10084

Bulk Soil (< 1 mm)

3,830 grams

DRAFT

Introduction "Kicking up some dust"

On the lunar surface, nine scoops of soil were added to ALSRC#1003 (rock box) in order to protect the large rock samples from bouncing around. This large "bulk soil sample" (~10 kg.) was split and a large portion sieved in the LRL "bioprep" nitrogen cabinets. The less than 1 mm sieve fraction was numbered 10084. It was widely distributed and may be the most studied and analyzed sample on Earth. Apparently, sample 10002 was similar soil picked up at the same time and placed in Teflon bag (details needed). Other portions of 10002 were also sieved and analyses indicate it is of similar composition.

Studies of the Apollo 11 soil showed that it was formed by meteorite impact comminution of fine-grained basalt and coherent microbreccia (Carrier 1973, Heiken 1975). Agglutinate grains and most glassy particles were formed by melting and fusion of soil particles by impact processes. A few glass particles were made by volcanic processes. Shock metamorphism of fragments was found to be less extensive than was expected.

10084 is one of the "reference" lunar soils (Lobatka et al. 1980, Papike et al. 1982). It is found to be a mix of about 66% local basalt, 5% red brown glass, 20% "anorthosite", 8% KREEP and 1% meteorite (Korotev and Gillis 2001). It is a mature soil with a fine grain size and lots of agglutinate.

Beaty and Albee (1980) give an excellent review of the geology and petrology of the Apollo 11 landing site, with emphasis on the types of mare basalt found there.

Petrography

10084 is a mature soil with Is/FeO = 78 (Morris 1978). The grain size distribution was determined by Duke et al. (1970), King et al. (1970), Frondel et al. (1970), Carrier (1973), Basu et al. (2001) and others. The average grain size is 51 microns with about 14% less

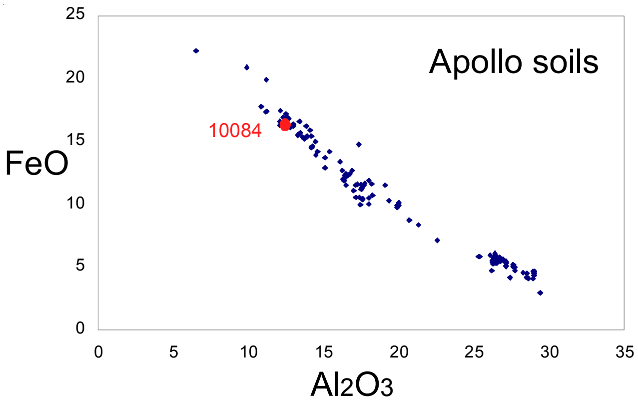


Figure 1: Chemical composition of Apollo soils with 10084 marked.

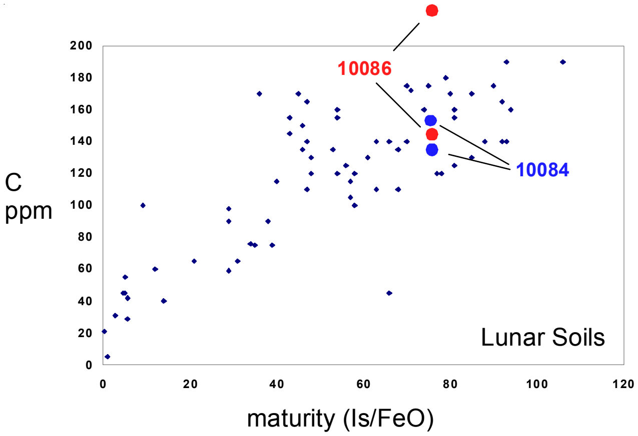


Figure 2: Maturity of Apollo soils determined by magnetic properties (Is/FeO) and carbon content, with samples 10084 and 10086 fines highlighted (data from Morris 1978 , Kaplan et al. 1970 and Moore et al. 1970).

Mineralogical Mode for 10084

Simon et al. 1981 (90 to 1000 micron)

Mare basalt	24
feldspathic basalt	1.1
anorthosite, norite	0.4
breccias, light	0.8
poikilitic breccias	
mafic mineral	4.2
plagioclase	1.9
opaque	1.1
glass	6.6
agglutinate	52
dark breccias	7.5

Note: Because there is a vast literature related to this sample, only a small portion of the relevant information can be summarized here – please excuse.

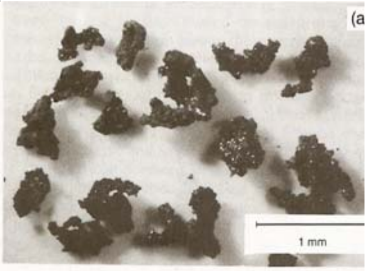


Figure 3: Agglutinate glass particles from soil. NASA S69-54827

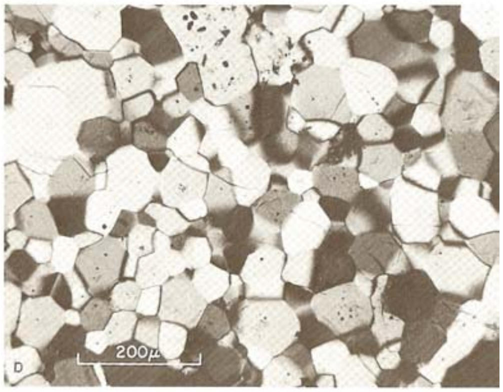


Figure 4: Thin section of lunar anorthosite fragment found in Apollo 11 soil (Wood et al. 1970).

Figure 5: Large metal grain from 10084 with zap pits (Mason et al. 1970).

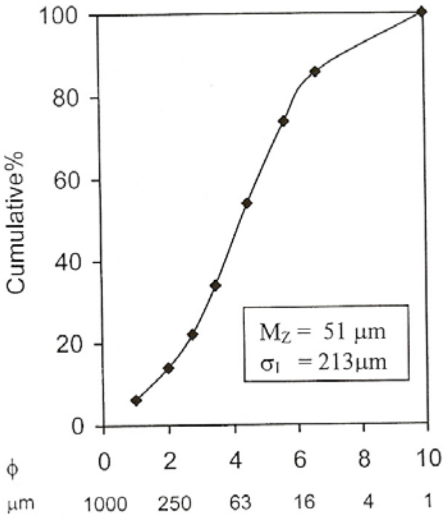


Figure 6: Grain size distribution of 10084 as determined by Basu et al. (2001).

than 10 microns (figure 6). The detailed mineralogy of 10084 was reported by many teams (Keil et al. 1970, Albee and Chodos 1970, Reid et al. 1970, Frondel et al. 1970 and others). The major minerals were found to be glass, Ca-plagioclase, pyroxene, olivine and ilmenite. Judith Frondel (1975) recorded many other phases. Shock features were studied by Sclar (1970), etc.

Perhaps the most interesting feature of the Apollo 11 soil was its high content of frothy, cinder-like glass aggregates – termed agglutinate (figure 3). These are produced by meteorite bombardment of the lunar soil, which has a substantial amount of solar-wind-implanted hydrogen (Basu 1977). Rhodes et al. (1975) found the agglutinates in 10084 were essentially identical in chemical composition with the bulk soil (table 2).

Another feature of 10084 was the presence of small red-brown glass beads (Essene et al. 1970), the importance of which became clear on the discovery of the orange glass deposit at Apollo 17 (Delano 1986; Shearer and Papike 1993). Korotev and Gillis (2001) recon that there could be as much as 5% red-brown volcanic glass in the Apollo 11 soil, much of it broken up and/or incorporated into the agglutinates.

Perhaps the most important foreign component is the "anorthosite" derived from distant, non-mare highlands, first recognized by the team led by John Wood (Dickey 1970). They found that about 4% of the particles from 10085 were white, plagioclase-rich rocks with a variety of textures (figure 4). Simon et al. (1983) have also studied this component.

There is also a meteorite component (~1%) , but most of it gets vaporized and incorporated into the fused component. However, a few percent survive (figure 5).

Chemistry

Many laboratories analyzed portions, or splits, of 10084. Not all analyses can be compiled here, but a few of the better analyses are given in table 1. Perhaps the best average of these analyses is given by Korotev and Gillis 2001 (Table 2). All of the Apollo 11 soils were found to be of similar composition.

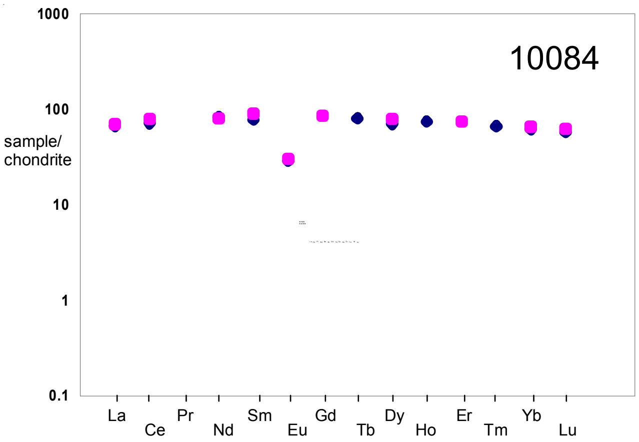


Figure 7: Normalized rare-earth-element diagram for lunar soil 10084 (see table).

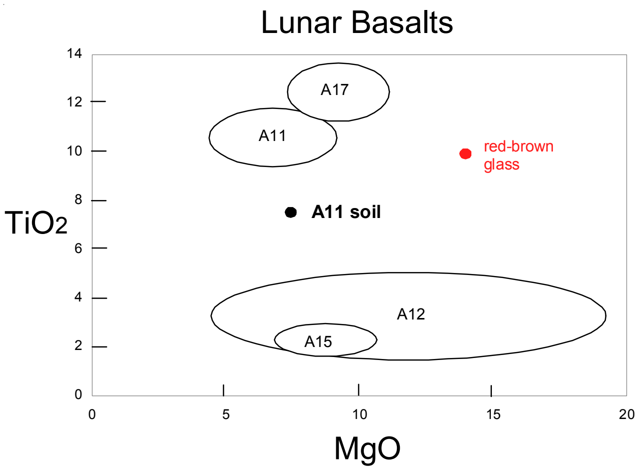


Figure 8: Composition of 10084 within the context of lunar mare basalts. The composition of the red-brown glass is also shown.

In brief, the Apollo 11 soil was Fe and Ti rich and Al poor (figure 1), containing mostly local mare basalt. However, there was a bit more K, Th, Rb and REE (partly explained by Luny Rock 1). Thus, the Apollo 11 soil is not simply ground up local mare basalt (figure 7 and 8). It also contains portions of highland materials, KREEP, volcanic glass and about 1 percent meteorite.

Numerous authors have attempted to calculate the mix of rock types that were incorporated into the Apollo 11 soil. Hubbard et al. (1971) recognized the need for a KREEP component. Goles et al. (1971), Lindsay (1971), Schonfeldt and Meyer (1972), Laul and Papike (1982), Korotev and Gillis (2001) and others have performed increasingly sophisticated mixxing models to explain the Apollo soil compositions. Laul et al. (1983) analyzed the highland component for Apollo 11.

Moore et al. (1970), Kaplan et al. (1970), Epstein and Taylor (1970) and others determined the carbon content of 10084 (figure 2).

Radiogenic age dating

Basford (1974) reported K-Ar data for 10084. Silver (1970), Tatsumoto (1970), and others reported U, Th and Pb isotope data.

Cosmogenic isotopes and exposure ages

The cosmic-ray-induced activity of 10084 is 26Al = 135 dpm/kg. and 22Na = 75 dpm/kg. (Wrigley and Quaide 1970). Perkins et al. (1970) determined 26Al = 134 dpm/kg, 22Na = 64 dpm/kg, 46Sc = 11 dpm/kg, 54Mn = 24 dpm/kg and 56Co = 53 dpm/kg.

Shedlowsky et al. (1970) and others studied the isotope variation caused by interaction of cosmic ray and solar flare radiation exposure.

Other Studies

Funkhauser et al. (1970), Hintenberger et al. (1970, 1971), Pepin et al. (1970) and others reported the rare gas abundances and isotopic ratios to great precision, and began many studies to identify the processes and components involved.

Processing

The initial processing of 10084 during the preliminary examination of ALSRC#1003 was not well recorded (Carrier 1973). Note that Wood et al. (1970) and Simon et al. (1983) published on 1-4 mm coarse fines numbered 10085. It is highly likely that this large sieving operation was not taken to completion, leaving a lot of fine material in 10085 and 10086 (the coarse fines from 10084?). How did Albee et al. (1970) come up with Luny Rock 1?

A number of contaminant phases were found in 10084 (Frondel 1975). Some contaminants were probably from the LRL and some from the individual PI labs.

Table 1a. Chemical composition of 10084.

reference	*LSPET69*		Wiesmann76			Laul80		Rhodes81		Agrell70		Compston70		Goles70			Haskin70	
weight			Gast70			bulk												
SiO2 %	*43*	(b)				41.3	(e)	41.9	(d)	42.16	(f)	41.79	(d)	45.2	43.5	(e)		
TiO2	*7*	(b)				7.5	(e)	7.56	(d)	7.75	(f)	7.55	(d)	8.5	8.8	(e)		
Al2O3	*13*	(b)				13.7	(e)	13.55	(d)	13.6	(f)	13.44	(d)	14	13.7	(e)		
FeO	*16*	(b)				15.8	(e)	15.94	(d)	15.34	(f)	15.91	(d)	14.4	14.7	(e)	15.7	(e)
MnO	*0.23*	(b)				0.213	(e)	0.21	(d)	0.2	(f)	0.21	(d)	0.2	0.21	(e)	0.2	(e)
MgO	*8*	(b)				8	(e)	7.82	(d)	7.76	(f)	7.66	(d)					
CaO	*12*	(b)				12.5	(e)	12.08	(d)	11.94	(f)	12.14	(d)					
Na2O	*0.54*	(b)	0.46			0.41	(e)	0.4	(d)	0.47	(f)	0.43	(d)	0.43	0.44	(e)		
K2O	*0.12*	(b)	0.145	0.138	(a)	0.14	(e)	0.13	(d)	0.16	(f)	0.14	(d)				0.13	(e)
P2O5								0.11	(d)	0.05	(f)	0.13	(d)					
S %										0.12	(f)	0.14	(d)					
sum																		
Sc ppm	*55*	(b)				60.2	(e)	61	(e)					59	60	(e)	61.7	(e)
V	*42*	(b)				70	(e)					36		107	81	(e)		
Cr	*2500*	(b)		2070	(a)	1984	(e)	1840	(e)			1850		1900	1940	(e)	1824	(e)
Co	*18*	(b)				28	(e)	29	(e)			34		30.3	30.6	(e)	27	(e)
Ni	*250*	(b)				200	(e)	238	(e)			230					200	(e)
Cu												33					10	(e)
Zn								37	(e)			37					23	(e)
Ga								5	(e)			4					5.1	(e)
Ge ppb																		
As																	37	(e)
Se																	0.8	(e)
Rb			2.79	2.81	(a)			3.3	(e)			2.96	(a)				3.2	(e)
Sr	*90*	(b)	174		(a)	160	(e)	169	(e)			164.8	(a)				169	(e)
Y	*130*	(b)						105	(e)			99						
Zr	*400*	(b)		310	(a)			312	(e)			318		290		(e)		
Nb								19	(e)			18						
Mo																		
Ru																		
Rh																		
Pd ppb																		
Ag ppb																	27	
Cd ppb																		
In ppb														0.8	0.9	(e)	0.86	
Sn ppb																		
Sb ppb																	5	
Te ppb																		
Cs ppm			0.102		(a)												0.11	(e)
Ba			188	163	(a)	170	(e)	188	(e)			134		140	170	(e)	168	(e)
La			16.6	15	(a)	15.8	(e)	16.6	(e)			21		14.5	14.2	(e)	16.9	(e)
Ce			47.7	44.5	(a)	43	(e)	47	(e)			58		50.4	52.8	(e)	47.3	(e)
Pr												10						
Nd			36.3	35.8	(a)	37	(e)					33					41	(e)
Sm			13.1	12.5	(a)	11.4	(e)	13.4	(e)					12.6	12.5	(e)	13.7	(e)
Eu			1.7	1.71	(a)	1.6	(e)	1.74	(e)					1.76	1.8	(e)	1.74	(e)
Gd			16.8	17.2	(a)												11.3	(e)
Tb						2.9	(e)	2.7	(e)					2.47	2.7	(e)	3.03	(e)
Dy			19.2	19.3	(a)	17	(e)							18.8			21	(e)
Ho						4.1	(e)							5.8	6.6	(e)	4.4	(e)
Er			11.8	11.4	(a)												10.4	(e)
Tm						1.6	(e)											
Yb			10.6	10.4	(a)	10	(e)	11.4	(e)					10.5	11.3	(e)	11.35	(e)
Lu			1.5	1.55	(a)	1.39	(e)	1.5	(e)					1.57	1.58	(e)	1.69	(e)
Hf						9	(e)							10.2	10.8	(e)	7.6	(e)
Ta						1.25	(e)	1.3	(e)					1.2	1.4	(e)	1.4	(e)
W ppb																		
Re ppb																		
Os ppb																		
Ir ppb																		
Pt ppb																		
Au ppb																	2.8	(e)
Th ppm	*1.6*	(c)				1.9	(e)											
U ppm	*0.46*	(c)				0.5	(e)							0.45	0.41	(e)		

technique: (a) IDMS, (b) emiss. spec. (c) radiation counting, (d) XRF, (e) INAA, (f) wet

Table 1b. Chemical composition of 10084.

reference	Tera70		Wanke70		Wrigley70		Perkins70		Wakita70		Philpotts70		Maxwell70				Morrison70	
weight						large samples							GSC	GSF	USGS			
SiO2 %			42.2	(f)									42.28	42.25	42.2	(f)	43.2	(b)
TiO2			7.17	(f)									7.35	7.54	7.32	(f)	6.84	(c)
Al2O3			13	(f)									13.76	13.83	14.07	(f)	13.8	(c)
FeO			15.4	(f)									16.02	15.8	15.81	(f)	16.1	(c)
MnO			0.2	(f)									0.2	0.2	0.21	(f)	0.206	(c)
MgO			7.96	(f)									7.93	7.97	7.73	(f)	7.63	(c)
CaO	11.93	(a)	11.3	(f)									12	11.92	12.01	(f)	13.4	(c)
Na2O	0.42	(b)	0.42	(f)									0.42	0.43	0.46	(f)	0.44	(c)
K2O	0.134	(a)	0.131	(f)			0.132	(e)			0.135	(a)	0.13	0.13	0.12	(f)	0.13	(c)
P2O5													0.11	0.14	0.08	(f)	0.32	(c)
S %													0.13		0.14	(f)		
sum																		
Sc ppm			61	(c)					58	(c)			51	59		(f)	60	(c)
V									63	(c)			67	71		(f)		
Cr			1830	(c)									2300	1880		(f)	2000	(c)
Co			27.2	(c)					31	(c)				32		(f)	40	(c)
Ni			280	(c)									190	200		(f)		
Cu			8.2	(c)										13		(f)	9.9	(c)
Zn													47	36		(f)	22	(c)
Ga			4.9	(c)													4.6	(c)
Ge ppb			1400	(d)													700	(f)
As																		
Se																		
Rb	2.68	(a)	3	(d)					3	(c)	2.78	(a)					*4.4*	(f)
Sr	162.8	(a)	176	(d)							162	(a)	140			(f)	200	(f)
Y									96	(c)			120	120		(f)	150	(f)
Zr									460	(c)			260	380		(f)	390	(f)
Nb																	33	(f)
Mo																	0.7	(f)
Ru																		
Rh																		
Pd ppb			12	(d)														
Ag ppb																	0.1	(f)
Cd ppb									0.06	(c)							0.3	(f)
In ppb			0.75	(d)					0.58	(c)							0.5	(f)
Sn ppb																	0.7	(f)
Sb ppb																	0.005	(f)
Te ppb																		
Cs ppm	0.101	(a)	0.12	(c)					0.18	(c)							0.2	(f)
Ba	169	(a)	176	(c)					200	(c)	170	(a)	150				220	(f)
La			15	(c)					14.2	(c)							22	(f)
Ce			47	(c)					47	(c)	46.1	(a)					50	(f)
Pr			5	(c)					6.9	(c)							9	(f)
Nd			47	(c)					43	(c)	40.5	(a)					46	(f)
Sm			12.1	(c)					12.6	(c)	13.9	(a)		18		(f)	18	(f)
Eu			1.67	(c)					2	(c)	1.77	(a)		1.8		(f)	1.9	(f)
Gd			18	(c)					17.2	(c)							20	(f)
Tb			2.8	(c)					3	(c)				3		(f)	3.8	(f)
Dy			17	(c)					23	(c)	19.5	(a)					25	(f)
Ho			4.6	(c)					6.3	(c)							6	(f)
Er			9.5	(c)					13	(c)	11.7	(a)					15	(f)
Tm									1.8	(c)							1.2	(f)
Yb			8.3	(c)					10.8	(c)	10.6	(a)		12		(f)	12	(f)
Lu			1.3	(c)					1.5	(c)				3		(f)	1.4	(f)
Hf			10.2	(c)					9	(c)				8		(f)	9	(f)
Ta			1.3	(c)										3		(f)	1.3	(c)
W ppb			220	(d)													250	(c)
Re ppb																		
Os ppb																		
Ir ppb																		
Pt ppb																		
Au ppb			2.1	(d)														
Th ppm			1.61	(c)	2.3	2.19	2.25	(e)	2.6					3		(f)	2.3	(f)
U ppm			0.35	(c)	0.64	0.64	0.55	(e)									0.48	(c)

technique: (a) IDMS, (b) AA, (c) INAA, (d) RNAA, (e) radiation counting, (f) various

Table 1c. Chemical composition of 10084 (cont.).

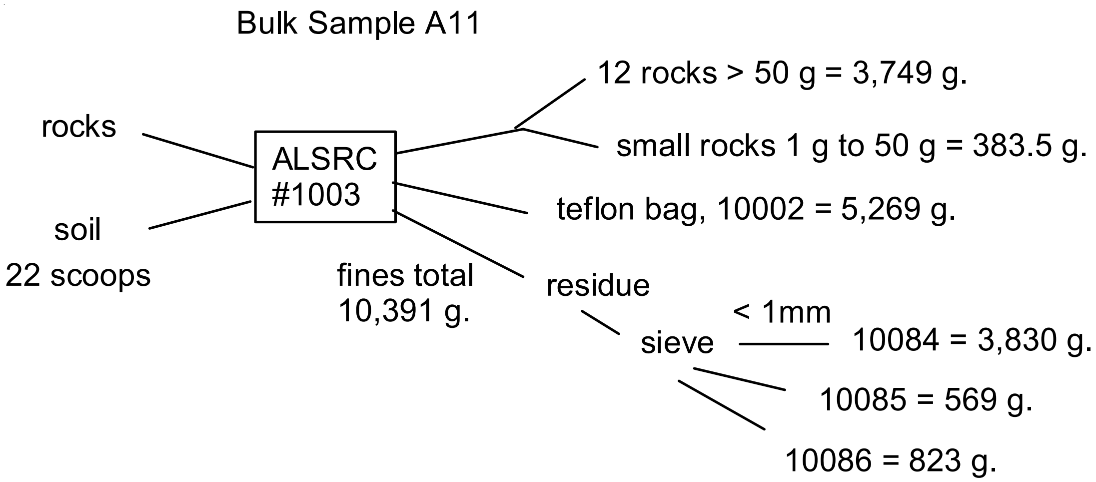
reference	Ganapathy70			Laul71		Wasson70		*Bouchet71*		LSPET73		Annell70		Evensen73			Baedecker74	
weight														coarse	fine			
SiO2 %								*42*	(b)	41.78	(d)							
TiO2								*9*	(b)	7.41	(d)							
Al2O3								*13.8*	(b)	13.47	(d)							
FeO				15.8	(a)			*15.8*	(b)	15.65	(d)						16	(a)
MnO								*0.2*	(b)	0.22	(d)						0.22	(a)
MgO								*7.96*	(b)	8.07	(d)							
CaO				12	(a)			*12*	(b)	12.13	(d)							
Na2O								*0.44*	(b)	0.37	(d)						0.46	(a)
K2O								*0.14*	(b)	0.15	(d)			0.145	0.196	(f)		
P2O5										0.14	(d)							
S %								*0.175*										
sum																		
Sc ppm								*62*	(c)			56	(e)				61	(a)
V								*22*	(c)			50	(e)					
Cr												1740	(e)				1950	(a)
Co	27	26.8	(a)	28	(a)			*14*	(c)			24	(e)				32	(a)
Ni				150	(a)			*163*	(c)			185	(e)					
Cu	8.6	8.1	(a)					*9*	(c)			10	(e)					
Zn	19.5	21.1	(a)	20	(a)			*22*	(c)			19	(e)					
Ga	5.25	5.41	(a)	5.1	(a)	4.8	(a)	*8.5*	(c)			3.8	(e)					
Ge ppb						390	(a)											
As								*0.1*	(c)									
Se				0.33	(a)													
Rb	3.22	3.33	(a)	3.1	(a)			*8*	(c)			2.7	(e)	2.77	4.6	(f)		
Sr								*186*	(c)			130	(e)	179	224	(f)		
Y								*173*	(c)			81	(e)					
Zr								*301*	(c)			273	(e)					
Nb								*23*	(c)			18	(e)					
Mo								*1*	(c)									
Ru																		
Rh																		
Pd ppb	8.9	11	(a)															
Ag ppb	8.7	8.9	(a)	8.7	(a)													
Cd ppb	29.6	53.3	(a)	46	(a)													
In ppb	*1470*	*524*	(a)			*656*	(a)											
Sn ppb																		
Sb ppb																		
Te ppb																		
Cs ppm	0.096	0.098	(a)	0.096	(a)			*0.8*	(c)									
Ba								*410*	(c)			210	(e)	181	265	(f)		
La								*37*	(c)			16	(e)					
Ce								*60*	(c)								48	(a)
Pr								*17*	(c)									
Nd								*44*	(c)									
Sm								*12*	(c)									
Eu								*3*	(c)								2	(a)
Gd								*15*	(c)									
Tb								*9*	(c)								3.2	(a)
Dy																		
Ho																		
Er																		
Tm																		
Yb																	8.9	(a)
Lu																		
Hf																	9.8	(a)
Ta																	1.35	(a)
W ppb																		
Re ppb																		
Os ppb																		
Ir ppb	6.88	7.62	(a)	7.2	(a)	10.7	(a)											
Pt ppb																		
Au ppb	2.38	4.15	(a)	3	(a)	1.4	(a)											
Th ppm								*3.9*									3.2	(a)
U ppm								*67*										

technique: (a) RNAA, (b) emission spec. (c) spark mass spec., (d) XRF, (e) emis. Spec., (f) IDMS

Table 2. Summary 10084 and agglutinate

reference	Korotev2001	±		Rhodes 76	
weight	average			agglutinate	
SiO_2 %	42	± 0.2	(a)	40.97	(b)
TiO_2	7.54	± 0.08	(a)	7.8	(b)
Al_2O_3	13.55	± 0.18	(a)	13.72	(b)
FeO	15.81	± 0.15	(a)	16	(b)
MnO	0.213	± 0.005	(a)	0.23	(b)
MgO	7.88	± 0.07	(a)	7.73	(b)
CaO	11.96	± 0.13	(a)	11.92	(b)
Na_2O	0.438	± 0.012	(a)	0.44	(b)
K_2O	0.135	± 0.005	(a)	0.13	(b)
P_2O_5	0.101	± 0.017	(a)	0.12	(b)
S %	0.11	± 0.03	(a)	0.12	(b)
sum					
Sc ppm	63	± 2	(a)	56.3	(c)
V	67	± 19	(a)		
Cr	2039	± 75	(a)	2240	(c)
Co	28.9	± 1.1	(a)	30	(c)
Ni	190	± 30	(a)	190	(c)
Cu					
Zn					
Ga					
Ge ppb					
As					
Se					
Rb	2.8	± 0.09	(a)		
Sr	163	± 4	(a)		
Y	115	± 15	(a)		
Zr	290	± 40	(a)		
Nb	18	± 2	(a)		
Mo					
Ru					
Rh					
Pd ppb					
Ag ppb					
Cd ppb					
In ppb					
Sn ppb					
Sb ppb					
Te ppb					
Cs ppm	0.108	± 0.01			
Ba	169	± 9			
La	15.5	± 0.6		15.7	(c)
Ce	46.6	1.4		45	(c)
Pr					
Nd	38	4			
Sm	12.7	0.5		12.5	(c)
Eu	1.77	0.08		1.61	(c)
Gd	17	2			
Tb	2.94	0.17		3.3	(c)
Dy	20	2			
Ho					
Er	11.5	1.5			
Tm					
Yb	10.6	0.6		10.4	(c)
Lu	1.53	0.09		1.52	(c)
Hf	9.8	0.5		9.7	(c)
Ta	1.33	0.09		1.5	(c)
W ppb					
Re ppb					
Os ppb					
Ir ppb					
Pt ppb					
Au ppb					
Th ppm	1.94	0.18		1.5	(c)
U ppm	0.51	0.06			

technique : (a) multiple, (b) XRF, (c) INAA



References for 10084

Albee A.L. and Chodos A.A. (1970) Microprobe investigations on Apollo 11 samples. *Proc. Apollo 11 Lunar Science Conf.* 135-157.

Albee, Burnett, Chodos, Eugster, Huneke, Papanastassiou, Podosek, Price, Sanz, Tera and Wasserburg G.J. (1970) Ages, irradiation history, and chemical composition of lunar rocks from the Sea. *Science* **167**, 463-466.

Annell C.S. and Helz A.W. (1970) Emission spectrographic determination of trace elements in lunar samples from Apollo 11. *Proc. Apollo 11 Lunar Sci. Conf.* 991-994.

Agrell S.O., Scoon J.H., Muir I.D., Long J.V.P., McConnell J.D.C. and Peckett A. (1970) Observations on the chemistry, mineralogy and petrology of some Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 93-128.

Baedecker P.A., Chou C.-L., Sundberg L.L. and Wasson J.T. (1974) Volatile and siderophile trace elements in the soils and rocks of Taurus-Littrow. *Proc. 5th Lunar Sci. Conf.* 1625-1643.

Basford J.R. (1974) K-Ar analysis of Apollo 11 fines 10084. *Proc. 5th Lunar Sci. Conf.* 1375-1388.

Basu A. (1977) Steady state, exposure age and growth of agglutinates in lunar soils. *Proc. 8th Lunar Sci. Conf.* 3617-3632.

Basu A., Wentworth S.J. and McKay D.S. (2001) Submillimeter grain-size distribution of Apollo 11 soil 10084. *Meteoroit. & Planet. Sci.* **36**, 177-181.

Beaty D.W. and Albee A.L. (1980) The geology and petrology of the Apollo 11 landing site. *Proc. 11th Lunar Planet. Sci. Conf.* 23-35.

Bouchet M., Kaplan G., Voudon A., and Bertoletti M.-J. (1971) Spark source spectrometric analysis of major and minor elements in six lunar samples. *Proc. 2nd Lunar Sci. Conf.* 1247-1252.

Carrier W.D. (1973) Lunar grain size distribution. *The Moon* **6**, 250-263.

Compston W., Chappell B.W., Arriens P.A. and Vernon M.J. (1970b) The chemistry and age of Apollo 11 lunar material. *Proc. Apollo 11 Lunar Sci. Conf.* 1007-1027.

Delano J.W. (1986) Pristine lunar glasses: Criteria, data and implications. *Proc. 16th Lunar Planet Sci. Conf.* in J. Geophys. Res. **91**, D201-D213.

Dickey J.S. (1970) Nickel-iron in lunar anorthosites. *Earth Planet. Sci. Lett.* **8**, 387-392.

Duke M.B., Woo C.C., Sellers G.A., Bird M.L. and Finkelman R.B. (1970) Genesis of lunar soil at Tranquillity base. *Proc. Apollo 11 Lunar Sci. Conf.* 347-362.

Engel A.E.J. and Engel Celeste G. (1970) Lunar rock compositions and some interpretations. *Proc. Apollo 11 Lunar Sci. Conf.* 1081-1084.

Engel A.E.J., Engel C.G., Sutton A.L. and Myers A.T. (1971) Composition of five Apollo 11 and Apollo 12 rocks and one Apollo 11 soil and some petrogenetic considerations. *Proc. 2nd Lunar Sci. Conf.* 439-448.

Essene E.J., Ringwood A.E. and Ware N.G. (1970) Petrology of the lunar rocks from Apollo 11 landing site. *Proc. Apollo 11 Lunar Sci. Conf.* 385-397.

Epstein S. and Taylor H.P. (1970) The concentration and isotopic composition of hydrogen, carbon and silicon in Apollo 11 lunar rocks and minerals. *Proc. Apollo 11 Lunar Sci. Conf.* 1085-1096.

Evensen N.M., Murthy V.R. and Coscio M.R. (1973) Rb-Sr ages of some mare basalts and the isotopic and trace element systematics in lunar fines. *Proc. 4th Lunar Sci. Conf.* 1707-1724.

Frondel J. W. (1975) **Lunar Mineralogy.** Wiley, N.Y. 325 pp.

Frondel C., Klein C., Ito J. and Drake J.C. (1970) Mineralogical and chemical studies of Apollo 11 lunar fines and selected rocks. *Proc. Apollo 11 Lunar Sci. Conf.* 445-474.

Funkhauser J.G., Schaeffer O.A., Bogard D.D. and Zahringer J. (1970) Gas analysis of the lunar surface. *Proc. Apollo 11 Lunar Sci. Conf.* 1111-1116.

Ganapathy R., Keays R.R., Laul J.C. and Anders E. (1970) Trace elements in Apollo 11 lunar rocks: Implications for meteorite influx and origin of moon. *Proc. Apollo 11 Lunar Sci. Conf.* 1117-1142.

Gast P.W. and Hubbard N.J. (1970a) Abundance of alkali metals, alkaline and rare earths and strontium-87/strontium-86 ratios in lunar samples. *Science* **167**, 485-487.

Gast P.W., Hubbard N.J. and Wiesmann H. (1970b) Chemical composition and peterogenesis of basalts from Tranquillity Base. *Proc. Apollo 11 Lunar Sci. Conf.* 1143-1163.

Goles G. (1971) Comments on the genesis and evolution of Apollo XI soil. *Lithos* **4**, 71-81.

Goles G.G., Randle K., Osawa M., Lindstrom D.J., Jerome D.Y., Steinborn T.L., Beyer R.L., Martin M.R. and McKay S.M. (1970) Interpretations and speculations on elemental abundances in lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1177-1194.

Haskin L.A., Allen R.O., Helmke P.A., Paster T.P., Anderson M.R., Korotev R.L. and Zweifel K.A. (1970) Rare earths and other trace elements in Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1213-1231.

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.

Hintenberger H., Weber H.W., Voshage H, Wanke H., Begeman F. and Wlotzka F. (1970) Concentrations and isotopic abundances of the rare gases, hydrogen and nitrogen in Apollo 11 lunar fines. *Proc. Apollo 11 Lunar Sci. Conf.* 1269-1282.

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., Schultz L. and Weber H.W. (1975a) A comparison of noble gases in lunar fines and soil breccias: Implications for the origin of soil breccias. *Proc. 6th Lunar Sci. Conf.* 2261-2270.

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

Kaplan I.R. and Smith J.W. (1970) Carbon and sulfur concentration and isotopic composition in Apollo 11 luanr samples. *Science* **167**, 541-543.

Kaplan I.R., Smith J.W. and Ruth E. (1970) Carbon and sulfur concentration and isotopic composition in Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1317-1329.

Keil K., Bunch T.E. and Prinz M. (1970) Mineralogy and composition of Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 561-598.

Korotev R.L. and Gillis J.J. (2001) A new look at the Apollo 11 regolith and KREEP. *J. Geophys. Res.* **106**, 12339-12353.

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.

Labotka T.C., Kempa M.J., White C., Papike J.J. and Laul J.C. (1980) The lunar regolith: Comparative petrology of the Apollo sites. *Proc. 11th Lunar Planet. Sci. Conf.* 1285-1305.

Larochelle A. and Schwarz E.J. (1970) Magnetic properties of Apollo 11 sample 10048,22. *Proc. Apollo 11 Lunar Sci. Conf.* 2305-2308.

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.

Laul J.C. and Papike J.J. (1980) The lunar regolith: Comparative chemistry of the Apollo sites. *Proc. 11th Lunar Planet. Sci. Conf.* 1307-1340.

Laul J.C., Papike J.J., Simon S.B. and Shearer C.K. (1983) Chemistry of the Apollo 11 highland component. *Proc. 14th Lunar Planet. Sci. Conf.* B139-149. JGR **88**

Lindsay J.F. (1971) Mixing models and the recognition of end-member groups in Apollo 11 and 12 soils. *Earth Planet. Sci. Lett.* **12**, 67-72.

LSPET (1969) Preliminary examination of lunar samples from Apollo 11. *Science* **165**, 1211-1227.

LSPET (1973a) Apollo 17 lunar samples : Chemical and petrographic description. *Science* **182**, 659-690.

Marquardt C.L. and Griscom D.L. (1976) On the spectral reflectance and maturation darkening of lunar soils. *The Moon,* **15**, 15-30.

Mason B., Fredricksson K., Henderson P., Jarosewich E., Melson W., Towe K. and White J.S. (1970) Mineralogy and petrology of lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 655-660.

Maxwell J.A., Peck L.C., and Wiik H.B. (1970) Chemical composition of Apollo 11 lunar samples 10017, 10020, 10072, and 10084. *Proc. Apollo 11 Lunar Sci. Conf.* 1369-1374.

Moore C.B., Gibson E.K., Larimer J.W., Lewis C.F. and Nichiporuk W. (1970) Total carbon and nitrogen abundances in Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1375-1382.

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.* 2287-2298.

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., Kashuba A.T., Gangadharam E.V., Rothenberg A.M., Potter N.M. and Miller G.B. (1970) Elemental abundances of lunar soil and rocks. *Proc. Apollo 11 Lunar Sci. Conf.* 1383-1392.

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., Nyquist L.E., Phinney D. and Black D.C. (1970) Rare gases in Apollo 11 lunar material. *Proc. Apollo 11 Lunar Sci. Conf.* 1435-1454.

Perkins R.W., Rancitelli L.A., Cooper J.A., Kaye J.H. and Wogman N.A. (1970) Cosmogenic and primordial radionuclide measurements in Apollo 11 lunar samples by nondestructive analysis. *Proc. Apollo 11 Lunar Sci. Conf. 1455*-1469.

Philpotts J.A. and Schnetzler C.C. (1970a) Potassium, rubidium, strontium, barium and rare-earth concentrations in lunar rocks and separated phases. *Science* **167**, 493-495.

Philpotts J.A. and Schnetzler C.C. (1970b) Apollo 11 lunar samples: K, Rb, Sr, Ba and rare-earth concentrations in some rocks and separated phases. *Proc. Apollo 11 Lunar Science Conf.* 1471-1486.

Reid A.M., Frazer J.Z., Fujita H. and Everson J.E. (1970) Apollo 11 samples: Major mineral chemistry. *Proc. Apollo 11 Lunar Sci. Conf.* 749-761.

Rhodes J.M., Adams J.B., Blanchard D.P., Charette M.P., Rodgers K.V., Jacobs J.W., Brannon J.C. and Haskin L.A. (1975) Chemistry of agglutinate fractions in lunar soils. *Proc. 6th Lunar Sci. Conf.* 2291-2308.

Rhodes J.M. and Blanchard D.P. (1981) Apollo 11 breccias and soils: Aluminous mare basalts or multi-component mixtures? *Proc. 12th Lunar Planet. Sci. Conf.* 607-620.

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.

Sclar C.B. (1970) Shock metamorphism of lunar rocks and fines from tranquillity base. *Proc. Apollo 11 Lunar Sci. Conf.* 849-864.

Shearer C.K. and Papike J.J. (1993) Basaltic magmatism on the Moon: A perspective from volcanic picritic glass beads. *Geochim. Cosmochim. Acta* **57**, 4785-4812.

Shedlovsky J.P., Honda M., Reedy R.C., Evans J.C., Lal D., Lindstrom R.M., Delany A.C., Arnold J.R., Loosli H.H., Fruchter J.S., Finkel R.C. and Kirschner Florence (1970) Pattern of bombardment-produced radionuclides in rock 10017 and in lunar soil. *Proc. Apollo 11 Lunar Sci. Conf.* 1503-1532.

Silver L.T. (1970) Uranium-thorium-lead isotopes in some Tranquillity Base samples and their implications for lunar history. *Proc. Apollo 11 Lunar Sci. Conf.* 1533-1574.

Simon S.B., Papike J.J. and Laul J.C. (1981) The lunar regolith: Comparative studies of the Apollo and Luna sites. *Proc. 12th Lunar Planet. Sci. Conf.* 371-388.

Simon S.B., Papike J.J., Shearer C.K. and Laul J.C. (1983) Petrology of the Apollo 11 highland component. *Proc. 14th Lunar Planet. Sci. Conf. in J. Geophys. Res.* **88**, B103-138.

Tatsumoto M. (1970) Age of the Moon: An isotopic study of U-Th-Pb systematics of Apollo 11 lunar samples - II. *Proc. Apollo 11 Lunar Sci. Conf.* 1595-1612.

Tera F., Eugster O., Burnett D.S. and Wasserburg G.J. (1970) Comparative study of Li, Na, K, Rb, Cs, Sr and Ba abundances in achondrites and in Apollo 11 lunar samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1637-1657.

Wakita H., Schmitt R.A. and Rey P. (1970) Elemental abundances of major, minor, and trace elements in Apollo 11 lunar rocks, soil, and core samples. *Proc. Apollo 11 Lunar Sci. Conf.* 1685-1717.

Wänke H., Rieder R., Baddenhausen H., Spettel B., Teschke F., Quijano-Rico M. and Balacesu A. (1970) Major and trace elements in lunar material. *Proc. Apollo 11 Lunar Sci. Conf.* 1719-1727.

Wänke H., Rlotzka F., Jagoutz E. and Begemann F. (1970) Composition and structure of metallic iron particles in lunar fines. *Proc. Apollo 11 Lunar Sci. Conf.* 931-935.

Wasson J.T. and Baedecker P.A. (1970) Ga, Ge, In, Ir, and Au in lunar terrestrial and meteoritic basalts. *Proc. Apollo 11 Lunar Sci. Conf.* 1741-1750.

Wood J.A., Marvin U.B., Powell B.N. and Dickey J.S. (1970) Mineralogy and petrology of the Apollo 11 lunar sample. Smithson. Astrophysi. Observ. Spec. Rep. 307

Wood J.A., Dickey J.S., Marvin U.B. and Powell B.N. (1970a) Lunar anorthosites. *Science* **167**, 602-604.

Wood J.A., Dickey J.S., Marvin U.B. and Powell B.N. (1970b) Lunar anorthosites and a geophysical model of the Moon. *Proc. Apollo 11 Lunar Sci. Conf.* 965-988.

Wiesmann H. and Hubbard N.J. (1975) A compilation of the Lunar Sample Data Generated by the Gast, Nyquist and Hubbard Lunar Sample PI-Ships. Unpublished. JSC

Wrigley R.C. and Quaide W.L. (1970) Al26 and Na22 in lunar surface materials: Implications for depth distribution studies. *Proc. Apollo 11 Lunar Sci. Conf.* 1751-1755.