12009

Olivine Vitrophyre Basalt

468.2 grams

Figure 1: Photo of 12009,0 after dusting. Rock is 10 cm across. NASA photo # S70-47874.

Introduction

12009 is an olivine vitrophyre (quickly cooled basalt). It has portions of walls of large vesicles (figure 1). The collection site and field orientation of 12009 is not known.

Petrography

McGee et al. (1977) describe 12009 as "a porphyritic basalt vitrophyre which consists of skeletal phenocrysts of olivine (0.3 -1 mm) and pyroxene (0.2 – 0.8 mm) set in a matrix of microcrystalline devitrified glass and quench crystals of olivine, pyroxene and ilmenite". Drever et al. (1972) compared the texture of the skeletal olivine with that of selected terrestrial equivalents and Donaldson et al. (1975) studied the crystallization conditions that lead to this texture (figure 2, 3). Walker et al. (1976) discuss the crystal settling time needed to effect differentiation.

The Apollo 12 basalts can be related to one another by addition or subtraction of olivine (Fo_{74}) where the samples with the lowest mg* represent the liquid magma composition into which the liquidus olivine accumulated (Kushiro and Haramura 1971; Compston et al. 1971, James and Wright 1972, Green et al 1971 and Walker et al. 1976).

Mineralogy

Olivine: Beautiful skeletal phenocrysts of olivine are abundant in 12009 (Brett et al. 1971, Drever et al. 1972, Donaldson et al. 1975). Butler (1973) determined the minor element content of olivine. Walker et al. (1976) determined that the range of olivine composition was Fo_{76-49}.

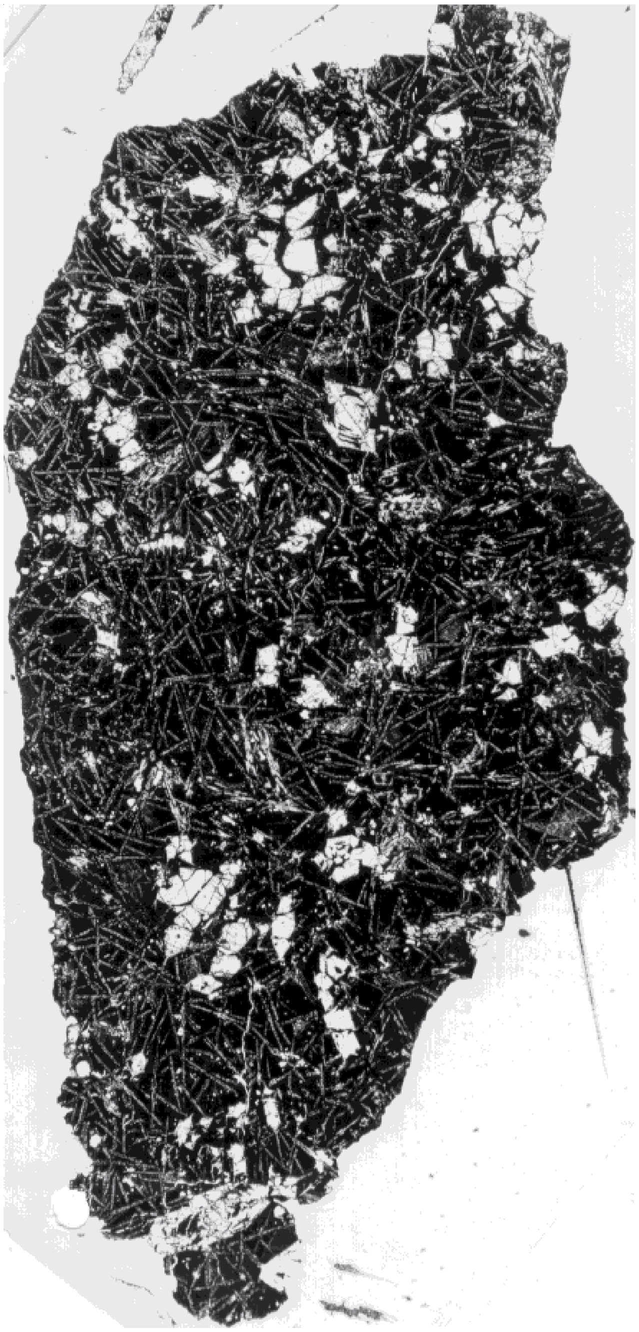

Figure 2: Photomicrograph of 12009,8 showing skeletal olivine phenocrysts in nearly opaque groundmass. NASA #S70-31568. Thin section is about 2 cm long.

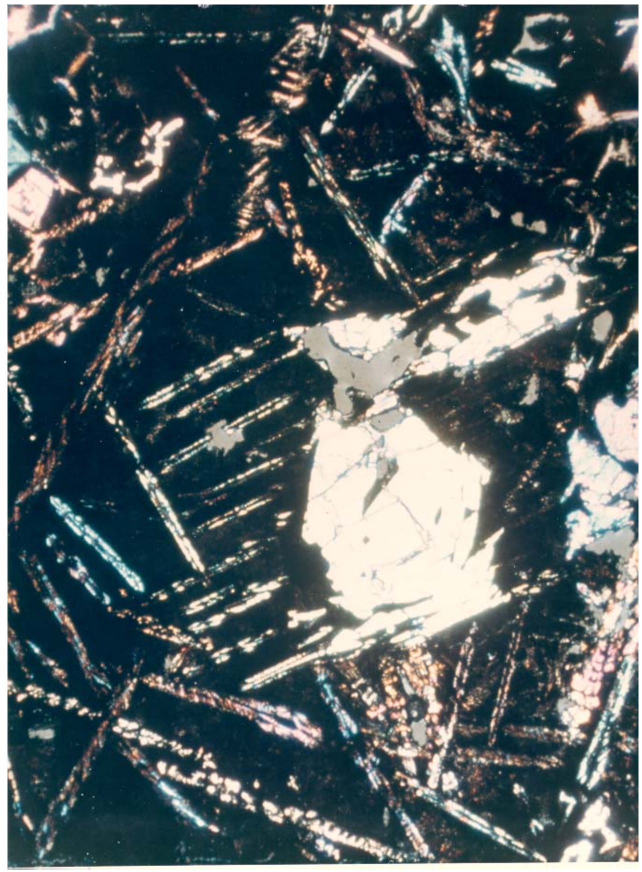

Figure 3: Photomicrograph of 12009,11 showing olivine phenocryst, olivine chains and feathery pyroxene in nearly opaque groundmass. NASA # S70-49828. Field of view is 2.2 mm.

Pyroxene: Pyroxene phenocrysts occur as bundles of elongate fibrous crystals that are often in optical continuity. Groundmass pyroxene is feathery. McGee et al. (1977) determined pyroxene composition (figure 4).

Metal: Brett et al. (1971) determined the Ni content of minute metallic iron grains in 12009 (figure 5).

Mineralogical Mode for 12009

	Neal et al. 1994	Brett et al. 1971	Papike et al. 1976
Olivine	48.8	23.6	21.7
Pyroxene		3.8	9.9
Plagioclase	0.1		
Ilmenite	1.2	0.3	0.6
Chromite +Usp	2.2		
mesostasis	47.2	72.3	68

List of Photo #s for 12009

S69-62296-62307	B&W mug
S69-62739-62743	B&W
S69-64090-091	color
S69-64115-116	
S70-31568	TS ,8
S70-47870-874	processing
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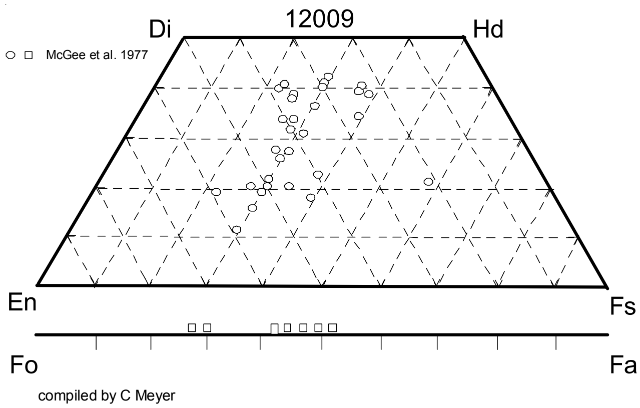


Figure 4: Pyroxene and olivine composition of 12009 (adapted from McGee et al. 1977).

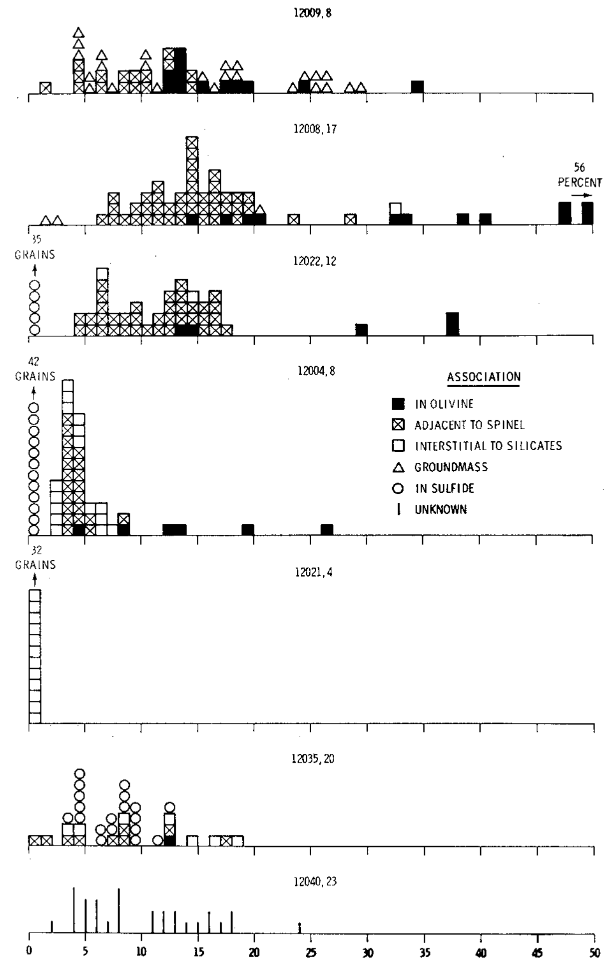


Figure 5: Histogram of Ni conentrations of metal grains in 7 lunar samples (lifted from Brett et al. 1971).

Chemistry

The chemical composition of 12009 seems to be the same as for 12015 (Table 1, figure 6 and 7). It has often been used in modeling the origin and differentiation of Apollo 12 basalts.

Radiogenic age dating

Stettler et al. (1973) determined an age for 12009 by total argon 39/40 (see table). The high temperature release represented a lower age (see figure in 12051). Snyder et al. (1997) reported the isotopic composition of Sr and Nd.

Cosmogenic isotopes and exposure ages

Stettler et al. (1973) determined an ^{38}Ar exposure age of 140-160 m.y. Marti and Lugmair (1971) determined an ^{81}Kr –^{83}Kr exposure age of 136 ± 24 m.y.

Other Studies

Bogard et al. (1971) reported the content and isotopic composition of rare gases in 12009. Green et al. (1971) studied the high pressure phase equilibria for 12009 (figure 8). Donaldson et al. (1975) studied the cooling history

Processing

12009 was broken to create subsamples (see figure). There are 18 thin sections.

Summary of Age Data for 12009

	Ar/Ar	Rb/Sr
Stettler et al. 1973	3.29 ± 0.07 b.y.	
	3.17 ± 0.07	

References for 12009

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.

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.

Brett R., Butler P., Meyer C., Reid A.M., Takeda H. and Williams R. (1971) Apollo 12 igneous rocks 12004, 12008, 12009 and 12022: A mineralogical and petrological study. *Proc. 2nd Lunar Sci. Conf.* 301-317.

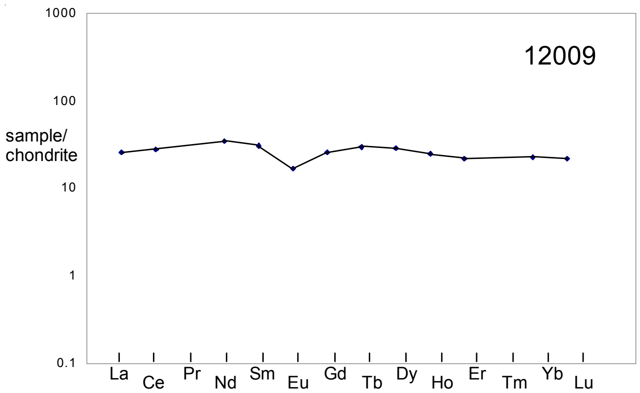


Figure 6: Normalized rare-earth-element diagram for 12009 (data from Haskin et al. 1971).

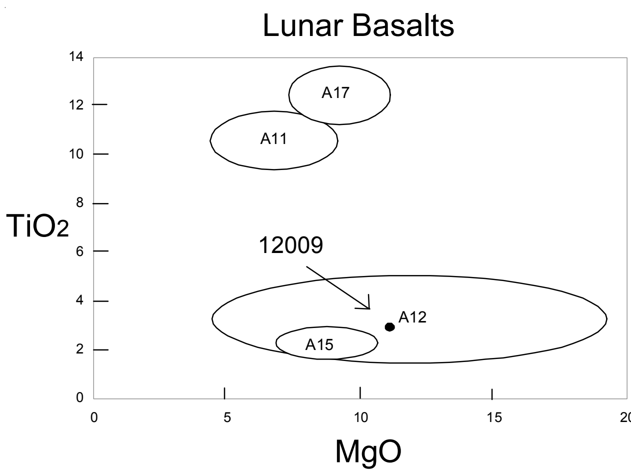


Figure 7: Composition of 12009 compared with that of lunar basalts.

Butler P. (1972b) Compositional characteristics of olivines from Apollo 12 samples. *Geochim. Cosmochim. Acta* **36**, 773-785.

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.

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.

Donaldson C.H., Drever H.I. and Johnston R. (1977) Supercooling on the lunar surface: a review of analogue information. *Phil. Trans. Roy. Soc. London* **A285**, 207-218.

Drever H.I., Johnston R., Butler P. and Gibb F.G.F. (1972) Some textures in Apollo 12 lunar igneous rocks and in terrestrial analogs. *Proc. 3rd Lunar Sci. Conf.* 171-184.

Green D.H., Ware N.G., Hibberson W.O. and Major A. (1971) Experimental petrology of Apollo 12 basalts: Part 1, Sample 12009. *Earth Planet. Sci. Lett.* **13**, 85-96.

Green D.H., Ringwood A.E., Ware N.G., Hibberson W.O., Major A. and Kiss E. (1971) Experimental petrology and petrogenesis of Apollo 12 basalts. *Proc. 2nd Lunar Sci. Conf.* 601-615.

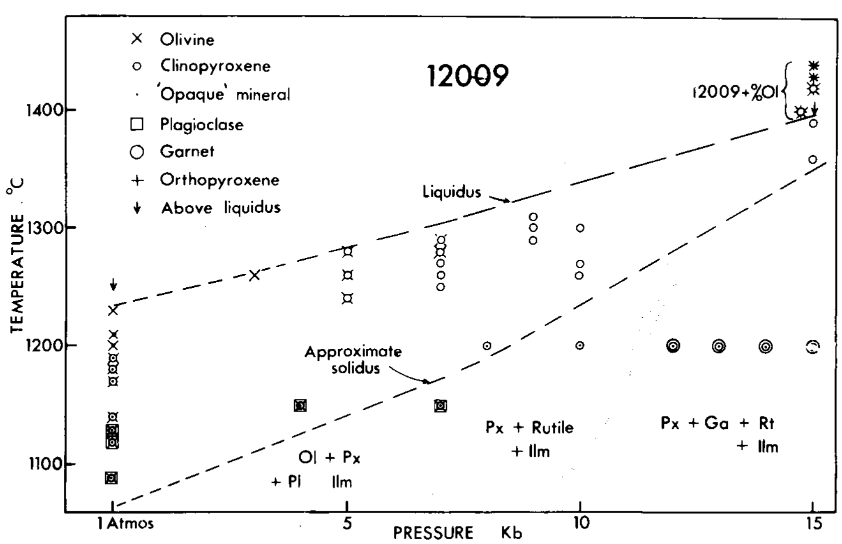
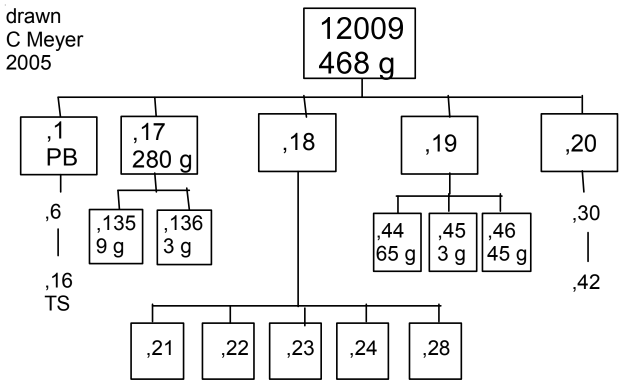


Figure 8: Experimental phase diagram for liquids with 12009 composition as function of temperature and depth of origin (Green et al. 1971).

Table 1. Chemical composition of 12009.

reference	LSPET70	Murthy71	Cuttitta71	Haskin71	Compston71	Tats71	Baedeck71	Snyder97	Neal2001
weight									
SiO2 %	41				45.03 (d)			45	
TiO2	3.3				2.9 (d)			2.9	
Al2O3	11				8.59 (d)			8.59	
FeO	20				21.03 (d)			21	
MnO	0.19		0.27 (b)		0.28 (d)			0.28	
MgO	12.5				11.55 (d)			11.6	
CaO	10				9.42 (d)			9.42	
Na2O	0.51				0.23 (d)			0.23	
K2O	0.063	0.047 (a)			0.064 (d)			0.06	
P2O5					0.07 (d)			0.07	
S %					0.06 (d)				
sum									
Sc ppm	42		44 (b)					46 (f)	46 (f)
V	77		166 (b)		153 (d)				186 (f)
Cr	5200		4390 (b)		3790 (d)			3960 (f)	4249 (f)
Co	46		59 (b)		49 (d)			50.1 (f)	
Ni	67		62 (b)		52 (d)			55 (f)	61 (f)
Cu			14 (b)					10.4 (f)	13 (f)
Zn			4 (b)				1.8 (e)	9.7 (f)	6.6 (f)
Ga			5 (b)		2 (d)		3.2 (e)	3.11 (f)	2.8 (f)
Ge ppb									
As									
Se									
Rb	0.57	1.09 (a)	1.4 (b)		1.03			0.987 (f)	1.08 (f)
Sr	110	89.8 (a)	75 (b)		95.6			86.4 (f)	99.6 (f)
Y	48		42 (b)		34			36.5 (f)	34.2 (f)
Zr	150		114 (b)		107			106.4 (f)	112 (f)
Nb					6			6.5 (f)	6.5 (f)
Mo									0.15 (f)
Ru									
Rh									
Pd ppb									
Ag ppb								82 (f)	
Cd ppb							2.2 (e)		
In ppb							1.6 (e)		
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm								0.068 (f)	0.04 (f)
Ba	65	76 (a)	71 (b)		60			55.5 (f)	63.4 (f)
La				6.1 (c)	4			5.62 (f)	5.86 (f)
Ce				16.8 (c)	10			16.1 (f)	16.3 (f)
Pr								2.45 (f)	2.58 (f)
Nd				16 (c)				12.7 (f)	12.4 (f)
Sm				4.53 (c)				3.91 (f)	4.26 (f)
Eu				0.94 (c)				0.89 (f)	0.89 (f)
Gd				5.2 (c)				4.15 (f)	6.33 (f)
Tb				1.11 (c)				0.9 (f)	1 (f)
Dy				7.13 (c)				5.7 (f)	6.96 (f)
Ho				1.4 (c)				1.14 (f)	1.4 (f)
Er				3.6 (c)				3.39 (f)	4.11 (f)
Tm								0.48 (f)	0.57 (f)
Yb			5.3 (b)	3.74 (c)				3.05 (f)	3.68 (f)
Lu				0.55 (c)				0.45 (f)	0.5 (f)
Hf									3.26 (f)
Ta								0.296 (f)	0.4 (f)
W ppb									170 (f)
Re ppb									
Os ppb									
Ir ppb							0.08 (e)		
Pt ppb									
Au ppb									
Th ppm						0.881 (a)		0.85 (f)	0.9 (f)
U ppm						0.243 (a)		0.23 (f)	0.24 (f)

technique: (a) IDMS, (b) mixed, (c) INAA, (d) XRF, (e) RNAA, (f) ICP-MS



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.

James O.B. and Wright T.L. (1972) Apollo 11 and 12 mare basalts and gabbros: Classification, compositional variations and possible petrogenetic relations. *Geol. Soc. Am. Bull.* **83**, 2357-2382.

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

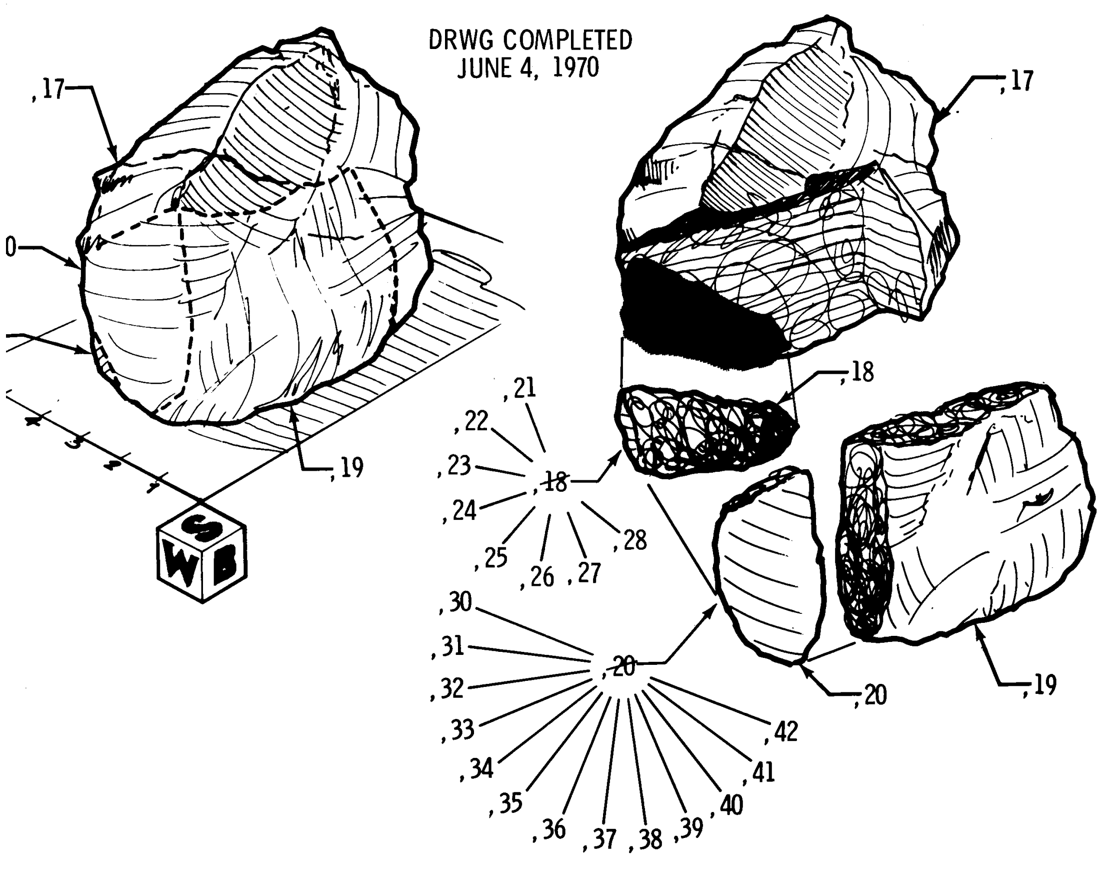
Kushiro I., Nakamura Y., Kitayama K. and Akimoto S-I. (1971) Petrology of some Apollo 12 crystalline rocks. *Proc. 2nd Lunar Sci. Conf.* 481-495.

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

McGee P.E., Warner J.L. and Simonds C.H. (1977) Introduction to the Apollo Collections. Part I: Lunar Igneous Rocks. Curators Office, JSC.

Murthy V.R., Evensen N.M., Jahn B.-M. and Coscio M.R. (1971) Rb-Sr ages and elemental abundances of K, Rb, Sr and Ba in samples from the Ocean of Storms. *Geochim. Cosmochim. Acta* **35**, 1139-1153.

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



Papike J.J., Hodges F.N., Bence A.E., Cameron M. and Rhodes J.M. (1976) Mare basalts: Crystal chemistry, mineralogy and petrology. *Rev. Geophys. Space Phys.* **14**, 475-540.

Reid A.M., Meyer C., Harmon R.S. and Brett R. (1970c) Metal grains in Apollo 12 igneous rocks. *Earth Planet. Sci. Lett*. **9**, 1-5.

Snyder G.A., Neal C.R., Taylor L.A. and Halliday A.N. (1997a) Anataxis of lunar cumulate mantle in time and space: Clues from trace-element, strontium and neodymium isotopic chemistry of parental Apollo 12 basalts. *Geochim. Cosmochim. Acta* **61**, 2731-2747.

Stettler A., Eberhardt Peter, Geiss J., Grogler N. and Maurer P. (1973) Ar^{39}-Ar^{40} ages and Ar^{37}-Ar^{38} exposure ages of lunar rocks. *Proc. 4th Lunar Sci. Conf.* 1865-1888.

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.

Walker D., Kirkpatrick R.J., Longhi J. and Hays J.F. (1976) Crystallization history of lunar picritic basalt sample 12002: Phase-equilibria and cooling-rate studies. *Geol. Soc. Am. Bull.* **87**, 646-656.