15535 and 15536

Olivine-normative Basalt

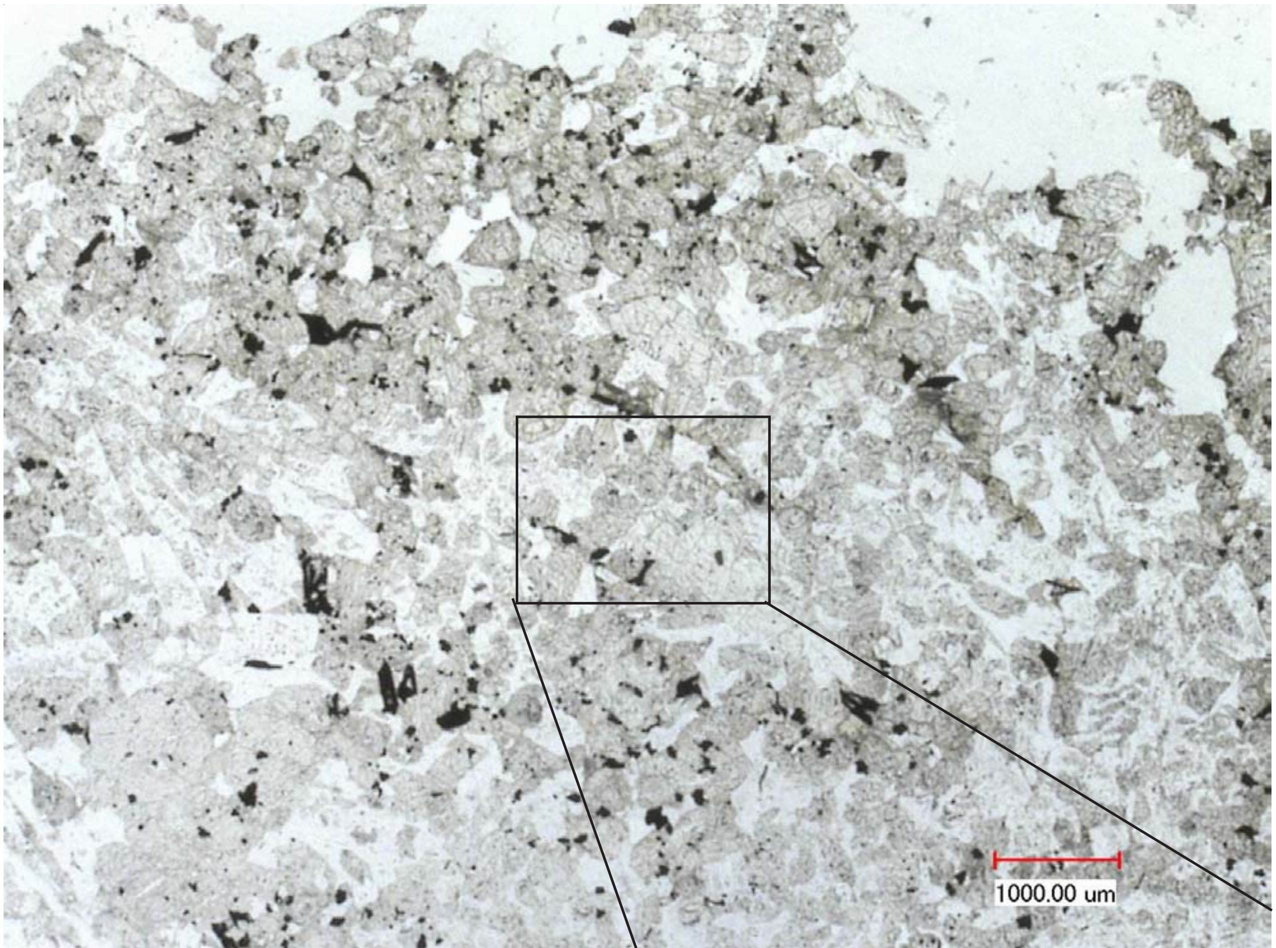
404.4 and 317.2 grams

Figure 1: Exterior surface of 15535 (known as the Bear). NASA S71-47029. Cube is 1 inch for scale. Note zap pits.

Figure 2: Photo of freshly broken surface of 15536. Sample is 9 cm across. NASA S71-47357.

Introduction

Lunar samples 15535 and 15536 were chipped from a small boulder (0.75 m) that was about 20 meters from the edge of Hadley Rille in an area called The Terrace (figure 4). The lunar regolith was thin in this area, with abundant rock samples (basalts) exposed (Swann et al. 1971). A small crater was nearby and these samples are about as close to "bedrock" as can be on the Moon. Distinct lava flows could be seen on the wall of the rille opposite this location.



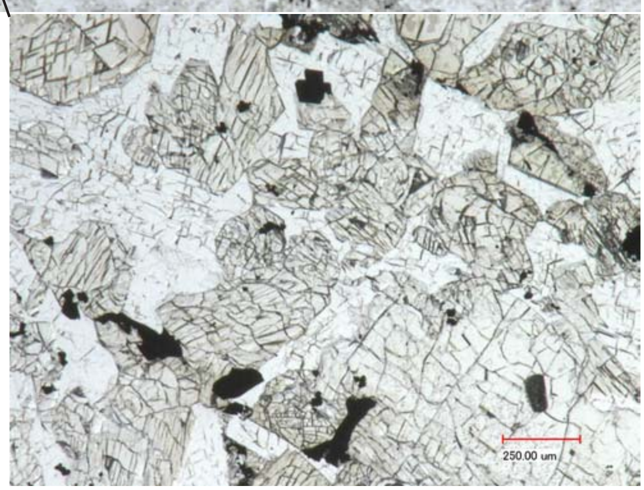


Figure 3a: Photomicrographs of thin section 15536,9 by C Meyer @ 30 and 150x.

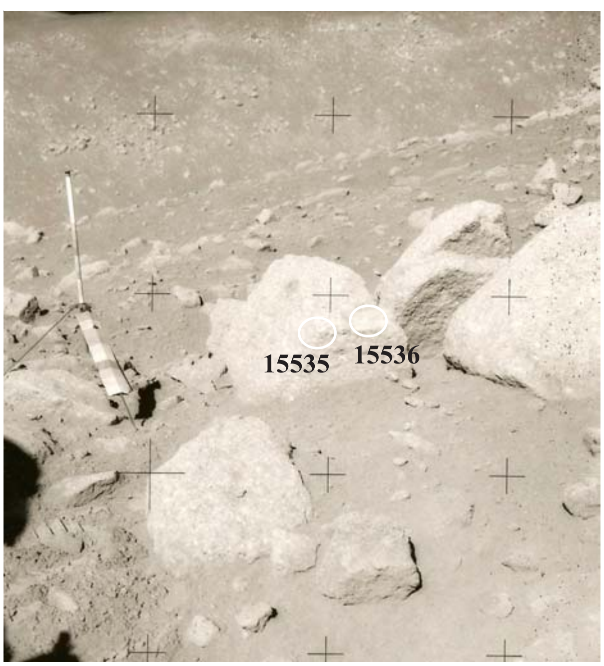
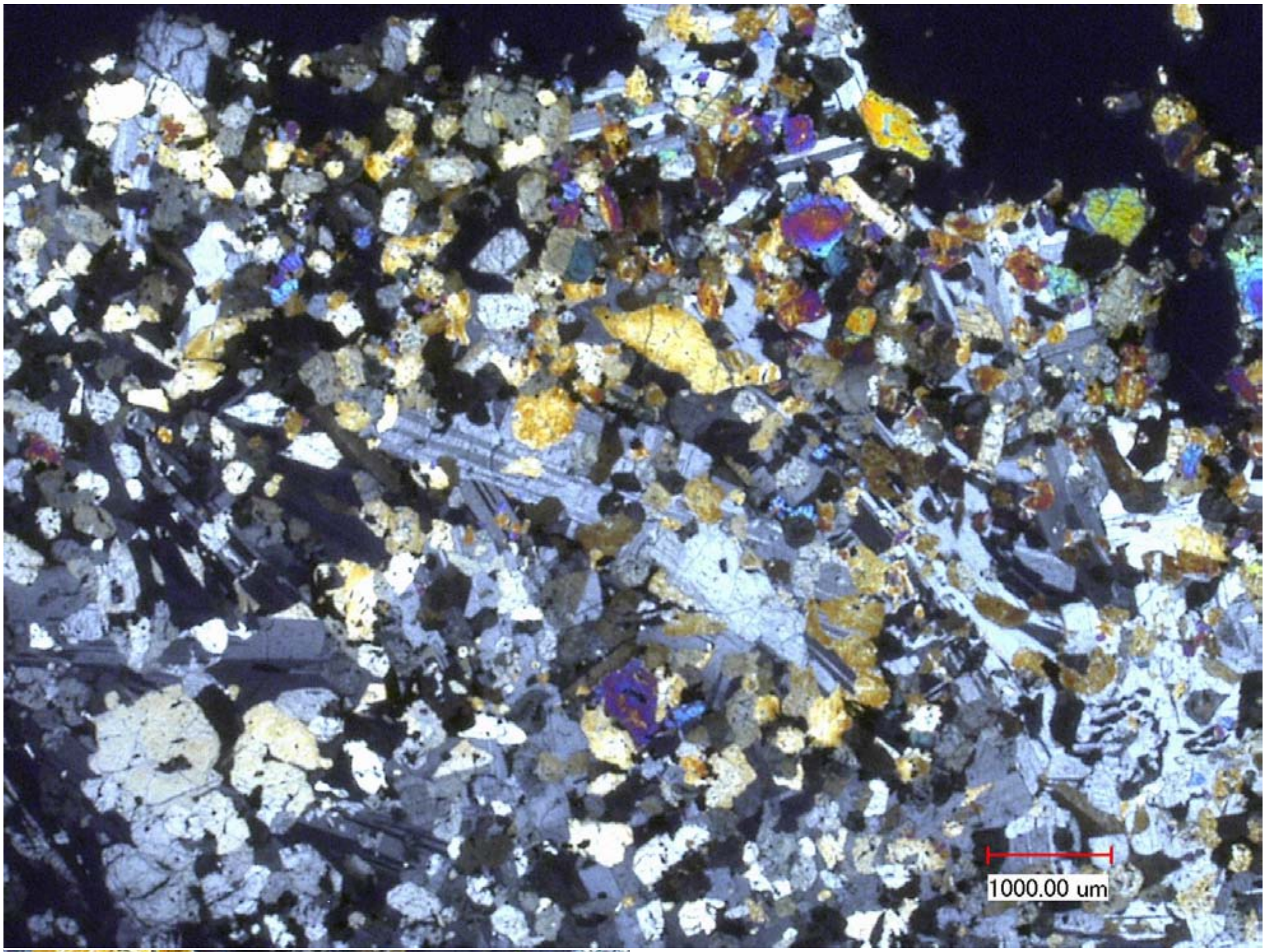


Figure 4: Basalt outcrop on edge of Hadley Rille with boulder from which samples 15535 and 15536 were taken. AS15-82-11138.

15535 and 15536 are both olivine-bearing mare basalts with olivine and pyroxene enclosed in poikilitic plagioclase. !5535 is finer-grained than 15536. 15535 has been more carefully studied. Neither sample has been dated. These samples can be "oriented" by comparing lunar surface and laboratory photography. Samples 15545, 15546 and 15547 are additional pieces of the same basaltic material from nearby.



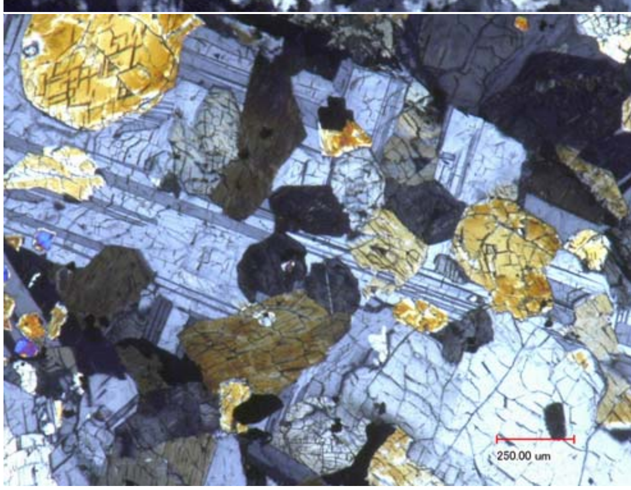


Figure 3a: Photomicrographs of thin section 15536,9 by C Meyer @ 30 and 150x (crossed polarizers).

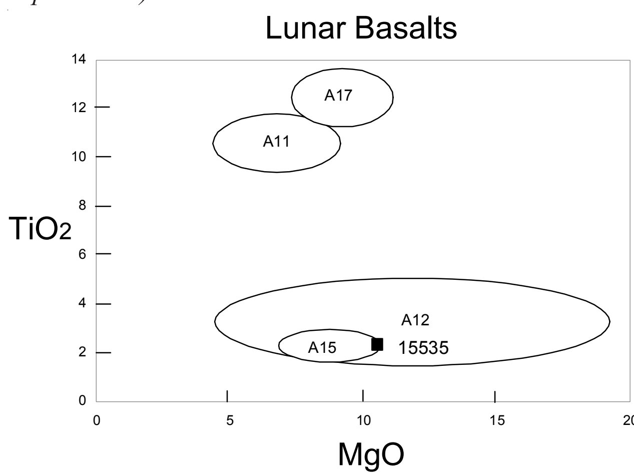
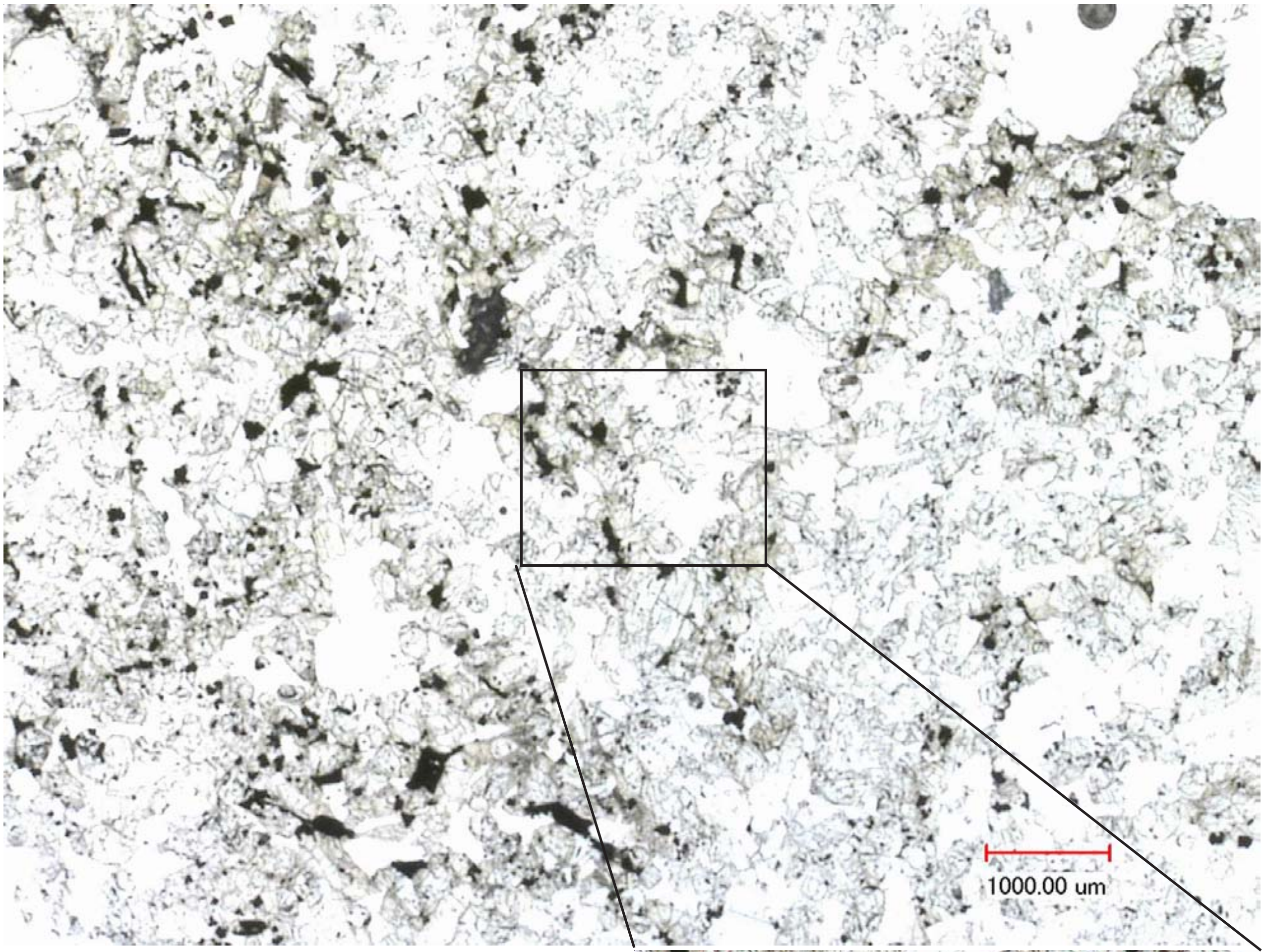


Figure 5: Chemical composition of 15535 compared with other lunar basalts.

Petrography

15535 and 15536 are samples of olivine-normative basalt common at the Apollo 15 site. They are made up of small equant crystals of olivine and pyroxene enclosed in poikilitic plagioclase. The mafic grains are found in clusters in places and opaque minerals also appear in clusters (figures 3 and 6). Ryder (1985) and Shervais et al. (1990) picture olivine phenocrysts in 15536 and Shervais et al. (1990) reported much higher modal olivine in 15536.



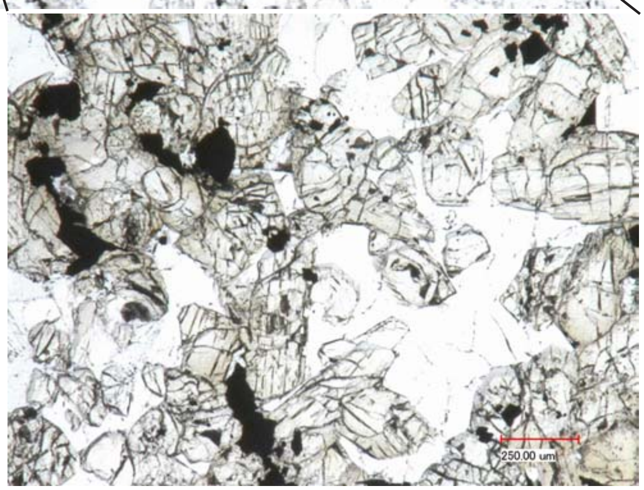


Figure 6a: Photomicrographs of thin section 15536,5 by C Meyer @ 30 and 150x.

The mesostasis of these rocks include K-rich glass, cristoblaite, fayalite, troilite and rare Fe-Ni-Co metal. There are about 3-5% small vugs.

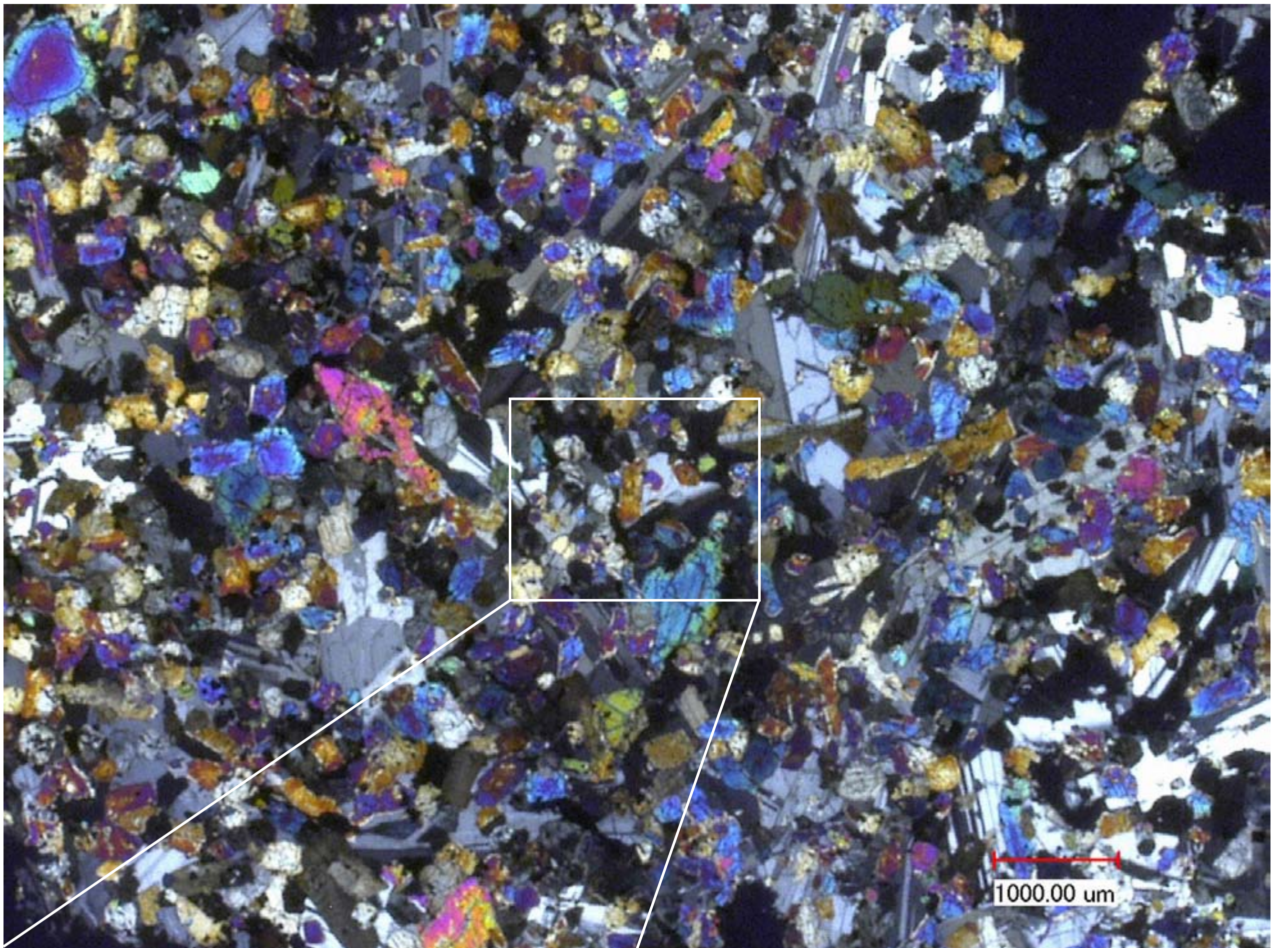
Mineralogy

Olivine: Shervais et al. (1990) found olivine phenocrysts in 15536 were zoned Fo_{70-20}.

Pyroxene: Shervais et al. (1990) reported pyroxene analyses very similar to that of other olivine-normative basalts for Apollo 15. Juan et al. (1972), Fernandez-

Mineralogical Mode for 15535 and 15536

	PET 1971 15535	**Juan 1972 15535**	**Shervais 1990 15536**
Olivine	10%	10	24
Pyroxene	53	60	38
Plagioclase	32	25	31
Opaques	3	4	4
Cristobalite	0.5		1.9
Glass	1	1	0.5



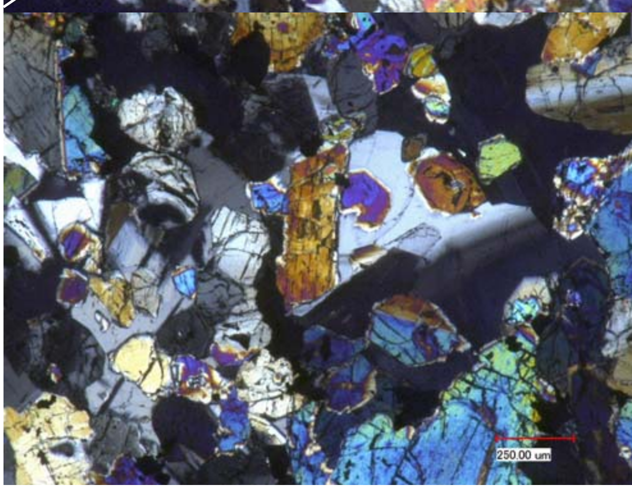


Figure 6b: Photomicrographs of thin section 15536,5 by C Meyer @ 30 and 150x (crossed polarizers)

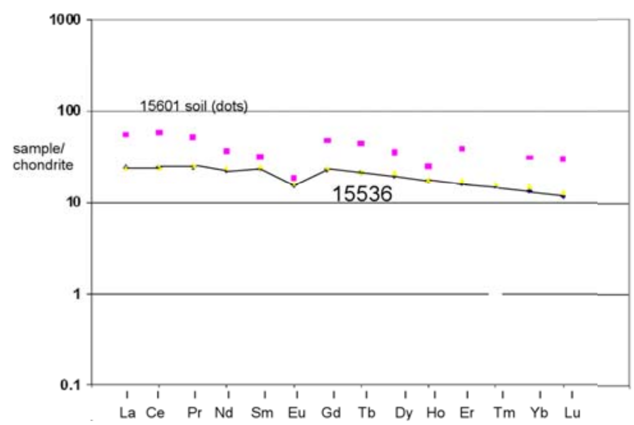


Figure 7: Normalized rare-earth-element diagram for 15536 (data by Ryder and Shuraytz 2001).

Moran (1973) and Virgo (1973) studied the pyroxene structure.

Plagioclase: Plagioclase grains are relatively large (up to 3 mm). Shervais et al. (1990) reported An_{93-85}.

Ilmenite: Engelhardt (1979) studied the shape (paragenesis) of ilmenite. Taylor and McCallister (1972) and Taylor et al. (1973) studied Zr partioning between ilmenite and ulvospinel in the hope of obtaining information on the cooling rate.

Spinel: Haggerty (1972) found more ulvospinel than chromite.

Metallic iron: Taylor et al. (1973) rediscovered secondary fluorescence (figure 8).

Chemistry

Rancitelli et al. (1972) determined K, U and Th by whole rock radiation counting. Figures 5, 7 and 9 summarize the chemical composition.

Radiogenic age dating

None

Cosmogenic isotopes and exposure ages

Alexander et al. (1973) and Arvidson et al. (1975) determined an exposure age of 110 m.y. with ^{81}Kr for 15535. Rancitelli et al. (1972) determined the cosmic-ray-induced activity of ^{22}Na = 39 dpm/kg, ^{26}Al = 61 dpm/kg, ^{46}Sc = 3 dpm/kg, ^{54}Mn = 21 dpm/kg and ^{56}Co = <16 dpm/kg.

Other Studies

Banerjee et al. (1972) and Hoffman and Banerjee (1975) reported the magnetic properties of 15535.

Bhandari et al. (1973) studied the track density of solar flare particles and determined a "suntan" age of 10 m.y.

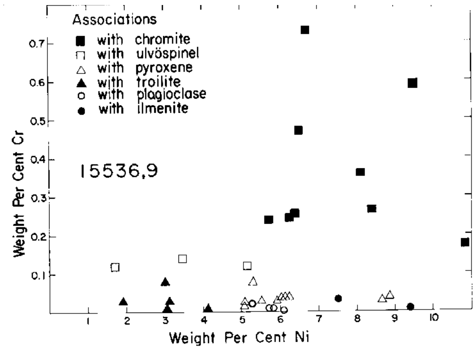


Figure 8: Cr content of native FeNi metal as a function of coexisting phases (from Taylor et al. 1973).

Processing

An oriented slab was cut from 15535. 15536 is nearly intact.

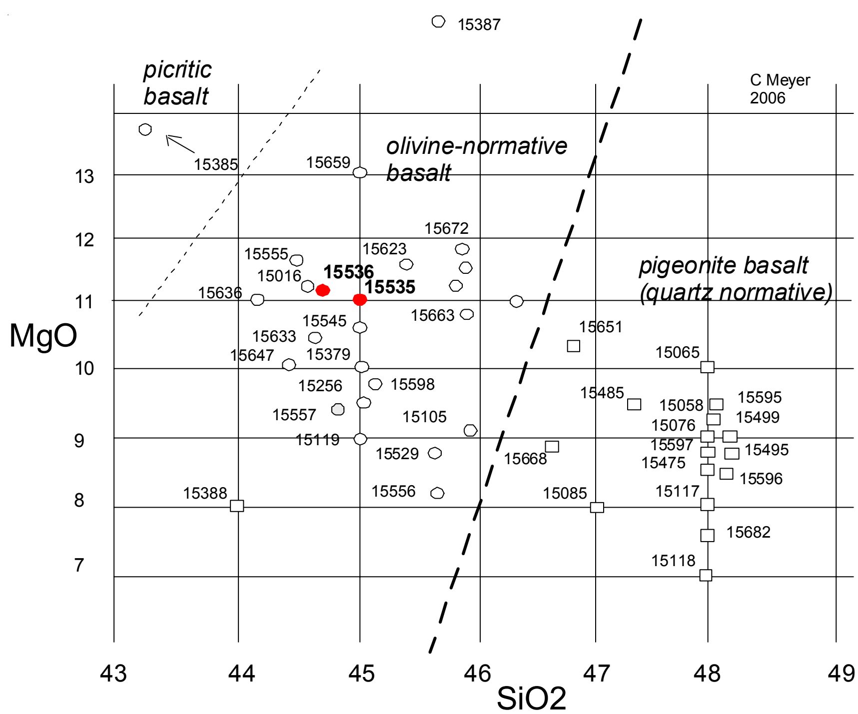


Figure 9: The big picture.

Table 1. Chemical composition of 15535.

reference	Ryder2001				Helmke73		Mason72		Mason72		Juan72		Baedecker73		Rancitelli73		Neal2001	
weight	5 g				Helmke72			0.5						relica				
SiO2 %	45.1	(a)			45.3	(f)	44.46	(c)			45.5	(e)						
TiO2	2.25	(a)			2.15	(f)	2.19	(c)			2.51	(e)						
Al2O3	8.49	(a)			8.37	(f)	8.68	(c)			9.7	(e)						
FeO	22.47	(a)	22.5	(b)	22.9	(f)	23.8	(c)			21.7	(e)						
MnO	0.28	(a)			0.28	(f)	0.33	(c)			0.29	(e)						
MgO	11.17	(a)			11.2	(f)	11.27	(c)			10.34	(e)						
CaO	9.37	(a)			9.68	(f)	9.2	(c)			9.3	(e)						
Na2O	0.22	(a)	0.244	(b)	0.267	(f)	0.28	(c)			0.195	(e)						
K2O	0.041	(a)			0.044	(f)	0.04	(c)			0.041	(e)			0.059	(h)		
P2O5	0.059	(a)					0.06	(c)										
S %																		
sum																		
Sc ppm			41.2	(b)													48	(i)
V									140	(d)							263	(i)
Cr	4702	(a)	4580	(b)			3900	(c)	4800	(d)	4120						5094	(i)
Co			56.6	(b)					52	(d)	77	(e)					68	(i)
Ni	72	(a)	70	(b)	46	(b)			70	(d)	92	(e)	75	(g)			83	(i)
Cu	18	(a)							8	(d)	3	(e)					14.5	(i)
Zn											12	(e)	1.4	(g)			18	(i)
Ga									3	(d)	10	(e)	3.1	(g)			3.8	(i)
Ge ppb													19	(g)				
As																		
Se																		
Rb	*8*	(a)									3.8	(e)					0.87	(i)
Sr	88	(a)	110	(b)	87	(b)			83	(d)	201	(e)					109	(i)
Y	21	(a)							42	(d)							29	(i)
Zr	79	(a)							85	(d)							90.5	(i)
Nb	7	(a)															6.5	(i)
Mo																	0.2	(i)
Ru																		
Rh																		
Pd ppb																		
Ag ppb											32	(e)						
Cd ppb													1.4	(g)				
In ppb													0.34	(g)				
Sn ppb																		
Sb ppb																	10	(i)
Te ppb																		
Cs ppm																	0.02	(i)
Ba			35	(b)	45	(b)			38	(d)							54	(i)
La			4.33	(b)	3.49	(b)											5.2	(i)
Ce			12.7	(b)	9.7	(b)											13.2	(i)
Pr																	2.1	(i)
Nd			12	(b)	6.7	(b)											9.21	(i)
Sm			3.11	(b)	2.6	(b)											3.06	(i)
Eu			0.81	(b)	0.69	(b)											0.81	(i)
Gd					3.6	(b)											4.2	(i)
Tb			0.68	(b)	0.59	(b)											0.72	(i)
Dy					4.07	(b)											4.6	(i)
Ho					0.73	(b)											0.9	(i)
Er																	2.5	(i)
Tm																	0.32	(i)
Yb			1.99	(b)	1.69	(b)											2.11	(i)
Lu			0.27	(b)	0.236	(b)											0.28	(i)
Hf			2.37	(b)													2.3	(i)
Ta			0.33	(b)													0.41	(i)
W ppb																		
Re ppb																		
Os ppb																		
Ir ppb													0.059	(g)				
Pt ppb																		
Au ppb											4	(e)	0.06	(g)				
Th ppm			0.38	(b)											0.45	(h)	0.48	(i)
U ppm															0.104	(h)	0.12	(i)

technique: (a) XRF, (b) INAA, (c) classical wet, (d) ES, (e) various, (f) AA, (g) RNAA, (h) radiation counting, (i) ICP-MS

Table 2. Chemical composition of 15536.

reference	Ryder2001				Shervais90				Neal2001		Warren87		
weight	4.18 g				0.2 g								
SiO2 %	44.1	(a)			44.6	(c)							
TiO2	2.39	(a)			2.14	(c)					2.32	2.7	(b)
Al2O3	8.11	(a)			7.52	(c)					8.9	7.6	(b)
FeO	23.05	(a)	23.4	(b)	23.29	(c)	22.2	(b)			24.2	24	(b)
MnO	0.29	(a)			0.29	(c)					0.27	0.3	(b)
MgO	10.99	(a)			11.63	(c)					12.4	10.8	(b)
CaO	9.24	(a)			9.32	(c)					9.7	9.24	(b)
Na2O	0.217	(a)	0.239	(b)	0.21	(c)	0.244	(b)			0.26	0.23	(b)
K2O	0.043	(a)			0.03	(c)					0.05	0.045	(b)
P2O5	0.065	(a)			0.04	(c)							
S %													
sum													
Sc ppm			41.2	(b)			40.5	(b)	50.6	(d)	42	42	(b)
V									359	(d)	202	211	(b)
Cr	4466	(a)	4430	(b)	4584	(c)	4645	(b)	6419	(d)	4140	4100	(b)
Co			57.1	(b)			55.6	(b)	73.5	(d)	56	60	(b)
Ni	127	(a)	93	(b)			65	(b)	93.4	(d)	56	57	(b)
Cu	17	(a)							23.5	(d)			
Zn									22.7	(d)	0.8		
Ga									4.15	(d)	3.1		
Ge ppb											20		
As													
Se													
Rb	4	(a)							1.07	(d)			
Sr	86	(a)	115	(b)			105	(b)	109	(d)			
Y	25	(a)							33.5	(d)			
Zr	86	(a)					70	(b)	113	(d)			
Nb	10	(a)							7.8	(d)			
Mo									0.6	(d)			
Ru													
Rh													
Pd ppb													
Ag ppb													
Cd ppb											0.93		
In ppb											0.5		
Sn ppb													
Sb ppb													
Te ppb													
Cs ppm									0.03	(d)			
Ba			68	(b)			32	(b)	57	(d)	54		
La			4.92	(b)			4.04	(b)	5.6	(d)	5.2	5.4	(b)
Ce			14.3	(b)			12.2	(b)	14.5	(d)	13.3	18	(b)
Pr									2.2	(d)			
Nd			8	(b)					9.94	(d)	10.4	9.9	(b)
Sm			3.47	(b)			2.97	(b)	3.43	(d)	3.3	3.7	(b)
Eu			0.84	(b)			0.774	(b)	0.86	(d)	0.97	0.85	(b)
Gd									4.5	(d)			
Tb			0.79	(b)			0.69	(b)	0.77	(d)	0.76	0.83	(b)
Dy									4.7	(d)	4	5.1	(b)
Ho									0.95	(d)			
Er									2.56	(d)			
Tm									0.36	(d)			
Yb			2.2	(b)			1.91	(b)	2.15	(d)	2.22	2.23	(b)
Lu			0.29	(b)			0.264	(b)	0.28	(d)	0.31	0.34	(b)
Hf			2.61	(b)			2.27	(b)	2.42	(d)	3.5	2.7	(b)
Ta			0.39	(b)			0.32	(b)	0.47	(d)	0.24	0.49	(b)
W ppb									30	(d)			
Re ppb												360	
Os ppb												27	
Ir ppb											0.023	0.022	
Pt ppb													
Au ppb											0.038	0.035	
Th ppm			0.4	(b)			0.29	(b)	0.76	(d)	0.44	0.53	(b)
U ppm							0.06	(b)	0.22	(d)			

technique: (a) XRF, (b) INAA, (c) fused bead, electon microprobe, (d) ICP-MS

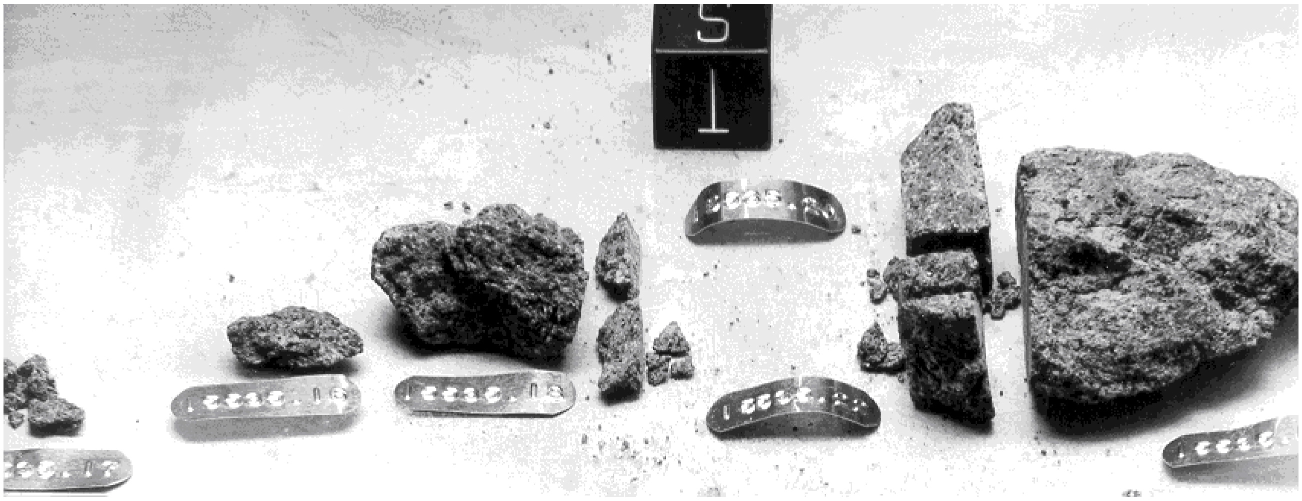
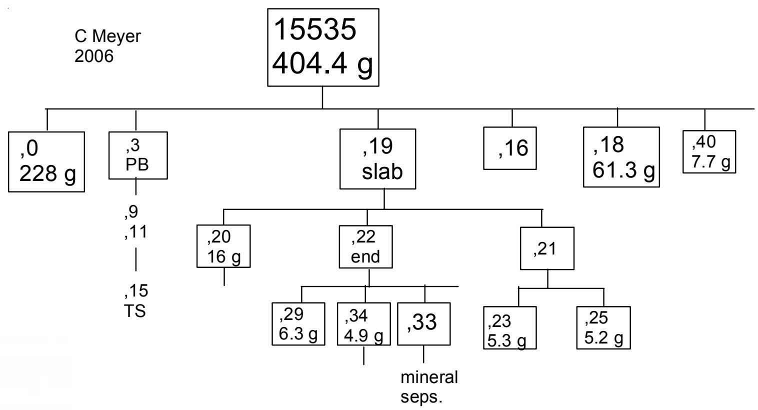


Figure 10: Photo of processing of 15535. NASA S7160284. Cube is 1 cm.



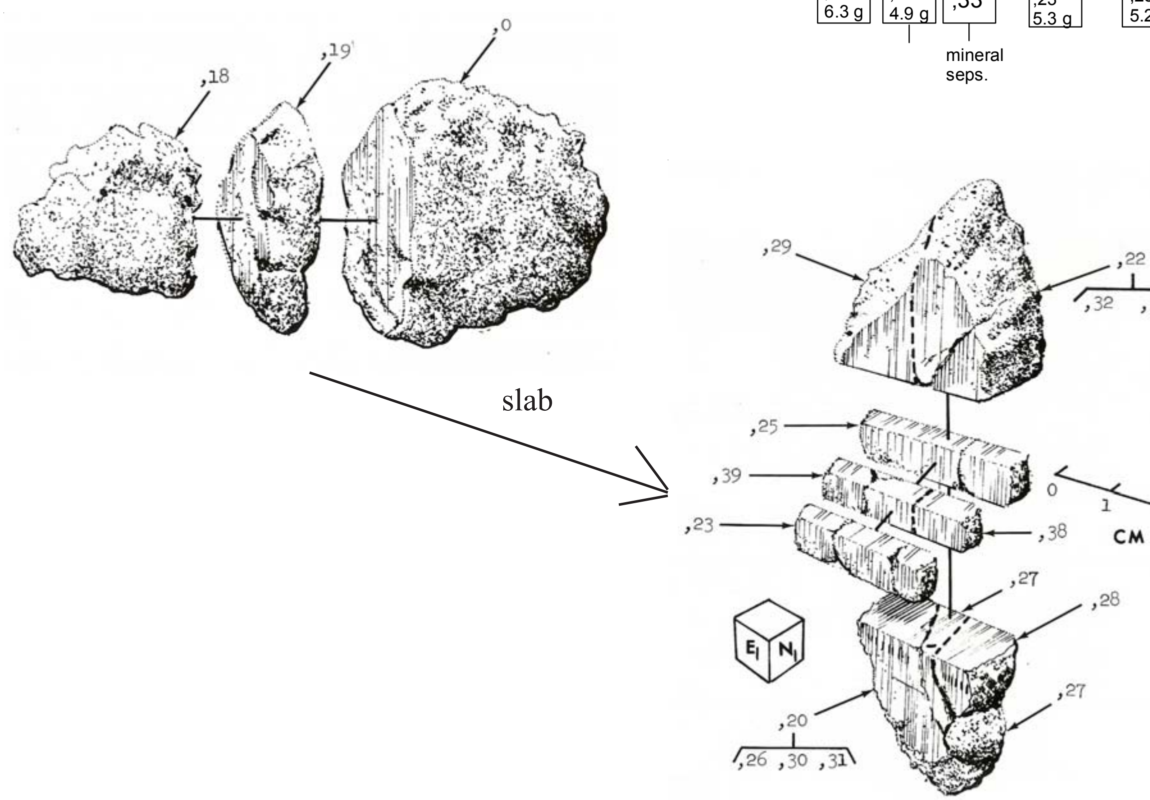
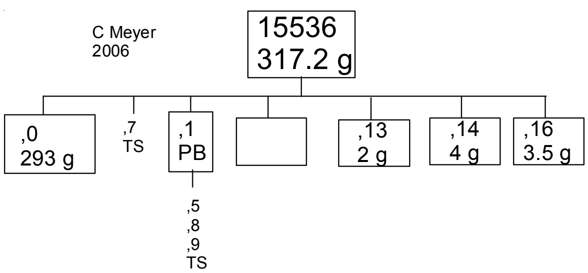


Figure 11: Another view of 15536 showing fresh hackly surface. NASA S71-60585. Sample is 9 cm.



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