61015

Dimict Breccia

1789 grams

Figure 1: Photo of 61015. NASA # S72-37758. Scale and cube in cm. Note the zap pits on the T1 surface and the residual black glass coating on the sides.

Introduction

Breccia 61015 is one of the best examples of the Apollo 16 dimict breccias (figures 1 and 2). These breccias consist of anorthositic material and impact melt rock with high Al content.

Breccia 61015 was collected from on top of the soil about 10 m south of Plum Crater. It was coated with black glass on one side and is thought to be ejecta from South Ray Crater. Micrometeorite bombardment

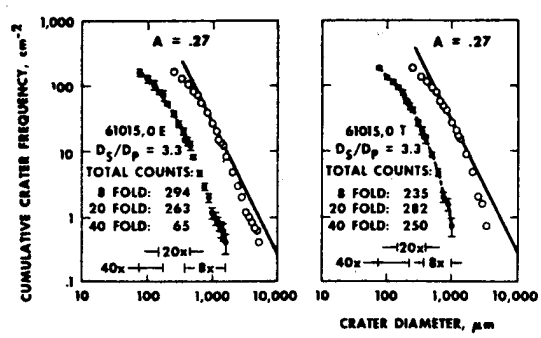


Figure 2: Micrometeorite count on top and side of 61015 (from Neukum et al. 1973).

Figure 3: Sawn surface of 61015,0 showing white anorthosite invaded by dark, recrystallized melt !!? Sample is 10 cm across. NASA # S83-36149.

apparently eroded the original glass coating on the top surface.

The melt rock potion has an age of 3.9 b.y., with an exposure to cosmic rays of about 2.3 m.y.

Petrography

The petrology of breccia 61015 is fully explained by James et al. (1984). It consists of roughly about ¾ impact melt and ¼ anorthosite lithologies (figure 3). The impact melt seems to have intruded the anorthosite lithology (McGee et al. 1979) and has recrystallized (figure 5).

The plagioclase in the anorthositic material is extremely fractured and deformed by impact processes. Plagioclase has patchy and undulatory extinction, contains healed shears, and locally contains patches of narrow shock-induced twin lamellae (James et al. 1984). Pyroxenes within the anorthosite show undulatory extinction and very locally augite contains shock-induced twinning. Fragments of single crystals of plagioclase are as much as 3.4 mm across and some

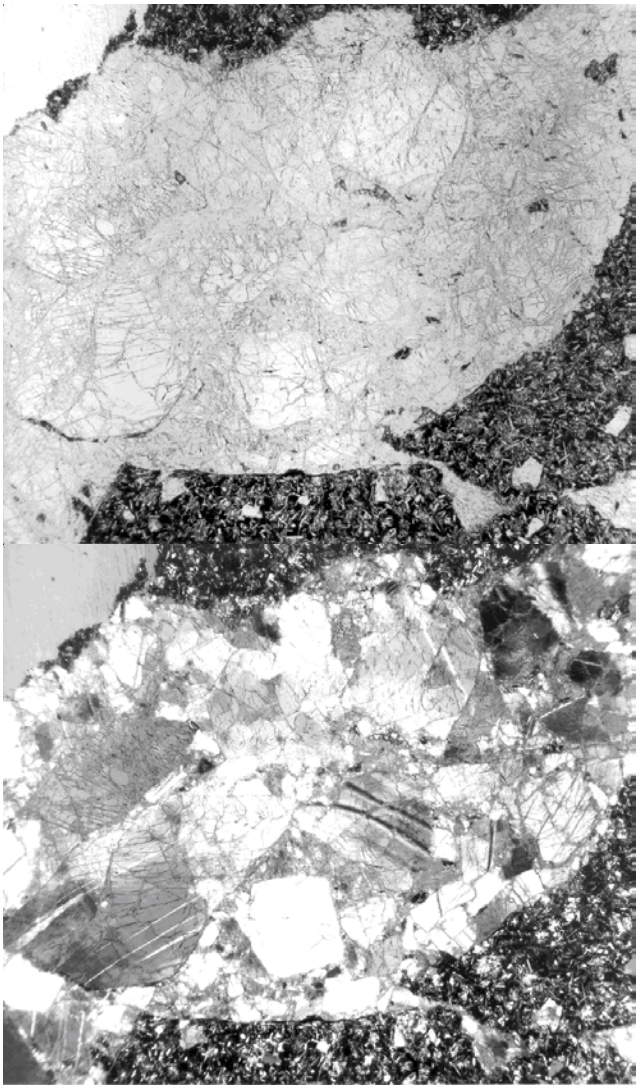


Figure 4: Photomicrographs of thin section 61015,5 showing anorthosite clast in transmitted and partially crossed polarized light. Field of view about 5 mm. NASA S72-45692 and 45688.

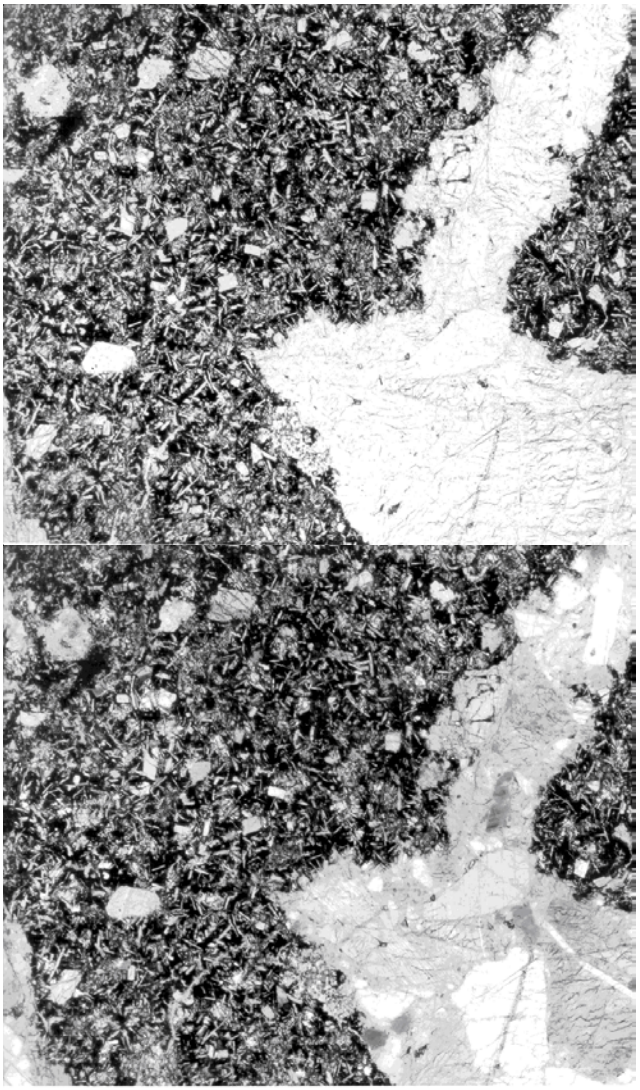


Figure 5: Photomicrographs of thin section of 61015 showing recrystallized melt-rock and portion of included anorthosite. Field of view about 5 mm. NASA S72-45703 and 45699.

pyroxenes are up to 0.9 mm, indicating the original coarse grain size of the parental rock. Based on mineral composition, the parental rock was ferroan anorthosite (figures 6 and 8).

Most of the melt-rock has a fine-grained intersertal texture (figures 4, 5) typical of other dimict breccias from Apollo 16 (James et al. 1984). It largely consists of a mat of randomly oriented plagioclase laths (~50 microns), equant grains of olivine (50-100 microns) subophitically enclosing the plagioclase, and microcrystalline dark brown mesostasis filling the intersticies. Included within this mat are rare large olivine grains, small pink spinels and globules of intergrown iron-schreibersite-troilite.

Rare, small, clasts of unusual rocks are also reported as clasts in the melt-rock by James et al. (1984). A rounded clast of granulitic spinel troctolite, about 2.1 mm across, consists of 70% olivine (Fo_{91}), 20%

Mineralogical Mode of Anorthosite in 61015

	James et al. 1984
Plagioclase	96 %
Pyroxene	3-4
Ilmenite	tr.
Chromite	tr.
Olivine	tr.
Silica	tr.
Troilite	tr.
Iron	tr.

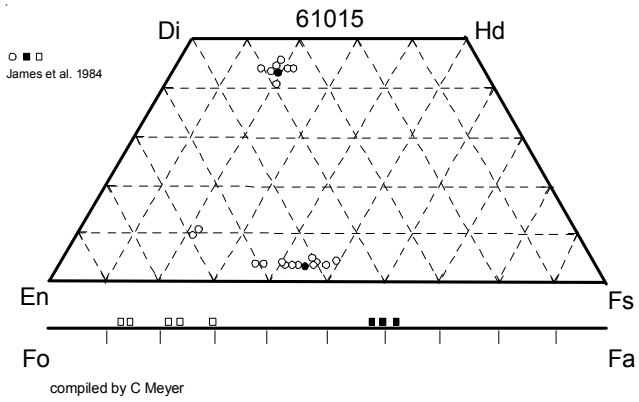


Figure 6: Olivine and pyroxene composition in anorthosite portion of 61015 (see James et al. 1984 for details).

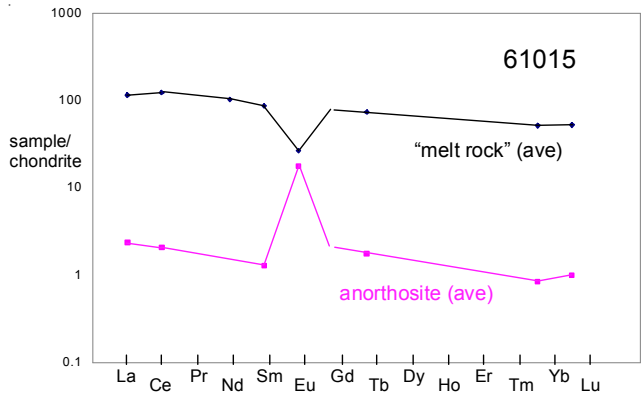


Figure 7: Normalized rare-earth-element diagram for the two main lithologies form 61015 (data averaged from James et al. 1984).

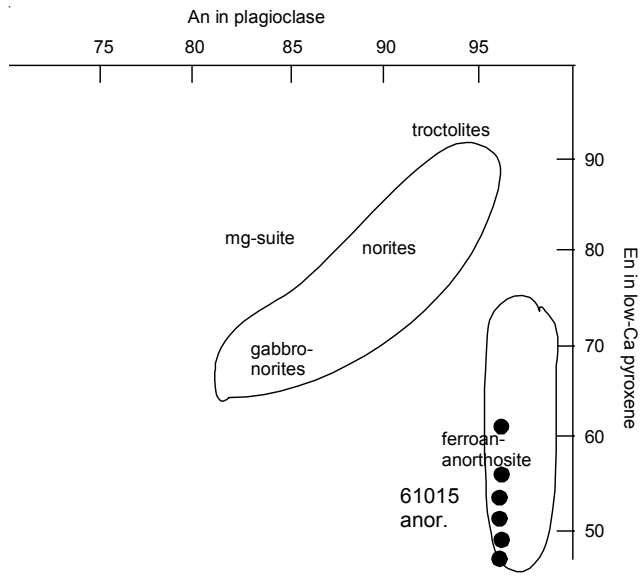


Figure 8: Composition of plagioclase and orthopyroxene in anorthositic portion of 61015. (from James et al. 1984).

plagioclase (An_{95}), 5% pink spinel, 5-10% intergrowth. Another unusual clast of "feldspathic, fragment-laden, melt rock" was described.

James et al. (1984), See et al. (1986) and Morris et al. (1986) studied the glass coating on 61015 and other rocks. The glass coating on 61015 is highly variable in color, texture and extent of crystallization. Glass splash is colorless, virtually free of inclusions and roughly follows the contours of the broken rock surface. Ropy glass on the bottom surface is almost entirely crystallized to an aggregate of brown spherulitic patches. Vesicles are sparce. Glass veins and "patches" are also reported within 61015 (James et al. 1984).

Neukum et al. (1973) reported identical crater count on the top (T) and side (E) of 61015 (figure 2).

Mineralogy

Olivine: Olivine inclusions in plagioclase in the anorthosite is Fe-rich (Fo_{40}), while olivine found in the melt-rock ranges from Fo_{71-95}. A single large olivine (360 microns) was found unzoned Fo_{91}.

Pyroxene: Both orthopyroxene and augite with a range of Fe content are found in the anorthositic portion (figure 6).

Plagioclase: Plagioclase in the anorthosite averages $Or_{0.025}Ab_{3.8}An_{96.1}$ while plagioclase in the melt rock averages $Or_{0.2}Ab_{5.8}An_{94}$.

Pink Spinel: A single large grain of pink Mg-Al spinel (80 microns) was reported by James et al.

Opaques: Analyses of both ilmenite and chromite are given in James et al.

Glass: James et al., See et al. and Morris et al. have each analyzed the glass.

Chemistry

Averages of the composition of several clasts are given in table 1. The VHA melt rock has high REE, while the anorthosite has a large Eu anomaly and extremely low REE (figure 7). Glass compositions are intermediate. The subsamples of VHA melt-rock have very high meteoritic siderophiles, including high Ni and Ir.

Table 1a. Chemical composition of 61015.

reference	Palme 78			Christian 76			James 84				Ebihara 92			Morris 86	
weight	light	dark					glass coat				anor.	melt		glass	
SiO2 %	45.5	44.8	(b)	45.23	45.8	(b)								45.07	
TiO2	0.27	0.62	(b)	0.45	0.79	(b)	0.33	0.23	0.14	(a)				0.25	
Al2O3	32.9	24.5	(b)	26.87	22.09	(b)	28.1	28.1	28.1	(a)				27.59	
FeO	2.95	6.69	(b)	4.42	6.4	(b)	5.14	4.79	4.48	(a)				5.06	
MnO	0.033	0.08	(b)	0.07	0.1	(b)									
MgO	2.9	8.9	(b)	6.61	10.5	(b)	7.01	5.85	5.47	(a)				6.44	
CaO	17.8	13.6	(b)	15.5	13.36	(b)	14.9	15.7	16	(a)				15.01	
Na2O	0.47	0.49	(b)	0.42	0.47	(b)	0.465	0.468	0.486	(a)				0.62	
K2O	0.048	0.13	(b)	0.09	0.21	(b)								0.49	
P2O5	0.087	0.195	(b)	0.09	0.19	(b)								0.09	
S %	0.05	0.215	(b)												
sum															
Sc ppm	3.85	8.85	(a)	<10	<10	(b)	4.89	4.06	4.04	(a)				4.72	(a)
V							14	20	16	(a)					
Cr	340	980	(b)	547	890	(b)	732	632	628	(a)				746	(a)
Co	39.5	60.9	(a)	14	30	(b)	58.7	66.5	61.8	(a)				56	(a)
Ni	690	1160	(a)	250	540	(b)	1150	1390	1200	(a)	7.12	1640	(c)	1167	(a)
Cu				3.8	5.9	(b)									
Zn				2	3.1	(b)					0.292	3.68	(c)		
Ga	3.8		(a)	2.3	3.1	(b)									
Ge ppb											15.9	4190	(c)		
As															
Se											0.022	0.43	(c)		
Rb				2.4	4	(b)	3.6	9	2.5	(a)	0.111	5.96	(c)		
Sr	197	166	(a)	130	140	(b)	193	206	206	(a)					
Y	24	67	(a)	50	100	(b)									
Zr	90	292	(a)	200	330	(b)	90	70	75	(a)					
Nb	5	16	(a)	<10	<10	(b)									
Mo															
Ru															
Rh															
Pd ppb											4.25	86.1	(c)		
Ag ppb											5.55	1.33	(c)		
Cd ppb											1.45	9.76	(c)		
In ppb											0.36	10.7	(c)		
Sn ppb															
Sb ppb											1.24	11.8	(c)		
Te ppb											11.2	146	(c)		
Cs ppm							0.07	0.07	0.09	(a)	0.004	0.22	(c)		
Ba	80	200	(a)	130	280	(b)	90	75	65	(a)				93	(a)
La	7.62	20.8	(a)	10	19	(b)	8	5.86	5.59	(a)				8.26	(a)
Ce	19.8	56.4	(a)				21.7	16	14.1	(a)				23	(a)
Pr															
Nd	14	34	(a)				13.7	9.5	9.2	(a)					
Sm	3.19	8.61	(a)				3.83	2.83	2.55	(a)				3.66	(a)
Eu	1.17	1.3	(a)				0.956	0.899	0.9	(a)				0.96	(a)
Gd		11	(a)												
Tb	0.63	1.87	(a)				0.8	0.55	0.574	(a)				0.82	(a)
Dy	4.25	11.3	(a)												
Ho	0.91	2.76	(a)												
Er															
Tm															
Yb	2.4	6.52	(a)				2.53	1.89	1.72	(a)				2.39	(a)
Lu	0.32	0.89	(a)				0.394	0.3	0.285	(a)				0.33	(a)
Hf	2.4	6.78	(a)				2.95	2.2	2.05	(a)				2.59	(a)
Ta	0.26	0.86	(a)				0.38	0.3	0.21	(a)				0.36	(a)
W ppb															
Re ppb											0.028	5.18	(c)		
Os ppb											0.126	45.7	(c)		
Ir ppb	13	29	(a)				30	36	39	(a)	0.216	42.8	(c)		
Pt ppb															
Au ppb	14	20	(a)						13	(a)	0.324	29.1	(c)		
Th ppm	0.73	2.55	(a)				1.5	1.26	0.91	(a)				1.93	(a)
U ppm	0.23	0.68	(a)				0.27	0.23	0.2	(a)	0.021	1.2	(c)	0.45	(a)

technique: (a) INAA, (b) mixed, (c) RNAA

Table 1b. Chemical composition of 61015 anorthosites.

reference	James et al. 1984								ave. anor.
weight	(b)								to plot
SiO2 %									
TiO2	0.23		0.09	0.06			0.07	(a)	
Al2O3	31.2	33.5	34.3	32.5	32.8	34.7	32.5	(a)	
FeO	2.96	0.233	0.765	0.881	0.789	0.539	2.12	(a)	
MnO									
MgO	3.72	0.36	0.74	1.36	0.67	0.66	1.9	(a)	
CaO	16.9	18.8	18.5	18.6	18	18.5	18.1	(a)	
Na2O	0.426	0.458	0.436	0.429	0.412	0.429	0.41	(a)	
K2O									
P2O5									
S %									
sum									
Sc ppm	3.32	0.322	1.545	1.645	1.495	1.065	5.13	(a)	
V									
Cr	290	4.46	102	79.5	64.1	46	3.44	(a)	
Co	36	0.345	1.2	2.01	1.09	0.762	2.83	(a)	
Ni	565	3	7	14	7	6	12	(a)	
Cu									
Zn									
Ga									
Ge ppb									
As									
Se									
Rb									
Sr	277	225	218	216	210	220	206	(a)	
Y									
Zr									
Nb									
Mo									
Ru									
Rh									
Pd ppb									
Ag ppb									
Cd ppb									
In ppb									
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm									
Ba	77	11	17	17	13	13	11	(a)	
La	6.54	0.294	0.785	0.733	0.368	0.543	0.647	(a)	0.56
Ce	18.3	0.67	1.8	1.7	1.02	1.33	1.36	(a)	1.3
Pr									
Nd									
Sm	3.12	0.088	0.313	0.294	0.125	0.149	0.151	(a)	0.19
Eu	1.11	1.04	1.02	1	0.99	1.03	0.98	(a)	1.01
Gd									
Tb	0.647	0.144	0.072	0.068	0.026	0.035	0.043	(a)	0.065
Dy									
Ho									
Er									
Tm									
Yb	2.04	0.0278	0.212	0.205	0.096	0.095	0.188	(a)	0.14
Lu	0.307	0.0033	0.034	0.036	0.0162	0.0144	0.039	(a)	0.024
Hf	2.36	0.006	0.19	0.15	0.05	0.06	0.06	(a)	
Ta	0.32	0.002	0.021	0.014	0.004	0.008	0.015	(a)	
W ppb									
Re ppb									
Os ppb									
Ir ppb									
Pt ppb									
Au ppb									
Th ppm	1.03		0.064	0.057	0.008	0.016	0.02	(a)	
U ppm	0.22		0.043	0.038		0.025	0.03	(a)	

technique: (a) INAA, (b) contaminated with matrix

Table 1c. Chemical composition of 61015 melt rock.

reference	James et al. 1984								av. VHA
weight	64.7 mg	112.3	124.6	100.5	71.5	31.8	2.18		
SiO2 %									
TiO2	0.96	0.98	0.89	0.94	1	0.94	0.99	(a)	0.96
Al2O3	20.5	24.1	21.1	20.5	21.3	21.9	28.1	(a)	22.5
FeO	8.94	8.57	6.9	7.93	7.98	6.89	7.79	(a)	7.8
MnO	0.09	0.1	0.09	0.09	0.1	0.09	0.08	(a)	0.09
MgO	12.8	13	12.7	12	12.5	12.7	10.6	(a)	12.3
CaO	11.6	13.3	12	11.9	11.7	11.6	15.5	(a)	12.5
Na2O	0.455	0.5	0.464	0.44	0.459	0.475	0.515	(a)	0.47
K2O					0.06	0.2	0.16	(a)	0.1
P2O5									
S %									
sum									
Sc ppm	10.8	11.6	10.8	10.8	11.6	11.2	9.53	(a)	
V	25	31	32	28	29	27	32	(a)	
Cr	1092	1150	1108	1094	1100	1070	974	(a)	
Co	88	65	23	53	49	23	90	(a)	
Ni	1420	1040	342	860	750	330	1420	(a)	
Cu									
Zn									
Ga									
Ge ppb									
As									
Se									
Rb	5	10	7	7	7	9	16	(a)	
Sr	211	240	164	227	168	178	190	(a)	
Y									
Zr	300	280	290	290	350	340	280	(a)	
Nb									
Mo									
Ru									
Rh									
Pd ppb									
Ag ppb									
Cd ppb									
In ppb									
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm	0.18	0.28	0.22	0.28	0.28	0.27	0.22	(a)	
Ba	290	310	290	290	270	260	240	(a)	
La	27.4	28.6	26.9	27.4	28.9	27.1	25.3	(a)	27.4
Ce	75.7	78.8	75.2	75.8	74.2	74	69.4	(a)	74.7
Pr									
Nd	46.2	48.2	45.9	46.9	48.4	48.9	42	(a)	46.6
Sm	13.01	13.63	12.86	12.91	12.87	12.53	11.54	(a)	12.8
Eu	1.47	1.61	1.48	1.48	1.49	1.5	1.46	(a)	1.5
Gd									
Tb	2.72	2.88	2.74	2.69	2.96	2.71	2.3	(a)	2.7
Dy									
Ho									
Er									
Tm									
Yb	8.68	9.15	8.65	8.73	8.75	8.5	7.18	(a)	8.5
Lu	1.3	1.35	1.29	1.31	1.38	1.31	1.14	(a)	1.3
Hf	10.05	10.45	9.98	10.1	10.4	10.1	8.2	(a)	
Ta	1.35	1.35	1.27	1.32	1.13	1.09	0.87	(a)	
W ppb									
Re ppb									
Os ppb									
Ir ppb	30	17	5.2	17	19	6.6	31	(a)	
Pt ppb									
Au ppb					11	5.7	24	(a)	
Th ppm	4.84	4.65	4.54	4.71	4.7	4.4	3.86	(a)	
U ppm	0.95	1.16	1.03	1.1	1.17	1.23	0.9	(a)	

technique: (a) INAA

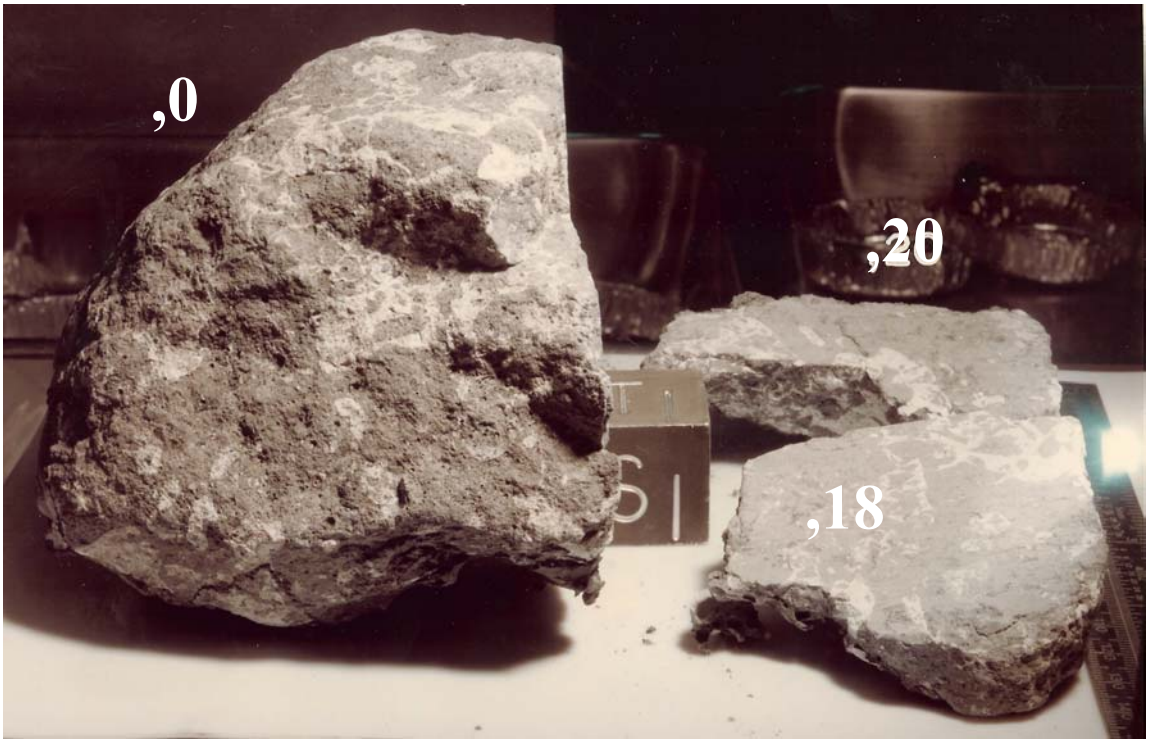


Figure 9: Processing photo of 61025 showing firest saw cut made in 1975. Cube is 1 inch. S75-20883.

Figure 10: Sawn surfaces exposed by first saw cut. Note marks by band saw blade. 1 inch = 2.54 cm. S75-20881. Compare with figure 9..

Radiogenic age dating

Norman et al. (2006) have reported age data for a very small piece of 61015. They obtained an Ar/Ar plateau age of 3.9 b.y. (figure 11).

Cosmogenic isotopes and exposure ages

Eugster (1999) determined a cosmic-ray exposure age of 2.34 ± 0.5 m.y. by the ^{38}Ar method.

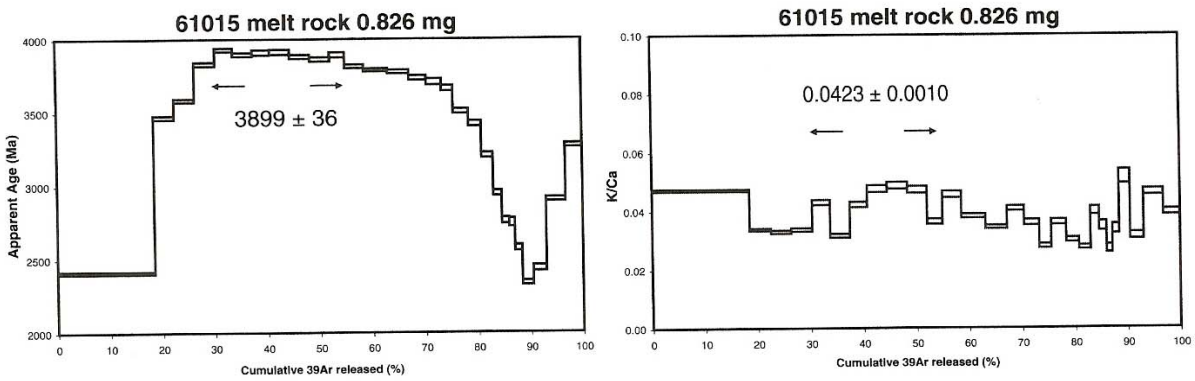
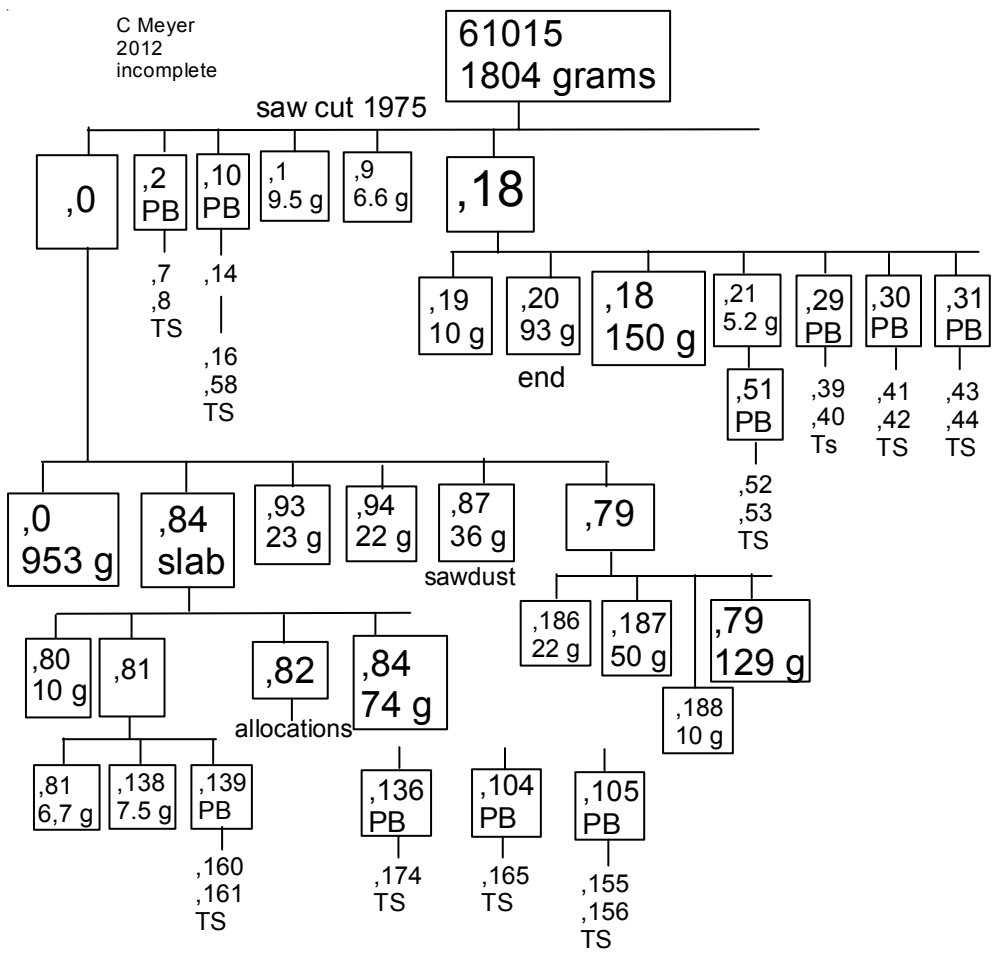


Figure 11: Ar/Ar plateau diagram for very small subsample of 61015 (Norman et al. 2006).



Processing

61015 was initially sawn once (not slabbed) creating end pieces ,18 and ,20 which were studied by the "James Consortium". Figures 9 and 10 shows the saw cut in 1975. In 1983 a slab (,84) was cut from ,0 at right angles to the first cut (figure 12) creating end piece ,79. Figures 14 and 15 shows slab ,84 and its subdivision. End piece ,79 has recently been subdivided. Figure 16 shows the glass on back side of 61015.

In 2005, 61015 was used to prepare a public display for the Astronaut Ambassador Program. There are 41 thin sections of 61015.

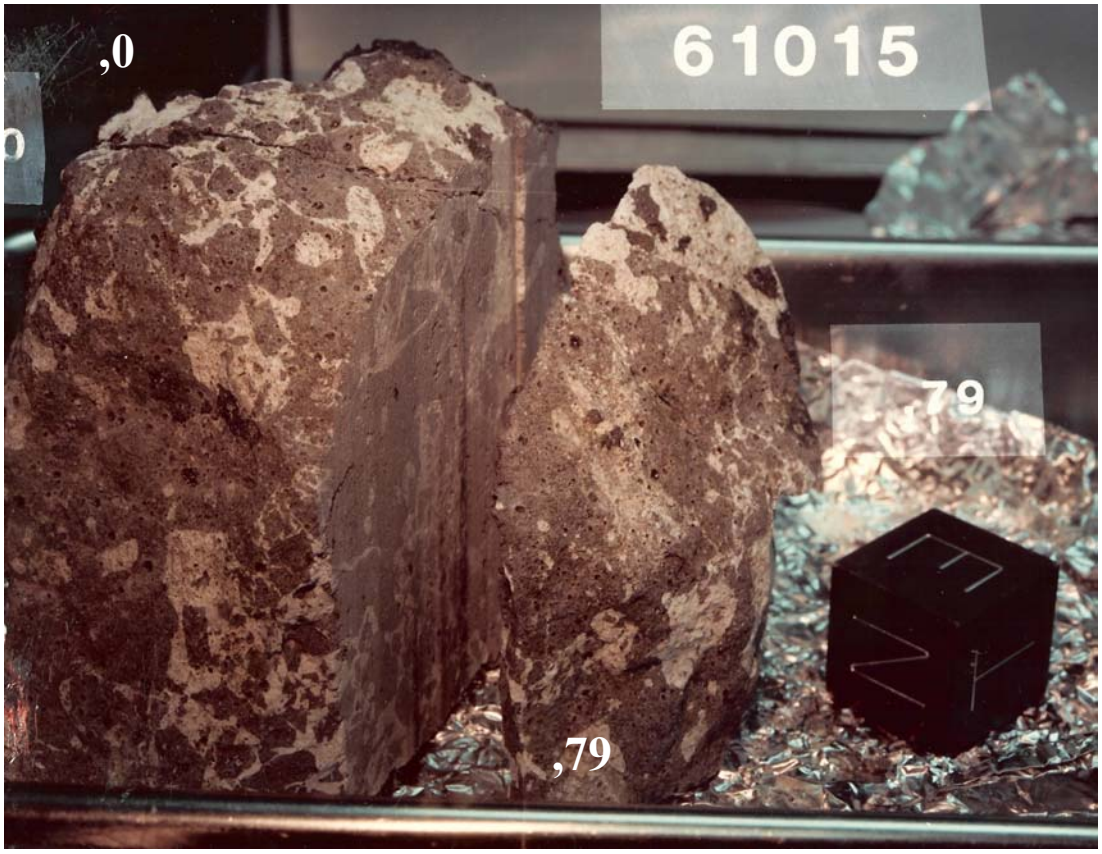


Figure 12: Second saw cut of 61015, at right angles to first saw cut. Cube is 1 inch. S83-40345.

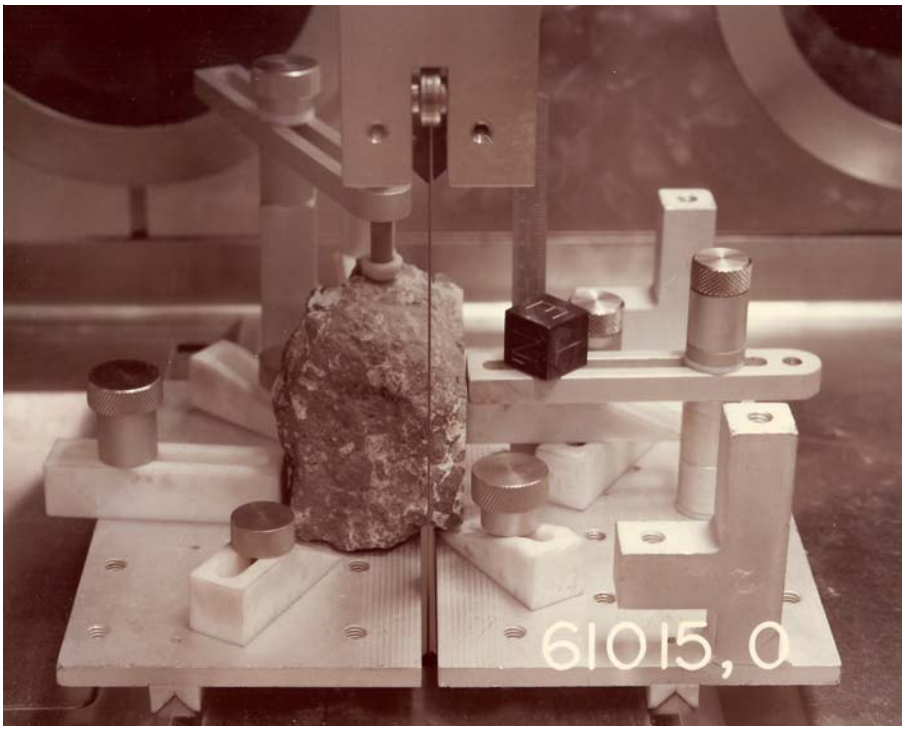
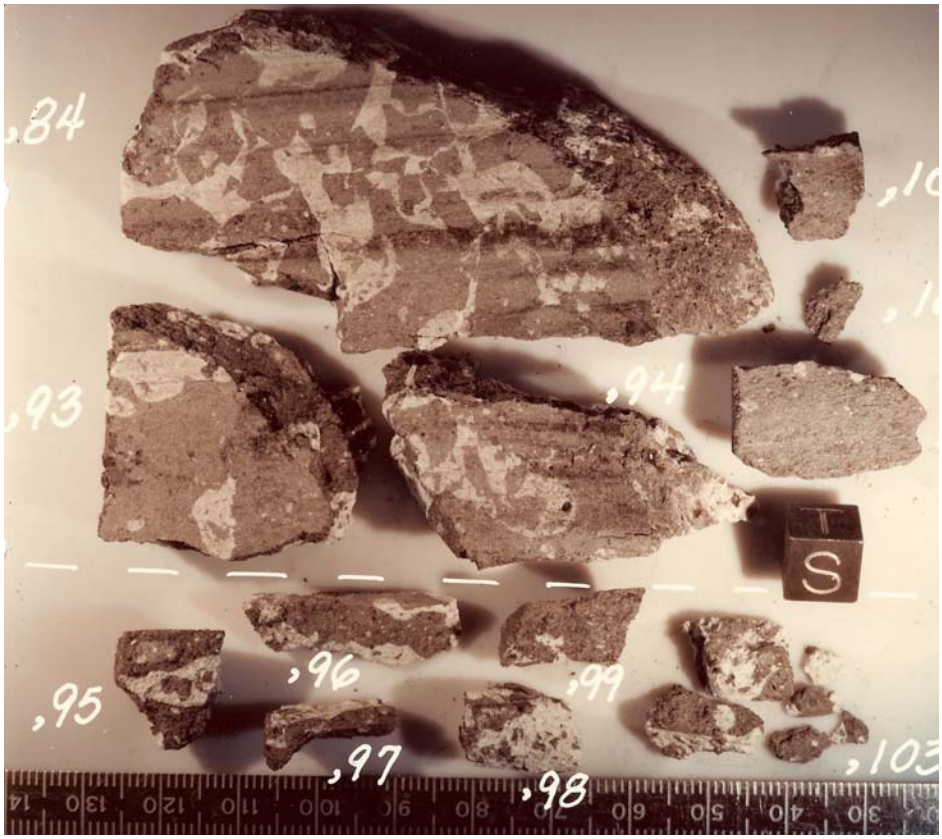


Figure 13: Processing photo of third saw cut, producing small slab ,84 from 61015. Cube is 1 inch. S83-36156.

Figures 14 and 15: Both sides of slab ,84 cut from 61015,0 in 1983. Cm cube is in field of view. S83-36151.



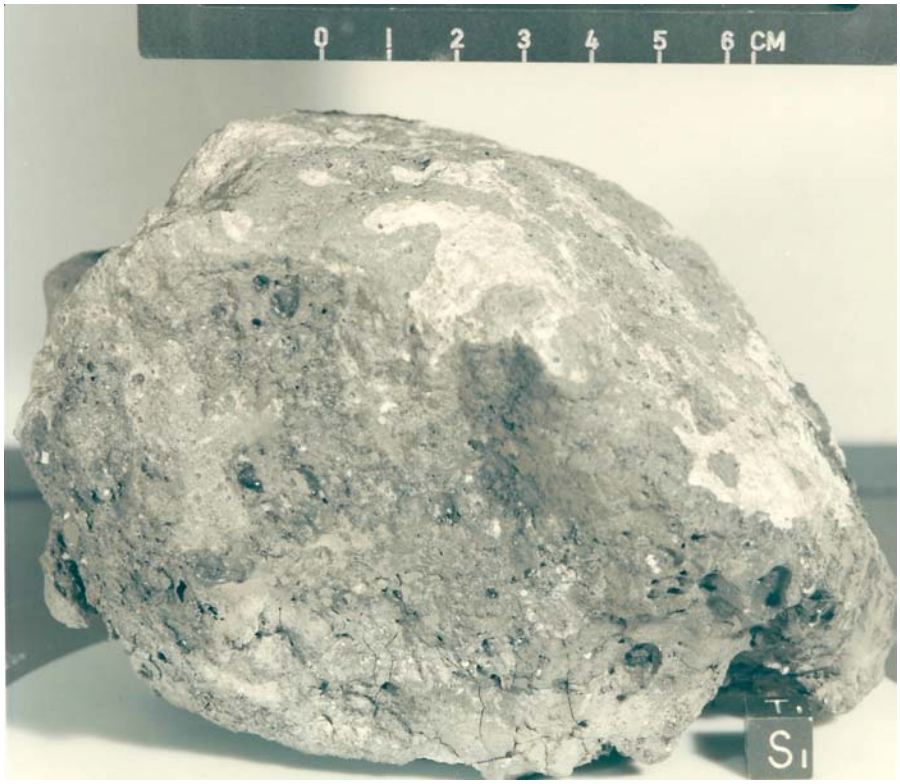


Figure 16: Another view of 65015 before it was cut up. Cube and scale are in cm. S72-37757. Compare with figure 1.

References for 61015

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