67015

Light matrix Breccia

1194 grams

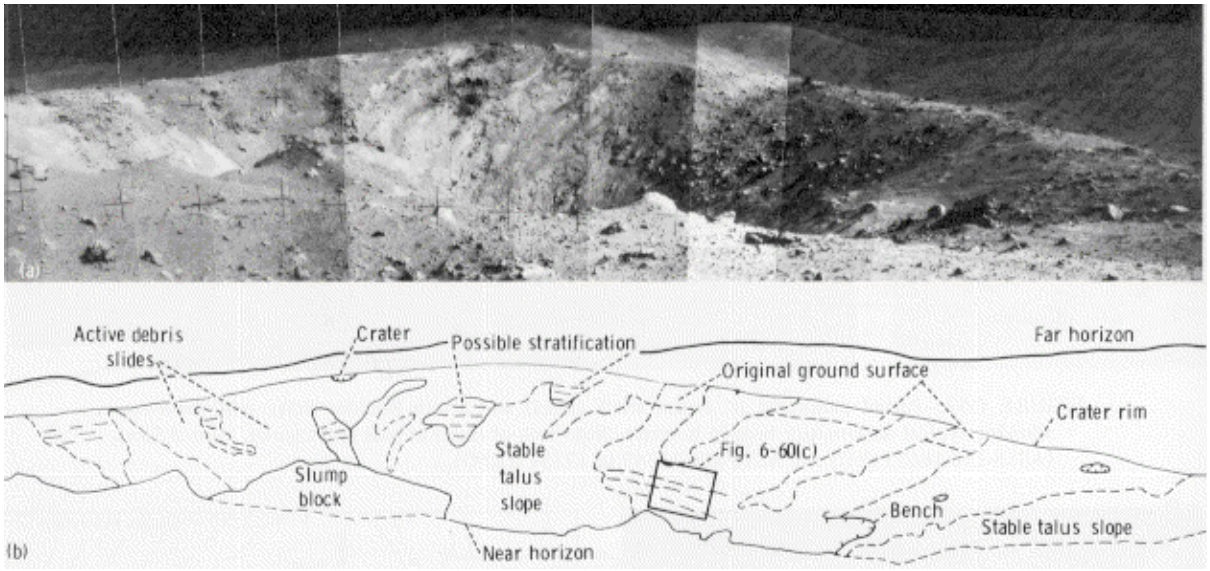


Figure 1: Panorama of North Ray Crater, Apollo 16, with sketch map of possible stratigaphy within (from Muehlberger et al. 1973). Mozaic of NASA AS16-106-17251 to 17262.

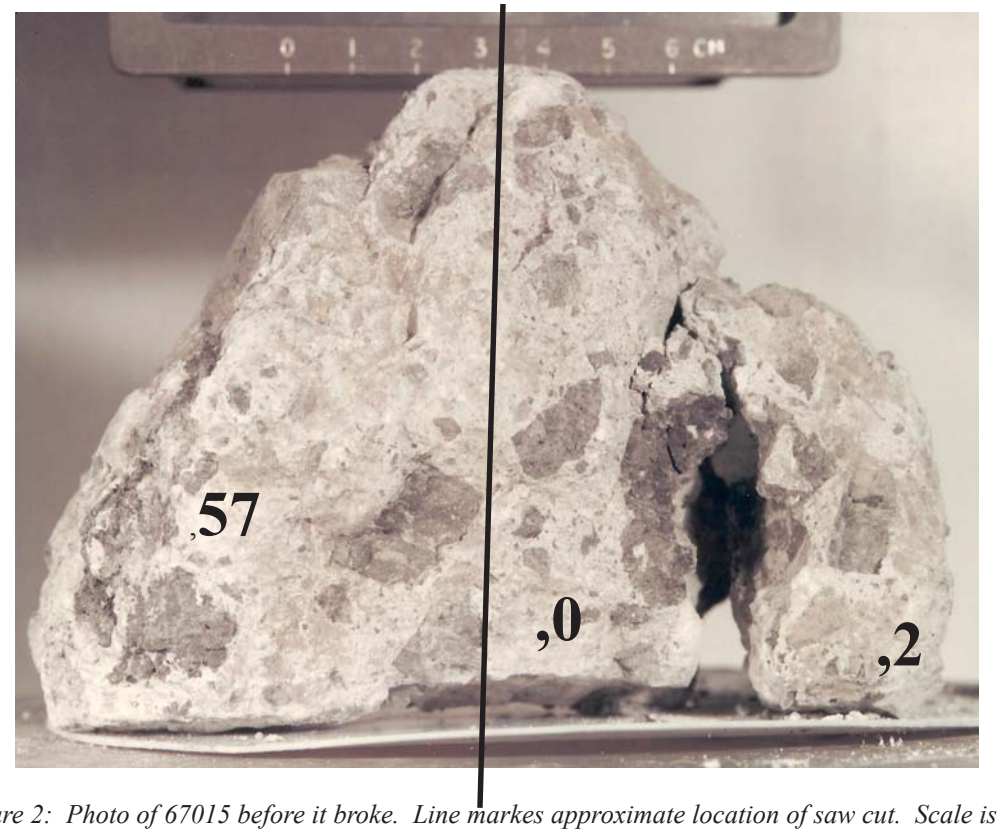


Figure 2: Photo of 67015 before it broke. Line markes approximate location of saw cut. Scale is in cm. S72-37216

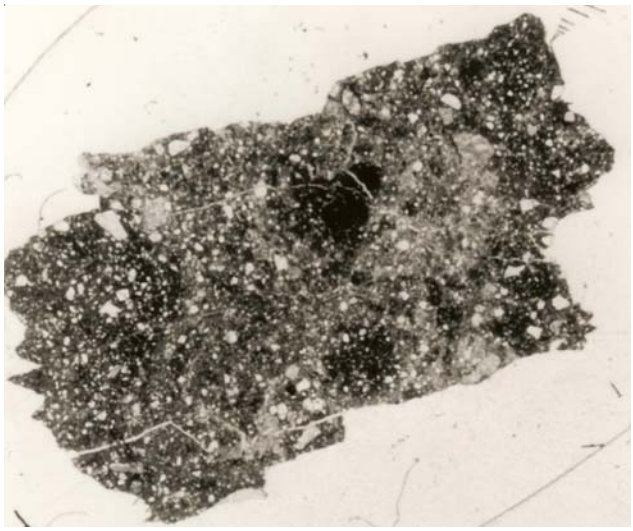


Figure 3: Photomicrograph of thin section 67015,10. Field of view is about 1 cm. S72-43607.

Introduction

67015 was collected just inside of the south rim of North Ray Crater (figure 1). It is a fragmental matrix breccia, made up mostly of feldspar, but with a wide range of highland lithologies represented as loose clasts in the matrix (figures 2 and 9). Clasts have been dated at 3.9 b.y. and the breccias, itself, has had an exposure to cosmic ray of 51 m.y. (age of NRC).

Petrography

Stoffler et al. (1985) classify 67015 as a "fragmental breccia" and Ryder and Norman (1980) recognized that it was "polymict". McGee et al. (1979) and Marvin et al. (1987) give apt and detailed descriptions, respectively. In general, it seems similar to 67016, from the same location. According to cratering theory, these materials should be from deep in the crater?

67015 "is a light-matrix breccia characterized by mineral, lithic and glass clasts contained in an unrecrystallized matrix of mineral grains (predominantly plagioclase, with minor mafic and opaque minerals) and orange-brown glass. Spinel grains are observed in the matrix but are relatively rare. The texture of 67015 is seriate with components ranging in size from the limit or resolution to 1.5 mm. Sample 67015 is porous, with micron-size intergranular voids which may be viewed in reflected light at high magnification. Pore space is also present as non-connecting veinlets and as rare, irregularly shaped vugs" (McGee et al. 1979).

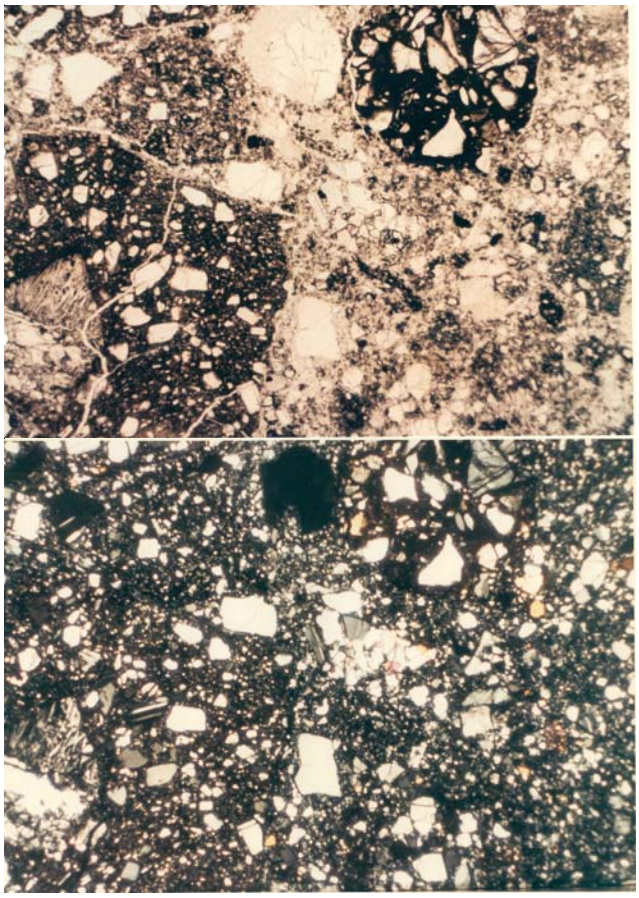


Figure 4: Plane- and crossed-polarized thin section photos of 67015. Note seriate grain size distribution, glass clasts and chondrules. S72-42350 and 351. Field of view about 2 mm.

Mineralogical Mode for 67015

	McGee et al. 1977
Matrix	55 %
Plag.	12
Mafic	1
Breccia	21.8
Granulite	2.8
Anor	7.13

Glass clasts are rare and typically orange –brown in color and partially to completely devitrified. One large round clast was observed which contained anhedral crystals of plagioclase and pyroxene (a chondrule!). Plagioclase clasts are the most abundant (95%). They are both rounded and angular with no overgrowths nor inclusions. Clasts of mafic minerals are typically very small and usually rounded in outline.

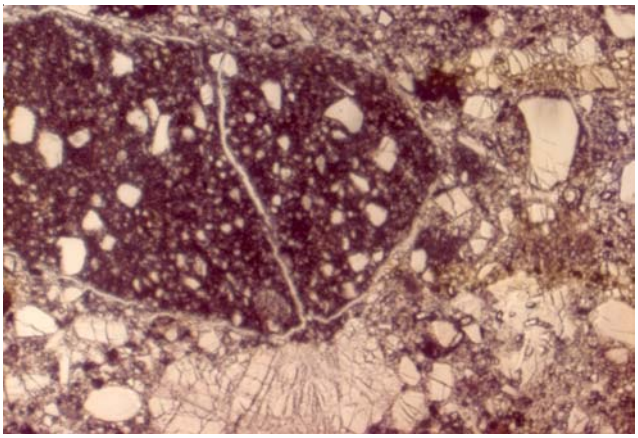


Figure 5: Another thin section of 67015 showing breccia-in-breccia texture - with gap between clast and matrix. S76-20800. Field of view about 1 mm.

The most common lithic clast type is also a breccia (plagioclase rich). Clasts of apparent anorthosite are present with 120 deg. triple junctions. Clasts with intergrown plagioclase and pyroxene laths are present – but probably not a basalt.

Marvin et al. (1987) found that 67015 was not dominated by any one clast type, but had "a wider range of clast types than any other" breccia. They found that plagioclase was dominant, followed by impact melt and granulites. Some of the impact melt clasts were KREEP-rich.

Significant Clasts

Large Basalt? Figure 17

This large clast is probably not a "basalt" as such. It seems to have been located on ,57 (Marvin 1980) and may be the same as the grey material in figure 16 a. If that is the case, then thin section ,291 and analysis ,282 may be of this material. Marvin and Lindstrom (1983) found this to be "poikiloblastic granulite" – see figure 8c this report. As can be seen in figure 16 a, there is a lot more of this clast.

Ferroan Anorthosite ,275 Figure 8d

Thin section ,288 is from ,276PB, which is from ,237, which is from, 161 (figure 15). This was a very small clast.

Chemistry

Wanke et al. (1975), Hertogen et al. (1977), Lindstrom and Salpus (1982), Marvin and Lindstrom (1983) and Marvin et al. (1987) have determined the chemical composition (tables 1 – 3). There is both pristine and meteorite-contaminated material in 67015. Some clast have high trace element content (figure 9).

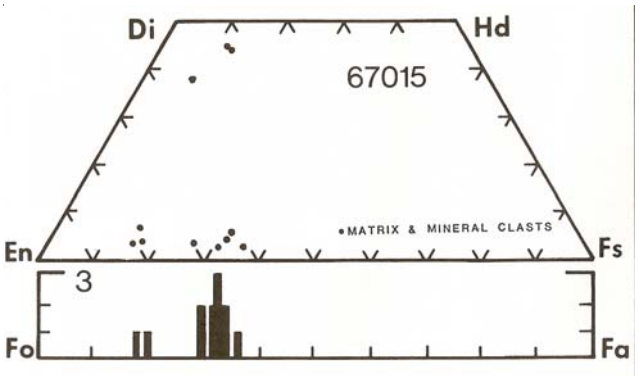


Figure 6: Pyroxene and olivine composition of 76015 (McGee et al. 1977).

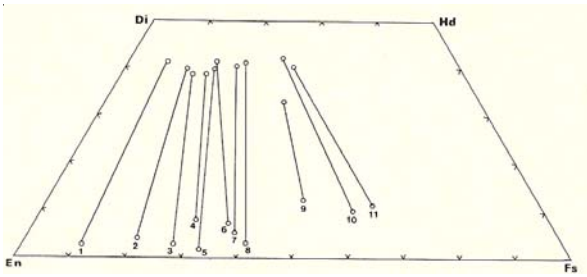


Figure 7: Pyroxene composition of clasts in 76015 (Marvin et al. 1987).

Kerridge et al. (1975) found ~ 20 ppm carbon.

Radiogenic age dating

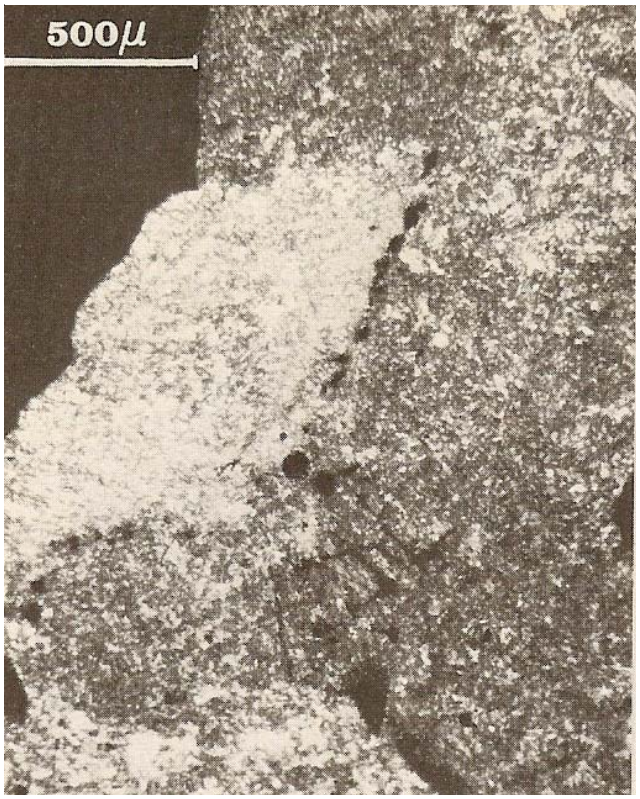
Marvin et al. (1987) reported 3.9 b.y. Ar/Ar "ages" for some of the materials in 67015 (figure 10). James (1981) summarizes the age data for Apollo 16 and concludes that the Apollo 16 breccias are 3.92 b.y.

Cosmogenic isotopes and exposure ages

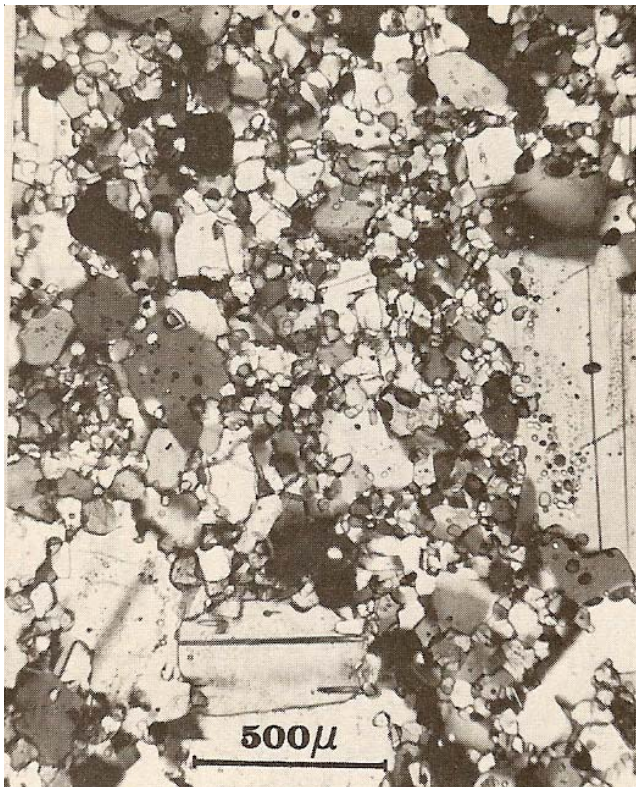
Marti et al. (1973) and Lightner and Marti (2023) reported a ^{81}Kr exposure age of 51.1 m.y. This is consistent with the age of North Ray Crater (Arvidson 1975). Regnier et al. (1979) compared the predicted vrs. observed Kr data. Marvin et al. (1987) reported ^{38}Ar exposure ages of 41 and 49 m.y. for clasts.

Other Studies

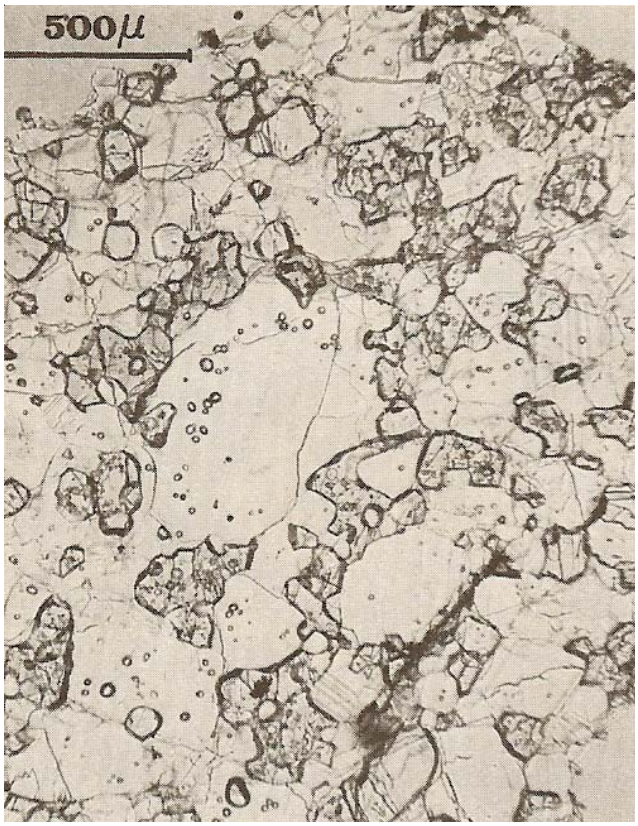
These are covered in the fine review by Ryder and Norman (1980).



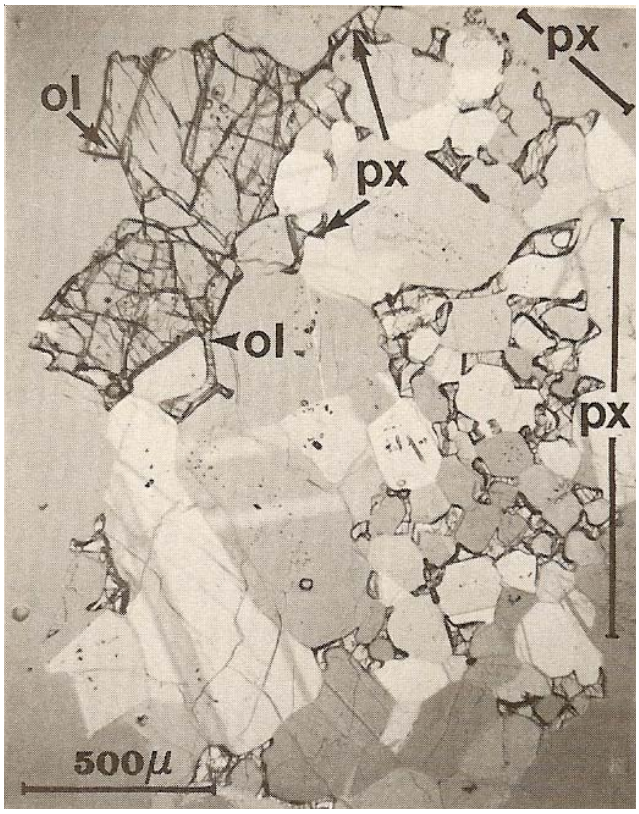
Shock-metamorphosed plagioclase clast in 67015



Granulite clast ,262 in 67015



Poikilobalstic granulite clast ,282 in 67015



Ferroan anorthosite clast ,275 in 67015

Figure 8 a,b,c,d

note: this figure copied from Marvin and Lindstrom 1983.

Table 1. Chemical composition of 67015

			clast	matrix					Lindstrom81			
reference	Wanke 75		Nunes73			Hertogen			Marvin83			
weight						matrix	d. clast		bulk		matrix	
SiO2 %	46	(b)										
TiO2	0.48	(b)							0.77	0.52	0.24	(b)
Al2O3	29.5	(b)							27	30.7	30.8	(b)
FeO	3.64	(b)							4.28	3.36	5.25	(b)
MnO	0.06	(b)										
MgO	3.86	(b)							5.3	3	6	(b)
CaO	15.4	(b)							15.5	16.5	16.1	(b)
Na2O	0.52	(b)							0.504	0.524	0.453	(b)
K2O	0.082	(b)										
P2O5												
S %												
sum												
Sc ppm	7.5	(b)							7.83	6.28	4.94	(b)
V	12	(d)										
Cr	438	(b)							605			(b)
Co	9.7	(b)							12.7	5.4	48	(b)
Ni	110	(b)				39	855	(c)	151	41	580	(b)
Cu	1.46	(b)										
Zn	3.6	(b)				10.2	5.6	(c)				
Ga	4.1	(b)										
Ge ppb	30	(b)				109	2230	(c)				
As	8.3	(b)										
Se	0.14	(b)				55	227	(c)				
Rb	1.42	(b)				0.87	6.73	(c)				
Sr	195	(b)							186	173	208	(b)
Y	14.5	(b)										
Zr	55	(b)										
Nb	4.1	(b)										
Mo												
Ru												
Rh												
Pd ppb	1	(b)				1.8	43	(c)				
Ag ppb						1.67	3.56	(c)				
Cd ppb						0.7	4	(c)				
In ppb						0.24	0.83	(c)				
Sn ppb												
Sb ppb						0.4	3.75	(c)				
Te ppb						35	21	(c)				
Cs ppm	0.05	(b)				0.07	0.3	(c)				
Ba	86.2	(b)							107	62	51	(b)
La	4.9	(b)							8.6	3.73	3.54	(b)
Ce	11.6	(b)							23	10	9.6	(b)
Pr	1.7	(b)										
Nd	7.9	(b)										
Sm	2.14	(b)							4.04	1.79	1.55	(b)
Eu	1.16	(b)							1.23	1.16	1.17	(b)
Gd	2.6	(b)										
Tb	0.47	(b)							0.86	0.4	0.3	(b)
Dy	3.1	(b)										
Ho	0.7	(b)										
Er	1.9	(b)										
Tm												
Yb	1.79	(b)							3.17	1.49	1.25	(b)
Lu	0.24	(b)							0.433	0.21	0.18	(b)
Hf	1.67	(b)							3.36	1.37	1.1	(b)
Ta	0.21	(b)							0.46	0.34	0.21	(b)
W ppb	400	(b)										
Re ppb	0.3	(b)				0.15	2	(c)				
Os ppb						1.72	17	(c)				
Ir ppb						1.78	20	(c)				
Pt ppb												
Au ppb	1.1	(b)				0.565	15.5	(c)				
Th ppm	0.7	(b)	4.3	0.7	(a)				1.52	0.61	0.85	(b)
U ppm	0.22	(b)	1.2	0.2	(a)	0.14	1.32	(c)	0.42	0.2	0.15	(b)

technique: (a) IDMS, (b) INAA, (c) RNAA, (d) Wanke77

Table 2. Composition of 67015 clasts.

reference	Marvin83									
weight	,284	,266	,265	G-16	,270	,186	,275	,282	,264	
SiO2 %										
TiO2	0.85	2.35	2.29	0.43	1.05		0.13	0.26	0.27	(a)
Al2O3	29.4	29.2	26.3	29	22.2	36.7	33.3	28.6	26.2	(a)
FeO	4.91	4.89	5.73	3.39	7.6	0.42	2.85	4.53	3.97	(a)
MnO										
MgO	4.3	3.4	4.7	2.6	10.7	0.4	3.5	7.3	6.7	(a)
CaO	16.6	16.9	15.7	16.4	13.5	19	17.9	15.4	14.7	(a)
Na2O	0.63	0.71	0.72	0.52	0.56	0.36	0.35	0.45	0.37	(a)
K2O										
P2O5										
S %										
sum										
Sc ppm	8.8	10.7	14	6.3	12.3	0.4	3.7	6.9	5.9	(a)
V										
Cr	472	691	725	383	1006	20	321	821	684	(a)
Co	9.7	6.3	9.6	7	41.8	1.5	5.7	24.4	14	(a)
Ni	76	34	43	40	570	12	34	296	110	(a)
Cu										
Zn										
Ga										
Ge ppb										
As										
Se										
Rb										
Sr	200	199	187	184	180	164	167	182	150	(a)
Y										
Zr										
Nb										
Mo										
Ru										
Rh										
Pd ppb										
Ag ppb										
Cd ppb										
In ppb										
Sn ppb										
Sb ppb										
Te ppb										
Cs ppm										
Ba	140	60	77	52	227	8.8	11	76	57	(a)
La	9.6	2.7	4.8	3.1	23.2	0.22	0.62	4.8	3	(a)
Ce	26.1	7.7	13.3	8.4	62.8	0.56	1.78	13	8.25	(a)
Pr										
Nd										
Sm	4.5	1.4	2.5	1.5	10.9	0.076	0.28	2	1.3	(a)
Eu	1.38	1.4	1.43	1.12	1.46	0.8	0.8	1	0.9	(a)
Gd										
Tb	0.95	0.32	0.6	0.34	2.29	0.013	0.06	0.48	0.33	(a)
Dy										
Ho										
Er										
Tm										
Yb	3.56	1.24	2.14	1.23	7.7	0.03	0.25	2.16	1.29	(a)
Lu	0.515	0.18	0.32	0.17	1.12	0.005	0.04	0.32	0.18	(a)
Hf	3.68	1.2	1.98	1.23	8.4	0.013	0.17	1.2	0.93	(a)
Ta	0.68	0.37	0.48	0.2	1.16	0.005	0.02	0.07	0.12	(a)
W ppb										
Re ppb										
Os ppb										
Ir ppb										
Pt ppb										
Au ppb										
Th ppm	1.8	0.33	0.74	0.48	4.15	0.005	0.04	0.45	0.38	(a)
U ppm		0.11	0.22	0.16	0.98				0.09	(a)

technique: (a) INAA

Table 3. Composition of clasts in 67015.

	igneous clasts			granulitic clasts			feldspathic clasts				mafic VHA melt rocks				
reference	Marvin87														
weight	,352	,310	,354	,295	,301	,305	,318	,340	,342	,349	,292	,306	,311	,351	
SiO2 %															
TiO2		3.03	12.8	0.23	0.27	0.35	0.39	0.54	0.33	0.43	1.29	1.2	1.16	1.01	(a)
Al2O3	32	26	20.7	28.3	25.2	21.2	29.5	30.1	29.8	29.6	19.7	21	20.2	22.9	(a)
FeO	1.86	3.64	12.7	4.35	4.99	5.33	3.4	3.43	3.28	3.77	9.02	7.43	8.34	6.52	(a)
MnO	0.034		0.17	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.1	0.09	0.1	0.09	(a)
MgO	1.81	5.2	4.9	7.9	8.9	15.2	3.21	3.07	3.8	3.22	10.9	9.4	10.3	10.5	(a)
CaO	18.4	16.2	12.1	15.8	15.2	12.2	16.9	17.4	17.7	17.5	14	14.6	14.4	14.7	(a)
Na2O	0.27	0.75	0.74	0.44	0.43	0.32	0.47	0.53	0.58	0.55	0.56	0.5	0.55	0.6	(a)
K2O															
P2O5															
S %															
sum															
Sc ppm	4.76	11.1	25.7	5.9	7.3	6.5	5.8	6.8	5.8	6.9	13.7	13	13.4	11.6	(a)
V	8		64	15	21	20	8	14			34	30	34	29	(a)
Cr															
Co	1.39	2.1	9.75	12.4	23.2	20	7.9	6.1	6.3	8.9	61	37	53	18	(a)
Ni	10			174	257	120	45	46	48	53	835	525	715	238	(a)
Cu															
Zn															
Ga															
Ge ppb															
As															
Se															
Rb	*2*	11		*4*	*5*	*3*	*2.4*	*5*	*5*	*5*	7	5.5	10	7	(a)
Sr	142	182	160	167	172	135	180	205	200	195	178	170	192	180	(a)
Y															
Zr	25	**300**	100	102	64	60	55	56	70	65	310	320	310	275	(a)
Nb															
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb															
In ppb															
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm	0.04	0.06	0.13				0.05	0.09	0.08	0.07	0.32	0.25	0.26	0.27	(a)
Ba	11	196	90				54	60	50	79	314	260	282	270	(a)
La	0.41	14.7	4.7				3.2	3.6	2.7	4.6	27.1	25.5	26.4	25.7	(a)
Ce	1.09	41.6	13.3				8.2	9.6	7.3	12.3	75	68	73.3	65	(a)
Pr															
Nd	0.7	25.2	7.5				4.7	5.5	4.8	7.6	48	42	43	39	(a)
Sm	0.204	6,74	2.36				1.6	1.7	1.2	2.2	13.9	12.4	12.7	11.7	(a)
Eu	0.643	1.35	1.37				1.07	1.1	1.16	1.1	1.53	1.4	1.53	1.41	(a)
Gd															
Tb	0.047	1.43	0.6				0.34	0.39	0.3	0.53	2.85	2.75	2.75	2.57	(a)
Dy															
Ho															
Er															
Tm															
Yb	0.224	4.9	2.02				1.12	1.3	0.99	1.68	8.42	7.9	8.25	8	(a)
Lu	0.034	0.712	0.345				0.18	0.2	0.16	0.26	1.37	1.27	1.33	1.2	(a)
Hf	1.41	9.4	2.7				1.15	1.35	1.81	1.79	10	8.8	9.5	8.9	(a)
Ta	0.024	2.25	1.41				0.19	0.18	0.13	0.23	1.45	1.3	1.36	1.06	(a)
W ppb															
Re ppb															
Os ppb															
Ir ppb							1.8			3.9	12	9.5	12	5.4	(a)
Pt ppb															
Au ppb			252					0.6	0.4	0.8	0.7	0.7	0.7	0.7	(a)
Th ppm	0.03	3.98	0.55				0.5	0.49	0.32	0.7	4.75	4.4	4.67	4.03	(a)
U ppm	0.2	0.9	0.2				0.1	0.17	0.17	0.18	1.19	1.09	1.2	1.1	(a)
technique	*(a) INAA*														

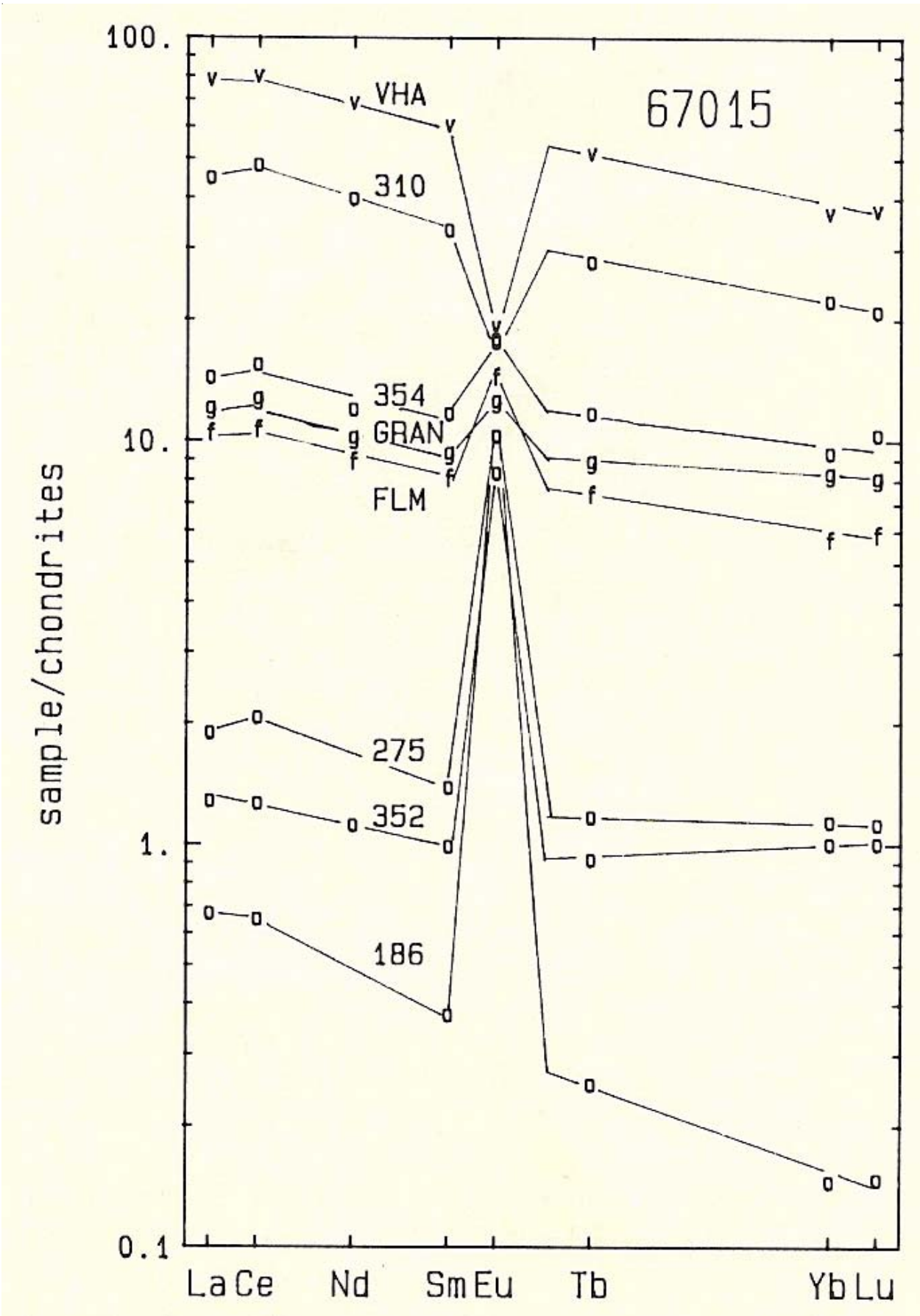


Figure 9: Normalized rare-earth-element diagram for clasts of 67015 (Marvin et al 1987).

Processing

Marvin (1980) produced a guidebook for the processing of ,58. The sample was sawn only once. A slab was unobtainable because the sample was very fractured and friable (with tough inclusions). Indeed, there were many "crumbs" from processing (figures 16 b,c).

"Humpty-dumpty had a great fall, all the King's men - - "

There are 57 thin sections, many from individual clasts.

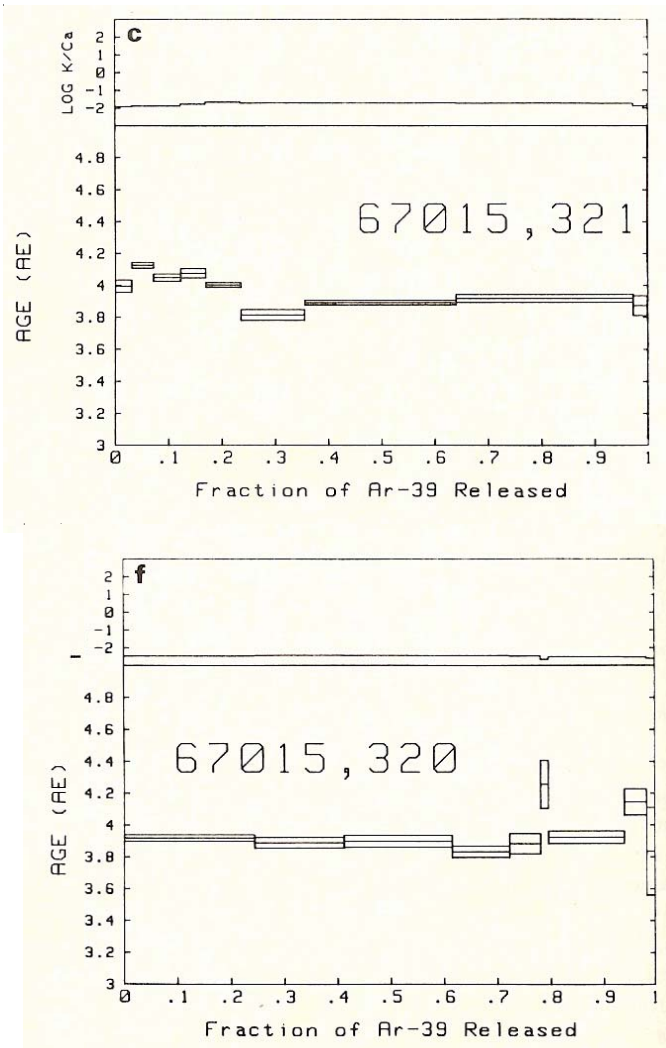
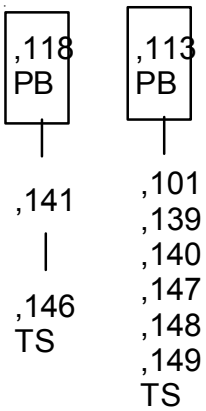
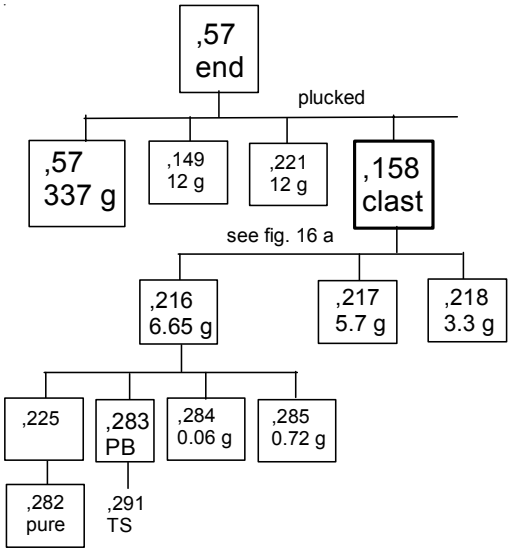
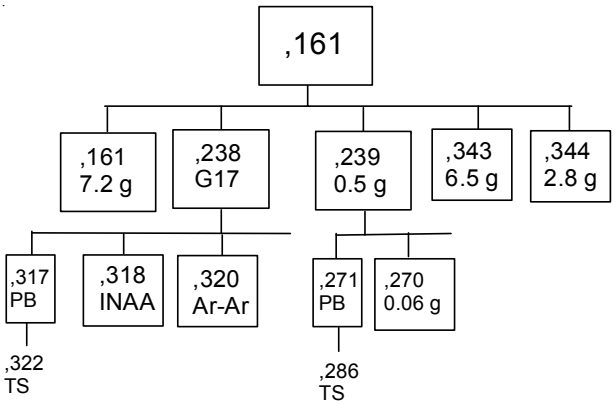
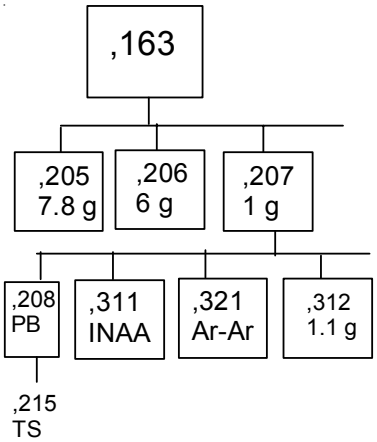


Figure 10: Two, rather poorly-determined, argon plateau diagrams for clasts from 67015 (Marivn et al. 1987).









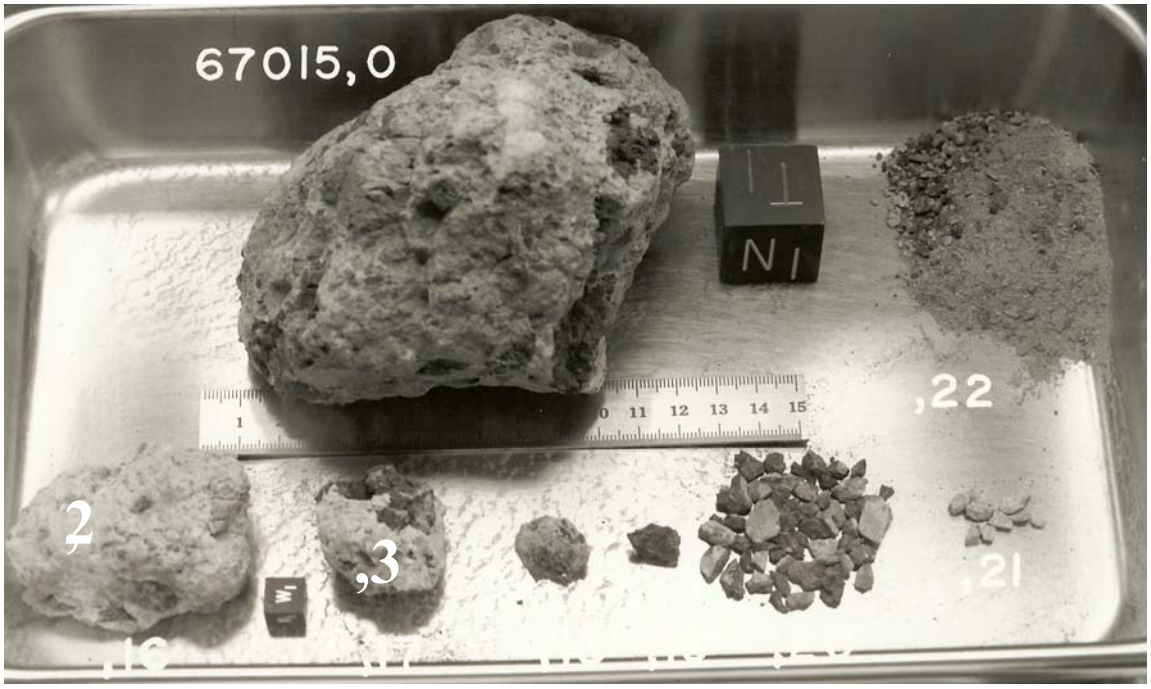


Figure 11: Initial processing of 67015. Cube is 1 inch. S72-44018

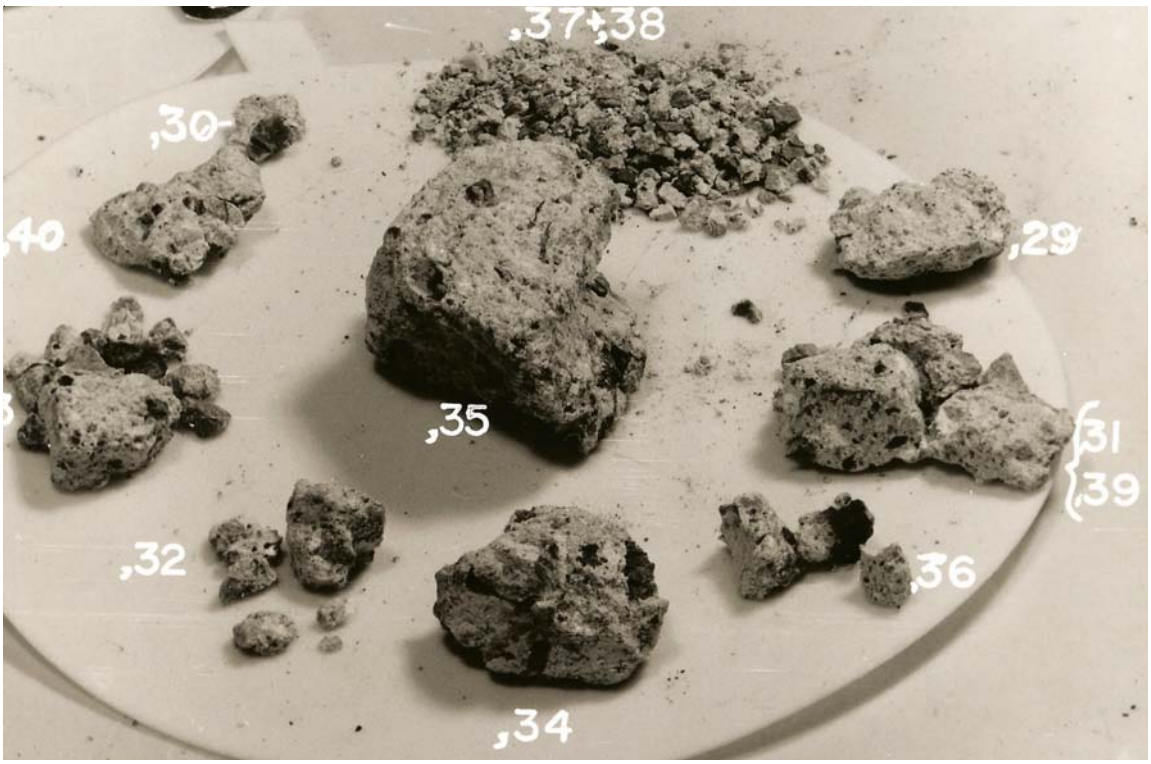


Figure 12: Processing photo of 67015,16. S72-50694

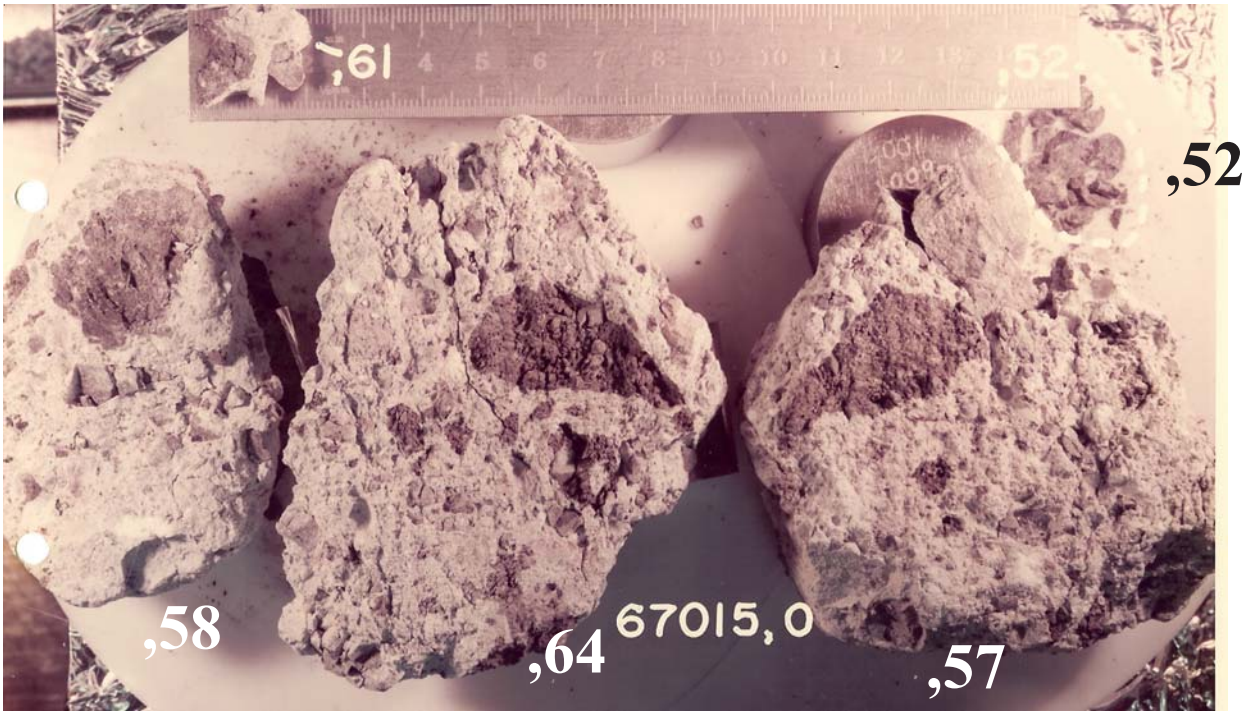
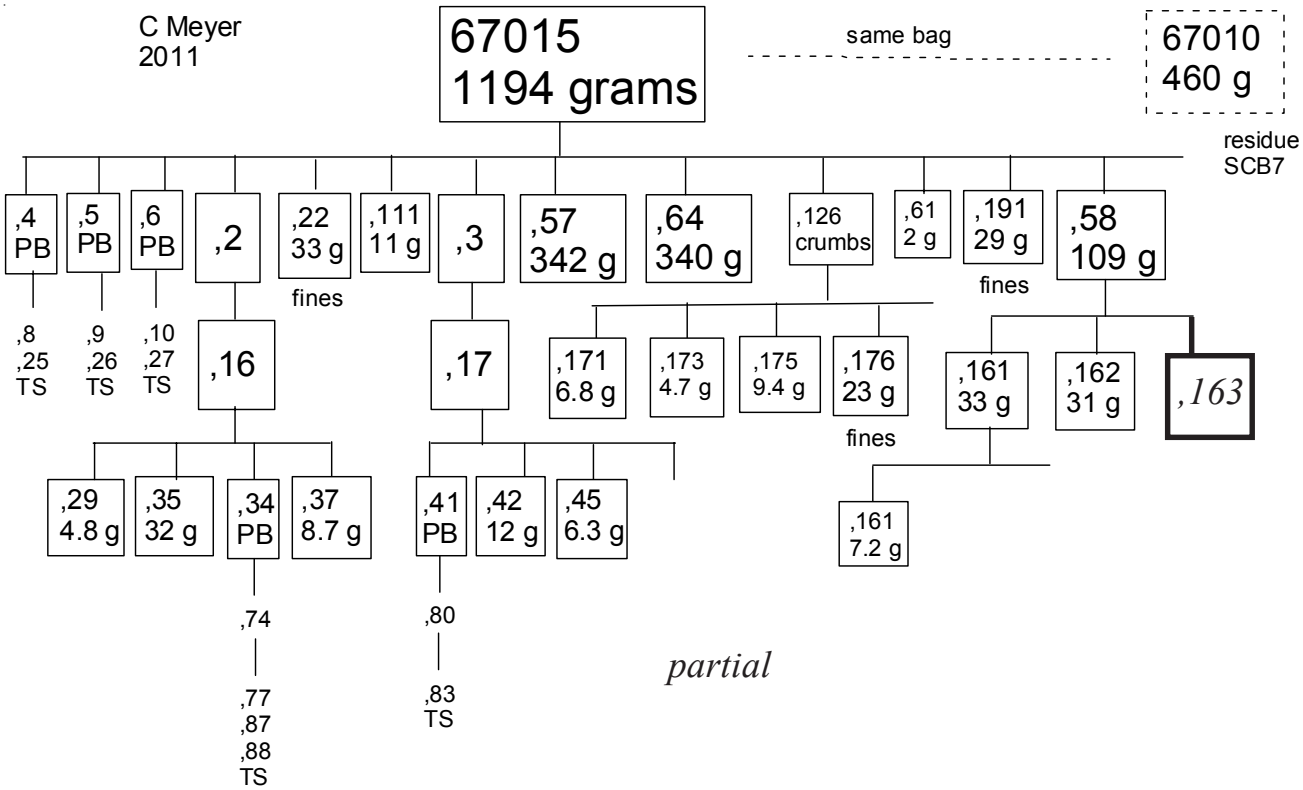


Figure 13: Saw cut of 67015. Scale in cm. S75-32669

Figure 14: Enlargement of photo of 67015,64 showing that dark clasts easily fell out of matrix, leaving empty "casts" in place. Cube is 1 cm. S75-32672.



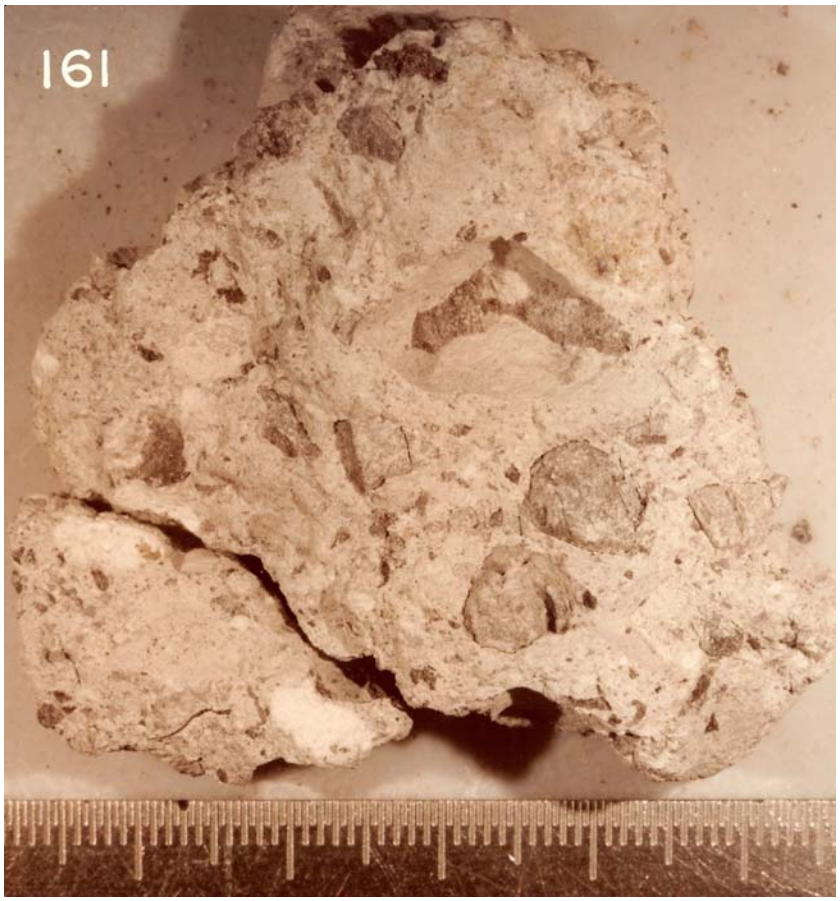


Figure 15: Close up of a portion of 67015,58. Scale in cm. S79-35316

Figure 16 a: Large dark clast ,158 plucked from 67015,57. S79-31999.. This may be the large "basalt" clast seen in figure 17.

Figure 16 b: Dark clasts from 67015. S79-31333

Figure 16c: "Crumbs" from 67015. S79-31332 Scale in cm.

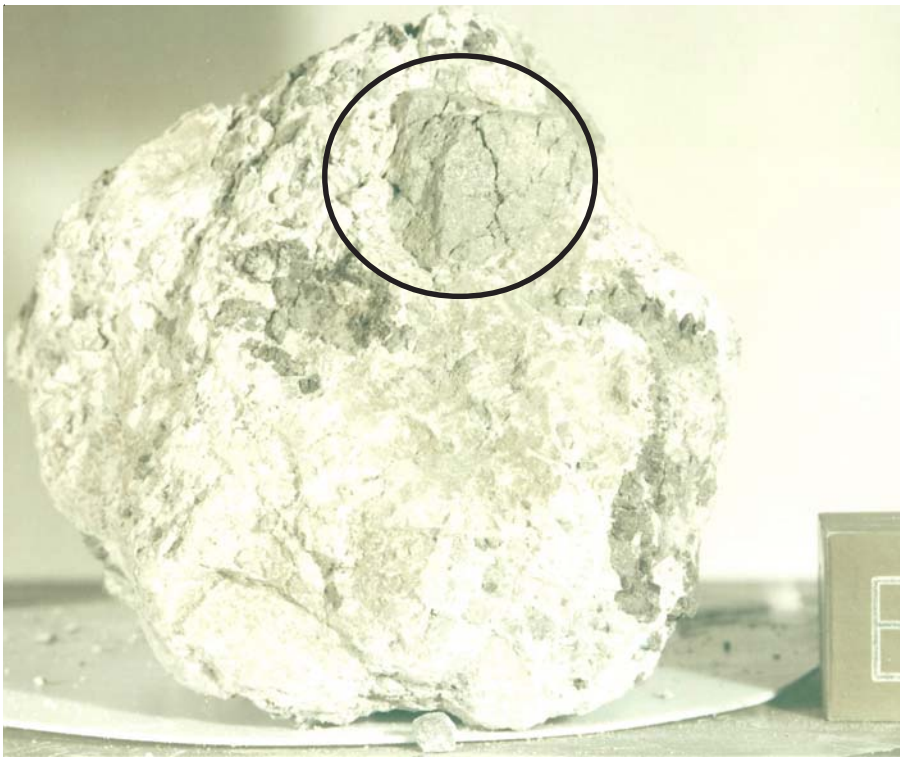


Figure 17: Large "basalt" clast on E1 face of 67015. Cube is 1 inch. S72-37217

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