63320 – 351 grams
63340 – 181 grams
Shadow Soils

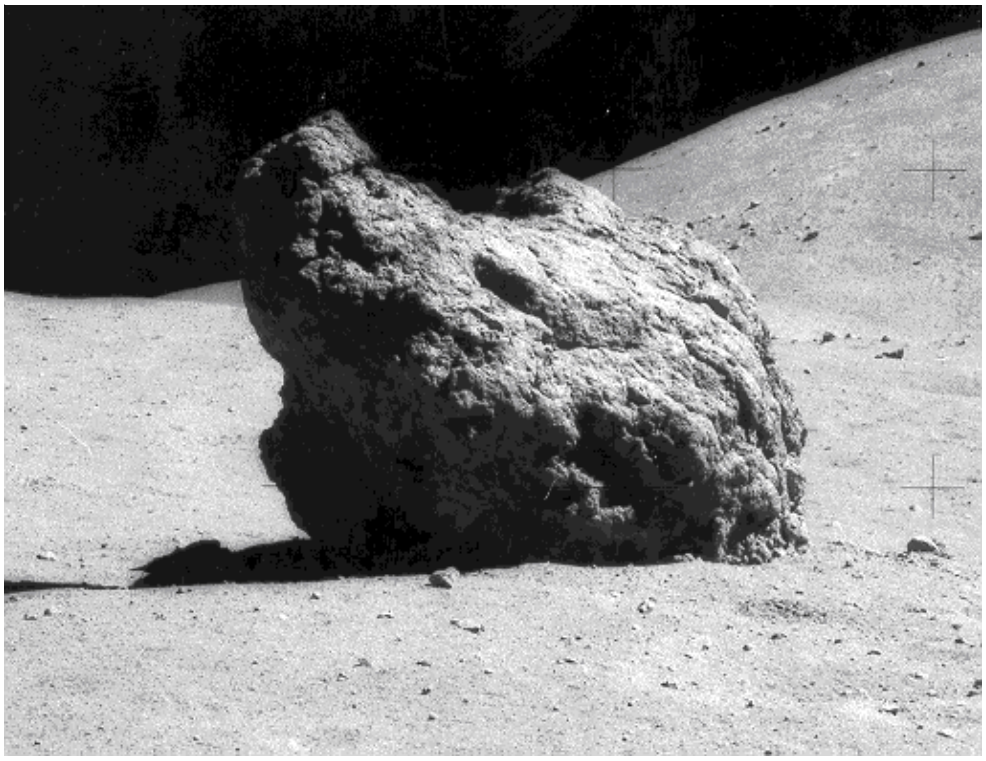


Figure 1: Shadow Rock at Apollo 16. AS16-106-17393. Rock is 5 meters across and 3 meters high (a giant sundial, ofsorts).

Introduction

Apollo 16 soil samples 63320 and 63340 were collected from a "recess" far under the shadow cast by Shadow Rock (figures 1 and 2). However, Ulrich (1981) calculates that sunlight could have reached this area during the movement of the Sun across the sky. 63320 was collected from the surface and 63340 from underneath 63320 (Sutton 1981). A "companion soil" 63501 was collected from the unshaded regolith, 15 m southeast of Shadow Rock.

Shadow Rock is located at the boundary of the Cayley Plains with the slope of Smoky mountain (figure 3). Shadow Rock is about 550 m south of the rim of North Ray Crater and the soils there are estimated to be about 50% young soil derived from North Ray Crater and 50% old soil (they have cosmic ray exposure ages of ~ 270 m.y.)

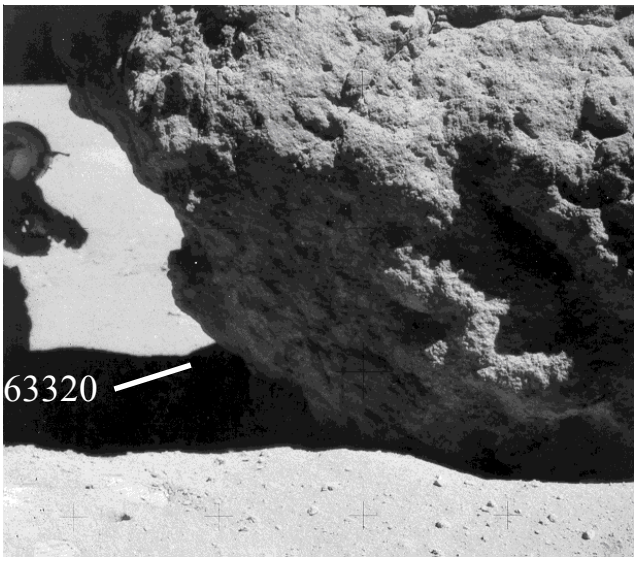


Figure 2: Shaded soil sample 63320 collected from "gopher hole" in shade. 63340 was collected from beneath 63320. AS16-160-17413.

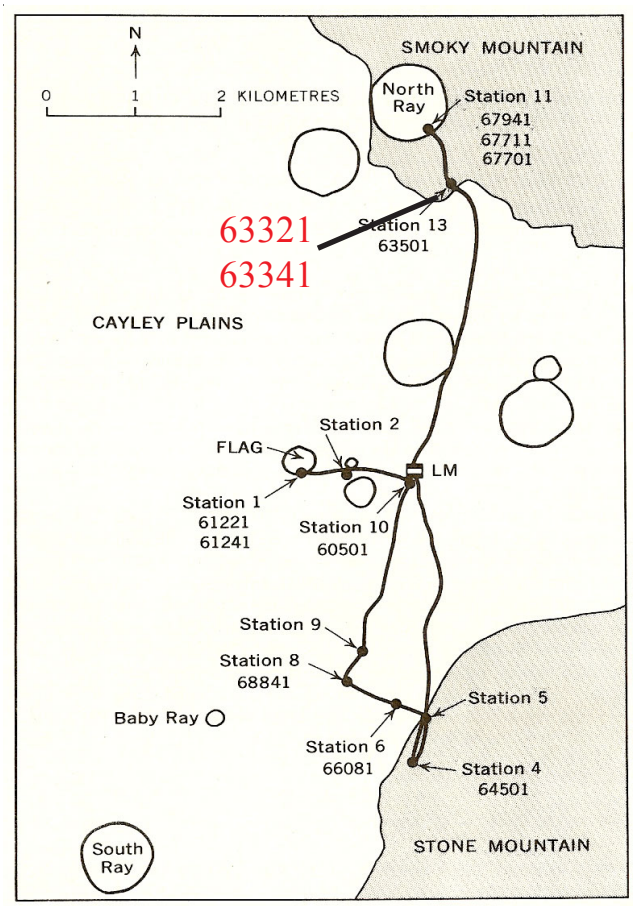


Figure 3: Map of Apollo 16 traverses showing location of station 13.

Eberhardt et al. (1976) found that ^{40}Ar and various volatile elements (In, Tl, Zn, Cd, Br and I) are enriched by about the same amount (~30-40%) in 63321 and 63341 compared with 63501. It is suggested that the shadowed area acted as a cold trap for volatiles in the lunar atmosphere.

Petrography

Horz et al. (1972) write *"a hole more than 1 m deep and approximately 50 cm wide was observed at the south end of Shadow Rock at station 13. Because of the shadowed condition, no precise surface photography is available, but the comments of the crew about the geometry of the "gopher hole" indicate that the soil materials were permanently shielded from the Sun. After the samples were received in the LRL, samples 63320 and 63340 were placed in specially sealed containers."*

63320 and 63340 are submature soils with I_s/FeO values of 47 and 54 respectively (Morris 1978). Companion soil 63501 has I_s/FeO = 46. Average grain

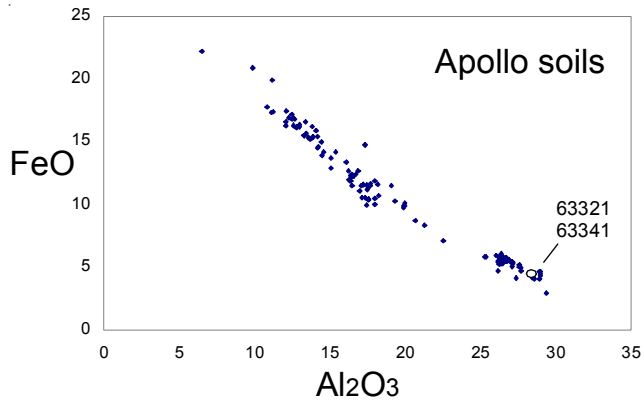


Figure 4: Samples 63321 and 63341 are among the most Al-rich lunar soils.

size is 88 microns for 63321, 80 microns for 63341 and 70 microns for 63501. Heiken et al. (1973) and Houck (1982) determined the mineralogic mode of 63321 and 63341 and compared them with nearby reference soil 63501 (they look similar). Graf (1991) reported the grain size distribution and determined the average grain size to be larger, if you take into account the > 1mm particles (figure 8 a,b).

Marvin (1972) cataloged the 4 – 10 mm coarse fine particles from these soils. Breccia samples 60017, 63335 and 63355 were chipped from Shadow Rock (Butler 1972).

Chemistry

The chemical compositions of the shadowed soils are given in tables 1 and 2 and figure 4 and 6. Eberhardt et al. (1976) compared the volatile element concentrations of 63321, 63341 and 63501 (figure 7).

Evensen et al. (1974) determined the composition of alkalis as a function of grain size. Jovanovic and Reed

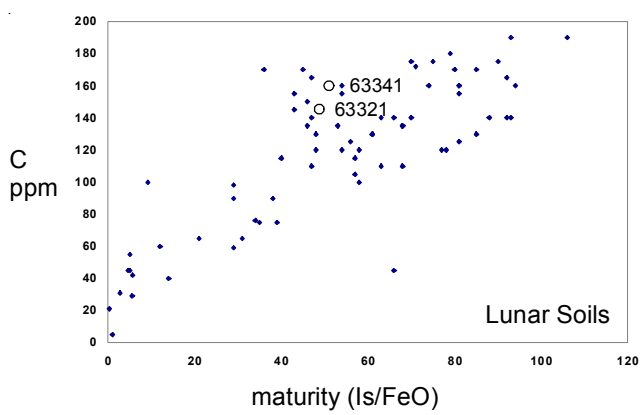


Figure 5: Samples 63321 and 63341 have relatively high carbon content (saturated?).

(1973) determined halogens, Hg, Ru, Os and U for 63321, 63341 and 63501 finding nothing unusual about their concentrations. Wanke et al. (1975) also determined halogens for 63320, finding them low in concentration. Muller (1973) and Kothari and Goel (1973) found nitrogen (~60 ppm) to be similar in all three samples. DesMarias et al. (1973) determined the carbon content (66 ppm) and Gibson and Moore (1973) found about 500 ppm sulfur (no more than elsewhere). The carbon content is relatively high (saturated?) for a submature soil (figure 5).

Cosmogenic isotopes and exposure ages

Eberhardt et al. (1976) determined the average cosmic ray exposure ages of 63321, 63241 and 63501 to be 260 m.y., 290 m.y. and 260 m.y. respectively using ^{78}Kr, ^{124}Xe and ^{126} Xe measurements. Fireman et al. (1973) determined the tritium content (^{3}H) of the shadowed soil 63321 (233 dpm/kg). Eldridge et al. (1976) determined the cosmic-ray-induced activity of ^{22}Na = 25 and 28 dpm/kg., ^{26}Al = 69 and 91 dpm/kg. and ^{54}Mn = 40 and 50 dpm/kg., for 63320 and 63340, respectively.

Imarura et al. (1974) determined the cosmic–ray-induced activity of ^{53}Mn = 359 dpm/kg. The high ^{53}Mn activity could be due to lateral transport of freshly irradiated material under the boulder, or Shadow Rock may have been emplaced in its present location a short time ago (the half-life of ^{53}Mn is 3.7 m.y.).

Other Studies

Kirsten et al. (1973) and Bogard and Nyquist (1973) reported the rare gas composition of shaded soils 63321 and 63341, but didn't find anything unusual with respect to other soils. However, Eberhardt et al. (1976) discovered an enrichment of ^{40}Ar of 38% for 63321 and 28% for 63341 relative to 63501 (figure 6). They

Modal content of soils 63321, 63341 and ref. 63501 (90-150 micron).
From Houck 1982.

	63321	**63341**	63501 (ref.)
Agglutinates	31.4 %	32	40.9
Basalt	-	-	-
Breccia	46.9	43.9	39.9
Anorthosite	0.3	0.7	-
Norite	-	-	-
Gabbro	-	-	-
Plagioclase	12.2	15.7	15.1
Pyroxene	3.6	2	0.3
Olivine	-	0.3	0.7
Ilmenite	-		
Glass other	5.3	5.6	2.6

Modal content of soils 63321, 63341 and ref. 63501 (90-150 micron).
From Heiken et al. 1973.

	63321	**63341**	63501 (ref.)
Agglutinates	32.6 %	40	44.6
Basalt	-	1.7	0.3
Breccia	42.5	35.5	36.3
Anorthosite	11.2	5.9	3
Norite	1.6	0.3	1.3
Gabbro	-	-	-
Plagioclase	9.6	12.6	10.3
Pyroxene	2.6	1.7	2
Olivine	-	-	-
Ilmenite	-		
Glass other	4.6	2	2.2

Imamura et al. (1974) studied 54Mn

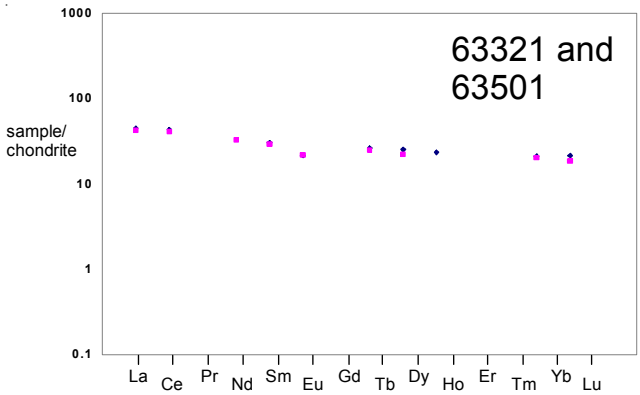


Figure 6: Normalized rare-earth-element diagram for 63321 and reference soil 63501 (data for both from Wanke et al. 1975).

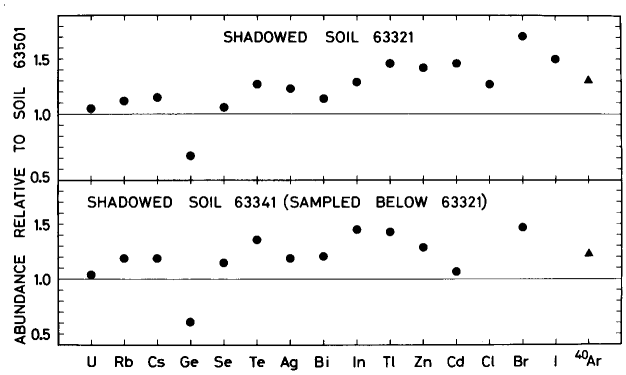
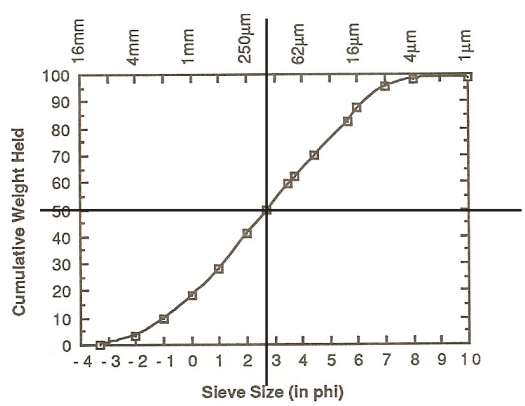


Figure 7: Volatile elements are enrich by about the same factor as 40Ar in the shadowed soils 63320 and 63240 when compared with soil 63501 (from Eberhardt et al. 1976).

found that the geometry of the shadowed area is such that reaccelerated lunar atmosphere ions, such as ^{40}Ar, can reach the soil, whereas the solar wind is effectively shielded.

Holmes et al. (1973) and Gammage and Holmes (1975) studied the influence of water vapor and liquid water on various adsorption isotherms for 63341 (figure 8). Cadenhead et al. (1977) found the surface area of 63221 and 63241 to be as expected for samples of that maturity.



average grain size = 148 microns

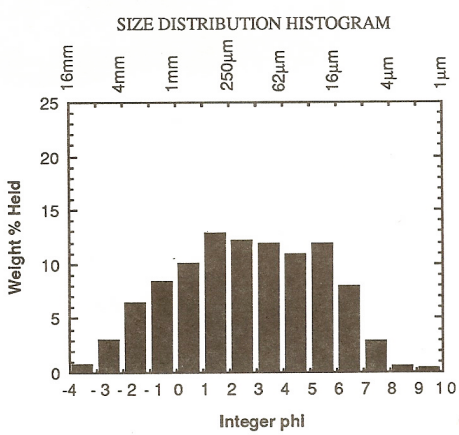
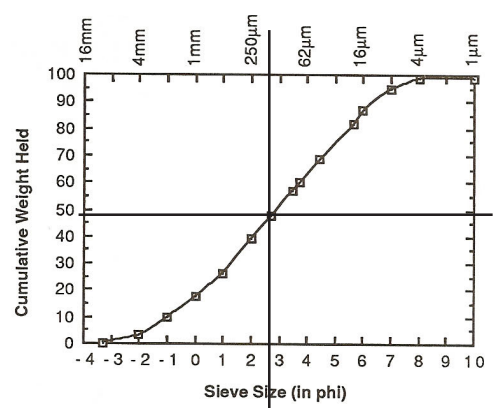


Figure 8a: Grain size analysis of 63320 (Grafe 1991, from data by McKay et al.).



average grain size = 140 microns

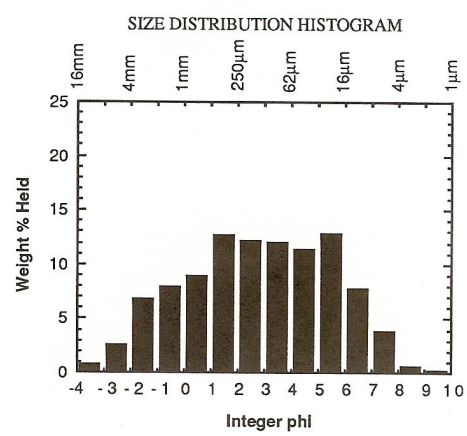


Figure 8b: Grain size distribution for 63340 (Graf 1991, data from McKay).

Table 3	U ppm	Th ppm	K ppm	technique
Eldridge et al. 1975				
63321	0.39	1.35	800	radiation
63341	0.4	1.33	790	counting
63501	0.41	1.53	728	

Processing

Sad to say, these shadowed soils were not returned in a sealed container. They were only protected from humid spacecraft cabin air and Pacific atmosphere by the Teflon bags that they were collected in, surrounded by layers of porous beta cloth (Teflon-coated, woven, fiberglass). They would have experienced several cycles of depressurization – repressurization in the LM, one in the CM. They were sealed in Pacific air during transfer to the LRL. Finally they were exposed to the residual moisture of the "dry" N_2 glove boxes during preliminary examination.

However, only small portions of 63320 and 63340 were sieved and large portions have apparently been kept in the original Teflon collection bags (DB). In 1979, portions were split off to go into remote storage, again temporarily exposing the sample to "dry" N_2 cabinet air in the new curation facility (N_2 cabinet air has variously 10-50 ppm H_2O).

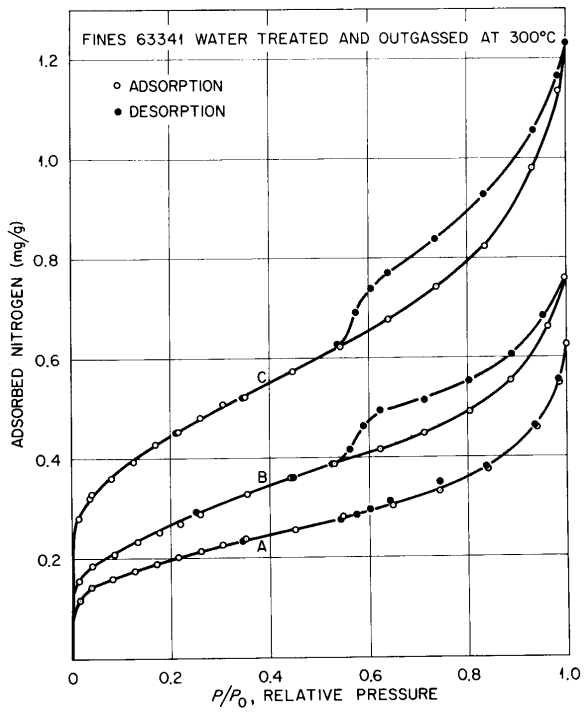
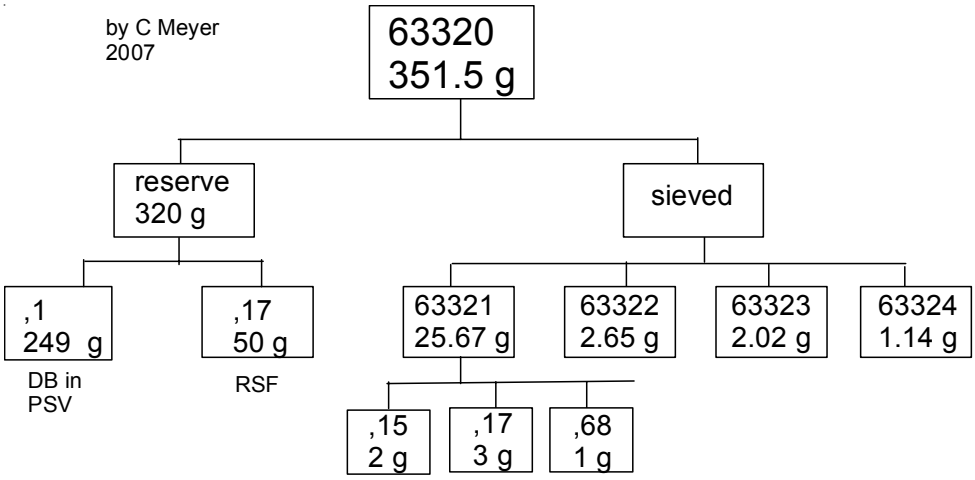


Figure 9: Adsorption isotherms of N2 for fines from 63341 (Gammage and Holmes 1975).



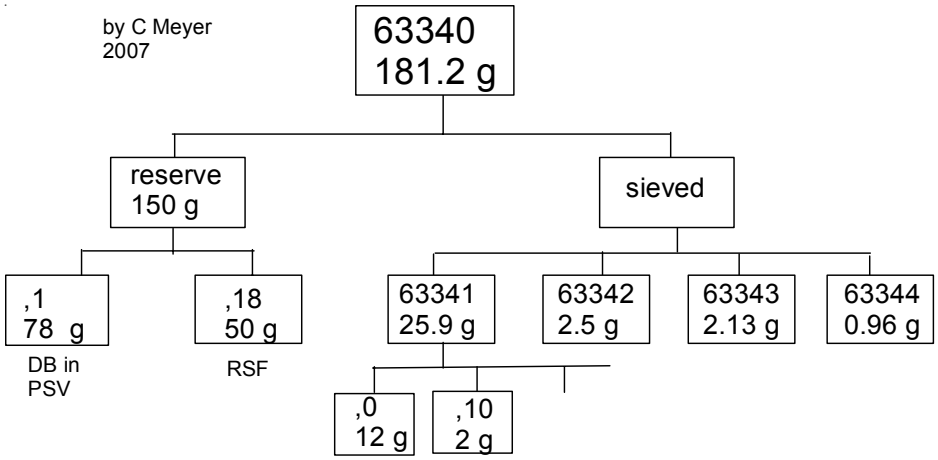


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Table 1. Chemical composition of 63321.

reference	Brunfeldt73		Philpotts73		Krahenbuhl73		Boynton76			Evensen73		Muller75		Nyquist76		Wanke75	
weight	63321						63320										
SiO2 %																44.93	
TiO2	0.35	(a)					0.65	0.58	(a)							0.53	
Al2O3	28.9	(a)					28.1	25.2	(a)			26.5	(d)			27.6	
FeO	4.7	(a)					4.76	4.63	(a)			4.8	(d)			4.73	
MnO	0.068	(a)					0.065	0.067	(a)							0.063	
MgO	6.93	(a)					5.8	5.97	(a)			5.7	(d)			5.29	
CaO	15.67	(a)					15.4	16.5	(a)			16.23	(d)			15.7	
Na2O	0.57	(a)					0.49	0.52	(a)			0.58	(d)			0.53	
K2O	0.077	(a)	0.096	(c)						0.11	(c)	0.106	(e)			0.1	
P2O5																0.09	(f)
S %																0.05	(f)
sum																	
Sc ppm	8.03	(a)					8.2	8.5	(a)							8.53	(a)
V	46	(a)					15	21	(a)								
Cr	642	(a)					660	666	(a)								
Co	23.5	(a)					19.7	19.8	(a)							22.5	(a)
Ni	311	(a)					244	250	(a)							330	(a)
Cu	9.3	(a)															
Zn	23	(a)			17	(b)	16.4	17	(b)								
Ga	5.5	(a)					5	5.6	(b)								
Ge ppb					404	(b)	510	540	(b)								
As																	
Se					199	(b)											
Rb	2.3	(a)	2.18	(c)	1.8	(b)				2.29	(c)	2.2	(e)	1.72	(c)		
Sr	170	(a)	179	(c)						181	(c)	172	(e)	191	(c)	198	(a)
Y																	
Zr																	
Nb																	
Mo																	
Ru								16	(b)								
Rh																	
Pd ppb																	
Ag ppb					7.9	(b)											
Cd ppb					78	(b)	102	93	(b)								
In ppb	40	(a)					9.6	10.5	(b)								
Sn ppb																	
Sb ppb					1.23	(b)											
Te ppb					17.3	(b)											
Cs ppm	0.2	(a)			0.083	(b)						0.1	(e)			0.1	(a)
Ba	147	(a)					120	130	(a)	116	(c)	113	(e)			115	(a)
La	10.8	(a)					10.6	9.3	(a)			9	(e)			10.5	(a)
Ce	24.8	(a)					26	24	(a)							26.2	(a)
Pr																	
Nd																	
Sm	4.56	(a)					4.6	4.1	(a)							4.49	(a)
Eu	1.35	(a)					1.15	1.21	(a)							1.21	(a)
Gd																	
Tb	0.88	(a)					1	0.78	(a)							0.96	(a)
Dy	4.88	(a)					5.4	5.9	(a)							6.12	(a)
Ho	1.4	(a)														1.3	(a)
Er																	
Tm																	
Yb	3.98	(a)					3.3	3.1	(a)							3.4	(a)
Lu	0.56	(a)					0.44	0.45	(a)							0.52	(a)
Hf	4.8	(a)					2.8	3.3	(a)							3.95	(a)
Ta	0.54	(a)					0.4	0.5	(a)							0.44	(a)
W ppb																	
Re ppb					0.669	(b)											
Os ppb																	
Ir ppb					8.29	(b)	6.5	5	(b)							10	
Pt ppb																	
Au ppb					8.6	(b)	4.4	3.8	(b)					Silver73			
Th ppm	1.2	(a)					1.6	1.3	(a)					1.726	(c)	1.35	(a)
U ppm	0.5	(a)			0.401	(b)	0.55	0.44	(a)			0.59	(e)	0.477	(c)		

technique: (a) INAA, (b) RNAA, (c) IDMS, (d) AA, (e) NA, (f) XRF

Table 1b. Chemical composition of 63321.

reference	Korotev81			Eldridge75	
weight	C	F			
SiO2 %					
TiO2					
Al2O3					
FeO	4.84	4.72	(a)		
MnO					
MgO					
CaO					
Na2O	0.56	0.53	(a)		
K2O				0.096	(b)
P2O5					
S %					
sum					
Sc ppm	8.4	7.9	(a)		
V					
Cr	685	780	(a)		
Co	20	17.6	(a)		
Ni	270	295	(a)		
Cu					
Zn					
Ga					
Ge ppb					
As					
Se					
Rb					
Sr					
Y					
Zr					
Nb					
Mo					
Ru					
Rh					
Pd ppb					
Ag ppb					
Cd ppb					
In ppb					
Sn ppb					
Sb ppb					
Te ppb					
Cs ppm					
Ba					
La	10.2	10	(a)		
Ce	26.5	27.5	(a)		
Pr					
Nd					
Sm	4.6	4.7	(a)		
Eu	1.25	1.22	(a)		
Gd					
Tb	1.05	0.99	(a)		
Dy					
Ho					
Er					
Tm					
Yb	3.5	3.25	(a)		
Lu	0.48	0.46	(a)		
Hf	3.3	3.2	(a)		
Ta	0.4	0.5	(a)		
W ppb					
Re ppb					
Os ppb					
Ir ppb					
Pt ppb					
Au ppb					
Th ppm	1.6	1.8	(a)	1.35	(b)
U ppm				0.39	(b)

technique: (a) INAA, (b) radiation count.

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Table 2. Chemical composition of 63340.

reference	Brunfeldt73		Philpotts73		Korotev81	Krahenbuhl73		Evensen73		Silver73		Eldridge75	
weight	63341				unpublished								
SiO2 %													
TiO2	0.6	(a)											
Al2O3	29	(a)											
FeO	4.53	(a)											
MnO	0.067	(a)											
MgO	7.3	(a)											
CaO	12.45	(a)											
Na2O	0.57	(a)											
K2O	0.147	(a)	0.107	(c)				0.097	(c)			0.095	(d)
P2O5													
S %													
sum													
Sc ppm	7.95	(a)											
V	34	(a)											
Cr	650	(a)											
Co	19.5	(a)											
Ni	345	(a)											
Cu	8.3	(a)											
Zn	17	(a)				15.5	(b)						
Ga	5.2	(a)											
Ge ppb						400	(b)						
As													
Se						216	(b)						
Rb	1.7	(a)	2.49	(c)		1.9	(b)	2.05	(c)				
Sr	140	(a)	181	(c)				180	(c)				
Y													
Zr													
Nb													
Mo													
Ru													
Rh													
Pd ppb													
Ag ppb						7.6	(b)						
Cd ppb						57.5	(b)						
In ppb	45	(a)											
Sn ppb													
Sb ppb						1.23	(b)						
Te ppb						18.5	(b)						
Cs ppm	0.05	(a)				0.086	(b)						
Ba	92	(a)						97.5	(c)				
La	11.2	(a)											
Ce	25.2	(a)											
Pr													
Nd													
Sm	4.45	(a)											
Eu	1.42	(a)											
Gd													
Tb	0.93	(a)											
Dy	6.18	(a)											
Ho	1.5	(a)											
Er													
Tm													
Yb	3.87	(a)											
Lu	0.56	(a)											
Hf	3.5	(a)											
Ta	0.45	(a)											
W ppb													
Re ppb						0.741	(b)						
Os ppb													
Ir ppb						11.1	(b)						
Pt ppb													
Au ppb						7.08	(b)						
Th ppm	1	(a)								1.8	(c)	1.33	(d)
U ppm	0.4	(a)				0.398	(b)			0.617	(c)	0.4	(d)

technique: (a) INAA, (b) RNAA, (c) IDMS, (d) radiation cout.

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