DRAFT

71055 – 669.6 grams
71035 – 141.8 grams
71036 – 118.4 grams (frozen)
71037 – 14.39 grams
Vesicular Ilmenite Basalt

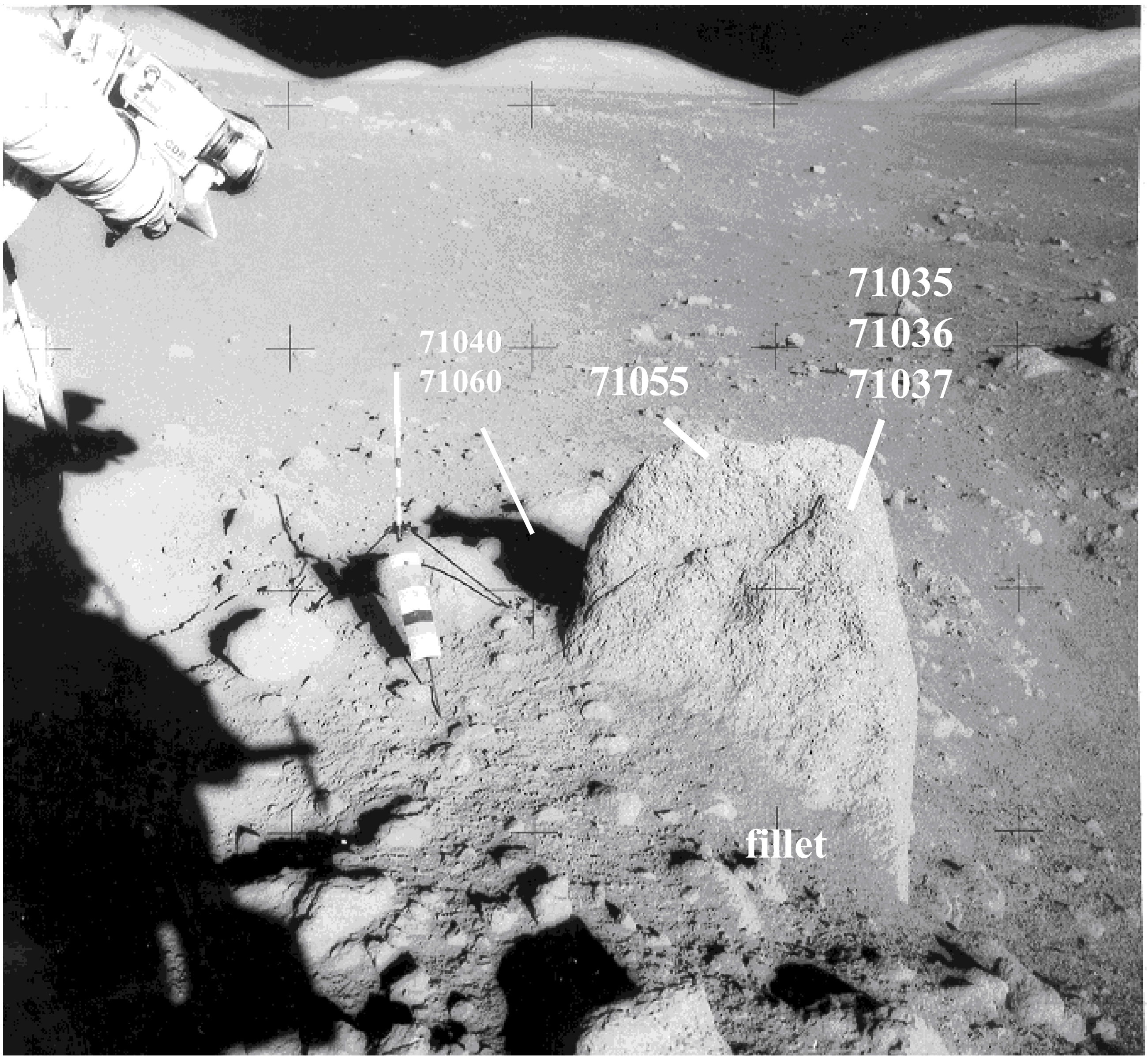


Figure 1: This boulder of vesicular basalt from a small crater on rim of Steno Crater had a significant fillet. It was found to have been exposed to cosmic rays and micrometeorite bombardment for ~110 m.y. Samples 71055 and 71035, 71036 and 71037 were chipped from the top knobs of this boulder. NASA surface photo AS17-136-20739.

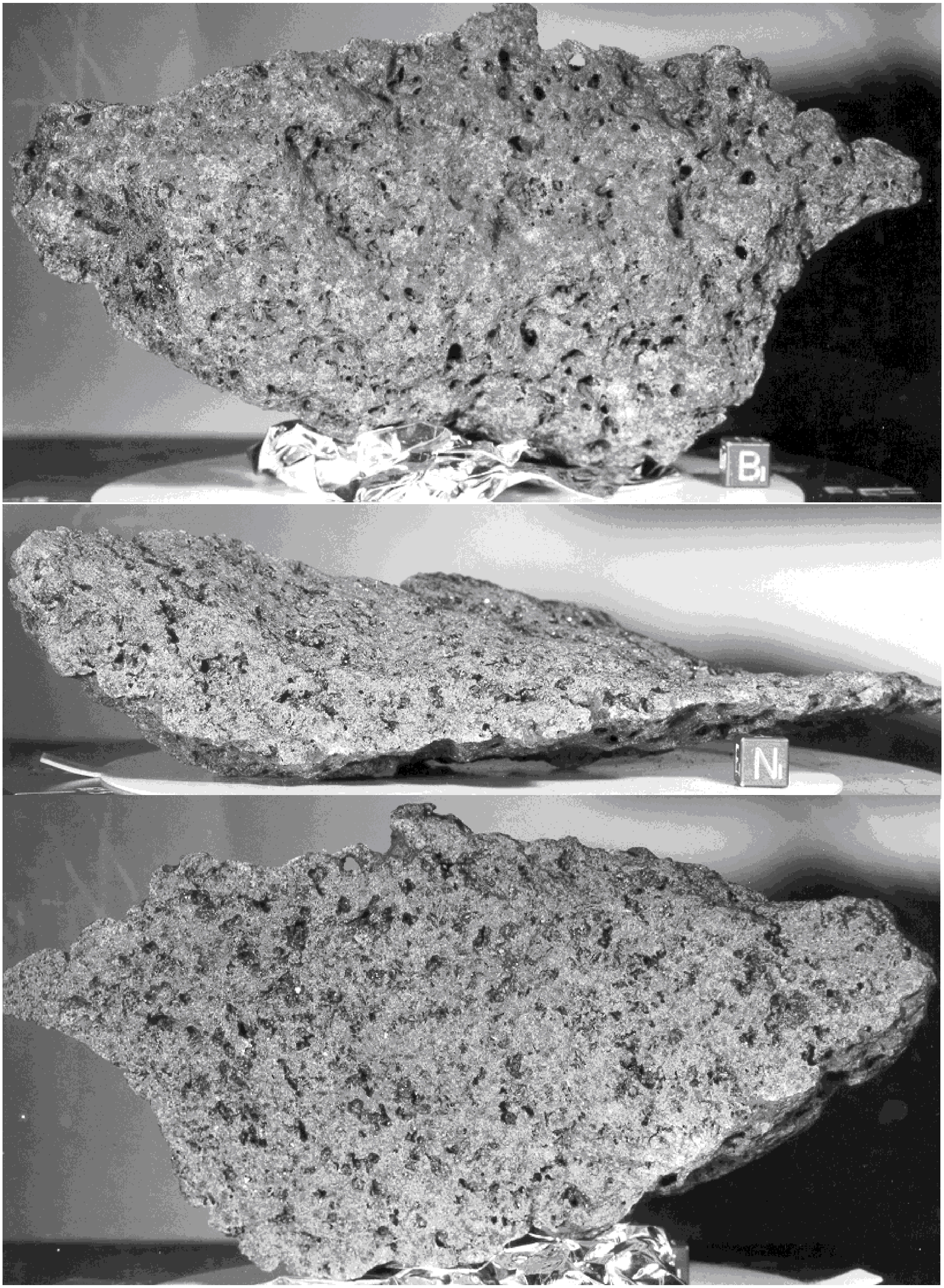


Figure 2: Three views of 71055. NASA photos S73-16172, 16164, 16168. Top is exterior surface.

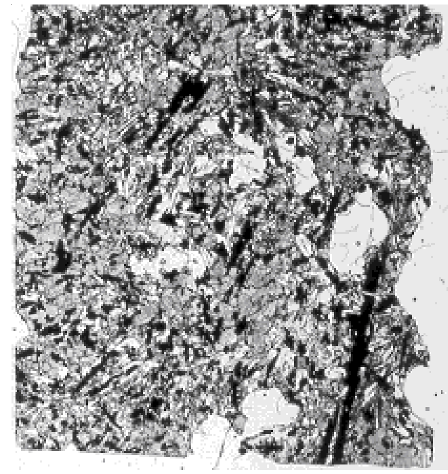


Figure 3a, b: Thin section photos showing abundant, platy ilmenite in 71055.

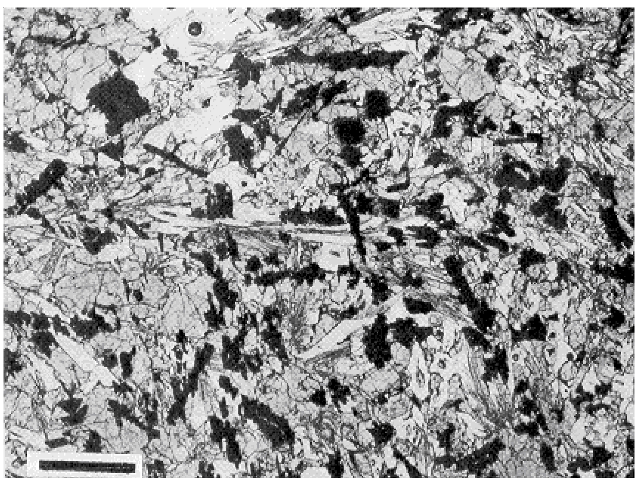


Figure 4: Photomicrograph of thin section of 71055 (from Lofgren and Lofgren 1981). Scale bar is 1 mm.

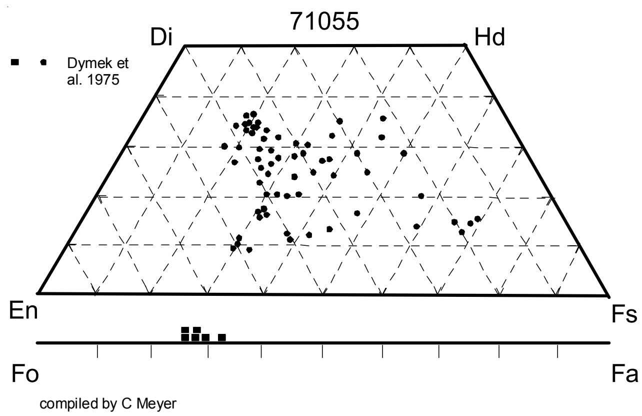


Figure 6: Pyroxene and olivine composition of 71055 (from Dymek et al. 1975).

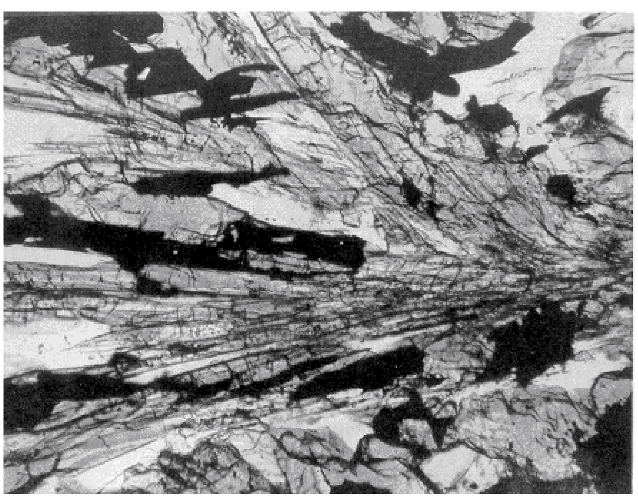


Figure 5: Thin section photo of 71055,68 showing unusual subvariolitic structure (by Neal and Taylor 1993). Field of view is 2.5 mm.

Introduction

Lunar basalts 71055 and 71035, 71036 and 71037 were all chipped from top of a small boulder (0.5 m) in small blocky crater (10 m) on rim of larger Steno Crater (figure 1). All samples are the same kind of high-Ti basalt. The crystallization age (of 71055) was determined by Rb-Sr as 3.64 ± 0.09 b.y. The cosmic ray exposure age was found to be 110 m.y.

Orientation of these samples was documented by photography (figure 35 in Wolfe et al. 1981). Thus, they have been in the Sun for 110 m.y. Sample 71036 was returned under vacuum and has been kept in a freezer since 1972. Although it has not been studied, it is the same lithology (basalt) as the other pieces of this boulder.

Soil samples 71040 (259 g) and 71060 (506 g) and assorted small rock fragments were scooped from the

Figure 7: Photo of 71035 showing exterior surface rounded by micrometeorite bombardment. NASA S73-15673. Sample is 7 cm across.

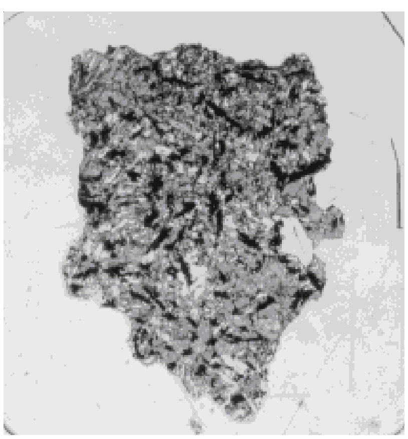


Figure 8: Photomicrograph of thin section 71035,30 showing ilmenite laths. Chip is about 0.8 cm.

Mineralogical Mode for 71055

	Brown et al. 1974	Dymek et al. 1975	Taylor et al. 1992
Olivine	1.9	3	3
Pyroxene	45.3	46	42
Plagioclase	21.2	27	29
Ilmenite	29	17	20
Silica	2.6	2	5

shadow area behind the boulder – but this shadow would not have been "permanent". They were returned "in vacuum" in ALSRC#1.

Petrography

Neal and Taylor (1993) summarize what is known about each of the samples of this basaltic boulder. Dymek et al. (1975) give a detailed petrologic description of 71055 and Warner et al. (1979) studied 71037. 71036 has not received attention, probably because it is another sample of the same material (*it has been kept in a freezer since the mission*).

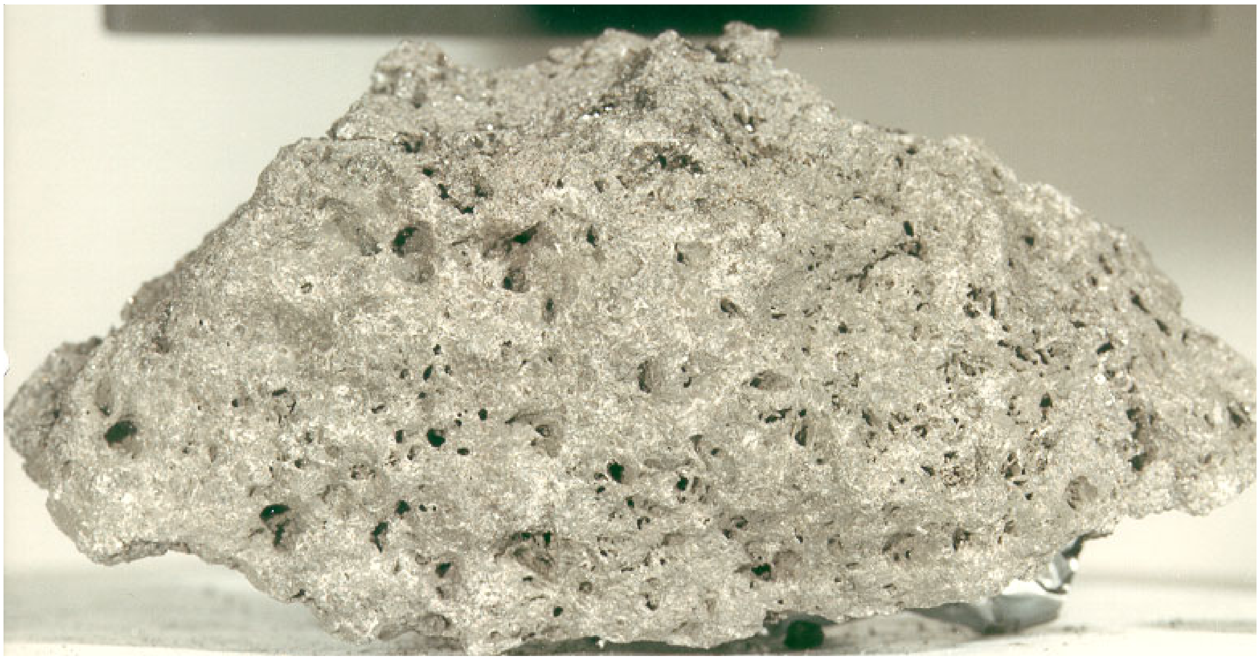


Figure 9: Photo of 71036; exterior surface. NASA S73-15674. Sample is 7 cm across.

Figure 10: Photo of 71037; exterior surface. NASA S73-15690. Sample is 2.5 cm across.

Warner et al. (1979) describe 71037 as a fine-grained, high-Ti basalt. Due to low trace element content they grouped 71037 with "Type B Apollo 17 basalts".

These samples are all very vesicular; up to 30% (figures 1, 2, 7, 9, 10). Vugs extend up to 12 mm. The texture is described as "plagioclase-poikilitic" (Neal and Taylor 1993). Average grain size is 1 – 2 mm with seriate grain size distribution.

Mineralogy

Olivine: Olivine in 71055 occurs as rounded cores of larger pyroxene and is Fo_{75-68} (Dymek et al. 1975).

Pyroxene: According to Dymek et al. (1975), pyroxene in 71055 is "highly complex, both chemically and texturally. The largest grains (up to 2 mm), typically composite, are composed of pale-pink (Al- and Ti-poor) to dark-pink (Al- and Ti-rich) regions arranged in parallel bands, in a radiating spehulitic pattern, or forming an hourglass structure". Pyroxene crystals are

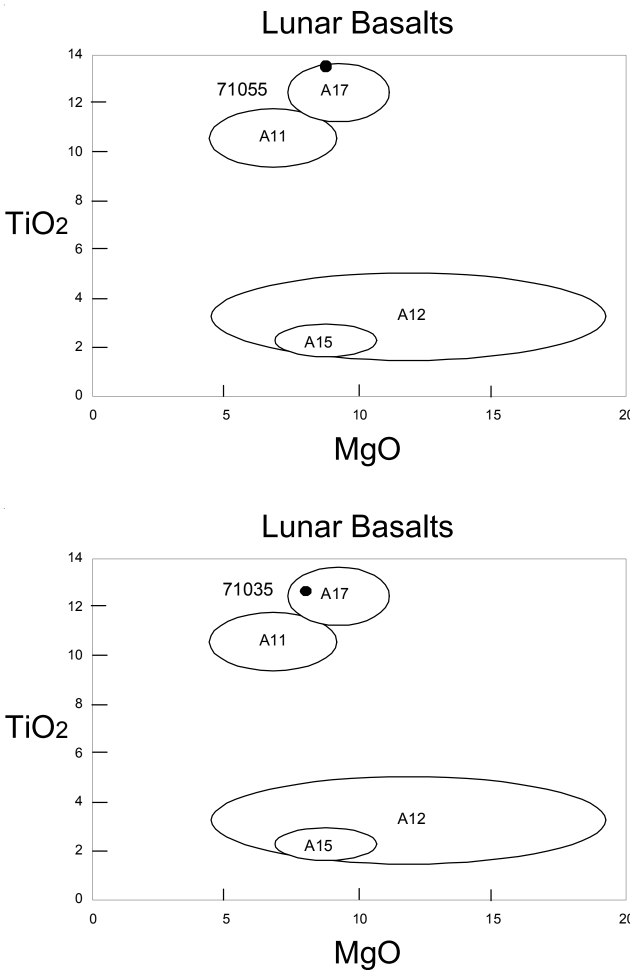


Figure 11: Chemical composition of 71055 and 71035 compared with other lunar basalts.

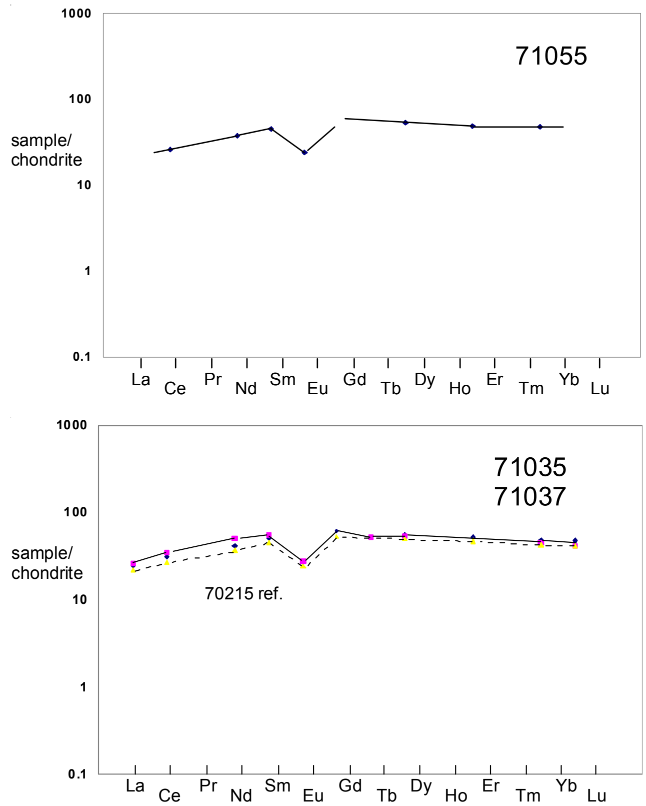


Figure 12: Normalized rare-earth-element diagram for 71055, 71035 and 71037 (data from tables). Note similar pattern.

found to have a wide range of chemical zoning (figure 6). Sung et al. (1974) found substantial Ti+3 in pyroxene.

Plagioclase: Large grains of plagioclase (up to 1.5 mm) poikilitically enclose pyroxene (Dymek et al. 1975). Other plagioclase forms elongate sheaves intergrown with pyroxene (figure 5). Plagioclase composition is An_{77-84}.

Ilmenite: Elongated blades of ilmenite in 71055 have been studied by Dymek et al. (1975), von Englehardt (1979) and Muhich et al. (1990). Taylor et al. (1992) have shown how to separate the ilmenite.

Chemistry

Tables 1 – 4 and figures 12 and 13 show that the chemical composition of 71055, 71035 and 71037 are typical of Apollo 17 basalts. Additional data for Zr and Hf are given in Garg and Ehman (1976) and Hughes and Schmitt (1985). Moore et al. (1974), Gibson et al. (1976), Moore and Lewis (1976) and Sill et al. (1974) determined C, S and N.

Radiogenic age dating

Tera et al. (1974) determined the age of 71055 by precise Rb-Sr isochron (figure 13). *Murthy and Coscio (1976) merely quote Tera et al.* Chen et al. (1979) and Taylor and Chen (1979) tried, but could not date 71055 by U-Th-Pb. Nyquist et al. (1976) determined the whole rock Rb and Sr isotopic composition of 71035, but did not obtain an isochron.

Cosmogenic isotopes and exposure ages

Rancitelli et al. (1974) determined the cosmic-ray-induced activity of 71035 (144 g). ^{22}Na was 92 dpm/kg., ^{26}Al = 79 dpm/kg, ^{46}Sc = 87 dpm/kg., ^{54}Mn = 164 dpm/kg. and ^{56}Co = 279 dpm/kg. Arvidson et al. (1976) determined the cosmic ray exposure age by Kr-Kr analysis as 110 ± 7 m.y.

Other Studies

Brecher (1974)	magnetic properties
Mayeda et al. (1975)	oxygen isotopes
Watson et al. (1974)	magnetics
Trice et al. (1974)	elastic properties
Usselman et al. (1975)	experimental
O'Hara and Humphries	experimental
Taylor et al. (1992)	ISRU benification

Processing

71036 was returned in a sealed rock box (ALSRC #1) and placed in a freezer (-20 C). It has not been studied. A small slab was sawn from 71055 (figure 14).

Summary of Age Data for 71055

	Rb/Sr	U/Pb
Tera et al. 1974	3.64 ± 0.09 b.y.	
Chen et al. 1979		
Tilton and Chen 1979		

Caution: Old decay constant used.

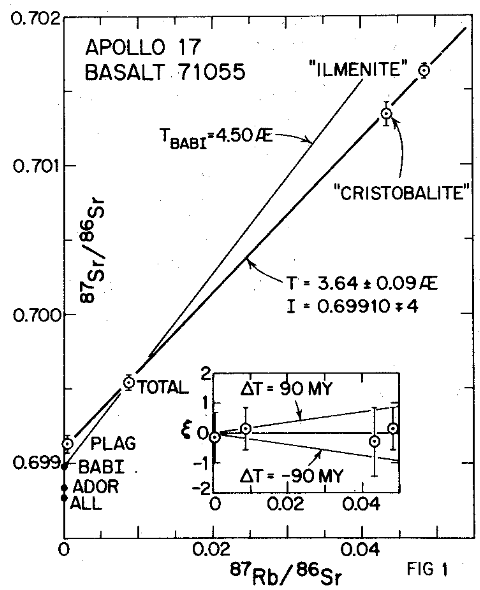


Figure 13: "Picture worth a 1000 words" (Tera et al. 1975).

Table 1. Chemical composition of 71055.

reference	Miller74		Brunfelt74		Boynton75		Rose 74		Philpotts74		Baedecker74		Dickenson89	
weight					241 mg				88.29					
SiO2 %	37.44	(a)					38.14	(b)						
TiO2	12.17	(a)	14.36	(a)	*14.51*	(a)	13.41	(b)						
Al2O3	8.31	(a)	9.31	(a)	10.01	(a)	8.62	(b)						
FeO	19.43	(a)	19.04	(a)	18.52	(a)	19.2	(b)			21.07		16	
MnO	0.26	(a)	0.26	(a)	0.26	(a)	0.26	(b)			0.27	(a)		
MgO	10.44	(a)	8.79	(a)			9.04	(b)						
CaO	*9.5*	(a)	11.33	(a)	10.63	(a)	10.77	(b)					12.2	
Na2O	0.44	(a)	0.42	(a)	0.41	(a)	0.31	(b)			0.42		0.34	
K2O			0.043	(a)			0.06	(b)	0.041	(c)				
P2O5							0.08	(b)						
S %														
sum														
Sc ppm			95	(a)	82	(a)	87	(b)			94	(a)	80	(d)
V			129	(a)			88	(b)					364	(d)
Cr			2790	(a)	2640	(a)	2805	(b)			2800	(a)	2805	(d)
Co			21.6	(a)	22	(a)	51	(b)			26	(a)	18	(d)
Ni			<10	(a)			43	(b)			2	(d)		
Cu			4.4	(a)			31	(b)						
Zn			3	(a)							1.9	(d)		
Ga			3	(a)			8.1	(b)			4.27	(d)	22	(d)
Ge ppb											3.3	(d)	2.4	(d)
As														
Se														
Rb			0.9	(a)			0.9	(b)	0.362	(c)				
Sr			104	(a)			170	(b)	121	(c)				
Y							69	(b)						
Zr							223	(b)						
Nb							27	(b)						
Mo														
Ru														
Rh														
Pd ppb														
Ag ppb														
Cd ppb											<1.5	(d)		
In ppb											4.7	(d)		
Sn ppb														
Sb ppb														
Te ppb														
Cs ppm			0.07	(a)										
Ba			39	(a)			315	(b)	62.4	(c)			63	(d)
La			4.67	(a)	4.6	(a)							4.6	(d)
Ce			13.4	(a)	22	(a)			15.6	(c)	23	(a)	13	(d)
Pr														
Nd									17	(c)			33	(d)
Sm			7.05	(a)	6.1	(a)			6.72	(c)			6	(d)
Eu			1.49	(a)	1.8	(a)			1.36	(c)	1.5	(a)	1.3	(d)
Gd														
Tb			1.74	(a)	2	(a)					2.1	(a)	1.6	(d)
Dy			14.3	(a)					13	(c)				
Ho														
Er									7.74	(c)			0.87	(d)
Tm														
Yb			5.4	(a)	6.3	(a)	5.4	(b)	7.75	(c)	5.7	(a)	6.4	(d)
Lu			1.1	(a)	1.1	(a)							1	(d)
Hf			6.6	(a)	6	(a)					7	(a)		
Ta			1.54	(a)	1.6	(a)					1.3	(a)		
W ppb			0.089	(a)										
Re ppb														
Os ppb														
Ir ppb											1.1	(d)		
Pt ppb														
Au ppb											0.082	(d)		
Th ppm			0.32	(a)										
U ppm			0.132	(a)										

technique: (a) INAA, (b) microchemical, (c) IDMS, (d) RNAA

Table 2. Chemical composition of 71035.

reference	Rhodes76	
weight		
SiO2 %	38.25	(a)
TiO2	13.06	(a)
Al2O3	8.77	(a)
FeO	19.74	(a)
MnO	0.29	(a)
MgO	7.98	(a)
CaO	10.87	(a)
Na2O	0.38	(a)
K2O	0.03	(a)
P2O5	0.1	(a)
S %	0.15	(a)
sum		
Sc ppm	87	(b)
V		
Cr	2669	(a)
Co	19	(b)
Ni		
Cu		
Zn		
Ga		
Ge ppb		
As		
Se		
Rb	0.41	(c)
Sr	130	(c)
Y		
Zr		
Nb		
Mo		
Ru		
Rh		
Pd ppb		
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb		
Te ppb		
Cs ppm		
Ba	66.3	(c)
La	5.77	(c)
Ce	18.7	(c)
Pr		
Nd	18.8	(c)
Sm	7.5	(c)
Eu	1.5	(c)
Gd	12.1	(c)
Tb		
Dy	13.6	(c)
Ho		
Er	8.27	(c)
Tm		
Yb	7.71	(c)
Lu	1.14	(b)
Hf	7	(b)
Ta		
W ppb		
Re ppb		
Os ppb		
Ir ppb		
Pt ppb		
Au ppb		
Th ppm		
U ppm		

technique: (a) XRF, (b) INAA, (c) IDMS

Table 3. Chemical composition of 71037.

	Ma 1979	
reference	Warner79	
weight	0.54 g	
SiO2 %		
TiO2	11.2	(a)
Al2O3	8.9	(a)
FeO	19.4	(a)
MnO	0.246	(a)
MgO	7	(a)
CaO	11.2	(a)
Na2O	0.425	(a)
K2O	0.046	(a)
P2O5		
S %		
sum		
Sc ppm	85	(a)
V	73	(a)
Cr	2121	(a)
Co	20	(a)
Ni		
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	6.1	(a)
Ce	21	(a)
Pr		
Nd	23	(a)
Sm	8.1	(a)
Eu	1.54	(a)
Gd		
Tb	1.9	(a)
Dy	13	(a)
Ho		
Er		
Tm		
Yb	7.4	(a)
Lu	1.02	(a)
Hf	7	(a)
Ta	1.7	(a)
W ppb		
Re ppb		
Os ppb		
Ir ppb		
Pt ppb		
Au ppb		
Th ppm		
U ppm		

technique: (a) INAA

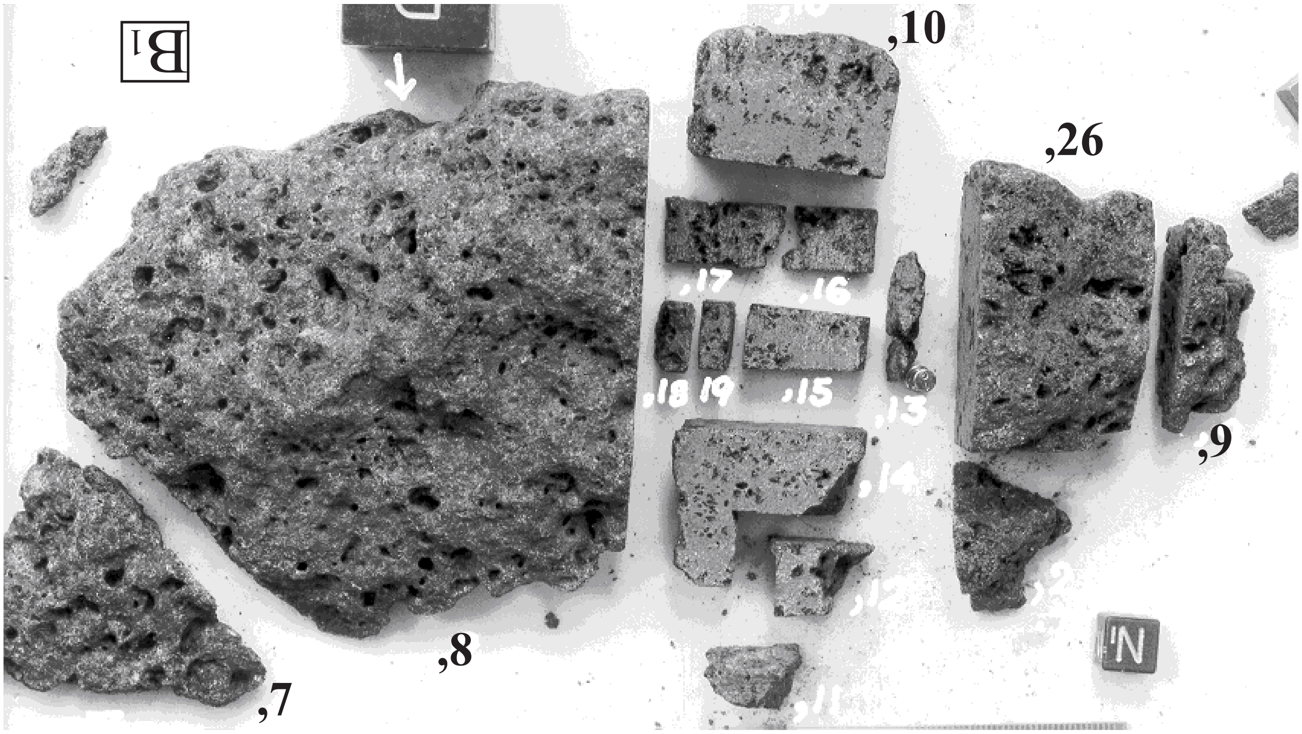
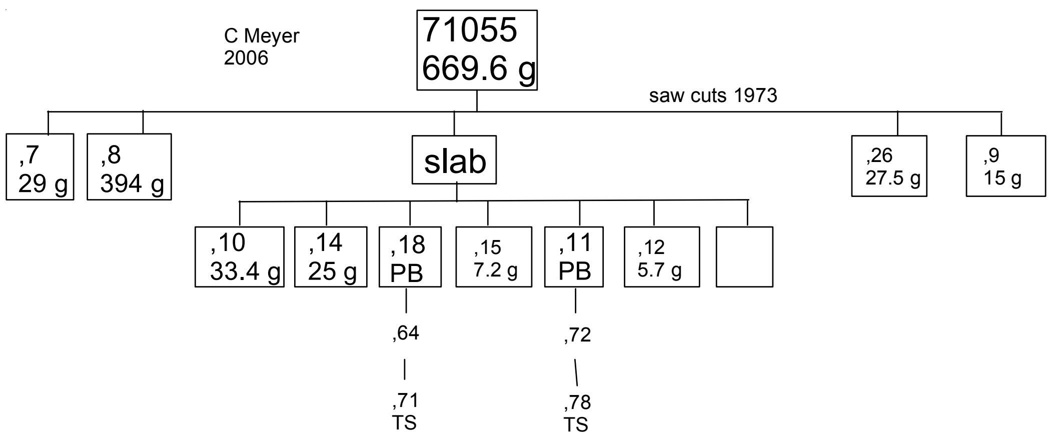
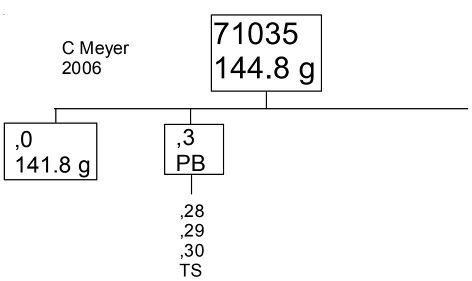
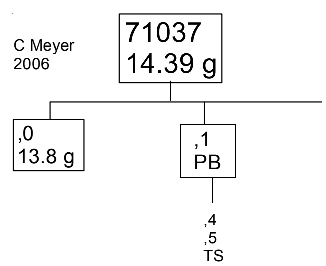


Figure 14: Group photo after cutting slab from 71055. Small cube is 1 cm. NASA S73-34148. This is the top, exposed lunar surface.







References

Arvidson R., Drozd R., Guiness E., Hohenberg C., Morgan C., Morrison R. and Oberbeck V. (1976) Cosmic ray exposure ages of Apollo 17 samples and the age of Tycho. Proc. 7th Lunar Sci. Conf. 2817-2832.

Baedecker P.A., Chou C.L., Sundberg L.L. and Wasson J.T. (1974) Volatile and siderophile trace elements in the soils and rocks of Taurus-Littrow. Proc. 5th Lunar Sci. Conf. 1625-1643.

Boynton W.V., Baedecker P.A., Chou C.L., Robinson K.L. and Wasson J.T. (1975) Mixing and transport of lunar surface materials: Evidence obtained by the determination of lithophile, siderophile and volatile elements. Proc. 6th Lunar Sci. Conf. 2241-2259.

Brecher A. (1974) Inferences from comparative magnetic studies of some Apollo 17 basalts, breccias and soils. LS V, 83-85.

Brown G.M., Peckett A., Emeleus C.H., Phillips R. and Pinsent R.H. (1975) Petrology and mineralogy of Apollo 17 mare basalts. Proc. 6th Lunar Sci. Conf. 1-13.

Brunfelt A.O., Heier K.S., Nilssen B., Steinnes E. and Sundvoll B. (1974) Elemental composition of Apollo 17 fines and rocks. Proc. 5th Lunar Sci. Conf. 981-990.

Chen J.H., Tilton G.R. and Mattinson J.M. (1979) Lead isotope systematics of three Taurus-Littrow mare basalts. LPS X, 195-197.

Dickinson T., Taylor G.J., Keil K. and Bild R.W. (1989) Germanium abundances in lunar basalts: Evidence of mantle metasomatism. Proc. 19th Lunar Planet. Sci. Conf. 189-198.

Dymek R.F., Albee A.L. and Chodos A.A. (1975) Comparative mineralogy and petrology of Apollo 17 mare basalts: Samples 70215, 71055, 74255, 75055. Proc. 6th Lunar Sci. Conf. 49-77.

Engelhardt W. von (1979) Ilmenite in the crystallization sequence of lunar rocks. Proc. 10th Lunar Planet. Sci. Conf. 677-694.

Garg A.N. and Ehmann W.N. (1976) Zr-Hf fractionation in chemically defined lunar rock groups. Proc. 7th Lunar Sci. Conf. 3397-3410.

Gibson E.K., Morris R.V. and Usselman T.M. (1976) Sulfur in the Apollo 17 basalts and their source regions. Proc. 7th Lunar Sci. Conf. 1491-1505.

Hughes S.S. and Schmitt R.A. (1985) Zr-Hf-Ta fractionation during lunar evolution. Proc. 16th Lunar Planet. Sci. Conf. D31-D45.

LSPET (1973) Preliminary examination of lunar samples. Apollo 17 Prelim. Sci. Rept. NASA SP-330

Ma M.-S., Schmitt R.A., Warner R.D., Taylor G.J. and Keil K. (1979) Composition, petrology and genesis of Apollo 17 high-Ti mare basalts. LPS X, 765-767.

Mayeda T.K., Shearer J. and Clayton R.N. (1975) Oxygen isotope fractionation of Apollo 17 rocks. Proc. 6th Lunar Sci. Conf. 1799-1802.

Miller M.D., Pacer R.A., Ma M.-S., Hawke B.R., Lockart G.L. and Ehmann W.D. (1974) Composition studies of the lunar regolith at the Apollo 17 site. Proc. 5th Lunar Sci. Conf. 1079-1086.

Moore C.B., Lewis C.F. and Cripe J.D. (1974) Total carbon and sulfur contents of Apollo 17 lunar samples. Proc. 5th Lunar Sci. Conf. 1879-1906.

Moore C.B and Lewis C.F. (1976) Total nitrogen contents of Apollo 15, 16 and 17 lunar rocks and soils. LS VII, 571-573.

Muhich T., Vaniman D. and Heiken G. (1990) Ilmenite in high-Ti Apollo 17 basalts: Variations in composition with degree of exsolution. LPSC XXI, 817-819.

Muthy V.R. and Coscio C. (1976) Rb-Sr ages and isotopic systematics of some Serenitatis mare basalts. Proc. 7th Lunar Sci. Conf. 1529-1544.

Neal C.R. and Taylor L.A. (1993) Catalog of Apollo 17 Rocks. Vol. 2

Nyquist L.E., Bansal B.M. and Wiesmann H. (1976) Sr isotopic constraints on the petrogenesis of Apollo 17 mare basalts. Proc. 7th Lunar Sci. Conf. 1507-1528.

O'Hara M.J. and Humphries D.J. (1975) Armalcolite crystallization, phenocryst assemblages, eruption conditions and origin of eleven high titanium basalts from Taurus Littrow. LS VI, 619-621.

Philpotts J.A., Schumann S., Kouns C.W., Lum R.K.L and Winzer S. (1974) Origin of Apollo 17 rocks and soils. Proc. 5th Lunar Sci. Conf. 1255-1267.

Rancitelli L.A., Perkins R.W., Fekix W.D., and Wogman N.A. (1974) Solar flare and lunar surface process characterization of Apollo 17 site. Proc. 5th Lunar Sci. Conf. 2185-2203.

Rhodes J.M., Hubbard N.J., Wiesmann H., Rodgers K.V., Brannon J.C. and Bansal B.M. (1976) Chemistry, classification and petrogenesis of Apollo 17 mare basalts. Proc. 7th Lunar Sci. Conf. 1467-1489.

Rose H.J., Cuttitta F., Berman S., Brown F.W., Carron M.K., Christian R.P., Dwornik E.J. and Greenland L.P. (1974) Chemical composition of rocks and soils at Taurus-Littrow. Proc. 5th Lunar Sci. Conf. 1119-1133.

Sill G.T., Nagy B., Nagy L.A., Hamilton P.B, McEwan W.S. and Urey H.C. (1974) Carbon compounds in Apollo 17 lunar samples: Implications of cometary contribution to breccia 78155? LS V, 703-705.

Sung C.-M., Abu-Eid R.M. and Burns R.G. (1974) Ti+3/Ti+4 ratios in lunar pyroxenes: implications to depth of origin of mare basalt magma. Proc. 5th Lunar Sci. Conf. 717-726.

Taylor L.A., McKay D.S., Patchen A., Wentworth S., Oder R. and Jerde E. (1992) Magnetic beneficiation of high-Ti mare basalts: Petrographic analysis. LPSC XXVIII, 1415-1516.

Tera F., Papanastassiou D.A. and Wasserburg G.J. (1974) The lunar time scale and a summary of isotopic evidence for a terminal lunar cataclysm. LS V, 792-794.

Tilton G.R. and Chen J.H. (1979) Lead isotope systematics of three Apollo 17 mare basalts. Proc. 10th Lunar Planet. Sci. Conf.259-274.

Trice R., Warren N. and Anderson O.L. (1974) Rock elastic properties and near-surface structure of Taurus-Littrow. Proc. 5th Lunar Sci. Conf. 2903-2911.

Usselman T.M., Lofgren G.E., Donaldson C.H. and Williams R.J. (1975) Experimentally reproduced textures and mineral chemistries of high-titanium mare basalts. Proc. 6th Lunar Sci. Conf. 997-1020.

Warner R.D., Taylor G.J., Conrad G.H., Northrup H.R., Barker S., Keil K., Ma M.-S. and Schmitt R. (1979) Apollo 17 high Ti mare basalts: New bulk composition data, magma types and petrogenesis. Proc. 10th Lunar Planet. Sci. Conf. 225-247.

Watson D.E., Larson E.E. and Reynolds R.L. (1974) Microscopic and thermomagnetic analysis of Apollo 17 breccia and basalt: feasibility of obtaining meaningful paleointensities of the lunar magnetic field. LS V, 827-829.

Wolfe E.W., Bailey N.G., Lucchitta B.K., Muehlberger W.R., Scott D.H., Sutton R.L. and Wilshire H.G. (1981) The geologic investigation of the Taurus-Littrow Valley: Apollo 17 landing site. USGS Prof. Paper 1080

Table 4	U ppm	Th ppm	K ppm	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique
Rancitelli et al. 1974	0.096	0.36	200					counting
LSPET 73	0.11	0.32	460					counting
Brunfelt et al. 1974	0.132	0.32						INAA
Tilton and Chen 1979	0.1077	0.353						idms
	0.0828	0.277						
	0.1285	0.448						
	0.077	0.266						