61016

Revised

Impact Melt Rock with Shocked/Melted Anorthosite Cap

11,745 grams

Figure 1: Close-up photo of a portion of the top surface of 61016,456 showing dimorphic nature of stone and numeraous zap pits. Cube is 1 cm. NASA#S98-01215.

Introduction

Lunar sample 61016 is the largest sample returned by the Apollo missions. It is know as "Big Muley"; named after Bill Muehlberger, the leader of the Apollo 16 field geology team. It was found perched on the east rim of Plum Crater and its lunar orientation is roughly known from television photos and zap-pitted top surface (Sutton 1981).

The Apollo 16 site was chosen to be in the lunar highlands, so that material could be collected that was distinctly different from that which was sampled in the Maria (A11, A12, A15). The pre-mission mapping, and consensus opinion, was that the rocks from the Descartes site would be volcanic (Milton 1968; Hodges 1972). However, the majority of the material returned from Apollo 16 turned out to be breccia with high plagioclase content. Chemists initially thought that the melt rock samples from Apollo 16 were "high alumina basalt", but when these samples were found to have high siderophile content, the evidence for impact origin was clear (Hubbard et al. 1973; Dowty et al. 1973; James 1981). Post mission analysis has pointed to an origin of a large portion of the Apollo 16 material as basin ejecta from Nectaris (Turner 1977; Maurer et al. 1978; James 1981 and others).

61016 has a cosmic ray exposure age (1.8 m.y.) that links it to the ejecta from South Ray Crater (Eugster 1999). The top side of 61016 is rounded, with thin patina and numerous micrometeorite "zap" pits (figure 1). Solar-cosmic-ray-produced ^{21}Ne profiles verify the top surface was exposed to the Sun (Rao et al. 1993). Surface photography (television shot) of 61016 was matched in the laboratory by Sutton (1981) (figure 2). The sample was found partially buried – see soil line drawn on photos in Sutton (1981).

Figure 2: Photo of E1 side of 61016 with lighting similar to lunar lighting, thus providing knowledge of lunar oritntation. Cube is 1 inch, showing approximate lunar orientation. NASA#S72-41841

Figure 3: Laboratory "mug shot" of E1 end of 61016, sitting on its flat bottom side. NASA photo# S72-41550. Scale same as for figure 2.

What was known about this rock in 1980 was discussed in great detail in the catalog by Ryder and Norman (1980). The rock has been highly shocked, as evidenced by most of the plagioclase being converted to maskelynite and/or plagioclase glass. Since 1980, the rock has been dated at about 3.97 ± 0.25 b.y. and used for determination of solar-cosmic-ray profile studies (see below). However, the petrology of the sample mostly remains undetermined.

Petrography

James (1981) has grouped 61016 with Apollo 16 samples termed "dimict" breccias, although the nature of 61016 is seemingly somewhat different (i.e. a piece of shocked anorthosite attached to a piece of troctolitic "melt rock"). Perhaps the best description of 61016 was provided by Stöffler et al. (1975), but this, the largest moon rock, seems to deserve further description in light of what is now known about lunar samples.

The majority of 61016 (figure 5) is apparently an impact "melt rock" with high Al_2O_3 (~25 wt %) *and* high KREEP content (figure 11). McGee et al. (1979) described the main lithology as "characterized by subangular to rounded clasts of partially to completely maskelynized plagioclase (up to 2 mm across) together with glassy and partially devirified lithig clast contained in a subophitic matrix of tabular (0.1 to 0.2 mm) and lath-shapped (2 x 0.5 mm) maskelynite intregrown with subhedral to euhedral (0.1 mm) olivine crystals. A dark-brown glassy mesostasis fills intersticies." Because of its high modal olivine, Stöffler et al. (1975) termed this lithology as a "troctolitic matrix" and noted that all the plagioclase is diaplectic. (However, a high modal olivine content as reported by Stöffler is not consistent with the high Al_2O_3 content). This "melt rock" lithology is apparently unusual and is lacking pyroxene. The relict olivine is apparently mafic (~Fo_{90}), while the relict plagioclase is calcic (~An_{96}).

The shocked/melted anorthosite that sits as a "cap" on 61016 is described by Steele and Smith (1973), Smith and Steele (1974), Dixon and Papike (1975) and Drake (1974) and is one of the largest pieces of anorthosite returned. Pyroxene analyses from the anorthosite (figure 10) show that it is typical of ferroan anorthosite. The boundary between the melt rock lithology and this anorthosite is made of melted plagioclase (figure 30).

The bottom surface of 61016 is covered by glass (figure 4) where it was protected from meteorite bombardment. This glass coating may have originally covered the rest of the sample as though the rock was once a "bomb".

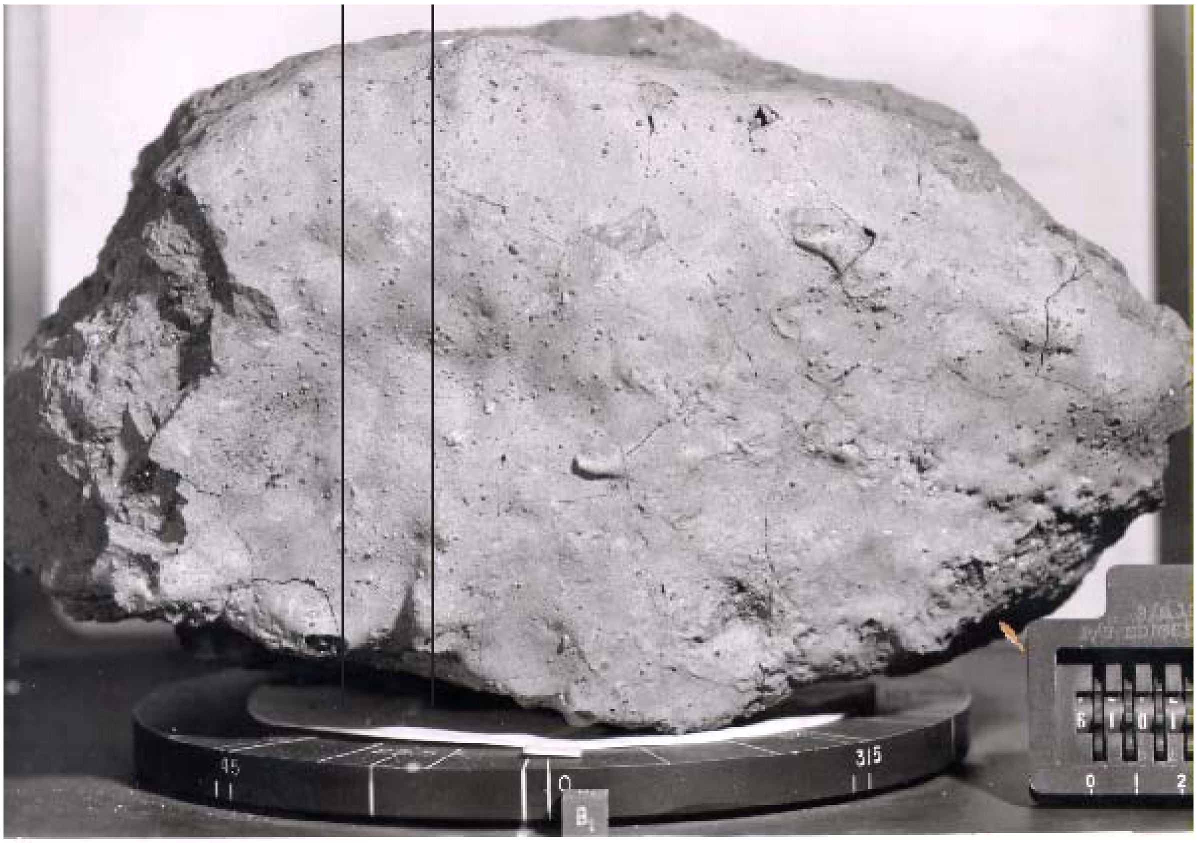

Figure 4: "Mug shot" of glass-coated bottom surface of 61016. Cube is 1 cm. NASA#S72-41556.

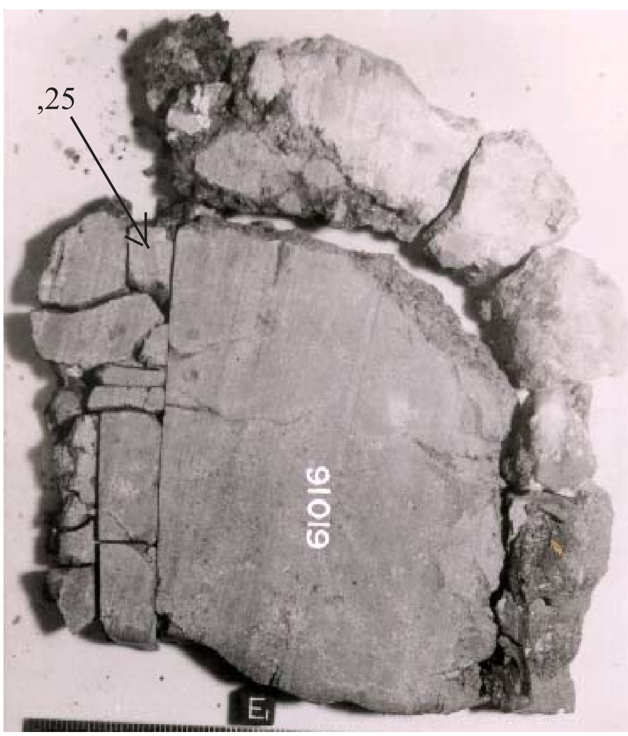

Figure 5: Photo of slab through middle of 61016 showing relation of anorthosite "cap" to the melt rock interior. Cube is 1 cm. NASA# S72-53505.

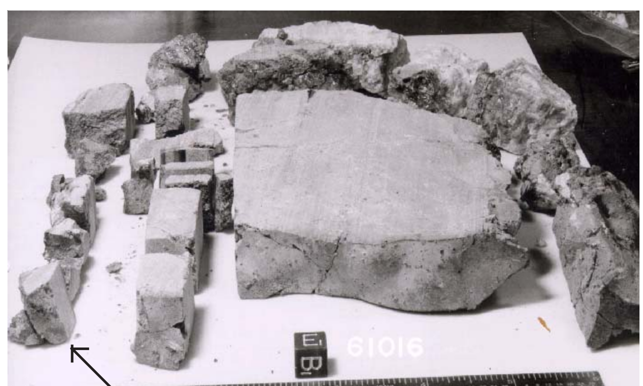

Figure 6: Exploded parts diagram for slab of 61016. NASA #S72-50676 (note glass coating on bottom)

See et al. (1986) and Stöffler et al. (1975) studied portions of the glass coating on 61016. There is reason to believe that 61016 was ejected from South Ray Crater.

Mineralogy

Olivine: Stöffler et al. (1975) found the olivine in the melt rock portion was Fo_{82-93}.

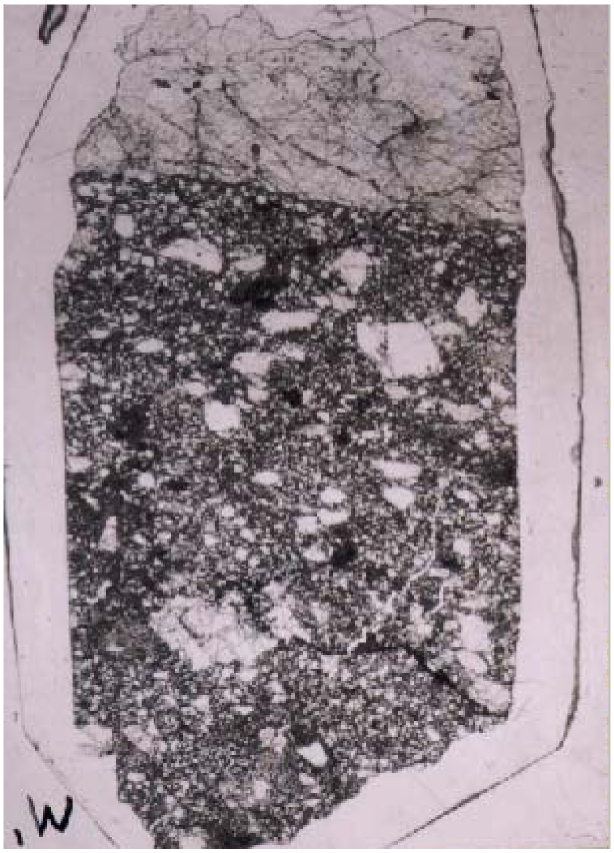

Figure 7: Thin section 61016,220 showing boundary of melt rock breccia and anorthosite cap (scale 20 mm).

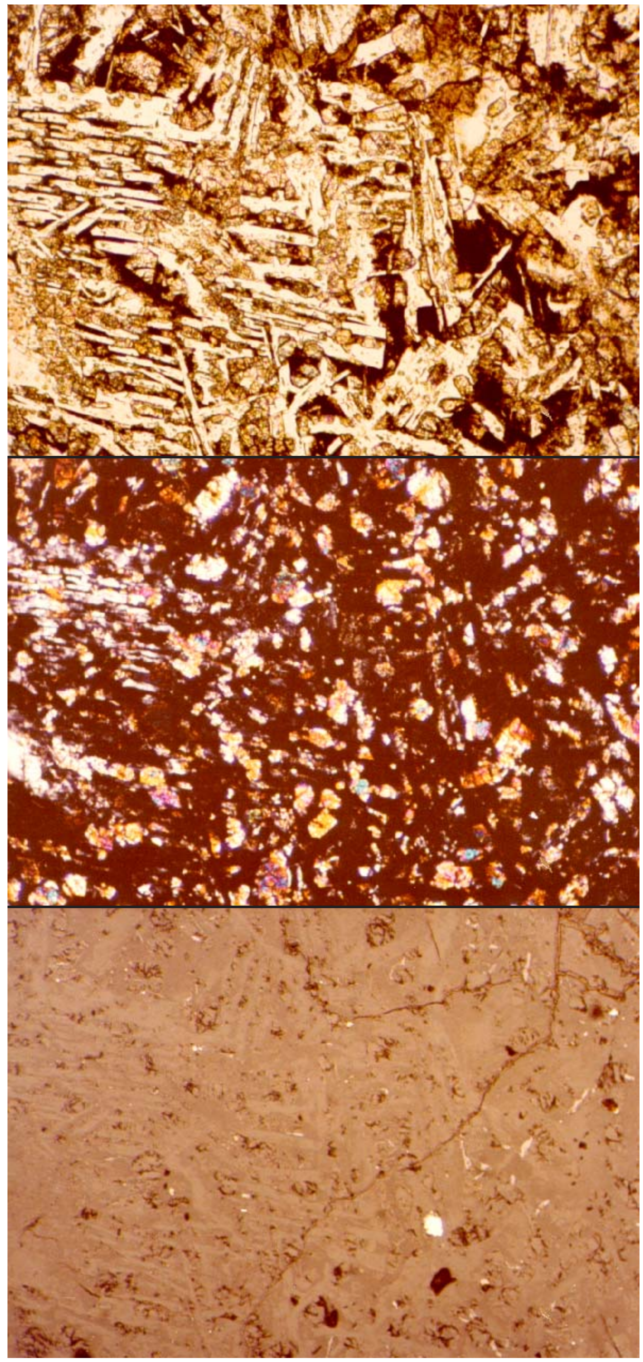

Figure 8: Three views (transmitted, X-nicol, and reflected) of same area (2.5 mm) within thin section 61016,220 showing that plagioclase is isotropic.

Pyroxene: No pyroxene is reported from the melt rock portion, but pyroxene grains in the anorthosite portion are found to be Fe-rich (figure 10).

Plagioclase: Plagioclase in the melt rock portion is An_{92-98}. Hansen et al. (1979) have studied the trace elements in plagioclase in the anorthosite. Almost all plagioclase in this sample has been converted to maskelynite or plagioclase glass.

Metal: Misra and Taylor (1975) and Stöffler et al. (1975) found that metal grains in 61016 fell within the range of meteorite metal (Ni 4-8%; Co 0.3-0.5%).

Chemistry

On the basis of chemical composition, Hubbard et al. (1973) grouped the dark "melt rock" portion of 61016 with rocks they termed VHA basalts (VHA stands for very high alumina). The melt rock portion has high REE content (table 1, figure 11). Note that the meteoritic siderophiles in this portion are high. Ganapathy et al. (1974) place this melt rock in their meteorite Group 1. Stöffler et al. (1975) made chemical analyses of various portions of 61016 by broad beam electron microprobe technique and compared them with the experimental phase diagram of Walker et al. (1973). These analysis fall well off of the coetectic lines on the phase diagram (figure 13) showing that the areas analyzed are partially fused rock clasts and/or mixtures produced by secondary impact processes.

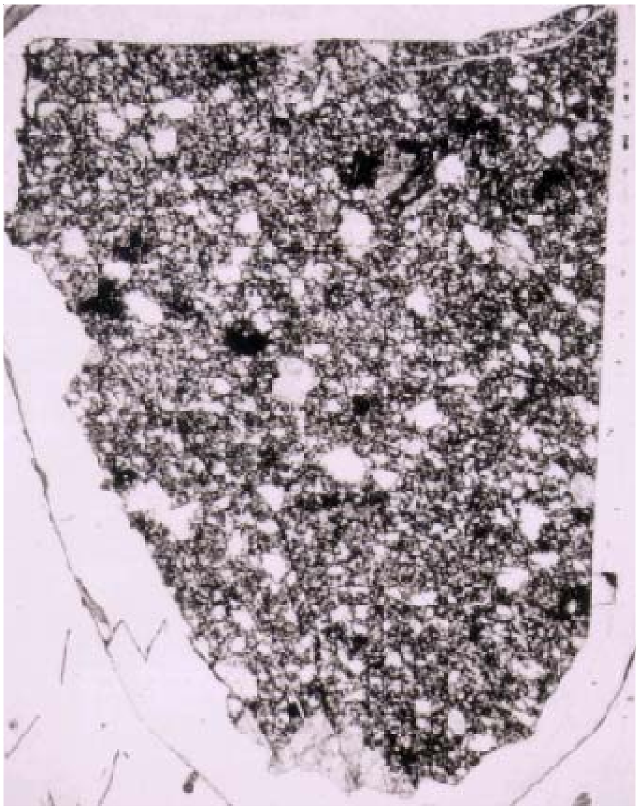

Figure 9: Photomicrograph of thin section from troctolitic "melt rock" portion of 61016,9 showing relict clastic texture (section is 20 mm across).

The anorthositic portion has been analyzed by Hubbard et al. (1974), Nava et al. (1974), Phillpotts et al. (1974) and others (table 2, figure 11). Meteoritic siderophiles in the anorthositic portion are low (Krahenbuhl et al. 1973) and it appears pristine (see figures 33, 34).

Stöffler et al. (1975), See et al. (1986) and Morris et al. (1986) determined the chemical composition of the glass coating (table 3, figure 12).

Radiogenic age dating

Stettler et al. (1973) reported an age of ~3.65 b.y., but this age is less than certain because they did not obtain a good Ar/Ar plateau (figure 14). Huneke et al. (1977) made several experiments to determine the age of the anorthosite (figure 15). Recently, Eugster et al. (1999) have dated the melt rock portion at 3.97 ± 0.25 b.y., seemingly consistent with the age of Nectaris (~3.95 b.y.) as determined by other rocks (see table).

Nyquist et al. (1973, 1979) determined Rb, Sr and $^{87}Sr/^{86}Sr$ for both main lithologies of 61016. The $^{87}Sr/^{86}Sr$ for the anorthosite was found to be very low (0.699).

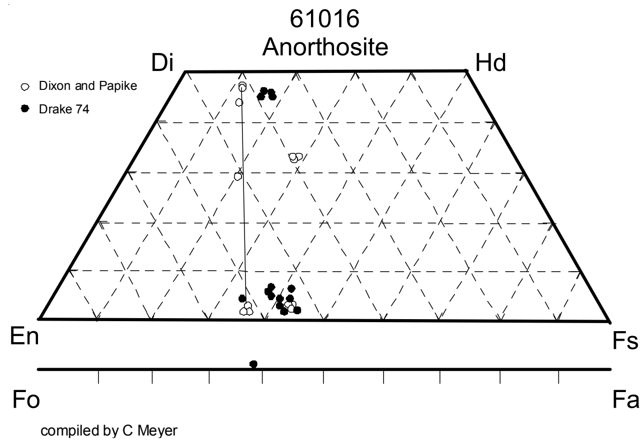

Figure 10: Pyroxene and olivine composition determined for the anorthositic portion of 61016,

Cosmogenic isotopes and exposure ages

Stettler et al. (1973) determined an exposure age of <7 m.y. by ^{38}Ar. Using sample ,287, Rao et al. (1979), Venkatesan et al. (1980), Nautiyal et al. (1981) and Rao et al. (1993) determined a cosmic ray exposure age of 1.7 ± 0.2 m.y. for an assumed erosion rate of 5 mm/m.y. Averaging the results from all techniques, Eugster (1999) determined an average cosmic ray exposure age of 1.84 ± 0.4 m.y. for 61016. This is consistent with ejecta from South Ray Crater.

Wrigley (1973) determined ^{26}Al = 104 dpm/kg and ^{22}Na = 36 dpm/kg on a 132 gram piece of anorthosite (,173). Eldridge et al. (1973) found ^{26}Al = 65 dpm/kg and ^{22}Na = 30 dpm/kg for 61016,120 (bottom piece of ,8, shielded by rock and soil). Bhandari et al. (1975, 1976) determined ^{26}Al depth profile.

Fleischer and Hart (1974) calculated cosmic-ray particle track ages of 20-40 m.y., whereas Bhattacharya and Bhandari (1975) obtained 1.7 m.y. using the same technique.

Rao et al. (1993) used the outer surface of 61016 to determine fine-scale, depth profiles for ^{21}Ne, ^{22}Ne and ^{38}Ar isotopes produced, in situ, from nuclear interactions of energetic solar flare protons (figure 17).

The density and size distribution of micrometeorite craters was studied by Mandeville et al. (1976) and Bhandari et al. (1975).

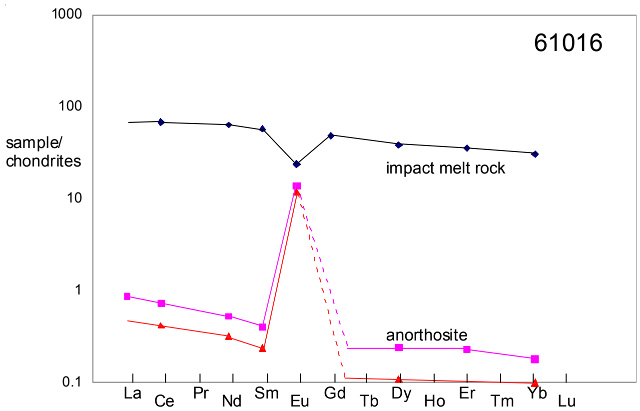

Figure 11: Rare-earth-element plot for 61016 interior melt rock and large anorthosite clast (i.d. data from Hubbard et al. 1974 and Philpotts et al. 1974, tables 1 and 2).

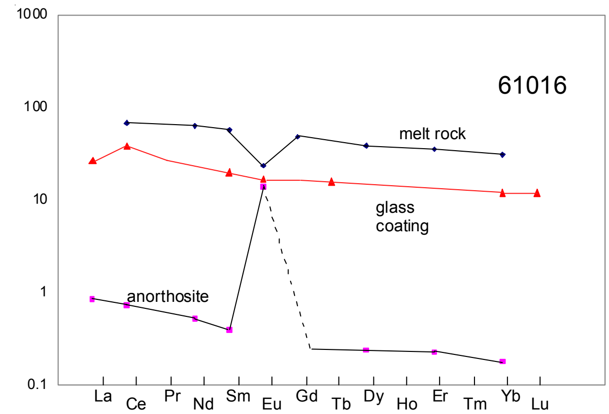

Figure 12: Rare-earth-element diagram for 61016 black glass coating (from Morris et al. 1986, table 3).

Other Studies

Reese and Thode 1974	S isotopes
Kerridge et al. 1975	S, C isotopes
DesMarais 1978	C isotopes
Allen et al. 1974	Pb isotopes
Tera et al. 1973	Pb isotopes
Nyquist et al. 1973	Sr isotopes
MacDougall et al 1973	tracks
Fleischer and Hart 1974	tracks
Bhattacharya, Bhandari 1975	tracks
Mandeville 1976	craters
Bhandari et al. 1975'	craters
Eldridge et al. 1973	26Al
Stephenson et al. 1977	magnetics
Housley et al. 1976	magnetics
Chung 1973	elastic wave velocity
Chung and Westphal 1973	electrical conductivity
Warren and Trice 1975	compressional modulus
Dolphus and Geake 1975	light polarization

Processing

In 1972 large thick slab (2 cm) was cut from the middle of 61016 (figures 4, 18-23). The east end piece (,8) and the slab have been entirely subdivided (figures 5,6). The large end piece (,7) remained unstudied until about 1990-94, when pieces of the anorthosite cap were removed (figures 23-25) for solar-cosmic-ray studies.

Subsamples ,385 and ,468 have been carefully sectioned to provide depth profiles of solar-flare-cosmic-ray radionuclide production (figures 16, 34).

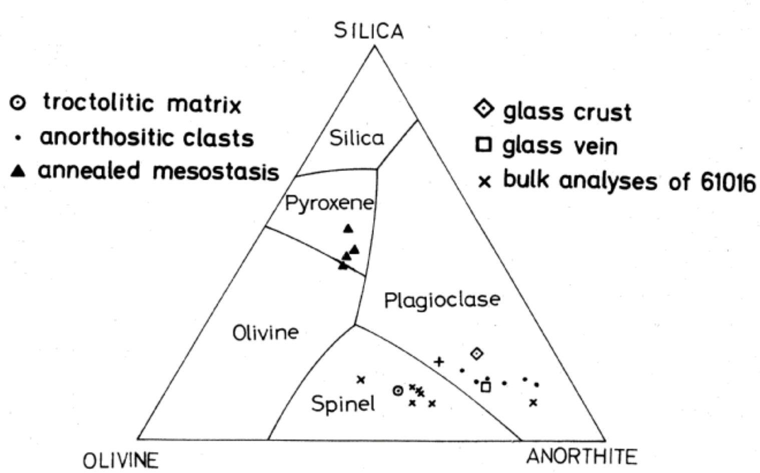

Figure 13: Broad beam electron microprobe analyses of regions within 61016 by Stoffler et al.

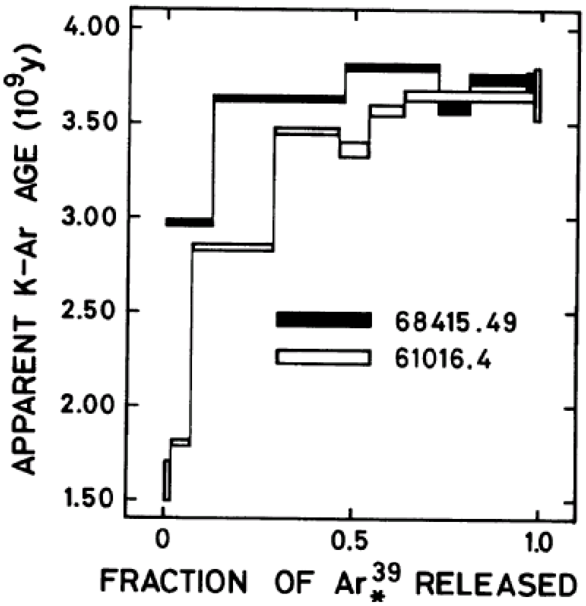

Figure 14: Ar release pattern for impact melt rock portion of 61016 (from Stettler et al. 1973).

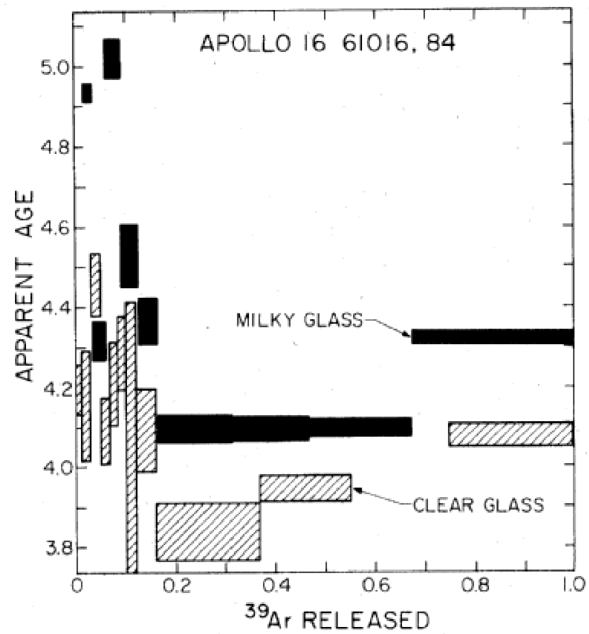

Figure 15: Ar release pattern for shocked - melted anorthositic portion of 61016 (from Huneke et al. 1977).

Summary of Age Data for 61016

	Ar39/40	U,Pu/^{136}Xe
Stettler et al. 1973	~3.65 ± 0.04 b.y.	
Huneke et al. 1977	~ 4.1	
Eugster 1999		3.97 ± 0.25 b.y.

List of Photo #s for 61016.

S72-41841	lighting
S72-38970-38975	color mug shots
S72-41548-41563	B & W mug
S72-53505	slab
S72-50676	slab
S72-50691-50692	exploded parts
S72-51172-51171	,8 B & W
S75-33581	
S75-33567	
S75-33676	
S78-33099	
S78-33101	sawn surface ,7 color
S90-33268-33275	,385 prep
S93-45943-45944	
S94-39612-39630	,7
S98-01206-01216	,456
S99-11494-11507	,456 prep

Table 1a. Chemical composition of 61016 (melt rock).

	Impact melt		matrix		Wiesmann 75										
reference	*Ryder 80*		Taylor 73		Hubbard 73			Wanke 74		Krahenbuhl 74			Rose 73	Laul 73	
weight	*average*		,149		,143	,121		,151		,132			,150	,152	
SiO2 %	43.3	(e)	42.9					43.43	(e)				43.82		
TiO2	0.76	(e)	0.76		0.88	0.67	(d)	0.78	(e)				0.69	0.7	(a)
Al2O3	25.1	(e)	23.9		24			24.56	(e)				25.06	25.6	(a)
FeO	5.1	(e)	5.31		5.4			5.16	(e)				4.97	5	(a)
MnO	0.05	(e)						0.05	(e)				0.05	0.052	(a)
MgO	10.7	(e)	12.5		11.5			10.26	(e)				10.48	10	(a)
CaO	14.3	(e)	13.3		13.7			14.42	(e)				14.31	14.4	(a)
Na2O	0.33	(e)	0.29		0.29	0.31		0.36	(a)				0.36	0.346	(a)
K2O	0.08	(e)	0.13		0.083	0.067	(d)	0.08	(a)				0.07	0.076	(a)
P2O5	0.12	(e)						0.12	(a)				0.12		
S %															
sum															
Sc ppm	6.6	(e)	3.5	(c)				6.6	(a)				6.6	7.4	(a)
V			21	(c)									15	20	(a)
Cr			250	(c)	697	433	(d)	600	(e)				752	643	(a)
Co	36	(e)	35	(c)				36.7	(a)				34	37	(a)
Ni	443	(e)	480	(c)				510	(a)	515	345	(f)	350	600	(a)
Cu	4.4	(e)	2.3	(c)				6.4	(a)				3.3		
Zn										0.84	0.74	(f)			
Ga								3.48	(a)				2.4		
Ge ppb								850	(a)	620	353	(f)			
As								270	(a)						
Se										181	112	(f)			
Rb	2	(e)	1.8	(c)	2.04	1.63	(d)	2.84	(a)	2	1.3	(f)	1.8		
Sr	160	(e)			166	170	(d)	130	(a)				110		
Y			60	(c)				44	(a)				34		
Zr			295	(c)	243		(d)	209	(a)				150	180	(a)
Nb			20.5	(c)				13	(a)				10		
Mo															
Ru															
Rh															
Pd ppb								25	(a)						
Ag ppb										21.4	1.7	(f)			
Cd ppb										29.5	9.6	(f)			
In ppb															
Sn ppb															
Sb ppb										3.13	1.74	(f)			
Te ppb										4.8	5.7	(f)			
Cs ppm								0.12	(a)	0.084	0.056	(f)			
Ba			240	(c)	172	137	(d)	160	(a)				105	130	(a)
La	15.3	(e)	19.2	(c)		13	(d)	16.7	(a)					14.9	(a)
Ce			52	(c)	41.8	32.7	(d)	46	(a)					39	(a)
Pr			6.71	(c)				5.8	(a)						
Nd			25.9	(c)	29.2	21.2	(d)							28	(a)
Sm			7	(c)	8.5	5.88	(d)	6.9	(a)					7	(a)
Eu			1.23	(c)	1.38	1.28	(d)	1.38	(a)					1.42	(a)
Gd			9.1	(c)	9.67	7.46	(d)	9.5	(a)						
Tb			1.28	(c)				1.5	(a)					1.3	(a)
Dy			8.5	(c)	9.4	7.5	(d)	9.7	(a)					8.5	(a)
Ho			1.83	(c)				2	(a)						
Er			5.4	(c)	5.68	4.38	(d)	4.8	(a)						
Tm			0.84	(c)											
Yb			5.1	(c)	4.97	3.87	(d)	4.4	(a)				2.8	4.3	(a)
Lu	0.65	(e)	0.79	(c)			(d)	0.61	(a)					0.6	(a)
Hf			4.2	(c)	5.99		(d)	4.9	(a)					5.2	(a)
Ta								1.02	(a)					0.73	(a)
W ppb								0.25	(a)						
Re ppb								14	(a)	1.28	0.841	(f)			
Os ppb															
Ir ppb	13	(e)						15	(a)	11.5	6.67	(f)		13	(a)
Pt ppb															
Au ppb	12	(e)						13	(a)	9.55	5.6	(f)		14	(a)
Th ppm					2.38		(d)	1.6	(a)					2.1	(a)
U ppm					0.497	0.394	(d)	0.46	(a)					0.47	(a)

technique: (a) INAA, (b) el. probe, (c) SSMS, (d) IDMS, (e) average value, (f) RNAA

Table 1b. Chemical composition of 61016 (melt rock).

reference	Nakamura 73		Garg 76			Wasson 75		Brunfelt 73		Eldridge 73		Juan 74	
weight	,148									,120		,146	
SiO2 %	43.2											44	(c)
TiO2	0.6							1.1				0.66	(c)
Al2O3	24.8							26.26				24.9	(c)
FeO	5.11		4.82		(a)			4.63				4.5	(c)
MnO	0.057							0.057				0.04	(c)
MgO	9.18							9.12				11	(c)
CaO	15.14							15.25				14.8	(c)
Na2O	0.37							0.34				0.4	(c)
K2O	0.09							0.078		0.067	(b)	0.07	(c)
P2O5	0.101												
S %													
sum													
Sc ppm			6.3		(a)			5.9	(a)				
V								40	(a)				
Cr			560		(a)			650	(a)			600	(c)
Co			37		(a)			33	(a)			51	(c)
Ni						569	(a)	540	(a)			268	(c)
Cu								6.6	(a)			2	(c)
Zn						0.52	(a)	3.4	(a)				(c)
Ga						3.69	(a)	2.5	(a)				
Ge ppb						641	(a)						
As													
Se													
Rb								3.2	(a)			2.1	(c)
Sr												180	(c)
Y													
Zr			224	196	(a)								
Nb													
Mo													
Ru													
Rh													
Pd ppb													
Ag ppb													
Cd ppb						8	(a)						
In ppb						4	(a)	10	(a)				
Sn ppb													
Sb ppb													
Te ppb													
Cs ppm								0.17	(a)				
Ba	152	(d)						125	(a)				
La	13	(d)						15.6	(a)				
Ce	34.12	(d)	34.7		(a)			40	(a)				
Pr													
Nd	21.91	(d)											
Sm	6.181	(d)						6.8	(a)				
Eu	1.346	(d)	1.17		(a)			1.53	(a)				
Gd	7.245	(d)											
Tb			1.1		(a)			1.02	(a)				
Dy	7.64	(d)						7.3	(a)				
Ho								1.6	(a)				
Er	4.42	(d)						4.4	(a)				
Tm													
Yb	3.96	(d)						3.9	(a)				
Lu	0.557	(d)	0.87		(a)			0.72	(a)				
Hf			4.72	4.42	(a)			4.5	(a)				
Ta								0.45	(a)				
W ppb													
Re ppb													
Os ppb													
Ir ppb						15	(a)						
Pt ppb													
Au ppb						9.7	(a)						
Th ppm			1.4		(a)			1.7	(a)	1.84	(b)		
U ppm								0.73	(a)	0.38	(b)		

technique: (a) INAA, (b) radiation counting, (c) AAS and coloremetric

Table 2a. Chemical composition of 61016 (anorthosite?).

			Wiesmann 75												
reference	LSPET 73		Hubbard 74		grey			*Ryder 80*	Nava 74	Philpotts 74		Krahenbuhl		Fruchter 74	
weight	,3		,3	,79	plag.	,84		*average*	,184	,184		,156		,180	
SiO2 %	44.15	(a)						*45*	45						
TiO2	0.2	(a)	0.18	0.02	0.02	0.017	(b)	*0.02*	0.02						
Al2O3	33.19	(a)						*34.6*	34.85					34.39	(c)
FeO	1.4	(a)						*0.3*						0.26	(c)
MnO	0.02	(a)													
MgO	2.51	(a)		0.16	0.25	0.16	(b)	*0.2*							
CaO	18.3	(a)						*19.6*	19.58						
Na2O	0.34	(a)	0.34	0.43	0.32	0.32		*0.4*	0.41					0.41	(c)
K2O	0.02	(a)	0.022	0.088	0.005	0.0048	(b)	*0.01*	0.005	0.0054	(b)				
P2O5	0.05	(a)						*0.05*	0.047						
S %	0.01	(a)													
sum															
Sc ppm								*0.5*						0.5	(c)
V															
Cr	200	(a)	190		375	<40	(b)							21	(c)
Co														0.5	(c)
Ni	39	(a)						*~ 1*				<1	(d)		
Cu															
Zn												1.45	(d)		
Ga															
Ge ppb												13	(d)		
As															
Se												0.4	(d)		
Rb	0.7	(a)	0.446	0.038	0.017	0.04	(b)	*0.1*		0.03	(b)	0.018	(d)		
Sr	179	(a)	177.9	180.4	179	182	(b)	*180*		149	(b)				
Y	11	(a)													
Zr	48	(a)	51.2	3	2		(b)								
Nb	2.4	(a)													
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb												0.29	(d)		
Cd ppb												190	(d)		
In ppb															
Sn ppb															
Sb ppb												0.15	(d)		
Te ppb												<0.4	(d)		
Cs ppm												0.0012	(d)		
Ba			40.7	6.97	7.05	7.11	(b)			6.01	(b)				
La			3.47		0.143	0.204	(b)	*0.1*							
Ce			8.61		0.37	0.44	(b)			0.253	(b)			0.3	(c)
Pr															
Nd			5.6	0.2	0.205	0.239	(b)			0.145	(b)				
Sm			1.56	0.045	0.058	0.058	(b)			0.036	(b)			0.1	(c)
Eu			0.926	0.805	0.77	0.814	(b)			0.671	(b)				
Gd			1.84	0.045	0.054		(b)								
Tb														0.9	(c)
Dy			1.91	0.025	0.065	0.059	(b)			0.027	(b)				
Ho															
Er			1.16	0.067	0.04	0.037	(b)			0.014	(b)				
Tm															
Yb			1.01	0.02	0.045	0.03	(b)			0.017	(b)				
Lu			0.149	0.005	0.024		(b)	*0.01*							
Hf			1.06												
Ta															
W ppb															
Re ppb															
Os ppb															
Ir ppb															
Pt ppb															
Au ppb															
Th ppm	1.7	(a)	0.486												
U ppm			0.101	0.002	0.002		(b)					0.0009	(d)		

technique (a) XRF, (b) IDMS, (c) INAA, (d) RNAA

Table 2b. Chemical composition of 61016 (anorthosite?).

	,173		Baedecker 74			
reference	Wrigley 73		Wasson 75		Hughes 73	
weight	132 gr		,161			
SiO2 %						
TiO2						
Al2O3						
FeO						
MnO						
MgO						
CaO						
Na2O						
K2O	0.0084	(a)				
P2O5						
S %						
sum						
Sc ppm						
V						
Cr						
Co						
Ni			3.1	(b)		
Cu						
Zn			1.7	(b)		
Ga			3.46	(b)		
Ge ppb			23	(b)		
As						
Se						
Rb						
Sr						
Y						
Zr						
Nb						
Mo						
Ru						
Rh						
Pd ppb						
Ag ppb					0.6	(b)
Cd ppb			170	(b)		
In ppb			250	(b)		
Sn ppb						
Sb ppb						
Te ppb						
Cs ppm						
Ba						
La						
Ce						
Pr						
Nd						
Sm						
Eu						
Gd						
Tb						
Dy						
Ho						
Er						
Tm						
Yb						
Lu						
Hf						
Ta						
W ppb						
Re ppb					0.018	
Os ppb					0.72	
Ir ppb			0.2	(b)	0.82	
Pt ppb						
Au ppb			0.94	(b)	0.024	
Th ppm	0.11					
U ppm	0.05	(a)				
technique	*(a) radiation counting, (b) INAA*					

Table 3. Chemical composition of 61016 black glass.

			glass		black	
reference	Stoffler 75		Morris 86		Hubbard 74	
weight			See 86		glass	
SiO2 %	44.48	(a)	44.12	(b)		
TiO2	0.17	(a)	0.19	(b)	0.43	(d)
Al2O3	29.83	(a)	31.74	(b)		
FeO	3.65	(a)	3.1	(b)		
MnO						
MgO	4.87	(a)	3.22	(b)		
CaO	15.64	(a)	17.51	(b)		
Na2O	0.66	(a)	0.34	(b)	0.42	
K2O	0.08	(a)	0.07	(b)	0.1	(d)
P2O5	0.08	(a)				
S %						
sum						
Sc ppm			3.75	(c)		
V						
Cr			480	(c)	861	(d)
Co			24	(c)		
Ni			280	(c)		
Cu						
Zn						
Ga						
Ge ppb						
As						
Se						
Rb					1.877	(d)
Sr					145	(d)
Y						
Zr					190	(d)
Nb						
Mo						
Ru						
Rh						
Pd ppb						
Ag ppb						
Cd ppb						
In ppb						
Sn ppb						
Sb ppb						
Te ppb						
Cs ppm						
Ba					132	(d)
La			6.3	(c)	13.6	(d)
Ce			23.5	(c)	29.8	(d)
Pr						
Nd					10.9	(d)
Sm			3	(c)	3.06	(d)
Eu			0.97	(c)	0.526	(d)
Gd					3.61	(d)
Tb			0.59	(c)		
Dy					7.9	(d)
Ho						
Er					5.1	(d)
Tm						
Yb			2	(c)	4.25	(d)
Lu			0.29	(c)	0.619	(d)
Hf			2.25	(c)	3.8	(d)
Ta						
W ppb						
Re ppb						
Os ppb						
Ir ppb						
Pt ppb						
Au ppb						
Th ppm			0.59	(c)	2.07	(d)
U ppm			0.09	(c)	0.6	(d)

technique (a) el. Probe, (b) (c) INAA, (d) IDMS

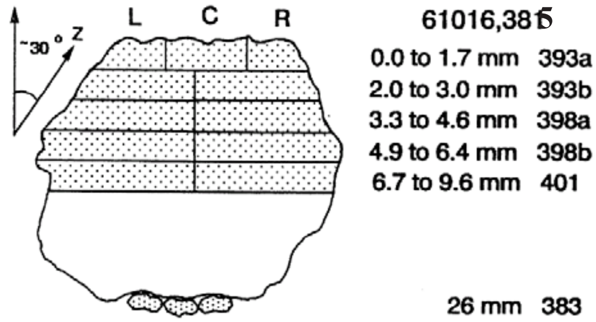

Figure 16: Near surface sample of 61016,385 used for solar cosmic ray profiles by Rao et al. 1993.

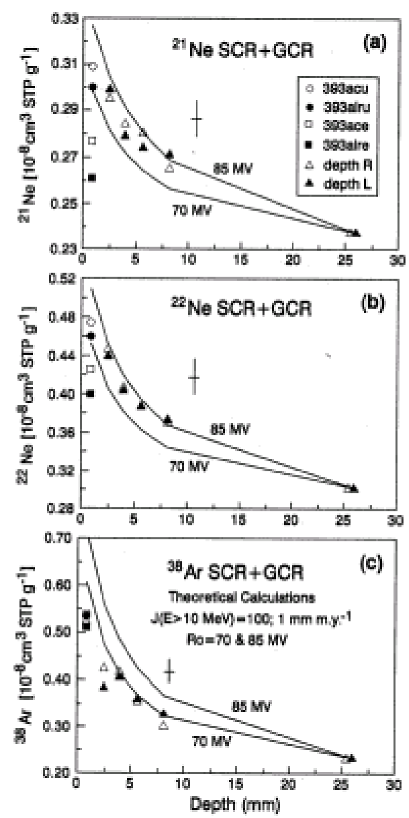

Figure 17: Solar cosmic ray profiles in surface samples of 61016 (from Rao et al. 1993).

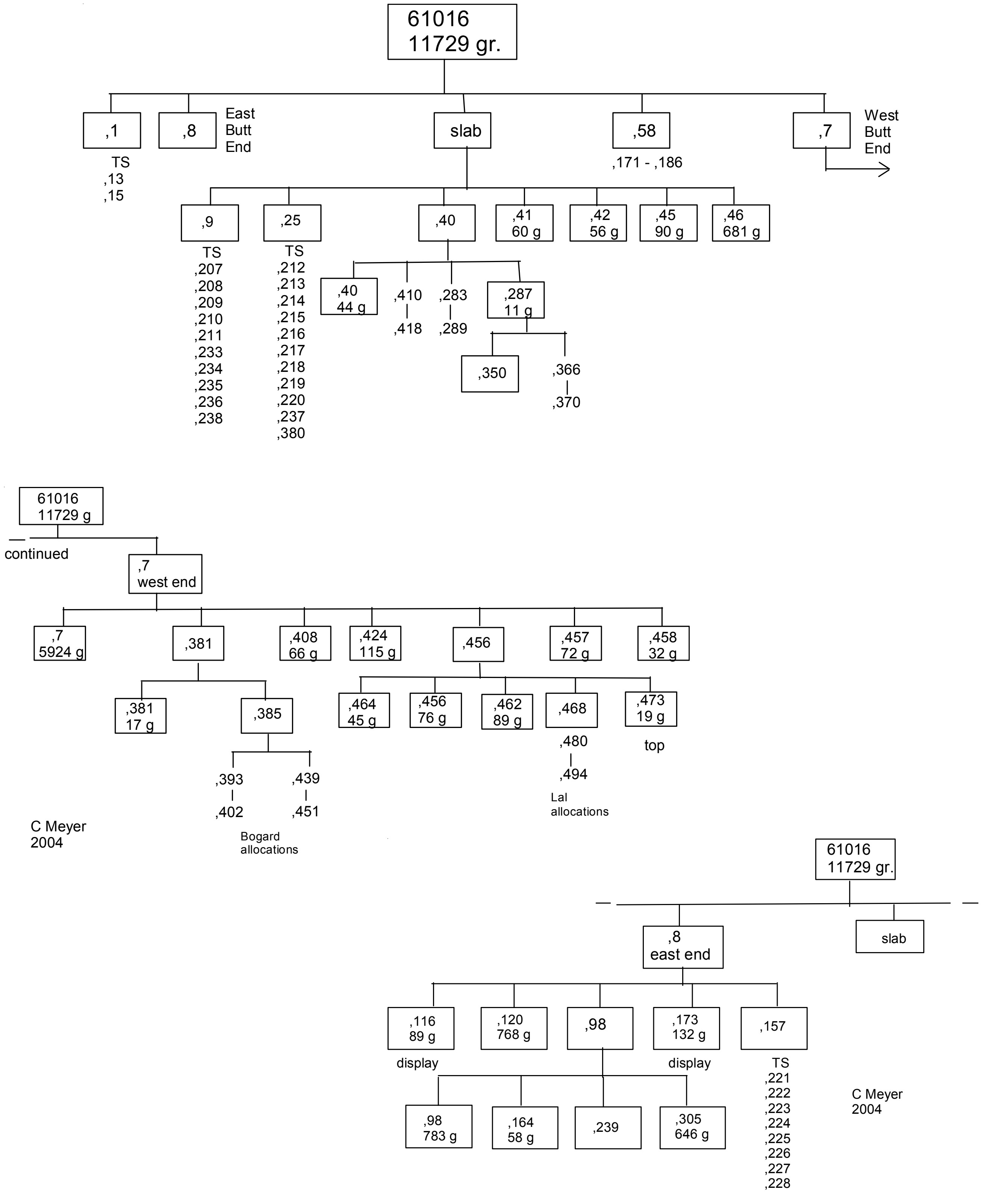

Figure 18: Generalized flow diagram for 61016 showing subdivisions (see pictures for details). Caution: not all samples shown.

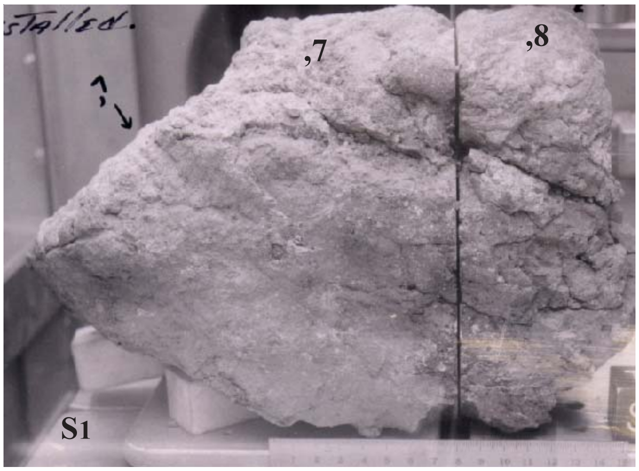

Figure 19: First saw cut 61016 (from data pack).

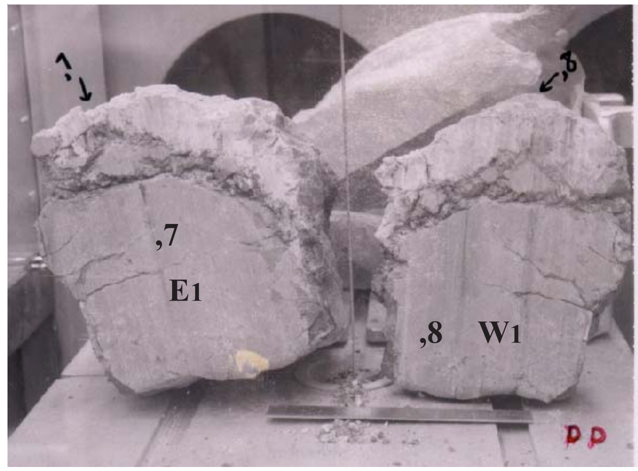

Figure 21: Sawn surfaces of 61016 after first saw cut showing anorthosite "cap" on dense, dark gray, "melt rock" interior (from data pack). Figure shows E1 face of large butt end ,7 (before slab is cut) and W1 face of butt end ,8 (see figure).

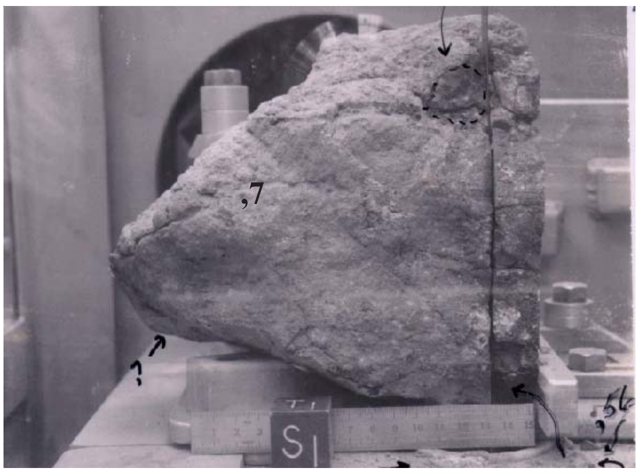

Figure 20: Position of second saw cut of 61016 in 1972 producing 2 cm thick slab (see flow diagram).

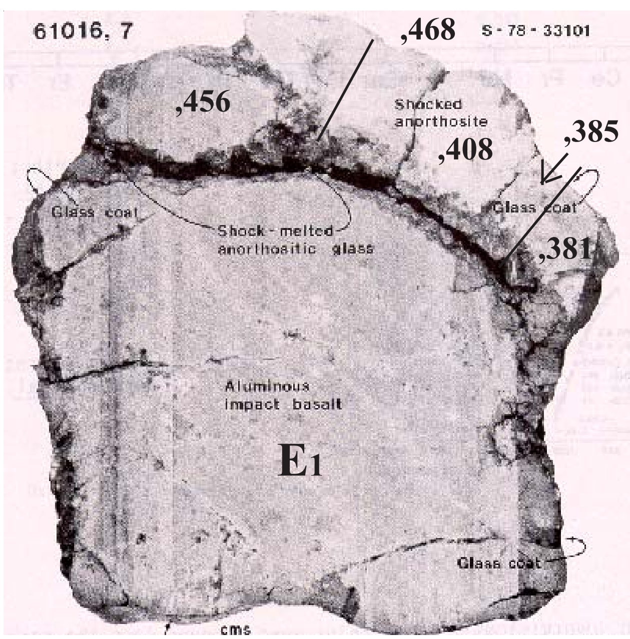

Figure 22: Photo after 2nd saw cut of 61016,7 (from Ryder and Norman 1980).

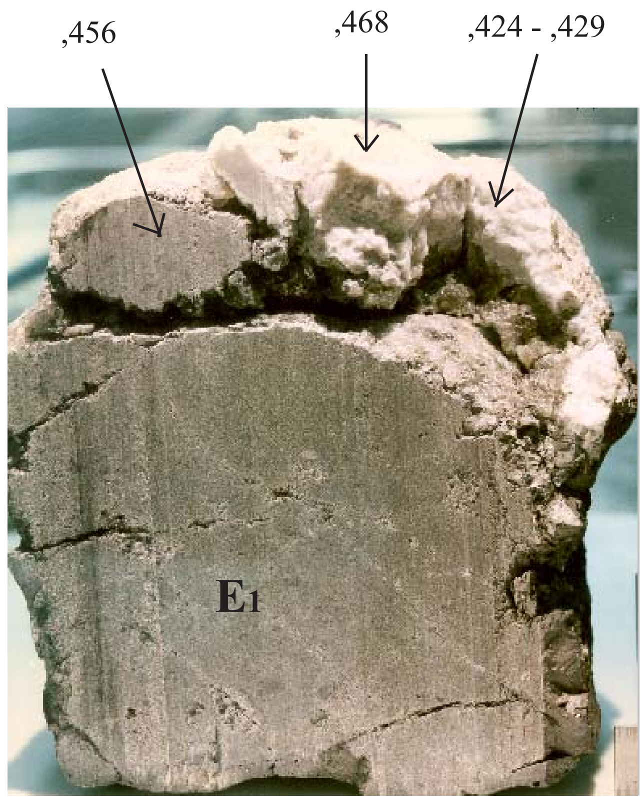

Figure 23: Sawn surface of 61016,7 (west end piece) showing E1 face and position of subsamples on top. Subsamples ,381 ,385 and ,408 (already removed) were in front of ,424-,429. NASA S94-39613. One inch cube seen in bottom corner. Compare with figure 22.

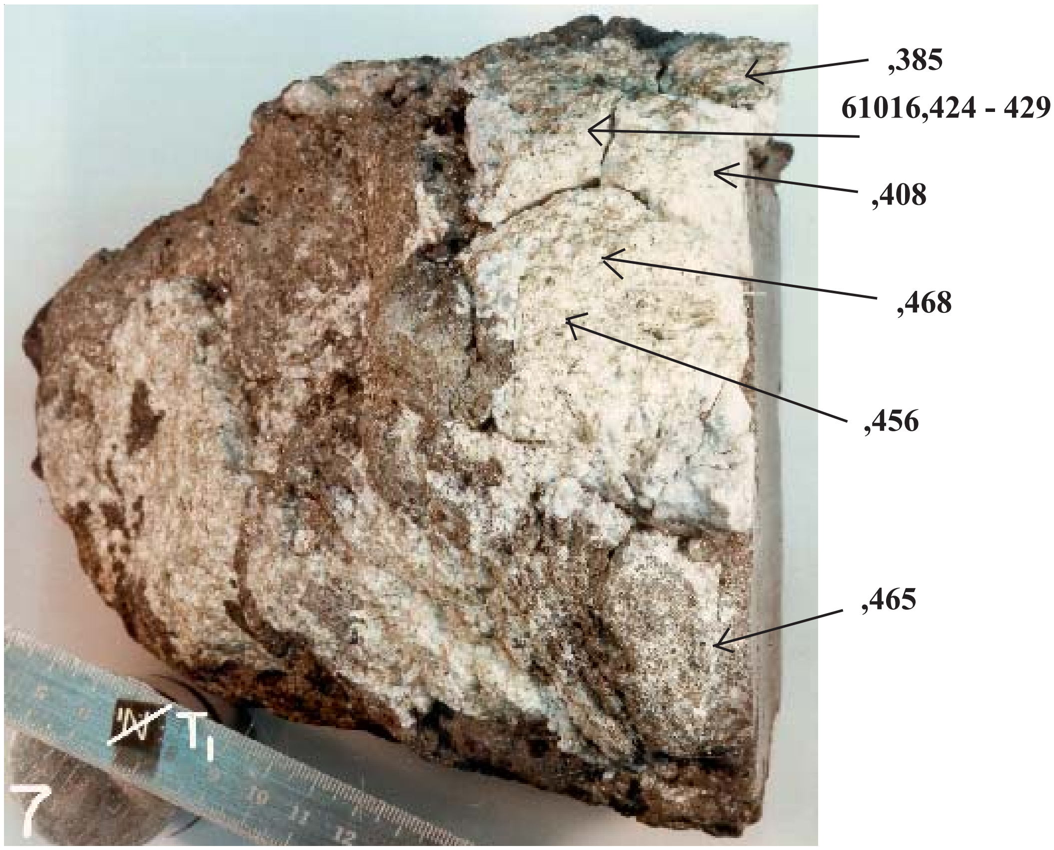

Figure 24: Photo of top surface of 61016,7 , showing thin brown patina on anorthosite and zap pits all over. NASA# S78-33099. Cube is 1 cm. Compare with figures 1 and 23.

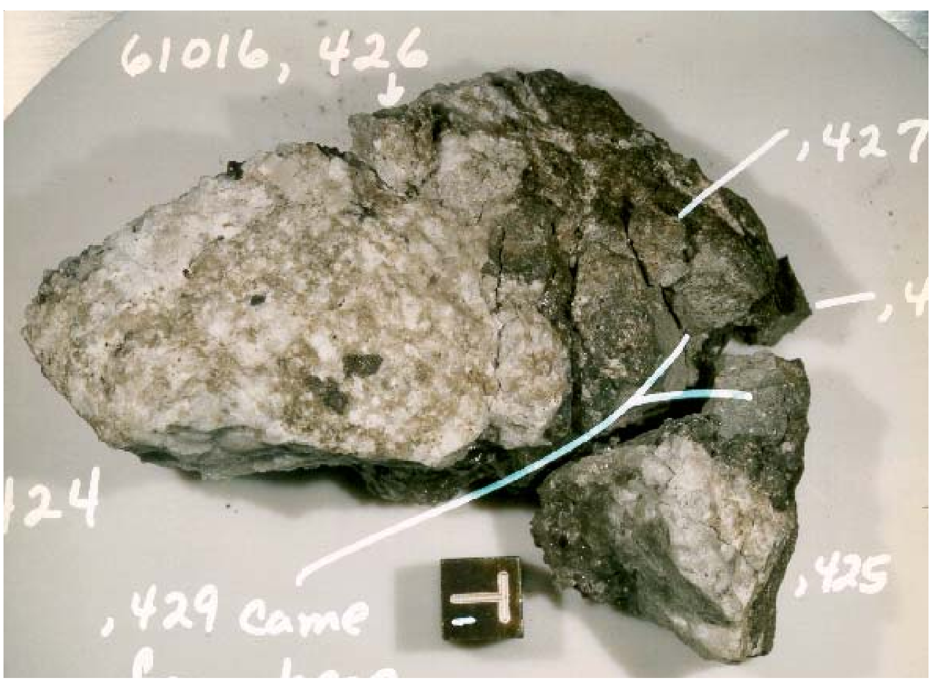

Figure 25: Top surface of 61016 faceing the sun. Note the light brown patina on pure white anorthosite. NAS# S94-39620. Cube is 1 cm. (see figure 24).

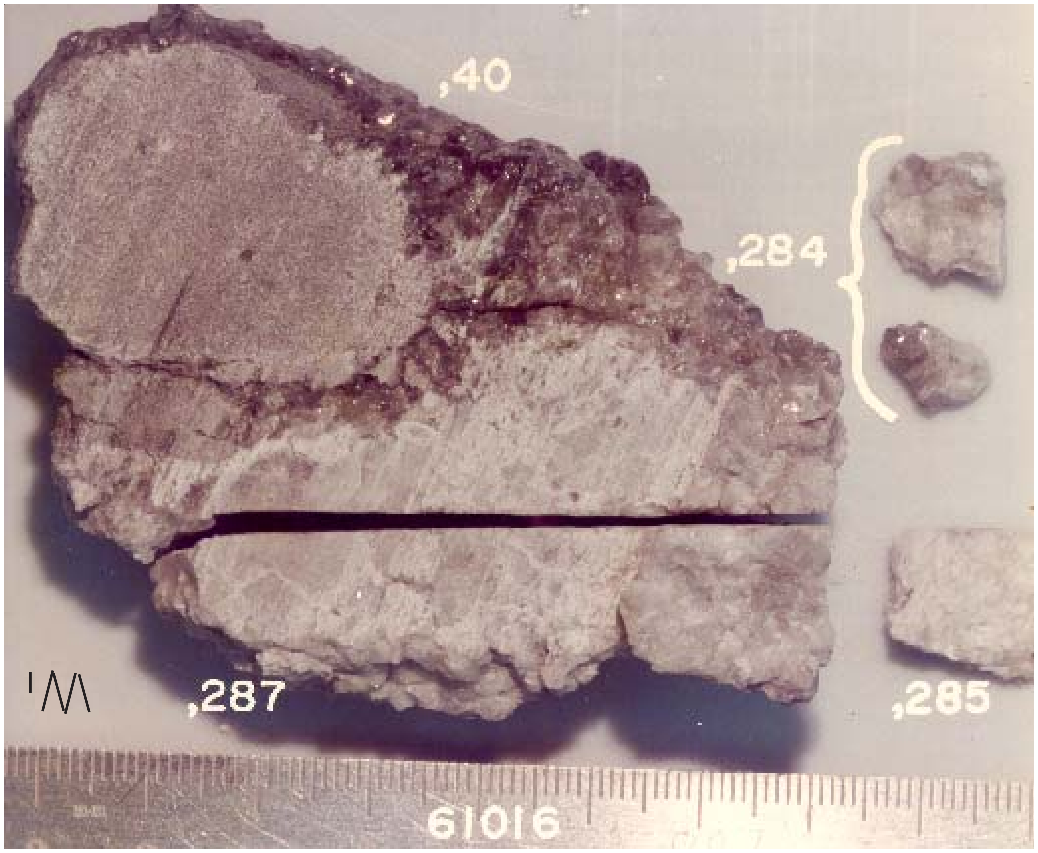

Figure 26: Photo of top portion of slab from 61016 (with T1 surface facing the ruler). NASA S74-33208. Scale in cm. Compare with figure 5 (top piece).

Figure 27: 61016,40 after sawing off the top (,287). Small cube is 1 cm. NASA S74-33206. Streaks are from saw blade.

Figure 28: Top portion of 61016,8 showing anorthosite cap with thin brown patina. Compare with figure 3. NASA #S75-33567. Cube is 1 cm.

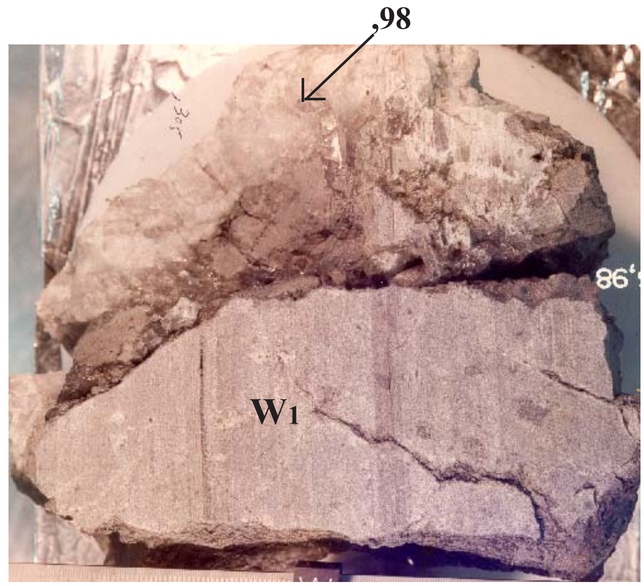

Figure 29: Top portion of 61016,8 (the east end piece) showing the W1 face (see figure 28). NASA #S75-33676. Cube is 1 cm

Figure 30: Plagioclase glass boundary on bottom surface of 61016,98. Cube is 1 cm. NASA S75-33581.

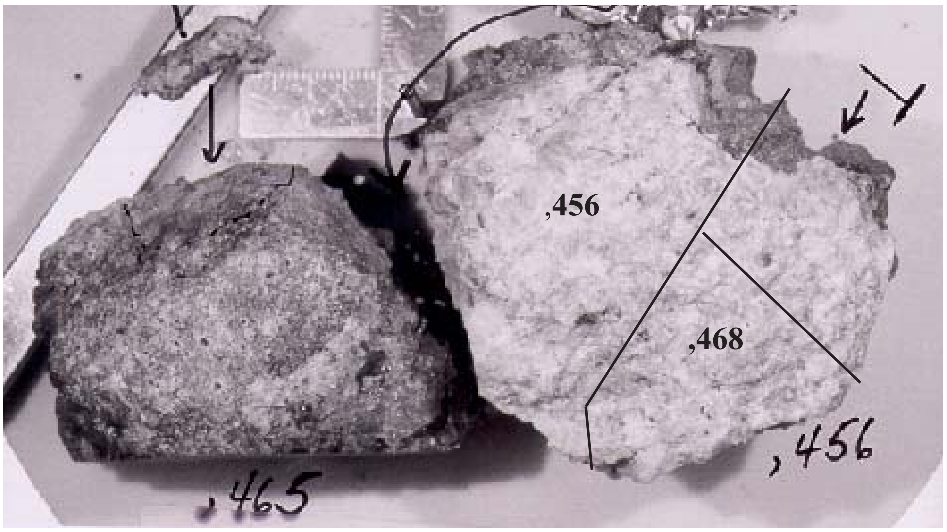

Figure 31: Photo of top of 61016,456 (from top of butt end ,7). Compare with figures 1 and 24. Scale is in cm. Location of cuts is approximate. Photo from data pack.

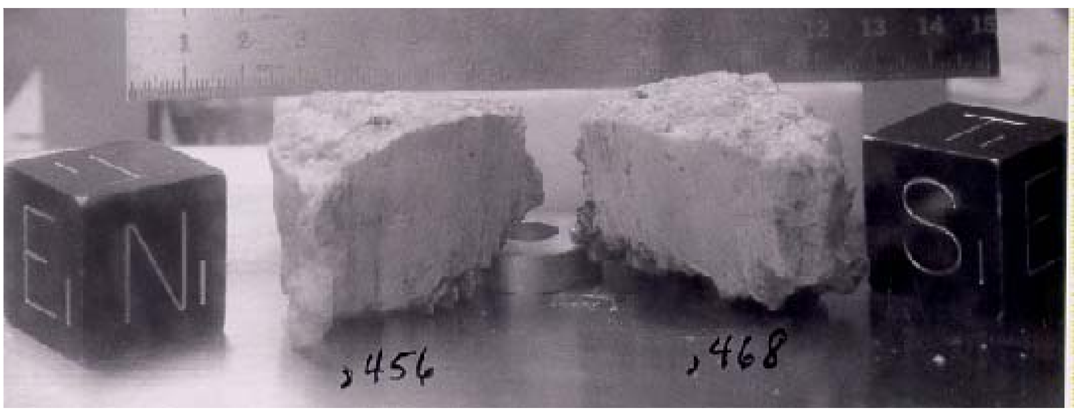

Figure 32: Saw cut through 61016,456, producing ,468. Cube is 1 inch (cm scale in background). Photo from data pack.

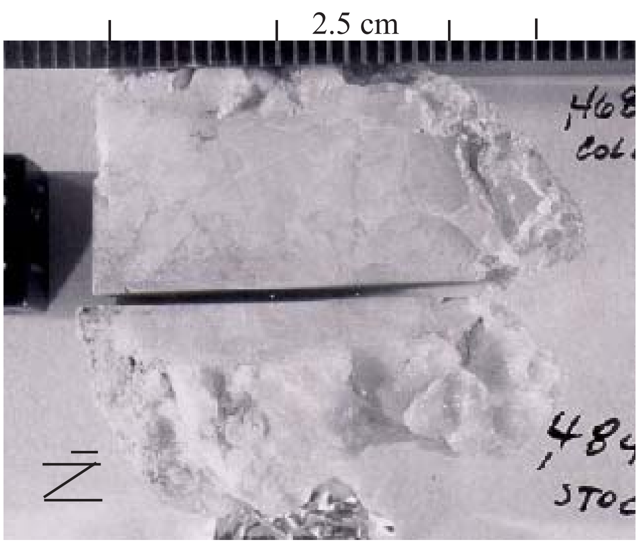

Figure 33: Photo of 61016,468 after sawing ,484.

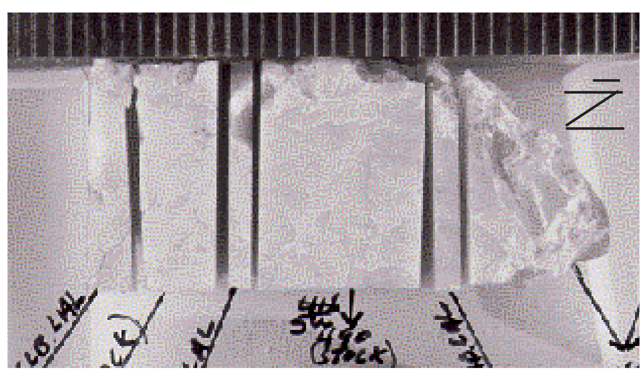

Figure 34: Saw cuts of ,468. Scale in mm. Photo from data pack.

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