12038

Feldspathic Basalt

746 grams

Figure 1: Picture of surface of 12038,7 and ,205 showing zap pits. Cube is 1 inch. NASA #S75-34403.

Introduction

Lunar basalt 12038 is distinctly different from the other Apollo 12 basalts. It has more feldspar, higher Na_2O and Al_2O_3, higher REE and is characterized by a distinct isotopic composition (Nyquist et al. 1981).

According to Hörz and Hartung (1971), rock 12038 has micrometeorite craters on only one surface orientation with a well-developed "soil line" made up of glass splashes and welded dust indicating only one orientation during its history on the lunar surface.

Petrography

The petrology of 12038 is discussed by Keil et al. (1971), Simpson and Bowie (1971) and Beaty et al. (1979). Beaty et al. describe the texture of 12038 as "hypidiomorphic and dominantly equigranular (~0.6 mm). Plagioclase laths form a loose, randomly oriented network in which pyroxene is either interstitial or partially enclosed. Also present is acicular ilmenite, interstitial cristobalite, trace Ca-phosphate, fayalite, ulvöspinel, K-feldspar, troilite, K-glass and Fe-metal."

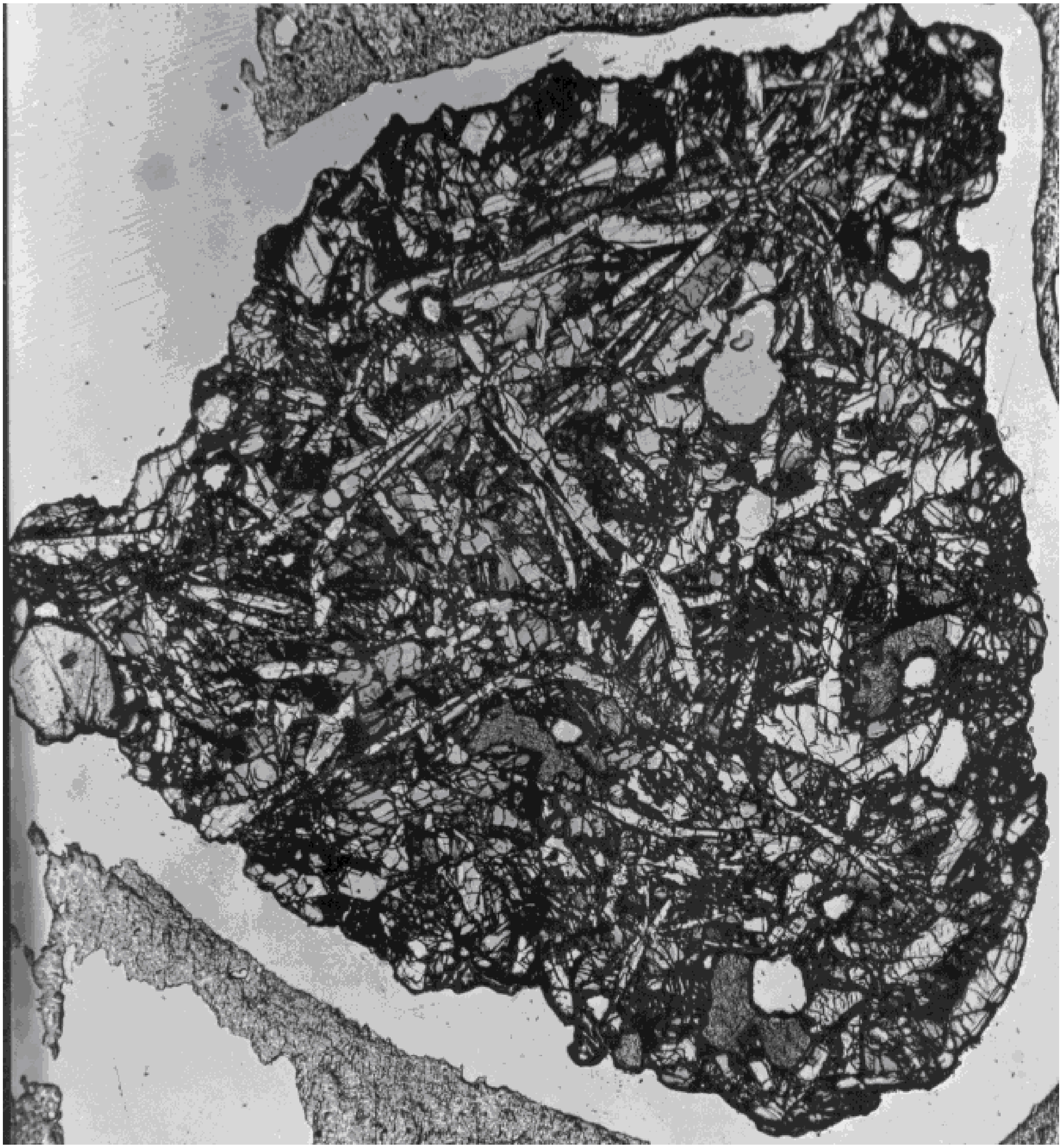


Figure 2: Thin section 12038,29 showing abundant feldspar. NASA photo. Scale is 2 cm.

Mineralogical Mode of 12038

	Beaty et al. 1979	Neal et al. 1994	Christie et al. 1971
Olivine		0.1	
Pyroxene	49	48.8	55
Plagioclase	44	43.8	30
Ilmenite	3.46	3.5	10
Chromite	0.2	0.2	
“silica”	2.7	2.7	
mesostasis	0.05	0.7	

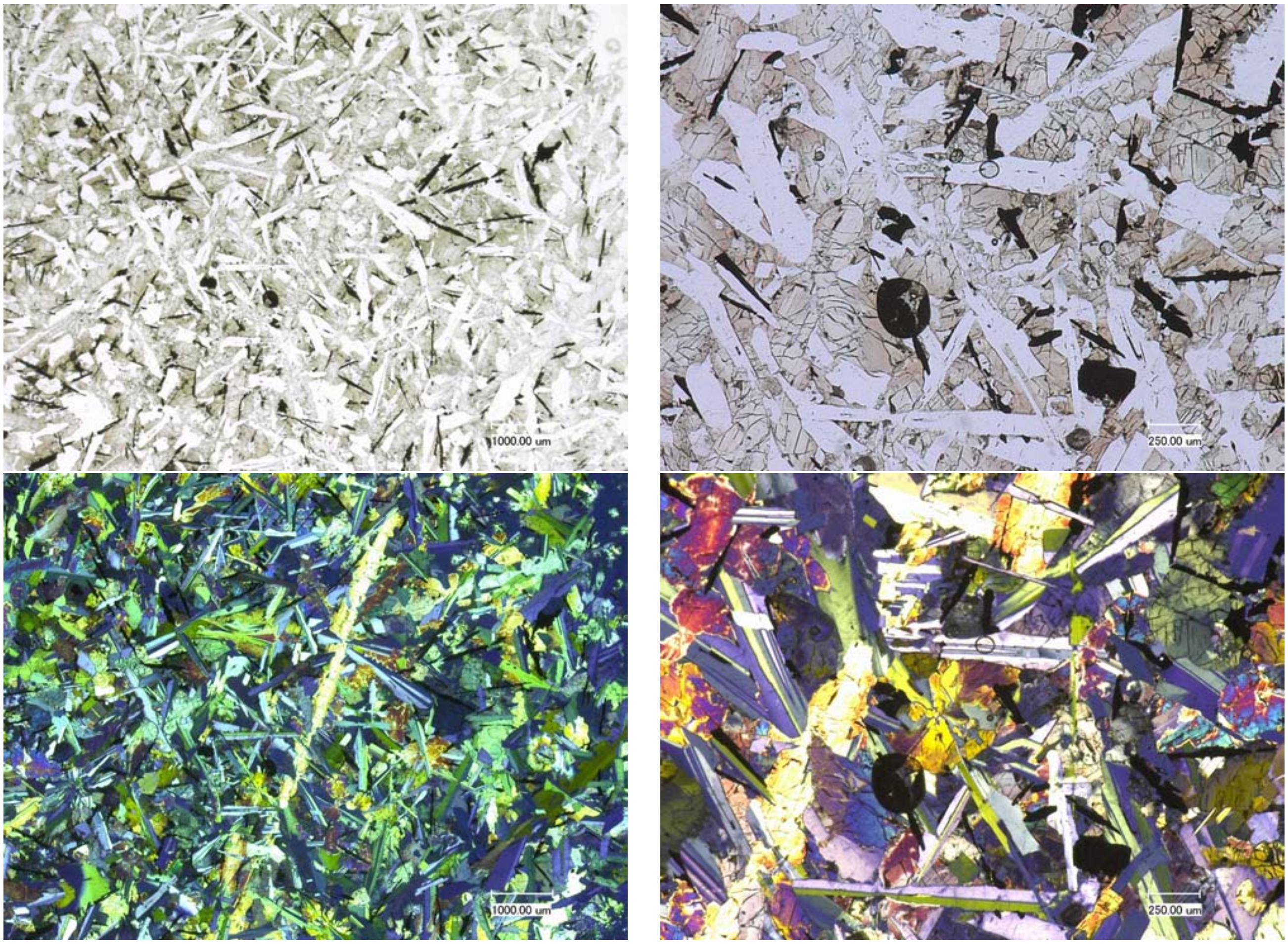


Figure 3a: Photomicrographs of 12038,64 by C Meyer. 30xvideo and 100xvideo

12038 has an average grain size of about 600 microns (Beaty et al.) and also contains a few % vesicles.

The origin of 12038 has been modeled by Nyquist et al. (1981) in the context of other Apollo 12 basalts. It points to a few % plagioclase in the source region for 12038 magma.

Mineralogy

Olivine: A minor amount of "resorbed" or "cumulus" olivine (Fo_{60}) as well as some fayalite is reported by Keil et al. (1971).

Pyroxene: Keil et al. (1971), Busche et al. (1971) and Beaty et al. (1979) reported the pyroxene composition (figure 4). Gose et al. (1972) determined the cell dimensions of exsolved pyroxenes in 12038.

Pyroxferroite: Busche et al. (1971) reported pyroxferroite in 12038. Beaty et al. determined that the composition was $Wo_{17}En_3Fs_{80}$.

Plagioclase: The plagioclase in 12038 (An_{82}) has high Fe content (up to 1.9 wt. % FeO, Keil et al. 1971). Beaty et al. (1979) found most plagioclase to be lath-like, typically twinned and zoned from An_{82-73}. Christie et al. (1971) observed laths-shaped plagioclase crystals ranging up to 3 mm long occur locally in radiating clusters (figure 3). The last plagioclase to crystallize is anhedral and poikilitically surrounds the earlier formed minerals.

Ilmenite: Busche et al. (1971) and Beaty et al. (1979) determined the composition of ilmenite.

Metallic iron: Simpson and Bowie (1971) reported low Ni in iron in 12038 (figure 5).

Chemistry

12038 has more sodium and aluminum than other Apollo 12 basalts (table 1). The REE pattern is also distinctly different (figure 6). *Note the importance of*

Figure 3b: Photomicrographs of thin section 12038,2 (top = plane-polarized light; bottom = crossed-nicols). Scale 2.2 mm. NASA S70-49437-438.

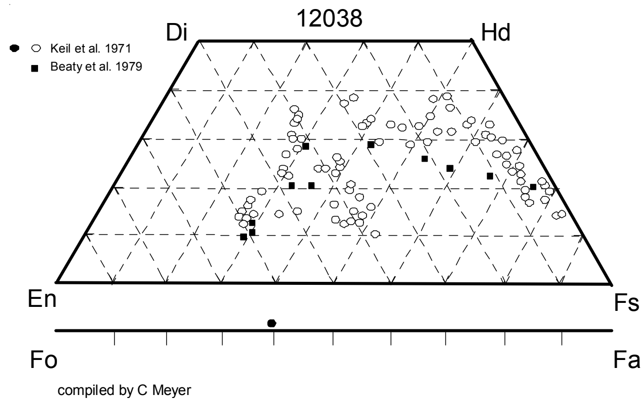


Figure 4: Pyroxene composition for 12038 (adapted from Keil et al. 1971 and Beaty et al. 1977).

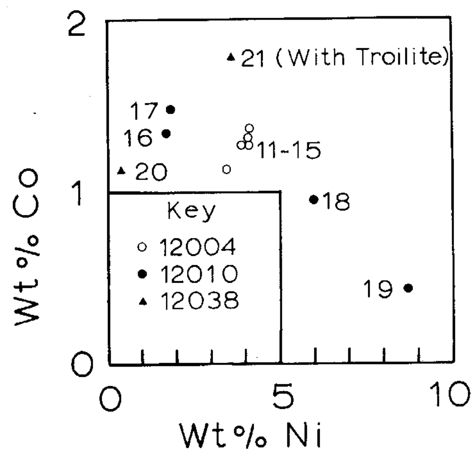


Figure 5: Ni and Co in 12038 and 12004 as determined by Simpson and Bowie (1971).

high-quality analyses (and/or correct sample size) is clearly indicated by the dispersion of the data in figure 6.

Radiogenic age dating

Compston et al. (1971) dated 12038 at 3.28 ± 0.21 b.y. by Rb/Sr (figure 8). Nyquist et al. (1981) obtained ages 3.35 ± 0.09 b.y. by Rb/Sr (figure 9) and 3.28 ± 0.23 b.y. by Nd/Sm (figure 10).

Nyquist showed that the initial Sr and Nd isotope ratios were distinctly different from those of other Apollo 12 basalts (figure 11).

Cosmogenic isotopes and exposure ages

Burnett et al. (1975) determined an exposure age of 230 ± 15 m.y. by $^{81}Kr/^{83}Kr$. The suntan age for 12038 (from etched solar flare track studies) is 1.3 m.y. (Bhandari et al. 1971).

Other Studies

Biggar et al. (1971) used the composition of 12038 in their experimental studies. At 1 atm. they found olivine was the liquidus phase (1160 C), followed closely by pigeonite and plagioclase, such that they could say 12038 was “multiply saturated” at low pressure.

Bogard et al. (1971) reported the content and isotopic composition of rare gases in 12038.

Processing

A slab (,6) was cut through the middle of 12038 (figure 12) and a column (,8) was cut from the slab (figure 13). A piece of the end (,74) is on public display (figure 14).

There are 14 thin sections of 12038.

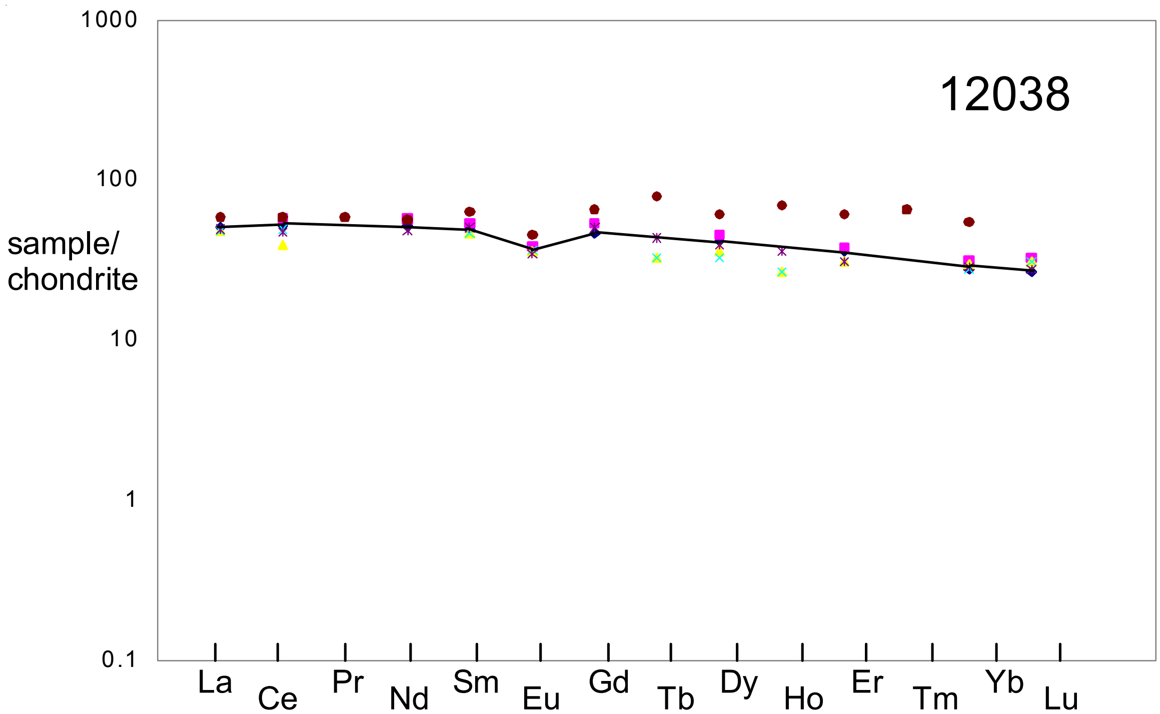


Figure 6: Normalized rare-earth-element diagram for 12038 comparing neutron activation analysis (Brunfelt et al. 1971, Haskin et al. 1971) and spark source mass spectroscopy (Taylor et al. 1971) with isotope dilution mass spectroscopy (line, Schnetzler and Phillpotts 1971, Nyquist et al. 1979).

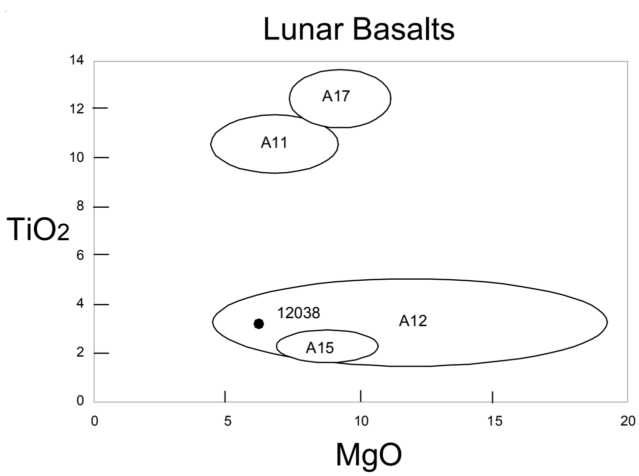


Figure 7: Composition of 12038 compared with that of other lunar basalts.

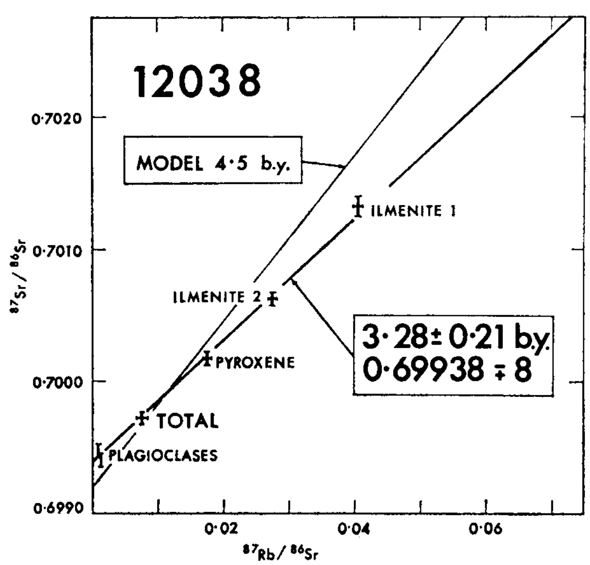


Figure 8: Rb-Sr mineral isochron for 12038 (from Compston et al. 1971).

Table 1a. Chemical composition of 12038.

reference	LSPET70	Kushiro 71		Cuttita 71		Compston71				Biggar71		Willis72		Beaty79	Taylor71	
weight										Peck				ave.		
SiO2 %	49	47.05	(a)	47.1	(b)	46.56	(e)			47.13	(a)	46.61	(e)	46.85		
TiO2	3.2	3.33	(a)	3.17	(b)	3.31	(e)			3.28	(a)	3.25	(e)	3.25		
Al2O3	12	12.12	(a)	12.8	(b)	12.53	(e)			13.03	(a)	12.45	(e)	12.7		
FeO	17	17.91	(a)	17.4	(b)	17.99	(e)			17.73	(a)	17.75	(e)	17.72		
MnO	0.26	0.24	(a)	0.24	(b)	0.27	(e)			0.25	(a)	0.251	(e)	0.25		
MgO	6.5	7.09	(a)	6.8	(b)	6.71	(e)			6.6	(a)	6.83	(e)	6.74		
CaO	11	11.46	(a)	11.4	(b)	11.62	(e)			11.43	(a)	11.48	(e)	11.48		
Na2O	0.6	0.64	(a)	0.64	(b)	0.66	(e)			0.69	(a)	0.67	(e)	0.67		
K2O	0.057	0.07	(a)	0.07	(b)	0.073	(e)			0.06	(a)	0.067	(e)	0.07		
P2O5		0.02	(a)			0.14	(e)			0.14	(a)	0.12	(e)	0.14		
S %						0.06	(e)					0.07	(e)	0.07		
sum																
Sc ppm	55			50	(b)									48.2	50	(f)
V	70			126	(b)	104	(e)								120	(f)
Cr	2200	2326	(a)	2210	(b)	1840	(e)					2190	(e)	2050	2100	(f)
Co	23			34	(b)	25	(e)							29.1	29	(f)
Ni	14			6.7	(b)	2	(e)								1	(f)
Cu				10	(b)	8	(e)								5	(f)
Zn						3	(e)									
Ga						3.8	(e)									
Ge ppb																
As																
Se																
Rb	0.7					0.48	(e)	0.6	(d)							
Sr	230			158	(b)	185.8	(e)	186	(d)			185	(e)	173	180	(f)
Y	68			71	(b)	46	(e)					50.5	(e)	59	68	(f)
Zr	260			186	(b)	160	(e)					182	(e)	182	200	(f)
Nb						7	(e)					9.3	(e)	9	7.8	(f)
Mo															0.05	(f)
Ru																
Rh																
Pd ppb																
Ag ppb																
Cd ppb																
In ppb																
Sn ppb															100	(f)
Sb ppb																
Te ppb																
Cs ppm															0.02	(f)
Ba	230			142	(b)	120	(e)					107	(e)	119	125	(f)
La						10	(e)							12.47	14	(f)
Ce						25	(e)							30	36	(f)
Pr															5.3	(f)
Nd															26	(f)
Sm															9.4	(f)
Eu														2.2	2.6	(f)
Gd															13	(f)
Tb														1.9	2.9	(f)
Dy															15	(f)
Ho															3.9	(f)
Er															9.9	(f)
Tm															1.6	(f)
Yb				6.3	(b)									6.05	9	(f)
Lu														0.75		
Hf														6.5	6.5	(f)
Ta																
W ppb																
Re ppb																
Os ppb																
Ir ppb																
Pt ppb																
Au ppb																
Th ppm															1	(f)
U ppm															0.25	(f)

technique (a) conventional wet, (b) mixed microchem. XRF emiss. Spec. (c) INAA, (d) IDMS, (e) XRF, (f) SSMS

Table 1b. Chemical composition of 12038.

reference	Schnetzler71		Brunfelt71			Haskin71		Anders71		Tatsumoto71		Baedecker71		Nyquist79		Dickenson89	
weight	124 mg																
SiO2 %																	
TiO2			3.18	3.4	(h)												
Al2O3			12.6	12.6	(h)												
FeO			18.14	17.7	(h)											17.1	(h)
MnO			0.24	0.32	(h)												
MgO																	
CaO																11.2	(h)
Na2O			0.63	0.63	(h)											0.66	(h)
K2O	0.076	(d)	0.064	0.6	(h)									0.074	(d)		
P2O5																	
S %																	
sum																	
Sc ppm			44.6	42.7	(h)											49	(h)
V			154	144	(h)												
Cr			2040	2010	(h)											1400	(h)
Co			28.4	28	(h)			25	(g)							28	(h)
Ni																	
Cu			16.6	10.3	(h)												
Zn			6.1	3.2	(h)			2.09	(g)			1.3	(g)				
Ga			5.1	5.5	(h)			4.3	(g)			5.2	(g)				
Ge ppb																4.3	(h)
As			0.15	0.1	(h)												
Se			0.182	0.174	(h)			0.12	(g)								
Rb	0.604	(d)	0.43	0.44	(h)			0.41	(g)					0.578	(d)		
Sr	190	(d)	137	152	(h)											219	(h)
Y																	
Zr																274	(h)
Nb																	
Mo																	
Ru																	
Rh																	
Pd ppb																	
Ag ppb			80	60	(h)			*80*	(g)								
Cd ppb								*5.2*	(g)			6.1	(g)				
In ppb			171	149	(h)			*77*	(g)			1.1	(g)				
Sn ppb																	
Sb ppb			10	20	(h)												
Te ppb																	
Cs ppm			0.014	0.021	(h)			0.015	(g)								
Ba	130	(d)	91	89	(h)									118	(d)	198	(h)
La			11.6	11.5	(h)	11.8	(c)							12.1	(d)	11.8	(h)
Ce	35	(d)	24	30	(h)	29.1	(c)							31.7	(d)	31	(h)
Pr																	
Nd	26.3	(d)				22	(c)							23.7	(d)	28	(h)
Sm	8.02	(d)	6.93	6.87	(h)	7.57	(c)							7.35	(d)	7.2	(h)
Eu	2.19	(d)	2.04	2.05	(h)	1.969	(c)							2.1	(d)	2.2	(h)
Gd	10.6	(d)				10.1	(c)							9.28	(d)		
Tb			1.19	1.19	(h)	1.61	(c)									1.7	(h)
Dy	11.1	(d)	8.8	8	(h)	9.73	(c)							10.2	(d)		
Ho			1.48	1.48	(h)	1.99	(c)										
Er	6.12	(d)	5	4.9	(h)	5	(c)							5.71	(d)		
Tm																1.2	(h)
Yb	5.26	(d)	4.9	4.5	(h)	4.8	(c)							4.64	(d)	4.8	(h)
Lu	0.814	(d)	0.75	0.76	(h)	0.689	(c)							0.65	(d)	0.78	(h)
Hf			5	4.8	(h)											4.8	(h)
Ta			0.59	0.63	(h)											0.67	(h)
W ppb			108	106	(h)												
Re ppb																	
Os ppb																	
Ir ppb			0.1		(h)			0.04	(g)			0.09	(g)				
Pt ppb																	
Au ppb			42	3.5	(h)			0.36	(g)								
Th ppm			0.29	0.18	(h)					0.615	(d)					0.6	(h)
U ppm			0.14	0.1	(h)					0.157	(d)						

technique: (c) INAA, (d) IDMS, (g) RNAA, (h) various NAA

Table 1c. Chemical composition of 12038.

reference	Neal2001	
weight		
SiO2 %		
TiO2		
Al2O3		
FeO		
MnO		
MgO		
CaO		
Na2O		
K2O		
P2O5		
S %		
sum		
Sc ppm	50.4	(a)
V	133	(a)
Cr	2221	(a)
Co	32.4	(a)
Ni	4.42	(a)
Cu	18.9	(a)
Zn	23.8	(a)
Ga	4.84	(a)
Ge ppb		
As		
Se		
Rb	0.67	(a)
Sr	207	(a)
Y	60	(a)
Zr	185	(a)
Nb	9.3	(a)
Mo	0.03	(a)
Ru		
Rh		
Pd ppb		
Ag ppb		
Cd ppb		
In ppb		
Sn ppb		
Sb ppb		
Te ppb		
Cs ppm		
Ba	122	(a)
La	12	(a)
Ce	30.8	(a)
Pr	4.64	(a)
Nd	22	(a)
Sm	6.91	(a)
Eu	1.99	(a)
Gd	9.28	(a)
Tb	1.48	(a)
Dy	9.77	(a)
Ho	1.94	(a)
Er	5.52	(a)
Tm	0.74	(a)
Yb	4.67	(a)
Lu	0.61	(a)
Hf	4.7	(a)
Ta	0.55	(a)
W ppb	100	(a)
Re ppb		
Os ppb		
Ir ppb		
Pt ppb		
Au ppb		
Th ppm	0.61	(a)
U ppm	0.16	(a)

technique: (a) ICP-MS

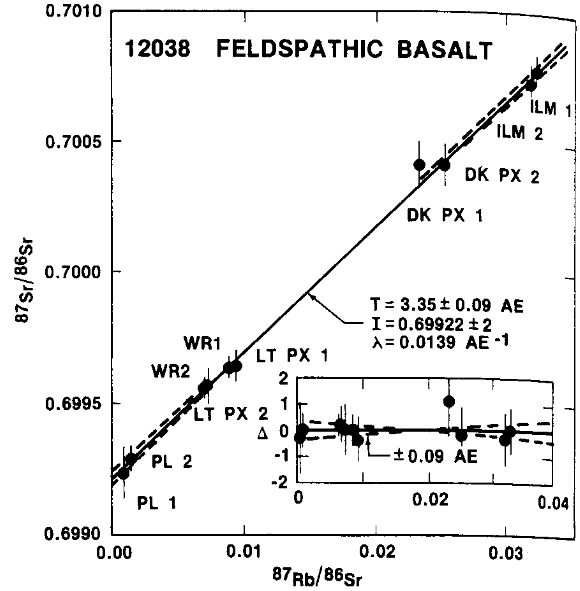


Figure 9: Rb-Sr mineral isochron diagram for feldspathic basalt 12038 (from Nyquist et al. 1981).

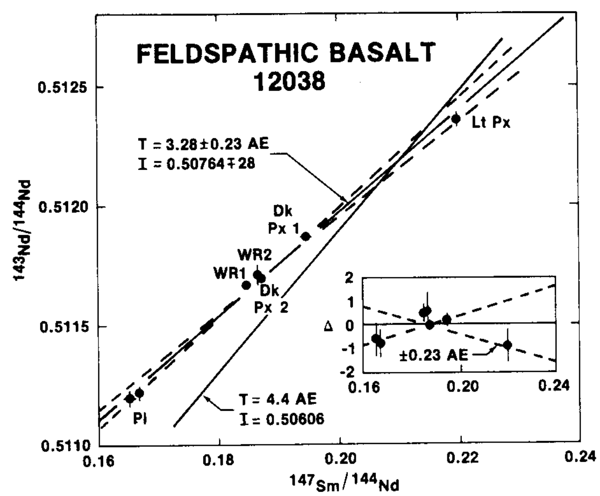


Figure 10: Nd-Sm mineral isochron for 12038 (from Nyquist et al. 1981).

Summary of Age Data for 12038

	Ar/Ar	Rb/Sr	Nd/Sm	Nyquist 1977 (recalculated)
Nyquist et al. 1981		3.35 ± 0.09 b.y.	3.28 ± 0.23	
Compston et al. 1971		3.28 ± 0.21		(3.22 ± 0.21)

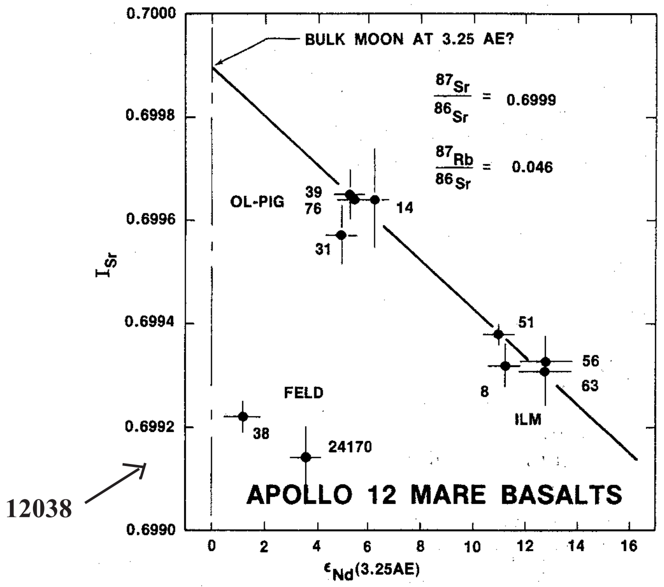
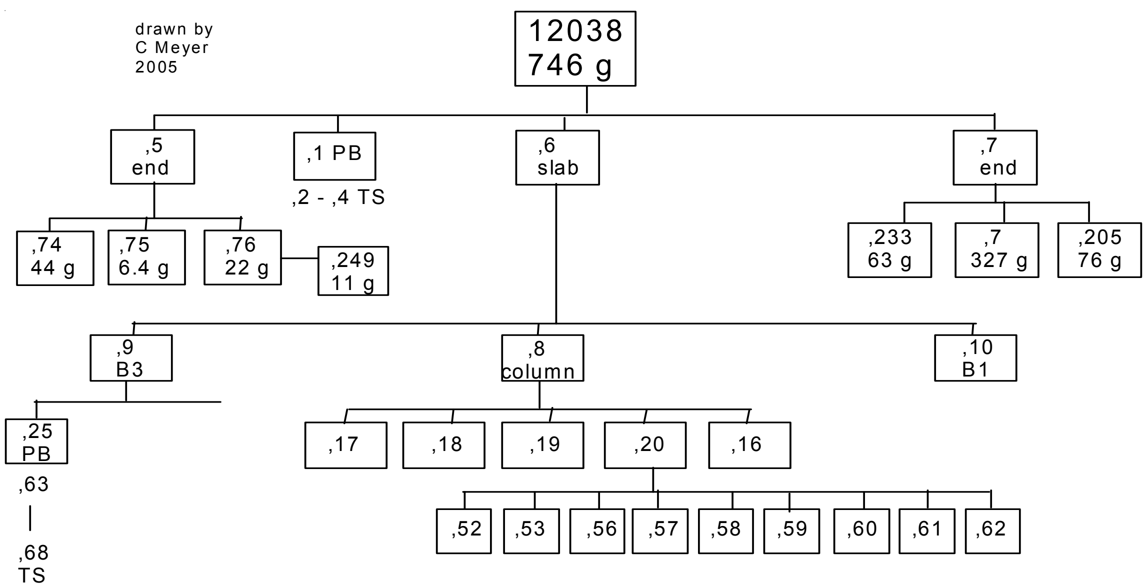


Figure 11: Initial isotopic compositions of 12038 compared wtih those of Apollo 12 and Luna 24 basalts (Nyquist et al. 1981).



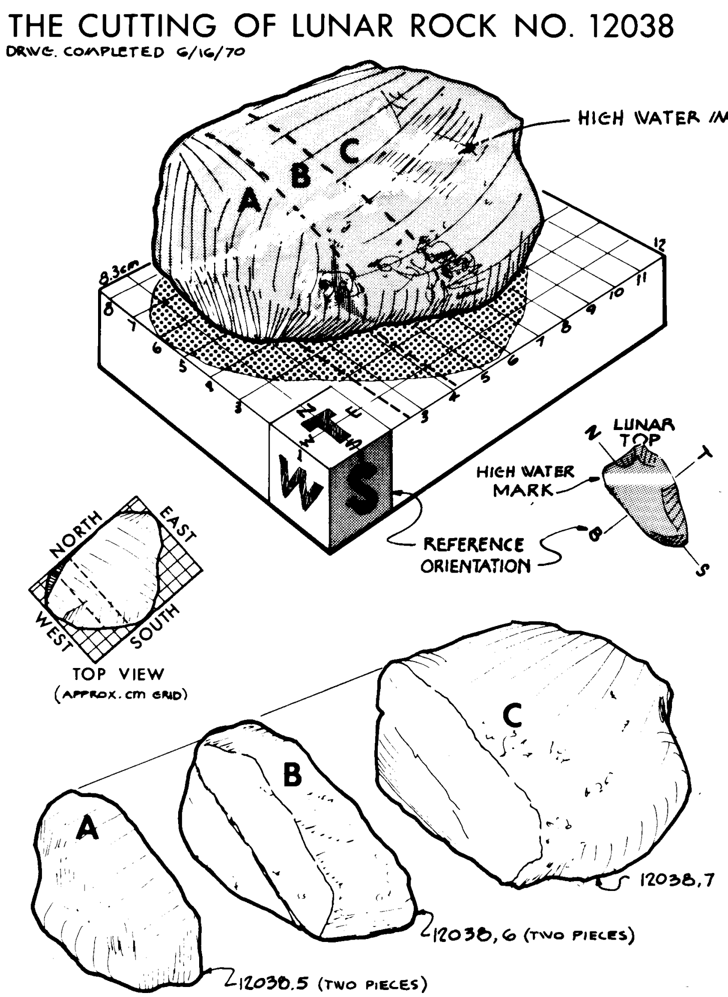
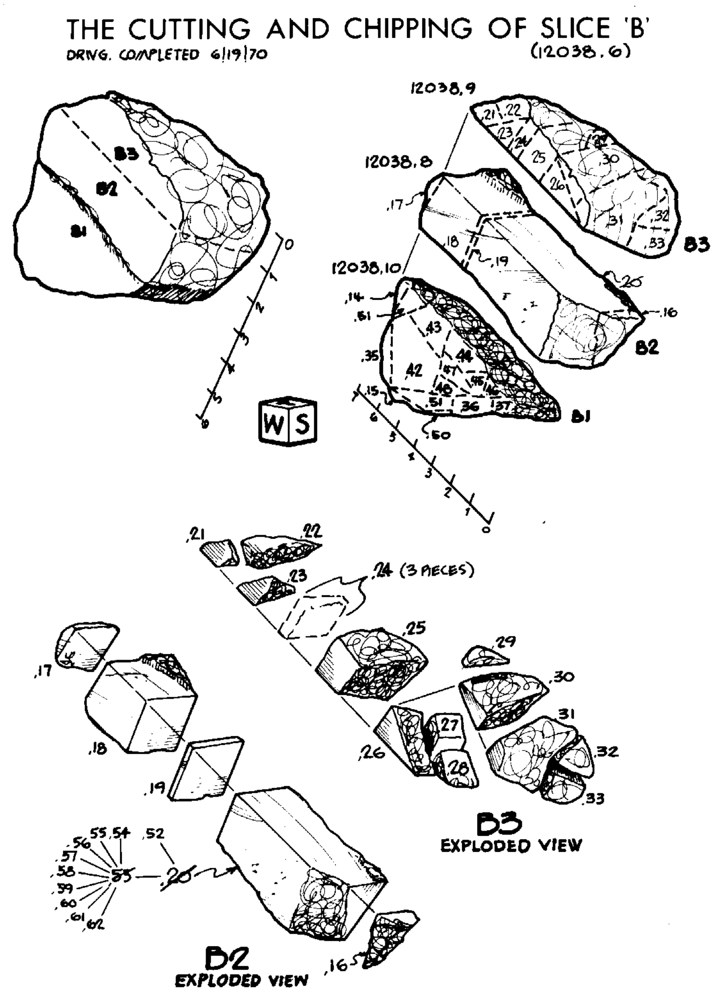


Figure 12: Group photo of 12038 after initial cutting showing slab "B" (12038,6) and butt ends 12038,7 and 12038,5 (top facing up). NASA #S70-48268. Scale in cm.



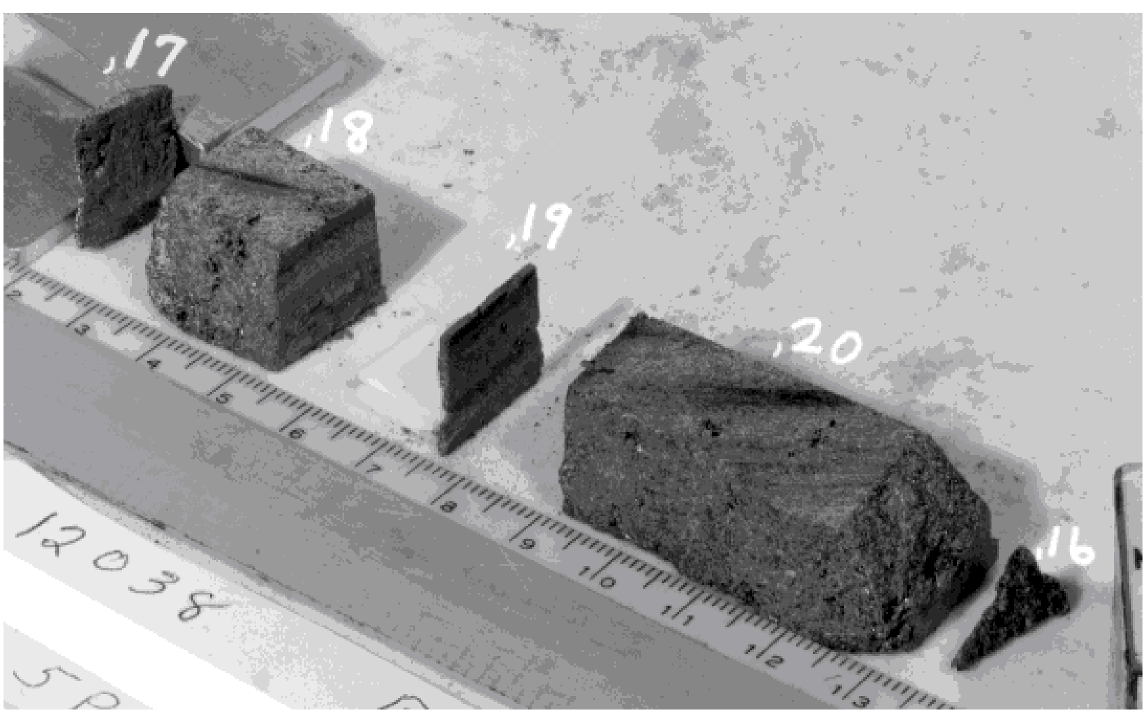


Figure 13: Group photo of column cut from 12038,6 (slab "B"). Scale in cm. NASA #S70-48291.

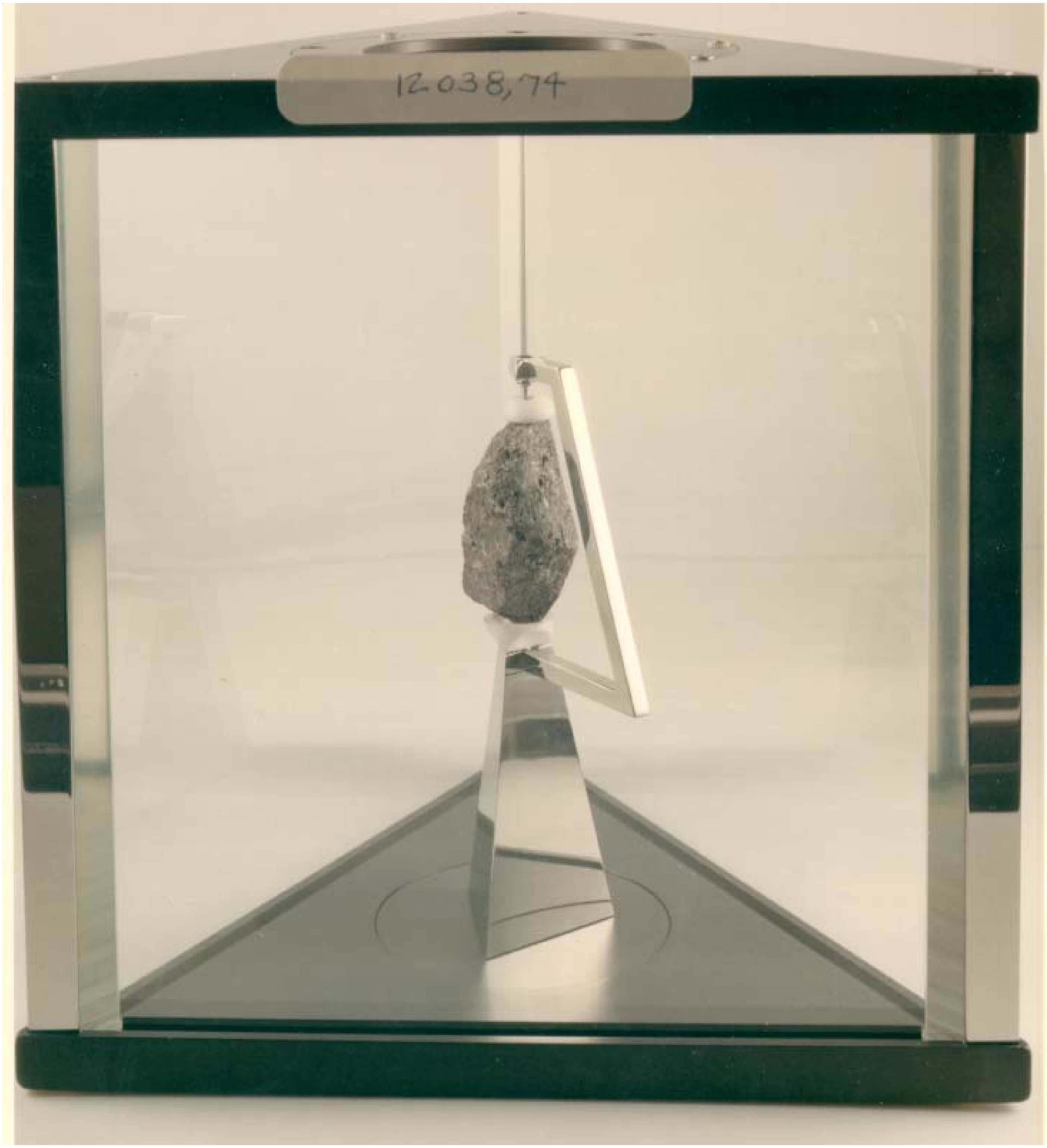


Figure 14: Lunar basalt 12038,74 in hermetically-sealled, glass display case.

References for 12038

Anders E., Ganapathy R., Keays R.R., Laul J.C., and Morgan J.W. (1971) Volatile and siderophile elements in lunar rocks: Comparsion with terrestrial and meteoritic basalts. *Proc. 2nd Lunar Sci. Conf.* 1021-1036.

Anders E., Ganapathy R., Krahenbuhl U. and Morgan J.W. (1973) Meteoritic material on the Moon. *The Moon* **8**, 3-24.

Baedecker P.A., Schaudy R., Elzie J.L., Kimberlin J., and Wasson J.T. (1971) Trace element studies of rocks and soils from Oceanus Procellarum and Mare Tranquilitatis. *Proc. 2nd Lunar Sci. Conf.* 1037-1061.

Beaty D.W., Hill S.M.R., Albee A.L. and Baldridge W.S. (1979b) Apollo 12 feldspathic basalts 12031, 12038, and 12072: Petrology, comparison and interpretations. *Proc. 10th Lunar Sci. Conf.* 115-139.

Bhandari N., Bhat S., Lal D., Rajagopalan G., Tamhane A.S. and Venkatavaradan V.S. (1971) High resolution time averaged (millions of years) energy spectrum and chemical composition of iron-group cosmic-ray nuclei at 1 A.U. based on fossil tracks in Apollo samples. *Proc. 2nd Lunar Sci. Conf.* 2611-2619.

Biggar G.M., O'Hara M.J., Peckett A. and Humphries D.J. (1971) Lunar lavas and the achondrites: Petrogenesis of protohypersthene basalts in the maria lava lakes. *Proc. Second Lunar Sci. Conf.* 617-643.

Bogard D.D., Funkhouser J.G., Schaeffer O.A. and Zahringer J. (1971) Noble gas abundances in lunar material-cosmic ray spallation products and radiation ages from the Sea of Tranquillity and the Ocean of Storms. *J. Geophys. Res.* **76**, 2757-2779.

Busche F.D., Conrad G.H., Keil K., Prinz M., Bunch T.E., Erlichman J. and Quaide W.L. (1971) Electron microprobe analysis of minerals from Apollo 12 lunar samples. Special Pub. #3, UNM Institute of Meteoritics. ABQ

Busche F.D., Prinz M., Keil K. and Bunch T.E. (1972) Spinels and the petrogenesis of some Apollo 12 igneous rocks. *Am. Mineral.* **57**, 1729-1747.

Compston W., Berry H., Vernon M.J., Chappell B.W. and Kay M.J. (1971) Rubidium-strontium chronology and chemistry of lunar material from the Ocean of Storms. *Proc. 2nd Lunar Sci. Conf.* 1471-1485.

Christie J.M., Lally J.S., Heuer A.H., Fischer R.M., Griggs D.T. and Radcliffe S.V. (1971) Comparative electron petrography of Apollo 11, Apollo 12 and terrestrial rocks. *Proc. Second Lunar Sci. Conf.* 69-89.

Cuttitta F., Rose H.J., Annell C.S., Carron M.K., Christian R.P., Dwornik E.J., Greenland L.P., Helz A.P. and Ligon D.T. (1971) Elemental composition of some Apollo 12 lunar rocks and soils. *Proc. 2nd Lunar Sci. Conf.* 1217-1229.

Haskin L.A., Helmke P.A., Allen R.O., Anderson M.R., Korotev R.L. and Zweifel K.A. (1971) Rare-earth elements in Apollo 12 lunar materials. *Proc. 2nd Lunar Sci. Conf.* 1307-1317.

Hörz F. and Hartung J.B. (1971c) The lunar-surface orientation of some Apollo 12 rocks. *Proc. 2nd Lunar Planet. Sci. 2629*-2638.

Keil K., Prinz T.E. and Bunch T.E. (1971) Mineralogy, petrology and chemistry of some Apollo 12 samples. *Proc. 2nd Lunar Sci. Conf.* 319-341.

Kushiro I. and Haramura H. (1971) Major element variation and possible source materials of Apollo 12 crystalline rocks. *Science* **171**, 1235-1237.

Kushiro I., Nakamura Y., Kitayama K. and Akimoto S-I. (1971) Petrology of some Apollo 12 crystalline rocks. *Proc. 2nd Lunar Sci. Conf.* 481-495.

LSPET (1970) Preliminary examination of lunar samples from Apollo 12. *Science* **167**, 1325-1339.

Neal C.R. (2001) Interior of the moon: The presence of garnet in the primitive deep lunar mantle. *J. Geophys. Res.* **106**, 27865-27885.

Nyquist L.E., Shih C.-Y., Wooden J.L., Bansal B.M. and Wiesmann H. (1979) The Sr and Nd isotopic record of Apollo 12 basalts: Implications for lunar geochemical evolution. *Proc. 10th Lunar Planet. Sci.* Conf. 77-114.

Nyquist L.E., Wooden J.L., Shih C.-Y., Wiesmann H. and Bansal B.M. (1981c) Isotopic and REE studies of lunar basalt 12038: Implications for the petrogenesis of aluminous mare basalts. *Earth Planet. Sci. Lett.* **55**, 335-355.

Schnetzler C.C. and Philpotts J.A. (1971) Alkali, alkaline earth, and rare earth element concentrations in some Apollo 12 soils, rocks, and separated phases. *Proc. 2nd Lunar Sci. Conf.* 1101-1122.

Simpson P.R. and Bowie S.H.U. (1971) Opaque phases in Apollo 12 samples. *Proc. Second Lunar Sci. Conf.* 207-218.

Taylor S.R., Rudowski R., Muir P., Graham A. and Kaye M. (1971b) Trace element chemistry of lunar samples from the Ocean of Storms. *Proc. 2nd Lunar Sci. Conf.* 1083-1099.

Tatsumoto M., Knight R.J. and Doe B.R. (1971) U-Th-Pb systematic of Apollo lunar samples. *Proc. 2nd Lunar Sci. Conf.* 1521-1546.

Willis J.P., Ahrens L.H., Danchin R.V., Erlank A.J., Gurney J.J., Hofmeyr P.K., McCarthy T.S. and Orren M.J. (1971) Some inter-element relationships between lunar rocks and fines, and stony meteorites. *Proc. 2nd Lunar Sci. Conf.* 1123-1138.

Willis J.P., Erlank A.J., Gurney J.J., Theil R.H. and Ahrens L.H. (1972) Major, minor, and trace element data for some Apollo 11, 12, 14 and 15 samples. *Proc. 3rd Lunar Sci. Conf.* 1269-1273.