12070

Soil

1102 grams

Figure 1: Photo of area where 12070 was collected. Photo taken from LM window. AS12-48-7031

Introduction

12070 is the fines from the contingency sample taken by the astronauts. It was collected in front of the Lunar Module (figure 1). Rock samples 12071 – 12077 were also collected as part of the contingency sample and returned in this bag.

12070 is the best studied of the Apollo 12 soils, with many analyses.

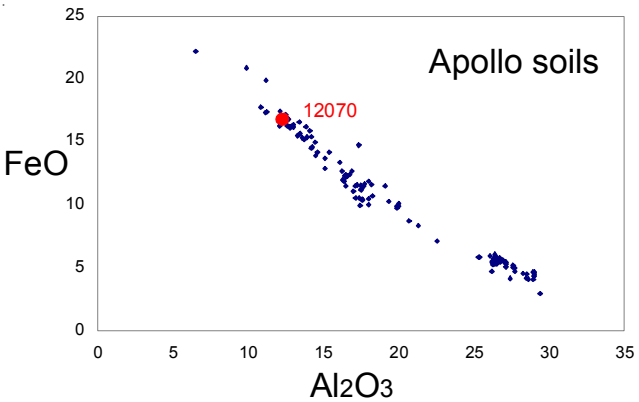


Figure 2: Composition of 12070 compared with other Apollo soil samples.

Petrography

The maturity index of 12070 is I_s/FeO = 47 and the average grain size of is 51 microns (figure 5).

At the time of Apollo 12, different research groups did not report consistent mineral modes for soils samples, because they didn't use the same criteria and they

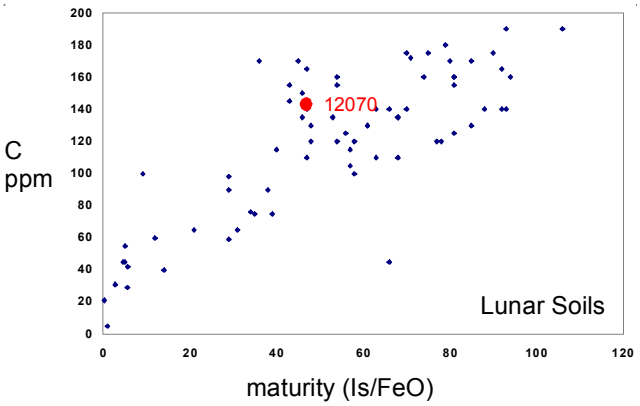


Figure 3: Carbon content and maturity index of 12070 compared with that of other Apollo soil samples.

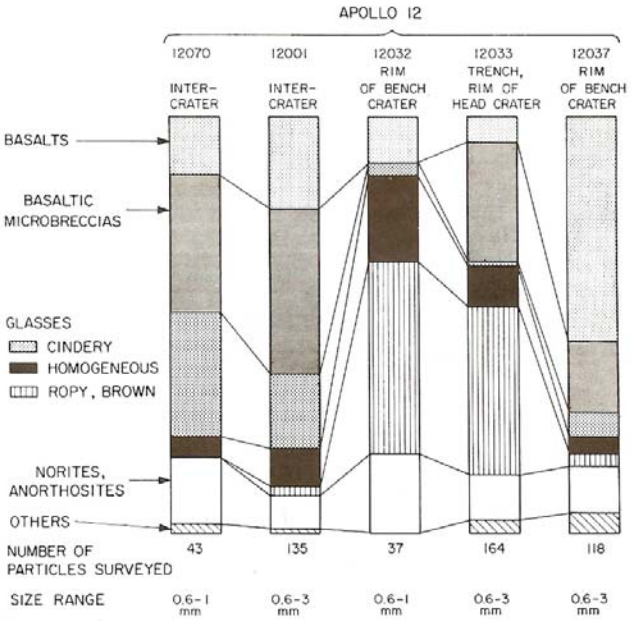


Figure 4: Modal analysis of coarse particles in Apollo 12 soils (Marvin et al. 1971).

Mineralogical Mode

Frondel et al. 1971

Olivine + Pyroxene	60%
Plagioclase	18.9
Opaques	3.5
Glass, angular	11.9
Glass, rounded	5.8
Silica	0

Mineralogical Mode

McKay et al. 1971

Grain size	37-62.5	62.5-125 microns
Olivine	3 %	4
Pyroxene	27	23
Plagioclase	12	7
Glass	33	22
Aggregates	**26**	**45**

Mineralogical Mode (250-1000 microns)

McKay et al. (1971)

Glazed Aggregates	26 %
Single xtl.	16
Glasses	36
Rocks	7
Breccias	7
Spherules	1.2

studied different size fractions. Frondel et al. (1971) determined the mineral mode, but did not specify agglutinates. McKay's group recognized "glazed aggregates" which were later called agglutinates. Marvin et al. (1971) found about 30% "cindery glasses" (figure 4).

Delano et al. (1981) reported on the trends in composition of numerous glass particles from 12070 (figure 7). Chao et al. (1970), Engelhardt et al. (1971), Bunch et al. (1972), Barra et al. (2006) and others also give the composition of glass particles from 12070). Stone et al. (1982) studied a few individual glass beads using magnetic means.

Marvin et al. (1991) report on the nature of a granitic particle from 12070 first reported by Marvin et al. (1971). Dence et al. (1971) studied the mineralogy of basalt particles from 12070.

Chemistry

Lunar soil sample 12070 is one of the most analyzed of all lunar samples, and rightly or wrongly, is the true test of accuracy and precision of various analytical techniques (and labs) during the early Apollo era. For example, the preliminary PET results, as reported by LSPET, were specifically meant to be "quick and dirty" for the first three mission, but were improved to be "state of the art" for Apollo 15, 16 and 17. Note that 12070 was reanalyzed during the Apollo 15 mission, by XRF instead of SSMS (table 1a). However, please also note that although 12070 was sieved (sifted), it was not split according to analytical standards and that analysts frequently got widely different results on different splits analyzed at the same time in the same lab by the same technique (i.e. the sample was inherently heterogeneous).

Figure 6 shows the REE content of 12070. Hubbard et al. (1971), Schoenfelt and Meyer (1972), Goles et al. (1971) and Wanke et al. (1972) all tried to calculate the amount of KREEP material in 12070 and other Apollo 12 soils.

The carbon content of 12070 was reported by Epstein and Taylor (1971) as 145 ppm. Muller (1972) determined 80 ppm N by the Kjeldahl technique. Kerridge et al. (1978) found 128 ppm C and 67 ppm N (figure 3). These analyses also indicate that this soil has a high maturity and was exposed to the solar flux a long time.

Age Dating

Barra et al. (2006) reported Ar/Ar ages for glass particles.

Cosmogenic isotopes and exposure ages

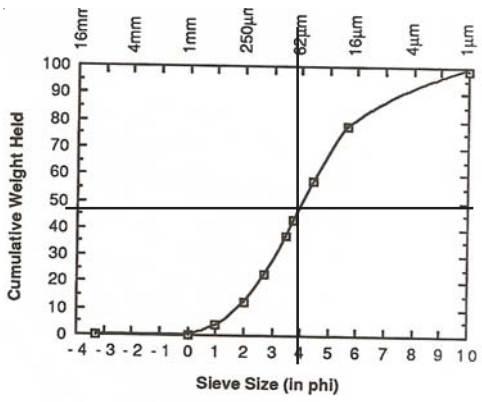
Rancitellli et al. (1971), Wrigley (1971) and O'Kelly et al. (1971b) reported the cosmic-ray-induced activity of ^{22}Na = 80 dpm/kg, 75 dpm/kg and 70 dpm/kg respectively. The activity of ^{26}Al = 165 dpm/kg, 171 dpm/kg and 146 dpm/kg, respectivly. The activity of ^{46}Sc = 5.9 dpm/kg. The activity of ^{54}Mn = 21 dpm/kg and 41 dpm/kg. The activity of ^{56}Co = 57 dpm/kg, and 55 dpm/kg. Herr et al. (1972) reported 14.1 cpm for ^{54}Mn and 380 dpm/kg for ^{53}Mn.

D'Amico et al. (1971) studied radioactivity of tritium in 12070 and other soils.

Hintenberger and Weber (1973) calculate the ^{21}Ne exposure age of 12070 as 300 m.y. and the ^{38}Ar exposure age is 610 m.y.

Other Studies

Some rare gas data is given in the Apollo 11 catalog (Warner 1970) and in LSPET (1970). Yanif and Heymann (1972), Pepin et al. 91972), Funkhauser et al. (1971), and Hintenberger et al. (1971) also reported rare gas measurements.



average grain size = 51 microns

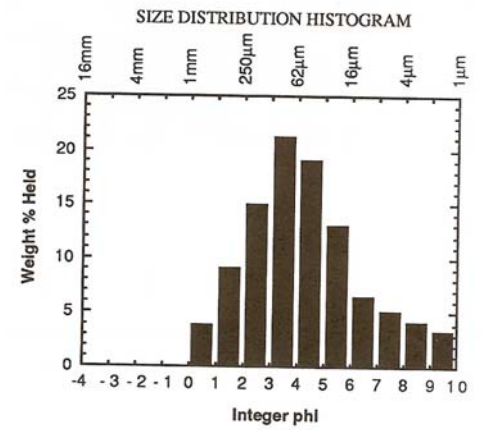
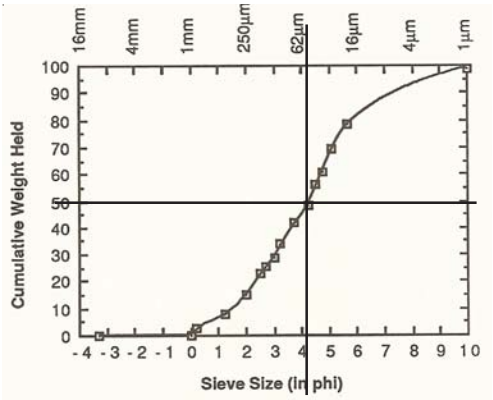


Figure 5a: Grain size distribution for 12070 (Graf 1993, from data by McKay et al. 1971).



average grain size = 52 microns

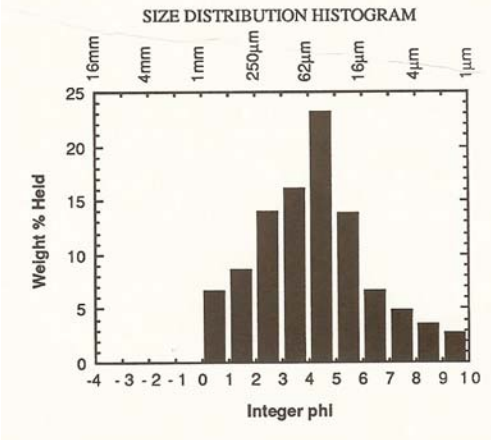


Figure :5b Grain size distribution for 12070 (Graf 1993, from data by King et al. 1971).

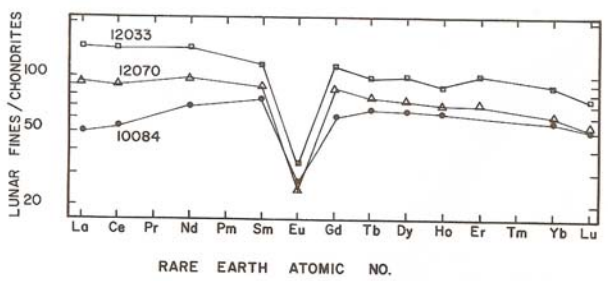


Figure 6: Normalized rare-earth-element diagram for 12070 (Haskin et al. 1971).

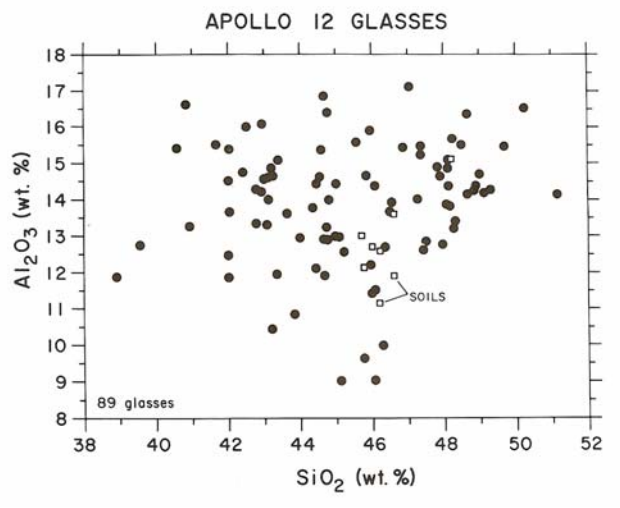


Figure 7: Composition of 89 glass particles from 12070 (Delano et al. 1981).

Arrhenius et al. (1971) studied the frequency of grains with high fossil nuclear tracks in 12070 (and all other Apollo 12 soil and core samples)(figure 8).

Gammage and Holmes (1975) determined the specific surface area of 12070 and other lunar fines.

Processing

Portions of 12070 were sieved at different times, and it is difficult to determine which splits are < 1 mm, 1 – 2 mm, 2 – 4 mm and 4 – 10 mm. With regard the large number of chemical analyses this sample, it is important to recognize that the fines were not split in a scientific manner.

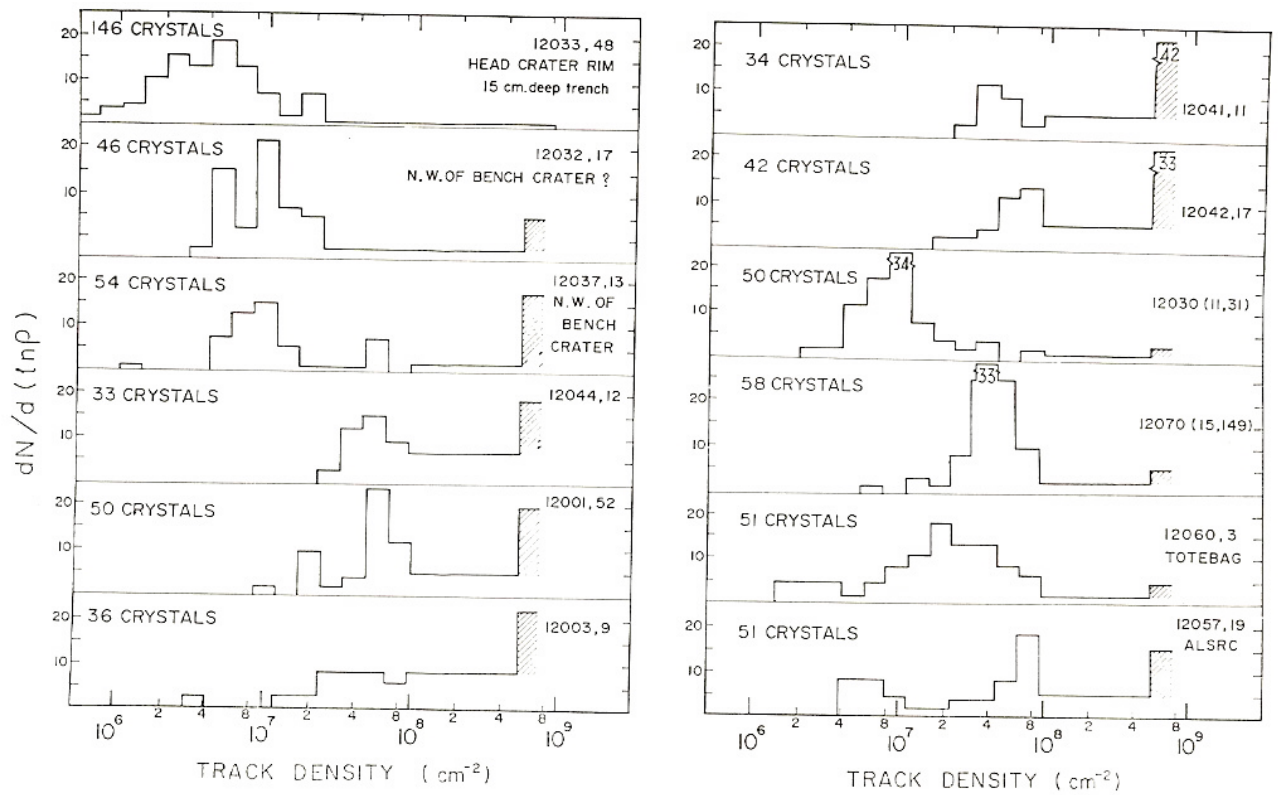


Figure 8: Density of fossil nuclear track in Apollo 12 soil samples (Arrhenius et al. 1971).

Table 1a. Chemical composition of 12070.

reference	LSPET70		LSPET70		LSPET72		Wiesmann75		Compston71		Hubbard72		Laul71		O'Kelly71		Wanke71		Goles71	
weight							Gast71				Wiesmann75				354g					
SiO2 %	42	(a)			45.9	(c)			45.83	(c)							46	(d)		
TiO2	3.1	(a)			2.81	(c)	2.9	(e)	2.81	(c)							2.7	(d)	2.73	(d)
Al2O3	14	(a)			12.5	(c)			12.48	(c)							12.7	(d)	12.1	(d)
FeO	17	(a)			16.4	(c)			16.81	(c)							16.3	(d)	16.2	(d)
MnO	0.25	(a)			0.22	(c)			0.23	(c)							0.2	(d)	0.2	(d)
MgO	12	(a)			10	(c)			10.18	(c)							9.7	(d)		
CaO	10	(a)			10.4	(c)	10	(e)	10.45	(c)							10.6	(d)	9.1	(d)
Na2O	0.4	(a)			0.41	(c)	0.46	(e)	0.43	(c)							0.42	(d)	0.44	(d)
K2O	0.18	(a)	0.25	(b)	0.25	(c)	0.26	(e)	0.27	(c)	0.25	(e)			0.24	(g)	0.23	(d)		
P2O5					0.27	(c)			0.31	(c)										
S %					0.08	(c)			0.12	(c)										
sum																				
Sc ppm	47	(a)															37.3	(d)	36.8	(d)
V	64	(a)							91	(c)										
Cr	2800	(a)			2942	(c)			2080	(c)	2552	(e)					2270	(d)	2480	(d)
Co	42	(a)							45	(c)							41.5	(d)	44.7	(d)
Ni	200	(a)			276	(c)			186	(c)							200	(d)		
Cu									6	(c)							7.2	(d)		
Zn									6	(c)			6.9	(f)						
Ga									2.5	(c)			4.3	(f)			3.3			
Ge ppb																	210			
As																	22			
Se													0.26	(f)						
Rb	3.2	(a)			6.9	(c)	6.46	(e)	6.33	(c)	6.636	(e)	6.3	(f)			8.7			
Sr	170	(a)			136	(c)	150	(e)	143.3	(c)	146	(e)					140			
Y	130	(a)			110	(c)			111	(c)										
Zr	670	(a)			529	(c)			512	(c)	430	(e)							370	(d)
Nb					33	(c)			30	(c)										
Mo																				
Ru																				
Rh																				
Pd ppb																	6.5			
Ag ppb													*46*	(f)						
Cd ppb													45	(f)						
In ppb													*220*	(f)			*486*			
Sn ppb																				
Sb ppb																				
Te ppb													100	(f)						
Cs ppm													0.25	(f)			0.39	(d)		
Ba	420	(a)					404	(e)	350	(c)	375	(e)					390	(d)	340	(d)
La							30.3	(e)	29	(c)	33.8	(e)					33	(d)	32.1	(d)
Ce							90	(e)	62	(c)	86.7	(e)					86	(d)	87	(d)
Pr																	10.6	(d)		
Nd							55.1	(e)			55.2	(e)							40	(d)
Sm							16.4	(e)			15.9	(e)					14.7	(d)	15.8	(d)
Eu							1.74	(e)			1.68	(e)					1.8	(d)	1.71	(d)
Gd											19.8	(e)					15.7	(d)		
Tb																	4	(d)	3.69	(d)
Dy							21.7	(e)			21.5	(e)					20.2	(d)		
Ho																	5.2	(d)	4.3	(d)
Er							13.5	(e)			12.7	(e)					15.8	(d)		
Tm																				
Yb							13	(e)			11.8	(e)					10.6	(d)	11.7	(d)
Lu							1.78	(e)									1.52	(d)	1.68	(d)
Hf																	15.6	(d)	11.3	(d)
Ta																	1.46	(d)	2.05	(d)
W ppb																	740			
Re ppb																				
Os ppb																				
Ir ppb													8.5	(f)			7.5			
Pt ppb																				
Au ppb													2.4	(f)			1.8			
Th ppm			6	(b)	6.7	(c)			6.6	(c)	6.1	(e)			6.25	(g)	5.52	(d)	6.7	(d)
U ppm			1.5	(b)					1.6	(c)	1.74	(e)			1.65	(g)	1.69	(d)		

technique: (a) es, (b) rad. Count, (c) XRF, (d) INAA, (e) IDMS, (f) RNAA, (g) radiation counting

Table 1b. Chemical composition of 12070.

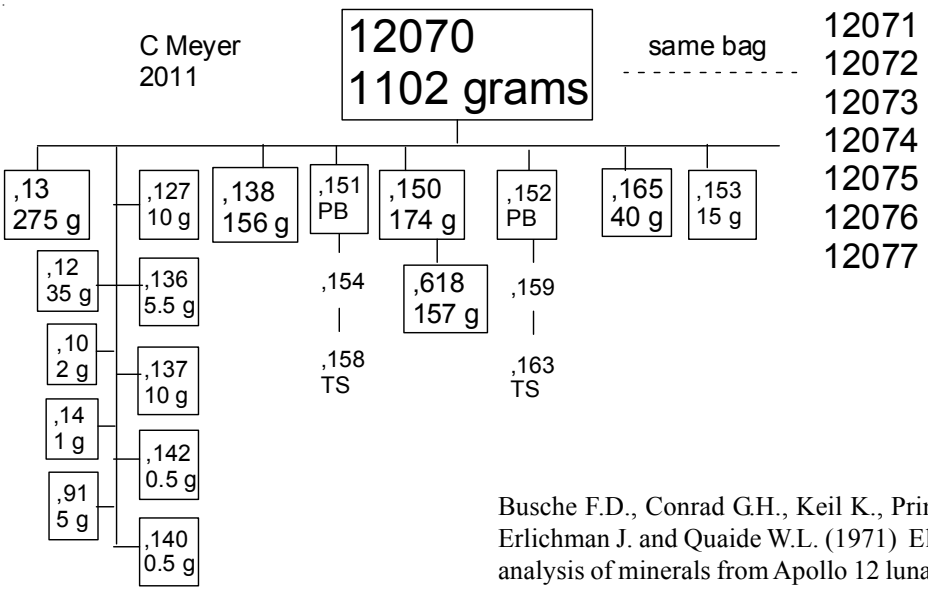
reference	Willis71		Schnetzler71		Frondel71		Taylor71		Baedecker71		Ganapathy70		Morrison71		Brunfeldt71		
weight	Willis72																
SiO2 %	45.74	(e)			46	(a)											
TiO2	2.79	(e)			3.1	(a)							2.5	?	2.78	2.92	(h)
Al2O3	12.69	(e)			14.84	(a)							13	?	12.55	12.73	(h)
FeO	16.52	(e)			14.7	(a)							15.7	?	16.08	15.57	(h)
MnO	0.222	(e)			0.22	(a)							0.245	?			
MgO	10.42	(e)			9.43	(a)							11.3	?			
CaO	10.45	(e)			10.67	(a)							9.52	?			
Na2O	0.39	(e)			0.48	(a)							0.43	?	0.43	0.44	(h)
K2O	0.241	(e)	0.235	(b)	0.28	(a)							0.23	?	0.24	0.23	(h)
P2O5	0.3	(e)											0.275	?			
S %	0.075	(e)											0.53	?			
sum																	
Sc ppm	39	(d)					40	(c)					35	?	39.3	38.3	(h)
V	112	(d)					110	(c)					72	?	143	142	(h)
Cr	2870	(e)			1984	(a)	2800	(c)					2800	?	2570	2620	(h)
Co	40	(d)					45	(c)					44	?	41.3	40.2	(h)
Ni	202	(e)					180	(c)					210	?			
Cu	8	(e)					5	(c)					7.7	?			
Zn	9.7	(e)							8.9	(g)	6.9	(g)	8.7	?	7.1	7.6	(h)
Ga									4.5	(g)	4.26	(g)	3.8	?	4.1	4	(h)
Ge ppb									355	(g)							
As													0.1	?	0.57	0.58	(h)
Se											259	(g)		?	0.24	0.25	(h)
Rb	6.4	(e)	6.47	(b)							6.3	(g)	5.8	?	8.3	8.1	(h)
Sr	140	(e)	144.2	(b)			135	(c)					130	?			
Y	126	(e)					120	(c)					130	?			
Zr	523	(e)					500	(c)					460	?			
Nb	33.2	(e)					25	(c)					35	?			
Mo							0.03	(c)					0.05	?			
Ru																	
Rh																	
Pd ppb																	
Ag ppb											*46*	(g)			140	290	(h)
Cd ppb									195	(g)	45	(g)					
In ppb									131	(g)	*218*	(g)			360	*880*	(h)
Sn ppb							300	(c)									
Sb ppb													9	?	50	30	(h)
Te ppb											100	(g)					
Cs ppm							0.3	(c)			0.248	(g)	0.2	?	0.29	0.31	(h)
Ba	373	(e)	373	(b)			340	(c)					330	?	321	304	(h)
La	33	(e)					32	(c)					36	?	33.2	33.7	(h)
Ce			89.4	(b)			76	(c)					97	?	84	90	(h)
Pr							12	(c)					12	?			
Nd			55.4	(b)			54	(c)					59	?			
Sm			16	(b)			19	(c)					19	?	16.1	15.8	(h)
Eu			1.77	(b)			1.9	(c)					1.7	?	1.77	1.84	(h)
Gd			20.1	(b)			25	(c)					23	?			
Tb							3.8	(c)					4.1	?	3.22		(h)
Dy			22.3	(b)			23	(c)					21	?	22.7	24.1	(h)
Ho							6	(c)					4.8	?	4.3	5.2	(h)
Er			13	(b)			15	(c)					13	?	13.1	14.2	(h)
Tm							2.4	(c)					1.6	?			
Yb	12	(d)	11.9	(b)			14	(c)					13	?	12.9	12.6	(h)
Lu			1.84	(b)									2.1	?	1.9	1.9	(h)
Hf							14	(c)					13	?	13.4	11.6	(h)
Ta													3.3	?	1.53	1.3	(h)
W ppb							500	(c)					730	?	640	640	(h)
Re ppb																	
Os ppb																	
Ir ppb									7.7	(g)	8.5	(g)			4.36	4.33	(h)
Pt ppb																	
Au ppb											2.39	(g)			4.5	5.4	(h)
Th ppm							5.6	(c)					6.9	?	4.6	4.2	(h)
U ppm							1.6	(c)					1.4	?	1.5	1.6	(h)

technique: (a) wet, (b) IDMS, (c) SSMS, (d) OES, (e) XRF, (g) RNAA, (h) INAA, RNAA

Table 1c. Chemical composition of 12070 (cont.)

reference	Cuttitta71				Smales71		Wakita71			Haskin71			Kharkar71		Rancitelli71	
weight													ave.		1.1 kg	
SiO2 %	45.8	45.7	46	(a)			43.5		(c)							
TiO2	2.83	2.78	2.82	(a)			2.8		(c)				3.67	(c)		
Al2O3	12.9	13	12.7	(a)			12.8		(c)							
FeO	16.3	16.4	16.7	(a)			16		(c)				15.57	(c)		
MnO	0.22	0.23	0.22	(a)	0.226		0.208		(c)				0.21	(c)		
MgO	10.2	10.5	9.56	(a)			13.1		(c)							
CaO	10.5	10.4	10.5	(a)			10.5		(c)				11.76	(c)		
Na2O	0.5	0.48	0.47	(a)	0.5		0.462		(c)				0.46	(c)		
K2O	0.25	0.23	0.23	(a)	0.26										0.239	(e)
P2O5	0.33	0.32	0.32	(a)												
S %																
sum																
Sc ppm	42	38	44	(b)	43			36	(c,d)				40	(c)		
V	121	110	114	(b)	110	(b)		130	(c,d)							
Cr	3060	3220	2430	(b)	2800		2429		(c)				2400	(c)		
Co	52	49	49	(b)	43			44	(c,d)				43	(c)		
Ni	222	215	150	(b)	200	(b)										
Cu	12	14	11	(b)												
Zn	8	7.6	8.2	(b)	11											
Ga	4.9	5.2	5.9	(b)												
Ge ppb																
As																
Se																
Rb	6.2	5.2	5.9	(b)	6.5		5.8		(c,d)							
Sr	123	115	125	(b)	190											
Y	145	133	142	(b)	130	(b)	110		(c,d)							
Zr	498	462	410	(b)	600	(b)		370	(c,d)							
Nb	29	29	30	(b)				12	(c,d)							
Mo																
Ru																
Rh																
Pd ppb																
Ag ppb					26											
Cd ppb							*460*		(c,d)							
In ppb							*470*		(c,d)							
Sn ppb																
Sb ppb																
Te ppb																
Cs ppm					0.31		0.24		(c,d)							
Ba	423	420	430	(b)	370			270	(c,d)							
La	40	46	39	(b)	38		37.7	36	(c,d)	34.9	31.6	(c)	33.4	(c)		
Ce					90		87.2		(c,d)	86.3	80.2	(c)	74	(c)		
Pr							12.6		(c,d)							
Nd					57		51		(c,d)	57	60	(c)				
Sm					17		16.6	16	(c,d)	18.1	16.3	(c)	15.1	(c)		
Eu					1.7		1.73	1.67	(c,d)	1.79	1.67	(c)	1.8	(c)		
Gd							19		(c,d)	17.6	22	(c)				
Tb					6		3.3		(c,d)	3.7	3.6	(c)	3.3	(c)		
Dy					29		20.5		(c,d)	24.3	23.3	(c)	26.7	(c)		
Ho					6.7		4.9		(c,d)	4	4.9	(c)				
Er							12.9		(c,d)	18	14	(c)				
Tm							2		(c,d)							
Yb	14	14	12	(b)	13.6		11.4	12	(c,d)	12.9	12.2	(c)	12.8	(c)		
Lu					1.9		1.67	1.66	(c,d)	1.9	1.75	(c)	1.75	(c)		
Hf					12								14.2	(c)		
Ta													1.8	(c)		
W ppb																
Re ppb																
Os ppb																
Ir ppb																
Pt ppb																
Au ppb																
Th ppm								5.6	(c,d)						6.73	(e)
U ppm															1.7	(e)

technique: (a) "microchemical.", (b) OES, (c) INAA, (d) RNAA, (e) radiation count.



References for 12070

Anderson A.T. and Smith J.V. (1971) Nature, occurrence and exotic origin of "grey mottled" (Luny Rock) basalts in Apollo 12 soils and breccias. *Proc. Second Lunar Sci. Conf.* 431-438.

Arrhenius G., Liang S., MacDougal D., Wilkening L., Bhandari N., Bhat S., Lal D., Rajagopalan G., Tamhane A.S., and Venkatavaradan V.S. (1971) The exposure history of the Apollo 12 regolith. *Proc. 2nd Lunar Sci. Conf.* 2583-2598.

Baedecker P.A., Schaudy R., Elzie J.L., Kimberlin J., and Wasson J.T. (1971) Trace element studies of rocks and soils from Oceanus Procellarum and Mare Tranquilitatis. *Proc. 2nd Lunar Sci. Conf.* 1037-1061.

Baedecker P.A., Chou C-L. and Wasson J.T. (1972) The extralunar component in lunar soils and breccias. *Proc. 3rd Lunar Sci. Conf.* 1343-1359.

Barra F., Swindle T.D., Korotev R.L., Jolliff B.L., Zeigler R.A. and Olson E. (2006) $^{40}Ar/^{39}Ar$ dating of Apollo 12 regolith: Implications for the age of Copernicus and the source of nonmare materials. *Geochim. Cosmochim. Acta* **70**, 6016-6031.

Bottino M.L., Fullagar P.D., Schnetzler C.C. and Phillpotts J.A. (1971) Sr isotopic measurements in Apollo 12 samples. *Proc. 2nd Lunar Sci. Conf.* 1487-1491.

Brunfelt A.O., Heier K.S. and Steiennes E. (1971a) Determination of 40 elements in Apollo 12 materials be neutron activation analysis. *Proc. 2nd Lunar Sci. Conf.* 1281-1290.

Busche F.D., Conrad G.H., Keil K., Prinz M., Bunch T.E., Erlichman J. and Quaide W.L. (1971) Electron microprobe analysis of minerals from Apollo 12 lunar samples. Special Pub. #3, UNM Institute of Meteoritics. ABQ

Bunch T.E., Prinz M. and Keil K. (1972c) Electron microprobe analyses of lithic fragments and glasses from Apollo 12 lunar samples. Special. Pub. #4, UNM Institute of Meteoritics, ABQ.

Cadenhead D.A., Brown M.G., Rice D.K. and Stetter J.R. (1977) Some surface area and porosity characterizations of lunar soils. *Proc. 8th Lunar Sci. Conf.* 1291-1303.

Cadogen P.H., Eglinton G., Firth J.N.M., Maxwell J.R., Mays B.J. and Pillinger C.T. (1972) Survey of lunar carbon compounds: II. The carbon chemistry of Apollo 11, 12, 14 and 15 samples. *Proc. 3rd Lunar Sci. Conf.* 2069-2090.

Carter J.L. (1971) Chemistry and surface morphology of fragments from Apollo 12 soil. *Proc. Second Lunar Sci. Conf.* 873-892.

Champness P.E., Dunham A.C., Gibb F.G.F., Giles H.N., MacKenzie W.S., Stumpel E.F. and Zussman J. (1971) Mineralogy and petrology of some Apollo 12 lunar samples. *Proc. 2nd Lunar Sci. Conf.* 359-376.

Chao E.C.T., Boreman J.A. and Desborough G.A. (1971) The petrology of unshocked and shocked Apollo 11 and Apollo 12 microbreccias. *Proc. Second Lunar Sci. Conf.* 791-816.

Chao E.C.T., Boreman J.A., Minkin J.A. and James O.B. (1970) Lunar glasses of impact origin: Physical and chemical characteristics and geologic implications. *J. Geophy. Res.* **75**, 7445-7479.

Cliff R.A., Lee-Hu C. and Wetherill G.W. (1971) Rb-Sr and U, Th-Pb measurements on Apollo 12 material. *Proc. 2nd Lunar Sci. Conf.* 1493-1502.

Compston W., Berry H., Vernon M.J, Chappell B.W. and Kaye M.J. (1971) Rubindium-strontium chronology and chemistry of lunar material from the Ocean of Storms. *Proc. 2nd Lunar Sci. Conf.* 1471-1485.

Cuttitta F., Rose H.J., Annell C.S., Carron M.K., Christian R.P., Dwornik E.J., Greenland L.P., Helz A.P. and Ligon D.T. (1971) Elemental composition of some Apollo 12 lunar rocks and soils. *Proc. 2nd Lunar Sci. Conf.* 1217-1229.

Delano J.W., Lindsley D.H. and Rudowski R. (1981) Glasses of impact origin from Apollo 11, 12, 15 and 16: Evidence for fractional vaporization and mare/highland mixing. *Proc. 12th Lunar Planet. Sci. Conf.* 339-370.

D'Amico J., DeFelice J., Fireman E.L., Jones C. and Spannagel G. (1971) Tritium and argon radioactivities and their depth variations in Apollo 12 samples. *Proc. 2nd Lunar Sci. Conf.* 1825-1839.

Dence M.R., Douglas J.A.V., Plant A.G. and Traill R.J. (1971) Mineralogy and peterology of some Apollo 12 samples. *Proc. Second Lunar Sci. Conf.* 285-299.

Doe B.R. and Tatsumoto M. (1971) Volatilized lead from Apollo 12 and 14 soils. *Proc. 3rd Lunar Sci. Conf.* 1981-1988.

Dwornik E.J., Annel C.S., Christian R.P., Cuttitta F., Finkelman R.B., Ligon D.T. and Rose H.J. (1974) Chemical and mineralogical composition of Surveyor 3 scoop sample 12029,9. *Proc. 4th Lunar Sci. Conf.* 1009-1014.

Ehmann W.D. and Morgan J.W. (1971) Major element abundances in Apollo 12 rocks and fines by 14 MeV neutron activation. *Proc. 2nd Lunar Sci. Conf.* 1237-1245.

Ehmann W.D., Gillum D.E. and Morgan J.W. (1972) Oxygen and bulk element composition studies of Apollo 14 and other lunar rocks and soil. *Proc. 3rd Lunar Sci. Conf.* 1149-1160.

Ehmann W.D., Chyi L.L., Garg A.N., Hawke B.R., Ma M.-S., Miller M.D., James W.D. and Pacer R.A. (1975a) Chemical studies of the lunar regolith with emphasis on zirconium and hafnium. *Proc. 6th Lunar Sci. Conf.* 1351-1361.

von Engelhardt W., Arndt J., Muller W.F. and Stoffler D. (1971) Shock mdtamorphism and origin of regolith and breccias at the Apollo 11 and Apollo 12 landing sites. *Proc. Second Lunar Sci. Conf.* 833-854.

von Engelhardt W., Hurrle H. and Luft E. (1976) Microimpact-induced changes of textural parameters and modal composition of the lunar regolith. *Proc. 7th Lunar Sci. Conf.* 373-392.

Epstein S. and Taylor H.P. (1971) O^{18}/O^{16}, Si^{30}/Si^{28}, D/H, and C^{13}/C^{12} ratios in lunar samples. *Proc. Second Lunar Sci. Conf.* 1421-1441.

Eugster O. (1971) Li, Be and B abundances in fines from the Apollo 11, Apollo 12, Apollo 14 and Luna 16 missions. *Earth Planet. Sci. Lett.* **12**, 273-281.

Friedman I., O'Niel J.R., Gleason J.D. and Hardcastle K.G. (1971) The carbon and hydrogen content and isotopic composition of some Apollo 12 materials. *Proc. 2nd Lunar Sci. Conf.* 1407-1415.

Frondel C., Klein C. and Ito J. (1971) Mineralogical and chemical data on Apollo 12 lunar fines. *Proc. Second Lunar Sci. Conf.* 719-726.

Fuchs L.H. (1970) Orthopyroxene-plagioclase fragments in lunar soil from Apollo 12. *Science* **169**. 866-867.

Funkhauser J. (1971) Noble gas analysis of KREEP fragments in lunar soil 12033 and 12070. *Earth Planet. Sci. Lett.* **12**, 263-272.

Funkhauser J.G., Jessberger E., Muller O. and Zahringer J. (1971) Active and inert gasses in Apollo 12 and 11 samples released by crushing at room temperature and heating at low temperature. *Proc. 2nd Lunar Sci. Conf.* 1381-1396.

Gammage R.B. and Holmes H.F. (1975b) Specific surface area as a maturity index of lunar fines. *Earth Planet. Sci. Lett*. **27**, 424 – 426.

Ganapathy R., Keays R.R. and Anders E. (1970) Apollo 12 lunar samples: Trace element analysis of a core and the uniformity of the regolith. *Science* **170**,533-535.

Goldstein J.I. and Yakowitz H. (1971) Metallic inclusions and metal particles in the Apollo 12 lunar soil. *Proc. Second Lunar Sci. Conf.* 177-191.

Goles G.G., Duncan A.R., Lindstrom D.J.,Martin M.R., Beyer R.L., Osawa M., Randle K., Meek L.T., Steinborn T.L. and McKay S.M. (1971) Analyses of Apollo 12 specimens: Compositional variations, differentiation processes, and lunar soil mixing models. *Proc. 2nd Lunar Sci. Conf.* 1063-1081.

Graf J.C. (1993) Lunar Soils Grain Size Catalog. NASA Pub. 1265

Haskin L.A., Helmke P.A., Allen R.O., Anderson M.R., Korotev R.L. and Zweifel K.A. (1971) Rare-earth elements in Apollo 12 lunar materials. *Proc. 2nd Lunar Sci. Conf.* 1307-1317.

Heiken G.H. (1974) A catalog of lunar soils. JSC Curator

Heiken G.H. (1975) Petrology of lunar soils. *Rev. Geophys. Space Phys.* **13**, 567-587.

Herr W., Herpers U. and Woelfle R. (1972) Study on the cosmic ray produced long-lived Mn53 in Apollo 14 samples. *Proc. 3rd Lunar Sci. Conf.* 1763-1769.

Hintenberger H., Weber H.W. and Takaoka N. (1971) Concentrations and isotopic abundances of the rare gases in lunar matter. *Proc. 2nd Lunar Sci. Conf.* 1607-1625.

Hintenberger H. and Weber H.W. (1973) Trapped rare gases in lunar fines and breccias. *Proc. 4th Lunar Sci. Conf.* 2003-2019.

Hubbard N.J. and Gast P.W. (1972) Chemical composition and origin of non-mare lunar basalts. *Proc. 2nd Lunar Sci. Conf.* 999-1020.

Hubbard N.J., Meyer C., Gast P.W. and Wiesmann H. (1971) The composition and derivation of Apollo 12 soils. *Earth Planet. Sci. Lett*. **10**, 341-350.

Keil K., Prinz T.E. and Bunch T.E. (1971) Mineralogy, petrology and chemistry of some Apollo 12 samples. *Proc. 2nd Lunar Sci. Conf.* 319-341.

Kerridge J.F., Kaplan I.R., Kung C.C., Winter D.A., Friedman D.L. and DesMarais D.J. (1978) Light element geochemistry of the Apollo 12 site. *Geochim. Cosmochim. Acta* **42**, 391-402.

Kharkar D.P. and Turekian K.K. (1971) Analyses of Apollo 11 and Apollo 12 rocks and soils by neutron activation. *Proc. 2nd Lunar Sci. Conf.* 1301-1305.

King E.A., Butler J.C. and Carman M.F. (1971) The lunar regolith as sampled by Apollo 11 and 12: Grain size analyses, modal analyses and origins of particles. *Proc. 2nd Lunar Sci. Conf.* 737-746.

Laul J.C., Morgan J.W., Ganapathy R. and Anders E. (1971) Meteoritic material in lunar samples: Characterization from trace elements. *Proc. 2nd Lunar Sci. Conf.* 1139-1158.

LSPET (1970) Preliminary Examination of Lunar Samples from Apollo 12. *Science* **167**, 1325-1339

Marvin U.B. (1971) Lunar niobian rutile. *Earth Planet. Sci. Lett*. **11**, 7-9.

Marvin U.B. (1978) Apollo 12 coarse fines (2-10 mm): Sample locations, description and inventory. Curators Office, JSC#14434

Marvin U.B., Wood J.A., Taylor G.J., Reid J.B., Powell B.N., Dickey J.S. and Bower J.F. (1971) Relative proportions and probable sources of rock fragments in the Apollo 12 soil samples. *Proc. 2nd Lunar Sci. Conf.* 679-699.

Marvin U.B., Lindstrom M.M., Holmberg B.B. and Martinez R.R. (1991) New observations of quartz monozodiorite-granite suite. *Proc. 21st Lunar Planet. Sci. Conf.* 119-136. Lunar Planetary Institute, Houston.

McKay D.S., Morrison D.A., Clanton U.S., Ladle G.H. and Lindsay J. (1971) Apollo 12 soil and breccias. *Proc. Second Lunar Sci. Conf.* 755-774.

Meyer C., Brett R., Hubbard N.J., Morrison D.A., McKay D.S., Aitken F.K, Taketda H. and Schonfeld E. (1971) Mineralogy, chemistry and origin of the KREEP component in soil samples from the Ocean of Storms. *Proc. 2nd Lunar Sci. Conf.* 393-411.

Morris R.V. (1976) Surface exposure indicies of lunar soils: A comparative FMR study. *Proc. 7th Lunar Sci. Conf.* 315-335.

Morris R.V. (1978) The surface exposure (maturity) of lunar soils: Some concepts and Is/FeO compilation. *Proc. 9th Lunar Sci. Conf.* 2287-2297.

Morris R.V., Score R., Dardano C. and Heiken G. (1983) Handbook of Lunar Soils. Two Parts. JSC 19069. Curator's Office, Houston.

Morrison G.H., Gerard J.T., Potter N.M., Gangadharam E.V., Rothenberg A.M. and Burdo R.A. (1971) Elemental abundances of lunar soil and rocks from Apollo 12. *Proc. 2nd Lunar Sci. Conf.* 1169-1185.

Müller O. (1972) Chemically bond nitrogen abundances in lunar samples, and active gases released by heating at lower temperatures. *Proc. 3rd Lunar Sci. Conf.* 2059-2068.

Murthy V.R., Evensen N.M., Jahn B.-M. and Coscio M.R. (1971) Rb-Sr ages and elemental abundances of K, Rb, Sr and Ba in samples from the Ocean of Storms. *Geochim. Cosmochim. Acta* **35**, 1139-1153.

O'Kelly G.D., Eldridge J.S., Schonfeld E. and Bell P.R. (1971a) Abundances of the primordial radionuclides K, Th, and U in Apollo 12 lunar samples by nondestructive gamma-ray spectroscopy: implications for the origin of lunar soils. *Proc. Second Lunar Sci. Conf.* 1159-1168.

O'Kelly G.D., Eldridge J.S., Schonfeld E. and Bell P.R. (1971b) Cosmogenic radionuclide concentrations and exposure ages of lunar samples from Apollo 12. *Proc. Second Lunar Sci. Conf.* 1747-1755.

Papanastassiou D.A. and Wasserburg G.J. (1971a) Lunar chronology and evolution from Rb-Sr studies of Apollo 11 and 12 samples. *Earth Planet. Sci. Lett*. **11**, 37-62.

Papike J.J., Simon S.B. and Laul J.C. (1982) The lunar regolith: Chemistry, Mineralogy and Petrology. *Rev. Geophys. Space Phys*. **20**, 761-826.

Pepin R.O., Bradley J.G., Dragon J.C. and Nyquist L.E. (1972) K-Ar dating of lunar fines: Apollo 12, Apollo 14 and Luna 16. *Proc. 3rd Lunar Sci. Conf.* 1569-1588.

Quaide W., Overbeck V.R., Bunch T. and Polkowski G. (1971) Investigations of the natural history of the regolith at the Apollo 12 site. *Proc. Second Lunar. Sci. Conf.* 701-718.

Rancitelli L.A., Perkins R.W., Felix W.D. and Wogman N.A. (1971) Erosion and mixing of the lunar surface from cosmogenic and primordial radionuclide measurements in Apollo 12 samples. *Proc. 2nd Lunar Sci. Conf.* 1757-1772.

Reed G.W. and Jovanovic S. (1971) The halogens and other trace elements in Apollo 12 samples and the implications of halides, platimum metals, and mercury on surfaces. *Proc. 2nd Lunar Sci. Conf.* 1261-1276.

Reid A.M., Warner J., Ridley W.I., Johnston D.A., Harman R.S., Jakes P. and Brown R.W. (1972a) The mojor element compositions of lunar rocks inferred from glass compositions in lunar soils. *Proc. 3rd Lunar Sci. Conf.* 363-379.

Runcorn S.K., Collinson D.W., O'Reilly W., Stephenson A., Batty M.H., Manson A.J. and Readman P.W. (1971) Magnetic properties of Apollo 12 lunar samples. *Proc. Roy. Soc. London* **A325**, 157-174.

Schnetzler C.C. and Philpotts J.A. (1971) Alkali, alkaline earth, and rare earth element concentrations in some Apollo 12 soils, rocks, and separated phases. *Proc. 2nd Lunar Sci. Conf.* 1101-1122.

Schonfeld E. and Meyer C. (1972) The abundances of components of the lunar soils by a least-squares mixing model and the formation age of KREEP. *Proc. 3rd Lunar Sci. Conf.* 1397-1420.

Smales A.A., Mapper D., Webb M.S.W., Webster R.K., Wilson J.D., and Hislop J.S. (1971) Elemental composition of lunar surface material (part 2). *Proc. Seond Lunar Sci. Conf.* 1253-1258.

Stone C.D., Taylor L.A., McKay D.S. and Morris R.V. (1982) Ferromagnetic resonance intensity: A rapid method for determining lunar glass bead origin. *Proc. 13th Lunar Planet. Sci. Conf*. in J. Geophys. Res. **87**, A182-A196.

Tatasumoto M., Knight R.J. and Doe B.R. (1971) U-Th-Pb systematics of Apollo 12 lunar samples. *Proc. 2nd Lunar Sci. Conf.* 1521-1546.

Taylor S.R., Rudowski R., Muir P., Graham A. and Kaye M. (1971b) Trace element chemistry of lunar samples from the Ocean of Storms. *Proc. 2nd Lunar Sci. Conf.* 1083-1099.

Wakita H. and Schmitt R.A. (1971) Bulk elemental composition of Apollo 12 samples: Five igneous and one breccia rocks and four soils. *Proc. 2nd Lunar Sci. Conf.* 1231-1236.

Wakita H., Rey P. and Schmitt R.A. (1971) Abundances of the 14 rare earth elements and 12 other trace elements in Apollo 12 samples: Five igneous and one breccia rocks and four soils. *Proc. 2nd Lunar Sci. Conf.* 1319-1329.

Wänke H., Wlotzka F., M. and Rieder R. (1971) Apollo 12 samples: Chemical composition and its relation to sample locations and exposure ages, the two component origin of the various soil samples and studies on lunar metallic particles. *Proc. 2nd Lunar Sci. Conf.* 1187-1208.

Wänke H., Baddenhausen H., Balacescu A., Teschke F., Spettel B., Dreibus G., Palme H., Quijano-Rico M., Kruse H., Wlotzka F. and Begemann F. (1972) Multielement analysis of lunar samples and some implications of the results. *Proc. 3rd Lunar Sci. Conf.* 1251-1268.

Warner J. (1970) Apollo 12 Lunar Sample Information. NASA TR R-353. JSC (catalog)

Wiesmann H. and Hubbard N. (1975) unpublished

Willis J.P., Ahrens L.H., Danchin R.V., Erlank A.J., Gurney J.J., Hofmeyr P.K., McCarthy T.S. and Orren M.J. (1971) Some inter-element relationships between lunar rocks and fines, and stony meteorites. *Proc. 2nd Lunar Sci. Conf.* 1123-1138.

Willis J.P., Erlank A.J., Gurney J.J., Theil R.H. and Ahrens L.H. (1972) Major, minor, and trace element data for some Apollo 11, 12, 14 and 15 samples. *Proc. 3rd Lunar Sci. Conf*. 1269-1273.

Wrigley R.C. (1971) Some cosmogenic and primordial radionuclides in Apollo 12 lunar surface materials. *Proc. Second Lunar Sci. Conf.* 1791-1796.

Wood J.A. (1972b) Fragments of Terra rock in the Apollo 12 soil samples and a structural model of the moon. *Icarus* **16**, 462-501.

Wood J.A., Marvin U.B., Reid J.B., Taylor G.J., Bower J.F., Powell B.N. and Dickey J.S. (1971a) Mineralogy and

petrology of the Apollo 12 lunar sample. Smithson. Astrophysi. Observ. Spec. Rep. 333

Yaniv A. and Heymann D. (1972) Inert gases from Apollo 11 and Apollo 12 fines: Reversals in the trends of relative element abundances. *Earth Planet. Sci. Lett.* **10**, 387-391.

Zellner N.E.B., Delano J.W., Swindle T.D., Barra F., Olsen E. and Whittet D.C.B. (2009a) Evidence from $^{40}Ar/^{39}Ar$ ages of lunar impact glasses for an increase in the impact rate ~800 Ma ago. *Geochim. Cosmochim. Acta* **73**, 4590-4597.