65015
Poikilitic Impact Melt Breccia
1802 grams

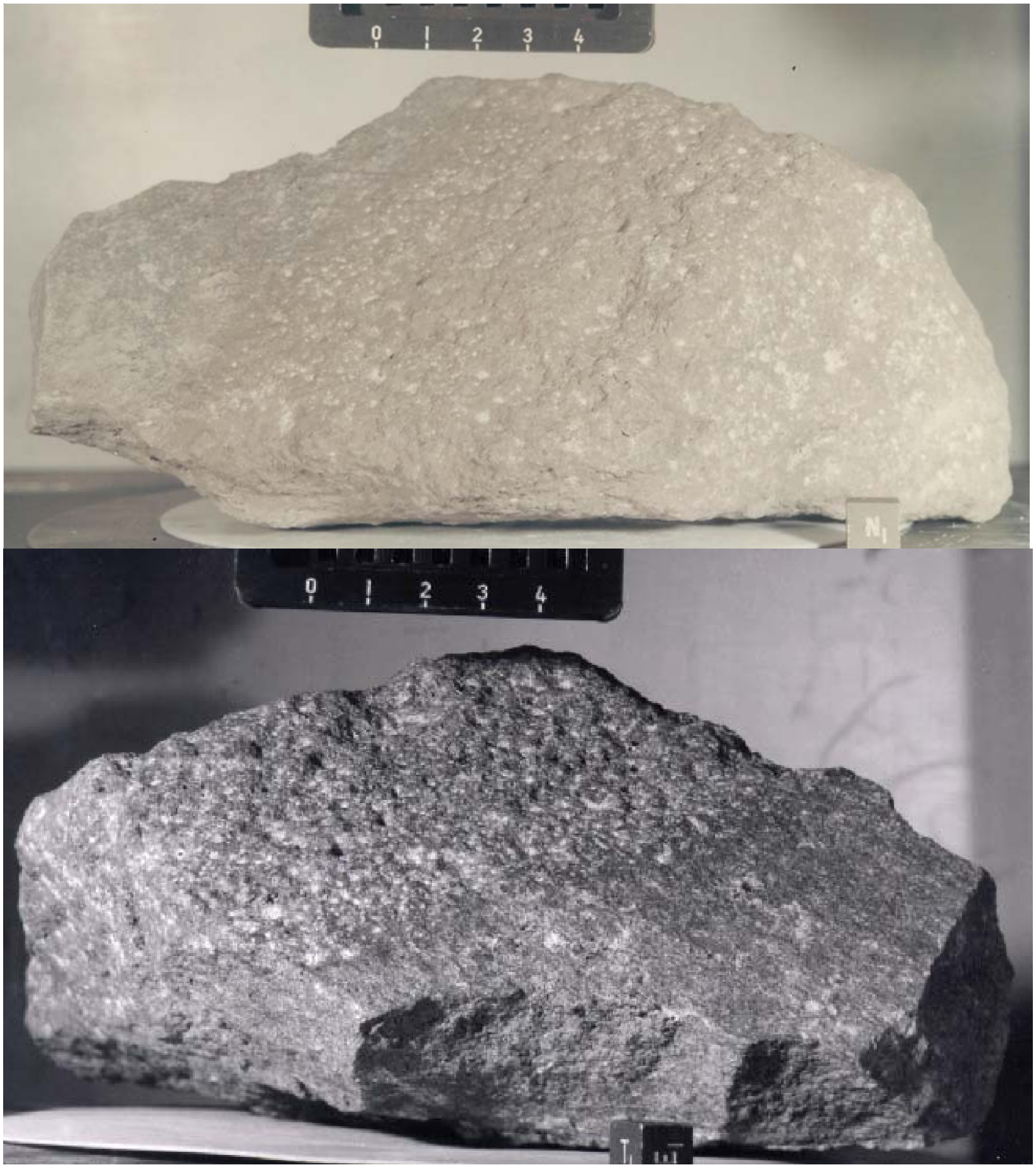
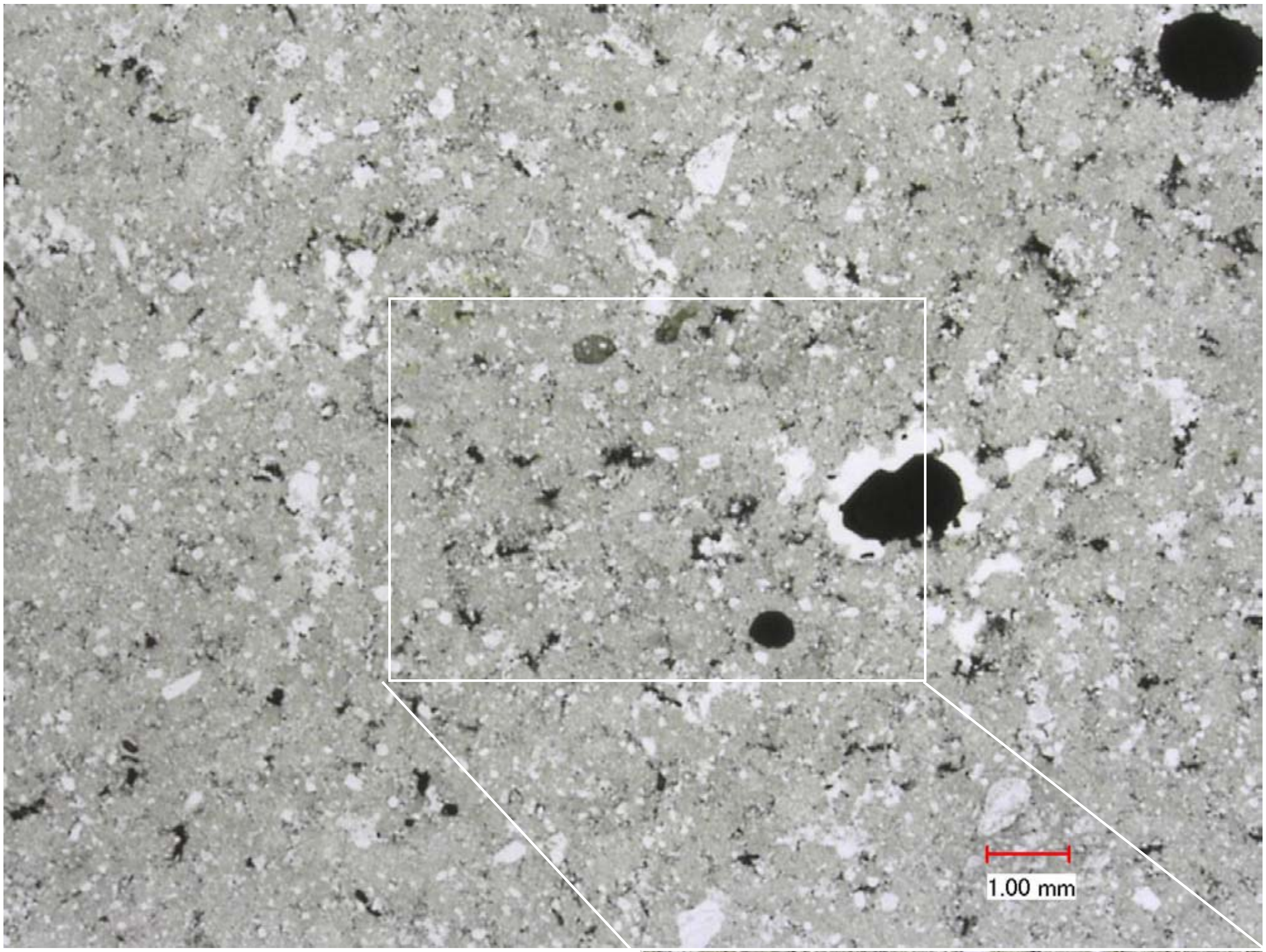


Figure 1: Photos of 65015 showing rounded exposed surface with numerous zap pits and angular portion without zap pits protected by burial in soil. NASA photos # S72-39209 and 49436. Cube and scale are 1 cm.

Introduction

Sample 65015 was collected from the lower slope of Stone Mountain. It was about half buried in the soil, as judged by the obvious “soil line”, below which there are no micrometeorite pits (figure 1). It is a very coherent, dense rock with little void space. This KREEP-rich rock is broadly similar to 60315 and 62235.



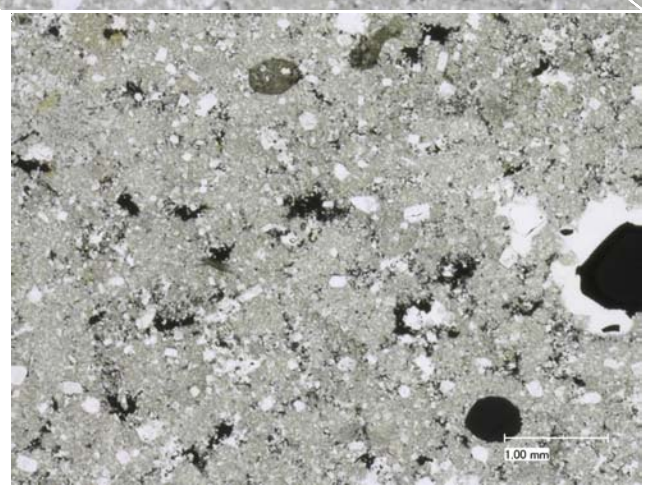


Figure 2: Photomicrographs of 65015,164 taken by C Meyer @ 20 and 50x.

The research on 65015 was well summarized in the catalog by Ryder and Norman (1980). The age of 65015 is 3.85 b.y. and its exposure to cosmic radiation is about 400 m.y.

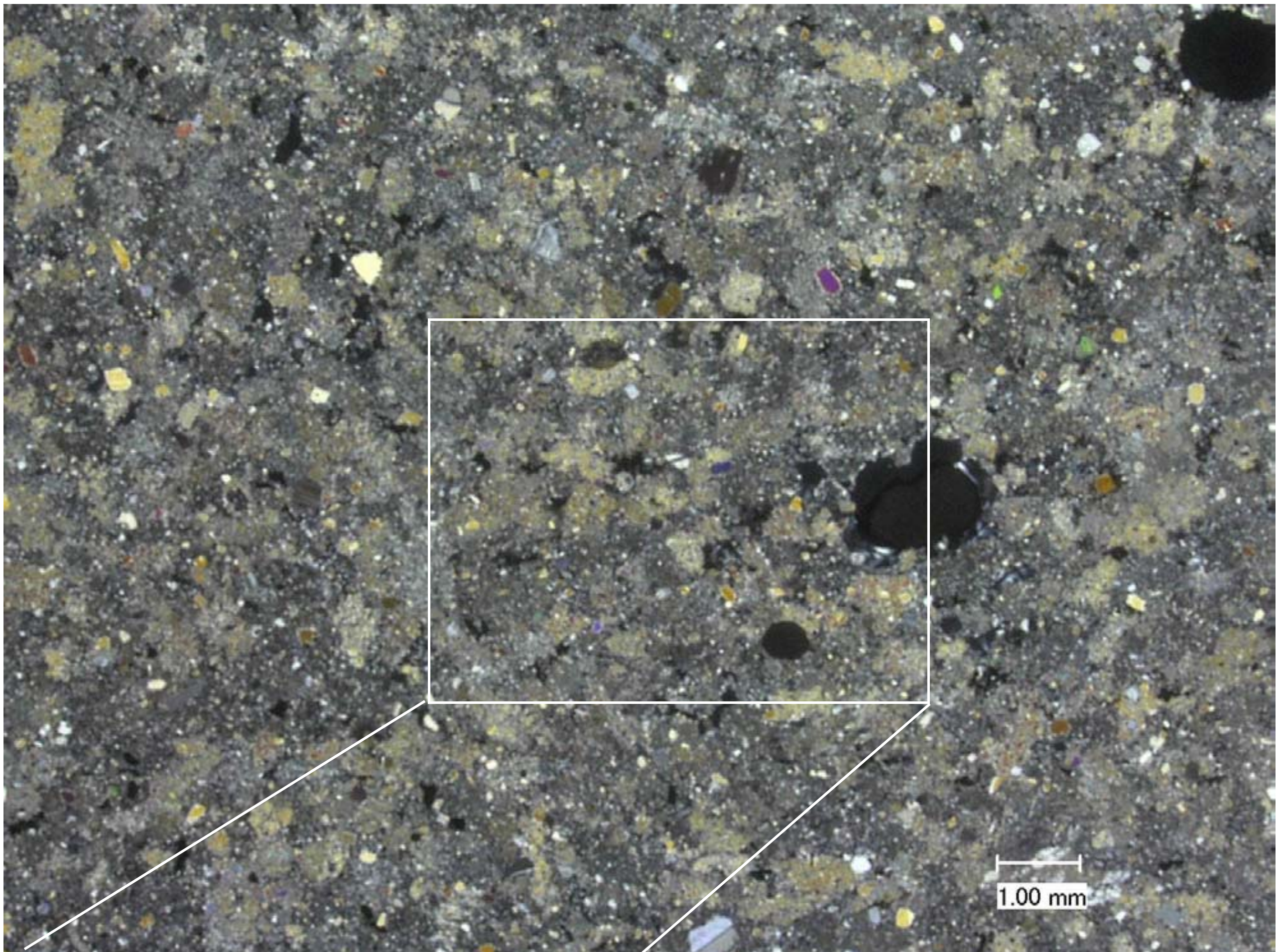
Petrography

65015 is a feldspathic impact melt rock characterized by a well developed poikilitic texture in which oikocrysts of pyroxene enclose abundant clasts and chadocrysts (figures 2-4). Most, but not all, of the chadocrysts are plagioclase. Albee et al. (1973) also report numerous relict lithic fragments as clasts in 65015. Samples 62235 and 60315 are similar rocks.

Large interlocking oikocrysts of pyroxene (up to 0.6 mm) dominate the texture (figures 2-4). Boundaries between the oikocrysts are characterized by lath-shaped plagioclase intergrown with granular olivine and accessory ilmenite, Fe-Ni metal, troilite, phosphates and K-feldspar. The ilmenite (0.2 mm) occurs in chains

Mineralogical Mode

	Albee et al. 1973	Simonds et al. 1973
Plagioclase	57.1 vol. %	61
Low-Ca pyroxene	28.9	29
High-Ca pyroxene	6.4	6
Olivine	1.1	1
Opaques	1.7	3
Mesostasis	3.6	
Whitlockite	0.7	



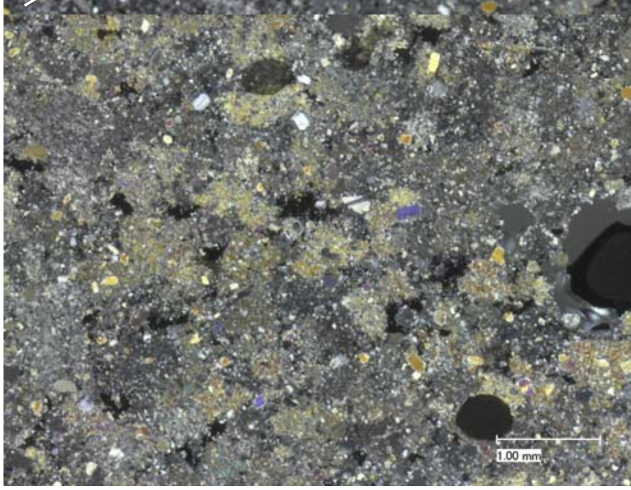


Figure 3: Photomicrographs of 65015,164 with crosssed nicols, taken by C Meyer @ 20 and 50x.

and is itself poikilitic. Abundant plagioclase grains (up to 1.5 mm), occurring as chadocrysts throughout the rock, are found to be very calcic (An_{93-95}). Papanastassiou and Wasserburg (1972) and Meyer et al. (1974) found that the large plagioclase grains were not in equilibrium with the trace element content of the bulk sample.

The rock has a high content of trace elements and meteoritic siderophiles (Ni, Ir, Au). Wasson et al. (1975) found that the ratios of siderophile elements in metal grains separated from the rock were different from those in the bulk rock.

The distinctive poikilitic texture of this rock, the inclusion of relict lithic and mineral clasts and the high meteoritic siderophile content are also common features of the Apollo 17, Boulder 6 samples as well as the melt sheets found in large terrestrial craters. Simonds et al. (1976) modeled the formation of these rocks as a mix of impact melt and cold clastic material.

Mineralogy

Olivine: Relict, partially reacted, olivine grains (Fo_{65-74}) are reported by Albee et al. (1973)

Pyroxene: Albee et al. (1973) determined the chemical composition of pyroxene in 65015 (figure 5). The

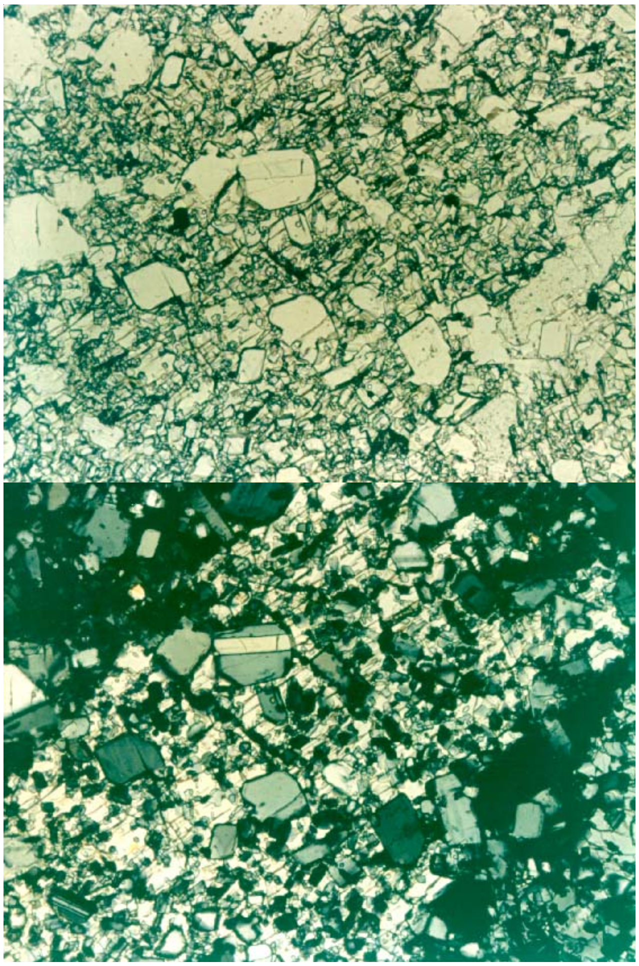


Figure 4: Photomicrographs of large pyroxene oikocryst enclosing numerous chadocrysts of plagioclase. Bottom photo is with cross-polarizers. Field of view 5 mm.

low-Ca pyroxene occurs as large oikocrysts and is generally homogenous. The high-Ca pyroxene is found in the intergranular regions and in clasts and is somewhat variable in composition.

Plagioclase: Abundant plagioclase grains (up to 1.5 mm) occur as chadocrysts throughout the rock and are found to be very calcic (An_{93-95}). Laths of plagioclase (An_{85-90}) are found in the mesostasis between the oikocrysts (figure 5). Albee et al. (1973) found that the trace FeO content of the plagioclase in the clasts was lower than for the plagioclase in the groundmass. Meyer et al. (1974) found that the trace element (Li, Ba etc.) content of the plagioclase phenocrysts was well below the level expected for plagioclase in equilibrium with the bulk rock content. Papanastassiou and Wasserburg (1972) also showed that the plagioclase was not in isotopic equilibrium (figure 9).

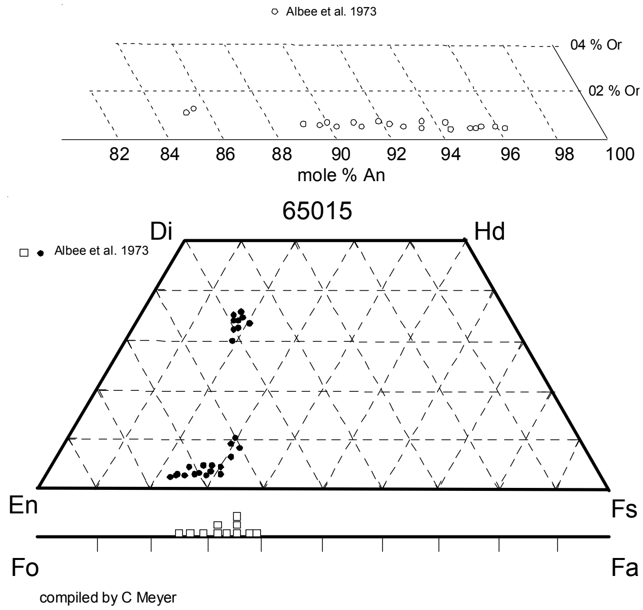


Figure 5: Plagioclase, pyroxene and olivine composition for 65015 (data replotted from Albee et al. 1973).

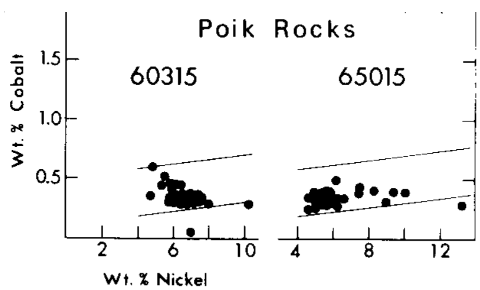


Figure 6: Ni and Co content of metallic iron grains in 60315 compared with 65015 (from Misra and Taylor 1975).

Ilmenite: Ilmenite occurs as irregular poikilitic grains intergrown with other minor phases in the mesostasis (figure 7). It rarely has exsolution of rutile, baddeleyite and Cr-rich spinel (Albee et al. 1973).

Metal: El Goresy et al. (1973), Albee et al. (1973) and Misra and Taylor (1975) analyzed the Fe-metal grains (including one large ball, 400 microns) and found they were generally homogeneous 5-6% Ni, 0.2-0.3% Co, 0.12% P and 0.01 % S. Taylor et al. (1976) found that this composition did not change during annealing experiments. Wasson et al. (1975) proved an analysis of one metal sphere from 65015 (very high Ge!).

Whitlockite: Long needles (40 microns) of whitlockite are the only phosphate (Albee et al. 1973).

Figure 7: Ilmenite and metal grains in 65015. Reflected light photo of polished thin section.

Chemistry

Hubbard et al. (1973), Haskin et al. (1973), Wanke et al. (1977) and others have analyzed 65015 (table 1). The rare earth elements are in high abundance and similar to KREEP (figure 9). The meteoritic siderophiles are relatively high (Ir > 10 ppb) indicating that this is not a pristine rock, but rather an impact melt (Krahenbuhl et al. 1973, Wanke et al. 1977) contaminated with a significant meteoritic component. Jovanovic and Reed (1976) reported small amounts of Ru and Os (3 ppb and 0.43 ppb, respectively). Wanke et al. (1977) reported a superior measurement for vanadium (36.7 ppm). Kerridge et al. (1975) reported 9 ppm carbon and some sulfur.

Radiogenic age dating

Because of the included old component, it has proven difficult to accurately date 65015. Papanastassiou and Wasserburg (1972) found that the plagioclase separates were not on the isochron defined by quintessence and whole rock (figure 10). But these and various other investigators (figure 11) have concluded that 65015 was last melted or "metamorphosed" at about 3.9 b.y.

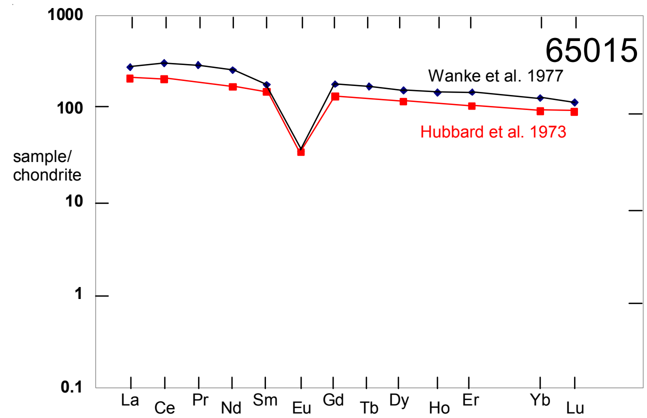


Figure 8: Normalized rare-earth-element diagram for 65015 (data from table 1).

(see table). Kirsten et al. (1973), Jessberger et al. (1974) and Norman et al. (2006) all reported ages around 3.85 b.y. (figures 10 - 14).

Lugmair and Carlson (1978) determined a "model age" of 4.32 ± 0.12 b.y. by Sm-Nd. Nunes et al. (1973) found that U/Pb ages were concordant at 3.99 b.y. and that initial Pb was extremely low. Schaeffer et al. (1978, 1979) studied laser extraction of Ar.

Recently Bouvier et al. (2011) have precisely dated 65015 by U-Pb and Pb-Pb.

Cosmogenic isotopes and exposure ages

Kirsten et al. (1973) reported a cosmic ray exposure age of 365 ± 20 m.y. for 65015 by the ^{38}Ar method. Jessberger et al. (1974) found it to be about 490 m.y. Bhandari et al. (1973) determined the "suntan" age as 1.2 m.y. by track studies.

Other Studies

Sato (1976) measured the in-situ oxygen fugacity as a function of temperature.

The magnetic properties were studied by Brecher (1977) , Stephenson et al. (1977)and Cisowski et al. (1983); electrical properties were determined by Olhoeft et al. (1973) and Alvarez (1977); thermal expansion by Todd et al. (1973); electron spin resonance by Tsay and Live (1974) and ultraviolet reflectance spectra by Hapke et al. (1978).

Table 1a. Chemical composition of 65015.

reference	Hubbard 73		Hubbard 73		Duncan 73		Haskin 73		Krahenbuhl 73		Boynton 75	Wasson 77	Wanke 77	Garg 76
weight														
SiO2 %	47.18	(a)			46.99	(a)	47.6	(b)					46.77	
TiO2	1.04	(a)	1.1	(d)	1.26	(a)	1.23	(b)			1.2	1.22	1.27	
Al2O3	19.98	(a)	23.2	(c)	19.68	(a)	19.5	(b)			20.03	20.6	19.33	
FeO	7.91	(a)	8.71	(b)	8.59	(a)	8.52	(b)			7.98	8.33	8.81	
MnO	0.12	(a)			0.112	(a)	0.11				0.13	0.11	0.11	
MgO	10.34	(a)	9.5	(b)	9.31	(a)	9.66	(b)				8.34	9.61	
CaO	12.03	(a)	12	(b)	11.9	(a)	12.3	(b)			12.73	11.75	11.98	
Na2O	0.44	(a)	0.59	(b)	0.55	(a)	0.57				0.63	0.52	0.57	
K2O	0.32	(a)	0.34	(d)	0.36	(a)	0.35	(b)					0.36	
P2O5	0.4	(a)			0.409	(a)							0.39	
S %	0.13	(a)			0.079	(a)							0.139	
sum	99.89				99.24								99.339	
Sc ppm							14.9	(e)			17	16.1	17.1	
V												40	36.7	
Cr			2350	(d)			1280	(e)			1270	1320	1300	
Co							27.1	(e)				49	42.6	
Ni					185	(a)	400	(e)	580	(f)	30		730	
Cu					1.8	(a)							5.06	
Zn									0.48	(f)			1.46	
Ga							4.25	(e)					3.81	
Ge ppb									380	(f)			600	
As													0.17	
Se									0.245	(f)			0.29	
Rb			9.09	(d)	9.55	(a)	9.2	(e)	7.8	(f)			10.2	
Sr			164	(d)	157	(a)							146	
Y					179	(a)							174	
Zr					909	(a)						920	940	933
Nb					55.2	(a)								
Mo														
Ru														
Rh														
Pd ppb														
Ag ppb									1.5	(f)				
Cd ppb									9.25	(f)				
In ppb														
Sn ppb														
Sb ppb									4.34	(f)				
Te ppb									3.25	(f)				
Cs ppm							0.42	(e)	0.405	(f)			0.423	
Ba			492	(d)	609						460	560	570	
La			49.5	(d)			60	(e)			47	55.6	65.5	
Ce			125	(d)			153	(e)			180	132	185	
Pr							98	(e)					26	
Nd			78	(d)								80	118	
Sm			22.2	(d)			26.5	(e)			35	24.8	26.7	
Eu			1.91	(d)			2.12	(e)			2.28	2.1	1.97	
Gd			26.6	(d)			33	(e)					36	
Tb							5.2	(e)			5.4	5.2	6.28	
Dy			28.8	(d)			38	(e)				33	38.1	
Ho							7.4	(e)					8.3	
Er			16.8	(d)			22	(e)					23.8	
Tm														
Yb			15.3	(d)			19.1	(e)			20.8	17.1	21.1	
Lu			2.24	(d)			2.6	(e)			2.87	2.44	2.84	
Hf							19.3	(e)			22	19.2	21.6	20.6
Ta											2.4	2.1	2.46	
W ppb													883	
Re ppb									1.16	(f)			1.8	
Os ppb														
Ir ppb									11.6	(f)			17	
Pt ppb										(f)				
Au ppb									10.2	(f)			10.9	
Th ppm											10.7	9.4	8.92	
U ppm			3.42	(d)					3.42	(f)		2.6	2.22	

technique (a) XRF, (b) AA, (c) colorimetry, (d) IDMS, (e) INAA, (f) RNAA

Table 1b. Chemical composition of 65015.

reference	Lugmair 78	Nyquist 73	Nunes 73		Ehmann 74		Miller 74		Taylor 73		LSPET 73	
weight												
SiO2 %									47.1	(g)		
TiO2									1.16	(g)		
Al2O3									20.7	(g)		
FeO							8.1	(e)	7.37	(g)		
MnO												
MgO									9.58	(g)		
CaO									11.9	(g)		
Na2O									0.52	(g)		
K2O									0.47	(g)	0.48	(h)
P2O5												
S %												
sum												
Sc ppm							14.4	(e)	9.5	(g)		
V									44	(g)		
Cr							1230	(e)	1400	(g)		
Co							30	(e)	25	(g)		
Ni									260	(g)		
Cu									6.5	(g)		
Zn												
Ga												
Ge ppb												
As												
Se												
Rb		9.09		(d)					8.3	(g)		
Sr		163.8		(d)								
Y									182	(g)		
Zr					920	1010		(e)	960	(g)		
Nb									58	(g)		
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb									400	(g)		
Sb ppb												
Te ppb												
Cs ppm									0.35	(g)		
Ba									540	(g)		
La							56	(e)	58	(g)		
Ce									145	(g)		
Pr									21	(g)		
Nd	101			(d)					81	(g)		
Sm	28			(d)					24.5	(g)		
Eu							2	(e)	2	(g)		
Gd									32	(g)		
Tb									4.86	(g)		
Dy									30.5	(g)		
Ho									7.44	(g)		
Er									21	(g)		
Tm									3.1	(g)		
Yb									19	(g)		
Lu									2.9	(g)		
Hf					19.8	21.4		(e)	19	(g)		
Ta												
W ppb												
Re ppb												
Os ppb												
Ir ppb												
Pt ppb												
Au ppb												
Th ppm			10.32	(d)					10.4	(g)	10	(h)
U ppm			2.58	(d)					2.34	(g)	3	(h)

technique (a) XRF, (b) AA, (c) colorimetry, (d) IDMS, (e) INAA, (f) RNAA, (g) SSMS, (h) radiation counting

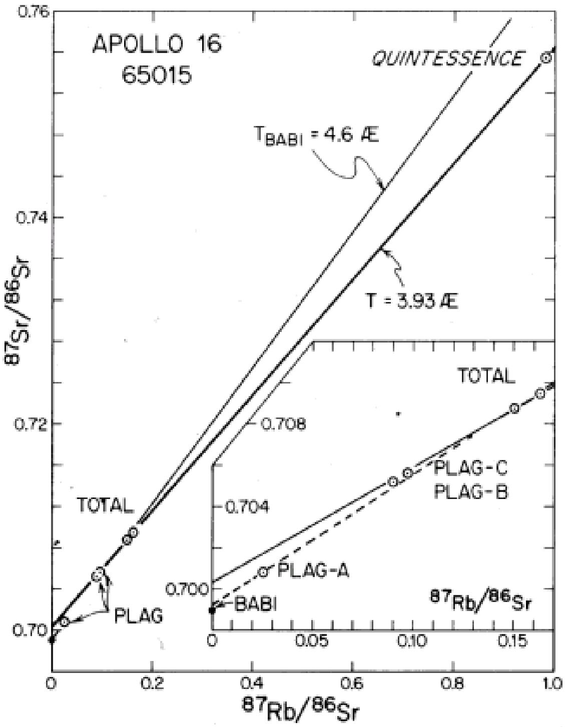


Figure 9: Rb-Sr isochron diagram for 65015 (from Papanastassiou et al. 1972).

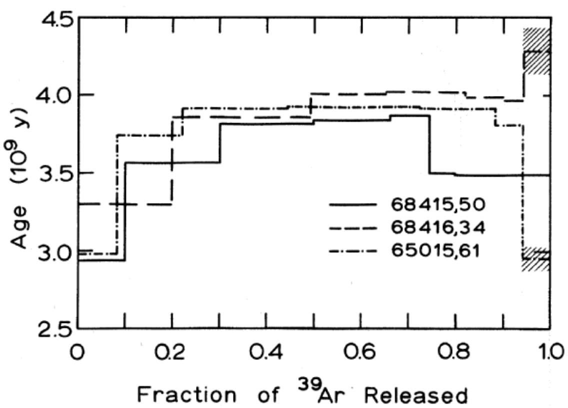


Figure 10: Ar/Ar release pattern for 65015, 68415 and 68416 (fKirsten et al. 1973).

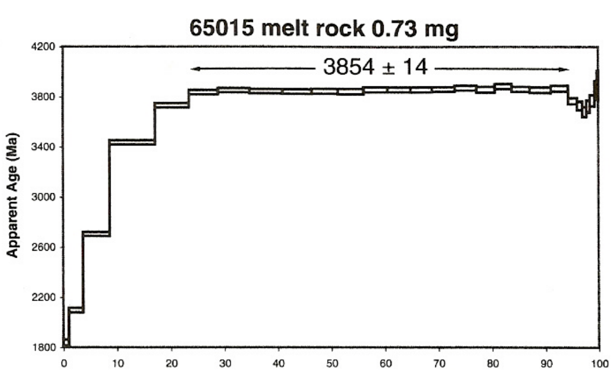


Figure 14: Ar/Ar plateau diagram for carefully selected piece of 65015 (Norman et al. 2006).

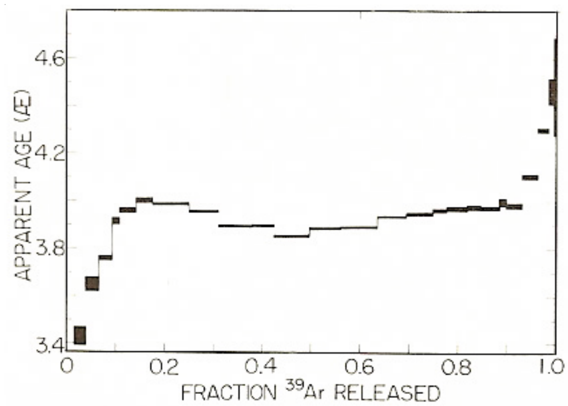


Figure 11: Ar/Ar release pattern for plagioclase separate from 65015 (Jessberger et al. 1974).

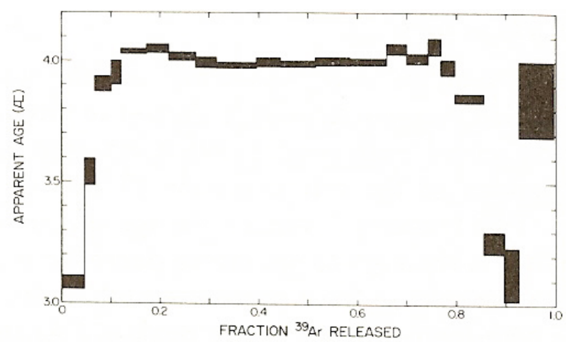


Figure 12: Ar/Ar release pattern for pyroxene separate from 65015 (Jessberger et al. 1974).

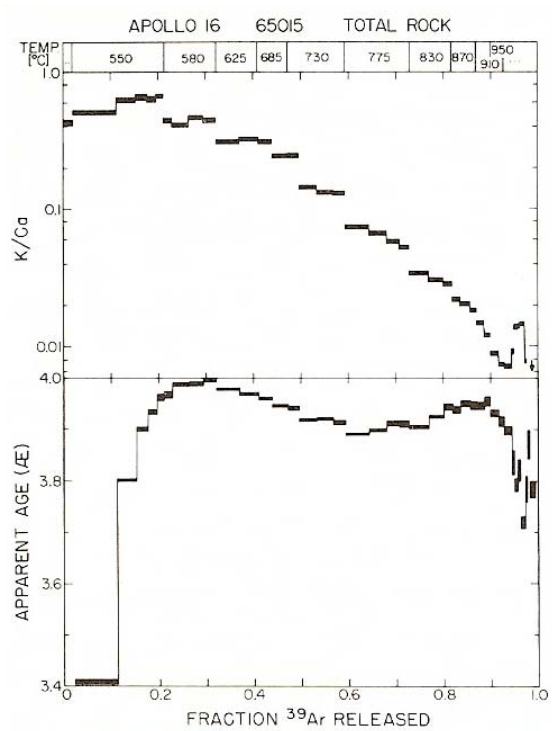


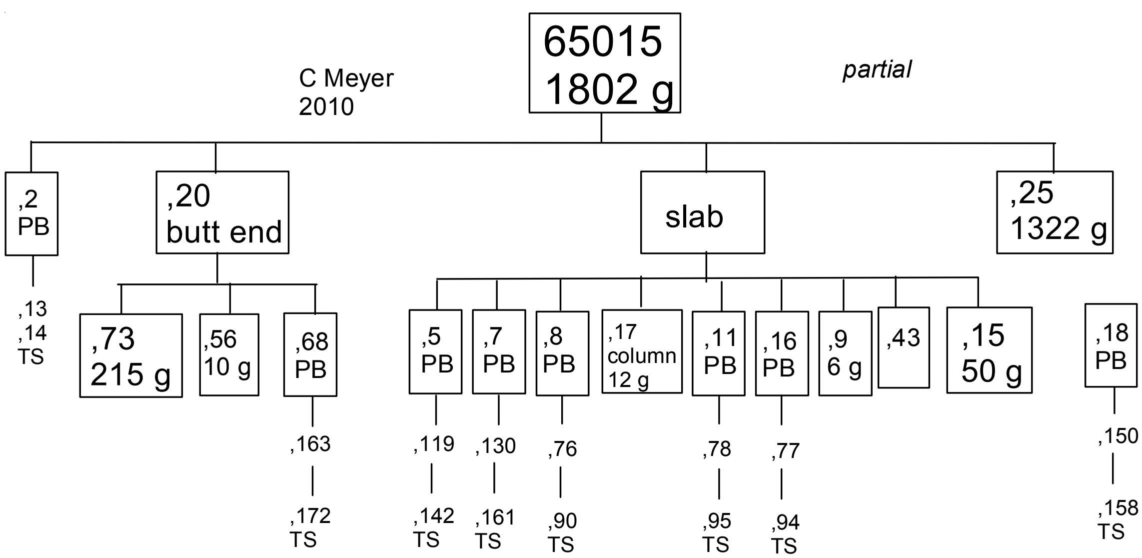
Figure 13: Ar/Ar release pattern and K/Ca ratio for whole rock sample of 65015 (Jessberger et al. 1974).

Figure 15: First saw cut of 65015 and approximate position of slab. Cube is 1 inch in this processing photo.

Summary of Age Data for 65015

	Ar-Ar	Rb/Sr	Sm/Nd	Pb/Pb
Papanastassiou and Wasserburg 1972		3.93 ± 0.02 b.y.		
Kirsten et al. 1973	3.92 ± 0.04			
Jessberger et al. 1974	~3.98			
Nunes et al. 1973				3.99
Norman et al. 2006	3.854 ± 0.014			
Bouvier et al. 2011				3.935 ± 0.002

Caution: Old Rb, K decay constants.



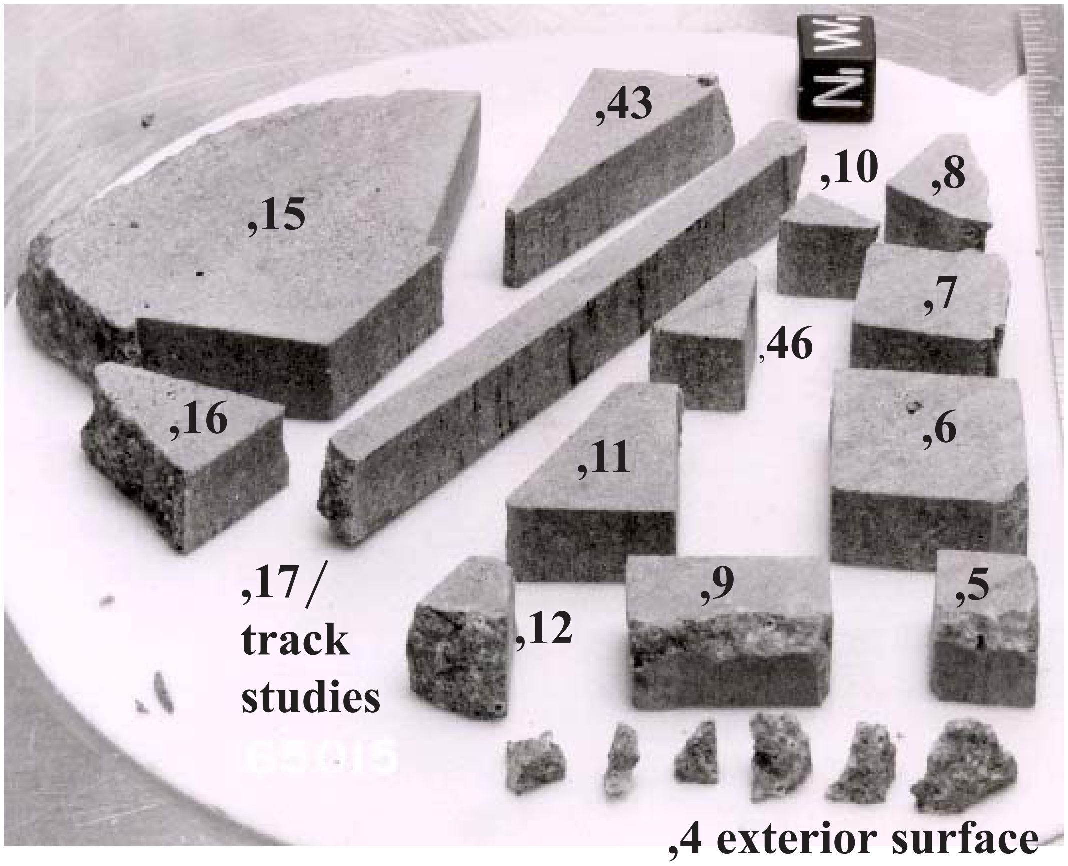


Figure 16: Group photo of pieces cut from slab of 65015. The cube is 1 cm. NASA photo # S72-47359.

Processing

In 1972 a small slab was cut from this rock (figure 15). Allocations were also made from the small butt end. There are 58 thin sections of 65015 and some are used in the education lunar thin section sets.

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