15475

Porphyritic Pigeonite Basalt

406.8 grams

Figure 1: Photo of 15475. NASA S71-46626. Sample is 5 cm across.

Introduction

15475 was collected from the rim of Dune Crater – along with 15476, 15485, 15495 and 15499 (Swann et al. 1971). It is a porphyritic pigeonite basalt with beautiful texture (figures 2, 3 and 11). The vuggy nature of the sample is illustrated in figures 1 and 10.

15475 has been found to be about 3.4 b.y. old and has been exposed to cosmic rays for about 500 m.y. It has micrometeorite craters on some surfaces and its lunar orientation is known from surface photography.

Petrography

McGee et al. (1977), Takeda et al. (1975), Ryder (1985) and Schnare et al. (2008) described 15475. It is a coarse-grained porphyritic basalt dominated by large subhedral pyroxene crystals (up to 1.5 cm) set in a subophitic matrix of anhedral pyroxene and plagioclase (figure 2). Pore space is vuggy, rather than vesicular. Interstitial phases include pyroxferroite, chromite-ulvospinel, cristobalite, ilmenite, K-rich glass, tranquillityite, whitlockite and rare blebs of troilite.

Lofgren et al. (1975) and Grove and Walker (1977) performed nucleation and cooling rate experiments on basaltic melts made from synthetic mixtures that approximated Apollo 15 basalt. Takeda et al. (1975) used augite exsolution in pigeonite to determine that 15475 was one of the slowest cooling basalts fro Apollo 15. Taylor et al. (1973) used the partioning of Zr between ilmenite and ulvospinel to determine cooling rate.

Mineralogy

Olivine: none

Pyroxene: The large clinopyroxene crystals in 15475 are chemically zoned towards Fe-enrichment. Brown et al. (1972), Takeda et al. (1975) and McGee et al. (1977) reported the composition (figure 4).

Mineralogical Mode of 15475

	Sample Catalog Butler 1971	Rhodes and Hubbard 1973	McGee et al. 1975	Schnare et al. 2008
Olivine		- -	- -	0.6
Pyroxene	75	64	64	59.7
Plagioclase	20	24	24	30.2
Opaque	4	2.9	2.5	2.1
Silica	0.5	0.6	2.6	3.6
Mesostasis		1.7	2	7.4

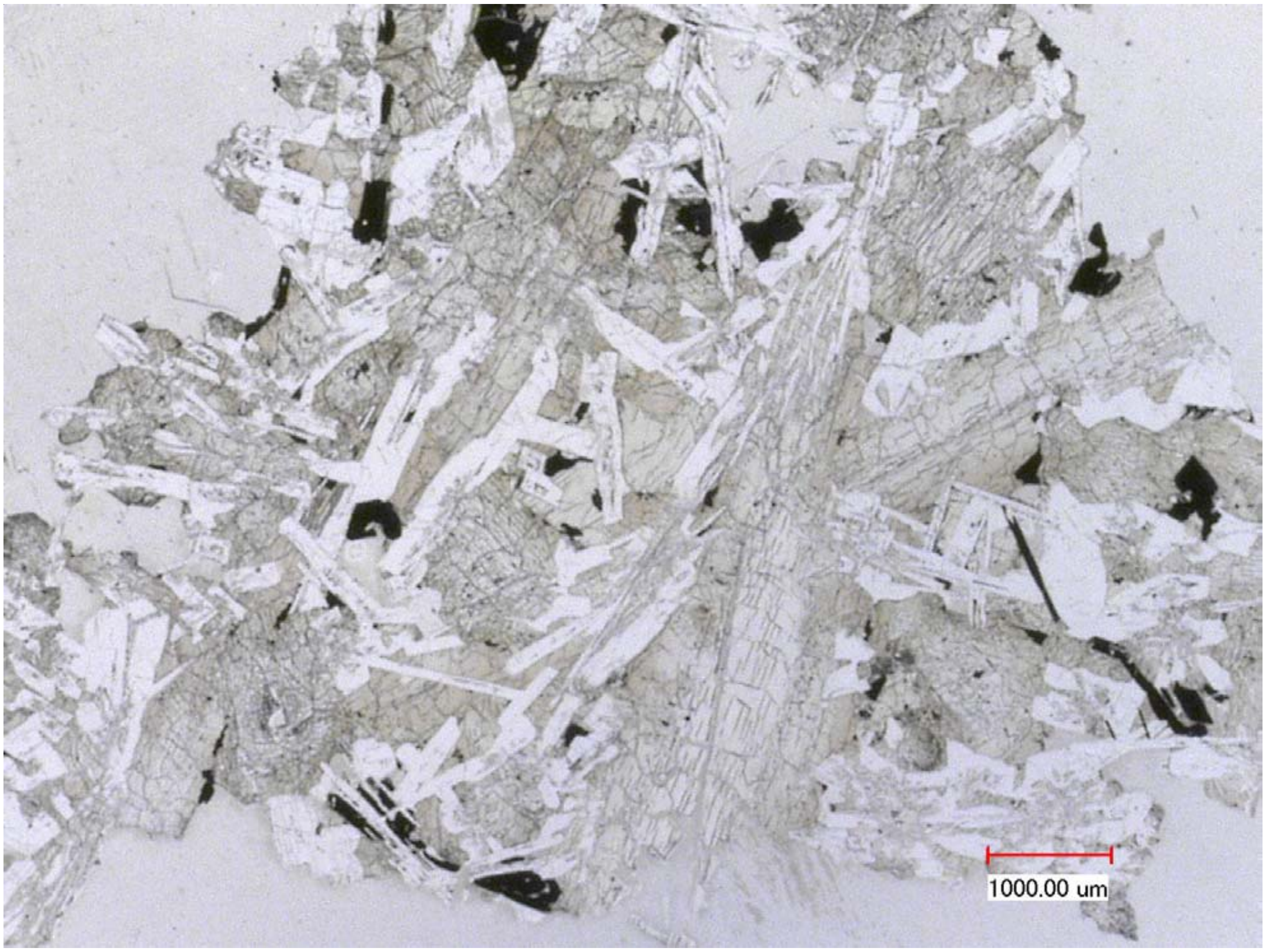


Figure 2a: Photomicrograph of 15475,13 by C Meyer @ 30 x. **see also figures 11 a,b**

Plagioclase: McGee et al. (1977) and Schnare et al. (2008) give the composition of plagioclase as An_{84-93}.

Tranquillityite: Brown et al. (1972) reported finding 12 grains of tranquillityite (table 2) within interstitial cristobalite crystals in 15475.

Whitlockite: Brown et al. (1972) determined the chemical composition of whitlockite in 15475 by electron microprobe.

Spinel: 15475 contains opaques with chromite cores zoned to Cr-ulvospinel (El Goresy et al. 1976).

Chemistry

Mason et al. (1972), Chappell and Green (1973), Rhodes and Hubbard (1973), and Wanke et al. (1975) determined the major element composition, while Wanke et al., Gros et al. (1976), Wolf et al. (1979) and Hughes and Schmidt (1985) reported trace elements (table 1). The composition is that of a typical pigeonite basalt (figures 5 and 6).

Schnare et al. (2008) determined the composition of mineral separates, but they probably aren't pure.

Radiogenic age dating

In an abstract, Snyder et al. (1997) reported Rb/Sr and Sm/Nd internal mineral isochrons for 15475 (figures 7 and 8). Lee et al. (1997, 2000 and 2002) and Kleine et al. (2005) studied the Hf-W and W isotope systematics of 15475, while Compston et al. (1972) and Nyquist et al. (1973) reported the isotopic composition of Sr.

Cosmogenic isotopes and exposure ages

Eldridge et al. (1972) and O'Kelley et al. (1972) determined the cosmic ray induced activity of ^{22}Na = 32 dpm/kg., ^{26}Al = 40 dpm/kg., ^{46}Sc = 3 dpm/kg., ^{54}Mn = 23 dpm/kg. and ^{56}Co = 11 dpm/kg. for 15475.

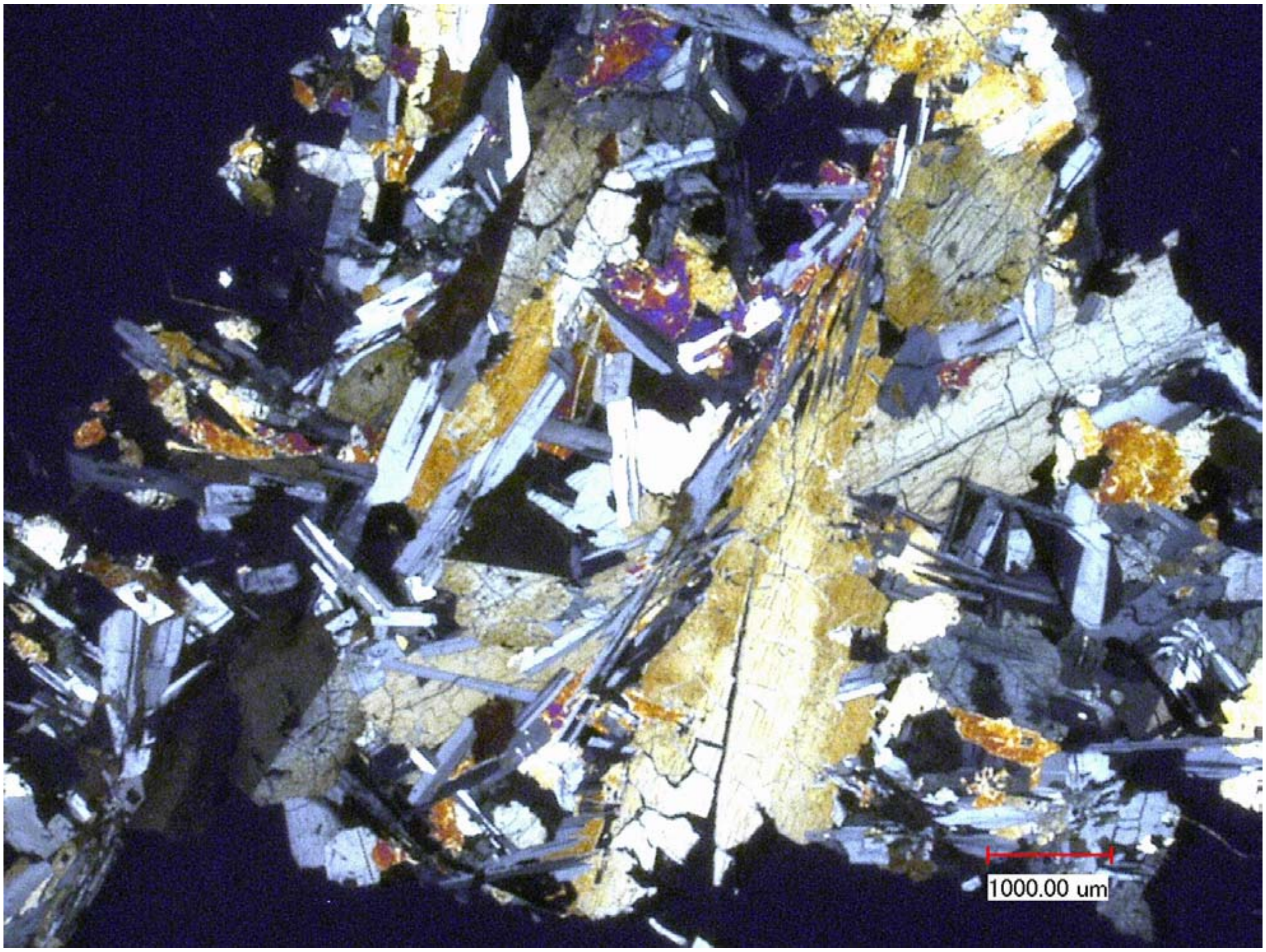


Figure 2b: Photomicrograph of 15475,13 by C Meyer @ 30 x (crossed polarizer).

Pepin et al. (1974) and Drozd et al. (1974) determined a cosmic ray exposure age of 473 ± 20 m.y. by ^{81}Kr method.

<u>**Other Studies**</u>

Bhandari et al. (1973) studied solar and cosmic ray tracks as function of depth.

<u>**Processing**</u>

A slab was cut through the middle of 15475 (figures 9 and 10). There are 19 thin sections. One end piece is on public display at the American Museum of Natural History in New York.

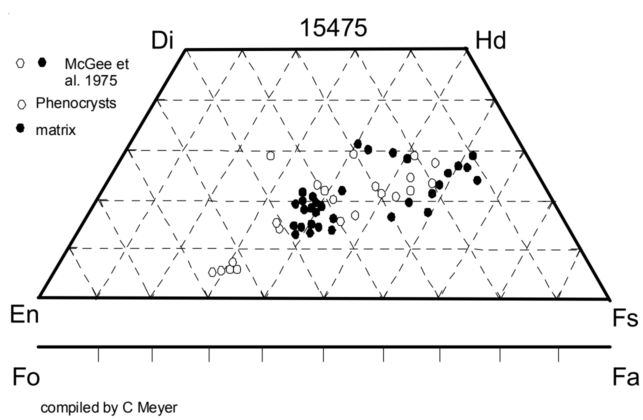


Figure 4: Composition of pyroxene in 15475.

Figure 3: Thin section photomicrograph of 15475,11. NASA S71-52216. Scale unknown, but about 4 mm.

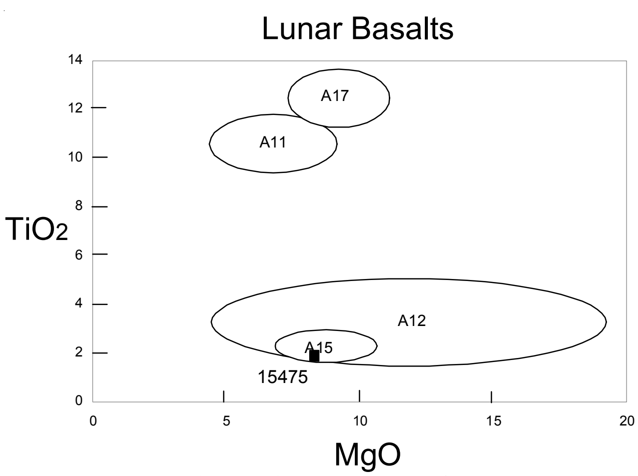


Figure 5: Chemical composition of 15475 compared with that of other lunar basalts.

Table 2: Composition of tranquillityite in 15475.

	Brown et al. 1972
SiO2	14.4
TiO2	21.8
Al2O3	1.4
FeO	43.5
MnO	0.3
MgO	0.6
CaO	1.4
ZrO2	14

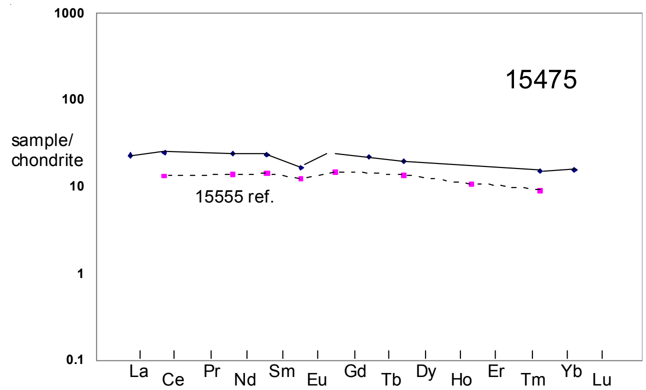


Figure 6: Normalized rare-earth-element diagram for 15475 (data from Wanke et al. 1975); 15555 for comparison.

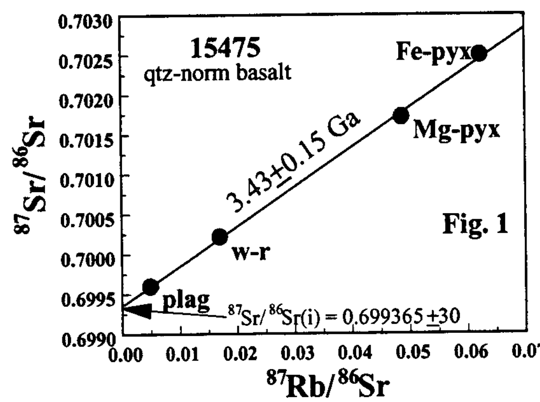


Figure 7: Rb/Sr isochron for 15475 (from Snyder et al. 1997).

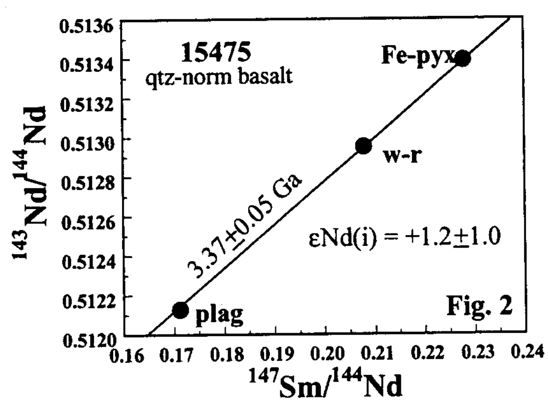


Figure 8: Sm/Nd isochron for 15475 (from Snyder et al. 1997).

Summary of Age Data for 15475

	Rb/Sr	Sm/Nd
Snyder et al. (1997)	3.43 ± 0.15 b.y.	3.37 ± 0.05

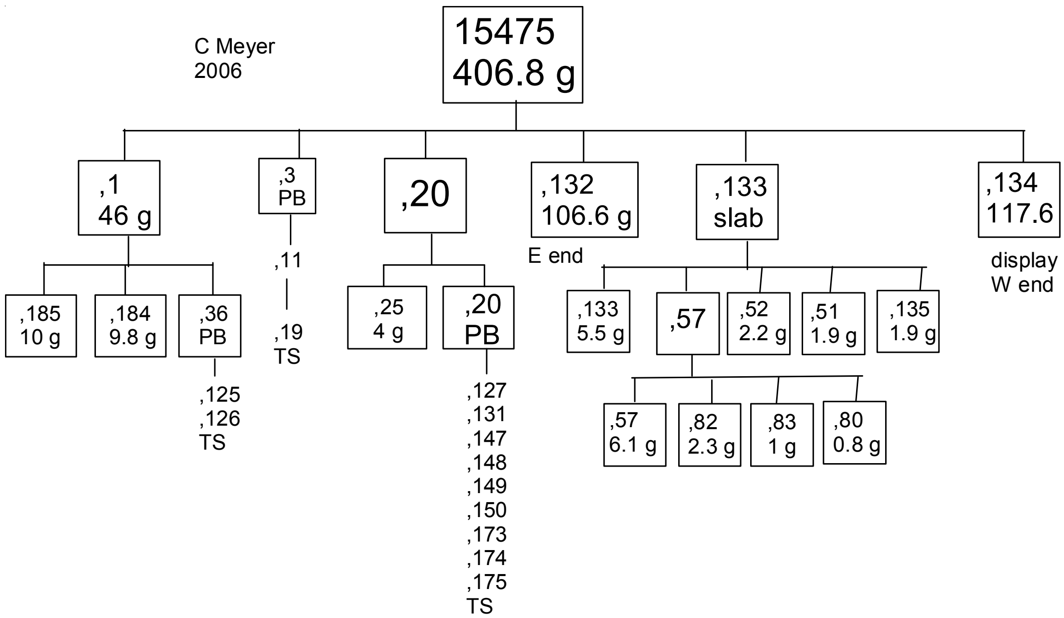
These are reported with the new decay constants.

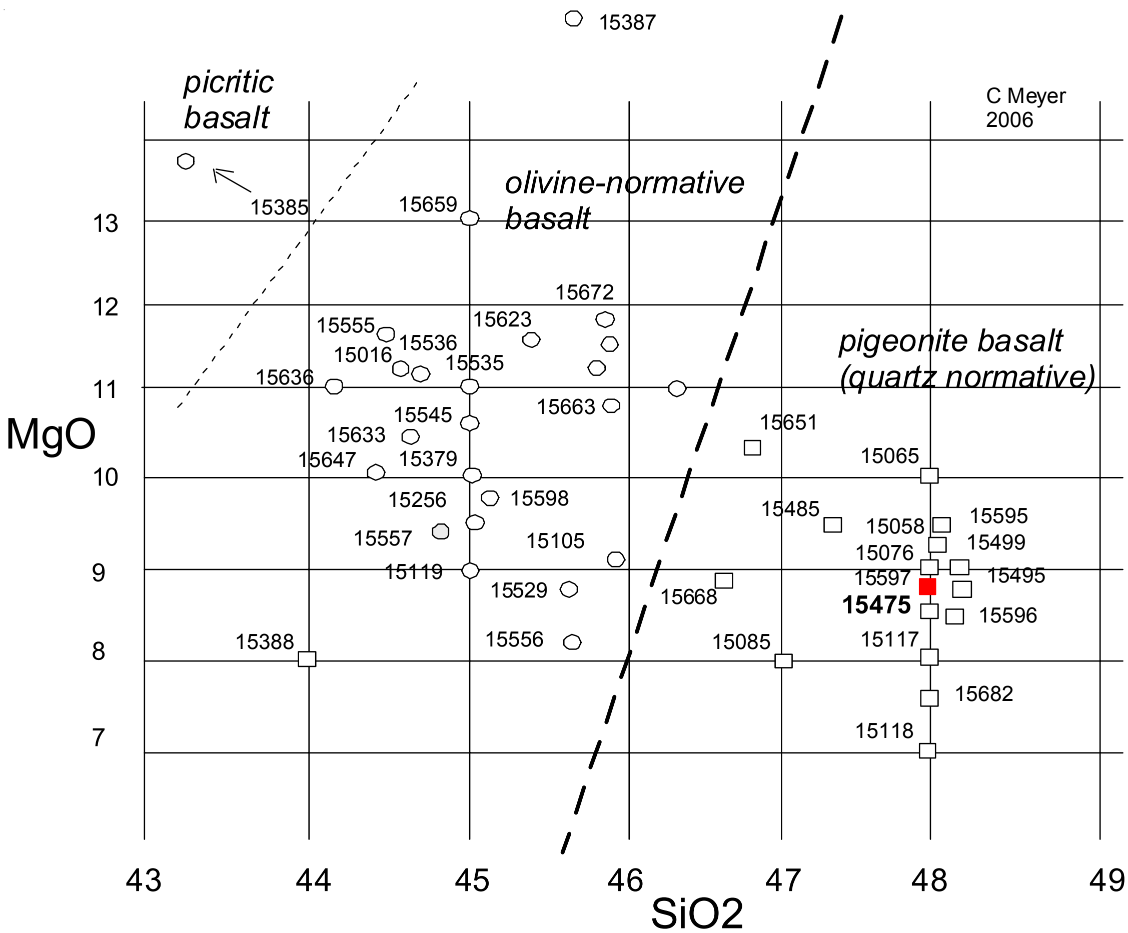
Table 1. Chemical composition of 15475.

reference	Rhodes73		Wiesmann75			Gros76		O'Kelley72		Mason 72		Wanke 75		Chappell73	
weight			Hubbard73			Wolf 79									
SiO2 %	47.82	(c)								48.32	(e)	48.99	(d)	48.32	(c)
TiO2	1.96	(c)	1.65	1.9	(b)					1.57	(e)	1.75	(d)	1.77	(c)
Al2O3	9.52	(c)								9.23	(e)	9.77	(d)	9.59	(c)
FeO	19.95	(c)								20.17	(e)	19.8	(d)	19.83	(c)
MnO	0.29	(c)								0.31	(e)	0.25	(d)	0.3	(c)
MgO	8.28	(c)	8.29		(b)					9.54	(e)	8.4	(d)	8.72	(c)
CaO	10.65	(c)								10.33	(e)	10.76	(d)	10.77	(c)
Na2O	0.24	(c)	0.32	0.3	(b)					0.27	(e)	0.3	(d)	0.31	(c)
K2O	0.04	(c)	0.042	0.05	(b)			0.051	(a)	0.05	(e)	0.05	(d)	0.05	(c)
P2O5	0.07	(c)								0.05	(e)	0.05	(d)	0.06	(c)
S %	0.07	(c)										0.06	(d)	0.04	(c)
sum															
Sc ppm												47.7	(d)		
V										130	(f)				
Cr				3092	(b)					4500	(f)	3630	(d)	4174	(c)
Co										56	(f)	44.6	(d)		
Ni	9	(c)				35	(d)			50	(f)				
Cu										6	(f)				
Zn						1.1	(d)								
Ga										3	(f)			2.9	(c)
Ge ppb						5.2	(d)								
As															
Se						92	(d)								
Rb	*1.2*	(c)	0.696	0.514	(b)	0.89	(d)			<5	(f)			0.58	(c)
Sr	*117*	(c)	111	110	(b)					96	(f)			106.8	(c)
Y	*29*	(c)								37	(f)			22	(c)
Zr	*89*	(c)	84	107	(b)					65	(f)			75	(c)
Nb	*5.9*	(c)												6	(c)
Mo															
Ru															
Rh															
Pd ppb						<0.4	(d)								
Ag ppb						0.72	(d)								
Cd ppb						2	(d)								
In ppb						0.46	(d)								
Sn ppb															
Sb ppb						0.34	(d)								
Te ppb						2.5	(d)								
Cs ppm						0.037	(d)								
Ba			45.2	61.2	(b)					47	(f)	59	(d)		
La			4.01	5.76	(b)							5.47	(d)		
Ce			13.1	15.5	(b)							15	(d)		
Pr															
Nd			8.87	11.5	(b)							11	(d)		
Sm			2.93	3.66	(b)							3.45	(d)		
Eu			0.481	0.96	(b)							0.92	(d)		
Gd															
Tb												0.79	(d)		
Dy			4.59	5.45	(b)							4.72	(d)		
Ho															
Er			2.7		(b)										
Tm															
Yb			2.35		(b)							2.45	(d)		
Lu			0.35		(b)							0.38	(d)		
Hf			2.7	3	(b)							2.37	(d)		
Ta												0.34	(d)		
W ppb															
Re ppb						0.003	(d)								
Os ppb						0.01	(d)								
Ir ppb						0.015	(d)								
Pt ppb															
Au ppb						0.009	(d)					7	(d)		
Th ppm								0.4	(a)						
U ppm			0.11	0.15	(b)	0.135	(d)	0.12	(a)						

technique: (a) radiation counting, (b) IDMS, (c) XRF, (d) RNAA, (e) wet chem., (f) OES

Table 3	U ppm	Th ppm	K ppm	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique
Compston et al. 1972				0.73	105			IDMS
				0.58	106.8			XRF
Nyquist et al. 1972				0.688	110.7			IDMS
O'Kelley et al. 1972	0.12	0.4	354					counting





,135

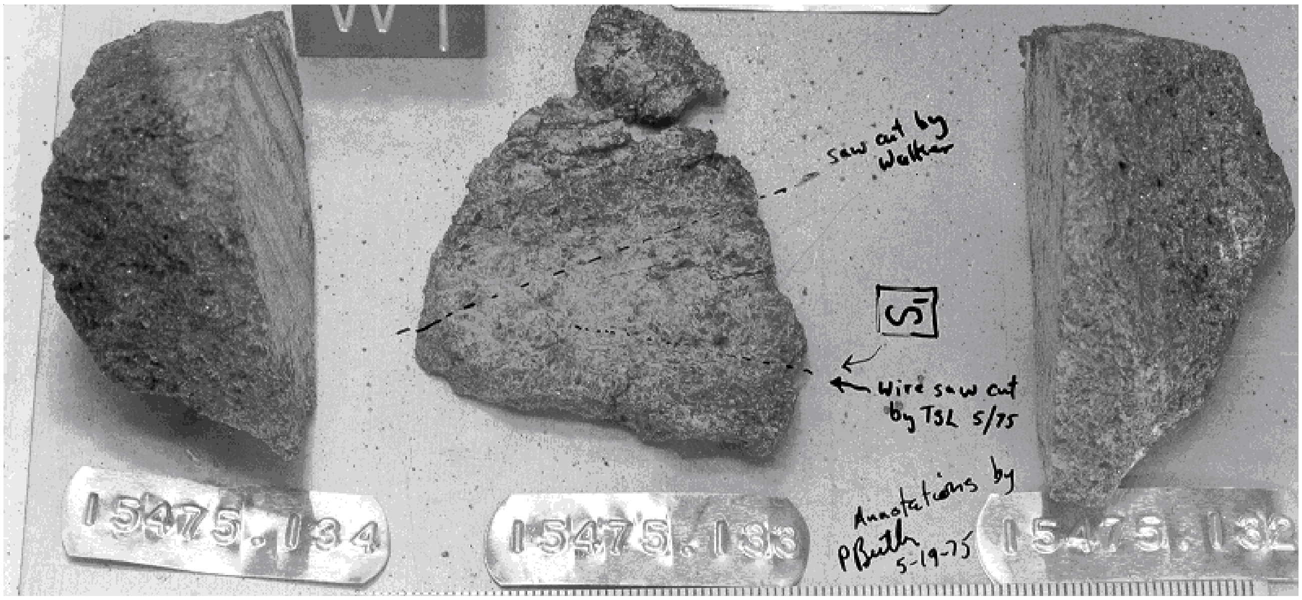


Figure 9: Cutting plan for 15475. NASA S72-33024. Edge of cube is 1 inch.

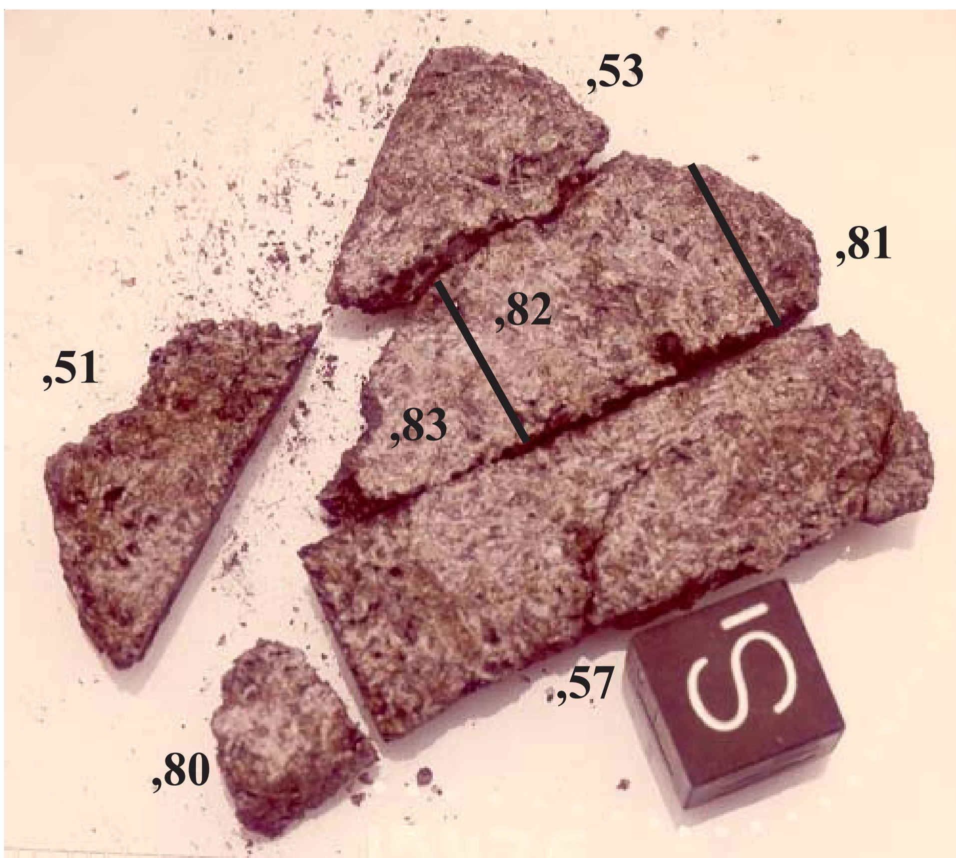


Figure 10: Subdivision of slab (,133) cut from 15475. NASA S75-27005. Cube is 1 cm.

References for 15475

Arvidson R., Crozaz G., Drozd R.J., Hohenberg C.M. and Morgan C.J. (1975) Cosmic ray exposure ages of features and events at the Apollo landing sites. *The Moon* **13**, 259-276.

Bhandari N., Goswami J. and Lal D. (1973) Surface irradiation and evolution of the lunar regolith. Proc. *4th Lunar Sci. Conf.* 2275-2290.

Brown G.M., Emeleus C.H., Holland G.J., Peckett A. and Phillips R. (1972) Mineral-chemical variations in Apollo 14 and Apollo 15 basalts and granitic fractions. *Proc. 3rd Lunar Sci. Conf.* 141-157.

Butler P. (1971) Lunar Sample Catalog, Apollo 15. Curators' Office, MSC 03209

Chappell B.W. and Green D.H. (1973) Chemical compositions and petrogenetic relationships in Apollo 15 mare basalts. *Earth Planet. Sci. Lett.* **18**, 237-246.

Church S.E., Bansal B.M. and Wiesmann H. (1972) The distribution of K, Ti, Zr, U, and Hf in Apollo 14 and 15 materials. *In* **The Apollo 15 Lunar Samples** (Chamberlain J.W. and Watkins C., eds.), 210-213. The Lunar Science Institute, Houston.

Compston W., de Laeter J.R. and Vernon M.J. (1972) Strontium isotope geochemistry of Apollo 15 basalts. *In* **The Apollo 15 Lunar Samples** (Chamberlain and Watkins , eds.), 347-351. Lunar Science Institute, Houston.

Drozd R.J., Hohenberg C.M., Morgan C.J. and Ralston C.E. (1974) Cosmic-ray exposure history at the Apollo 16 and other lunar sites: lunar surface dynamics. *Geochim. Cosmochim. Acta* **38**, 1625-1642.

Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1972) Concentrations of cosmogenic radionuclides in Apollo 15 rocks and soils. *In* **The Apollo 15 Lunar Samples** 357-359. Lunar Sci. Institute, Houston.

Gros J., Takahashi H., Hertogen J., Morgan J.W. and Anders E. (1976) Composition of the projectiles that bombarded the lunar highlands. *Proc. 7th Lunar Sci. Conf.* 2403-2425.

Hubbard N.J., Rhodes J.M., Gast P.W., Bansal B.M., Shih C.-Y., Wiesmann H. and Nyquist L.E. (1973b) Lunar rock types: The role of plagioclase in non-mare and highland rock types. *Proc. 4th Lunar Sci. Conf.* 1297-1312.

Hughes S.S. and Schmitt R.A. (1985) Zr-Hf-Ta fractionation during lunar evolution. *Proc. 16th Lunar Planet. Sci. Conf.* D31 in J. Geophys. Res. **90**.

Kleine T., Palme H., Mezger K. and Halliday A.N. (2005) Hf-W chronometry of lunar metals and the age and early differentiation of the Moon. *Science* **310**, 1671-1674.

Lee D-C., Halliday A.N., Snyder G.A. and Taylor L.A. (1997) Age and origin of the Moon. *Science* **278**, 1098-1103.

Lee D-C., Halliday A.N., Snyder G.A. and Taylor L.A. (2000) Lu-Hf systematics and evolution of the moon (abs#1288). *Lunar Planet. Sci.* **XXXI**, Lunar Planetary Institute, Houston.
.

Lee D.C., Halliday A.N., Leya I., Wieler R. and Weichert U. (2002) Cosmogenic tungsten and the origin and earliest differentiation of the Moon. *Earth Planet. Sci. Lett.* **198**, 267-274.

Lofgren G.E., Donaldson C.H. and Usselman T.M. (1975) Geology, petrology and crystallization of Apollo 15 quartz-normative basalts. *Proc. 6th Lunar Sci. Conf.* 79-99.

LSPET (1972a) The Apollo 15 lunar samples: A preliminary description. *Science* **175**, 363-375.

LSPET (1972b) Preliminary examination of lunar samples. Apollo 15 Preliminary Science Report. NASA SP-289, 6-1—6-28.

Mason B., Jarosewich E., Melson W.G. and Thompson G. (1972) Mineralogy, petrology, and chemical composition of lunar samples 15085, 15256, 15271, 15471, 15475, 15476, 15535, 15555 and 15556. *Proc. 3rd Lunar Sci. Conf.* 785-796.

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

Nyquist L.E., Hubbard N.J., Gast P.W., Bansal B.M., Wiesmann H. and Jahn B-M. (1973) Rb-Sr systematics for chemically defined Apollo 15 and 16 materials. *Proc. 4th Lunar Sci. Conf.* 1823-1846.

O'Kelley G.D., Eldridge J.S. and Northcutt K.J. (1972a) Abundances of primordial radioelements K, Th, and U in Apollo 15 samples, as determined by non-destructive gamma-ray spectrometry. *In* **The Apollo 15 Lunar Samples** (Chamberlain J.W. and Watkins C., eds.), 244-246. Lunar Science Institute, Houston.

O'Kelley G.D., Eldridge J.S., Northcutt K.J. and Schonfeld E. (1972c) Primordial radionuclides and cosmogenic radionuclides in lunar samples from Apollo 15. *Proc. 3rd Lunar Sci. Conf.* 1659-1670.

Pepin R.O., Basford J.R., Dragon J.C., Johnson N.L., Coscio M.R. and Murthy V.R. (1974) Rare gases and trace elements in Apollo 15 drill fines: Depositional chronologies and K-

Figure 11a: Photomicrograph of thin section 15475,150 by C Meyer @ 20x.

Ar ages and production rates of spallation-porduced ^{3}He, ^{22}Ne and ^{38}Ar vrs depth. *Proc. 5th Lunar Sci. Conf.* 2149-2184.

Rhodes J.M. and Hubbard N.J. (1973) Chemistry. classification, and petrogenesis of Apollo 15 mare basalts. *Proc. 4th Lunar Sci. Conf.* 1127-1148.

Ryder G. (1985) Catalog of Apollo 15 Rocks (three volumes). Curatoial Branch Pub. # 72, JSC#20787

Schnare D.W., Day J.M.D., Norman M.D., Liu Y. and Taylor L.A. (2008) A laser-ablation ICP-MS study of Apollo 15 low-titanium olivine-normative and quartz-normative mare basalts. *Geochim. Cosmochim. Acta* **72**, 2556-2572.

Snyder G.A., Borg L.E., Lee D.C., Taylor L.A., Nyquist L.E. and Halliday A.N. (1997b) Nd-Sr-Hf isotopic and geochronologic studies of Apollo 15 basalts (abs#1505). *Lunar Planet. Sci.* **XXVIII**, 1347-1348. Lunar Planetary Institute, Houston.

Swann G.A., Hait M.H., Schaber G.C., Freeman V.L., Ulrich G.E., Wolfe E.W., Reed V.S. and Sutton R.L. (1971b) Preliminary description of Apollo 15 sample environments. U.S.G.S. Interagency report: 36. pp219 with maps

Swann G.A., Bailey N.G., Batson R.M., Freeman V.L., Hait M.H., Head J.W., Holt H.E., Howard K.A., Irwin J.B., Larson K.B., Muehlberger W.R., Reed V.S., Rennilson J.J., Schaber G.G., Scott D.R., Silver L.T., Sutton R.L., Ulrich G.E., Wilshire H.G. and Wolfe E.W. (1972) 5. Preliminary Geologic Investigation of the Apollo 15 landing site. In Apollo 15 Preliminary Science Rpt. NASA SP-289. pages 5-1-112.

Takeda H., Miyamoto M., Ishii T. and Lofgren G.E. (1975) Relative cooling rates of mare basalts at the Apollo 12 and 15 sites as estimated from pyroxene exsolution data. *Proc. 6th Lunar Sci. Conf.* 987-996.

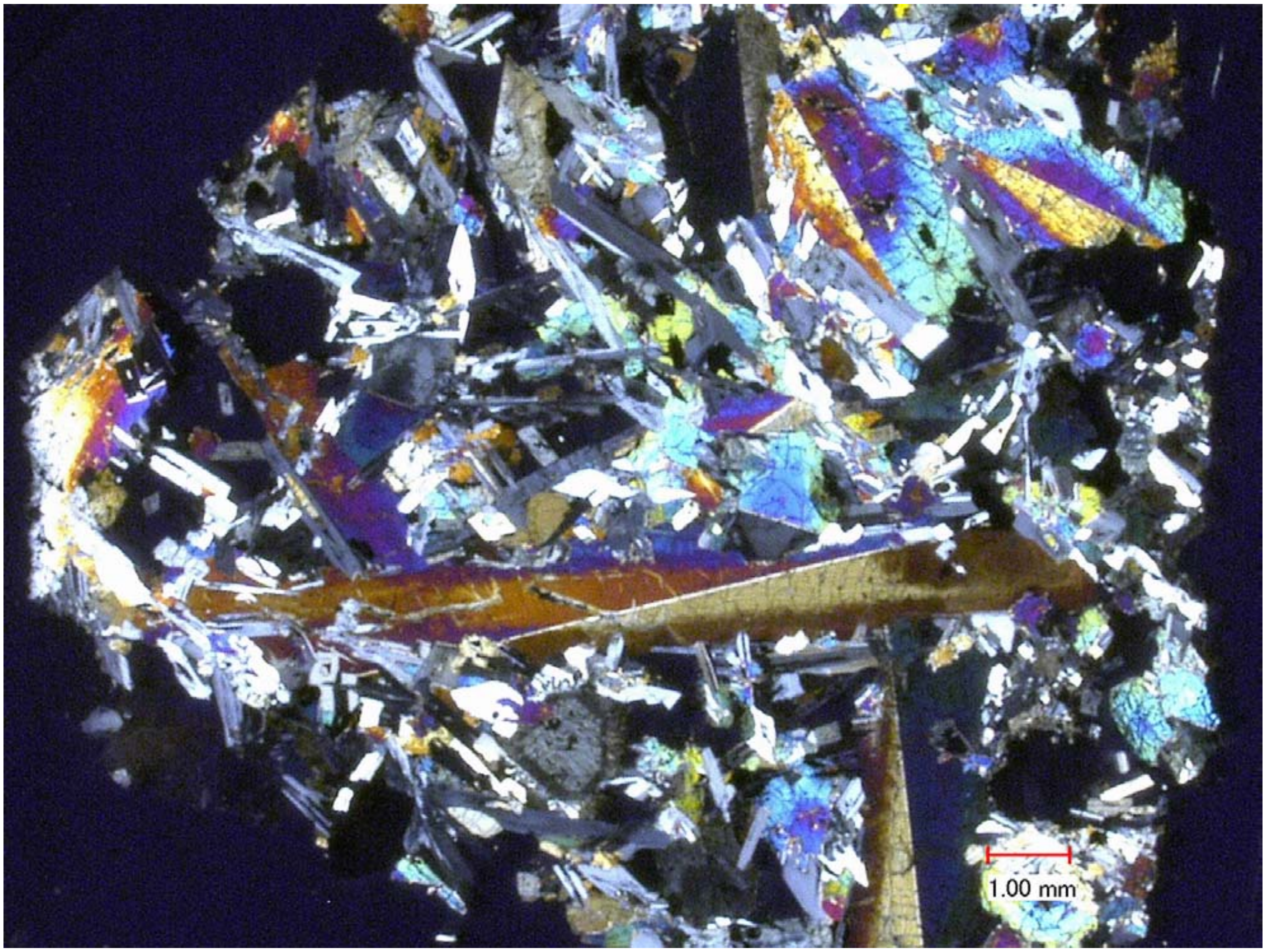


Figure 11b: Photomicrograph of thin section 15475,150 by C Meyer @ 20x (crossed polarizer).

Wänke H., Palme H., Baddenhausen H., Dreibus G., Jagoutz E., Kruse H., Palme C., Spettel B., Teschke F. and Thacker R. (1975a) New data on the chemistry of lunar samples: Primary matter in the lunar highlands and the bulk composition of the moon. *Proc. 6th Lunar Sci. Conf.* 1313-1340.

Wiesmann H. and Hubbard N.J. (1975) A compilation of the Lunar Sample Data Generated by the Gast, Nyquist and Hubbard Lunar Sample PI-Ships. Unpublished. JSC

Wolf R., Woodrow A. and Anders E. (1979) Lunar basalts and pristine highland rocks: Comparison of siderophile and volatile elements. *Proc. 10th Lunar Planet. Sci. Conf.* 2107-2130.