67455

Anorthositic Breccia

942 grams

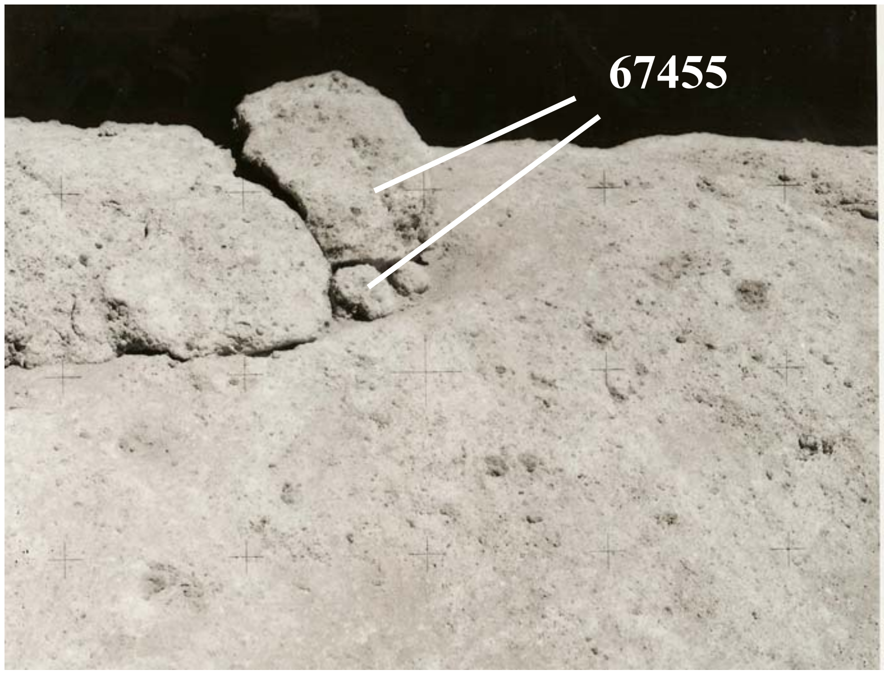


Figure 1: Close-up photo of top of "white breccia boulder" on rim of North Ray Crater showing that 67455 was part of larger boulder. AS16-106-17332.

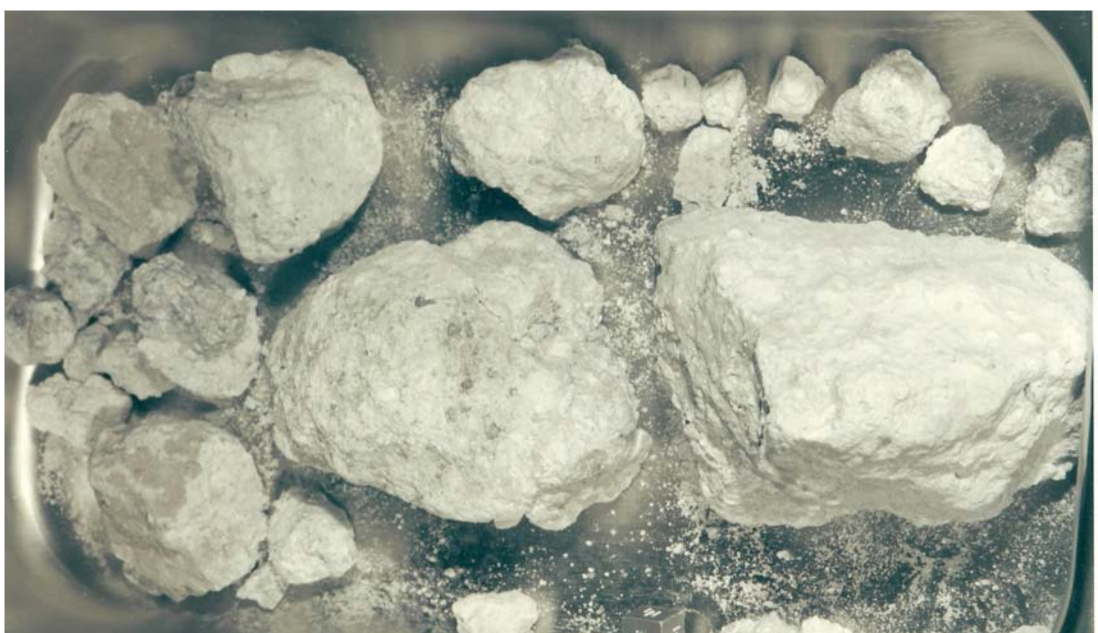


Figure 2: Photo of 67455 in tray during PET. Cube is 1 cm. S72-38194.

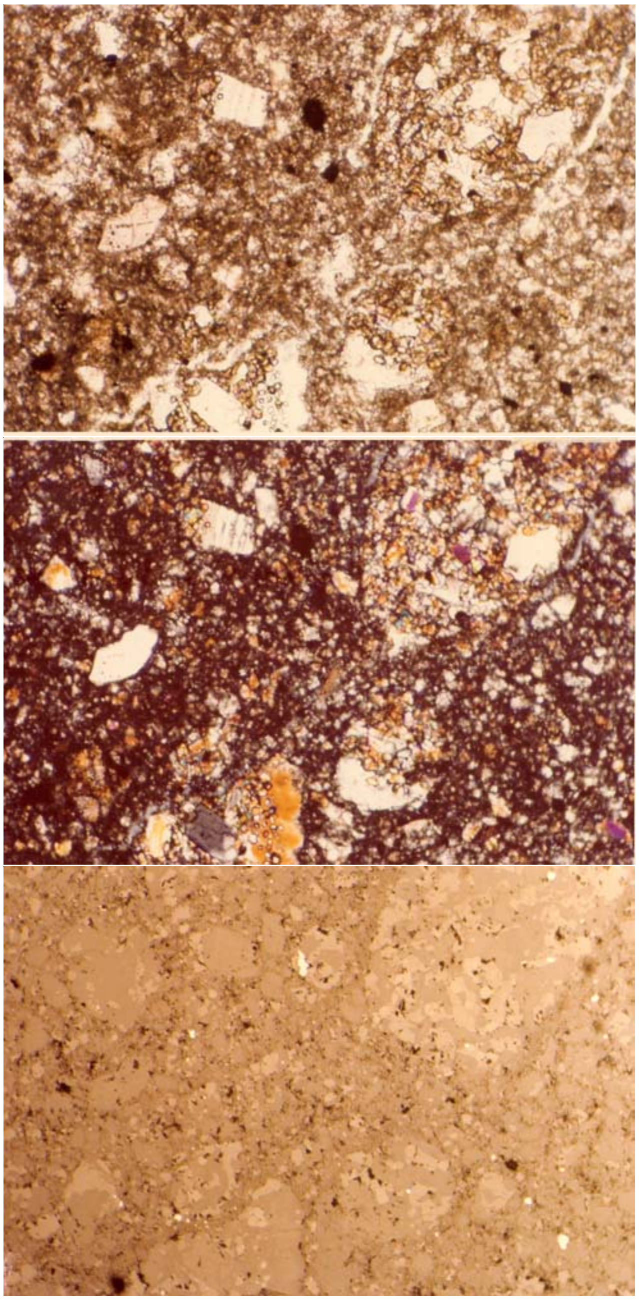


Figure 3: Photomicrographs of thin section 67455,49. Field of view is 1.4 mm. Top is plane-polarized light, middle is crossed-nicols, bottom is reflected light. NASA S79-27732, 27723 and 27731.

Introduction

Lunar sample 67455 is a very friable, white polymict feldspathic breccia that was collected from the top of a large boulder on the rim of North Ray Crater, Apollo 16 (Ulrich et al. 1973, 1981, Hodges et al. 1973). It arrived in Houston as broken fragments (figure 2). *According to the overturned flap concept, samples on the rim should be from the deepest part of the crater.*

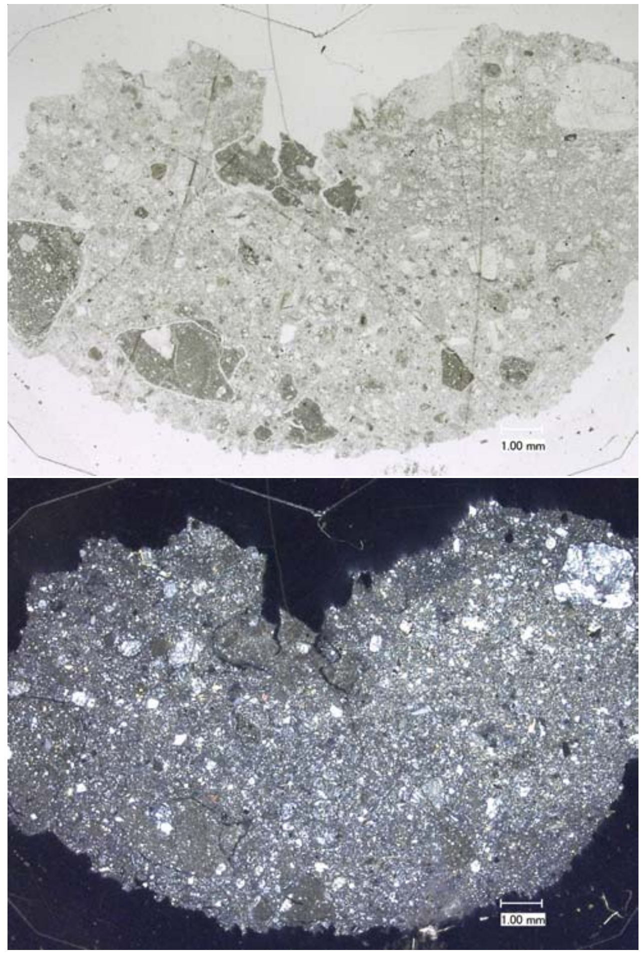


Figure 3a: Photomicrographs of thin section 67455,46 by C Meyer @20x.

Pristine anorthosite clasts in this fragmental breccias have been dated at 3.9 to 4.0 b.y. The exposure age of this sample (50 m.y.) determines the age of North Ray Crater.

Petrography

The white breccia boulder on the rim of North Ray Crater is a highly-shocked, fragmental-matrix breccia (figure 1). It contains, as clasts, various cataclastic anorthosites (Minkin et al. 1977, Lindstrom et al. 1977, 1981, Norman et al. 2010).

The matrix of 67455 is made up of crushed and compacted plagioclase grains (Ryder and Norman 1979, 1980). Within the crushed matrix are numerous clasts of weakly shocked, cataclastic anorthosite with relic cumulate texture. Mineral chemistry indicate they are ferroan anorhtosite. Three clasts (,30 ,31 and ,32) were found to be chemically "*pristine*".

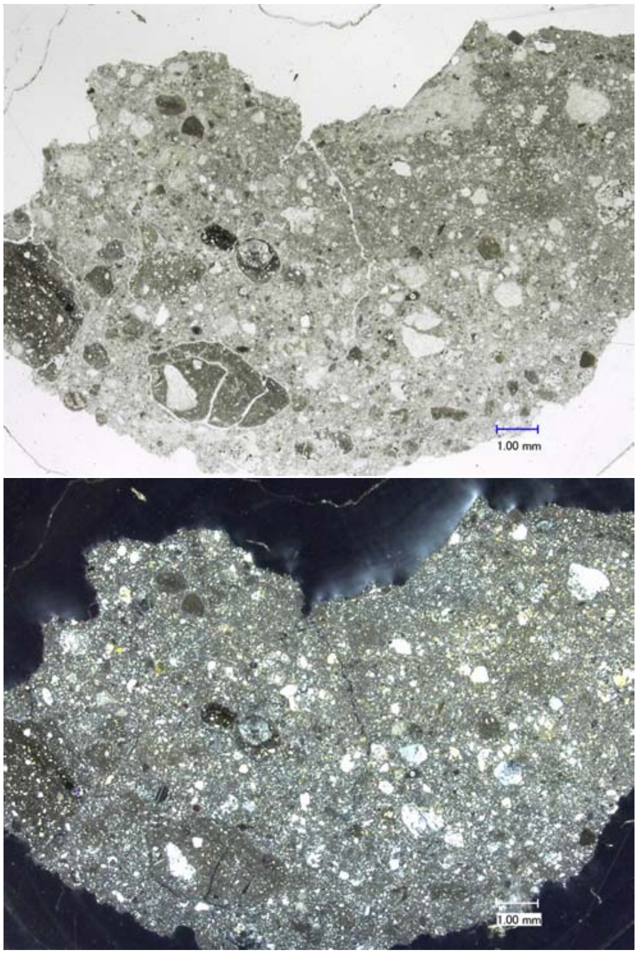


Figure 3b: Photomicrographs of thin section 67455,47 by C Meyer @20x.

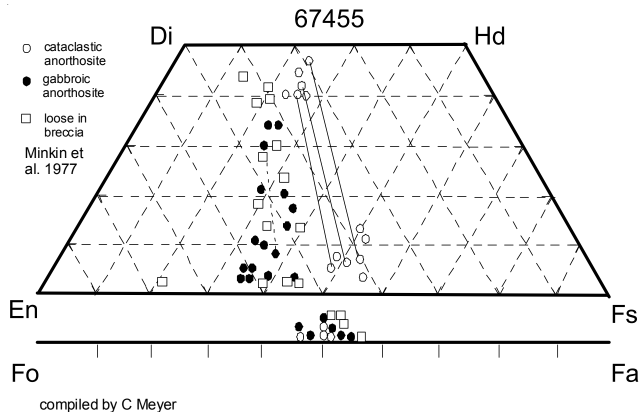


Figure 4: Composition of pyroxene and olivine in 67455.

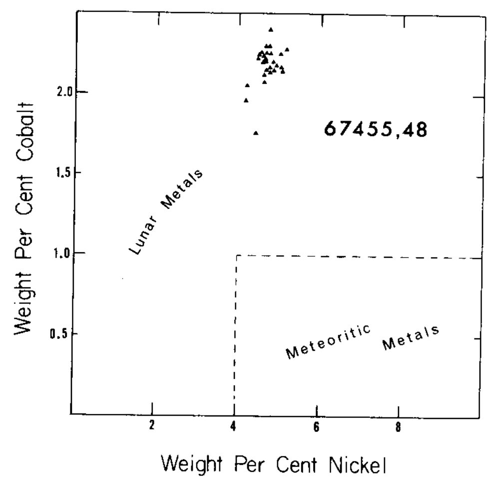


Figure 5: Composition of metal in 67455 (Taylor et al. 1973).

Clasts of gabbroic anorthosite have a range of texture from coarse granoblastic to fine-grained "hornfelsic" (Minkin et al 1977).

Dark clasts have a matrix of melt-glass often containing abundant xenocrysts and laths of plagioclase. The glassy matrix breccias clasts are coherent, often with distinct boundaries with breccia matrix, allowing them to be easily separated (figures 3b and 10).

Mineralogical Mode for 67455

	Minkin et al. 1977	
Olivine	3.7	6.2
Pyroxene	8.2	3.2
Plagioclase	51	46
Opaque	2.2	2.3
Glass	2.7	6
"Anorthosite"	22	20
feld. microbx.	2.7	6.8
"melt"	7.6	9

LMP There's one of these white rocks up here, John, that's got a fracture on it.
CDR Got a hammer?
LMP Yeah, I've got the hammer. It's just loose, the stuff is lying up there on top.
- - - - -
CC Charlie, if possible we'd like some samples on that stuff on top of the boulder.
LMP That's what I'm going to do. I'm not going to give you any scale, though.
- - - - -

LMP It looks like the same thing that John had described. It's a friable breccia with a black clast being aphanatic. The largest clast I see is not in the sample but it's a black one that's a centimeter across. It has a bluish tint to it. It looks like all those shocked rocks that Fred Horz was telling us about. Exactly, and that's in bag 416.

Mineralogy

Olivine: Smith et al. (1980) determined the trace element content of olivine in 67455.

Pyroxene: Minkin et al. (1977) determined the composition of olivine, pyroxene and plagioclase in various clasts (figure 4).

Metallic iron: Metallic iron with 'rust' and sphalerite was reported by Taylor et al. (1973) and El Goresy et al. (1973). Hunter and Taylor (1981) also reported 'rust' was "abundant" in 67455. The metallic iron has high Co content and does not appear to be of meteoritic origin (figure 5).

Chemistry

Wrigley (1973) found that 67455 was very low in K, U and Th (whole rock). Lindstrom et al. (1977), and Lindstrom and Salpus (1981, 1982) have determined the composition of various clasts (figure 6). Hertogen et al. (1977) and Wolf et al. (1979) reported trace element contents of matrix and various clasts, finding that they were low in meteoritic siderophiles (table). Moore et al. (1973) reported 8 ppm carbon (very low). Reed et al. (1977) determined Pb, Bi, Tl and Zn in 67455 and Jovanovic and Reed (1978) determined Cl, Br, I and phosphorus.

Hunter and Taylor (1981) mention that 67455 may be "volatile rich", but the evidence for this is poorly documented..

Radiogenic age dating

Kirsten et al. (1973) determined an age of 3.91 ± 0.12 b.y. from a poorly-defined Ar plateau (figure 7). Norman and Duncan (2008) and Norman et al. (2010) have two dated anorthositic clasts from 67455 with ages from 3889 ± 23 to 3987 ± 27 m.y., along with one melt breccia clast at 3987 ± 21 m.y. (figure 8).

Cosmogenic isotopes and exposure ages

Wrigley (1973) determined the cosmic ray induced activity for ^{26}Al = 103 dpm/kg and ^{22}Na = 29 dpm/kg.

Marti et al. (1973), Drozd et al. (1974) and Bernatowicz et al. (1978) determined an expsoure age of 50 m.y. by ^{81}Kr. Kirsten et al. (1973) determined ~33 m.y by ^{38}Ar. Pepin et al. (1974) and Eugster and Niedermann (1986) determined the exposure age for 67455 by ^{3}He, ^{21}Ne, ^{38}Ar, ^{83}Kr, ^{128}Xe and ^{81}Kr – averaging 49±10 m.y. It was concluded that this sample had no prior exposure, and that its 'shielding depth' was about 22 ± 2 g/cm^{2}.

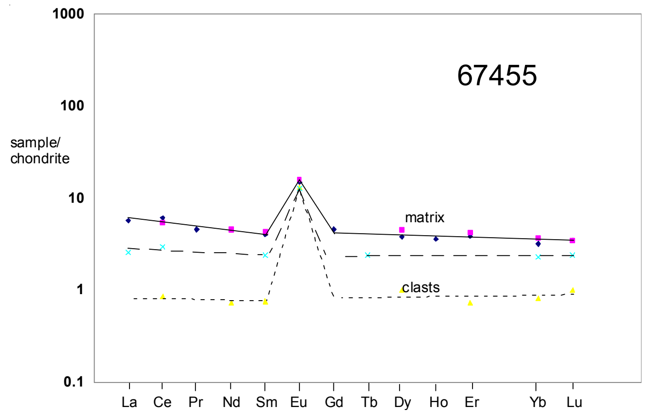


Figure 6: Normalized rare-earth-element diagram for matrix and some clasts in 67455 (data from Tables).

Other Studies

Bernatowicz et al. (1978) studied the Kr and Xe isotopic content of 67455, finding "excess" fission Xe. Pepin et al. (1974) and Eugster and Niedermann (1986) determined isotopic ratios of rare gases.

Adams and McCord (1973) determined the reflectance spectra (figure 9), but this should be done on the patina covered surface and compared with the interior (50 m.y. exposure on top of White Breccia Boulder, figure 1). Nagata et al. (1973) determined the magnetic properties. Storzer et al. (1973) reported cosmic-ray tracks in feldspar and calculated a 30 m.y. exposure age.

Table 1a. Chemical composition of 67455 and clasts.

reference	Lindstrom et al. 1977				Haskin 77						Lindstrom 81		
weight	matrix	melt	norite	anor.	cat. anor.	anor	anor	micro	micro		Haskin 81		
SiO2 %	44.5	44.4	44.8	44.4	44	44.9	45.3	44.1	44.6	(a)			
TiO2	0.21	0.23	0.23	<0.05	<0.05	0.13	0.05	0.18	0.13	(a)			
Al2O3	30.75	28.69	28.96	34.5	34.21	32.28	33.03	30.17	30.59	(a)	35.5		(c)
FeO	3.58	4.99	5.04	0.61	1.46	2.62	1.94	4.11	3.9	(a)	0.422	3.85	(c)
MnO	0.05	0.07	0.07	0.01	0.02	0.04	0.03	0.05	0.05	(a)	0.009		(c)
MgO	2.83	3.47	3.87	0.51	0.94	1.31	1.12	2.81	2.69	(a)	0.6		(c)
CaO	17.13	17.01	17.32	19.83	18.73	18.1	18.45	17.68	17.75	(a)	19.8		(c)
Na2O	0.44	0.47	0.31	0.33	0.32	0.42	0.42	0.39	0.37	(a)	0.314	0.24	(c)
K2O	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	(b)			
P2O5	0.03	0.02	0.04	0.03	0.04	0.02	0.04	0.04	0.04	(a)			
S %													
sum													
Sc ppm											0.267	2.93	(c)
V													
Cr											28.3	114	(c)
Co											0.21	1.61	(c)
Ni											14	10	(c)
Cu													
Zn													
Ga													
Ge ppb													
As													
Se													
Rb	0.378	0.169	0.634	0.706	0.492	0.87	0.751	0.559	0.529	(b)			
Sr	174	152	144	161	155	116	163	150	148	(b)	152	154	(c)
Y													
Zr													
Nb													
Mo													
Ru													
Rh													
Pd ppb													
Ag ppb													
Cd ppb													
In ppb													
Sn ppb													
Sb ppb													
Te ppb													
Cs ppm												0.052	(c)
Ba	23.6	19.4	13.2	11.5	9.97	13.6	11.3	12.7	23.6	(b)	9	15	(c)
La											0.096	0.097	(c)
Ce	3.32	2.96	2.47	0.513	0.66	0.924	0.676	1.66	3.29	(b)	0.22	0.31	(c)
Pr													
Nd	2.08	1.92	1.88	0.33	0.283	0.673		1.14	1.54	(b)			
Sm	0.641	0.6	0.571	0.112	0.0601	0.228	0.122	0.341	0.379	(b)	0.0293	0.0462	(c)
Eu	0.905	0.792	0.745	0.727	0.687	0.802	0.799	0.739	0.724	(b)	0.688	0.64	(c)
Gd						0.324							
Tb											0.0065	0.012	(c)
Dy	1.11	0.777	1.01	0.249	0.08	0.394	0.199	0.62	0.595	(b)			
Ho													
Er	0.68	0.536	0.642	0.118	0.05	0.235	0.124	0.388	0.374	(b)			
Tm													
Yb	0.597	0.454	0.632	0.135		0.26	0.15	0.399	0.388	(b)	0.0145	0.08	(c)
Lu	0.084	0.089	0.087	0.0245		0.03	0.0215	0.0566	0.056	(b)	0.0014	0.0136	(c)
Hf											0.0066		(c)
Ta													
W ppb													
Re ppb													
Os ppb													
Ir ppb													
Pt ppb													
Au ppb													
Th ppm													
U ppm													

technique (a) mixed, (b) IDMS, (c) INAA

Table 1b. Chemical composition of 67455 and clasts.

reference	Hertogen et al. (1977)									Muller76	Wanke 73		Wrigley73	
weight	,69	,74	,77	,122	,126	,133	,142	,150					133.5 g	
SiO2 %											45.1	(e)		
TiO2											0.2	(e)		
Al2O3										29.8	30.6	(e)		
FeO										4.35	4.36	(e)		
MnO											0.054	(e)		
MgO										3.38	3.35	(e)		
CaO										17.8	18	(e)		
Na2O										0.39	0.38	(e)		
K2O										0.025	0.026	(e)	0.016	(f)
P2O5											0.01	(e)		
S %														
sum														
Sc ppm											6.8	(e)		
V														
Cr											420	(e)		
Co											9.95	(e)		
Ni	7.9	2.5	20	<8	<7	<5	3.8	33	(d)		28	(e)		
Cu											1.65	(e)		
Zn	4.13	2.71	4.2	6.73	1.34	4.82	3.91	4.99	(d)		8.5	(e)		
Ga											3.4	(e)		
Ge ppb	16	1.8	5.7	5.5	1.4	1.8	7.5	17.4	(d)					
As											0.01	(e)		
Se														
Rb	0.16	0.9	0.82	0.56	0.49	0.74	0.58	1.01	(d)	0.89				
Sr										151	130	(e)		
Y											4.4	(e)		
Zr											17	(e)		
Nb											1.3	(e)		
Mo														
Ru														
Rh														
Pd ppb	0.4	<0.3	0.043	0.024	<0.0004	0.0003	0.018	0.1	(d)					
Ag ppb	1.21	0.41	8.68	0.79	0.2	0.38	0.39	0.76	(d)					
Cd ppb	0.29	1.45	4.74	3.08	0.52	0.26	0.21	1.37	(d)					
In ppb	0.35	0.73	1.37	0.54	0.21	0.24	0.31	1.09	(d)					
Sn ppb														
Sb ppb	3.57	0.11	0.86	0.15	0.052	0.085	0.057	0.1	(d)					
Te ppb	1	<0.24	2.3	<3.5	<3.2	<0.54	0.8	2.5	(d)					
Cs ppm	0.015	0.056	0.067	0.046	0.035	0.052	0.037	0.072	(d)	0.06				
Ba										20	40	(e)		
La										1.1	1.35	(e)		
Ce											3.7	(e)		
Pr											0.41	(e)		
Nd														
Sm											0.6	(e)		
Eu											0.84	(e)		
Gd											0.9	(e)		
Tb														
Dy											0.92	(e)		
Ho											0.2	(e)		
Er											0.63	(e)		
Tm														
Yb											0.52	(e)		
Lu											0.085	(e)		
Hf											0.4	(e)		
Ta														
W ppb											0.035	(e)		
Re ppb	0.085	<0.0003	0.043	0.024	<0.0004	0.0003	0.018	0.1	(d)		0.0002	(e)		
Os ppb	1.31	<0.012	0.345	0.439	<0.004	<0.003	0.307	1.19	(d)					
Ir ppb	1.23	0.001	0.475	0.43	0.0028	0.004	0.323	1.08	(d)		0.004	(e)		
Pt ppb														
Au ppb	0.119	0.003	0.145	0.045	0.0073	0.015	0.046	0.355	(d)		0.001	(e)		
Th ppm													0.03	(f)
U ppm	0.038	0.006	0.031	0.046	0.016	0.011	0.018	0.069	(d)	0.04	0.053	(e)	0.01	(f)

technique: (d) RNAA, (e) various, (f) radiation counting

Table 1c. Chemical composition of 67455 (cont.).

reference	Lindstrom et al. 1981										Rose 73	
weight	-1	-2	116	124	143	168-1	168-2	170-1	170-2			
SiO2 %											44.87	(b)
TiO2	0.24	0.26	0.25		0.32	0.4	0.42	0.19			0.3	(b)
Al2O3	27.9	28.2	29.8	33.5	30	26.8	29.5	30.4			30.42	(b)
FeO	5.72	5.27	4.83	1.74	4.14	6.38	4.56	4.25	5.96	(a)	3.41	(b)
MnO	0.086	0.077	0.069	0.03	0.06	0.1	0.067	0.059			0.05	(b)
MgO	4.1	4	3.3	1.6	2.8	4.8	3.8	2.6			2.3	(b)
CaO	17	17.2	17.3	19.7	17.7	16.4	16.6	17.9	13.5		18.3	(b)
Na2O	0.291	0.297	0.461	0.324	0.344	0.301	0.421	0.364	0.382	(a)	0.41	(b)
K2O											0.03	(b)
P2O5											0.02	(b)
S %												
sum												
Sc ppm	11.62	10.32	8.87	3.7	7.54	12.35	7.77	6.77	5.98	(a)	6.2	(b)
V											6.9	(b)
Cr	706	580	559	205	428	710	515	410	795	(a)		
Co	9.34	9.33	6.75	1.22	3.14	9.2	9.25	5.96	46.3	(a)	4.3	(b)
Ni	15	17	22	18		24	45	14	280	(a)	16	(b)
Cu											2.2	(b)
Zn											6.5	(b)
Ga											2.2	(b)
Ge ppb												
As												
Se												
Rb												
Sr	120	125	134	137	128	108	130	131	159	(a)	145	(b)
Y												
Zr											12	(b)
Nb												
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb												
Te ppb												
Cs ppm												
Ba	12	7	20	9	11	20	15	11	44	(a)	28	(b)
La	0.944	0.922	1.137	0.487	0.692	1.199	1.09	0.616	3.3	(a)		
Ce	2.76	2.76	3.37	1.4	2.01	3.28	3.18	1.83	9.17	(a)		
Pr												
Nd												
Sm	0.555	0.573	0.614	0.262	0.381	0.69	0.58	0.35	1.46	(a)		
Eu	0.705	0.74	0.79	0.71	0.71	0.73	0.79	0.723	0.91	(a)		
Gd												
Tb	0.138	0.137	0.131	0.065	0.093	0.163	0.158	0.086	0.361	(a)		
Dy												
Ho												
Er												
Tm												
Yb	0.6	0.6	0.6	0.263	0.425	0.73	0.535	0.374	1.42	(a)		
Lu	0.095	0.095	0.096	0.045	0.064	0.115	0.087	0.059	0.23	(a)		
Hf	0.38	0.397	0.445	0.168	0.265	0.5	0.479	0.235	1.03	(a)		
Ta	0.068	0.071		0.03		0.086	0.069	0.03	0.247	(a)		
W ppb												
Re ppb												
Os ppb												
Ir ppb												
Pt ppb												
Au ppb												
Th ppm	0.16	0.09	0.11	0.042	0.048	0.089	0.14	0.044	1.06	(a)		
U ppm												

technique (a) INAA, (b) 'microchemical'

Table 1d. Chemical composition of 67455.

reference	Norman et al. 2010				
weight					
SiO2 %	47.9	45.4	44.6	46.6	(a)
TiO2	0.05	0.07	0.14	0.53	(a)
Al2O3	33.2	33.5	29	29.8	(a)
FeO	0.6	1.27	5.5	3.3	(a)
MnO	0.01	0.02	0.07	0.05	(a)
MgO	0.41	1.37	4.23	2.86	(a)
CaO	17.6	18.1	16.2	16.3	(a)
Na2O	0.27	0.28	0.21	0.47	(a)
K2O	0.02	0.04	0.03	0.04	(a)
P2O5					
S %					
sum					
Sc ppm	1.7	2.3	8.3	7	(a)
V	4.1	6.8	12.2	11.1	(a)
Cr	48	149	294	351	(a)
Co	1.1	4.3	3.9	15.5	(a)
Ni	3	10	5	89	(a)
Cu	1.2	1.2	1.4	5.1	(a)
Zn	1.8	2.5	10.7	3.6	(a)
Ga	3.4	3.3	2.8	3.8	(a)
Ge ppb					
As					
Se					
Rb	0.8	0.8	0.5	0.5	(a)
Sr	160	160	142	212	(a)
Y	1.2	1.7	3.3	9.5	(a)
Zr	2.6	4.4	8.3	35.8	(a)
Nb	0.2	0.3	0.4	2.4	(a)
Mo					
Ru					
Rh					
Pd ppb					
Ag ppb					
Cd ppb	2	1	2	7	(a)
In ppb					
Sn ppb	72	134	219	45	(a)
Sb ppb	4.4	16	2	1.1	(a)
Te ppb					
Cs ppm	0.043	0.052	0.036	0.026	(a)
Ba	8.9	9.9	9.9	43.1	(a)
La	0.27	0.43	0.55	2.6	(a)
Ce	0.69	1.1	1.46	6.72	(a)
Pr	0.1	0.15	0.21	0.94	(a)
Nd	0.46	0.68	1.01	4.24	(a)
Sm	0.14	0.19	0.32	1.26	(a)
Eu	0.72	0.74	0.68	1.2	(a)
Gd	0.18	0.24	0.43	1.47	(a)
Tb	0.033	0.045	0.081	0.27	(a)
Dy	0.21	0.3	0.56	1.69	(a)
Ho	0.043	0.067	0.13	0.37	(a)
Er	0.13	0.19	0.36	1	(a)
Tm					
Yb	0.13	0.2	0.38	0.99	(a)
Lu	0.018	0.029	0.057	0.14	(a)
Hf	0.07	0.13	0.24	0.97	(a)
Ta	0.011	0.014	0.024	0.13	(a)
W ppb					
Re ppb					
Os ppb					
Ir ppb					
Pt ppb					
Au ppb					
Th ppm	0.021	0.051	0.054	0.38	(a)
U ppm	0.005	0.013	0.013	0.11	(a)

technique: (a) ICP

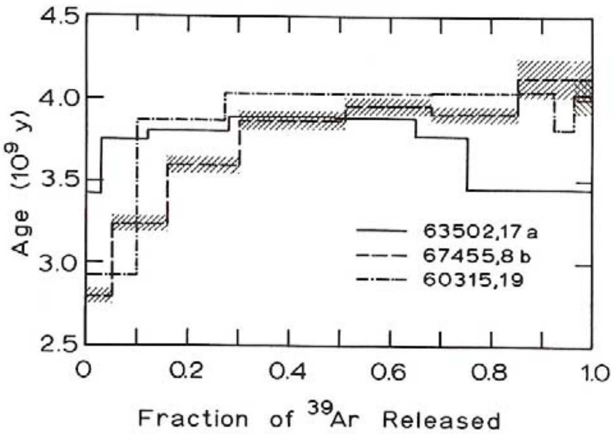


Figure 7: Plateau ages for several Apollo 16 samples by Kirsten et al. 1973).

Summary of Age Data for 67455

	Ar/Ar
Kirsten et al. 1973	3.91 ± 0.12 b.y
Norman et al. 2010	3.889 ± 0.023
	3.987 ± 0.027
	3.987 ± 0.021

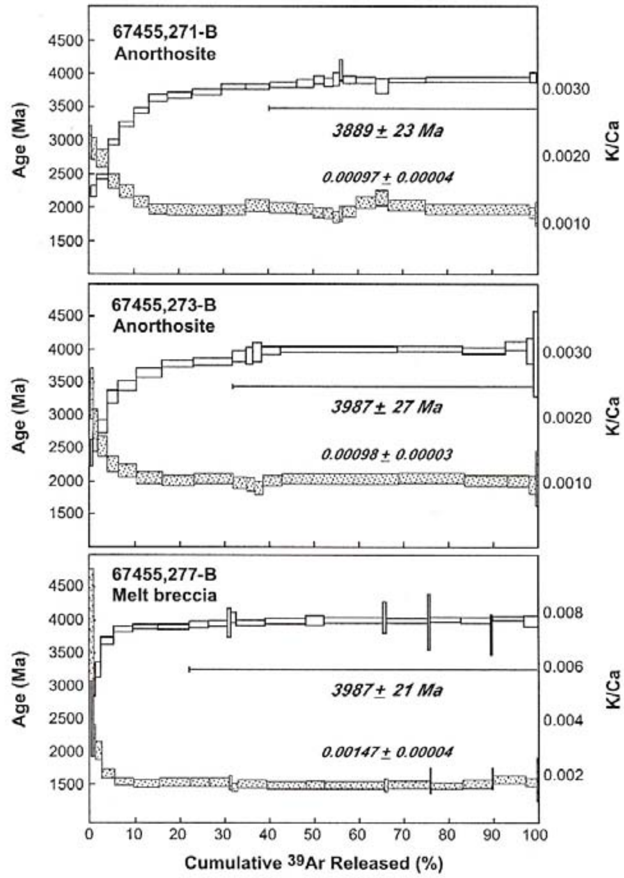


Figure 8: Ar/Ar plateau diagrams forindiviual clasts in 67455 (Norman et al. 2010).

Processing

67455 was the subject of a consortium led by Ed Chou (see Minkin et al. 1977). Since the rock was very friable and had already broken into numerous pieces, they simply sorted the pieces, making thin section and analyses of each. Norman et al. (2010) describe their selection of subsamples.

A small piece of 67455 is a public display sample at Dayton Ohio.

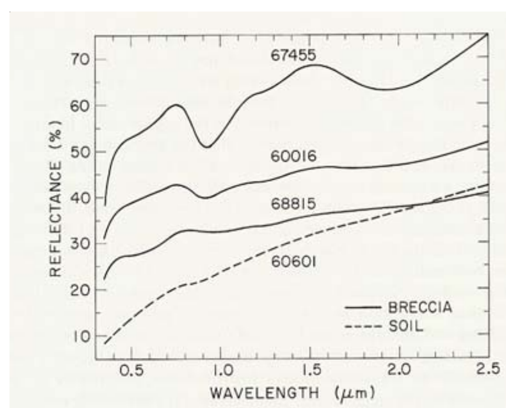
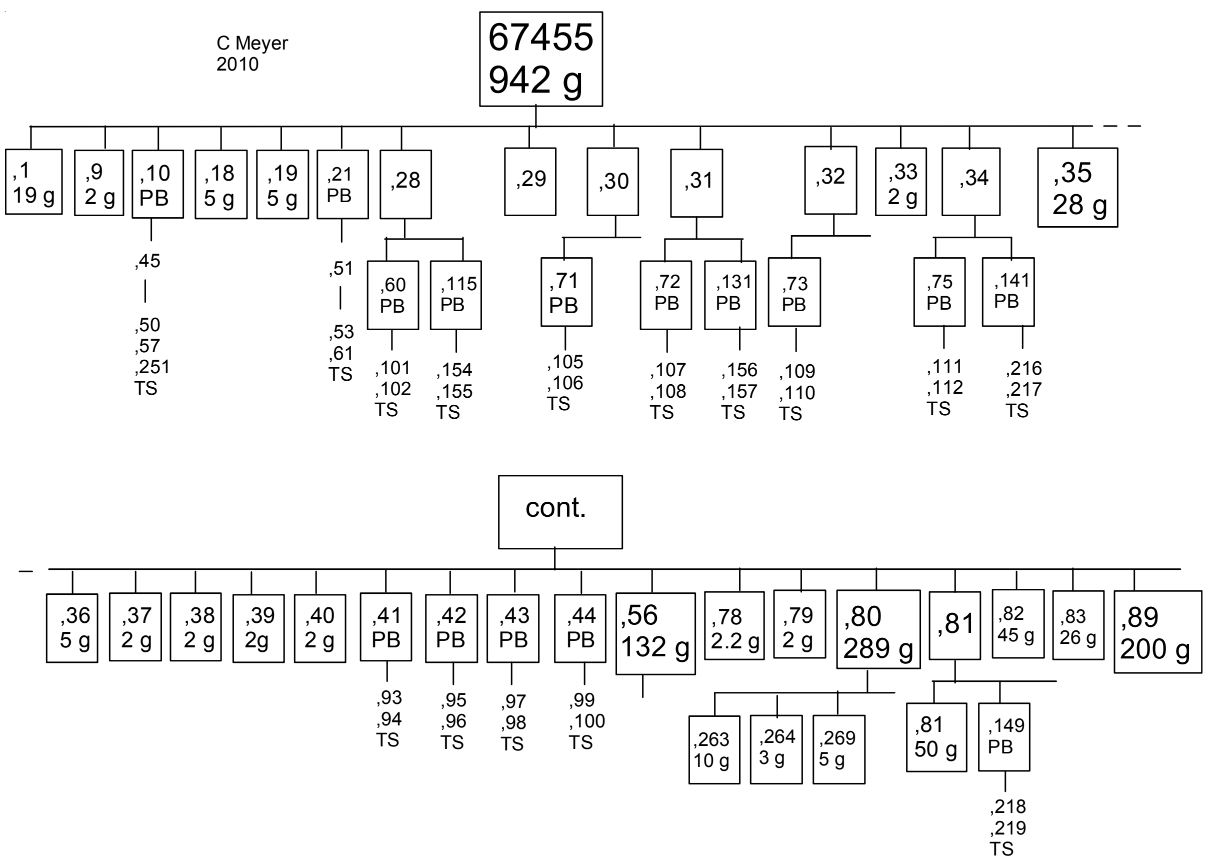


Figure 9: Refectance spectra of lunar soil and breccias (Adams and McCord 1973).

Figure 10: Photo of 67455,56 showing dark clasts in white matrix. Round clast is about 6 mm. NASA S75-33575.



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