

15016

Vesicular Olivine Basalt

923.7 grams

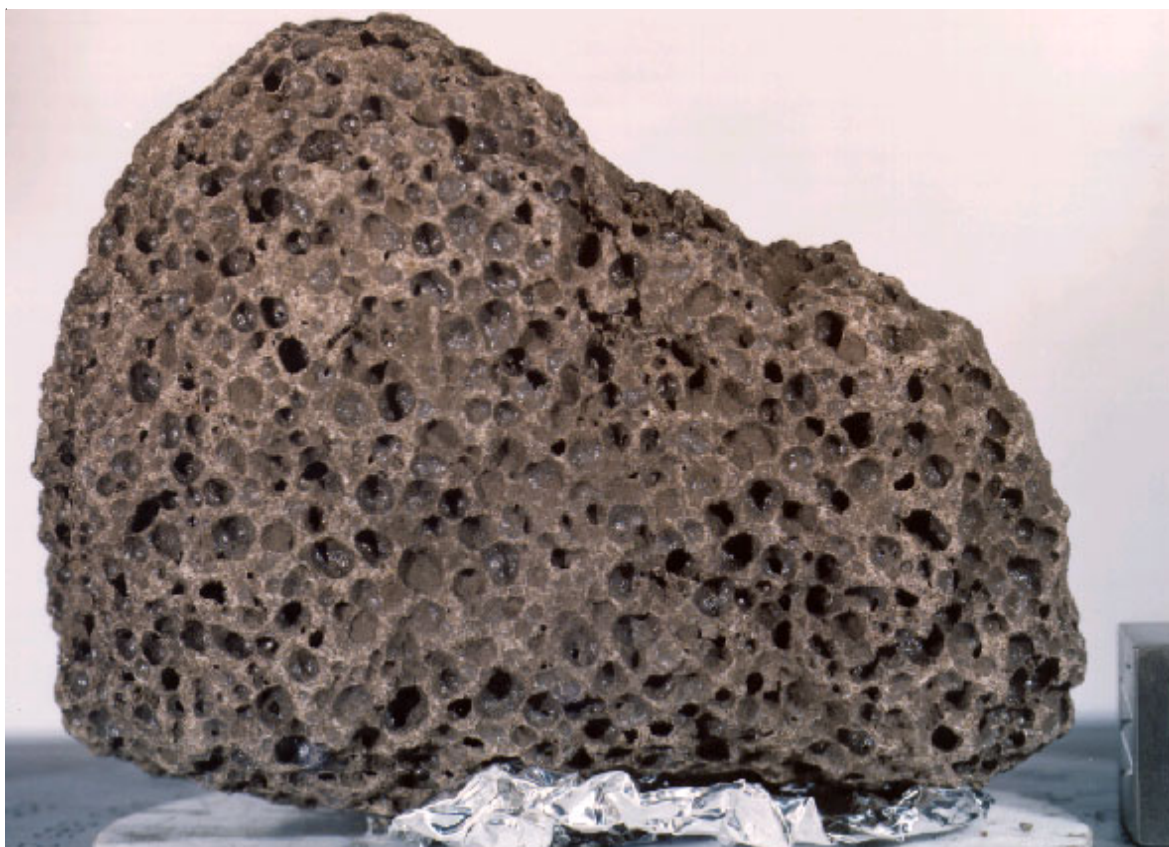


Figure 1: Photograph of vesicular basalt 15016. NASA# S71-46632. Cube is 1 inch.

Introduction

Lunar Sample 15016 is a highly vesicular, olivine-normative, basalt with a major element composition similar to that of non-vesicular basalt 15555 (figure 1). These basalts are typical of many of the basalt samples returned from the Apollo 15, Hadley Rille site, and their composition has been studied experimentally to conclude that this volcanic magma came from a depth of greater than 250 km.

Petrography

Lunar sample 15016 is a medium-grained basalt with subhedral phenocrysts of zoned pyroxene (1-2 mm) and olivine (~1 mm) set in a matrix of subophitic intergrowths of pyroxene and plagioclase (figure 2). Vesicles (1 to 5 mm) make up about 50 % of the volume. Opaque minerals (ilmenite and ulvöspinel) frequently border the vesicles. Plagioclase platelets are sometimes hollow, with pyroxene cores. Subrounded grains of

Cr-spinel are found in the pyroxene and olivine phenocrysts. Troilite and Fe-Ni metal are found in the mesostasis.

Experiments show that the paragenetic sequence is Cr-spinel (above 1300 C), olivine (1280 C), pyroxene (1170 C) and plagioclase (below 1150 C) matching the texture of the thin sections. Brown et al. (1972) found both low-K and high-K glass in the mesostasis, and speculate on Na loss during vesiculation. The interior walls of the vesicles have been studied by Goldberg et al. (1976).

Mineralogy

Olivine: Olivine ranges in composition Fo₇₀₋₁₀ (Bence and Papike 1972).

Pyroxene: Pyroxene analyses are given in Bence and Papike (1972), Papike et al. (1976), and Kushiro (1973)

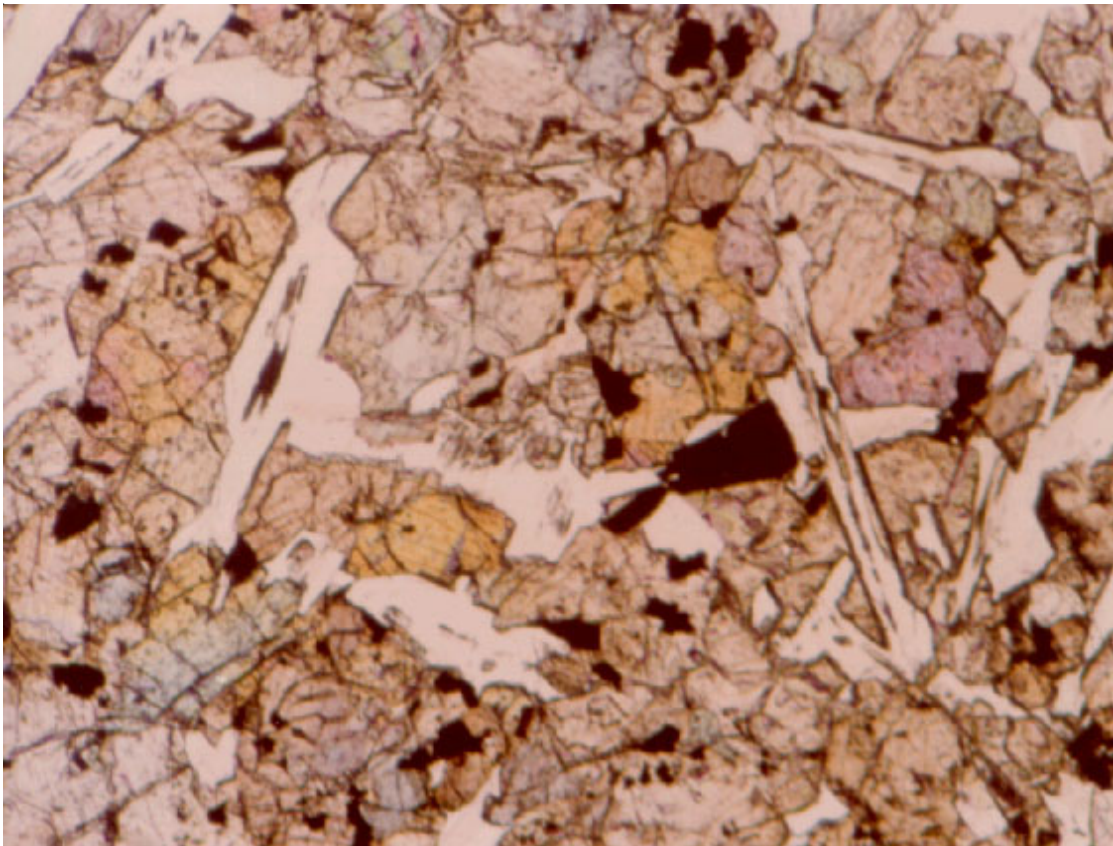


Figure 2: Photomicrograph of thin section 15016,146 in partially-crossed nicols. Field of view is 2.5 mm. NASA# S79-26733. (out of focus)

(figure 3). Large pyroxene grains are highly zoned first towards Ca-rich, then Fe-rich, indicating rapid crystallization.

Plagioclase: Plagioclase ranges An₉₄₋₈₀ (Bence and Papike 1972). Brown et al. (1972) found reverse zoning indicating volatile loss.

Ilmenite: Ilmenite was studied by Engelhardt (1979).

Silica: Brown et al. (1972) finds that residual silica is cristobalite.

Chemistry

Although the major element composition of 15016 is very similar to that of 15555, the trace element composition is higher (figure 5). Cr may also be higher in 15016 than 15555.

Barker (1974) and Gibson et al. (1975) studied the gas (CO, CO₂ etc.) released by heating or mechanically crushing the sample.

Radiogenic age dating

Murthy et al. (1973) and Evensen et al. (1973) determined the age of 15016 as 3.29 ± 0.05 b.y. by the

Mineralogical Mode for 15016

	Brown et al. 1972	Papike et al. 1976	McGee et al. 1977
Olivine	6-10 vol. %	7.5	7-8
Pyroxene	59-63	63.9	64-67
Plagioclase	21-27	22.2	20-22
Opaques	4-7	5.9	
Ilmenite			6
Chromite			0.1
Ulvöspinel			0.4
Mesostasis			0.3
Silica	1-2	0.2	

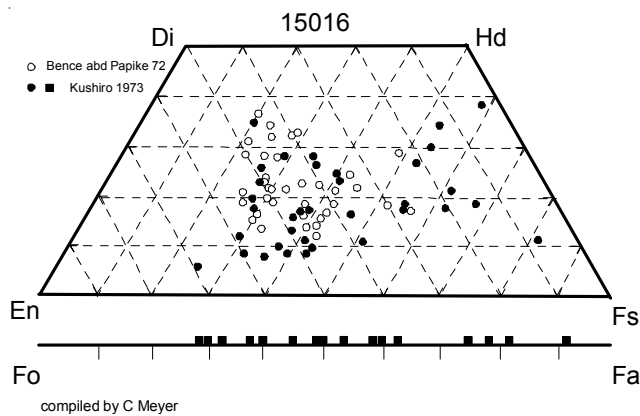


Figure 3: Pyroxene and olivine composition of 15016, showing extreme Fe-enrichment (data from Bence and Papike 1972 and Kushiro 1973).

Rb-Sr method (figure 6). Both the age and the initial Sr isotopic ratio ($^{87}\text{Sr}/^{86}\text{Sr} = 0.69914 \pm 0.00005$) are similar to that of 15555 measured in the same lab. Kirsten et al. (1973) determined a plateau age of 3.38 ± 0.08 b.y.

Cosmogenic isotopes and exposure ages

O'Kelley et al. (1972) and Eldridge et al. (1972) determined the ^{26}Al , ^{22}Na , ^{46}Sc , ^{48}V , ^{54}Mn and ^{56}Co activity by whole rock radiation counting. Aluminum 26 is saturated.

Kirsten et al. (1973) determined a ^{38}Ar exposure age of 285 m.y. Husain (1974) determined 315 m.y.

Other Studies

15016 and 15555 are among the more magnesian of the Apollo 15 basalts (figure 4). Phase diagrams have been prepared from the experimental studies of Humphries et al. (1972), Kushiro (1972) (figure 7) and Kesson (1975, 1977). These liquids are multi-saturated at ~ 12 kbar and 1350 deg C, indicating that the basaltic liquid may have come from an olivine-pyroxenite at greater than 250 km depth in the moon.

Gose et al. (1972) and Pearce et al. (1973) studied the magnetic remanence of chips of 15016. Cisowski et al. (1975) gives a low field estimate for magnetization.

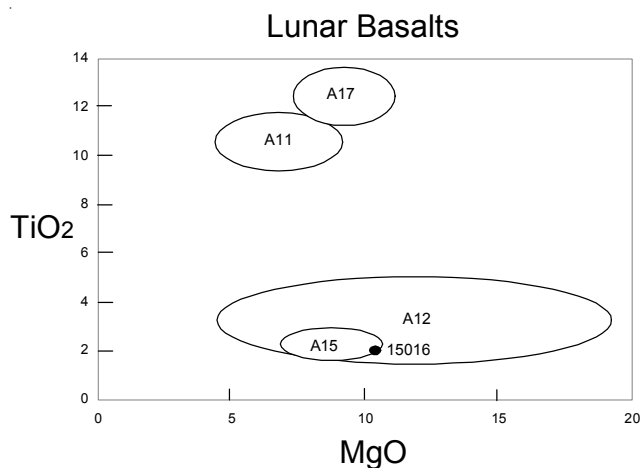


Figure 4: Composition diagram for lunar basalts.

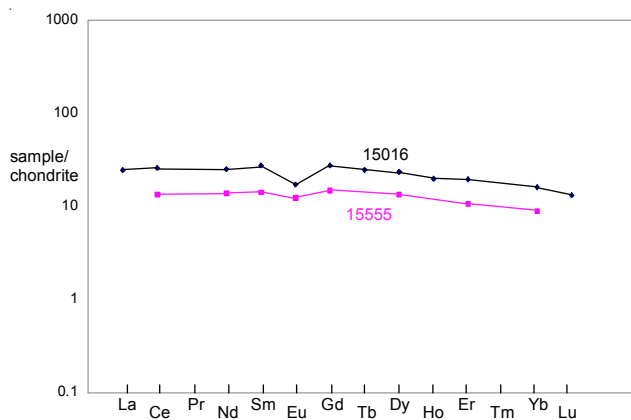


Figure 5: Normalized rare-earth-element diagram for 15016 (Helmke et al. 1973), with 15555 for comparison.

Charette and Adams (1975) found the reflectance spectra was similar to that of 15555.

Processing

Pieces of 15016 are used for public display. There are 21 thin sections.

Summary of Age Data for 15016

	Ar/Ar	Rb/Sr	Pb/Pb
Evensen et al. 1973		3.29 ± 0.05 b.y.	
Kirsten et al. 1973	3.38 ± 0.08		
Husain 1974	no plateau		
Anderson and Hinthorne 1973			3.75 ± 0.27 (ion probe, phosphate)

Caution: Decay constants are old.

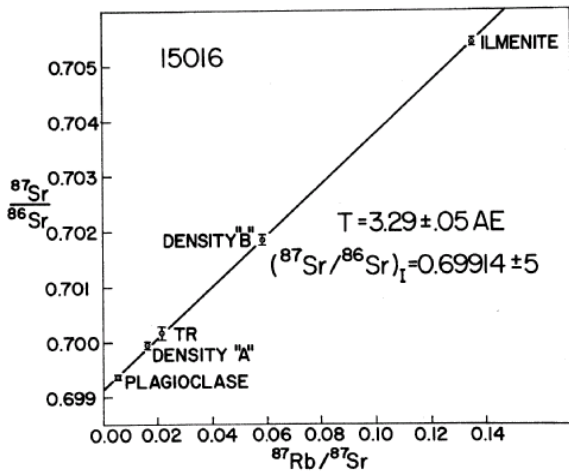


Figure 6: Rb/Sr isochron diagram for 15016 (from Evensen et al. 1973).

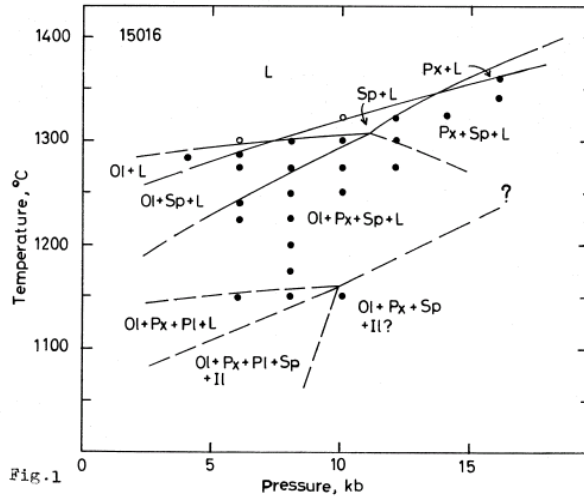


Fig. 1

Figure 7: High-pressure phase diagram for 15016 (from Kushiro 1972).

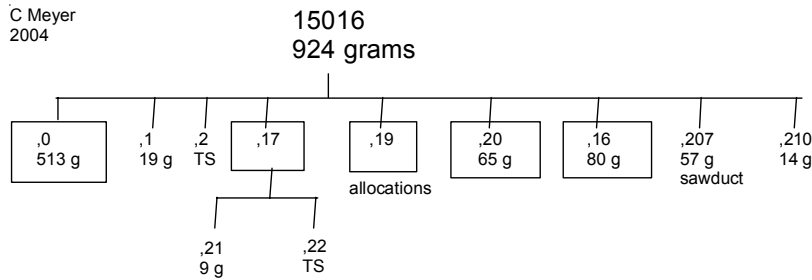


Photo #s of 15016

- | | |
|-----------------|-------|
| S71-45477-45481 | color |
| S71-46630-46635 | color |
| S71-46962-46993 | B&W |
| S71-52221 | TS |
| S71-58683 | group |

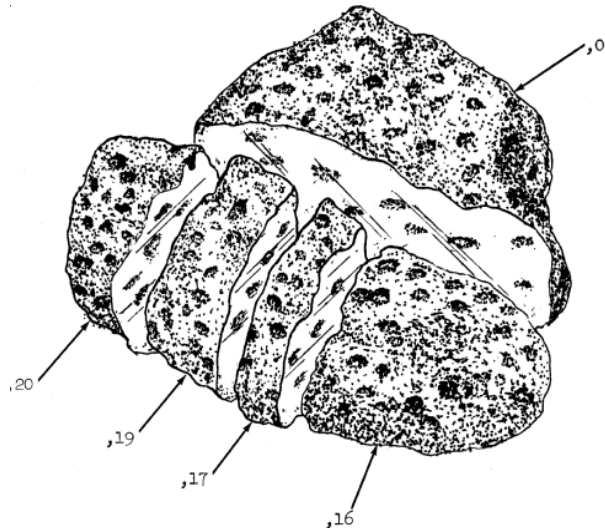


Figure 8: Cutting diagram for 15016 (top).

Table 1a. Chemical composition of 15016.

reference weight	A15PET Rhodes 73	Kushiro 72	Cuttitta 73 Christian 72	Laul 73 365 mg	Muller 75	Taylor 73	Janghorbani 73	Baedecker 73 replica
SiO ₂ %	43.97	(a) 43.78	(b) 44.3	(b)			43.86	
TiO ₂	2.31	(a) 2.28	(b) 2.27		2.1 (c)	1.77	(d) 3	
Al ₂ O ₃	8.43	(a) 8.17	(b) 8.39		8.8 (c)		8.31	
FeO	22.58	(a) 22.5	(b) 22.95		21.8 (c)	16.53	(d) 21.84	
MnO	0.33	(a) 0.33	(b) 0.29		0.26 (c)		0.27	
MgO	11.14	(a) 11.58	(b) 11.65		11 (c) 11.12		11.44	
CaO	9.4	(a) 9.06	(b) 9.2		9 (c) 10.73	10.93	(d)	
Na ₂ O	0.21	(a) 0.24	(b) 0.32		0.251 (c) 0.25	0.32	(d)	
K ₂ O	0.03	(a) 0.04	(b) 0.05		0.041 (c) 0.041			
P ₂ O ₅	0.07	(a) 0.25	(b) 0.06					
S %	0.07	(a) 0.19	(b)					
sum								
Sc ppm			32	36	(c)	25	(d)	
V			200	250	(c)	140	(d)	
Cr		7526	(b) 4516	5866	(c)	4100	(d)	
Co			65	53	(c)	56	(d)	
Ni			86			74	(d)	85 (e)
Cu			0.11			10	(d)	
Zn								1.8 (e)
Ga			4.6					3.6 (e)
Ge ppb								28 (e)
As								
Se								
Rb					1	0.83	(d)	
Sr	83	(a)	80		90			
Y			21			26	(d)	
Zr	95	(a)	69	150	(c)	94	(d)	
Nb			<10			6.2	(d)	
Mo								
Ru								
Rh								
Pd ppb								
Ag ppb								
Cd ppb								2 (e)
In ppb								0.36 (e)
Sn ppb						190	(d)	
Sb ppb								
Te ppb								
Cs ppm					0.04			
Ba			30	70	(c) 53	61	(d)	
La			<10	5.5	(c) 5.2	5.3	(d)	
Ce						14.4	(d)	
Pr						2	(d)	
Nd						9.6	(d)	
Sm				3.6	(c)	3.42	(d)	
Eu				0.8	(c)	0.87	(d)	
Gd						4.5	(d)	
Tb				0.59	(c)	0.73	(d)	
Dy						4.55	(d)	
Ho						1.1	(d)	
Er						2.86	(d)	
Tm						0.4	(d)	
Yb			4.2	2.2	(c)	2.42	(d)	
Lu				0.35	(c)	0.38	(d)	
Hf				2.5	(c)	2.04	(d)	
Ta				0.4	(c)			
W ppb								
Re ppb								
Os ppb								
Ir ppb								0.12 (e)
Pt ppb								
Au ppb								0.27 (e)
Th ppm						0.5	(d)	
U ppm					0.15	0.12	(d)	

technique (a) XRF, (b) conventional, (c) INAA, (d) SSMS, (e) RNAA

Table 1b. Chemical composition of 15016.

reference weight	Chappell 73	Helmke 73 1.04 g	Wolf 79	Garg 76	O'Kelly 72 923 grams	Evensen 73	Compston 72	Gibson 75			
SiO ₂ %	44.26	(f)									
TiO ₂	2.29	(f)									
Al ₂ O ₃	8.52	(f)									
FeO	22.93	(f)									
MnO	0.31	(f)									
MgO	10.84	(f)									
CaO	9.43	(f)									
Na ₂ O	0.32	(f)									
K ₂ O	0.05	(f)			0.045	(l)	0.0405	(j)			
P ₂ O ₅	0.08	(f)									
S %	0.04							0.086			
sum											
Sc ppm		39.1	(g)								
V											
Cr	5500	(f)	6400	(g)							
Co			54	(g)							
Ni				68	(h)						
Cu											
Zn			<4	1.05	(h)						
Ga	2.7	(f)	3.2	(g)							
Ge ppb				4.38	(h)						
As											
Se				0.114	(h)						
Rb	0.65	(f)		0.879	(h)	0.67	(j)	0.73	0.81	0.65	(j)
Sr	93.3	(f)				90.7	(j)	89.7	91.4	93.3	(j)
Y	23	(f)									
Zr	86	(f)			94.7	(h)					
Nb	7	(f)									
Mo											
Ru											
Rh											
Pd ppb											
Ag ppb				0.84	(h)						
Cd ppb				2.05	(h)						
In ppb				0.34	(h)						
Sn ppb				<60	(h)						
Sb ppb				3.8	(h)						
Te ppb				2.4	(h)						
Cs ppm		0.029	(g)	0.0335	(h)						
Ba											
La		5.77	(g)								
Ce		15.6	(g)								
Pr											
Nd		11.4	(g)								
Sm		4.05	(g)								
Eu		0.97	(g)								
Gd		5.4	(g)								
Tb		0.9	(g)								
Dy		5.74	(g)								
Ho		1.1	(g)								
Er		3.1	(g)								
Tm											
Yb		2.62	(g)								
Lu		0.321	(g)								
Hf		2.6	(g)		2.53	(h)					
Ta											
W ppb											
Re ppb				0.033	(h)						
Os ppb				<0.01	(h)						
Ir ppb				0.018	(h)						
Pt ppb											
Au ppb				0.025	(h)						
Th ppm						0.52	(l)				
U ppm			0.16	(h)		0.15	(l)				

technique (f) XRF (g) INAA, (h) RNAA, (l) radiation counting, (j) IDMS

Table 1c. Chemical composition of 15016.

reference	Ryder 2001			
weight	5 g			
SiO ₂ %	44.6	(a)		
TiO ₂	2.24	(a)		
Al ₂ O ₃	8.54	(a)		
FeO	21.74	(a)	21.8	(b)
MnO	0.28	(a)		
MgO	11.22	(a)		
CaO	9.37	(a)		
Na ₂ O	0.222	(a)	0.244	(b)
K ₂ O	0.043	(a)		
P ₂ O ₅	0.068	(a)		
S %				
sum				
Sc ppm			40.7	(b)
V				
Cr	6000	(a)	5840	(b)
Co			54.6	(b)
Ni	72	(a)	66	(b)
Cu	9	(a)		
Zn				
Ga				
Ge ppb				
As				
Se				
Rb	2	(a)		
Sr	90	(a)	100	(b)
Y	26	(a)		
Zr	85	(a)		
Nb	9	(a)		
Mo				
Ru				
Rh				
Pd ppb				
Ag ppb				
Cd ppb				
In ppb				
Sn ppb				
Sb ppb				
Te ppb				
Cs ppm				
Ba			57	(b)
La			5.22	(b)
Ce			15.2	(b)
Pr				
Nd			8	(b)
Sm			3.67	(b)
Eu			0.82	(b)
Gd				
Tb			0.82	(b)
Dy				
Ho				
Er				
Tm				
Yb			2.18	(b)
Lu			0.31	(b)
Hf			2.49	(b)
Ta			0.37	(b)
W ppb				
Re ppb				
Os ppb				
Ir ppb				
Pt ppb				
Au ppb				
Th ppm			0.41	(b)
U ppm				
technique	(a) XRF, (b) INAA			