

66075
Ancient Regolith Breccia
347 grams

revised

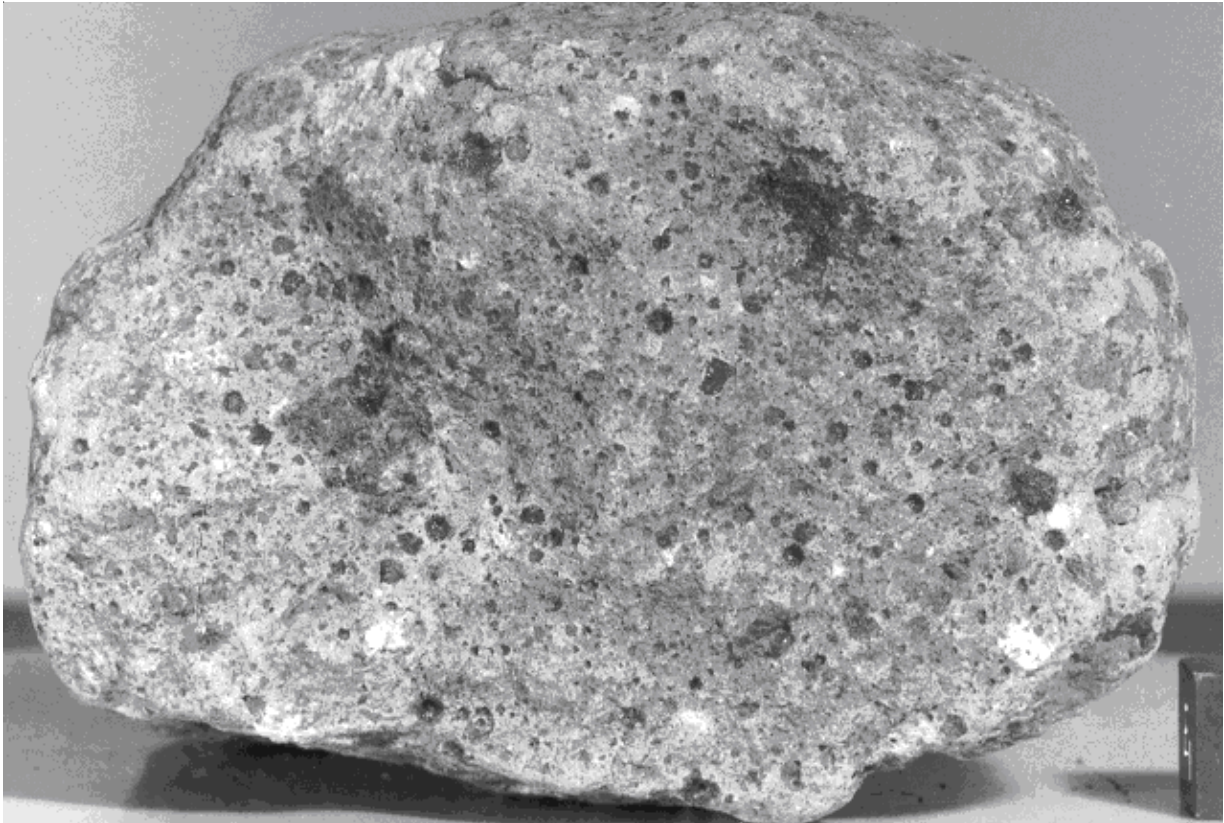


Figure 1: Photo of micrometeorite-cratered surface of 66075. NASA S72-40609. Cube is 1 cm.

Introduction

66075 is one of many coherent, light matrix breccias from Apollo 16 and has about equal amounts of both dark and light aphanitic clasts (figures 4 and 13). It was collected from the rim of a small crater at the base of Stone Mountain and has micrometeorite craters on only one side (figure 1). The matrix contains glass with a wide variety of composition. Fruland (1983), James (1981) and Korotev (1996) list 66075 as a regolith breccia and Korotev suggests that 66075 may be ejecta from North Ray Crater. The clasts have been dated at about 3.8 b.y.

66075 is rather like 66035 from the other side of the same crater.

Petrography

66075 is a highland regolith breccia with light grey friable matrix containing both white and dark clasts

(Quick et al. 1978). The matrix is coherent, porous (20%), unsorted and seriate (5 to 200 microns) and made of angular fragments of plagioclase and other minerals along with lithic and glass fragments. Plagioclase and devitrified maskelynite (An_{92-97}) constitute the majority of the matrix, followed in abundance by aphanites and glass.

Quick et al. (1978), McKay et al. (1986) and Simon et al. (1988) found 5 – 10 % glass in the matrix. Simon et al. concluded that at least some of the glass was agglutinate, while McKay et al. found the maturity index (I_s/FeO) was low (0.5). However, the rare gas data indicate a trapped solar wind component. According to Wentworth and McKay (1985), McKay et al. (1986), Simon et al. (1988) and Joy et al. (2011), 66075 is an “ancient regolith breccia”, because it has a high ratio of ^{40}Ar to ^{36}Ar .

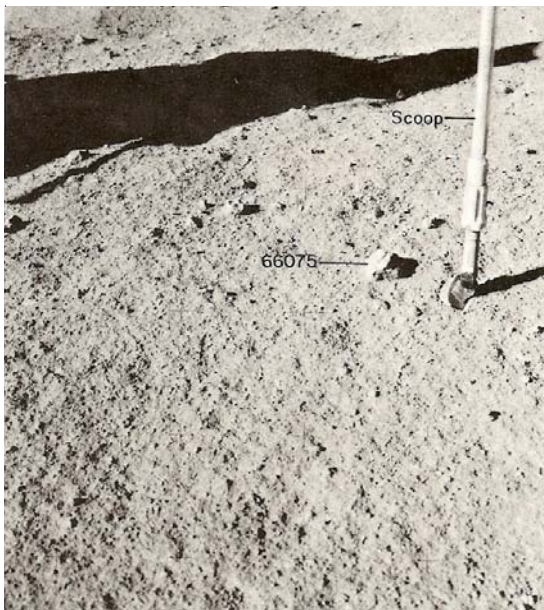


Figure 2: Photo of 66075 perched on surface. AS16-107-17522.

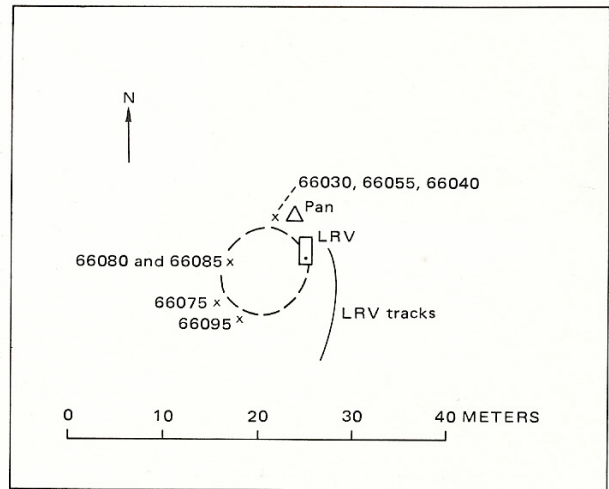


Figure 3: Map of station 6, Apollo 16.

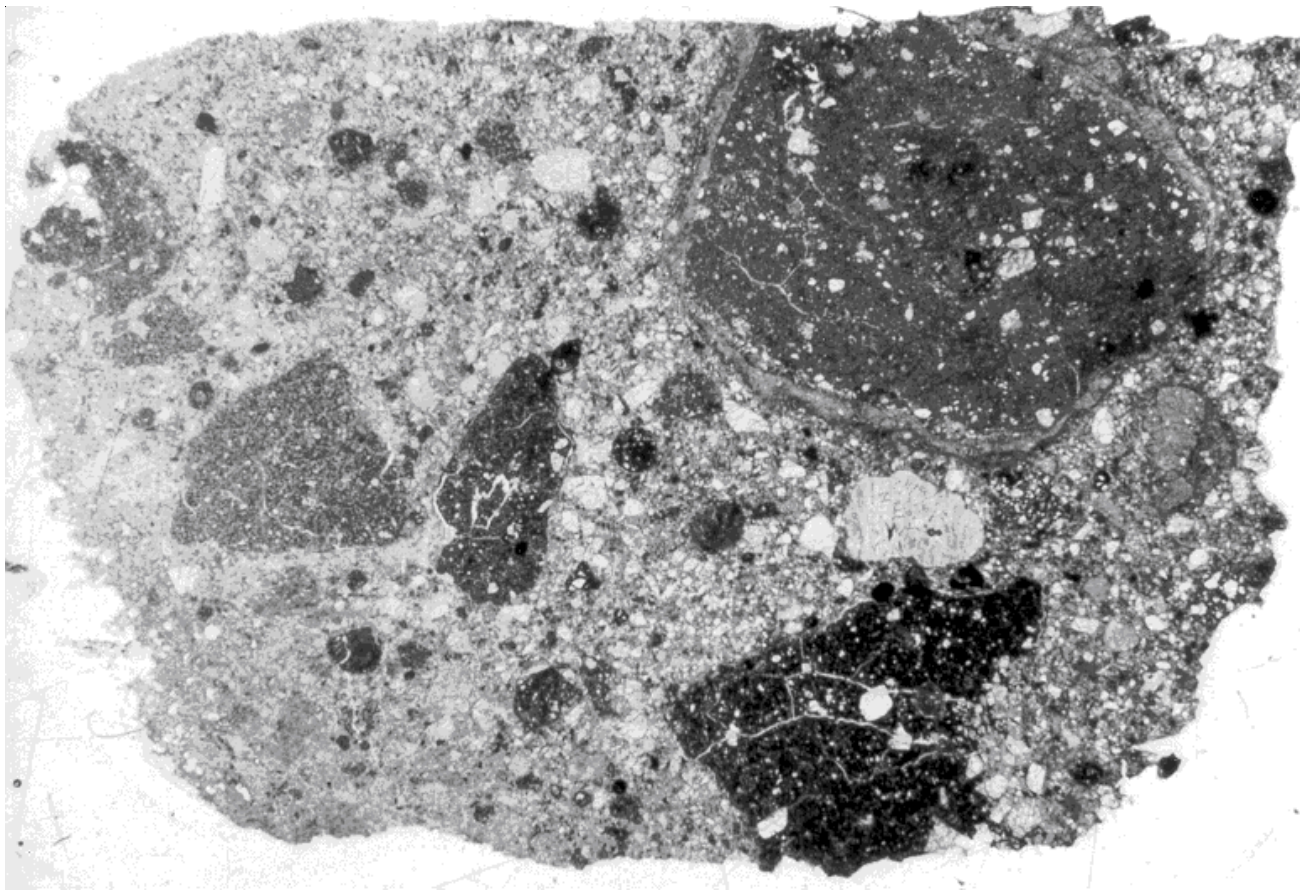


Figure 4: Thin section photomicrograph of 66075,3. Section is about 1.5 cm long. S72-43671.

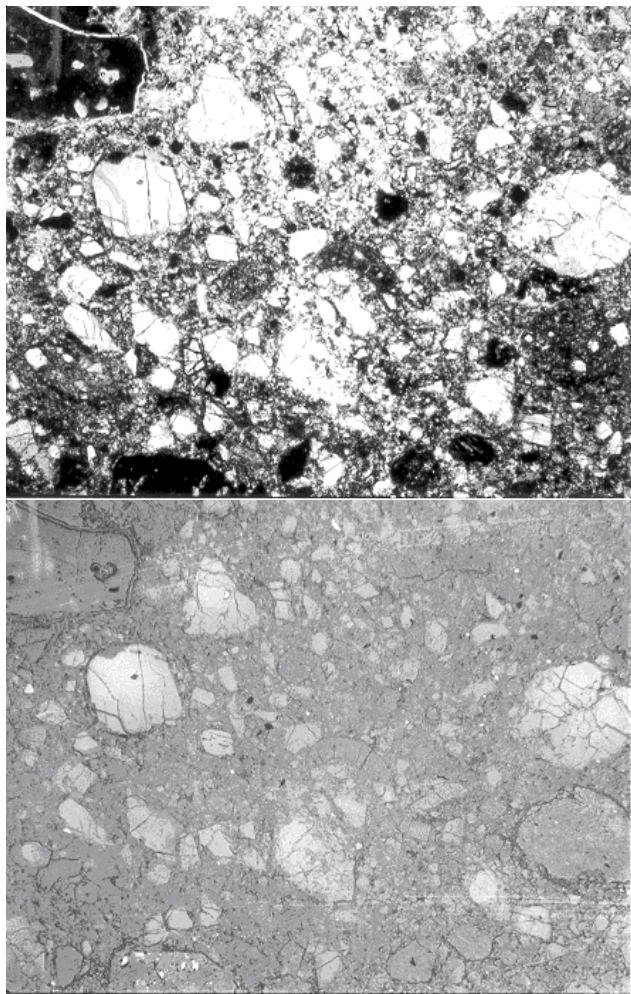


Figure 5: Photomicrographs of thin section 66075,63. Top is plane polarized light, bottom is reflected light (with internal reflections). About 3 mm across.

Mineralogical Mode for 66075

(from Simon et al. 1988)

	20-90 micron	90-1000 micron
Matrix < 20 micron	44.4 %	
Mare basalt	0	0
KREEP basalt	0	1
Feldspathic basalt	0	0
Plutonic rock frag.	0.3	3.7
Granulite	0	0
Poik. rocks	0.2	1.1
Impact melts	0.5	6.7
Regolith brec.	0	1.1
Agglutinate	0.5	4.7
Plagioclase	12.4	9.6
Olivine	2	0.9
Pyroxene	2	1
Opagues	0.2	0
Glass	2.6	4.5

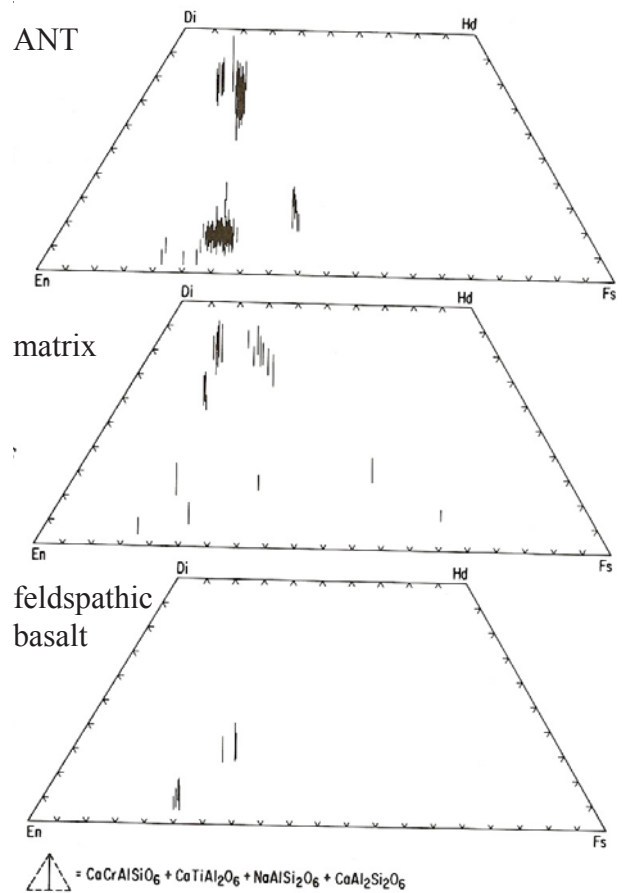


Figure 6: Pyroxene composition in 66075 (Quick et al. 1978).

Mineralogical Mode for 66075

(from McKay et al. 1986) ("Optical")

	>500 micron	20-500 micron
Mare basalt	0	0
KREEP basalt	0	0.3
Plutonic rock frag.	10.6	10.4
Other lithic	0	3
Granulite	0.4	0.3
Poik. Rocks	5.7	1
Subophitic	69.2	69.2
Intergranular	4.6	1.7
Intersertal	0.8	0.7
Vitric breccia	4.2	5
Frag. Breccia		0
Plagioclase	3	57.7
Olivine		6
Pyroxene		4
Opagues		
Glass		10.7
Agglutinate		



Figure 7: Photomicrograph of "basalt" clast in 66075 (from Ryder and Norman 1980).

Significant Clasts

The lithologies which have been identified in 66075 are: anorthosite, gabbroic anorthosite, noritic anorthosite, basalt and troctolite (Quick et al. 1978). The composition of pyroxene in these clasts is presented in figure 6. Olivine ranges from Fo₆₅₋₉₅. Plagioclase is An₉₀₋₉₇.

Quick et al (1978) found that metal particles were ~4.5 – 5.5 % Ni and 0.05 – 2.0 % Co (meteoritic in origin).

Neither Quick et al. (1978) nor Hunter and Taylor (1981) found "rust" in 66075.

Figure 7 pictures a "basalt" clast – rare at Apollo 16.

Chemistry

Eldridge et al. (1973), Clark and Keith (1973), Wanke et al. (1974), McKay et al. (1986), Wasson et al. (1975), Simon et al. (1988) and Boynton et al. (1975) determined the bulk composition of 66075. Moore and Lewis (1976) reported 28 ppm nitrogen and 54 ppm carbon for 66075 (figure 8). The conclusion is that 66075 has a composition similar to the local soil where it was collected (figure 9).

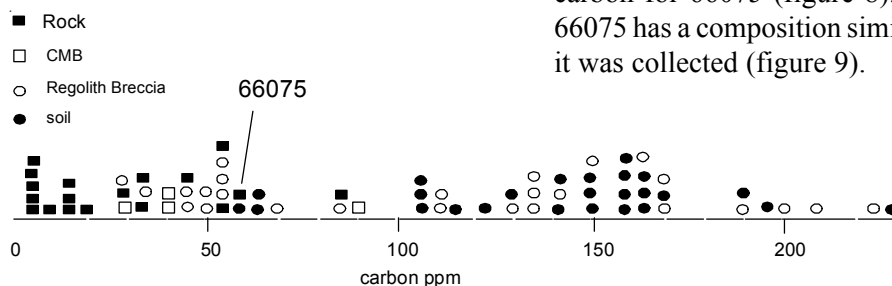


Figure 8: Carbon content of lunar samples (Moore and Lewis 1976).

Table 1. Chemical composition of 66075.

reference weight	Miller74 Clark73	Wanke74	Boynton75	Garg76 Eldridge73	McKay 86	Korotev96	Wasson75	Simon88	
SiO ₂ %	45.6	45.6	(b)						
TiO ₂	0.8	0.45	(b) 0.17	(a)	0.77			0.79	(a)
Al ₂ O ₃	28	26.6	(b) 27.2	(a)	25.7			27.8	(a)
FeO	5	4.7	(b) 5	(a) 4.6	(a) 5.6	4.17	(a)	5.07	(a)
MnO	0.06	0.056	(b) 0.066	(a)				0.068	(a)
MgO	6.6	6.5	(b) 6.3	(a)	7.3			7.5	(a)
CaO	15.3	15.7	(b) 16.2	(a)	14.6	15.7	(a)	17.2	(a)
Na ₂ O	0.52	0.49	(b) 0.57	(a)	0.505	0.505	(a)	0.51	(a)
K ₂ O	0.1	(c) 0.09	(b)	0.1	(c)			0.113	(a)
P ₂ O ₅		0.1	(b)						
S %									
sum									
Sc ppm		6.62	(b) 7.6	(a) 6.62	(a) 8.63	6.14	(a)	7.7	(a)
V					20			29	(a)
Cr		530	(b) 580	(a) 489	(a) 662	498	(a)	635	(a)
Co		25.3	(b) 24	(a) 27.4	(a) 27.6	18.4	(a)	29.9	(a)
Ni		350	(b)		342	225	(a) 195	303	(b) 440 (a)
Cu		4.3	(b)						
Zn		7.6	(b)				5.3	19	(b)
Ga		5.1	(b)				4.47	4.51	(b)
Ge ppb		1.7	(b)				1210	2100	(b)
As		94	(b)						
Se									
Rb		2.01	(b)					3.5	(a)
Sr		200	(b)		187	185	(a)	100	(a)
Y									
Zr				73	(a) 310	127	(a)	200	(a)
Nb									
Mo									
Ru									
Rh									
Pd ppb		17	(b)						
Ag ppb									
Cd ppb							111	151	(b)
In ppb							58	87	(b)
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm		0.12	(b)		0.15			0.15	(a)
Ba		106	(b) 90	(a)	186	101	(a)	165	(a)
La		11.8	(b) 9.3	(a)	20.1	8.84	(a)	17	(a)
Ce		28	(b) 28	(a) 26.1	(a) 52	22.4	(a)		(a)
Pr		4.3	(b)					44.3	(a)
Nd					33			27.8	(a)
Sm		5.5	(b)		9.34	4.04	(a)	7.84	(a)
Eu		1.2	(b) 1.45	(a) 1.16	(a) 1.345	1.19	(a)	1.36	(a)
Gd								9.2	(a)
Tb		1	(b) 0.9	(a) 0.97	(a) 1.7	0.81	(a)	1.5	(a)
Dy		6.9	(b)					10.8	(a)
Ho		1.4	(b)					2.2	(a)
Er		4.1	(b)						
Tm									
Yb		3.44	(b) 3.2	(a)	6	2.89	(a)	5.1	(a)
Lu		0.46	(b) 0.51	(a)	0.87	0.396	(a)	0.69	(a)
Hf		3.8	(b) 3.6	(a) 1.5	(a) 7.24	3.01	(a)	5.3	(a)
Ta		0.56	(b) 0.54	(a)	0.84	0.34	(a)	0.67	(a)
W ppb		0.21	(b)						
Re ppb		1	(b)						
Os ppb									
Ir ppb		10	(b)		8.5	5.5	(a) 5.4	6.6	(b) 8.6 (a)
Pt ppb								1.7	(a)
Au ppb		7.8	(b)		5.5	4.1	(a) 3.2	5.1	(b)
Th ppm	2.05	(c) 1.6	(b) 1.8	(a) 1.86	(c) 3.72	1.37	(a)	2.37	(a)
U ppm	0.55	(c) 0.41	(b)	0.51	(c) 0.8	0.36	(a)	0.72	(a)

technique: (a) INAA, (b) INAA, RNAA, (c) radiation counting

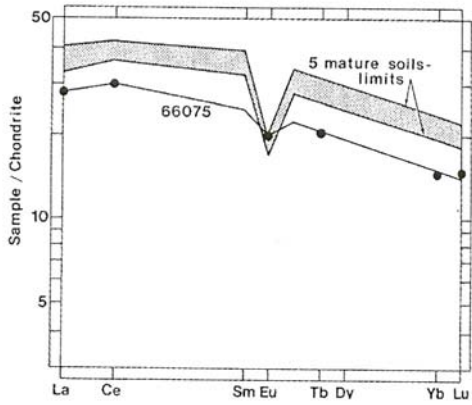


Figure 9: Normalized rare-earth-element diagram for 66075 compared with Apollo 16 soils (data from Boynton et al. 1975)..

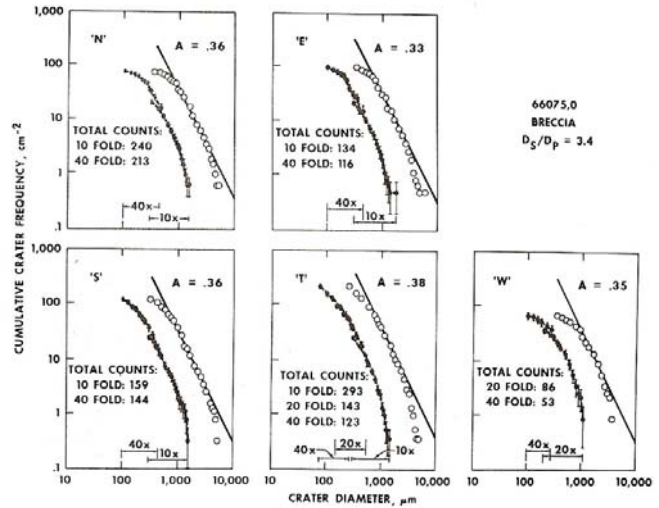


Figure 11: Density of micrometeorite craters on surfaces of 66075 (Neukum et al. 1973).

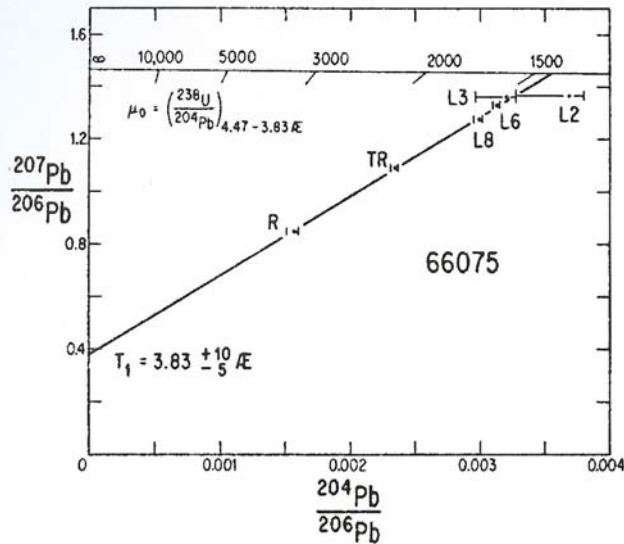


Figure 10: The age of 66075 (Oberli et al. 1979).

Summary of Age Data for 66075

	Ar/Ar	Pb/Pb
Oberli et al. 1979		3.83 b.y
Cohen et al. 2007	3.83	
	3.76	
	4.08	

Table 2. Chemical composition of 66075.

reference	Quick et al. 1978				olivine	aphanite		ANT clasts
weight	low-Ti glass	high-Ti glass	high-K glass	vitrophyre	aphanite	ANT clasts		
SiO2 %	45.59	49.06	75.38	46.9	45.9	44.3		(a)
TiO2	0.34	1.58	1.1	0.6	0.4	0.15		(a)
Al2O3	27	18	10.9	20	24.7	29.4		(a)
FeO	4.6	7.3	2.8	5.7	4.6	4		(a)
MnO	0.07	0.11	0.08	0.1	0.1	0.06		(a)
MgO	5.8	10.96	0.2	12.4	6.5	4.8		(a)
CaO	15.8	11.3	1.8	12.6	15.5	16.5		(a)
Na2O	0.4	0.62	0.57	0.5	0.5	0.4		(a)
K2O	0.07	0.39	6.19	0.2	0.1	0.01		(a)
P2O5	0.05	0.28	0.1	0.1	0.1			(a)
S %	0.03	0.03	0.04	0.1	0.2			(a)

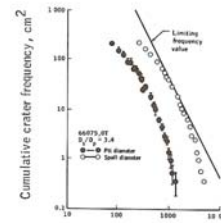


Figure 112: Density of micrometeorite craters on 66075 (Morrison et al. 1973).

Quick et al. (1978) collected data on glass fragments and small clasts within 66075 (table 2) and created a “mixing model” to explain the matrix composition as ~20% high-Ti glass and ~80% ANT. Wanke et al. (1976) and Boynton et al. (1975) also reported results of “mixing models”.

Radiogenic age dating

Oberli et al. (1979) measured the Pb isotopes in 66075 and determined an age of 3.85 ± 10^{-5} b.y. (figure 10). Cohen et al. (2006 and 2007) studied the age of small clasts from 66075 by Ar/Ar. Oberli et al. also reported bulk Rb-Sr and Sm-Nd data and calculated model ages.

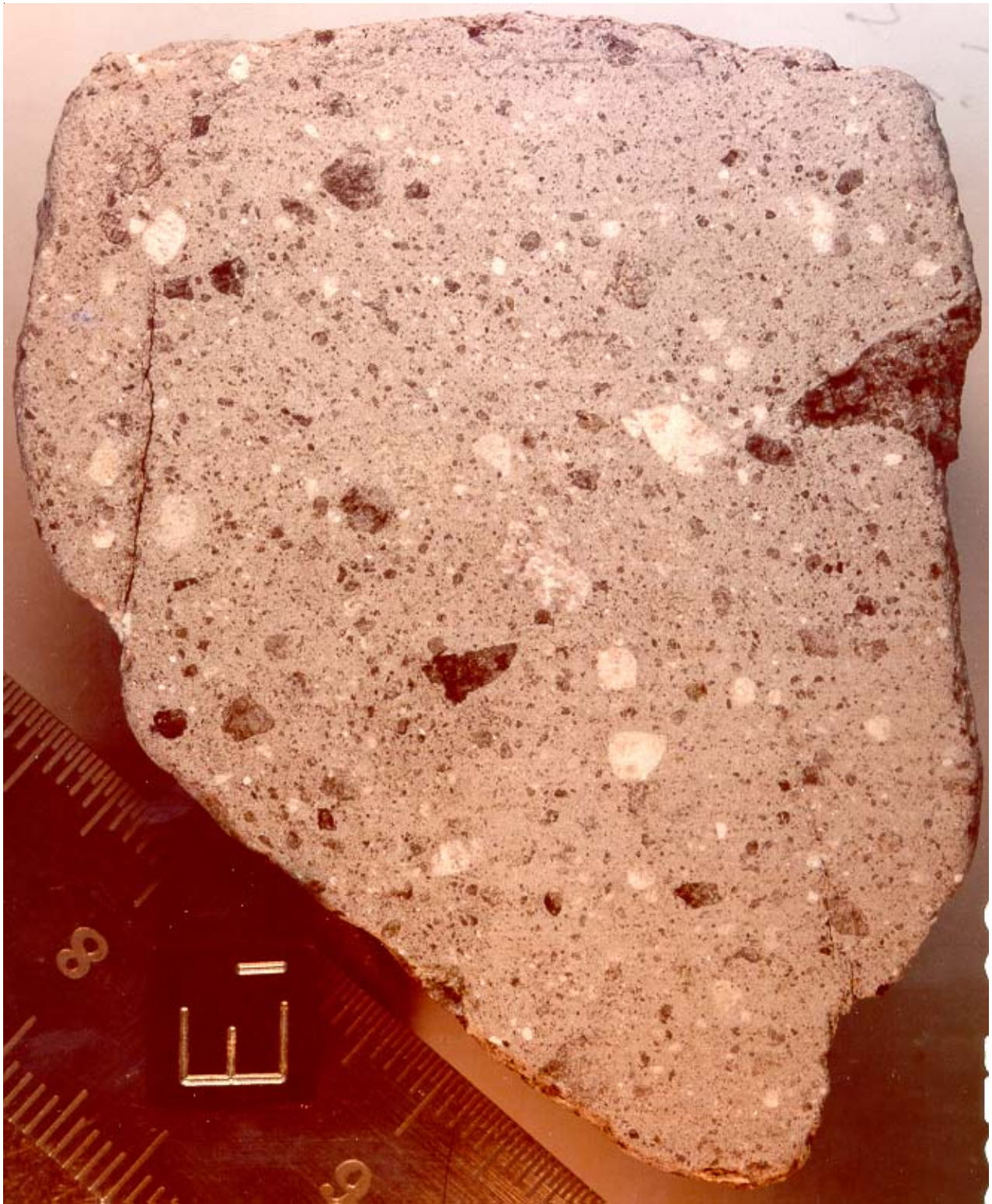


Figure 13: Sawn surface of 66075,26. NASA S78-31377. Cube is 1 cm for scale.

Cosmogenic isotopes and exposure ages

Eldridge et al. (1973) reported the cosmic ray induced activity of $^{26}\text{Al} = 130$ dpm/kg and $^{22}\text{Na} = 49$ dpm/kg. Clark and Keith (1973) determined $^{26}\text{Al} = 149$ dpm/

kg, $^{22}\text{Na} = 39$ dpm/kg, $^{54}\text{Mn} = 3$ dpm/kg, $^{56}\text{Co} = 5$ dpm/kg and $^{46}\text{Sc} = 1.3$ dpm/kg.

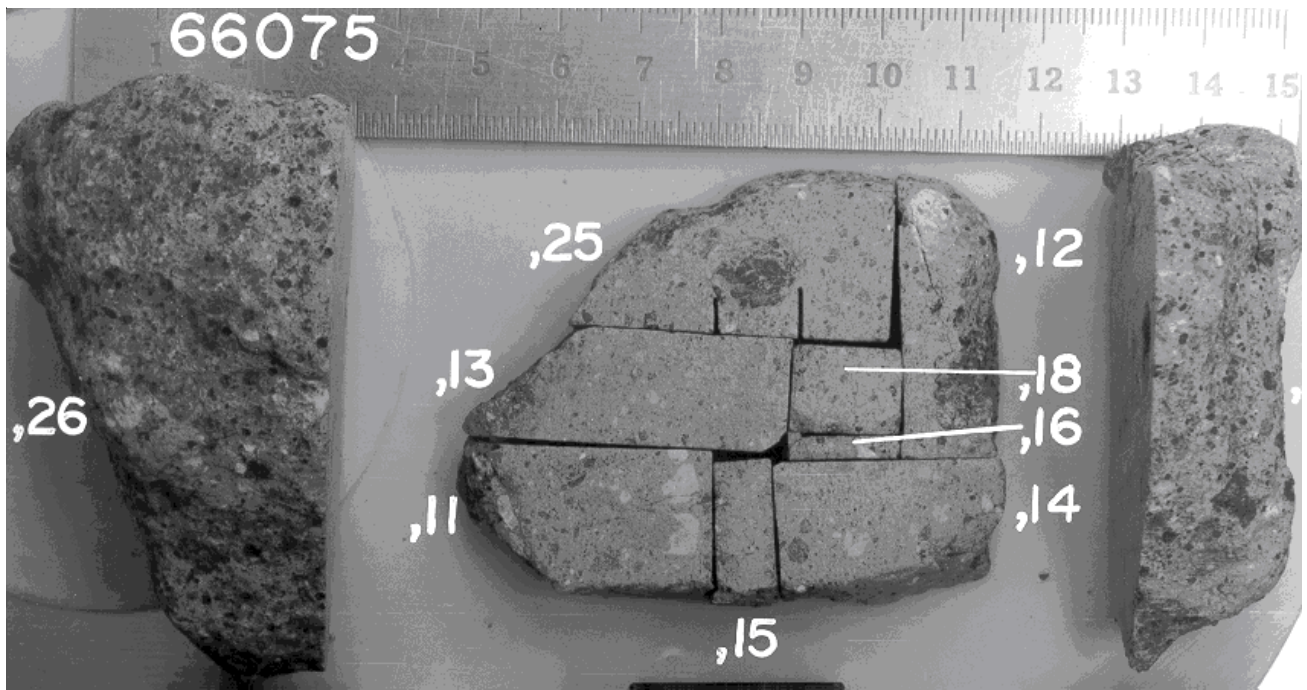


Figure 14: Slab cut from 66095. Scale is in cm.

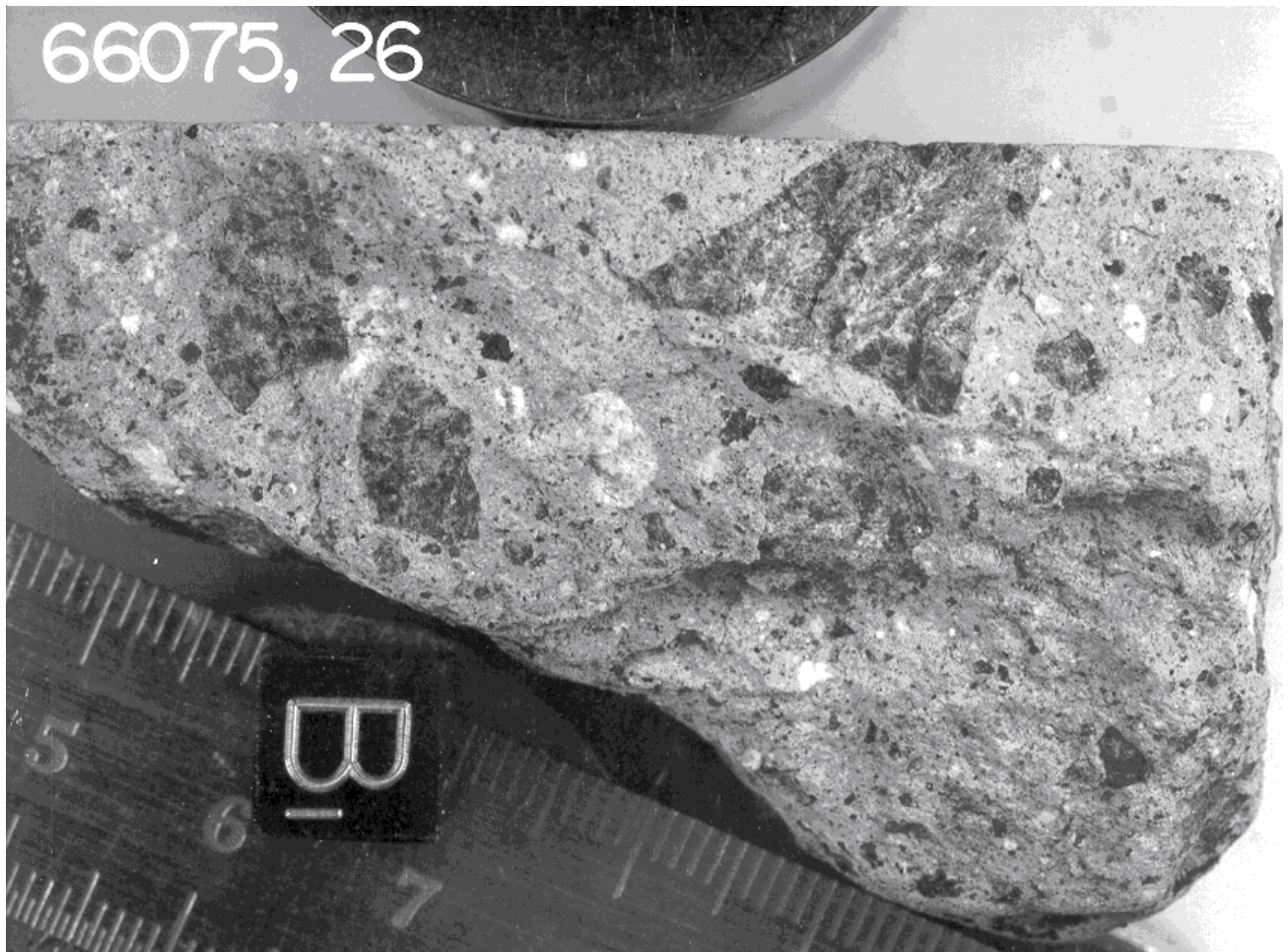


Figure 15: Photo of 66075,26. NASA S78-31382. Cube is 1 cm.

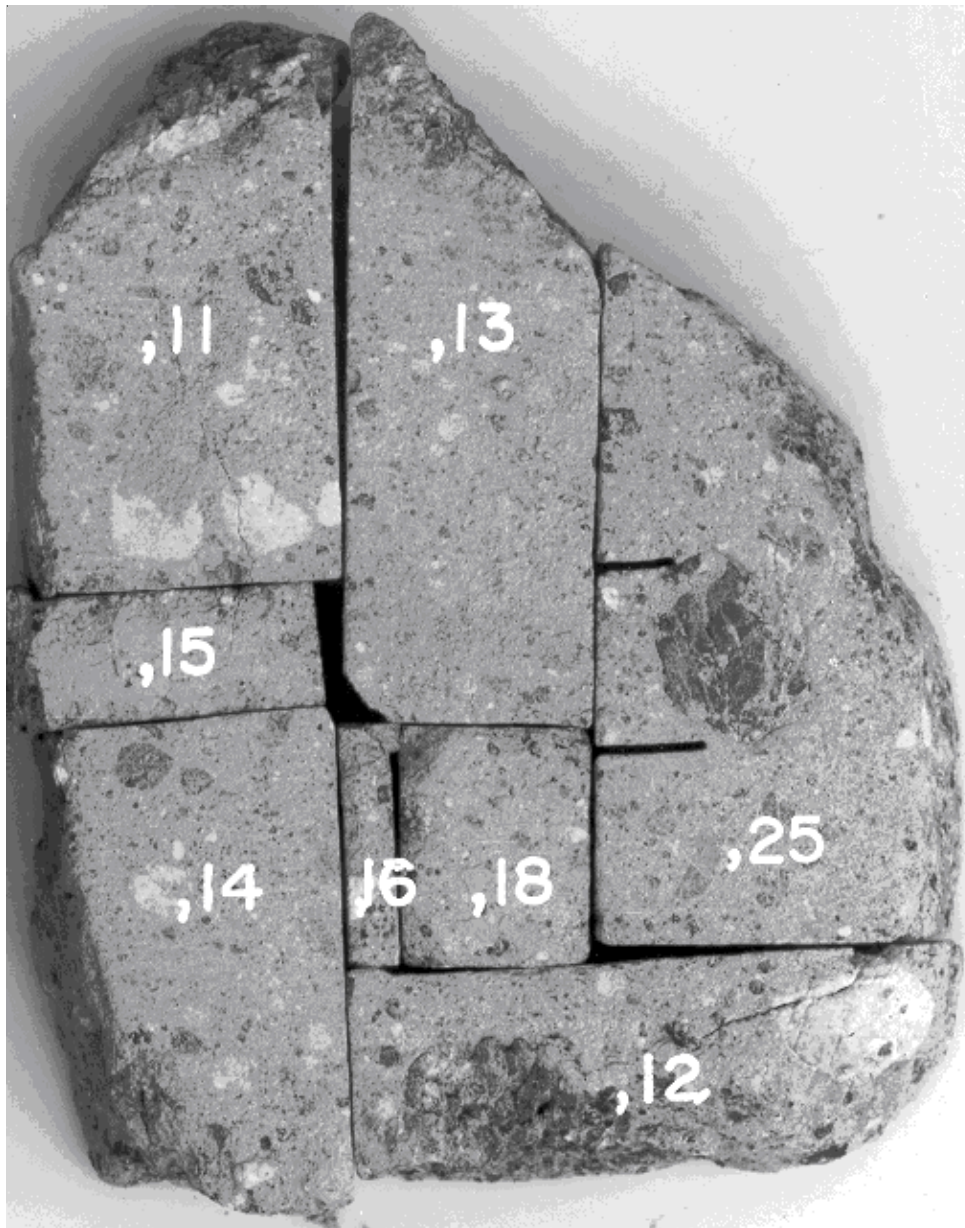


Figure 16: Photo of slab of 66075. NASA S73-28303. Central piece ,18 is 1 cm tall.

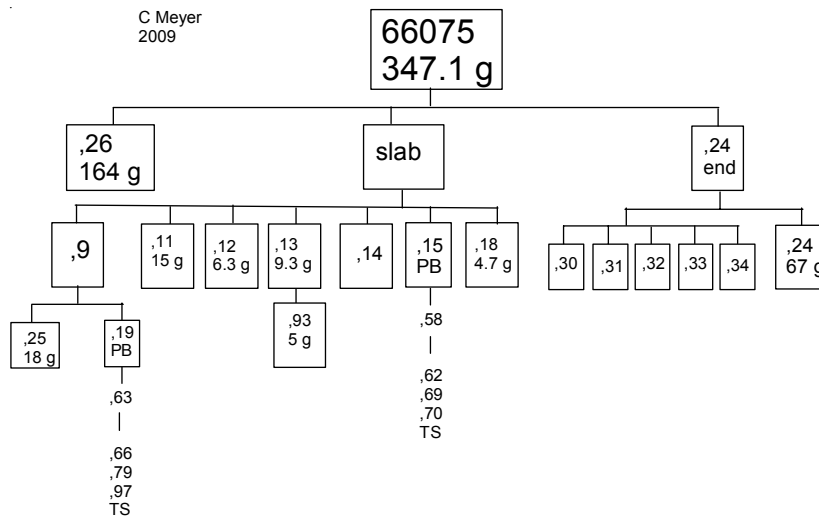




Figure 17: Sawn surface of 66075,26 as mounted for public display. NASA S88-36000.

Other Studies

Neukum et al. (1973) and Morrison et al. (1973) studied the micrometeorite craters (figures 11 and 12).

McKay et al. (1986) and Joy et al. (2012) reported the rare gas content and isotopic ratios.

Processing

A slab was cut through the middle of 66075 (figures 14 and 16). The large end piece (,26) is a public display sample at the Nordlingen-Ries Crater Museum in Germany (figure 17). There are 21 thin sections of 66075 now (*which will increase significantly soon*). *Would someone who visits the museum please report on whether this rock is “seuvite” or not*.

References for 66075

Boynton W.V., Baedeker P.A., Chou C.-L., Robinson K.L. and Wasson J.T. (1975a) Mixing and transport of lunar surface materials: Evidence obtained by the determination of lithophile, siderophile, and volatile elements. *Proc. 6th Lunar Sci. Conf.* 2241-2259.

Clark R.S. and Keith J.E. (1973) Determination of natural and cosmic ray induced radionuclides in Apollo 16 lunar samples. *Proc. 4th Lunar Sci. Conf.* 2105-2113.

Cohen B.A., Symes S.J. and Swindle T.D. (2006) Petrography and chemistry of impact-melt clasts in Apollo 16 breccias (abs#1379). *Lunar Planet. Sci. XXXVII*, Lunar Planetary Institute, Houston.

- Cohen B.A., Symes S.J., Swindle T.D., Weirich J. and Isachsen C. (2007) Ages of Impact-melt clasts in Apollo 16 breccias (abs#1006). *Lunar Planet. Sci. XXXVIII*, Lunar Planetary Institute, Houston.
- Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1973) Radionuclide concentrations in Apollo 16 lunar samples determined by nondestructive gamma-ray spectrometry. *Proc. 4th Lunar Sci. Conf.* 2115-2122.
- Fruland Ruth M. (1983) Regolith Breccia Workbook. Curatorial Branch Publication # 66. JSC 19045
- Garg A.N. and Ehmann W.N. (1976a) Zr-Hf fractionation in chemically defined lunar rock groups. *Proc. 7th Lunar Sci. Conf.* 3397-3410.
- Hunter R.H. and Taylor L.A. (1981) Rust and schreibersite in Apollo 16 highland rocks: Manifestations of volatile-element mobility. *Proc. 12th Lunar Planet. Sci. Conf.* 253-259.
- James O.B. (1981a) Tentative classification of the Apollo 16 breccias (abs). *Lunar Planet. Sci. XII*, 506-508.
- Joy K.H., Kring D.A., Bogard D.D., McKay D.S. and Zolensky M.E. (2012) Re-examination of the formation ages of the Apollo 16 regolith breccias. *Geochim. Cosmochim. Acta* **75**, 7208-7225.
- Joy K.H., Zolensky M.E., Ross D.K., McKay D.S. and Kring D.A. (2012) Direct detection of projectile relicts on the Moon (abs#4035). Early Solar System Impact Bombardment II. Lunar Planet. Sci. Institute, Houston.
- Korotev R.L. (1996c) On the relationship between the Apollo 16 ancient regolith breccias and feldspathic fragmental breccias, and the composition of the prebasin crust in the Central Highlands of the Moon. *Meteor. & Planet. Sci.* **31**, 403-412.
- McKay D.S., Bogard D.D., Morris R.V., Korotev R.L., Johnson P. and Wentworth S.J. (1986) Apollo 16 regolith breccias: Characterization and evidence for early formation in the megaregolith. *Proc. 16th Lunar Planet. Sci. Conf.* in *J. Geophys. Res.* **91**, D277-D303.
- Miller M.D., Pacer R.A., Ma M.-S., Hawke B.R., Lookhart G.L. and Ehmann W.D. (1974) Compositional studies of the lunar regolith at the Apollo 17 site. *Proc. 5th Lunar Sci. Conf.* 1079-1086.
- Moore C.B. and Lewis C.F. (1976) Total nitrogen contents of Apollo 15, 16 and 17 lunar rocks and breccias (abs). *Lunar Sci. VII*, 571-573. Lunar Planetary Institute, Houston.
- Morrison D.A., McKay D.S., Fruland R.M. and Moore H.J. (1973) Microcraters on Apollo 15 and 16 rocks. *Proc. 4th Lunar Sci. Conf.* 3235-3253.
- Morrison G.H., Nadkarni R.A., Jaworski J., Botto R.I. and Roth J.R. (1973) Elemental abundances of Apollo 16 samples. *Proc. 4th Lunar Sci. Conf.* 1399-1405.
- Neukum G., Horz F., Morrison D.A. and Hartung J.B. (1973) Crater populations on lunar rocks. *Proc. 4th Lunar Sci. Conf.* 3255-3276.
- Oberli F., Huneke J.C. and Wasserburg G.J. (1979a) U-Pb and K-Ar systematics of cataclysm and precataclysm lunar impactites (abs). *Lunar Planet. Sci. X*, 940-942. Lunar Planetary Institute, Houston.
- Quick J.E., Brock B.S. and Albee A.L. (1978) Petrology of Apollo 16 breccia 66075. *Proc. 9th Lunar Planet. Sci. Conf.* 921-939.
- Ryder G. and Norman M.D. (1980) Catalog of Apollo 16 rocks (3 vol.). Curator's Office pub. #52, JSC #16904
- Simon S.B., Papike J.J., Laul J.C., Hughes S.S. and Schmitt R.A. (1988) Apollo 16 regolith breccias and soils: Recorders of exotic component addition to the Descartes region of the moon. *Earth Planet. Sci. Lett.* **89**, 147-162.
- Sutton R.L. (1981) Documentation of Apollo 16 samples. In *Geology of the Apollo 16 area, central lunar highlands.* (Ulrich et al.) U.S.G.S. Prof. Paper 1048.
- Wänke H., Palme H., Baddenhausen H., Dreibus G., Jagoutz E., Kruse H., Spettel B., Teschke F. and Thacker R. (1974) Chemistry of Apollo 16 and 17 samples: bulk composition, late-stage accumulation and early differentiation of the Moon. *Proc. 5th Lunar Sci. Conf.* 1307-1335.
- Wasson J.T., Chou C.L., Robinson K.L. and Baedeker P.A. (1975) Siderophiles and volatiles in Apollo 16 rocks and soils. *Geochim. Cosmochim. Acta* **39**, 1475-1485.
- Wentworth S.J. and McKay D.S. (1988) Glasses in ancient and young Apollo 16 regolith breccias: Populations and ultra-Mg glass. *Proc. 18th Lunar Planet. Sci. Conf.* 67-77. Lunar Planetary Institute, Houston.