10084

DRAFT

Bulk Soil (< 1 mm)
3,830 grams

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

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.

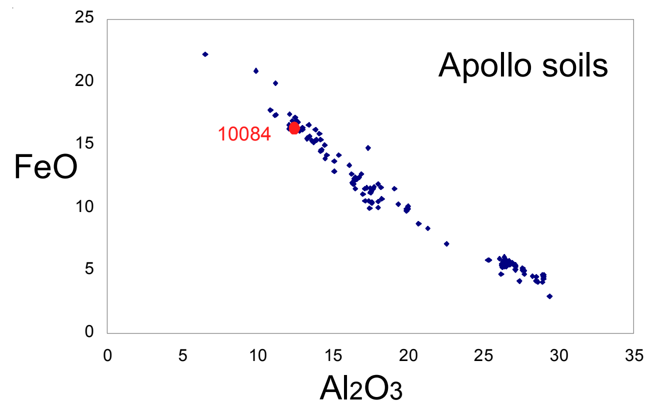


Figure 1: Chemical composition of Apollo soils with 10084 marked.

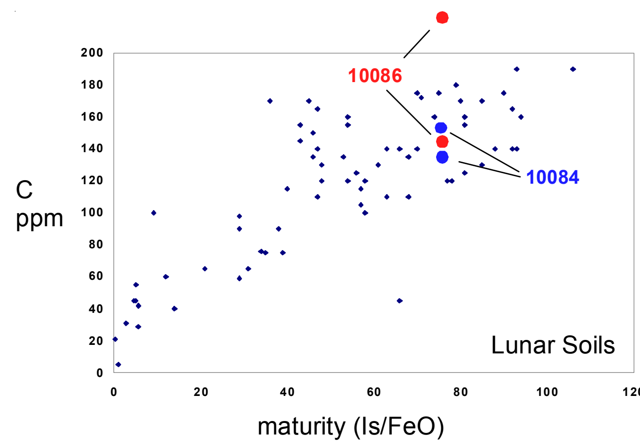


Figure 2: Maturity of Apollo soils determined by magnetic properties (Is/FeO) and carbon content, with samples 10084 and 10086 fines highlighted (data from Morris 1978 , Kaplan et al. 1970 and Moore et al. 1970).

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

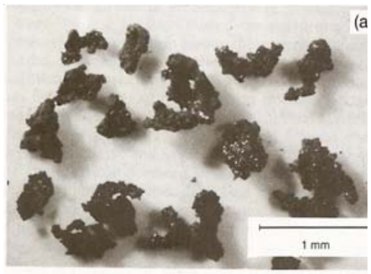


Figure 3: Agglutinate glass particles from soil. NASA S69-54827

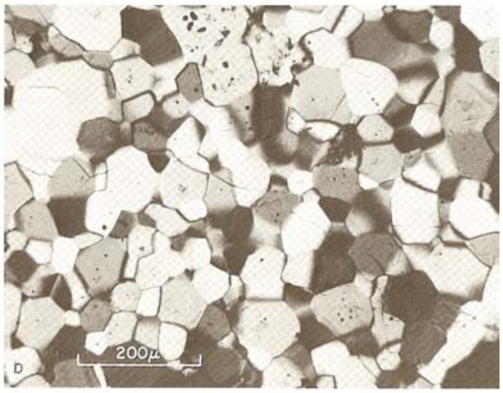


Figure 4: Thin section of lunar anorthosite fragment found in Apollo 11 soil (Wood et al. 1970).

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

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).

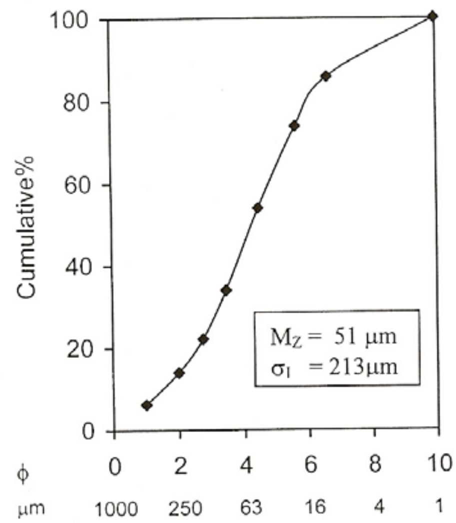


Figure 6: Grain size distribution of 10084 as determined by Basu et al. (2001).

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.

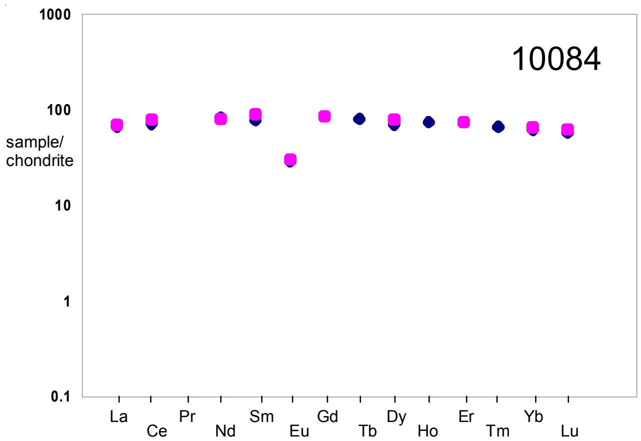


Figure 7: Normalized rare-earth-element diagram for lunar soil 10084 (see table).

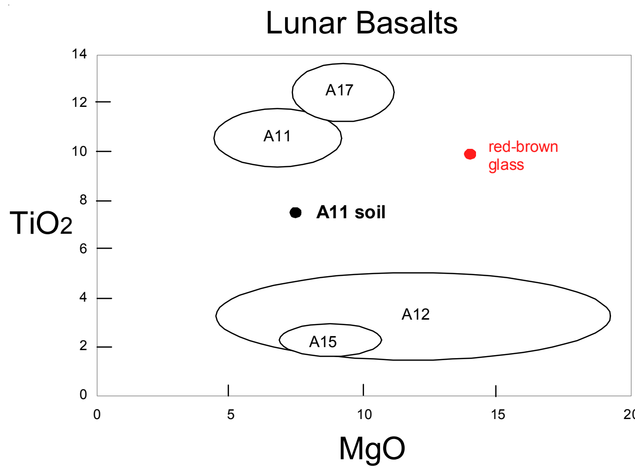


Figure 8: Composition of 10084 within the context of lunar mare basalts. The composition of the red-brown glass is also shown.

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.).

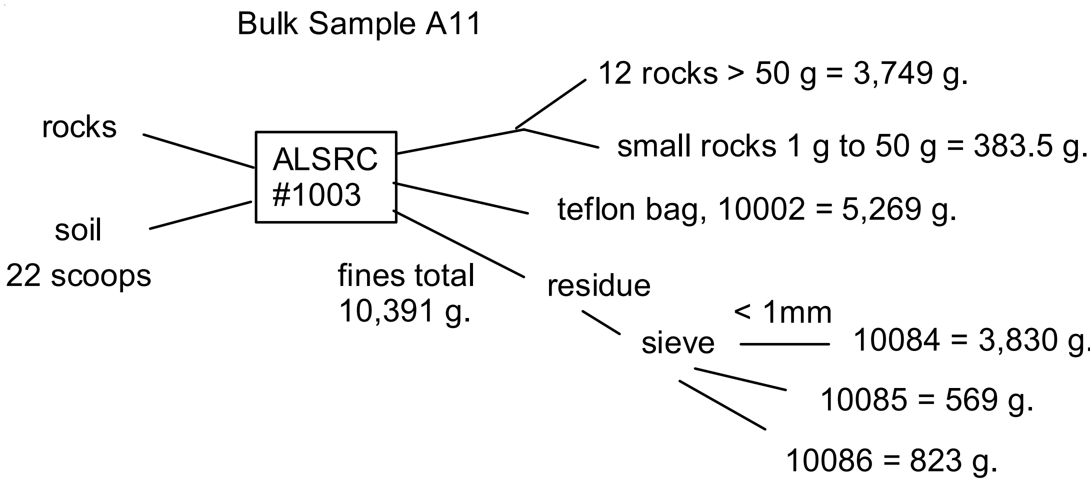
reference	Ganapathy70			Laul71		Wasson70		*Bouchet71*		LSPET73		Annell70		Evensen73			Baedecker74	
weight														coarse	fine			
SiO2 %								*42*	(b)	41.78	(d)							
TiO2								*9*	(b)	7.41	(d)							
Al2O3								*13.8*	(b)	13.47	(d)							
FeO				15.8	(a)			*15.8*	(b)	15.65	(d)						16	(a)
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	
SiO2 %	42	± 0.2	(a)	40.97	(b)
TiO2	7.54	± 0.08	(a)	7.8	(b)
Al2O3	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)
Na2O	0.438	± 0.012	(a)	0.44	(b)
K2O	0.135	± 0.005	(a)	0.13	(b)
P2O5	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



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