70017

Ilmenite Basalt

2957 grams

Figure 1: Photo of lunar basalt 70017 showing vugs and vesicles. Sample is about 10 cm across. Cube is 1 cm. NASA# S73-15723.

Introduction

Lunar sample 70017 is a vesicular, medium-grained, high-Ti basalt that was collected from the area near the Lunar Lander (figure 1). It was one of the last rocks collected from the moon and the astronauts made a speech about it referring to "the children of the world". Subsequently, small pieces of it were distributed widely. It has also been the subject of many science investigations (briefly summarized below).

70017 has a crystallization age about 3.7 b.y. and an exposure age about 220 m.y.

Petrography

Longhi et al. (1974) describe 70017 as "a medium-grained hypidiomorphic granular high-Ti basalt with textural relations suggesting relatively slow cooling. Large, equant, subhedral grains of clinopyroxene (1-2

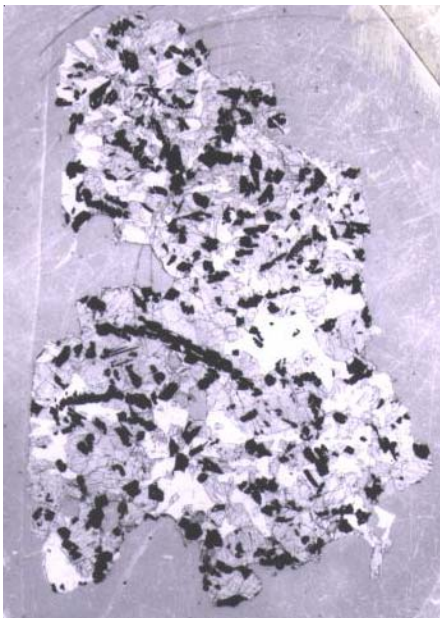


Figure 2: Thin section 70017,111 showing "chains" of ilmenite. Filed of view 1.5 cm.

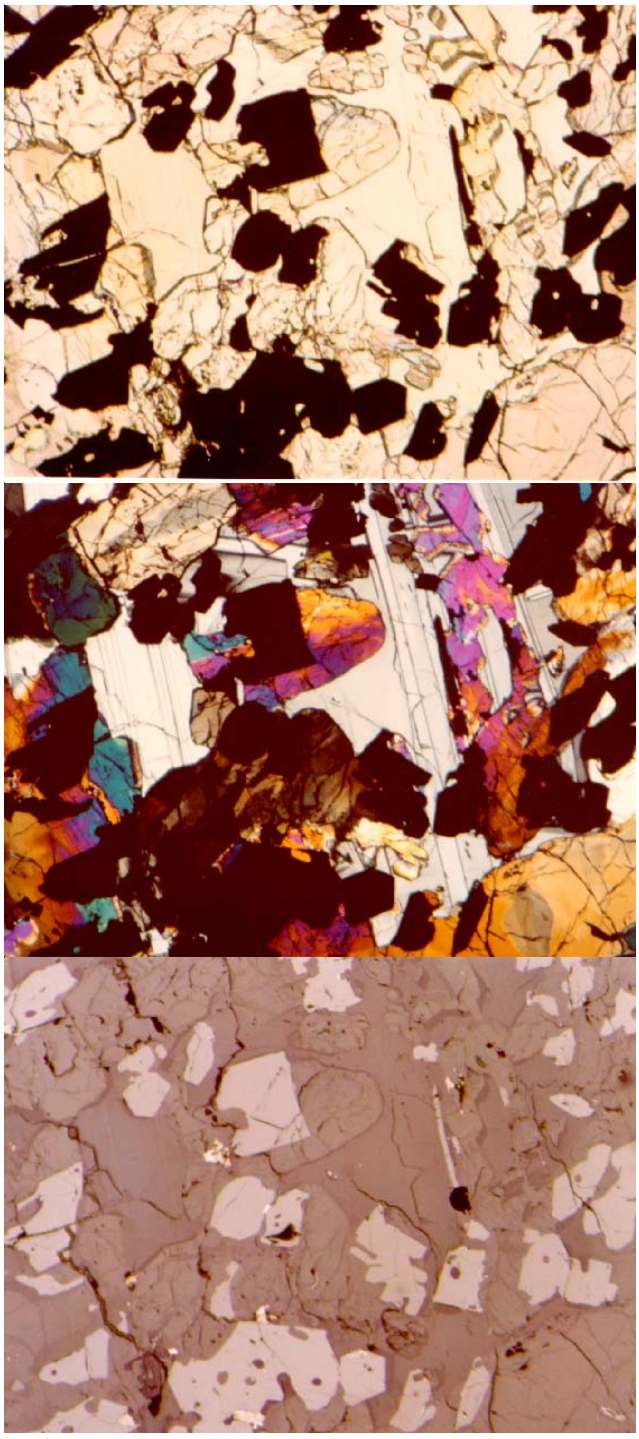


Figure 3. Three views of same area of thin section 70017,125 (transmitted light, crossed polorizers, and reflected light). Field of view is 2.5 mm. NASA # S79-26723-5.

mm) enclose embayed ilmenite (figure 3). Plagioclase (up to 2 mm) is anhedral and poikilitically encloses clinopyroxene, olivine and ilmenite. Cristobalite is present in interstices between clinopyroxene, plagioclase and ilmenite."

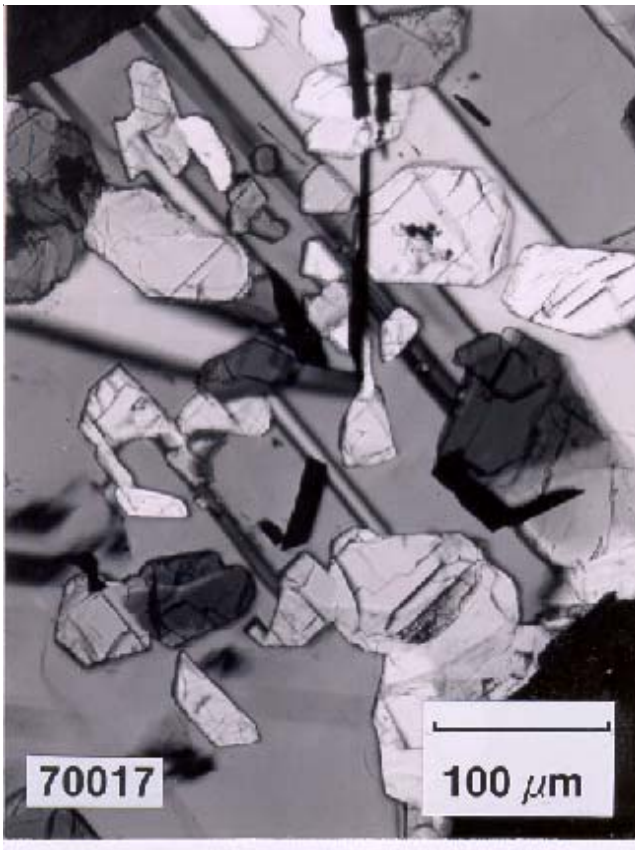


Figure 4: Partially polarized light photo of polysynthetic twinning in plagioclase poikilitically enclosing equant olivine and pyroxene crystals in 70017.

Roedder and Weiblen (1975) studied melt inclusions in ilmenite in 70017 and other Apollo 17 rocks and found evidence for silicate liquid immisibility.

Nord et al. (1974) determined that 70017 had a single-stage cooling history (<2 deg./hr.), by carefully studying the defect structure of pyroxene and plagioclase. Usselman et al. (1975) also calculated the cooling rate.

Mineralogy

Olivine: Olivine (Fo_{66-69}) is found in the cores of the large clinopyroxene grains and in plagioclase (figure 4).

Pyroxene: Pyroxene is abundant in 70017. Large pyroxene grains are zoned from subcalcic augite to pigeonite to Fe-rich (figure 6). Pyroxene cores contain up to 3.5% TiO_2 and 4.5% Al_2O_3 (Brown et al. 1973, Hodges and Kushiro 1974 and Longhi et al. 1974). Sung et al. (1974) studied the ratio of $^{3+}Ti/^{4+}Ti$ in pyroxene – perhaps 30% is ^{3+}Ti!

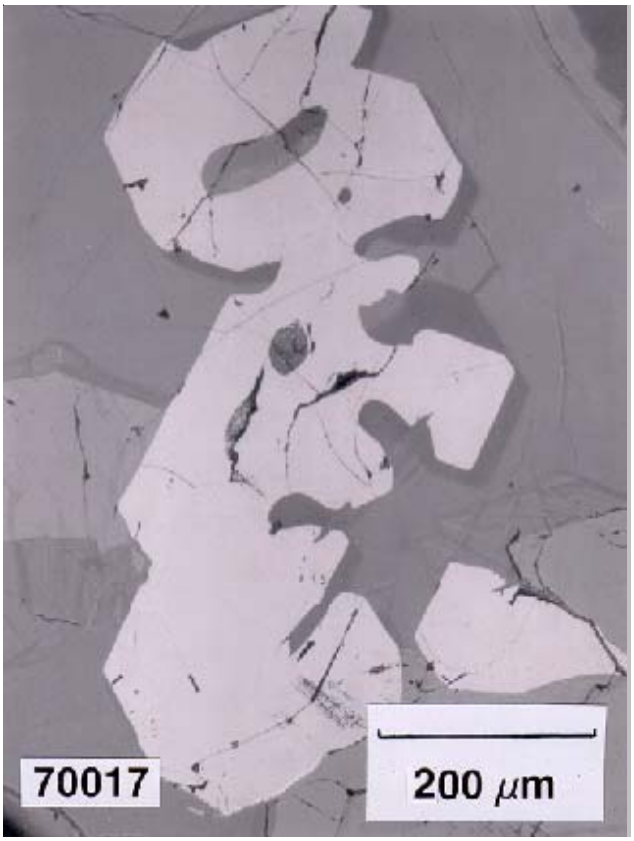


Figure 5: Reflected light photo of polished thin section illustrating habit of ilmenite in 70017.

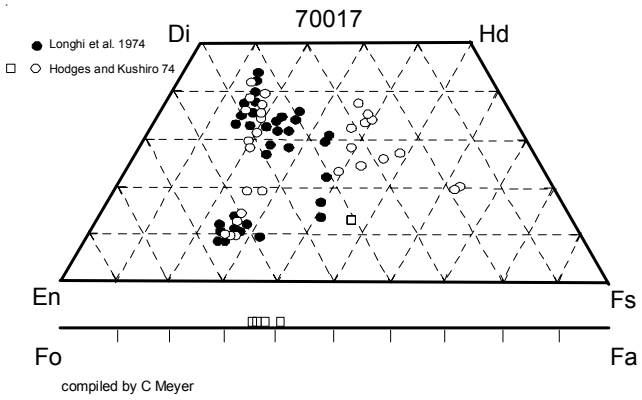


Figure 6: Pyroxene and olivine composition for mare base 70017 (data copied from Longhi et al. 1974 and Hodges and Kushiro 1974).

Plagioclase: Longhi et al. (1974) measured plagioclase as An_{69-88}.

Opaques: Ilmenite is abundant and found occuring in long "chains" (figure 2). It has exsolution of chromite and rutile (figure 5). Experiments show that armalcolite was an early phase, but it has mostly converted to ilmenite. Some relict armalcolite is found in pyroxene cores (figure 7). Small grains of chromite are reported in olivine (Hodges and Kushiro 1974). El Goresy and Ramdohr (1975) studied the opaque minerals in 70017 in order to determine the nature of subsolidus reduction producing elemental iron. Analyses of armalcolite in 70017 are given in table 2.

Silica: Silica found in 70017 is cristobalite (Hodges and Kushiro 1974, Roedder and Weiblen 1975) and has a characteristic cracked texture (figure 8).

Mesostasis: A very complex mesostasis of glass, silica, troilite-iron, whitlockite and trace tranquillityite occurs in this rock.

Chemistry

The chemical composition of 70017 is given in table 1 and figures 9 and 10. It is typical of the other basalts returned from Taurus-Littrow (figure 11) and is classified as a group B basalt (Paces et al. 1991). The chemical composition of high and low K melt inclusions is found in Roedder and Weiblen (1975).

Radiogenic age dating

Nyquist et al. (1975) and Schaeffer et al. (1977) have dated 70017 at 3.67 b.y. Note that the "ilmenite separates" are found to contain the most Rb (figure 12). The "ages" determined by Phinney et al. (1975) and Mattinson et al. (1977) were not convincing. Tilton

Mineralogical Mode for 70017

	Longhi et al. 1974	Brown et al. 1975	Roedder, Weiblen 1975
Olivine	1 %	0.9	0.4
Pyroxene	50	49.3	57.6
Plagioclase	26	25.4	19.8
Opaques	22	22.8	19.2
Fe	tr.		tr.
FeS	tr.		
Mesostasis	tr.	0.3	1.4
Silica		1.3	1.6

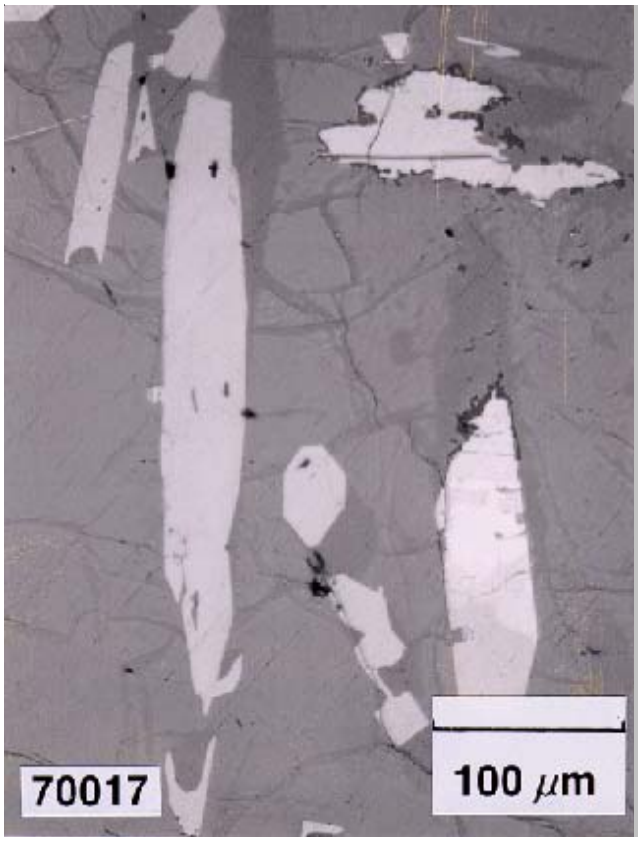


Figure 7: Reflected light photo of tan, barrel-shaped armalcolite in 70017. It is hexagonal in cross section (center of photo), but tapered in the elongate direction.

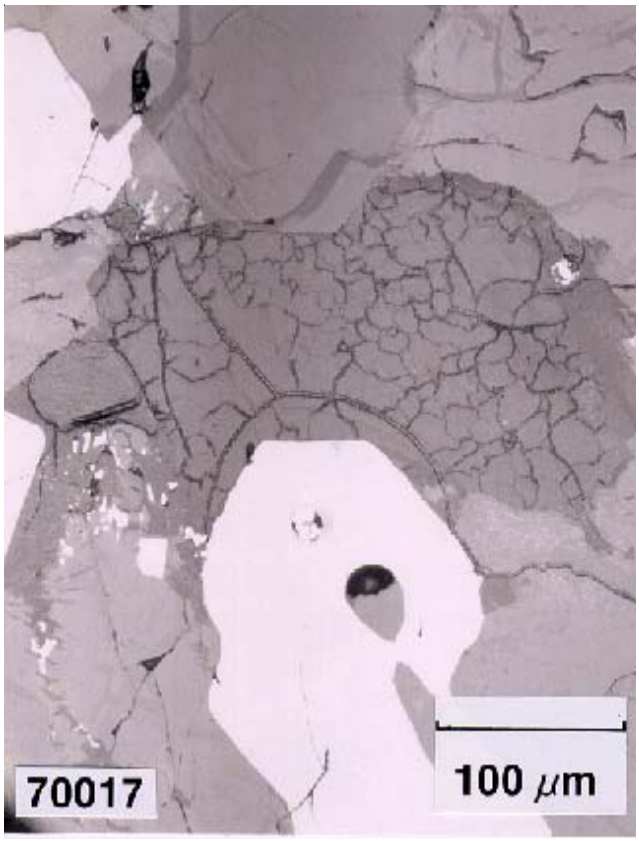


Figure 8: Reflected light photo of silica in 70017.

and Chen (1979) also reported U/Pb data for 70017. Additional isotopic data is found in Unruh et al. (1984).

Cosmogenic isotopes and exposure ages

Phinney et al. (1975) determined an exposure age of 220 ± 20 m.y. for 70017.

Yokoyama et al. (1974) report that 70017 was apparently saturated with ^{26}Al.

Table 2: Analysis of armalcolite in 70017.

from El Goresy et al. 1974

SiO2	0.33	0.3	0.32	0.3
Al2O3	1.72	1.77	1.6	1.57
TiO2	70.44	71.61	71.69	71.7
Cr2O3	1.63	1.69	1.46	1.39
FeO	18.43	16.3	15.24	15.5
MnO	0.08	0.09	0.1	0.1
MgO	5.47	6.63	7.16	7.41
CaO	0.57	0.44	0.4	0.45
V2O3	0.18	0.27	0.39	0.38
total	98.85	99.1	98.36	98.8

Other Studies

Rutherford et al. (1974) studied the "liquid line of decent" for the cooling of a basalt with the composition of 70017 and found experimental evidence for "liquid immisibility". Sato (1976) determined the *insitu* oxygen fugacity as a function of temperature (figure 13).

Petrowski et al. (1974) determined the concentration and isotopic composition of sulfur and carbon. Mayeda et al. (1974) reported the isotopic composition of oxygen.

Huffman et al. (1974) measured the Mössbauer spectra of 70017 (figure 14) and determined the amount of metallic iron (0.1%). Brecher et al. (1974), Nagata (1974), Stephenson et al. (1974) and Schwerer and Nagata (1976) studied the magnetic properties of 70017.

Hapke et al. (1978) and Osborne et al. (1978) used powered rock samples of 70017 to calibrate spectra that might be obtained from orbit.

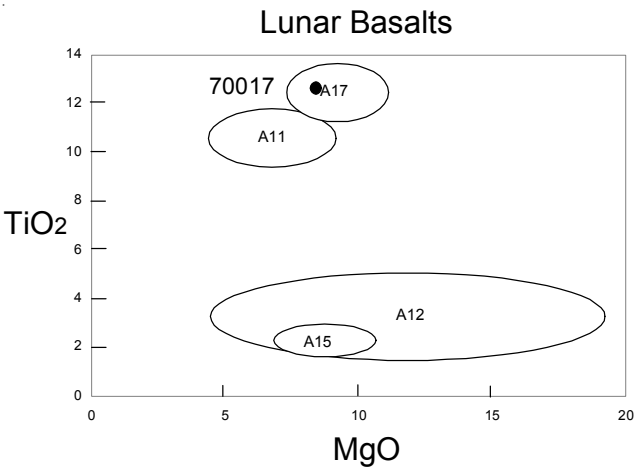


Figure 9: 70017 is a typical Apollo 17 basalt.

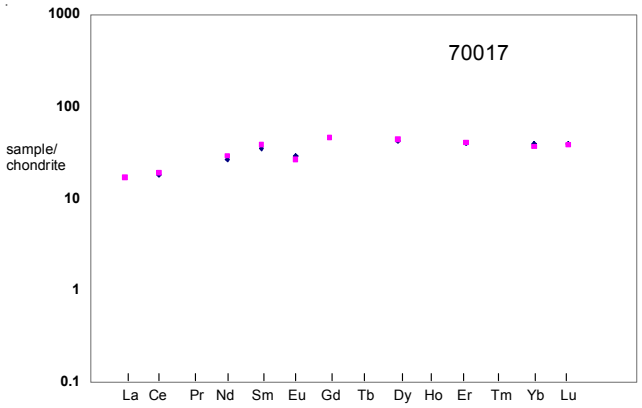


Figure 10: Normalized rare-earth-element pattern of 70017 (isotope dilution data from two different labs).

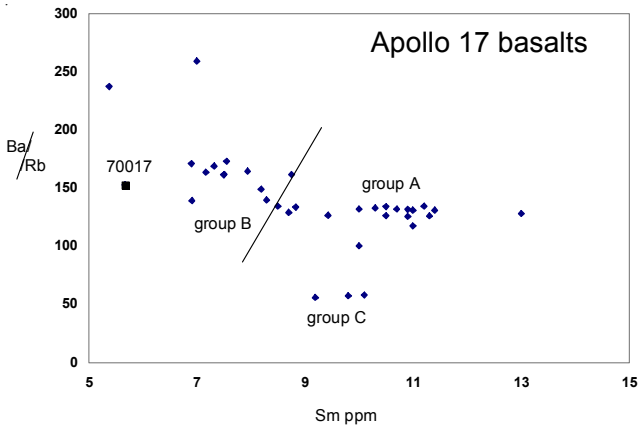


Figure 11: Trace element diagram used to distinguish Apollo17 basalt flows.

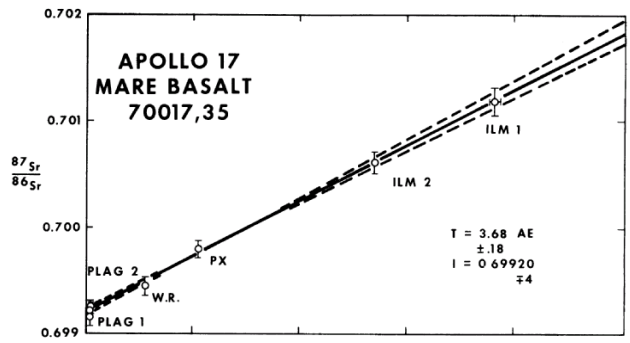


Figure 12: Rb-Sr isochron for 70017 (from Nyquist et al. 1974).

Processing

Figure 15 shows the initial cutting of 70017.

Neal and Taylor (1993) provide an extensive review of the work done on 70017 in their catalog. Sixty-four thin sections were prepared from 70017. Thin sections of this rock are featured in the Lunar Petrographic Educational Thin Section Set (Meyer 2003).

Small pieces of this rock were given to many countries of the world (70017 has been called the "children of the world rock"). A piece of this rock is on public display at the Virginia Air and Space Center, Hampton Virginia (figure 16).

List of Photo #s for 70017

S73-15719 – 724 color
S73-21892 – 907 B&W
S73-28689 processing
S76-21593
S79-26723 – 725 TS
S80-40284 – 287 TS
S80-42343 TS
S92-32791 – 793 display
S92-33835 – 837

Summary of Age Data for 70017

	Ar-Ar	Rb-Sr	U-Pb
Phinney et al. 1975	3.80 ± 0.03 b.y.		
Nyquist et al. 1975		3.67 ± 0.18	
Mattinson et al. 1977			3.7 b.y.
Schaeffer et al. 1977	3.67 ± 0.12		

Caution: Old decay constants

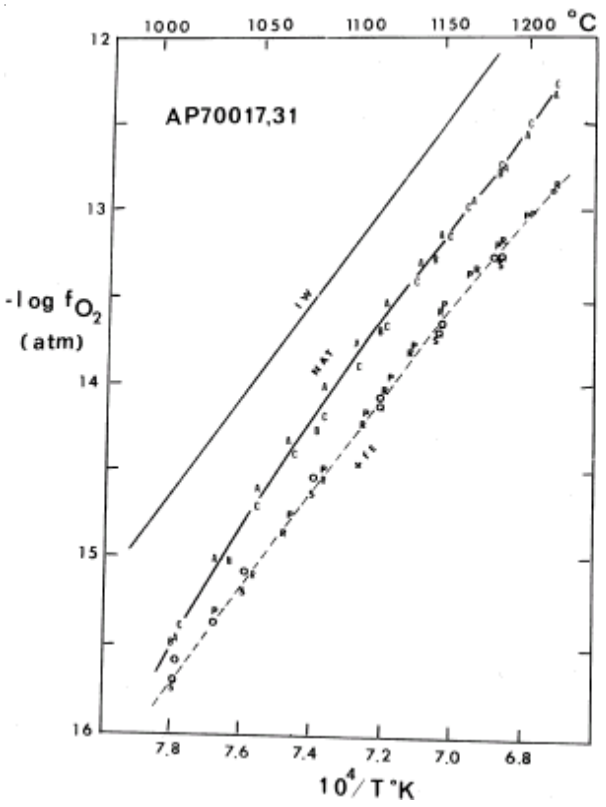


Figure 13: Oxygen fugacity vrs. temperature for 70017 (from Sato 1976).

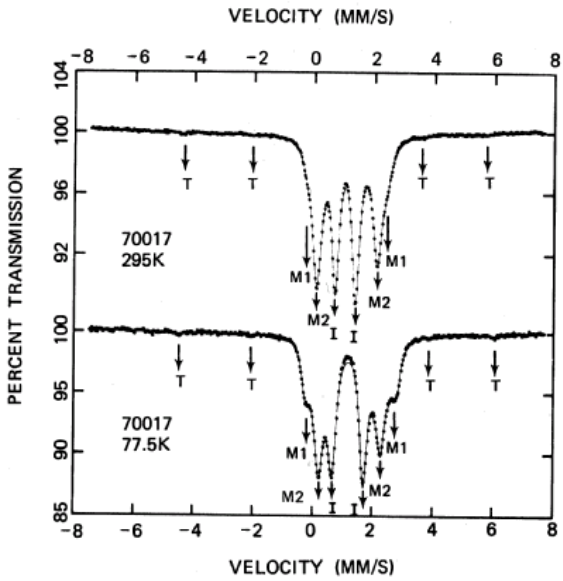


Figure 14: Moessbauer spectra of 70017 (from Huffman et al. 1974)

Figure 16: Display sample 70017,138.

Table 1. Chemical composition of 70017.

reference	Rose 74			Brunfelt 74		Miller 74	Nava 74	Rhodes 74		Duncan74		Philpotts74	Shih 75		Dickinson 89		
weight						Hughes85		Unruh84					Wiesmann75				
SiO2 %	38.8	38.68	(a)			38.52	38.8	38.07	(f)	38.37	(f)						
TiO2	12.84	13.75	(a)	13.58		12.21	12.44	13.1	(f)	12.83	(f)						
Al2O3	8.54	7.4	(a)	9.47		9.07	9.73	8.79	(f)	8.78	(f)						
FeO	18.12	18.77	(a)	18.32		18.19	17.6	18.07	(f)	18.71	(f)					17.5	(b)
MnO	0.24	0.25	(a)	0.254		0.233	0.232	0.27	(f)	0.247	(f)						
MgO	10.16	10.45	(a)	9.13		11.95	9.89	9.81	(f)	9.41	(f)						
CaO	10.56	10.05	(a)	11.48		10.36	10.04	10.3	(f)	10.43	(f)				7.14	13.4	(b)
Na2O	0.33	0.34	(a)	0.405		0.405	0.43	0.4	(f)	0.43	(f)		0.31		0.32	0.43	(b)
K2O	0.07	0.07	(a)	0.044			0.036	0.04	(f)	0.047	(f)		0.038	(e)			
P2O5	0.04	0.04	(a)				0.048	0.05	(f)	0.052	(f)						
S %								0.15	(f)	0.175	(f)						
sum								99.05									
Sc ppm	80	77	(a)	87	(b)								82.7	(e)	75	78	(b)
V	98	80	(a)	156	(b)					146	(f)					288	(b)
Cr	3350	3350	(a)	3550	(b)		3080			3948	(f)		3490	(e)			(b)
Co	32	32	(a)	20.6	(b)					18	(f)		14.5	(e)	132	22	(b)
Ni	<1	24	(a)	<10	(b)					<3	(f)						
Cu	28	84	(a)	2.8	(b)					<3	(f)						
Zn	<4	<4	(a)	2	(b)					<2	(f)						
Ga	5.8	5.4	(a)	3.1	(b)										21		(b)
Ge ppb															1.7	1.9	(b)
As																	
Se																	
Rb	0.9	0.7	(a)	0.4	(b)					1.2	(f)	0.28	0.299	(e)			
Sr	217	155	(a)	127	(b)					166	(f)	168	153	(e)	172	306	(b)
Y	94	100	(a)							71.2	(f)	32					
Zr	254	250	(a)			304	(b)			218	(f)	223	177	(e)		138	(b)
Nb	23	18	(a)							18.5	(f)						
Mo																	
Ru																	
Rh																	
Pd ppb																	
Ag ppb																	
Cd ppb																	
In ppb																	
Sn ppb																	
Sb ppb																	
Te ppb																	
Cs ppm				0.3	(b)												
Ba	250	180	(a)	55	(b)					83	(f)	43	45.8	(e)	78	68	(b)
La	<10	<10	(a)	4.11	(b)								3.99	(e)	4.6	4.4	(b)
Ce				13.5	(b)							10.7	11.3	(e)	16	15	(b)
Pr																	
Nd								17.5	(e)			12.1	13.2	(e)	20	14	(b)
Sm				7.53	(b)			7.4	(e)			5.13	5.67	(e)	6.7	*71*	(b)
Eu				1.77	(b)							1.62	1.49	(e)	1.6	1.7	(b)
Gd													9.05	(e)			
Tb				1.77	(b)										2.5	2	(b)
Dy				13.8	(b)							10.2	10.7	(e)			
Ho																	
Er												6.31	6.46	(e)	0.71		(b)
Tm																	
Yb	7.7	8.3	(a)	6.3	(b)							6.25	5.98	(e)	8.2	6.9	(b)
Lu				1.15	(b)			1	(e)			0.954	0.933	(e)	1.3	1.1	(b)
Hf				8	(b)	7.8	(b)	7	(e)						7.4	6	(b)
Ta				1.55	(b)										1.8	1.5	(b)
W ppb				0.075	(b)												
Re ppb																	
Os ppb																	
Ir ppb																	
Pt ppb																	
Au ppb																	
Th ppm				0.17	(b)								0.198	(e)	*4.8*	0.14	(b)
U ppm				0.088	(b)								0.06	(e)			

technique: (a) combined XRF, OES, chemical, (b) INAA, (e) IDMS, (f) XRF

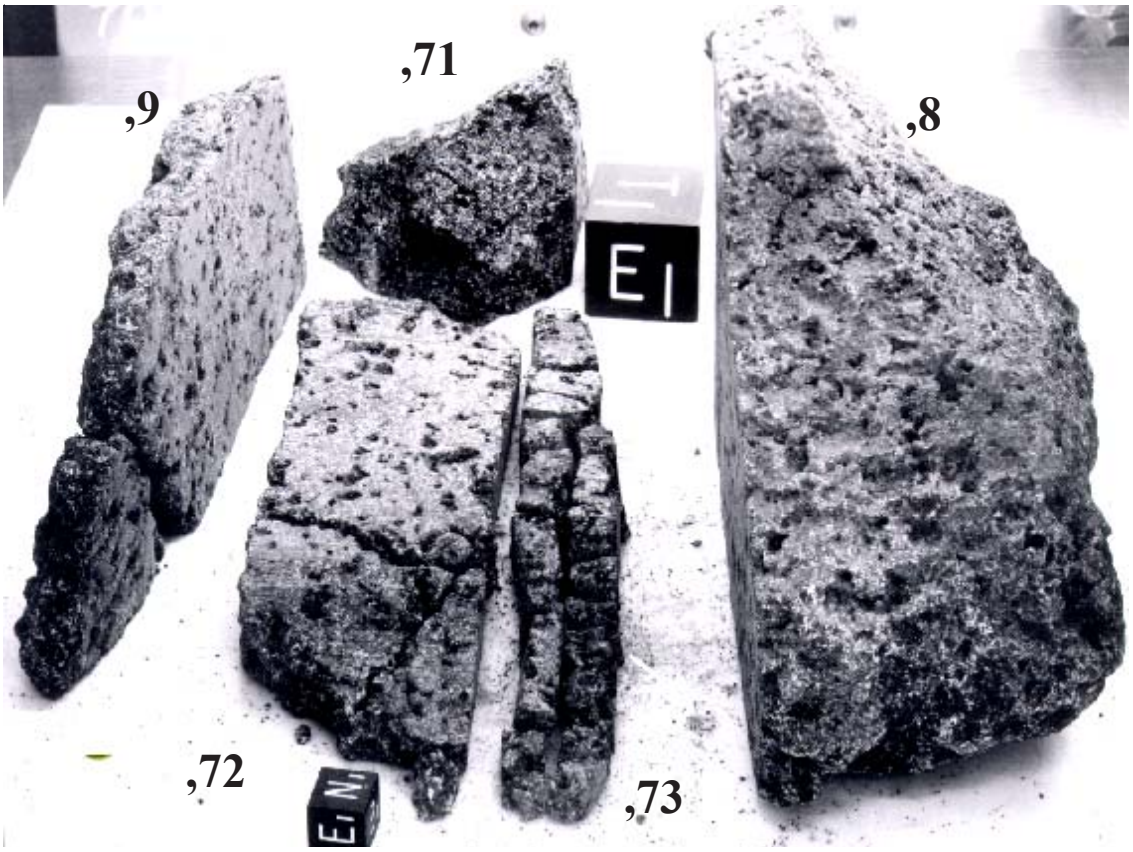
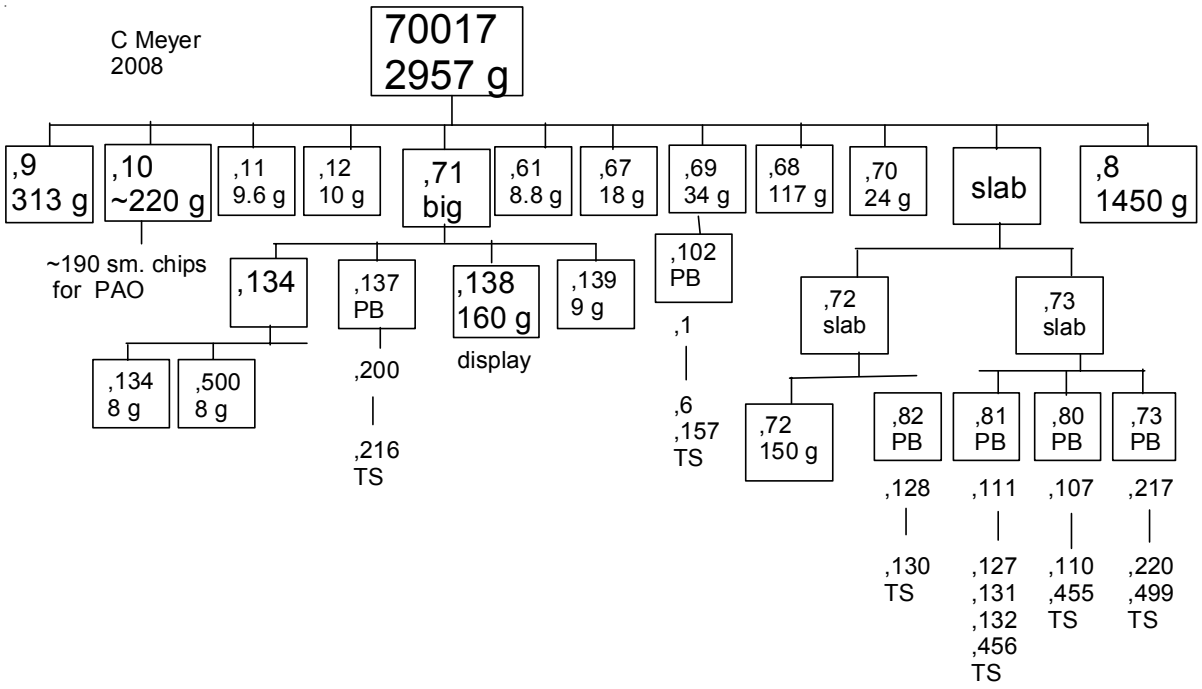


Figure 15: Sample 70017 after intial sawing. Note high proportion of vesicles. Small cube is 1 cm. NASA# S73-28689



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