15015	REGOLITH BRECCIA	LM	4770 g

INTRODUCTION: 15015 is a coherent, glassy matrix breccia containing abundant glass balls, shards, and schlieren, most of mare and KREEP basalt derivation. It is largely coated with a glass which is either splashed on or melted from the rock. The breccia has a composition very similar to LM soils.

15015 was collected ~20 m west of the LM +Z footpad, in a flat, smooth area, but its sampling was not documented. Its appearance on the surface was unique. Its lunar orientation has been approximately reconstructed from long-range photography. It is a brownish gray, blocky and angular breccia sample, with a glass surface (Fig. 1). The glass is vesicular, brownish black, and of varied thickness. Zap pits occur on only one side and are small. 15015 was extensively studied by the European Consortium (1974, 1977).

Figure 1. Sawing of 15015, showing vesicular glassy coat. S-71-58731

PETROLOGY: The petrology of 15015 has been extensively described by the European Consortium (1974, 1977), with many microprobe analyses, with less extensive studies by Sewell et al. (1974), Gleadow et al. (1974), McKay and Wentworth (1983), Wentworth and McKay (1984), and McKay et al. (1984). The rock is a shock-fused, polymict soil breccia (Fig. 3). The matrix is composed of glass and devitrified glass crowded with tiny mineral fragments. Larger rock, mineral, and glass fragments are set in the matrix. The whole is a low-grade breccia (Warner Grade 2). The rock fragments include basalts of several types (84%) including mare basalts, plagioclase basalts, Fra Mauro basalts; and subsidiary (16%) metaclastic fragments. No distinct banding or segregation is visible. McKay et al. (1983) found it to be compact but with a high fracture porosity, agglutinates to be very rare, spheres to be rare, and shock features to be common. Wentworth and McKay found it to have a bulk density of 2.53 g/cm^3 (intrinsic density 3.15 g/cm^3) and a calculated porosity of 19.7%. McKay et al. (1984) and Korotev (1984 unpublished) reported a very immature I_s/FeO of 3.

Most mineral clasts have shock features, and include coarser-grained varieties than the lithic clasts, indicating another source. Analyses are presented by the European Consortium (1977). Pyroxene varieties are shown in Figure 4a and embrace those of pyroxene in lithic clasts. Some magnesian varieties may represent noritic plutonic rocks. Plagioclases (Fig. 4b) range from An_{97} to An_{80}, and are not in general zoned. Part of the population is more An-rich than any in lithic clasts.

Vitric fragments constitute about 10% of 15015, and include indeterminate plastic forms, twisted and ropey forms, spheres, and broken fragments. Five main chemical categories have been recognized. Fra Mauro basaltic glass is most abundant, with agglutinates, mare-type basaltic glasses, highland basalt glasses, and green glass spheres subordinate. Representative analyses are quoted by the European Consortium and shown in Fig 4c.

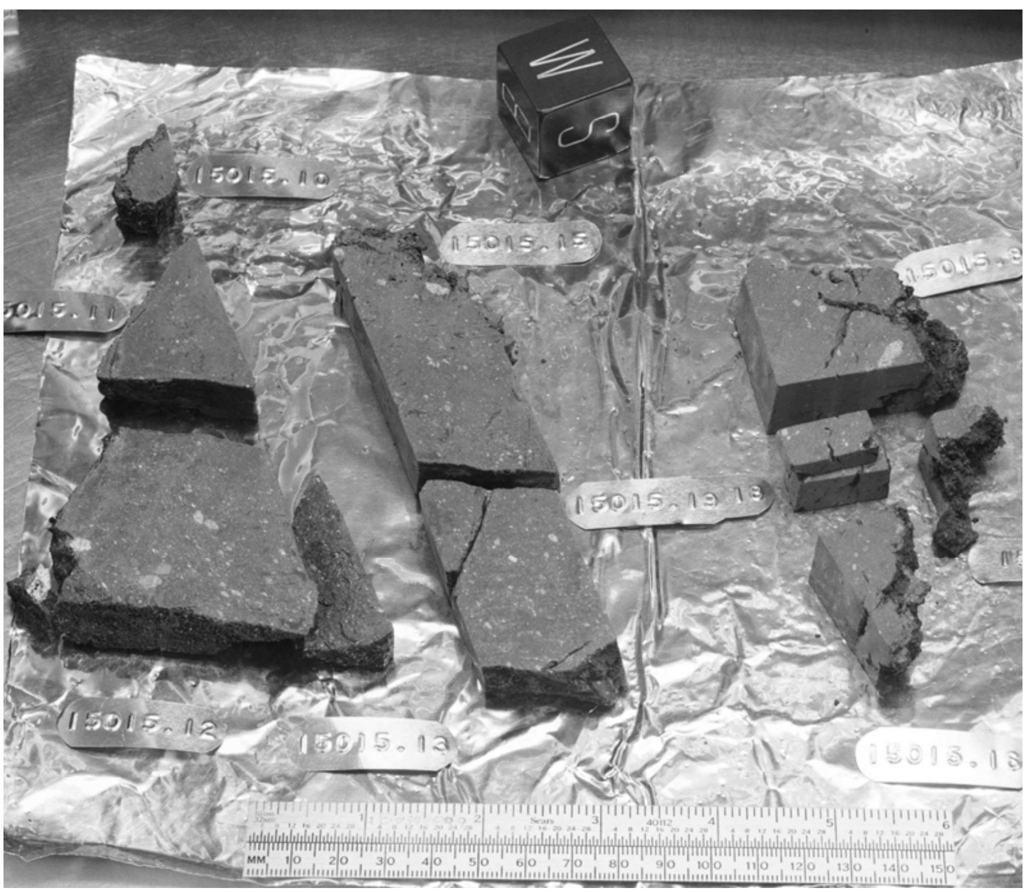


Figure 2. Pieces from subdivision of slab ,8. S-71-59080

Fig. 3a

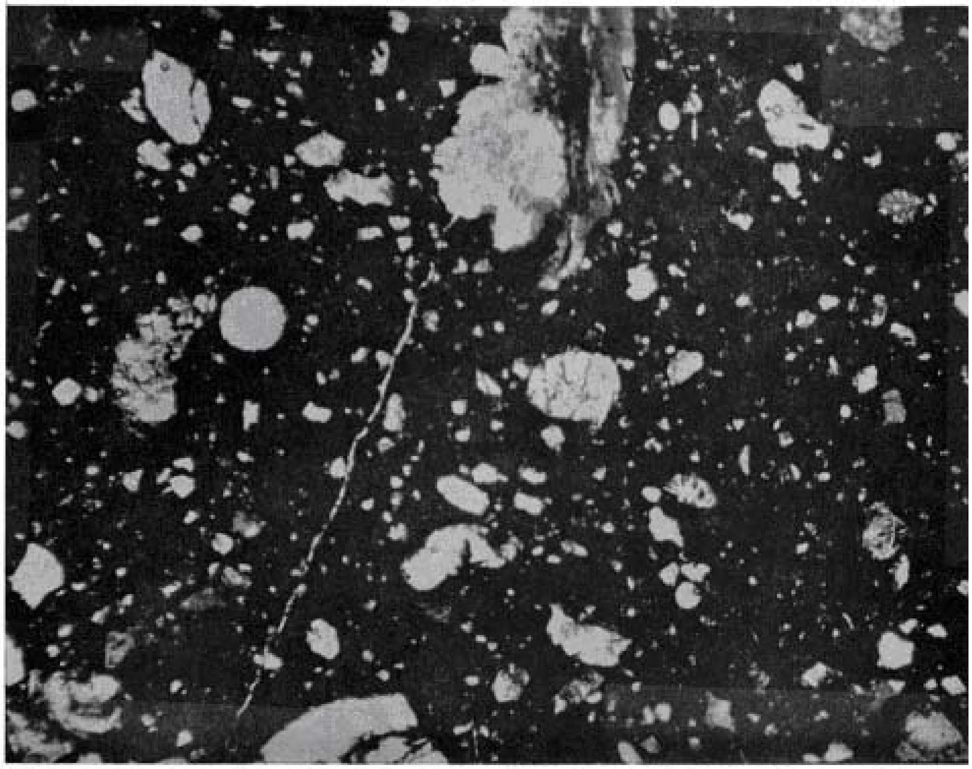


Fig. 3b

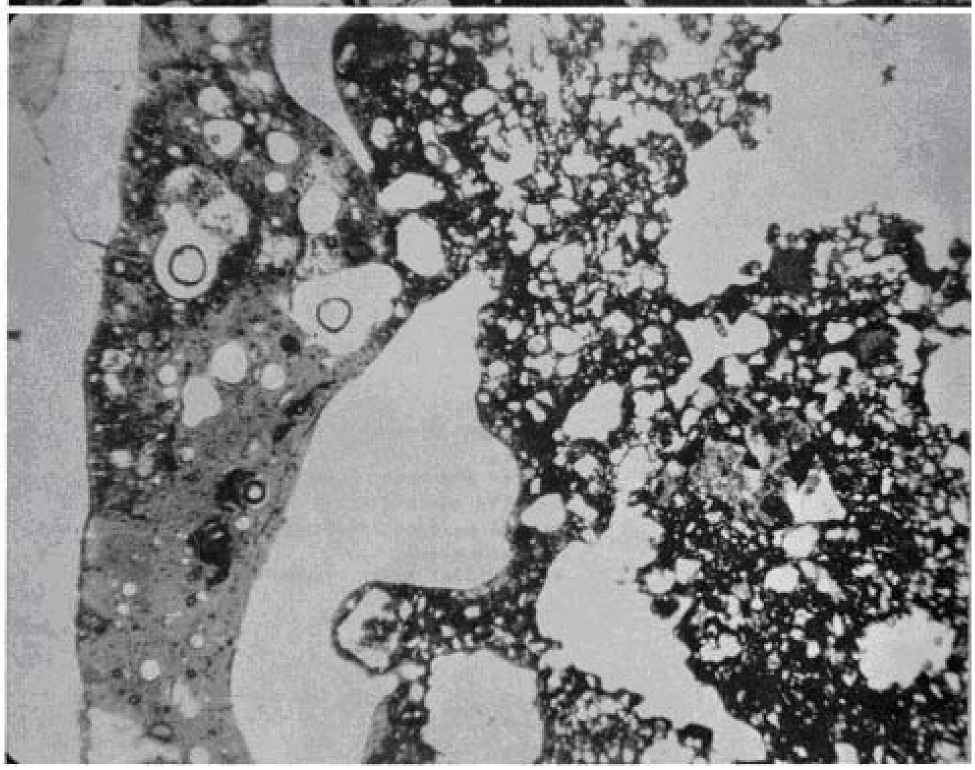
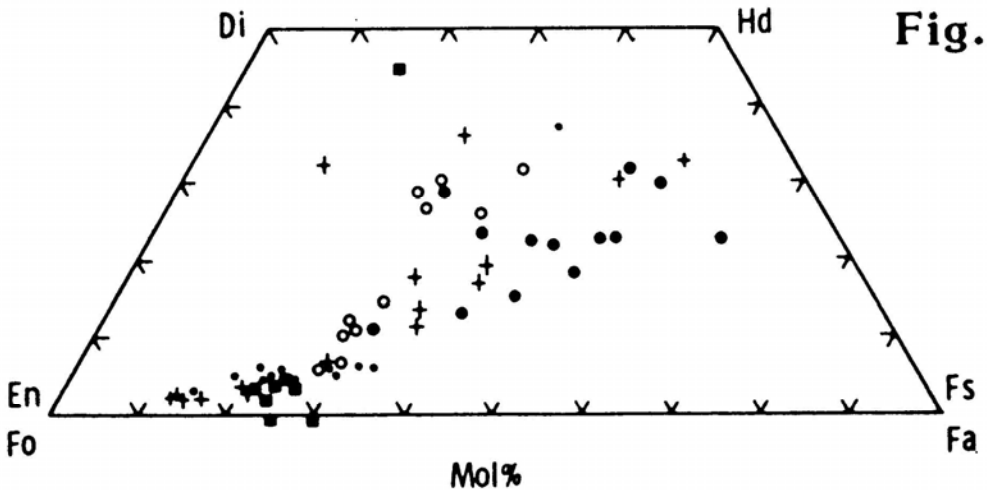


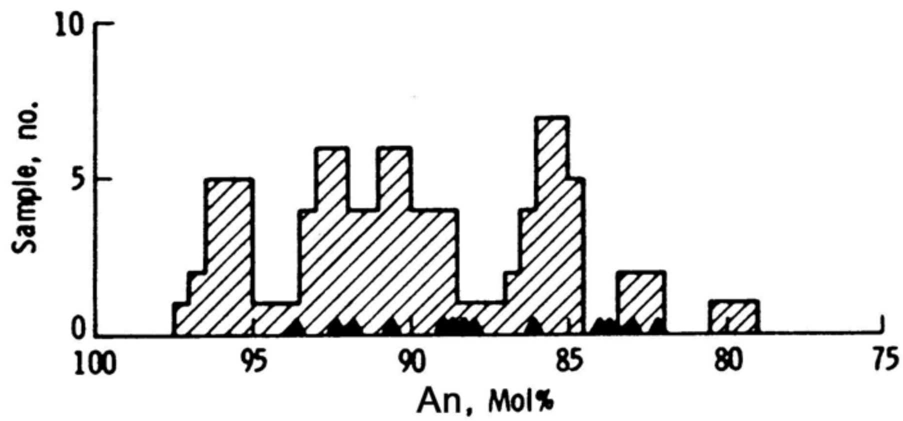
Figure 3. Photomicrographs of 15015.
Transmitted light. Widths about 3 mm.
a) general matrix; b) matrix (top) and vesicular glass coat.

Fig. 4a



- o Mare-type basalts
- • Feldspathic basalts
- · Fra Mauro-type basalts
- ■ Metamorphic (recrystallized) rocks, probably metaclastic, some Fra Mauro, others ANT suite
- + Single-crystal clasts

Fig. 4b



▲ Composition of plagioclase in lithic fragments

15015 histogram of plagioclase compositions in mineral clasts, size 100 to 400 μm.

Fig. 4c

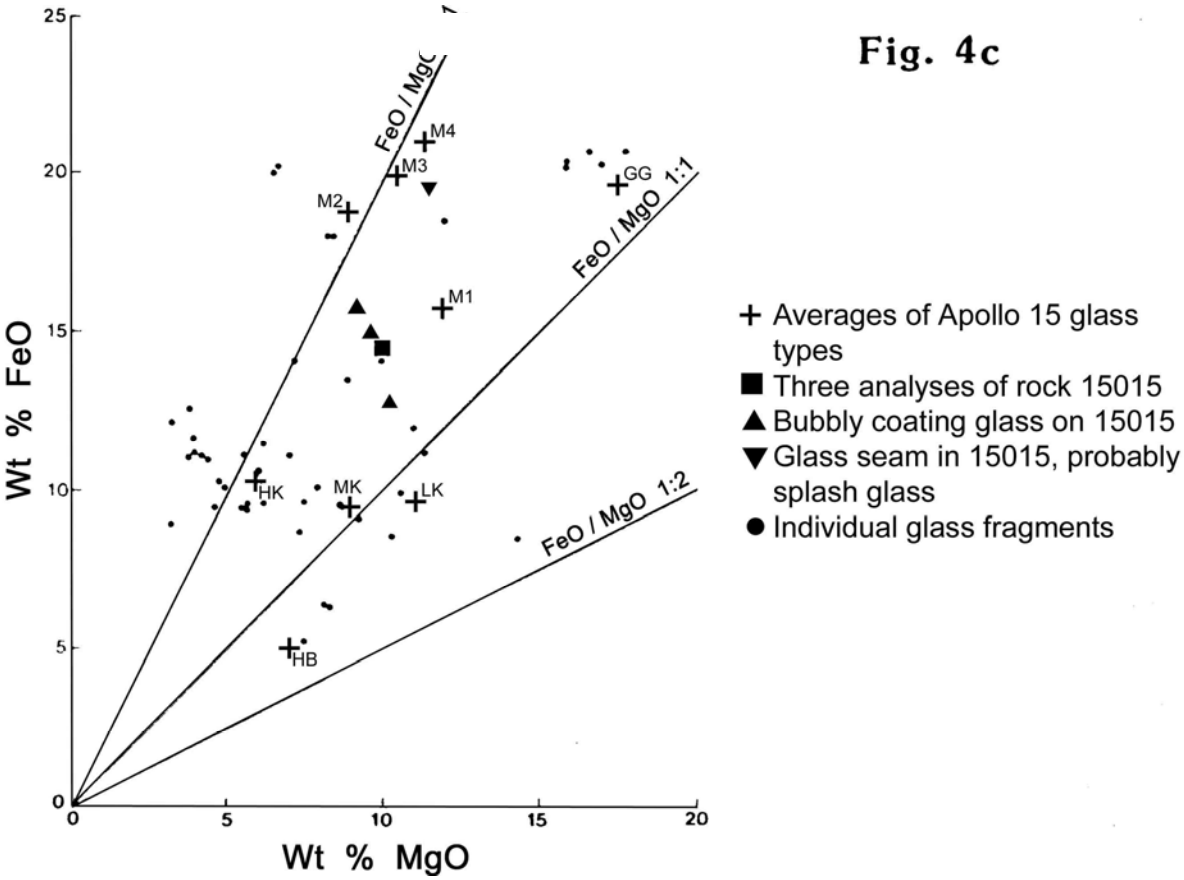


Figure 4. a) Pyroxene compositions; b) plagioclase compositions;
c) FeO vs. MgO for glasses in 15015 (all European Consortium, 1977).

Lithic clasts also constitute about 10%, of which 30% are mare basalts, 33% Fra Mauro basalts, 22% feldspathic basalts, and 15% metaclastic. The mare basalts can be matched texturally with larger samples of mare basalts, but olivine-bearing types are rare. Gleadow et al. (1974) also found mare basalts to be well represented in 15015. Fra Mauro basalts are the typical, olivine-free, clast-free KREEP basalts which are widely believed to be volcanic (represented by 15386, etc). These were also recognized by Gleadow et al. (1974). Feldspathic basalts have higher An in their plagioclase and typically higher Fe/(Fe + Mg) than the Fra Mauro basalts. The metaclastic samples include feldspathic granulites and porphyroclastic rocks with a fine-grained (5 to 30 micron) matrix.

The glass coat is thick and frothy on the upper surface, thinner and smoother lower down (European Consortium, 1974, 1977). Its polarization properties show it to be smooth and complex. The composition is similar to the composition of the bulk rock (European Consortium, 1977, Table 1-11), and is interpreted by those authors and by Cadenhead and Stetter (1975) as a melt of 15015, not a splash coat (however, local soils are the same

TABLE 15015-1. Chemical analyses of matrix of 15015

		15	,30	,11	,15,11	,15 2B	,15,2B	,40	
Wt %	SiO2	47.11			47.30		47.50		
	TiO2	1.90	1.5	1.70	1.74	1.04	1.76		
	Al2O3	14.46	14.2		14.16		13.99		
	FeO	14.38	15.2		14.56		14.63		
	MgO	9.93	10		10.09		10.12		
	CaO	10.49	10.2		10.62		10.52		
	Na2O	0.31	0.462	0.49	0.50	0.51	0.50		
	K2O	0.28a	0.25	0.234	0.22	0.248	0.24		
	P2O5	0.22			0.22		0.24		
(ppm)	Sc		27						
	V		130						
	Cr	2700	2800	2685		2755			
	Mn	1500	1400		1700		1650		
	Co		43						
	Ni							236	
	Rb			6.34		6.86			
	Sr			135.4		133.6			
	Y								
	Zr		560[b]	387		445			
	Nb								
	Hf		10.0	11.2		12.9			
	Ba		300	294		319			
	Th		4.5	4.4		4.9			5.049
	U		1.4	1.33		1.42			1.357
	Pb								2.837
	La		30	28.0		29.8			
	Ce		80	72.7		79.1			
	Pr								
	Nd			44.7		48.1			
	Sm		14.2	13.0		13.8			
	Eu		1.6	1.44		2.01			
	Gd			15.2		16.5			
	Tb		2.5						
	Dy		17	17.3		18.6			
	Ho								
	Er			10.2		11.2			
	Tm								
	Yb		9.9	9.30		9.86			
	Lu		1.4	1.34		1.46			
	Li			14.7		15.4			
	Be								
	B								
	C	121							
	N	54							
	S	630							
	F								
	Cl								
	Br								
	Cu								
	Zn							13.1	
(ppb)	I								
	At								
	Ga							4200	
	Ge							378	
	As								
	Se								
	Mo								
	Tc								
	Ru								
	Rh								
	Pd								
	Ag								
	Cd							40	
	In							3.0	
	Sn								
	Sb								
	Te								
	Cs								
	Ta		1400						
	W								
	Re								
	Os								
	Ir							7.3	
	Pt								
	Au							3.1	
	Hg								
	Tl								
	Bi								
		(1)	(2)	(3)	(1)	(3)	(1)	(4)	(5)

composition, so a splash coat is not precluded). Wilshire and Moore (1974) noted that the glass does not mask the very angular character of the rock, whose planar surfaces appear to be conjugate fractures formed in previously consolidated breccia. Thin sections of the glass and breccia show a gradual increase in glass and vesiculation outwards over the last few millimeters into the glass coat, without a sharp contact.

Electron microscope examination of micron-sized grains from a bottom chip (European Consortium, 1977) showed that less than 10% of grains were amorphous, but many showed evidence of shock. Almost 30% of the grains contain microcrystallites similar to those in artificially heated lunar dust grains and in mildly metamorphosed Apollo 11 and 14 breccias of Warner Grade 1 and 2.

Carter (1972, 1973) described various surface features on the glass coat from the lower part, as observed with the SEM and analyzed with an energy dispersive system. He found the glass surface to be very frothy and hummocky, with depressions and blisters connected by valleys. He described four types of features: (1) low-velocity impact features, rare (and no high-velocity), (2) out-gassing structures, e.g., blisters, (3) metallic mounds, which grew in place and were not splashed on, and (4) whisker structures--metallic iron (?) stalks 0.015 μm diameter with bulbous tips of iron and sulfur mixtures. Morrison et al. (1973) also describe the mounds, but as accretionary objects.

Fabel et al. (1972) tabulated x-ray emission shifts and diagrammed Raman spectra for glass particles with an apparent wide range of composition from mare to anorthositic.

Mehta and Goldstein (1979) conducted TEM and STEM x-ray studies to determine the composition and structure of submicroscopic metal inclusions in the glass. There are several sub-micron sized metal inclusions distributed throughout, most larger than 0.1 μm. The smallest have cubic symmetry with well-developed crystallographic facets; the larger ones are more spherical (they note that Morris pers. comm. found that a few pieces of glass contain a substantial amount of metal in the 40-330 Å range). The metal grains contain modest (1 to 3.8%) Ni, and microdiffraction studies (STEM) show them to be α-Fe. The metal probably precipitated from the melt because of solar-wind induced reduction of Fe^{2+} during impact. The size distribution suggests growth of some metal during slow cooling of the melt or during the time the rock may have been in a hot ejecta blanket. Twins are probably the result of low temperature deformation during shock in a hot debris cloud.

CHEMISTRY: All analyses in Table 1 and Figure 5 are for breccia matrix samples and are consistent with each other. The analysis of the European Consortium is a bulk analysis from dust produced during their sawing operations. These authors and Laul et al. (1972) stated that 15015 is identical in composition with the contingency soil sample 15021 from a nearby location, hence 15015 is probably lithified local soil; this similarity is also evident in elements not analyzed by Laul and Schmitt (1972), e.g., indium (Chou et al. 1974), and lead (Silver 1973). Glass analyses, including the surface glass, from microprobe determinations were given by the European Consortium (1977). They also made x-ray photoelectron spectroscopic studies from two chips showing three kinds of surface: bottom exterior glass face and interior chipped and sawn surfaces.

STABLE ISOTOPES/LIGHT ELEMENTS: Three samples from the top, middle, and bottom of the rock were analyzed for C, N, S and their isotopes (Table 2). C and S abundances are similar to local soils, but N is lower by almost half. All three elements show heavy isotopic depletion relative to the local fines 15012 and 15013: fines average δC^{13} = +11 °/oo, breccia -4.3 °/oo. δS^{34} fines = +8.1 °/oo, breccia +7.1 °/oo. δN^{15} fines = +35.6 °/oo, breccia = +0.9 °/oo. The European Consortium (1977) also studied methane and carbide in the sample.

Leich et al. (1973a,b) studied the depth distribution of hydrogen in two glass samples from the bottom part of 15015, finding a sharp near-surface peak, with very little hydrogen at depths greater than 1000 A. Running the interior side showed little contamination, with a peak 1/5 that of the exposed side. The data are tabulated in Leich et al. (1973a) who noted that they are unlike soil fragment data, and discussed the origin of the hydrogen.

GEOCHRONOLOGY AND RADIOGENIC ISOTOPES: Six samples from ,15 were subjected to ^{40}Ar-^{39}Ar analysis by the European Consortium (1974, 1977): (i) matrix (ii) gray clast (variolitic basalt) (iii) white clast (KREEP basalt), and (iv) (v) (vi) samples of bubbly glass from the upper surface. The release patterns for the two clasts are shown in Figure 6, and show the effects of extreme (75% or more) radiogenic argon loss. The high temperature release for the Fra Mauro (KREEP) basalt indicate that the parent crystallized 3.7 ± 0.1 b.y. or earlier. The variolitic basalt crystallized at 3.4 ± 0.2 b.y. or earlier; it is apparently not considered to be a mare basalt. The presence of mare basalt clasts however requires formation of the breccia less than 3.3 b.y. ago. The isochron ages of two of the glass samples, about 1.0 b.y., may represent the formation time of the glass, and possibly the time of lithification.

Nyquist et al. (1973) determined Rb and Sr isotopic ratios for two breccia matrix samples, which show old model ages (Table 3).

Silver (1973) presented Pb isotopic data showing characteristics similar to other breccias and soils.

TABLE 15015-2. Carbon, sulfur, and nitrogen in 15015, obtained by combustion in partial oxygen atmosphere (European Consortium, 1977)

Sample no.	Location in consortium slab	Weight, g	C, ppm	δC^{13} PDB (a)	S, ppm	δS^{34} C.D. (b)	N, ppm	δN^{15} air	He, ppm
15015,15,17	Top	0.5568	131	[c]-2.8	673	7.4	42	-1.5	[d]<1
15015,15,7	Middle	.6393	121	-4.5	586	7.6	61	3.2	<1
15015,15,3	Bottom	.4607	110	-5.5	628	6.3	59	(e)	<1
Average		--	121	-4.3	630	7.1	54	.9	

[a]PDB - Pee Dee belemnite.
[b]C.D. - Canyon Diablo.
[c]CO_2 repurified.
[d]Below detection limit.
[e]Impure.

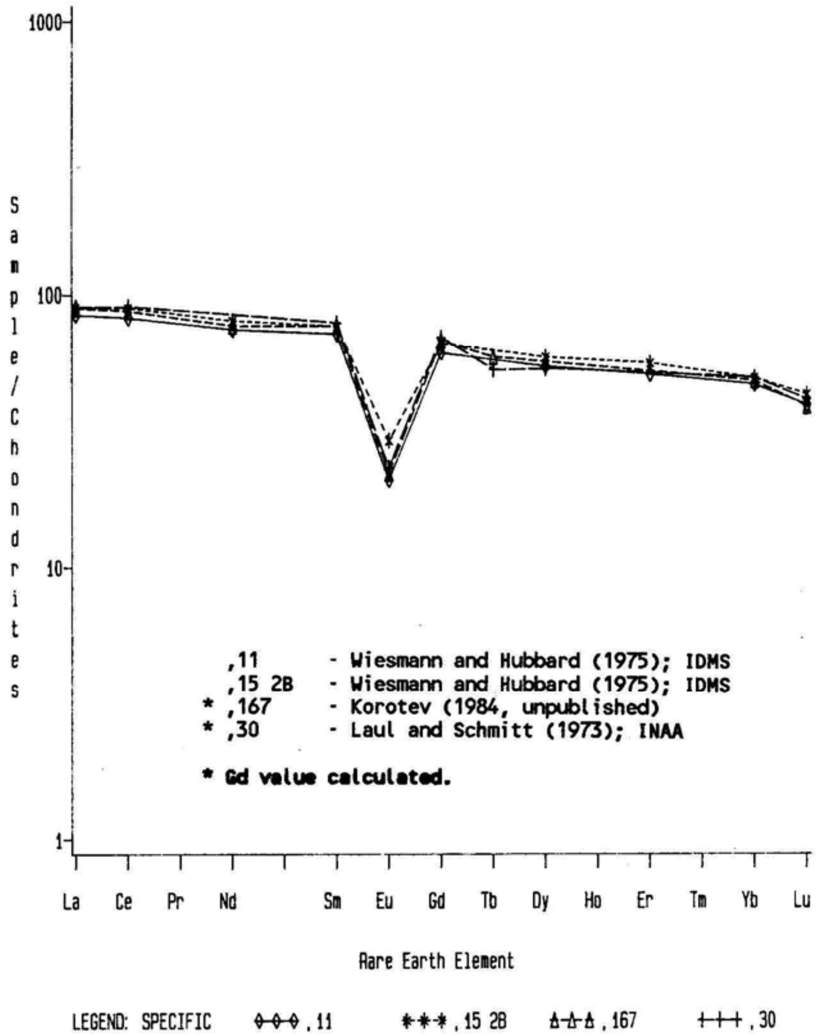


Figure 5. Rare earth elements for matrix analyses of 15015.

<u>EXPOSURE AGES, TRACKS, AND MICROCRATERS</u>: The European Consortium (1974, 1977) found different exposure ages for different clasts using the Ar method. The Fra Mauro basalt gave 490 m.y., the variolitic basalt 1290 m.y.; both samples had experienced 25% cosmogenic argon loss. ^{21}Ne on both matrix and the Fra Mauro clasts gave 250-310 m.y. exposure, and presumably there has been ^{21}Ne loss. ^{3}He gave an exposure age of less than 100 m.y. The overall conclusion is that 15015 formed from well-mixed local soil with components of varied exposure age and maturity, not before 2.7 ± 0.2 b.y., and probably 1.2 b.y. It was then buried at more than 2 meters depth until ejection ~30 m.y. ago. An extensive discussion of the noble gas data is given in the European Consortium (1977).
The European Consortium (1977) used high voltage and scanning electron microscopy to study radiation damage and textural features. Because bubbles are superimposed on the track distribution, no track density gradient from the exterior can be identified. The very heavy exposure of the glass coating is less than 107 years. Feldspar grains have track densities of

10^7 to 4 x 10^9 tracks 1 cm^2, pyroxenes from 10^6 to about 4 x 10^8 tracks/cm^2. These "intermediate" characteristics suggest that the breccia formed from a mixture of mature and immature soil or that a non-thermal process has been responsible for track metamorphism.

Schneider et al. (1972, 1973) and Storzer et al. (1973) deduced an exposure age of 13 yrs (actually 4<age<40 yrs) from track density/depth relationships (Fig. 7); a recalibration revised this age to 40 yrs (Fechtig et al. 1974). The sample used was a glass chip from the bottom side, free of microcraters. Morrison et al. (1973) studied crater densities (Fig. 8) and have a best guess exposure age of 0.01-0.02 m.y., a large extrapolation from their calibrated range but 15015 clearly shows a shorter exposure history than most other rocks. Essentially the surface is young and uneroded. The sample used was from the top surface, and counts are erratic from area to area. Mandeville (1975) also studied microcraters (SEM), finding 35 definite craters with diameters from 5 to 120 microns, and found the low solar flare track density and the microcrater density consistent with an exposure age of ~3,000 yrs.

PHYSICAL PROPERTIES: Todd et al. (1972) measured P-wave velocities for a breccia matrix (2x1x1 cm) sample at room temperature, up to 5 kb confining pressure (Table 4). The determination of S-wave velocity was not possible because of the poor coherence of the sample.

Baldridge et al. (1972) measured the thermal expansion of 15015 over the temperature range -1000°C to +25°C (Fig. 9). Cadenhead and Stetter (1975) measured a density of 3.0 ± 0.1 gm/cm^{-3} for a glass sample.

Greenman and Gross (1972) diagrammed luminescence data for visible wavelength luminescence from soft x-rays, and possible ultraviolet luminescence from the same source, for bottom glass, adjacent matrix, and a top glass sample. Dollfus and Geake (1975) measured polarimetric and photometric characteristics of reflected light (5800 to 3520 Å).

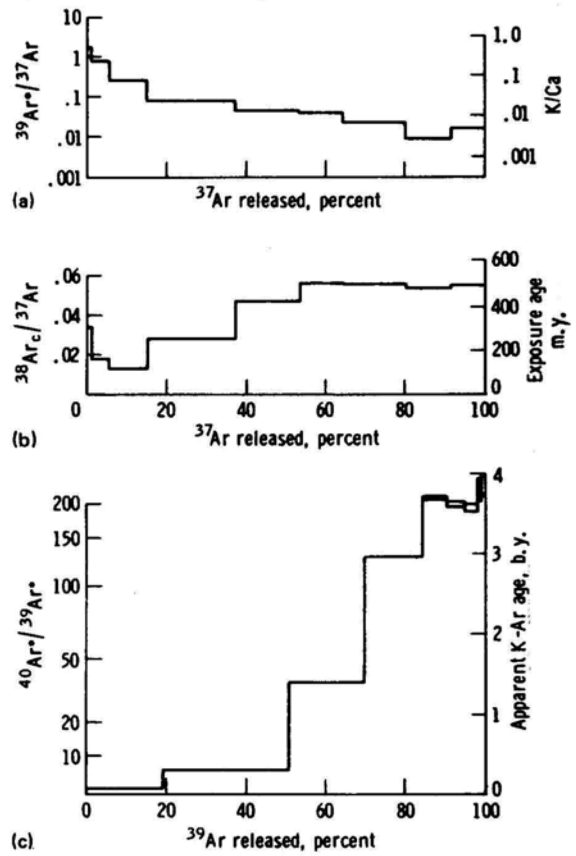
Cadenhead and Stetter (1974) studied water sorption on a cindery glass sample at 15-20°C following outgassing at 25° to 320°C, as part of an attempt to study the general characteristics of water sorption on lunar sample surfaces.

The European Consortium (1977) measured the geometric albedo and polarization properties of a dark, glassy piece from the top surface.

Table 15015-3. Rb-Sr Whole Rock Isotopic Data
(Nyquist et al., 1973)

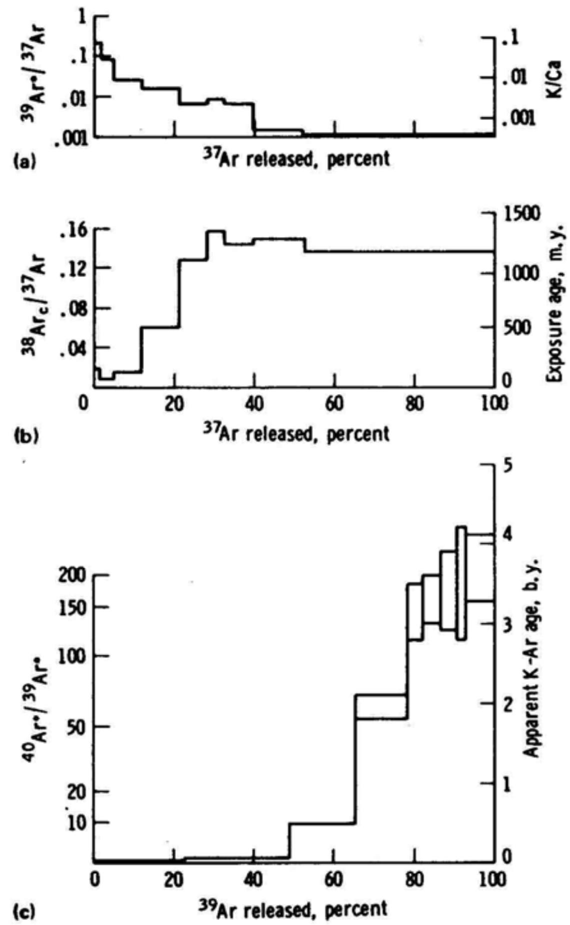
	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Rb$	T_{BABI}	T_{LUNI}
,11	0.1355±11	0.70785±7	4.50±0.07	4.55±0.07
,15 2B	0.1486±16	0.70885±8	4.57±0.09	4.62±0.09

Fig. 6a



Argon isotope release pattern for Fra Mauro basalt-type fragment 23b, indicating a 75-percent loss of radiogenic ^{40}Ar and a 20-percent loss of cosmogenic $^{38}Ar_c$. The high-temperature $^{40}Ar/^{39}Ar$ age attains a value of 3.7 ± 0.1 b.y. despite the extreme loss and is comparable to, but slightly lower than, more precise ages of other Fra Mauro basalts. A well-defined cosmic ray exposure age of 490 m.y. is determined.

Fig. 6b



Argon isotope release pattern for variolitic basalt fragment 5b, indicating ^{40}Ar and $^{38}Ar_c$ loss similar to that of fragment 23b. The high-temperature $^{40}Ar/^{39}Ar$ age is imprecise, 3.4 ± 0.2 b.y. The cosmic ray exposure age is well defined and extremely high, 1290 m.y., indicating that 5b received extensive cosmic ray irradiation for at least 800 m.y. after crystallization and before incorporation in the part of the regolith that was later to be lithified to form 15015.

Figure 6. Argon release patterns from
a) Fra Mauro basalt-type fragment 23b and (b) variolitic basalt fragment 5b.

PROCESSING AND SUBDIVISIONS: A slab was cut through the center of the breccia (Figs. 2, 10) and most allocations made from it. A piece of this slab, 15, was allocated to the European Consortium. All the thin sections (,132-,143) were made serially from ,14, except two made of the glass exterior from a small piece from ,7. ,0 is 2870 g. ,7 had four large pieces (100-200 gm) removed for PAO exhibits and the remainder of it, 808 g, was placed in remote storage.

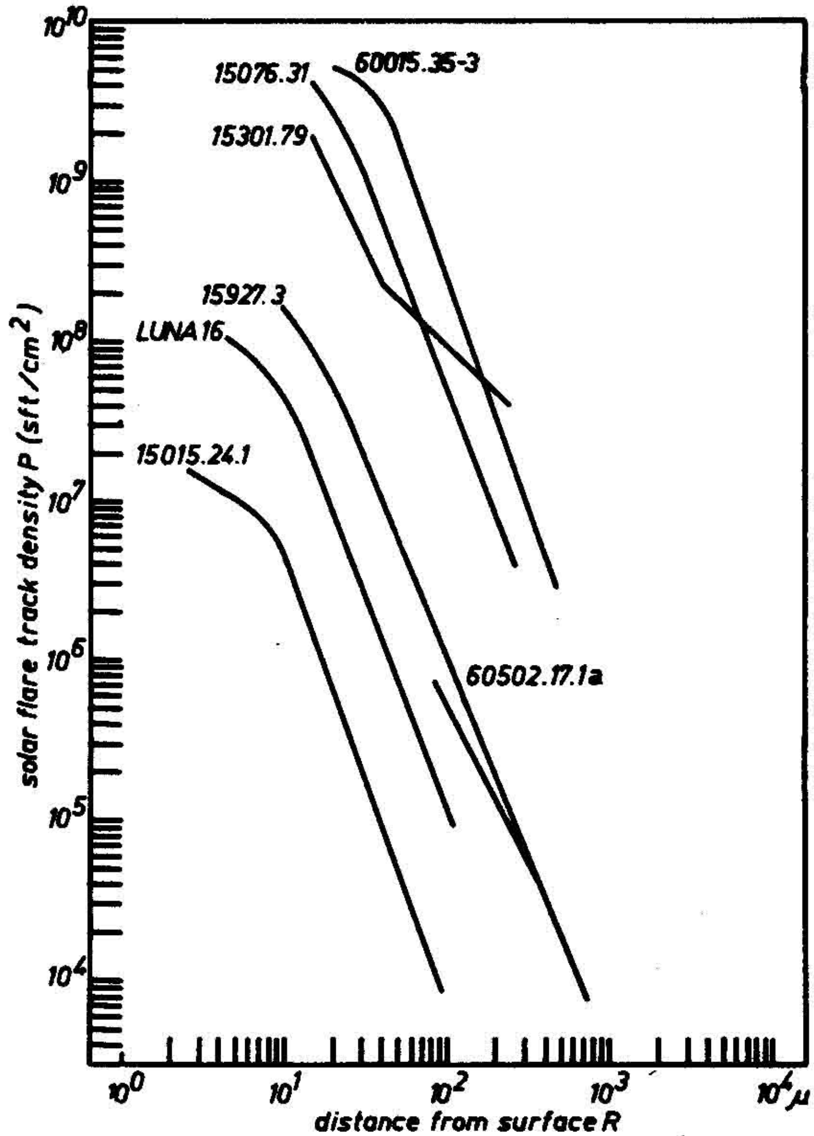
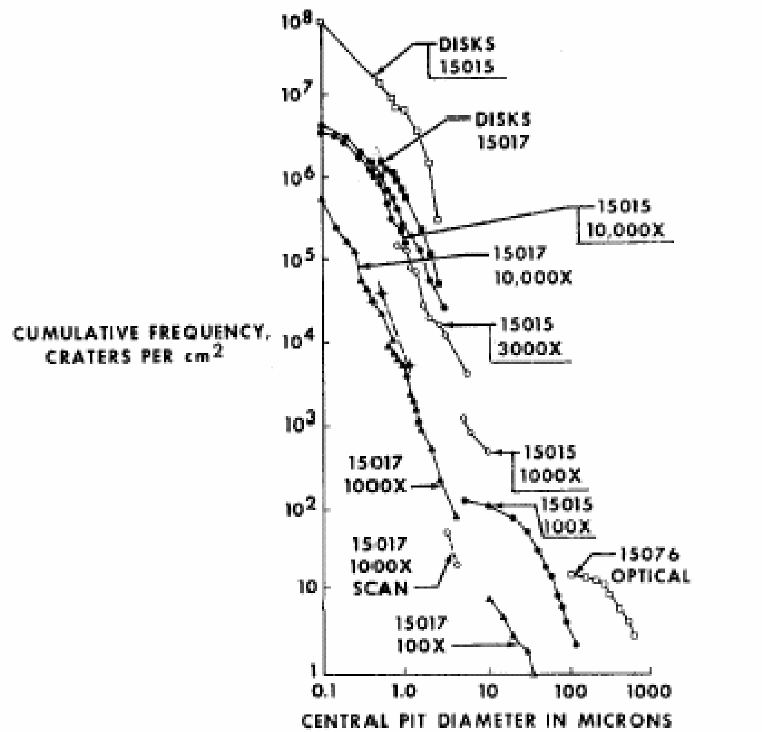


Figure 7. Track density vs. depth for a bottom glass sample (Storzer et al., 1973).

Table 15015-4. P-Wave Velocities (Todd et al. 1972)

bars	1	100	250	500	750	1000	1500	2000	3000	4000	5000
P-wave km/sec	3.50	3.68	3.90	4.13	4.27	4.38	4.49	4.54	4.64	4.74	4.85



Cumulative frequency distributions for category 4 rocks and accretionary objects
on 15017 and 15015. Numbers refer to magnifications of SEM mosaics.
15076 SEM points from Schneider et al. (1972) shown as crossed circles.
Open circles for diameters between 1 and 10 microns represent visual scans at 1000X.

Figure 8. Microcrater density data for a top glass sample
(Morrison et al., 1973).

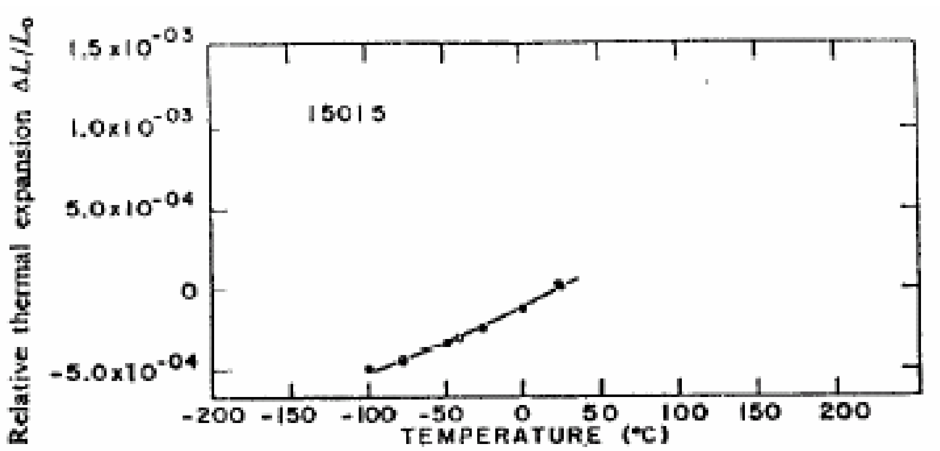


Figure 9. Thermal expansion of 15015
(Baldridge et al., 1972).

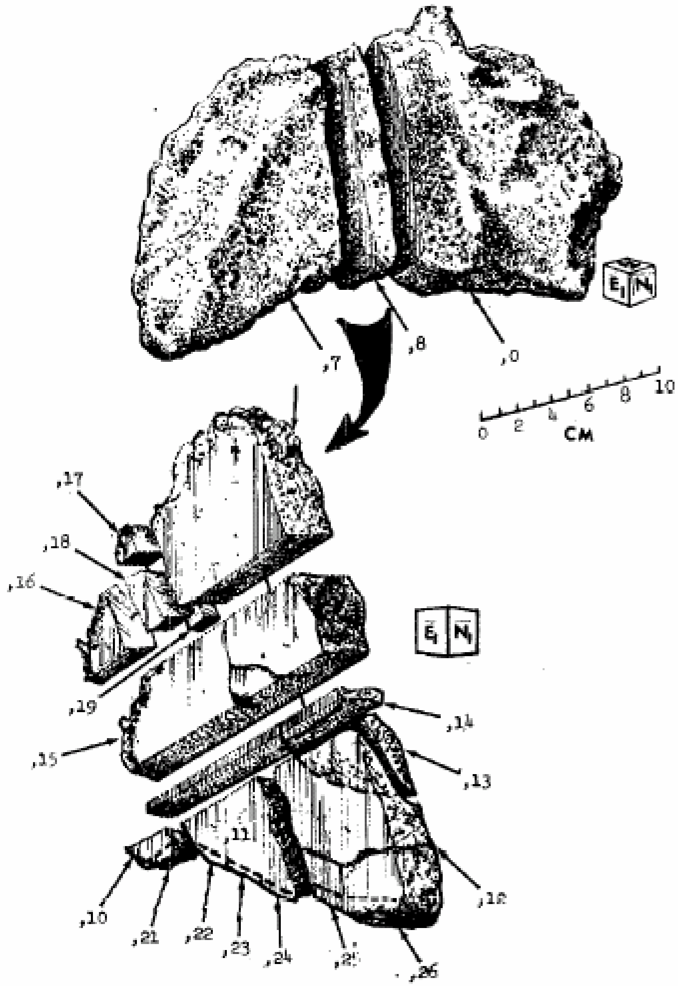


Figure 10. Main subdivisions of 15015 from sawing of a slab.