60315

Poikilitic Impact Melt

787 grams

Figure 1: Photo of top surface of 60315. Scale is in cm. Note the many zap pits on this surface. NASA S72-41576.

Introduction

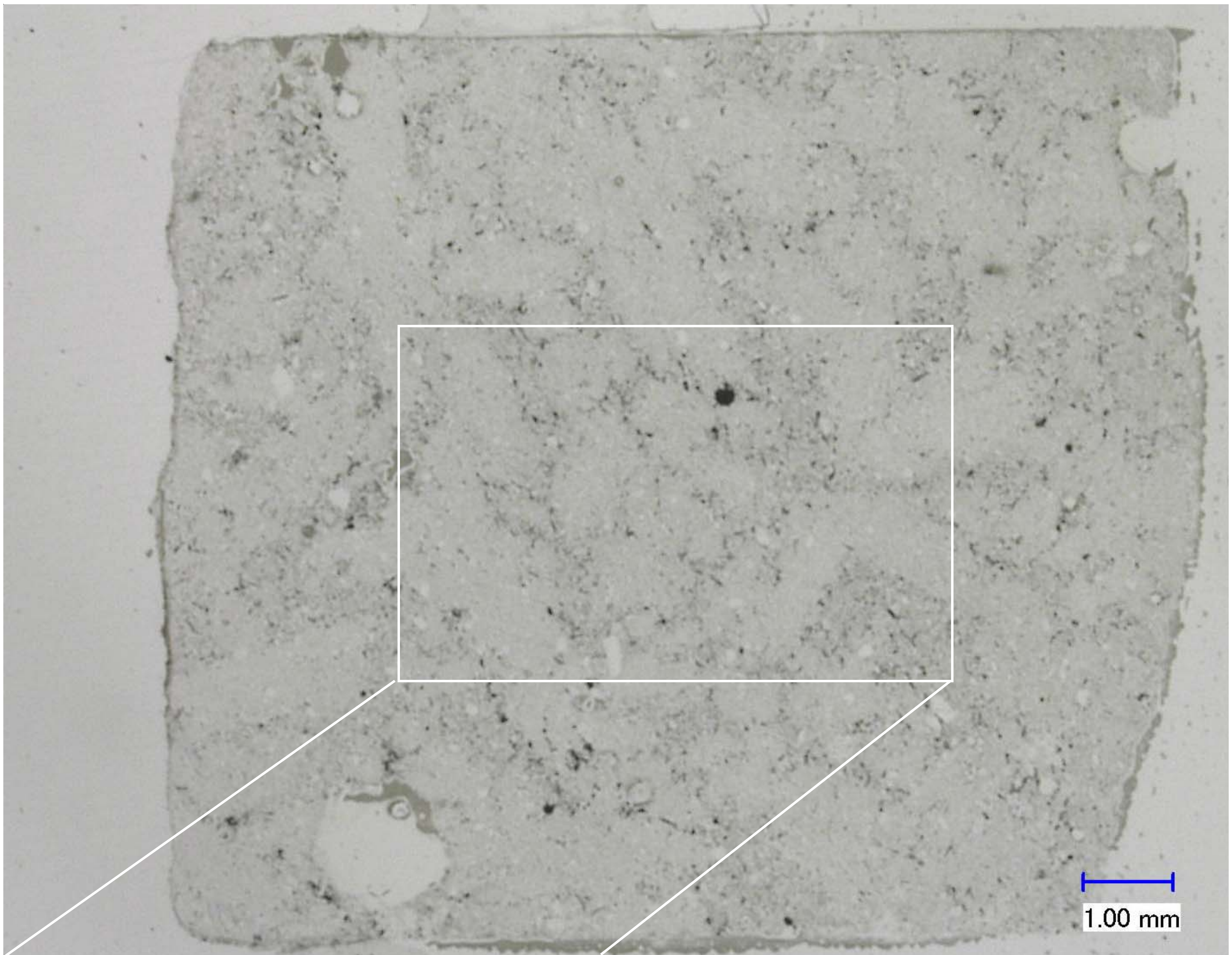
60315 is a flat rock, about 4 cm thick, found loose on the regolith near the LM. The top exposed surface is covered with micrometeorite craters (figure 1). The bottom surface is freshly broken and free of zap pits.

60315 is holocrystalline and dense (almost igneous), but contains significant siderophile content and relict anorthite xenocrysts indicating that it is a recrystallized impact melt. It has a poilkilitic texture where large oikocrysts of pyroxene enclose smaller plagioclase and olivine crystals.

Sample 60315 is 3.87 b.y. old and has been exposed on the surface to cosmic rays for only ~ 4.5 m.y. It would appear to be a good sample for inter-comparison of radioactive decay schemes.

Petrography

Bence et al. (1973), Simonds et al. (1973), Hodges and Kushiro (1973) and Walker et al. (1973) each described the poikilitic texture of 60315 (figure 2). Vaniman and Papike (1981) also provide a mode and mineral compositions for 60315. All note that 60315 is composed of a mesh of relatively large oikocrysts of orthopyroxene (Wo_4En_{80}) which enclose abundant laths



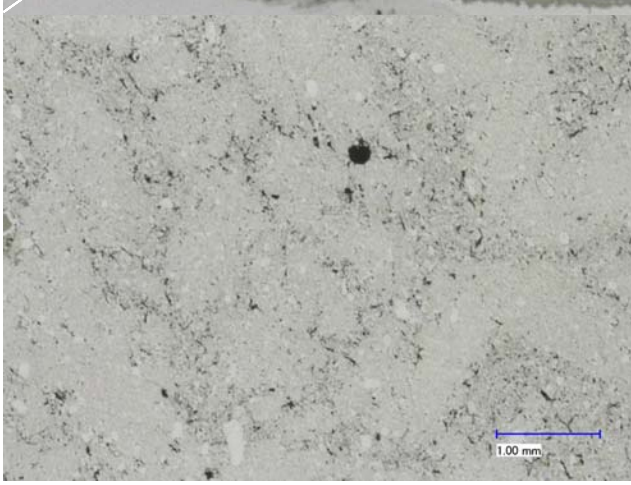


Figure 2: Photomicrographs of thin section 60315,61 by C Meyer @ 20 and 50x.

and clasts of plagioclase, rare olivine and opaques. Augite, olivine, ilmenite and armalcolite rim some pyroxene oikocrysts and/or make up the intersticies between oikocrysts. Rounded vesicles are common.

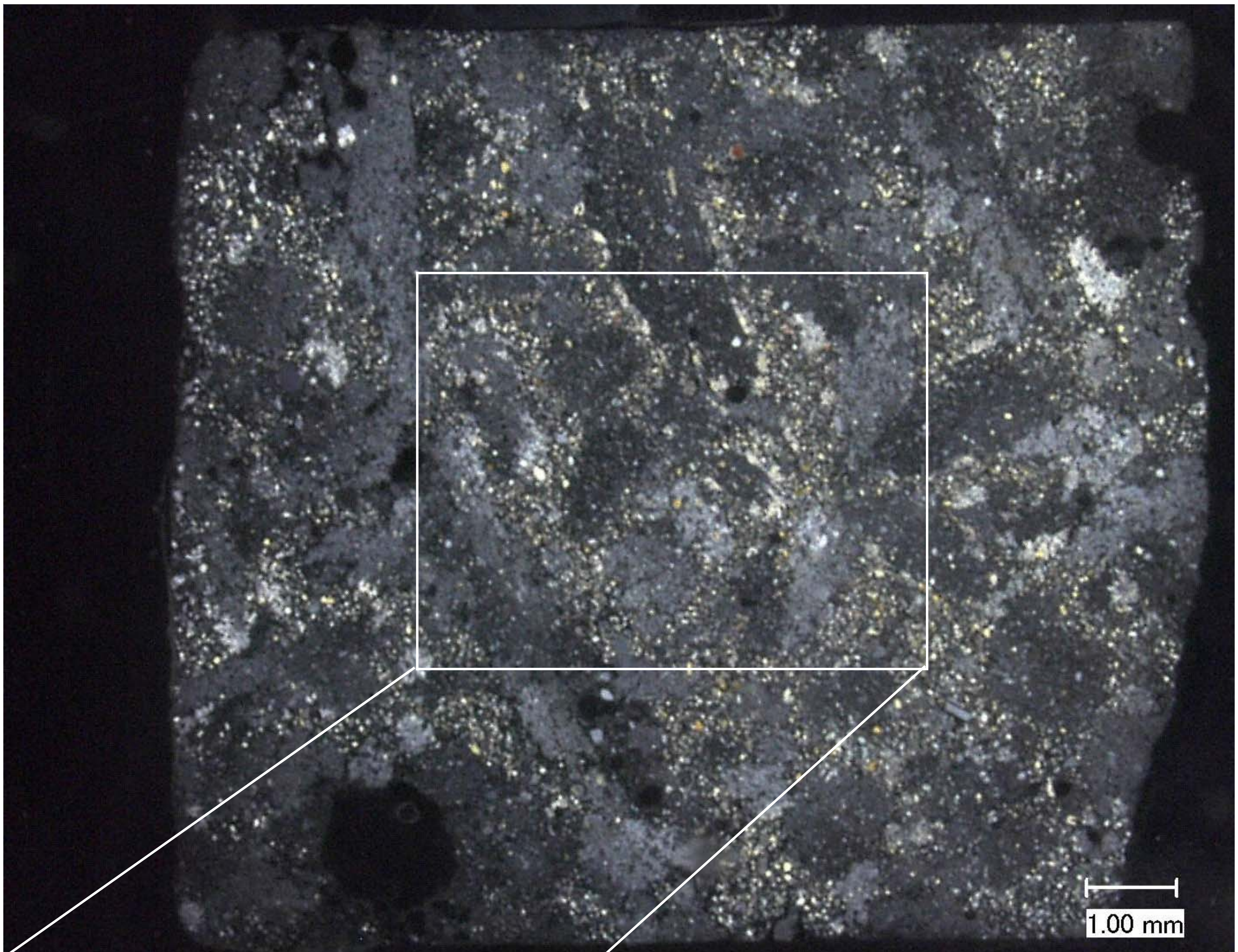
Bence et al. (1973) also noted some areas with diabasic texture. However, these are all small in size (Hodges and Kushiro 1973).

60315 is similar to 65015, and 62235 which were originally collectively termed "very high Al_2O_3 (VHA) basalts" by Hubbard et al. (1973a). However, this was refuted by Dowty et al. (1974d). The phase relations of a melt with this composition were worked out by Ford et al. (1974) and Walker et al. (1973), who determined that a liquid with this composition was not on the coetectic. Ridley and Adams (1976) compared the equilibrium temperature for pyroxene and olivine (~1000 deg. C) with that of metal (~600 deg. C).

Neukem et al. (1973) and Fectig et al (1974) have studied the size distribution of micrometeorite craters (figures 12 and 13).

Mineralogy

Olivine: Olivine is generally small and rounded Fo_{75-71}. Bence et al. (1973) found that olivine found included



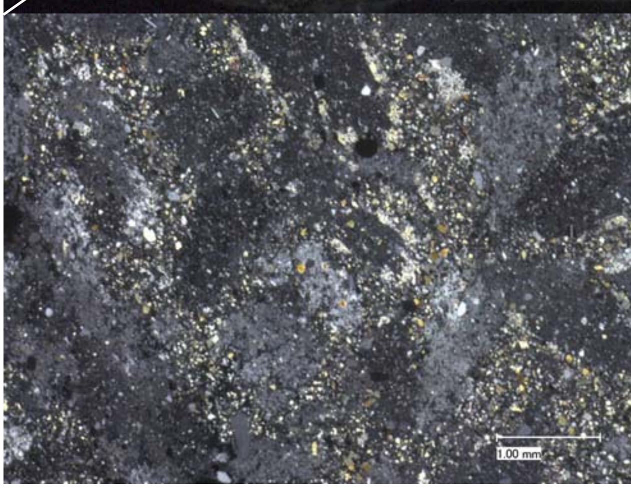


Figure 3: Photomicrographs of thin section 60315,61 with crossed-polarizer by C Meyer @ 20x and 50x.

in augite or orthopyroxene was slightly more mafic (figure 4).

Pyroxene: The largest grains in 60315 are orthopyroxene oikocrysts. Minor augite is enclosed (figure 4).

Plagioclase: Plagioclase clasts (chadocrysts) in 60315 have calcic cores (An_{97-95}) with narrow rims (An_{92}). Interstitial plagioclase ranges down to An_{78}. Meyer et al. (1974) determined the trace element content of plagioclase chadocrysts by ion probe.

Ilmenite: Ilmenite laths are found in the interstitial areas. Hodges and Kushiro (1973) determined 7-8% MgO in ilmenite.

Metallic iron: Rounded grains of metal (up to 2 mm in dia.) with ~5% Ni are found in interstitial areas (Hodges and Kushiro 1973). Taylor et al. (1973) and Misra and Taylor (1975) determined the composition of metallic iron found in 60315 (Co = 0.34%, Ni = 6.7%, P = 0.26% and S = 0.01%)(figures 5 and 6). Hunter and Taylor (1981) report "abundant" schreibersite and only minor rust(?).

Mineralogical Mode for 60315

	Simonds et al. 1973	Vaniman and Papike 1981
Plagioclase	55 %	46.2 %
Augite	4	4.9
Orthopyroxene	34	39
Olivine	6	7.1
Opaque	1	2.1
Metal		0.7

Chemistry

Rose et al. (1973) and others found high Ni contents in 60315. Ganapathy et al. (1974) and others found high Ir and Au.

The composition of 60315 is very similar to that of other Apollo 16 impact melt rocks (e.g. 65015). It has high rare-earth-element content with a KREEP-like pattern (figure 7).

Radiogenic age dating

Kirsten et. al. (1973)(figure 8) and Husain and Schaeffer (1973) (figure 9) determined the age of 60315, which seems to be in rough agreement with the precise Pb/Pb isochron determined by Nunes et al. (1973) (figure 10). Schaeffer et al. (1976) determined 3.907 ± 0.010 b.y. by Ar/Ar. However, Norman et al. (2006) determined an Ar/Ar plateau age of 3.868 ± 0.031 b.y. (figure 11). So one can't tell from the age if this rock is from Imbrium!

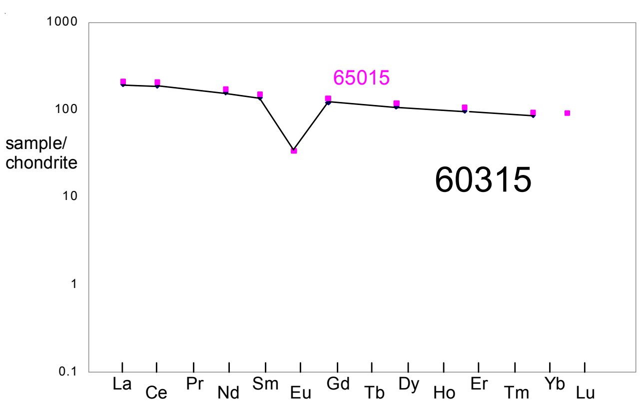


Figure 7: Normalized rare-earth-element composition of 60315 (connected dots) compared with that of 65015 (pink squares). All data by isotope dilution mass spectroscopy (Weismann and Hubbard 1977).

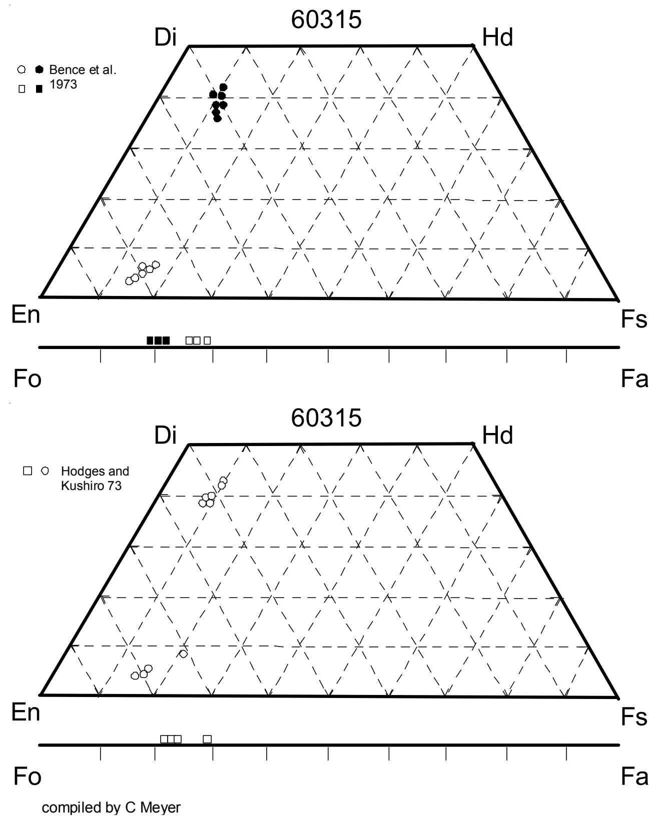


Figure 4: Pyroxene and olivine composition of 60315 (data replotted from Bence et al. and Hodges and Kushiro 1973).

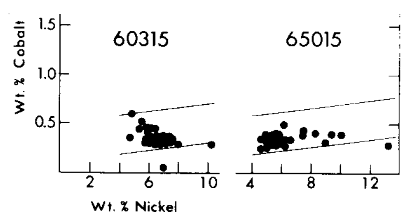


Figure 5: Ni and Co content of metallic iron grains in 60315 compared with 65015 (from Misra and Taylor 1975).

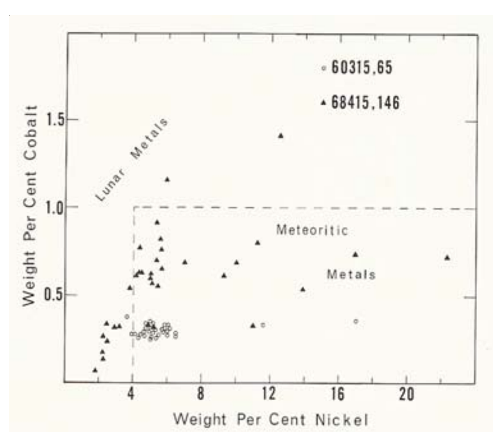


Figure 6: Metal composition in 60315 and 68415 (Taylor et al. 1973).

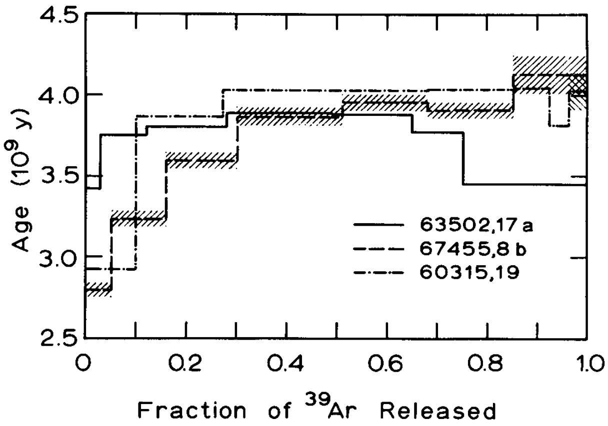


Figure 8: Ar/Ar plateau diagram for 60315 and other samples (from Kirsten et al. 1973).

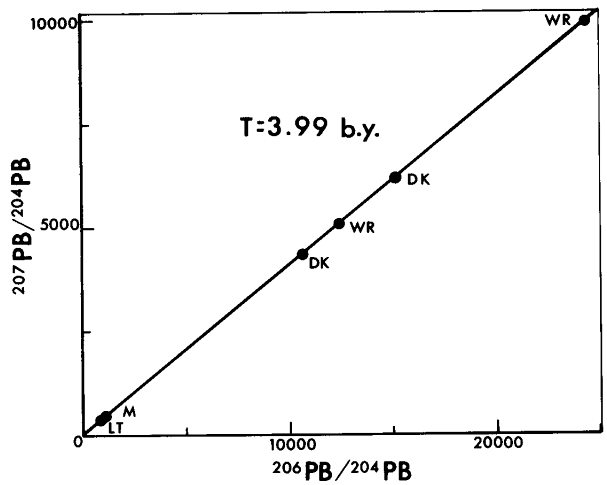


Figure 10: Pb/Pb isochron diagram for 60315 (from Nunes et al. 1973).

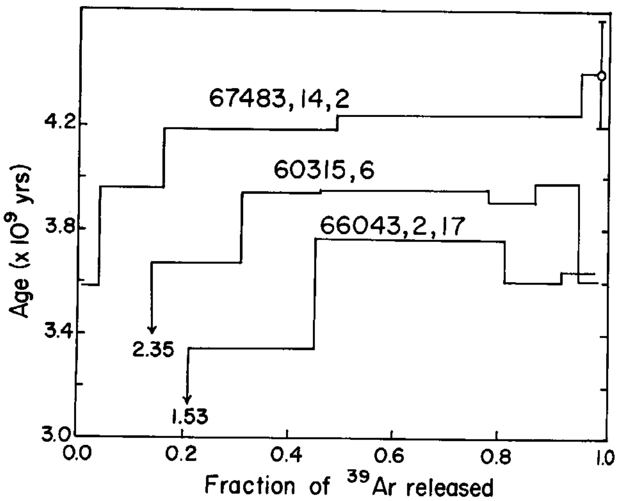


Figure 9: Ar/Ar plateau diagram for 60315 and other samples (from Husain and Schaeffer 1973).

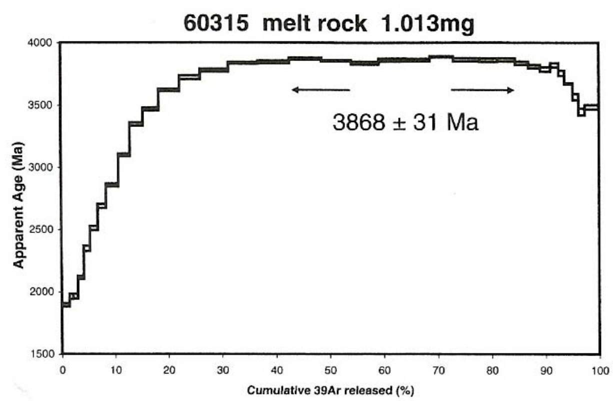


Figure 11: Ar/Ar plateau diagram for 60315 (Norman et al. 2006).

Summary of Age Data for 60315

	Ar/Ar	Pb/Pb
Kirsten et al. 1973	4.03 ± 0.03 b.y.	
Husain and Schaeffer 1973	3.94 ± 0.05	
Schaeffer et al. 1976	3.91 ± 0.02	
Nunes et al. 1973		3.99 ± 0.01
Nunes 1975		3.93
Norman et al. 2006	3.87 ± 0.03	

Caution: see disclaimer

Cosmogenic isotopes and exposure ages

The relatively young exposure age ^{37}Ar of 4.5 ± 0.1 m.y. for 60315 led Kirsten et al. (1973) to assign this to the age of a 27 meter-sized crater nearby, or possibly, to South Ray Crater (same age). Eldridge et al. (1973) determined the cosmic-ray-inducted activity of ^{26}Al = 92 dpm/kg. and ^{22}Na= 47 dpm/kg.

Other Studies

60315 is a relatively large, and homogeneous sample that has been used for measurement of physical properties of dry lunar rock. Sato (1976) determined the oxygen fugacity of 60315 as function of temperature.

Nagata et al. (1973), Brecher et al. (1973) and Scherer and Nagata (1976) determined magnetic properties and Brecher et al., Huffman et al. (1974) and Hufman and Dunmyer (1975) reported Mossbauer spectra (figure

Table 1a. Chemical composition of 60315.

reference	*LSPET 73*		Rose 73		Hubbard 73		Hubbard 73		Morrison 73		Taylor 73		Laul 74		Eldridge 73	
weight													44 mg			
SiO2 %	45.61	(b)	46.75	(a)	46.84	(b)					46.4	(g)				
TiO2	1.27	(b)	1.38	(a)	1.39	(b)	1.26	(c)	1	(d)	1.29	(g)	1.3	(e)		
Al2O3	17.18	(b)	17.1	(a)	17.24	(b)	17.7		16.5		17.6	(g)	17	(e)		
FeO	10.53	(b)	8.64	(a)	8.86	(b)	10.3		9.83		7.98	(g)	10.4	(e)		
MnO	0.12	(b)	0.11	(a)	0.12	(b)			0.11				0.112	(e)		
MgO	13.15	(b)	13.42	(a)	13.81	(b)	13.3	(c)	11.1		13.3	(g)	14	(e)		
CaO	10.41	(b)	10.5	(a)	10.5	(b)	10.1	(c)	10		10.4	(g)	9.4	(e)		
Na2O	0.56	(b)	0.61	(a)	0.51	(b)	0.55		0.62		0.63	(g)	0.76	(e)		
K2O	0.35	(b)	0.49	(a)	0.39	(b)	0.36	(c)	0.37		0.42	(g)	0.42	(e)	0.38	(f)
P2O5	0.45	(b)	0.48	(a)	0.48	(b)			0.57							
S %	0.14	(b)			0.14	(b)			0.105							
sum																
Sc ppm			20	(a)					13.4		9	(g)	14	(e)		
V			47	(a)					31		40	(g)	50	(e)		
Cr	1460	(b)	1642	(a)			1477	(c)	1300		800	(g)	1498	(e)		
Co			48	(a)					89		22	(g)	88	(e)		
Ni	191	(b)	810	(a)					1380		390	(g)	1400	(e)		
Cu			11	(a)					10.8		3.9	(g)				
Zn			12	(a)					8							
Ga			4.6	(a)					4.1							
Ge ppb																
As																
Se																
Rb	9.8	(b)	11	(a)			9.8	(c)	9		7.7	(g)				
Sr	156	(b)	135	(a)			156	(c)	156							
Y	142	(b)	140	(a)					120		131	(g)				
Zr	640	(b)	1370	(a)					840		630	(g)	640	(e)		
Nb	37	(b)	60	(a)					33		39	(g)				
Mo																
Ru																
Rh																
Pd ppb																
Ag ppb																
Cd ppb																
In ppb																
Sn ppb											0.4	(g)				
Sb ppb																
Te ppb																
Cs ppm									0.05		0.4	(g)				
Ba			550	(a)			445	(c)	466		560	(g)	460	(e)		
La			61	(a)			45.5	(c)	37		49	(g)	50	(e)		
Ce							113	(c)	98		123	(g)	120	(e)		
Pr											18	(g)				
Nd							71.3	(c)	47		73.6	(g)	73	(e)		
Sm							20.1	(c)	25		21.1	(g)	21.5	(e)		
Eu							1.89	(c)	1.6		2.18	(g)	1.9	(e)		
Gd							23.8	(c)	16		28	(g)				
Tb									3.7		4.13	(g)	4.4	(e)		
Dy							26.3	(c)	26		26.6	(g)	29	(e)		
Ho									3		6.17	(g)				
Er							15.5	(c)			17.7	(g)				
Tm									1.4		2.7	(g)				
Yb			16	(a)			14	(c)	12		16.3	(g)	15	(e)		
Lu									2.1		2.5	(g)	2.1	(e)		
Hf									13		14.5	(g)	16	(e)		
Ta													2	(e)		
W ppb																
Re ppb																
Os ppb																
Ir ppb													35	(e)		
Pt ppb																
Au ppb													30	(e)		
Th ppm	7.2	(b)							9.2		8.2	(g)	8.1	(e)	8.56	(f)
U ppm							2.05	(c)	2		2.3	(g)	1.7	(e)	2.34	(f)

technique (a) combined XRF, OES, (b) XRF, (c) IDMS, (d) (e) INAA, (f) radiation counting

Table 1b. Chemical composition of 60315.

reference	Wanke 76			Nyquist 73		Nunes 73			Ganapathy 74	
weight	,87	,103								
SiO2 %	46.9	46.6								
TiO2	1.37	1.37								
Al2O3	17.1	17.5								
FeO	8.4	8.6								
MnO	0.11	0.12								
MgO	13.6	13.4								
CaO	10.5	10.7								
Na2O	0.63	0.63								
K2O	0.37	0.38								
P2O5	0.44	0.45								
S %	0.1	0.09								
sum										
Sc ppm	15.7	15.1	(e)							
V										
Cr	1560	1510	(e)							
Co	37.5	35.8	(e)							
Ni	710	690	(e)						798	(e)
Cu		18.6	(e)							
Zn		2.37	(e)						0.3	(e)
Ga		3.85	(e)							
Ge ppb		600	(e)						625	(e)
As		340	(e)							
Se		440	(e)						520	(e)
Rb		9.54	(e)	9.8	(c)				10.8	(e)
Sr	160	159	(e)	156	(c)					
Y	123	131	(e)							
Zr	744	720	(e)							
Nb	27	31	(e)							
Mo										
Ru										
Rh										
Pd ppb										
Ag ppb									0.94	(e)
Cd ppb									5	(e)
In ppb										
Sn ppb										
Sb ppb									11	(e)
Te ppb									4.7	(e)
Cs ppm	0.55	0.58	(e)						0.54	(e)
Ba	475	479	(e)							
La	49.6	49.6	(e)							
Ce	142	136	(e)							
Pr		19.2	(e)							
Nd	87	88	(e)							
Sm	20.8	20.6	(e)							
Eu	1.94	1.95	(e)							
Gd		26	(e)							
Tb	4.6	4.67	(e)							
Dy	26.7	28.5	(e)							
Ho	5.8	6	(e)							
Er		18	(e)							
Tm										
Yb	16	15.8	(e)							
Lu	2.16	2.1	(e)							
Hf	17.1	17.1	(e)							
Ta	2.05	1.96	(e)							
W ppb		488	(e)							
Re ppb		1.3	(e)						1.36	(e)
Os ppb										
Ir ppb	8.5	9.4	(e)						11	(e)
Pt ppb										
Au ppb		16.7	(e)						18.3	(e)
Th ppm	6.82	6.84	(e)			8.164	7.712	(c)		
U ppm	1.82	2.19	(e)			2.221	2.064	(c)	2.28	(e)

technique: (c) IDMS, (e) INAA, RNAA

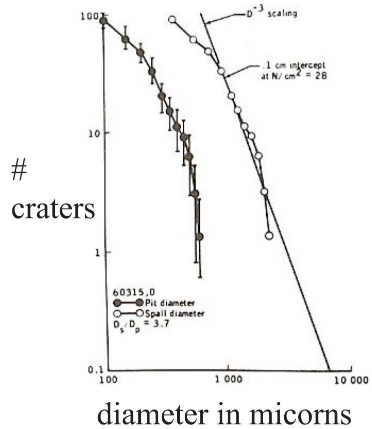


Figure 12: Cumulative frequency of micrometeorite craters on sufrace of 60315 (Morrison et al. 1973).

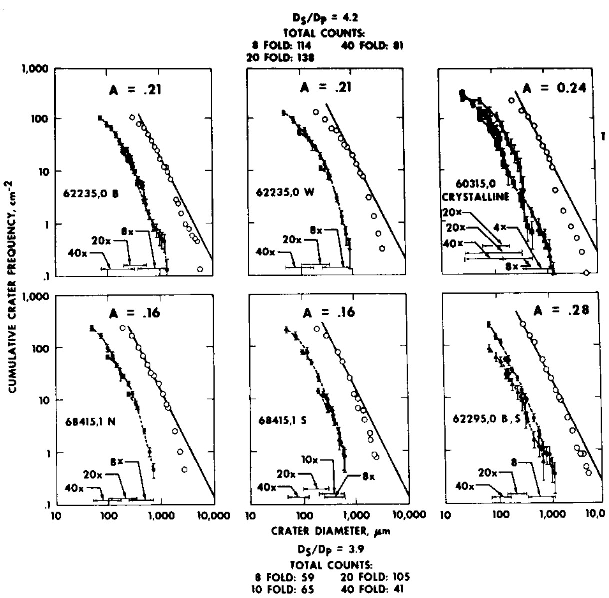


Figure 13: Crater-count size distribution for exposed surfaces on "crystalline" rocks from Apollo 16 including 60315 (by Neukem et al. 1973).

14). Tsay and Bauman (1977) studied electron spin resonance. All these measurements were influenced by the metallic iron in the sample.

Mizutani and Newbigging (1973) determined the seismic wave velocities of 60315 as function of pressure (depth)(figure 15). Chung and Westphal (1973) studied electrical properties (figure16).

Processing

The west end was cut off; followed with a 1 cm thick slab which was subdivided (figures 17 and 18). There are 27 thin sections.

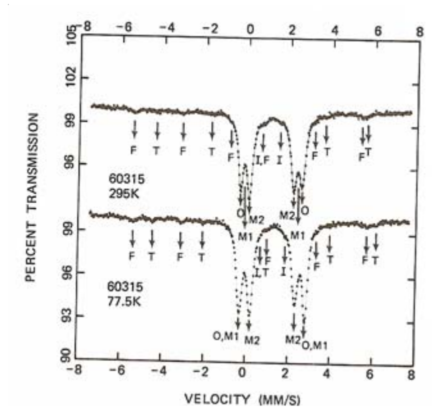


Figure 14: Mossbauer spectra of 60315 (Huffman et al. 1974).

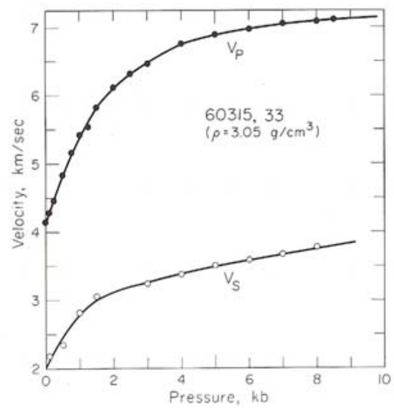


Figure 15: Elastic wave velocity as function of static pressure (depth)(Mizutani and Newbigging 1973).

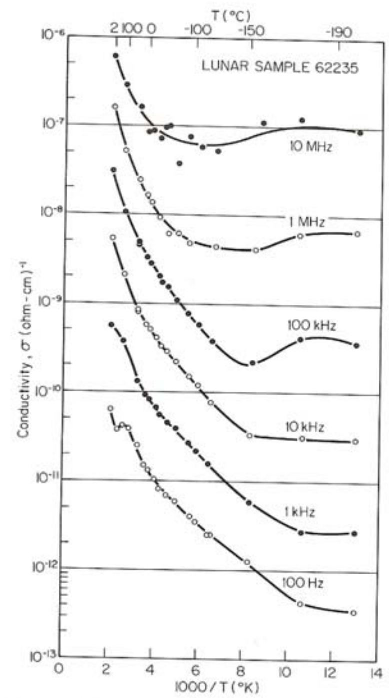
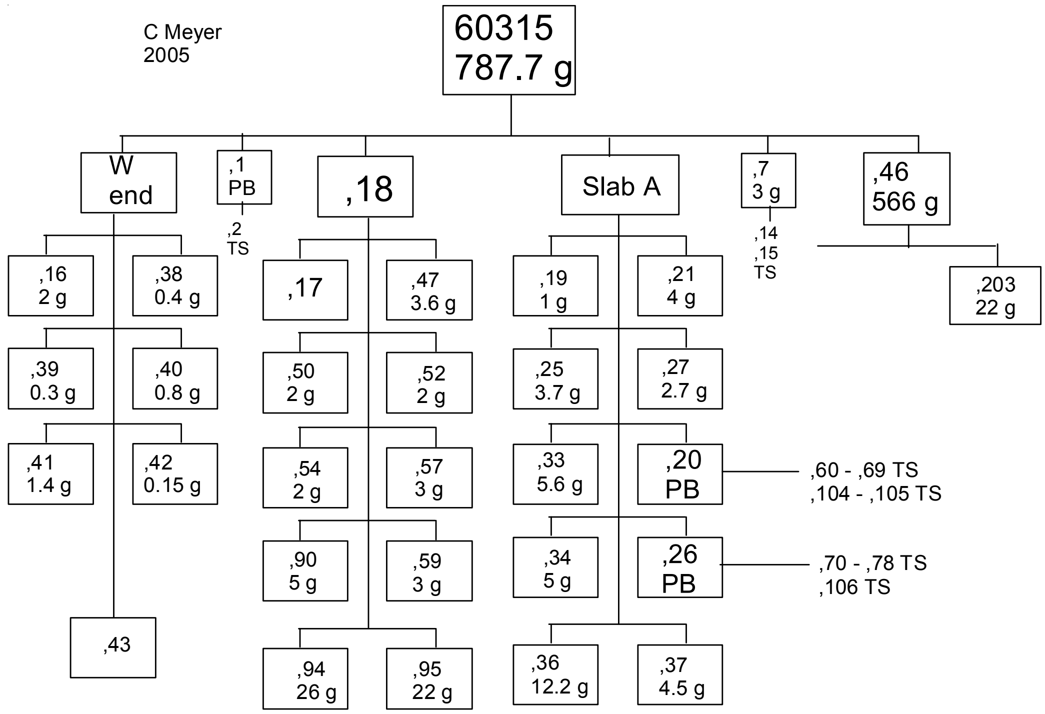
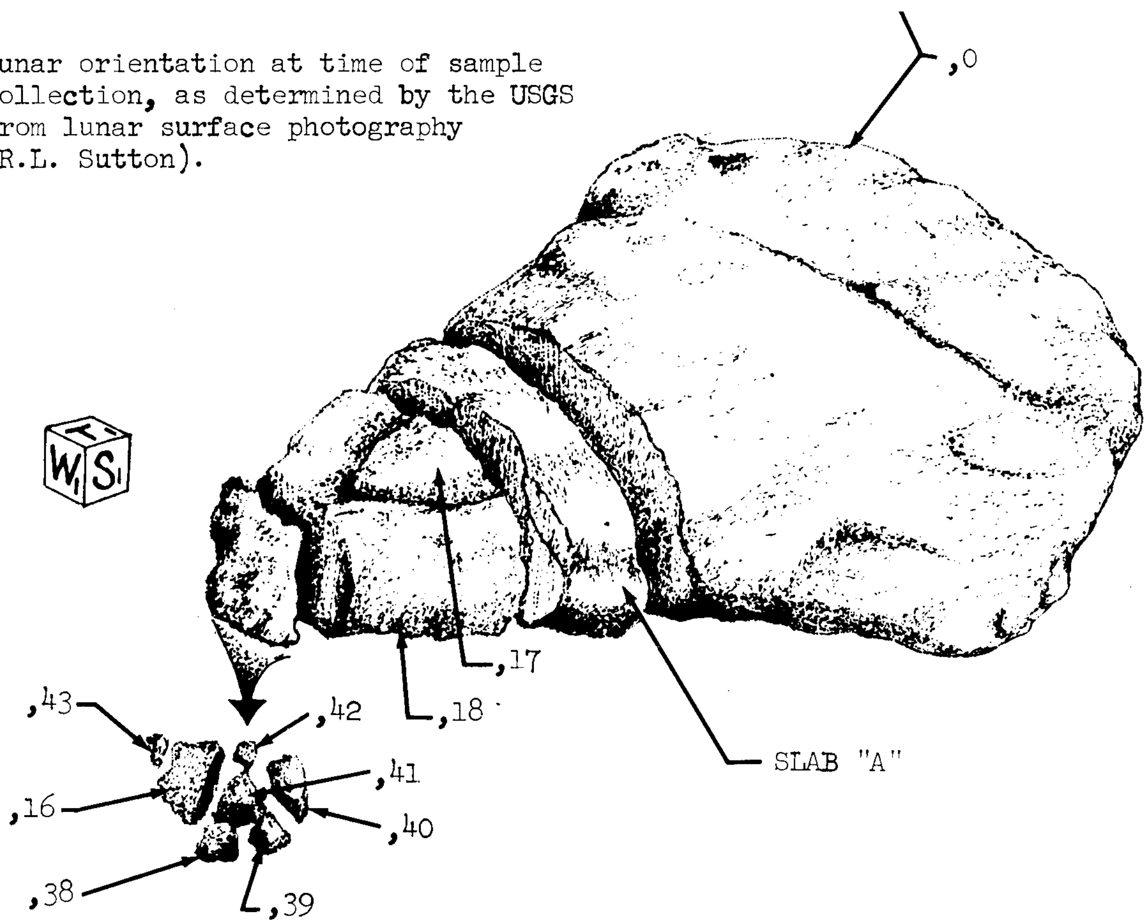


Figure 16: Electrical conductivity of dry lunar rock as function of temperature (Chung and Westphal 1973).



Lunar orientation at time of sample collection, as determined by the USGS from lunar surface photography (R.L. Sutton).



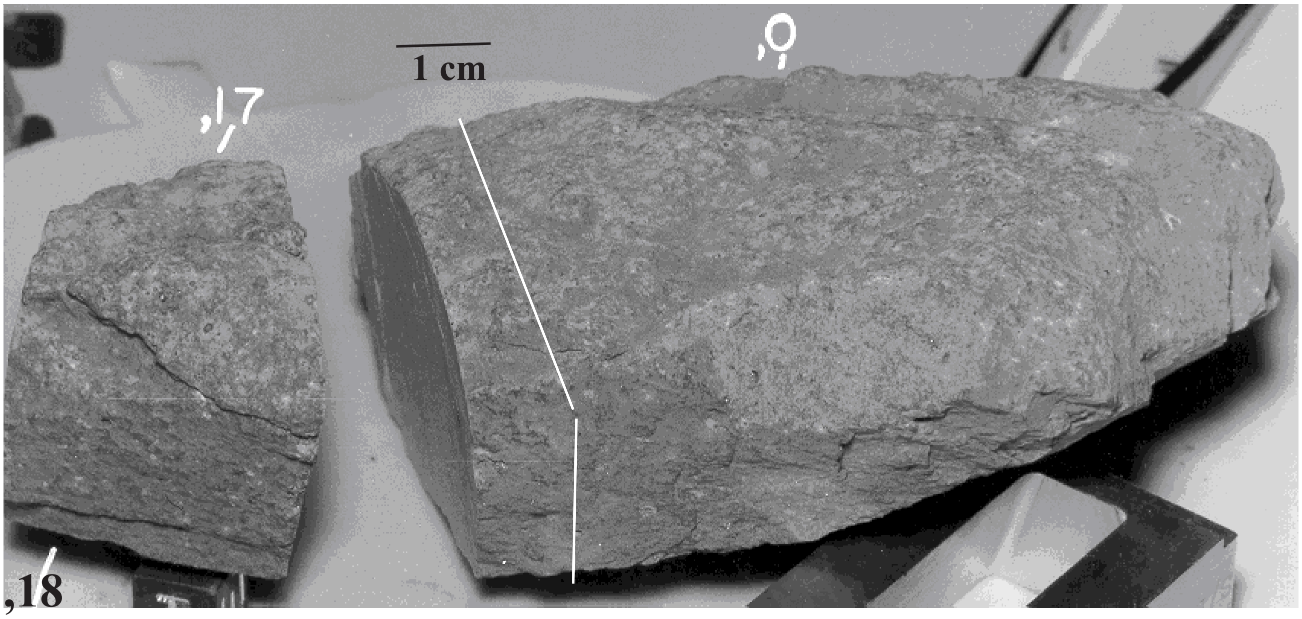


Figure 17: Second sawcut of 60315, before cutting slab. Approximate postion of slab indicated.. Scale is given. NASA S72-51834.

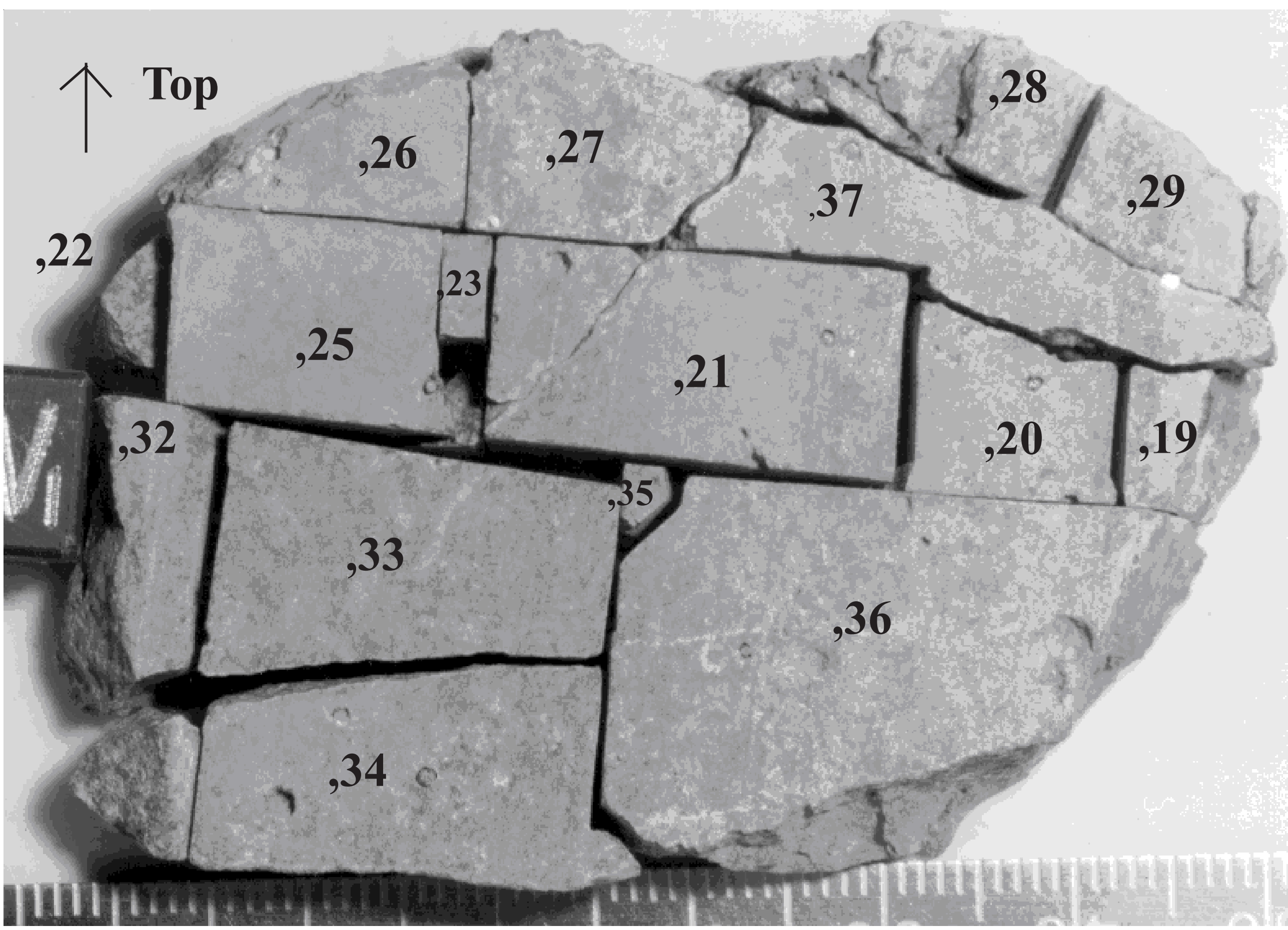


Figure 18: Slab of 60315. NASA S72-51843. Scale in cm and mm. Slab is about 1 cm thick.

References for 60315

Bence A.E., Papike J.J., Sueno S. and Delano J.W. (1973) Pyroxene poikiloblastic rocks from the lunar highlands. *Proc. 4th Lunar Sci. Conf.* 597-611.

Butler P. (1972) Lunar Sample Information Catalog Apollo 16. Lunar Receiving Laboratory. MSC 03210 Curator's Catalog. pp. 370.

Brecher A., Vaughan D.J., Burns R.G. and Morash K.R. (1974) Magnetic and Mossbauer studies of Apollo 16 rocks chips 60315 and 62295. *Proc. 4th Lunar Sci. Conf.* 2991-3001.

Chung D.H. and Westphal W.B. (1973) Dielectric spectra of Apollo 15 and 16 lunar solid samples. *Proc. 4th Lunar Sci. Conf.* 3077-3091.

Dowty E., Prinz M. and Keil K. (1974d) Very high alumina basalt: A mixture and not a magma type. *Science* **183**, 1214-1215.

Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1973) Radionuclide concentrations in Apollo 16 lunar samples determined by nondestructive gamma-ray spectrometry. *Proc. 4th Lunar Sci. Conf.* 2115-2122.

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

Fechtig H., Hartung J.B., Nagel K., Neukum G. and Storzer D. (1974a) Lunar microcrater studies, derived meteoroid fluxes, and comparison with satellite-borne experiments. *Proc. 5th Lunar Sci. Conf.* 2463-2474.

Ganapathy R., Morgan J.W., Higuchi H., Anders E. and Anderson A.T. (1974) Meteoritic and volatile elements in Apollo 16 rocks and in separated phases from 14306. *Proc. 5th Lunar Sci. Conf.* 1659-1683.

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

Haskin L.A., Helmke P.A., Blanchard D.P., Jacobs J.W. and Telunder K. (1973) Major and trace element abundances in samples from the lunar highlands. *Proc. 4th Lunar Sci. Conf.* 1275-1296.

Hodges C.A., Muelberger W.R. and Ulrich G.E. (1973) Geologic setting of Apollo 16. *Proc. 4th Lunar Sci. Conf*. 1-25.

Hodges F.N. and Kushiro I. (1973) Petrology of Apollo 16 lunar highland rocks. *Proc. 4th Lunar Sci. Conf*. 1033-1048.

Hubbard N.J., Rhodes J.M. and Gast P.W. (1973a) Chemistry of lunar basalts with very high alumina contents. *Science* **181**, 339-342.

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.

Huffman G.P., Schwerer F.C., Fisher R.M. and Nagata T. (1974a) Iron distributions and metallic-ferrous ratios for Apollo lunar samples: Mossbauer and magnetic analyses. *Proc. 5th Lunar Sci. Conf.* 2779-2794.

Huffman G.P. and Dunmyre G.R. (1975) Superparamagnetic clusters of Fe+2 spins in lunar olivine: Dissolution by high-temperature annealing. *Proc. 6th Lunar Sci. Conf.* 757-772,

Hunter R.H. and Taylor L.A. (1981) Rust and schreibersite in Apollo 16 highland rocks: Manifestations of volatile-element mobility. *Proc. 12th Lunar Planet. Sci. Conf.* 253-259.

Husain L. and Schaeffer O.A. (1973b) ^{40}Ar-^{39}Ar crystallization ages and ^{38}Ar-^{37}Ar ray exposure ages of samples from the vicinity of the Apollo 16 landing site (abs). *Lunar Sci.* IV, 406-408. The Lunar Sci. Institute, Houston.

Irving A.J. (1975) Chemical, mineralogical, and textural systematics of non-mare melt rocks: implications for lunar impact and volcanic processes. *Proc. 6th Lunar Sci. Conf.* 363-394.

Irving A.J. (1977b) Chemical variation and fractionation of KREEP basalt magmas. *Proc. 8th Lunar Sci. Conf.* 2433-2448.

Korotev R.L. (1996c) On the relationship between the Apollo 16 ancient regolith breccias and feldspathic fragmental breccias, and the composition of the prebasin crust in the Central Highlands of the Moon. *Meteor. & Planet. Sci.* **31**, 403-412.

Kirsten T., Horn P. and Kiko J. (1973a) ^{39}Ar/^{40}Ar dating and rare gas analysis of Apollo 16 rocks and soils. *Proc. 4th Lunar Sci. Conf.* 1757-1784.

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.

Krahenbuhl U., Ganapathy R., Morgan J.W. and Anders E. (1973a) Volatile elements in Apollo 16 samples: Possible evidence for outgassing of the Moon. *Science* **180**, 858-861.

Krahenbuhl U., Ganapathy R., Morgan J.W. and Anders E. (1973b) Volatile elements in Apollo 16 samples: Implications for highland volcanism and accretion history of the moon. *Proc. 4th Lunar Sci. Conf.* 1325-1348.

Laul J.C.. Hill D.W. and Schmitt R.A. (1974d) Chemical studies of Apollo 16 and 17 samples. *Proc. 5th Lunar Sci. Conf.* 1047-1066.

LSPET (1973) The Apollo 16 lunar samples: Petrographic and chemical description. *Science* **179**, 23-34.

LSPET (1972) Preliminary examination of lunar samples. Apollo 16 Preliminary Science Report. NASA SP-315, 7-1—7-58.

Meyer C. (1977) Petrology, mineralogy and chemistry of KREEP basalt. *Physics and Chemistry of the Earth* **10**, 239-260. (Ahrens and Runcorn , eds)

Meyer C., Anderson D.H. and Bradley J.G. (1974) Ion microprobe mass analysis of plagioclase from "non-mare" lunar samples. *Proc. 5th Lunar Sci. Conf.* 685-706.

Misra K.C. and Taylor L.A. (1975) Characteristics of metal particles in Apollo 16 rocks. *Proc. 6th Lunar Sci. Conf.* 615-639.

Mizutani H. and Newbigging D. (1973) Elastic wave velocities of Apollo 14, 15 and 16 rocks. *Proc. 4th Lunar Sci. Conf.* 2601-2609.

Moore C.B., Lewis C.F. and Gibson E.K. (1973) Total carbon contents of Apollo 15 and 16 lunar samples. *Proc. 4th Lunar Sci. Conf.* 1613-1923.

Morrison D.A., McKay D.S., Fruland R.M. and Moore H.J. (1973) Microcraters on Apollo 15 and 16 rocks. *Proc. 4th Lunar Sci. Conf.* 3235-3253.

Morrison G.H., Nadkarni R.A., Jaworski J., Botto R.I. and Roth J.R. (1973) Elemental abundances of Apollo 16 samples. *Proc. 4th Lunar Sci. Conf.* 1399-1405.

Nunes P.D., Tatsumoto M., Knight R.J., Unruh D.M. and Doe B.R. (1973b) U-Th-Pb systematics of some Apollo 16 lunar samples. *Proc. 4th Lunar Sci. Conf.* 1797-1822.

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.

Papanastassiou D.A. and Wasserburg G.J. (1972c) Rb-Sr age of Luna 20 and Apollo 16 samples. *Earth Planet. Sci. Lett.* **17**, 52-63.

Reed S.J.B. and Taylor S.R. (1974) Meteoritical metal in Apollo 16 samples. *Meteoritics* **9**, 23-24.

Ridley W.I. and Adams M.-L. (1976) Petrologic studies of poikiloblastic textured rocks (abs). *Lunar Sci.* **VII**, 739-740. Lunar Science Institute, Houston.

Rose H.J., Cuttitta F., Berman S., Carron M.K., Christian R.P., Dwornik E.J., Greenland L.P. and Ligon D.T. (1973) Compositional data for twenty-two Apollo 16 samples. *Proc. 4th Lunar Sci. Conf.* 1149-1158.

Ryder G. and Norman M.D. (1980) Catalog of Apollo 16 rocks (3 vol.). Curator's Office pub. #52, JSC #16904

Sato M. (1976b) Oxygen fugacity values of some Apollo 16 and 17 rocks (abs). *Lunar Sci.* **VII**, 758-760. Lunar Planetary Institute, Houston.

Schaeffer O.A., Husain L. and Schaeffer G.A. (1976) Ages of highland rocks: The chronology of lunar basin formation revisited. *Proc. 7th Lunar Sci. Conf.* 2067-2092.

Schwerer F.C. and Nagata T. (1976) Ferromagnetic-superparamagnetic granulometry of lunar surface materials. *Proc. 7th Lunar Sci. Conf.* 759-778.

Simonds C.H., Warner J.L. and Phinney W.C. (1973) Petrology of Apollo 16 poikilitic rocks. *Proc. 4th Lunar Sci. Conf.* 613-632.

Sutton R.L. (1981) Documentation of Apollo 16 samples. In Geology of the Apollo 16 area, central lunar highlands. (Ulrich et al.) U.S.G.S. Prof. Paper 1048.

Taylor L.A., McCallister R.T. and Sardi O. (1973c) Cooling histories of lunar rocks based on opaque mineral geothermometers. *Proc. 4th Lunar Sci. Conf.* 819-828.

Taylor S.R., Gorton M.P., Muir P., Nance W.B., Rudowski R. and Ware N. (1973) Composition of the Descartes region, lunar highlands. *Geochim. Cosmochim Acta* **37**, 2665-2683.

Touboul M., Kleine T., Bourdon B., Palme H. and Wieler R. (2007) Late formation and prolonged differentiation of the moon inferred from W isotopes in lunar metals. *Nature* **450**, 1206-1209.

Vaniman D.T. and Papike J.J. (1978) The lunar highland melt-rock suite. *Geophys. Res. Lett.* **5**, 429-432.

Vaniman D.T. and Papike J.J. (1980) Lunar highland melt rocks: Chemistry, petrology and silicate mineralogy. *In* Proc. **Conf. Lunar Highlands Crust** (Papike J.J. and Merrill R.B., eds.) 271-337. Pergamon. Lunar Planetary Institute, Houston.

Walker D., Longhi J., Grove T., Stolper E. and Hays J.F. (1973b) Experimental petrology and origin of rocks from the Descartes highlands. *Proc. 4th Lunar Sci. Conf.* 1013-1032.

Wänke H., Palme H., Kruse H., Baddenhausen H., Cendales M., Dreibus G., Hofmeister H., Jagoutz E., Palme C., Spettel B. and Thacker R. (1976) Chemistry of lunar highland rocks: a refined evaluation of the composition of the primary matter. *Proc. 7th Lunar Sci. Conf.* 3479-3499.

Wänke H., Baddenhausen H., Blum K., Cendales M., Dreibus G., Hofmeister H., Kruse H., Jagoutz E., Palme C., Spettel B., Thacker R. and Vilcsek E. (1977a) On the chemistry of lunar samples and achondrites. Primary matter in the lunar highlands: A re-evaluation. *Proc. 8th Lunar Sci. Conf.* 2191-2213.

Warner J.L., Simonds C.H. and Phinney W.C. (1973b) Apollo 16 rocks: Classification and petrogenetic model. *Proc. 4th Lunar Sci. Conf.* 481-504.

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