA and MIYAMOTO, 1988). All kinds of pyroxenes from non-mare crustal rocks are represented in the fragments. One large fragment is an inverted pigeonite with coarse blebby augite inclusions and another large fragment shows moderately coarse (100) exsolution in orthopyroxene. Augites are present in some granulitic breccia clasts. One subophitic clast includes iron-rich pyroxenes, but they may be a mesostasis portion. Mare basalt components as were found in ALH81005 (TREIMAN and DRAKE, 1983) and several other lunar meteorites were not found in Y-86032.

7. Preliminary Data of the Consortium Study

Major and trace element chemistry of Y-86032 is given as Part II of the Preliminary Report of our consortium studies (KOEBERL *et al.*, 1989) in this volume and data on noble gas, isotopes, oxygen isotopes and various exposure ages are given as Part III (EUGSTER *et al.*, 1989). Major element chemistry was obtained by a standard wet chemical analysis by H. HARAMURA and I. KUSHIRO, Geol. Inst., Univ. Tokyo. The analytical data will be included in Part II.

8. Discussion

All of the lithologic, petrographic, mineralogical and compositional observations confirm the lunar origin of this meteoritic breccia. It is a highly feldspathic breccia with composition very similar to the other lunar meteorites (OSTERTAG *et al.*, 1986; WARREN *et al.*, 1983) and to lunar granulites and Apollo 16 feldspathic fragmental breccias (LINDSTROM and SALPAS, 1983; MCKAY *et al.*, 1986). Compared to other lunar meteorites Y-86032 matrix has the highest Al_2O_3 and CaO contents, and the lowest FeO content, making it the most feldspathic lunar meteorite. The *mg* number ($=Mg\times 100/(Mg+Fe)$) of 66–69 in bulk samples is higher than in Y-82192/3 (typically 62–65, but one sample 71) and Y-791197 (*e.g.*, LINDSTROM *et al.*, 1986; OSTERTAG *et al.*, 1986; TAKEDA *et al.*, 1987) and lower than in ALHA81005 (*e.g.*, WARREN *et al.*, 1983). Concentrations of trace transition metals, of siderophile elements, and of REE are reported in the companion paper of the interim consortium reports. Y-86032 is compositionally most similar to Y-82192/3, but some compositional differences do exist.

Y-86032 is reported as an anorthositic regolith breccia (YANAI *et al.*, 1987), but is rather similar to feldspathic fragmental breccias of the Apollo 16 samples (MCKAY *et al.*, 1986). The minor regolith components and the low trapped noble gas contents suggest that Y-86032-type lunar meteorites can be viewed as either a well-mixed ordinary fragmental breccia never exposed to solar wind or an immature regolith breccia that may have lost part of its former contents of noble gases due to shock-metamorphism. Impact melt glass (devitrified) is present in Y-82192/3, but the presence of dark brown clast-laden impact melt glassy vein is more pronounced in Y-86032. The compositional results neither confirm nor reject pairing with Y-82192/3. Some of the results of these members are included as separate interim reports in this volume. O. EUGSTER's group reports their noble gas study, which indicates that Y-86032 is noble gas poor and may be paired with Y-82192 and Y-82193 (EUGSTER *et al.*, 1989). We await the results of detailed petrographic and mineralogical studies and of various exposure measurements to evaluate whether these samples are paired.

Acknowledgments

We thank National Institute of Polar Research for the samples to this consortium study, and Drs. M. M. LINDSTROM, P. H. WARREN, A. L. GRAHAM and Miss Robbie SCORE for their help on characterization and distribution. The consortium leader thanks Drs. C. KOEBERL and O. EUGSTER for compiling their preliminary reports of this consortium.

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(Received September 29, 1988; Revised manuscript received January 20, 1989)