10003

Ilmenite Basalt (low K)

213 grams

Figure 1: Photo of 10003,25. Sample is 5 cm across. NASA S76-25545.

Introduction

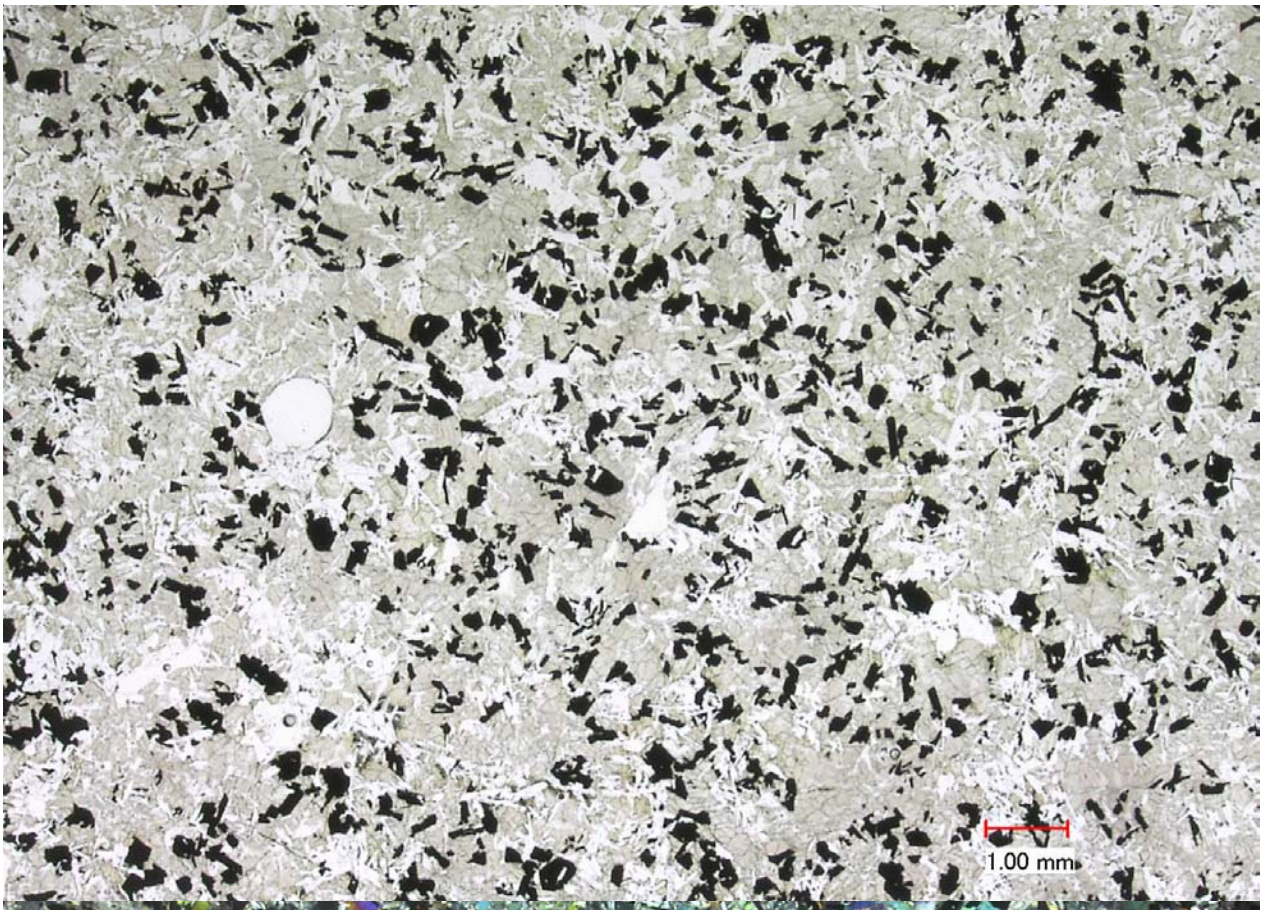
Lunar sample 10003 is a low-K, high-Ti basalt (figure 1). It is about 3.9 b.y. old, with a cosmic ray exposure age of 137 m.y. Its location on the lunar surface was not recorded. It was returned in ALSRC #1004, and was one of the first lunar samples studied.

Petrography

Schmitt et al. (1970) termed 10003 a "medium-grained, vuggy subophitic basalt" while Beaty and Albee (1978) and Gamble et al. (1978) described the texture as "ophitic". McGee et al. (1977) described sample 10003 as a "medium-grained porphyritic pyroxene basalt characterized by anhedral phenocrysts of pyroxene (1.0 – 2.7mm) set in a subophitic matrix of plagioclase, pyroxene and ilmenite" (figure 2). The mesostasis includes cristobalite, K-rich glass, troilite with metallic iron blebs, and small amount of pore space. Tablet-shaped plagioclase (0.1 – 0.6mm) occurs both subophitically intergrown with pyroxene phenocrysts and as an interstitial phase between phenocrysts. Ilmenite typically occurs as blocky, irregularly shaped bodies (0.5 – 1.0mm) intergrown with pyroxene and plagioclase, and as inclusions in pyroxene phenocrysts.

Mineralogy

Olivine: Olivine cores are found in some pyroxene (Beaty and Albee 1978).


1.00 mm

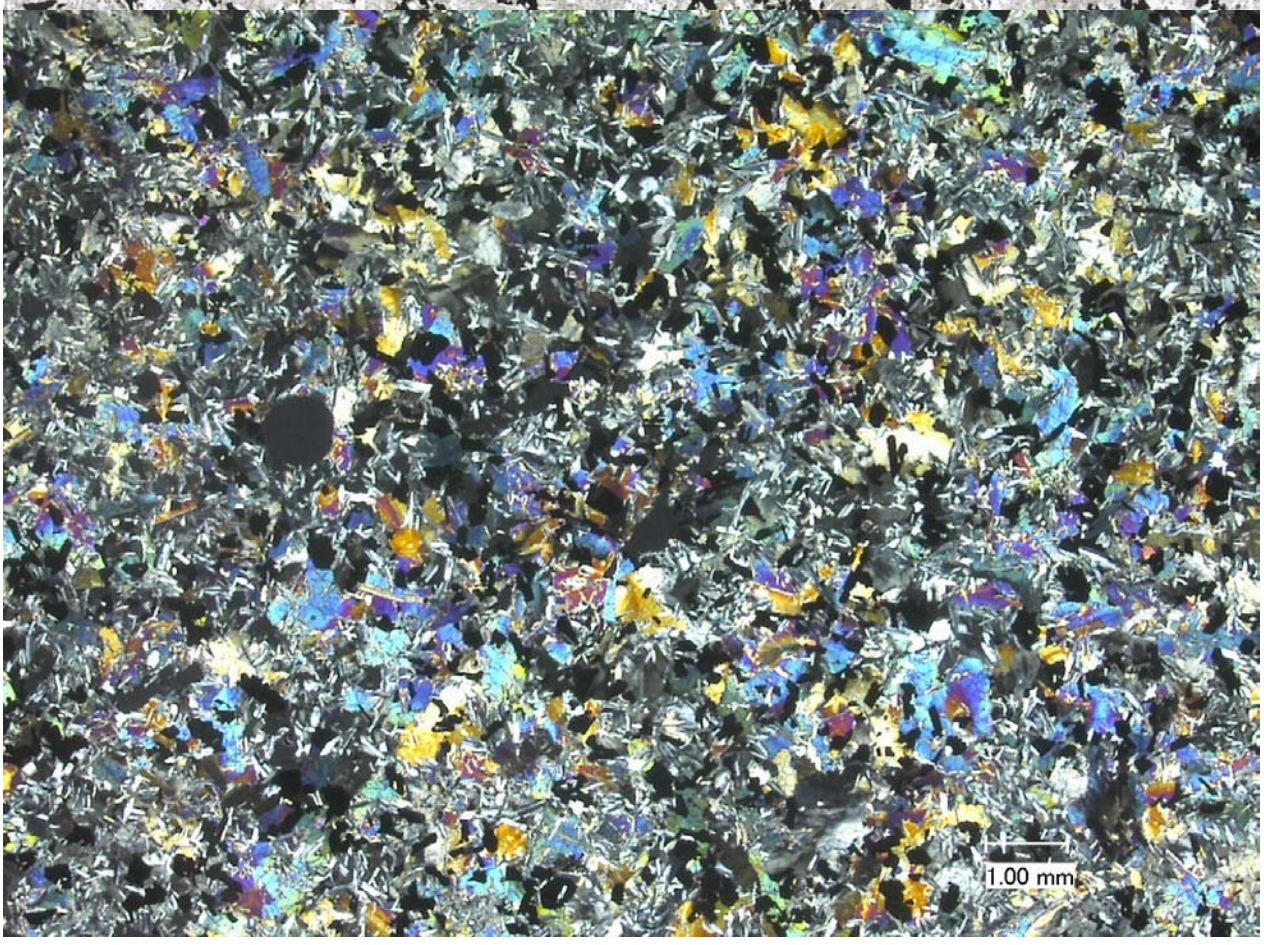

1.00 mm

Figure 2: Photomicrographs of thin section 10003,37 (plane polarized and crossed polarized). Width is 2.6 mm. NASA S70-49473-49474.

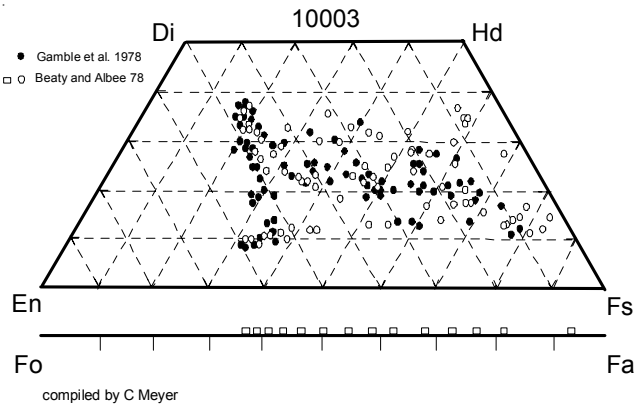


Figure 3: Pyroxene and olivine composition of 10003 (replotted from Beaty and Albee 1978 and Gamble et al. 1978).

Pyroxene: Hafner and Virgo (1970), Beaty and Albee (1978) and Gamble et al. (1978) determined pyroxene composition of 10003 (figure 3). Single crystal X-ray diffraction studies show that the pyroxene is an intergrowth of pigeonite and augite (Ross et al. 1970). The distribution of cations in pyroxene sites was studied by Hafner and Virgo. They determined that there was no Fe^{+3}.

Plagioclase: The chemical composition of plagioclase was found to be zoned from An_{93} to An_{67} by Beaty and Albee (1978). The composition of plagioclase (An_{85}) can also be estimated from the crystallographic data by Stewart et al. (1970).

Ilmenite: Gamble et al. (1978) describe the ilmenite in 10003 as elongate and euhedral. They found some grains were low in Mg, while others were high in Mg (up to 6.3% MgO). Stewart et al. (1970) determined the crystallographic data for ilmenite in 10003.

Rutile: Haggerty et al. (1970) studied the nature of rutile inclusions in ilmenite host in 10003.

Chemistry

The K and Rb content of 10003 is low while REE content is intermediate compared with other Apollo 11 basalts (figure 5). The modern analysis by Rhodes and Blanchard (1980) confirmed earlier work. The recent trace-element analysis reported by Neal (2001) is probably superior.

Mineralogical Mode for 10003

	James and Jackson 70	Beaty and Albee 1978	Haggerty et al. 1970	Gamble et al. 1978	Bailey et al. 1970
Olivine	0.5	0.52			tr.
Pyroxene	48.7	50	51.7	48.6	50
Plagioclase	34.8	34.2	29	33.5	33.8
Ilmenite	14.1	13.3	18.2	14.9	14
mesostasis				0.8	
silica	1	1.06	0.3	1.4	1.2
troilite	0.5	0.68		0.8	
phosphate	0.2	0.25			

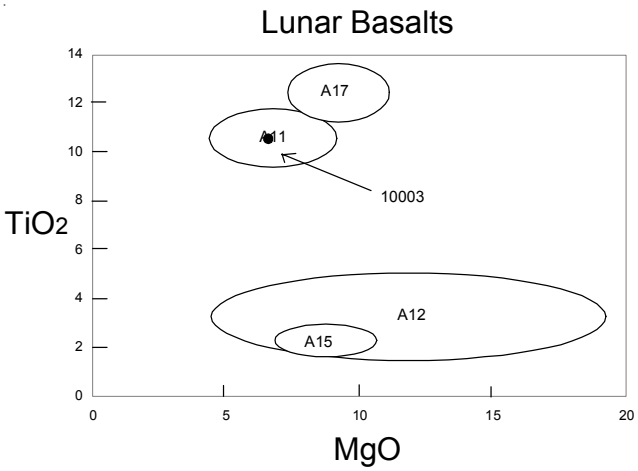


Figure 4: Composition of 10003 compared with that of other Apollo lunar samples.

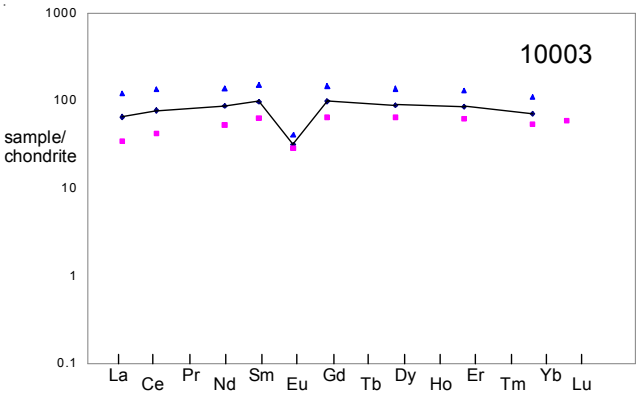


Figure 5: Normalized rare-earth-element composition for low-K basalt 10003 (the line) compared with that of low-K basalt 10020 and high-K basalt 10049 (the dots) (data from Wiesmann et al. 1975).

Radiogenic age dating

Eberhardt et al. (1971) determined a K/Ar age. Papanastassiou and Wasserburg (1975b) determined the age of 10003 by Rb/Sr (figure 6) which agreed closely with that of Stettler et al. (1974) and Turner (1970) by the Ar/Ar technique. Perhaps the most reliable age is that obtained by Ar/Ar plateau of the plagioclase 3.91 ± 0.03 b.y. (figure 7).

Cosmogenic isotopes and exposure ages

O'Kelley et al. (1970) determined the cosmic ray induced activity of ^{22}Na (41 dpm/kg), ^{26}Al (74 dpm/kg), ^{46}Sc (13 dpm/kg), ^{54}Mn (35 dpm/kg) and ^{56}Co (43 dpm/kg). Perkins et al. (1970) determined ^{22}Na (49 dpm/kg), ^{26}Al (75 dpm/kg), ^{46}Sc (8 dpm/kg) and ^{54}Mn (60 dpm/kg). Wrigley and Quaide (1970) determined ^{22}Na (56 dpm/kg) and ^{26}Al (74 dpm/kg).

Turner et al. (1970) and Hintenberger et al. (1971) reported ^{38}Ar exposure ages of 150 m.y and 140 m.y. (respectively). Arvidson et al. (1975) reported a ^{81}Kr exposure age of 140 m.y. (determined by Schwaller 1971). Eugster et al. (1984) reported ^{81}Kr exposure age of 137 m.y.

Other Studies

Oxygen isotopes were reported for mineral separates of 10003 by Onuma et al. (1970) and Taylor and Epstein (1970).

The concentrations of Sm, Nd, Lu and Hf and the isotopic ratios of ^{143}Nd/^{144}Nd and ^{176}Hf/^{177}Hf were determined by Unruh et al. (1984).

The abundance and isotopic composition of rare gases in 10003 were determined by Hintenberger et al. (1970) and Eugster et al. (1984).

Price and O'Sullivan (1970) studied the gradient of cosmic ray tracks and obtained the erosion rate by micrometeorite bombardment.

Processing

Apollo 11 samples were originally described and cataloged in 1969 and "recataloged" by Kramer et al. (1977). 10003 was sawn with a circular saw (figure 9 shows the pieces).

List of Photo #s for 10003

S69-45005 – 006 B&W PET
S69-45009
S69-45016
S69-45019
S69-45021
S69-45192 – 193
S70-49473 – 474
S70-50549 – 552 color TS
S75-28696 – 699 ,9 ,12
S75-20468 – 469 ,38 ,74 ,119
S76-25538
S76-25540
S76-25545
S76-25547 ,25
S76-26304 – 305 B&W TS
S79-27075 – 077 TS color

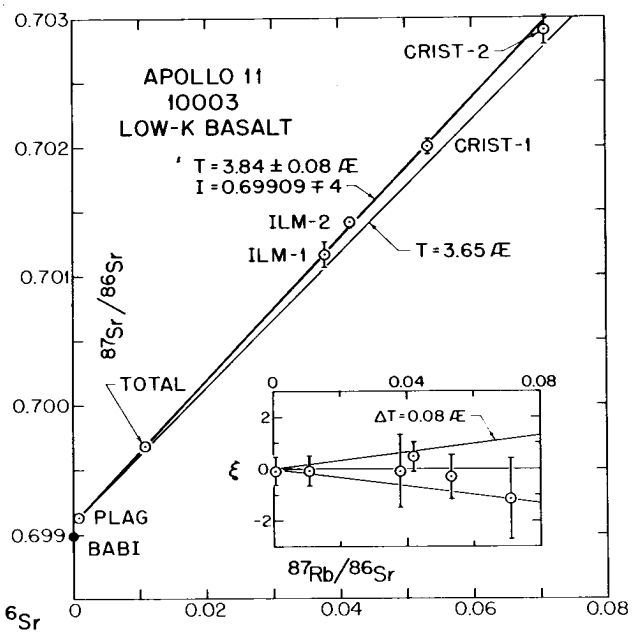


Figure 6: Rb/Sr internal mineral isochron for 10003 (from Papanastassiou and Wasserburg 1975b abs.).

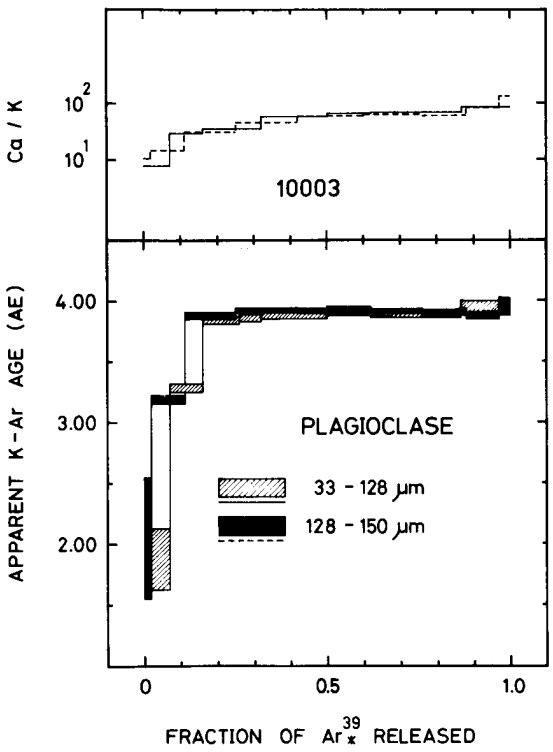


Figure 7: Argon release pattern for plagioclase seperated from 10003 (from Stettler et al. 1974).

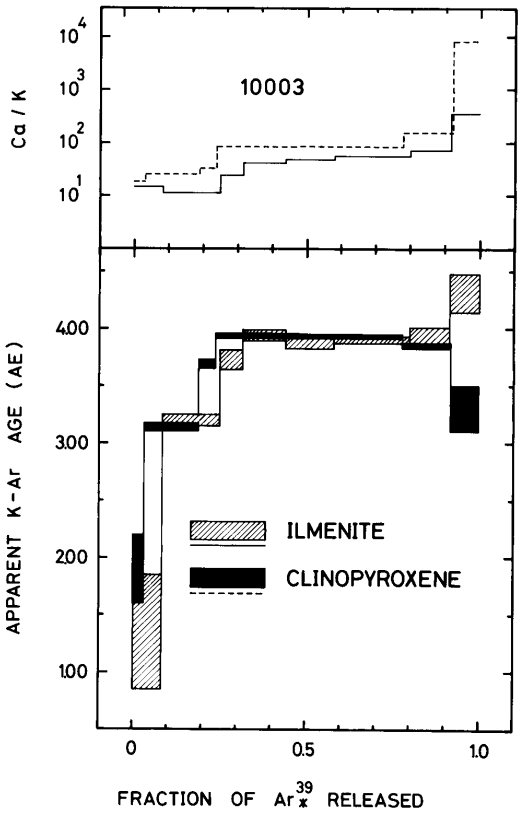


Figure 8: Argon release pattern for low K phases in 10003 (from Stettler et al. 1974).

Summary of Age Data for 10003

	Rb/Sr	Ar/Ar (plag)
Papanastassiou and Wasserburg 1975	3.84 ± 0.08 b.y.	
Stettler et al. 1974		3.91 ± 0.03
Turner 1970		3.92 ± 0.07
Eberhardt et al. 1971		K-Ar

Disclaimer: Uncorrected for new decay constants.

Table 1a. Chemical composition of 10003.

reference	Gast70			Wiesmann75			Compston70		Rose70		Goles70		Rhodes80		O'Kelley70		Perkins70		Wrigley70	
weight				303 mg	198 mg								1.03 g							
SiO2 %							39.76	(c)	37.8	(d)	38.3	(e)	39.53	(c)						
TiO2							10.5	(c)	12	(d)	11.8	(e)	10.67	(c)						
Al2O3							10.43	(c)	11	(d)	10.2	(e)	10.44	(c)						
FeO							19.8	(c)	19.8	(d)	19.7	(e)	20.51	(c)						
MnO							0.3	(c)	0.29	(d)	0.22	(e)	0.29	(c)						
MgO							6.69	(c)	7.2	(d)	8.1	(e)	7.1	(c)						
CaO							11.13	(c)	11	(d)	11.6	(e)	10.8	(c)						
Na2O	0.39		(a)	0.39		(a)	0.4		0.85	(d)	0.36	(e)	0.39	(c)						
K2O	0.057	0.053	(b)	0.057	0.053	(b)	0.06	(c)	0.05	(d)			0.06	(c)	0.058	(f)	0.046	(f)		
P2O5							0.12	(c)					0.14	(c)						
S %							0.18	(c)												
sum																				
Sc ppm											74	(e)	78	(e)						
V											63	(e)								
Cr									1779	(d)	1390	(e)	1620	(e)						
Co											14.1	(e)	14	(e)						
Ni																				
Cu																				
Zn																				
Ga																				
Ge ppb																				
As																				
Se																				
Rb	0.49	0.5	(b)	0.49	0.5	(b)	0.62	(c)												
Sr	159	153	(b)	159	153	(b)	161	(c)												
Y							112	(c)												
Zr							309	(c)			560	(e)								
Nb																				
Mo																				
Ru																				
Rh																				
Pd ppb																				
Ag ppb																				
Cd ppb																				
In ppb																				
Sn ppb																				
Sb ppb																				
Te ppb																				
Cs ppm	0.022		(b)	0.022		(b)														
Ba	108	106	(b)	108	106	(b)					220	(e)								
La	15.5	14.7	(b)	15.5	14.7	(b)					13.5	(e)	15.2	(e)						
Ce	47.2	45.5	(b)	47.2	45.5	(b)					37	(e)	53	(e)						
Pr																				
Nd	40	38.3	(b)	40	38.3	(b)														
Sm	14.4	14	(b)	14.4	14	(b)					13	(e)	14.8	(e)						
Eu	1.81	1.76	(b)	1.81	1.76	(b)					1.84	(e)	1.85	(e)						
Gd	19.5	19	(b)	19.5	19	(b)														
Tb											3.5	(e)	3.3	(e)						
Dy	21.9	21.6	(b)	21.9	21.6	(b)														
Ho											4	(e)								
Er	13.6	13.4	(b)	13.6	13.4	(b)														
Tm																				
Yb	13.2	13	(b)	11.7	11.6	(b)					15.3	(e)	12	(e)						
Lu	1		(b)	1		(b)					2.62	(e)	1.76	(e)						
Hf											11.6	(e)	11.4	(e)						
Ta													2	(e)						
W ppb																				
Re ppb																				
Os ppb																				
Ir ppb																				
Pt ppb																				
Au ppb																				
Th ppm							1.1	(c)					1.8	(e)	1.01	(f)	1.08	(f)	0.9	(f)
U ppm											0.31	(e)			0.26	(f)	0.29	(f)	0.25	(f)

technique: (a) AA, (b) IDMS, (c) XRF, (d) semi micro XRF, (e) INAA, (f) radiation counting

Table 1b. Chemical composition of 10003.

reference	Haskin70		Annell70		Neal2001	
weight						
SiO2 %						
TiO2						
Al2O3						
FeO						
MnO			0.33	(b)		
MgO						
CaO						
Na2O						
K2O						
P2O5						
S %						
sum						
Sc ppm			94	(b)	75.5	(c)
V			82	(b)	48.9	(c)
Cr			1860	(b)	1268	(c)
Co			15	(b)	15.7	(c)
Ni			2.7	(b)	8.32	(c)
Cu			6.7	(b)	37.6	(c)
Zn					58.4	(c)
Ga			4.7	(b)	4.02	(c)
Ge ppb						
As						
Se						
Rb			1	(b)	0.79	(c)
Sr			150	(b)	148.8	(c)
Y			113	(b)	117	(c)
Zr			380	(b)	338.8	(c)
Nb			21	(b)	20.3	(c)
Mo					0.18	(c)
Ru						
Rh						
Pd ppb						
Ag ppb						
Cd ppb						
In ppb						
Sn ppb						
Sb ppb					40	(c)
Te ppb						
Cs ppm					0.05	(c)
Ba			160	(b)	103.1	(c)
La	14.1	(a)	15	(b)	17.5	(c)
Ce	41.3	(a)			55.6	(c)
Pr					7.96	(c)
Nd	42.5	(a)			44.4	(c)
Sm	13.1	(a)			15.6	(c)
Eu	1.8	(a)			1.87	(c)
Gd	17	(a)			20.5	(c)
Tb	3.26	(a)			3.6	(c)
Dy	22.4	(a)			22.8	(c)
Ho					4.79	(c)
Er	12	(a)			14	(c)
Tm					1.85	(c)
Yb	11.9	(e)			13.2	(c)
Lu	1.69	(a)			1.84	(c)
Hf					10.2	(c)
Ta					1.32	(c)
W ppb					0.22	(c)
Re ppb						
Os ppb						
Ir ppb						
Pt ppb						
Au ppb						
Th ppm					0.94	(c)
U ppm					0.28	(c)

technique: (a) INAA, (b) emission spec., (c) ICP-MS

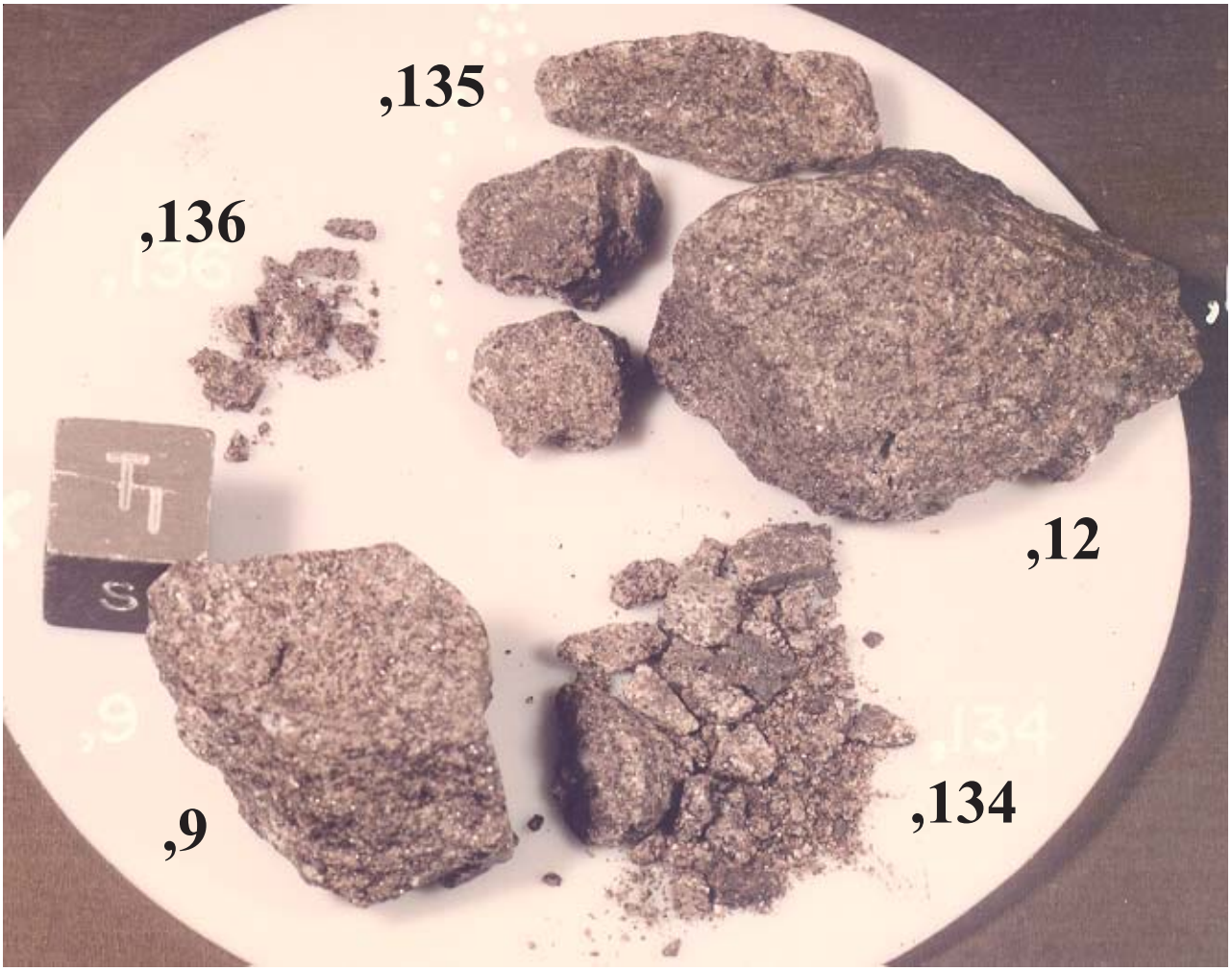


Figure 9: Group photo of 10003,12 and ,9. Cube is 1 cm. NASA S75-28698

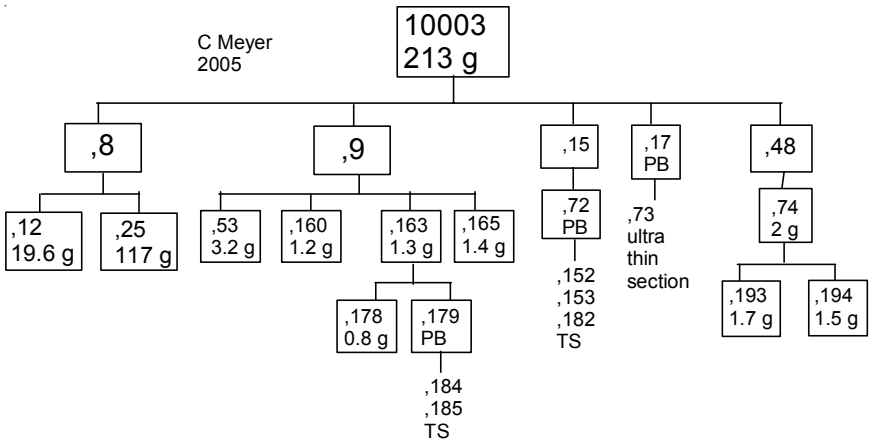


Table 2	U ppm	Th ppm	K ppm	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique
Papanastassiou 1975b			433	?				idms
Perkins et al. 1970	0.29	1.08	460					rad. Count.
O'Kelley et al. 1970	0.26	1.01	480					rad. Count.
Gast and Hubbard 1970			470	0.49	158.6	40	14.5	idms
Tatsumoto et al. 1970	0.268	1.029						idms
Compston et al. 1970		1.1		0.62	160.9			idms

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