

**67915**  
Feldspathic Polymict Breccia  
2600 grams



Figure 1: Photo of 67915 showing rounded external surface - sitting on freshly broken surface. Cube is 1 inch for scale. NASA S72-37143.

### **Introduction**

North Ray Crater is about 1 km across and about 230 meters deep, with steep slopes. Lunar sample 67915 was chipped off of Outhouse Rock, which is apparently a piece of House Rock (a large boulder perched on the rim of North Ray Crater, see section on 67935). According to cratering mechanics, material on the rim of a crater should be material from the greatest depth in the crater. One side of 67915 is freshly broken, the other sides are rounded by micrometeorite bombardment (figure 1).

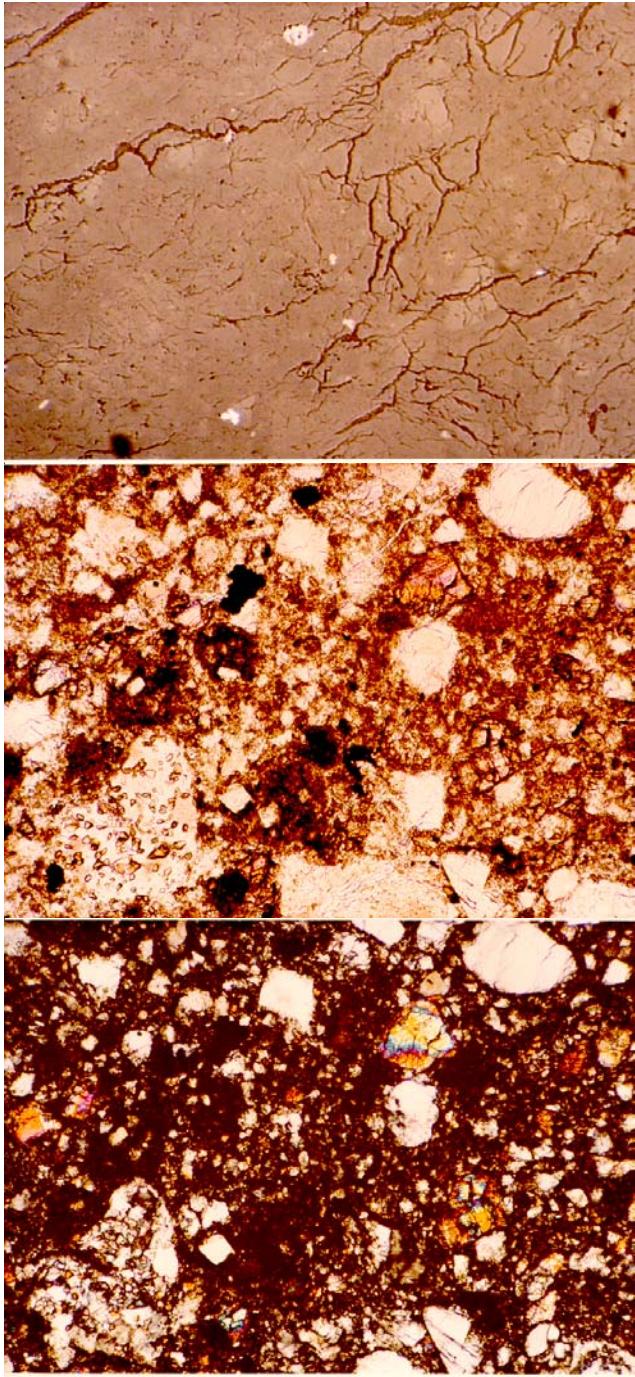
67915 is composed of two main lithologies; both are polymict (Taylor and Mosie 1979). The white breccia (WB) lithology is composed of rounded clasts of fine-grained anorthositic breccia, while the gray breccia (GB) lithology is composed of a collection of dark or gray-colored clasts, including sodic ferrogabbro and troctolitic anorthosite. The boundary between the WB and GB lithologies is generally sharp and the WB

lithology may be clasts within the GB lithology (figure 3). Both lithologies have about the same composition. 67915 is cemented by shock-melted glass and is also cut with thin black glass veins.

The exposure age of 67915 (~50 m.y.) gives the age of North Ray Crater (Marti et al. 1983, Drozd et al. 1974, Crozaz et al. 1974, Pepin et al. 1974). Crystallization ages of the matrix and of the clasts in this rock proved difficult to determine, but are about 3.9 - 4.0 b.y.

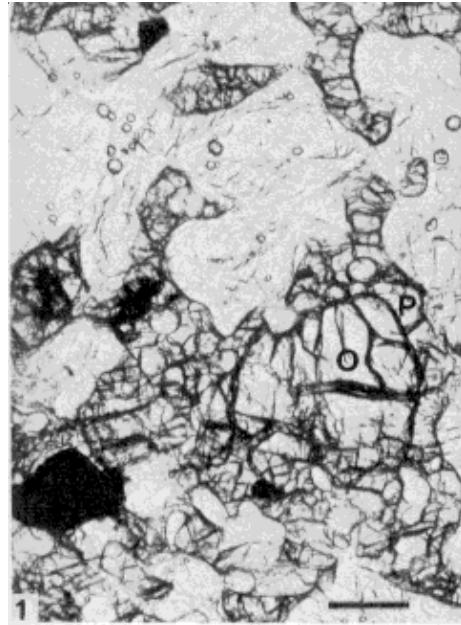
### **Petrography**

Weiben and Roedder (1973) and Roedder and Weiben (1974), provided the first description of 67915. Nord et al. (1975) found that the matrix was cemented by thin films of glass formed by shock (figure 2). Roedder and Weiben (1977) studied the thin glass veins in 67915 and discussed their method of formation. Ryder and Norman (1980) give a good summary description.



*Figure 2: Photomicrographs of thin section 67915,83 (top - reflected; middle - plane polarized; bottom - crossed polarizers). Field of view is 1.4 mm. NASA S79-27764-27766.*

This sample includes a wide variety of lithic clasts. Most of the gray clasts are fine-grained impact melt rocks with a variety of texture and shock features. The white clasts are microcrystalline, granulitic, feldspathic impactites. A few special clasts are discussed separately below (see also figure 6).



*Figure 3: Photomicrograph of noritic anorthosite clast in 67915 (Roedder and Weiblen 1973). Scale bar is 100 micron.*

### **Significant Clasts**

#### ***Ferroan Anorthosite***

Weiblen and Roedder (1973) describe a 3 mm clast with large shocked plagioclase ( $An_{98}$ ) including several small olivine grains ( $Fo_{55-58}$ ).

#### ***Noritic Anorthosite***

Roedder and Weiblen (1974) describe a noritic anorthosite with olivine ( $Fo_{81}$ ) surrounded by orthopyroxene ( $Wo_3En_{80}$ ) poikilitically enclosing plagioclase ( $An_{93}$ ) (figure 3).

#### ***Sodic Ferro Gabbro –***

Weiblen and Roedder (1973), Roedder and Weiblen (1974), Weiblen et al. (1980) and Taylor et al. (1980) describe several clasts of sodic ferro gabbro (see insert for modal analysis). These small clasts all appear to have cataclastic texture and don't have original texture. Plagioclase is sodic ( $Or_{3.9}An_{50-60}$ ) and pyroxene is Fe-rich ( $En_{35}$ ) and exsolved. Attempts to date these clast proved unsuccessful (see below).

#### ***Granulitic Troctolitic Anorthosite***

Sample 67915,67 (figure 9) has a granulitic texture (120 deg. grain boundaries) with ~85% plagioclase ( $An_{95}$ ) and ~15% olivine ( $Fo_{75}$ ) (see also figure 4b in Marti et al. 1983). It has relatively high REE content (analysis given in table 1b).



Figure 4: Photo of freshly broken surface of 67915 showing clastic nature of Outhouse Rock. Note the fine black glass veins. Cube is 1cm. NASA S72-43917.

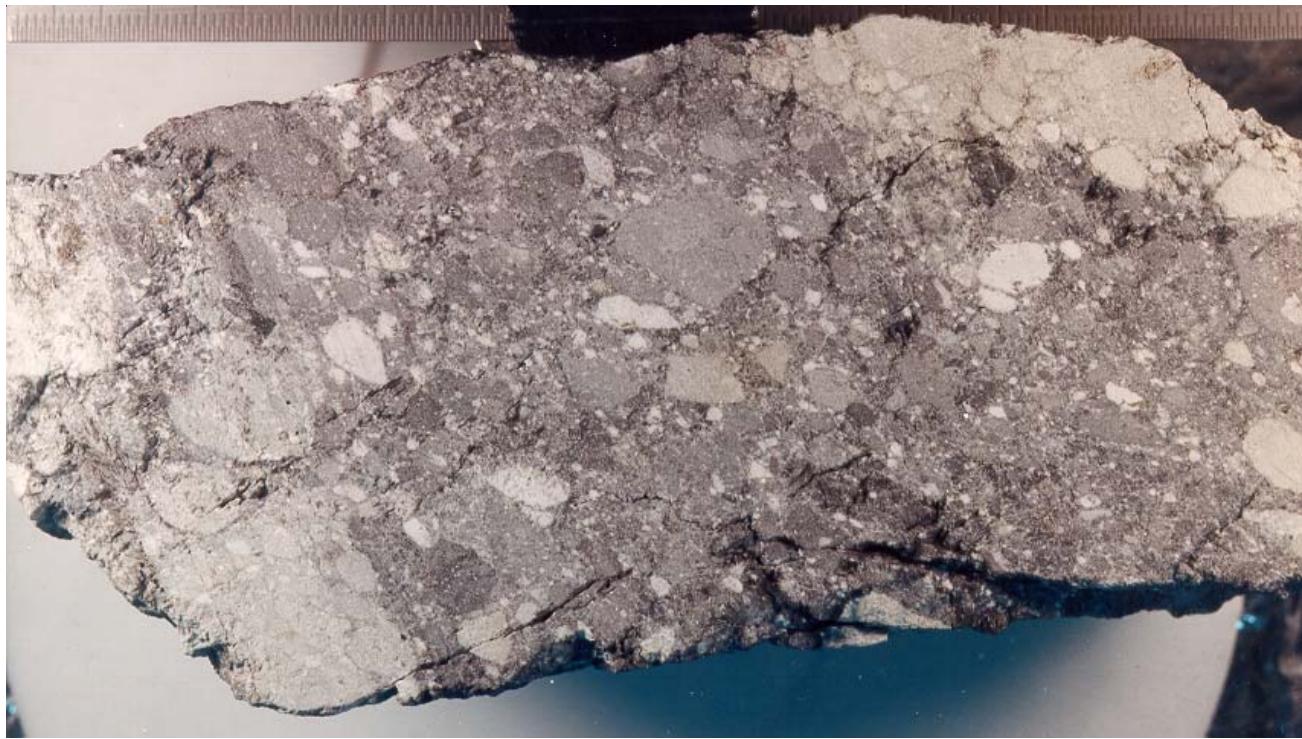


Figure 5: Photo of sawn surface of 67915,2 showing clastic nature of grey breccia lithology with portions of white breccia lithology at either end. Scale is in cm. NASA S75-33755.

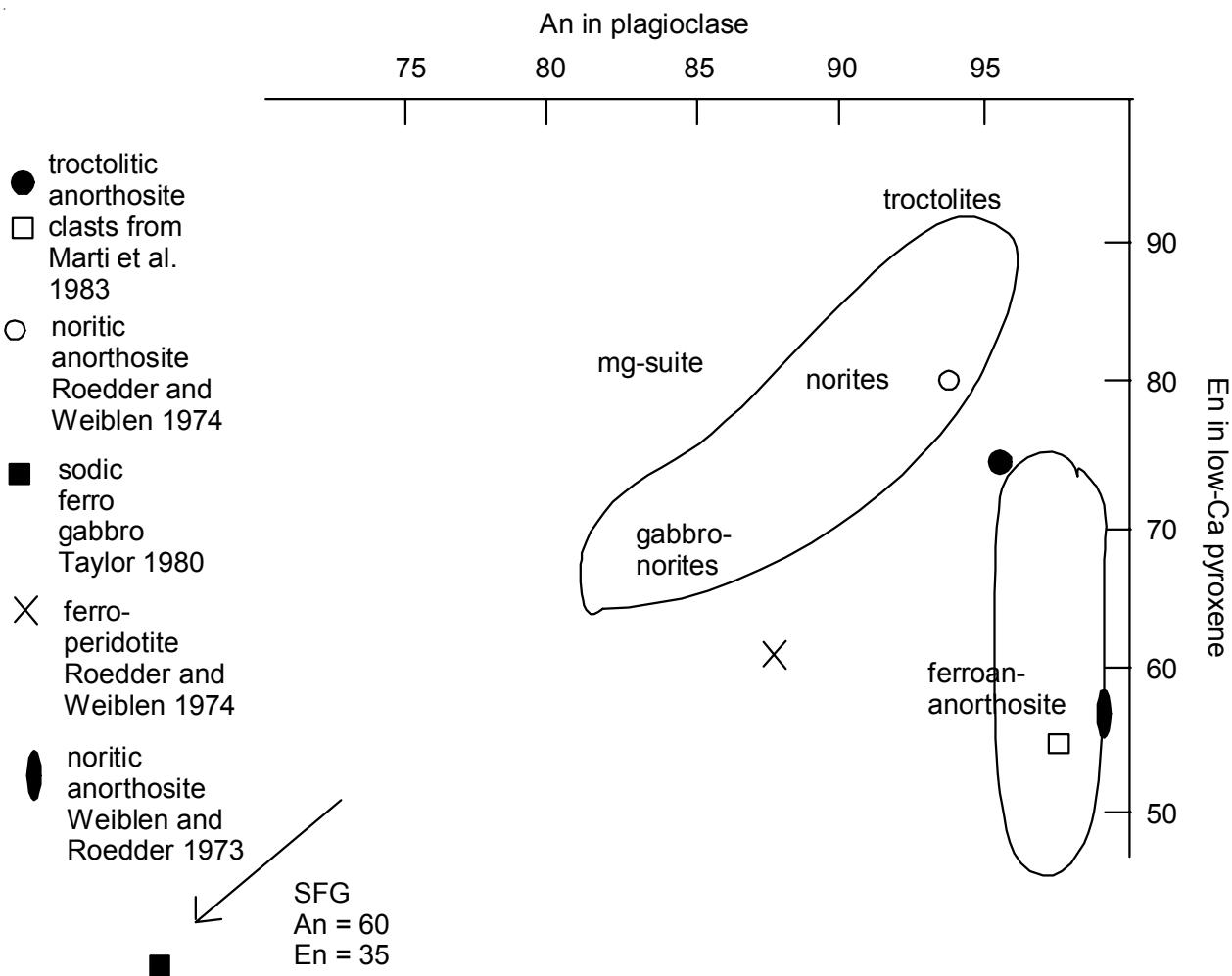


Figure 6: Figure showing mineral compositions of some of the various clasts in 67915.

### Pristine Troctolitic Anorthosite

Sample 67915,26 (figure 17) is a troctolitic anorthosite with cumulate texture (see figure 4a in Marti et al. 1983). It contains about 85% plagioclase ( $An_{97}$ ) with about 15% intercumulate olivine ( $Fo_{55}$ ).

### Ferro-peridotite

Roedder and Weiben (1974) illustrate and describe small mafic-rich clasts with Fe-rich, clinopyroxene ( $Wo_{40}En_{45}$ ) and olivine ( $Fo_{62}$ ) with minor plagioclase ( $An_{87}$ ). Some of the pyroxene is coarsely exsolved. They termed this material ferro-peridotite.

### Mineralogy

Note: The composition of minerals in this sample are recorded in an appendix to Roedder and Weiben.

**Plagioclase:** Most of the plagioclase in the matrix is  $An_{93-95}$ , but the plagioclase in the sodic ferrogabbro is

$An_{50-60}$ . Weiben et al. (1980) discuss trace element content of plagioclase in 67915 (figure 7).

**Metallic iron:** Misra and Taylor (1975) found that iron grains in 67915 had Co and Ni contents in the meteoritic range.

**Zircon:** Weiben and Roedder (1973) report a large zircon (35 -75 microns) in the matrix.

### Mineralogical Mode Sodic Ferrogabbro Clasts

	Marti et al. 1983	Taylor et al. 1980
Plagioclase	40-45%	42
Pyroxene	25-30	28
Ilmenite	5-10	10
K-spar	1	1
Silica	15-25	20
zircon		
phosphates	0.2-0.3	0.2
metal		tr.
troilite		tr.

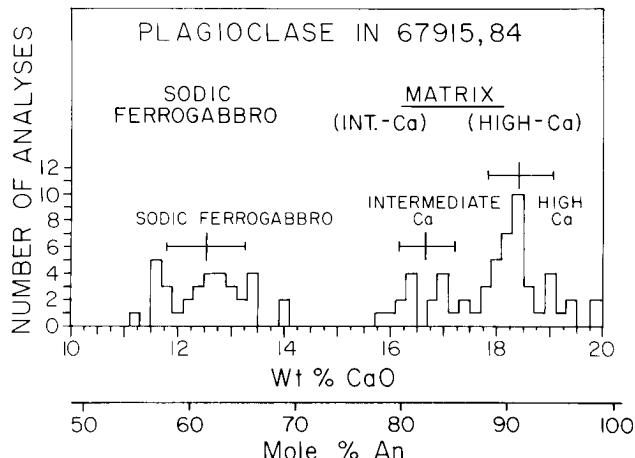


Figure 7: Composition of plagioclase in 67915 (Weiblen et al. 1980).

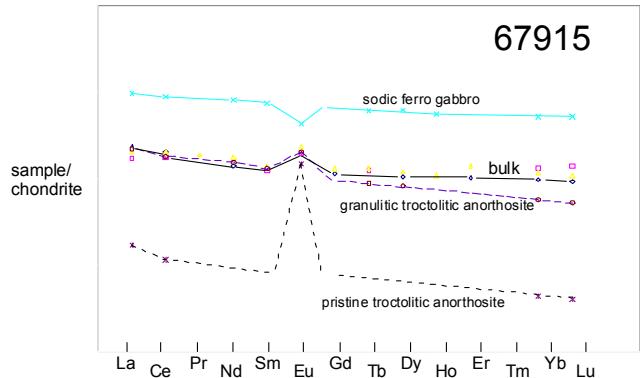


Figure 8: Normalized rare-earth-element diagram for 67915. Bulk rock from Nakamura et al. 1973 is black line connecting points. Data for clasts are from Marti et al. 1983. Data for sodic ferro gabbro is average from table 1b.

**Pink Spinels:** Weiblen and Roedder (1973) found low-Cr, high-Mg spinels as mineral clasts.

### Chemistry

Duncan et al. (1973) analyzed the light and dark regions of 67915 and found essentially the same composition (table 1a) for each region. Roedder and Weiblen (1977) found the black glass veins were the same composition as the bulk sample (as determined by Nakamura et al. 1973, Lindstrom and Salpus 1981 and Wanke et al. 1973). Probably the best way to estimate the bulk content is to compare splits with the data on the whole rock by Rancitelli et al. (1973) who determined the K, U, Th for the bulk rock (1180 grams). From this one can see that the main component is anorthositic; the sodic ferrogabbro lithology can only be a minor component!



Figure 9: Troctolite clast 67915, 67. S77-26866. Scale in mm.

Marti et al. (1983) analyzed several sodic ferro gabbro (SFG) clasts (average only plotted in figure 8). Ebihara et al. (1992) analyzed clasts only. Warren (1993) compiled the primitivity.

### Radiogenic age dating

Kirsten et al. (1973), Venkatsan and Alexander (1976), and Marti et al. (1978, 1983) determined Ar/Ar plateau ages for clasts in 67915 (figures 10 – 14). Ages for sodic ferro gabbro were unsuccessful. Plagioclase separates gave the best plateaus ~ 3.9 b.y.

### Cosmogenic isotopes and exposure ages

Behrmann et al. (1973), Marti et al. (1973), Drozd et al. (1974) and Pepin et al. (1974) reported exposure ages of  $48.9 \pm 1.7$  m.y. and  $50.6 \pm 1.5$  m.y.

(respectively) by the  $^{81}\text{Kr}$  method. Pepin et al. calculated  $^{21}\text{Ne} = 41.8$  m.y. and  $^{38}\text{Ar} = 60.3$  m.y. Rancitelli et al. (1973) determined the cosmic-ray-induced activity of  $^{22}\text{Na} = 34$  dpm/kg. and  $^{26}\text{Al} = 96$  dpm/kg.

### Other Studies

Moore et al. (1973), Cripe and Moore (1974) and Moore and Lewis (1976) determined that the light clast in 67915 was low in C, N and S.

Collinson et al. (1973), Runcorn et al. (1974), Tsay and Baumann (1975) and

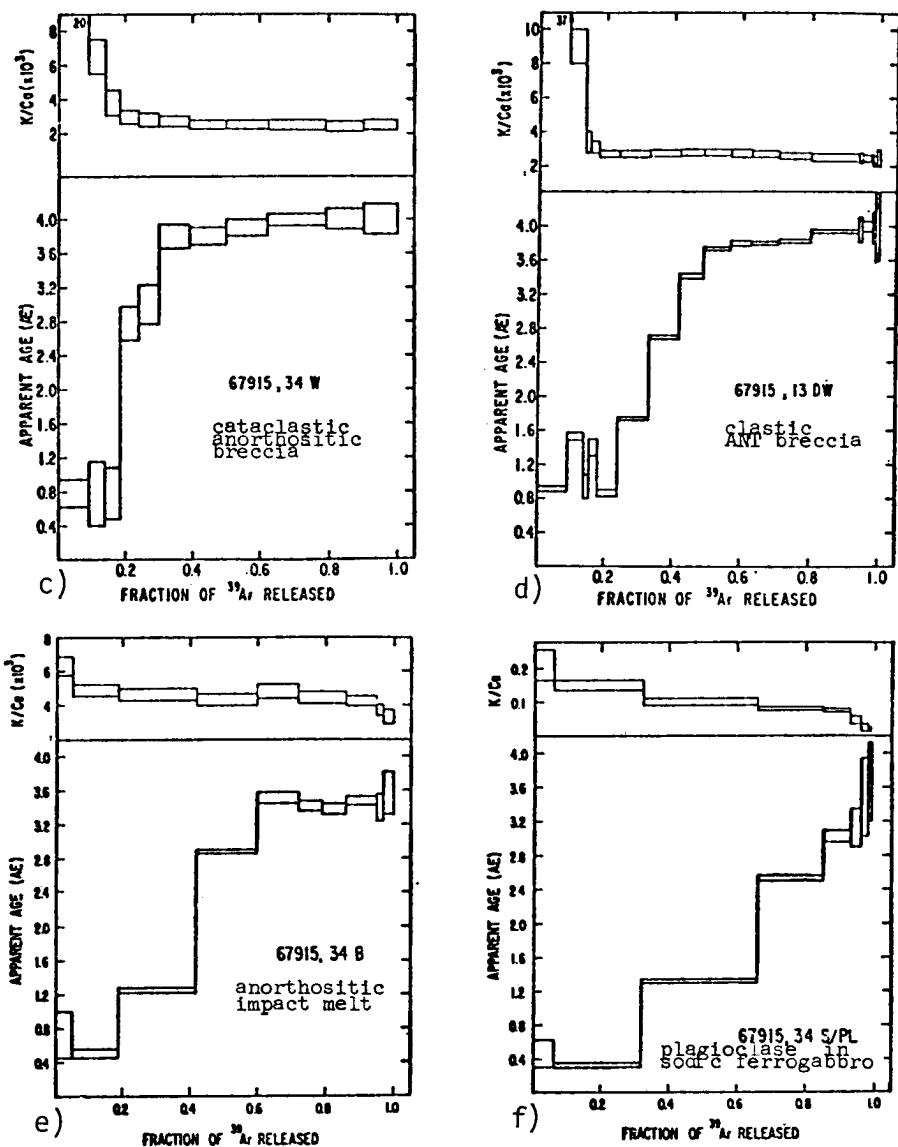


Figure 9: Ar/Ar plateau ages for materials in 67915 (Marti et al. 1978).

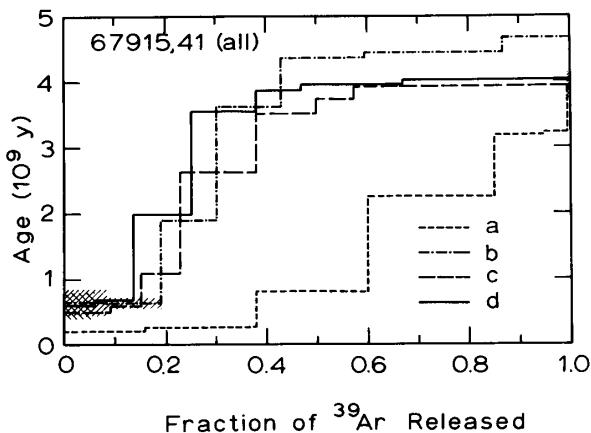


Figure 10: Ar/Ar plateau ages for clasts and matrix in 67915 (Kirsten et al. 1973).

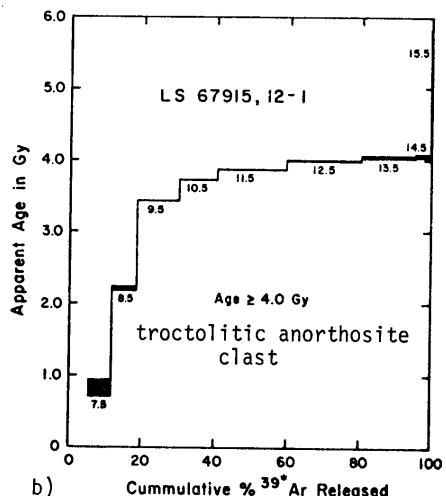


Figure 11: Ar/Ar plateau age for anorthositic clast in 67915 (Venkatesan and Alexander 1976).

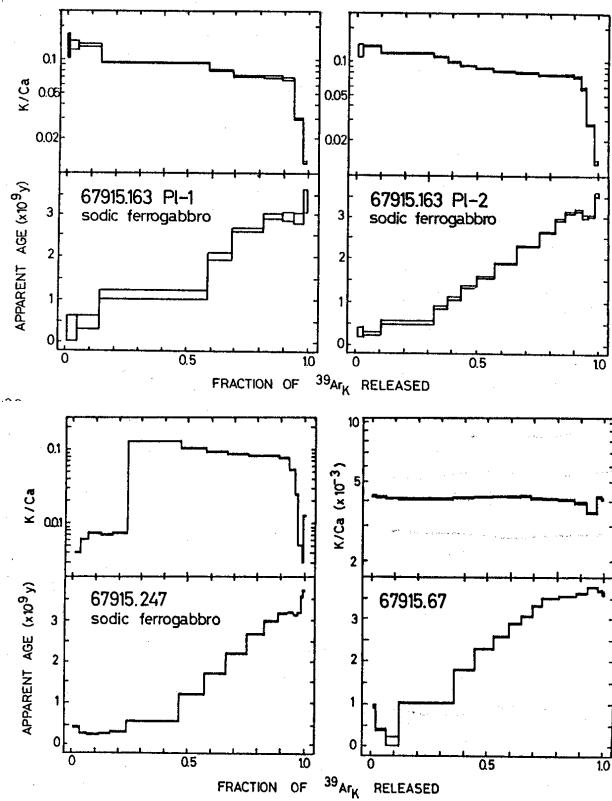


Figure 12: Ar/Ar plateau ages for plagioclase and whole rock samples of sodic ferro gabbro clasts in 67915 (Marti et al. 1983). NO PLATEAU!

Cisowski et al. (1983) reported magnetic data.

Fireman et al. (1973) reported  ${}^3\text{H}$  data.

### Processing

Three slabs have been cut from 67915; one for the Roedder consortium (1972-1978), a second for the Marti consortium (1978-1983) and a third in 1997 in order to prepare a display (the third has not been studied). Jeff Taylor and Andrea Mosie (1979) prepared a guidebook, mapping the clast types and describing the various clasts. Ryder and Norman (1980) summarized the research up to that date in their

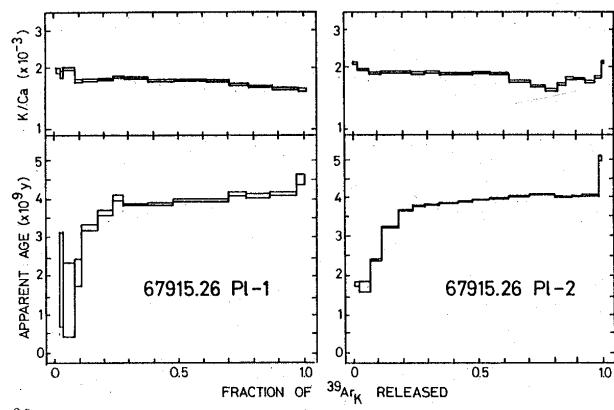


Figure 13: Ar/Ar plateau age for plagioclase from pristine troctolitic anorthosite clast in 67915 (Marti et al. 1983).

catalog of Apollo 16 rocks. As of 2008, 36 thin sections have been prepared for various lithologies of 67915.

Figures 5, 16 and 17 show the clastic nature of the first slab (.9), while figure 15 shows the position of the second slab (.223) and figures 16 to 21 show the sawn surfaces and clastic nature of 67915.

A large end piece (.276) and a thin section are on display at the Smithsonian Museum (figure 22).

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### Summary of Age Data for 67915

	Ar/Ar	Pu-Xe	clast
Kirsten et al. 1973	$3.91 \pm 0.05$ b.y.		
Kirsten et al. 1973	$3.99 \pm 0.05$		matrix
Kirsten et al. 1973	$(4.3 \pm 0.1)$		ganulitic impactite
Venkatesan and Alex. 76	$4.03 \pm 0.04$		troctolitic anorthosite
Marti et al. 1983	$(3.1 \pm 0.1)$		sodic ferro gabbro
Marti et al. 1983	$4.1 \pm 0.06$		troctolitic anorthosite
Marti et al. 1983	$\sim 3.71$	$\sim 4.3$	granulitic anorthosite

**Table 1a. Chemical composition of 67915.**

reference weight	Rancitelli73 1182 g	Duncan 73 WB	DB	Nakamura73 51 mg.	Lindstrom81 bulk	Wanke 76 bulk	Krahenbuhl73 <u>Ganapathy74</u> matrix clast	Roedder 77 veins (15)
SiO <sub>2</sub> %	44.8	45.1	(a)	43.71		45.12		45.71 (f)
TiO <sub>2</sub>	0.3	0.35	(a)	0.5	0.46	(b) 0.58		0.25 (f)
Al <sub>2</sub> O <sub>3</sub>	28.88	29.99	(a)	29.43	28.3	(b) 29.27		30.51 (f)
FeO	3.51	3.64	(a)	2.95	3.8	(b) 3.76		2.69 (f)
MnO	0.046	0.048	(a)	0.047	0.05	(b) 0.056		0.06 (f)
MgO	5.69	4.25	(a)	5.95	7.5	(b) 2.93		2.86 (f)
CaO	16.05	16.78	(a)	16.59	15.3	(b) 17		17.47 (f)
Na <sub>2</sub> O	0.39	0.46	(a)	0.45	0.46	(b) 0.63		0.39 (f)
K <sub>2</sub> O	0.063 (e)	0.056	0.07	(a) 0.061		0.09		0.06 (f)
P <sub>2</sub> O <sub>5</sub>				0.036		0.004		0.03 (f)
S %						0.06		
<i>sum</i>								
Sc ppm					5.84	(b) 8.22	(d)	
V								
Cr					675	(b) 380	(d)	
Co					20.5	(b) 5.77	(d)	
Ni	75.4	52.1	(a)		200	(b) 57	(d) 160	95 (d)
Cu	3.5	10.2	(a)			5.4	(d)	
Zn	6.4	9.1	(a)			7.4	(d) 5.1	4.8 (d)
Ga						3.4	(d)	
Ge							180	82 (d)
As						4.4	(d)	
Se						110	(d) 23	23 (d)
Rb	0.95	1.1	(a)			0.79	(d) 0.8	1.1 (d)
Sr	187	194	(a)		170	(b) 177	(d)	
Y	16.9	16	(a)			26	(d)	
Zr	71.8	56.8	(a)			49	(d)	
Nb	5.5	3.9	(a)			7	(d)	
Mo								
Ru								
Rh								
Pd ppb								
Ag ppb							2.8	4.8 (d)
Cd ppb							2.6	2.75 (d)
In ppb								
Sn ppb								
Sb ppb							0.41	0.33 (d)
Te ppb							18	13.5 (d)
Cs ppm					0.044	(d)	0.05	0.051 (d)
Ba	64	62		59.7 (c) 62	(b) 65	(d)		
La				5.395 (c) 4.03	(b) 4.75	(d)		
Ce				12.35 (c) 10.7	(b) 12.2	(d)		
Pr						1.7	(d)	
Nd			6.87 (c)		7.9	(d)		
Sm			1.922 (c)	1.83	(b) 2.02	(d)		
Eu			1.059 (c)	1.09	(b) 1.32	(d)		
Gd			2.27 (c)		2.55	(d)		
Tb				0.45	(b) 0.48	(d)		
Dy			2.55 (c)		2.9	(d)		
Ho					0.61	(d)		
Er			1.63 (c)		2.2	(d)		
Tm								
Yb			1.57 (c)	2.15	(b) 1.92	(d)		
Lu			0.224 (c)	0.34	(b) 0.26	(d)		
Hf				7.08	(b) 1.6	(d)		
Ta				0.246	(b) 0.34	(d)		
W ppb					66	(d)		
Re ppb							0.67	0.346 (d)
Os ppb								
Ir ppb							7.33	3.57 (d)
Pt ppb								
Au ppb					0.79	(d)	1.9	1.06 (d)
Th ppm	0.73 (e)			0.86	(b) 0.6	(d)		
U ppm	0.15 (e)			0.34	(b) 0.15	(d)	0.18	0.175 (d)

technique: (a) XRF, (b) INAA, (c) IDMS, (d) RNAA, (e) radiation counting, (f) EMP

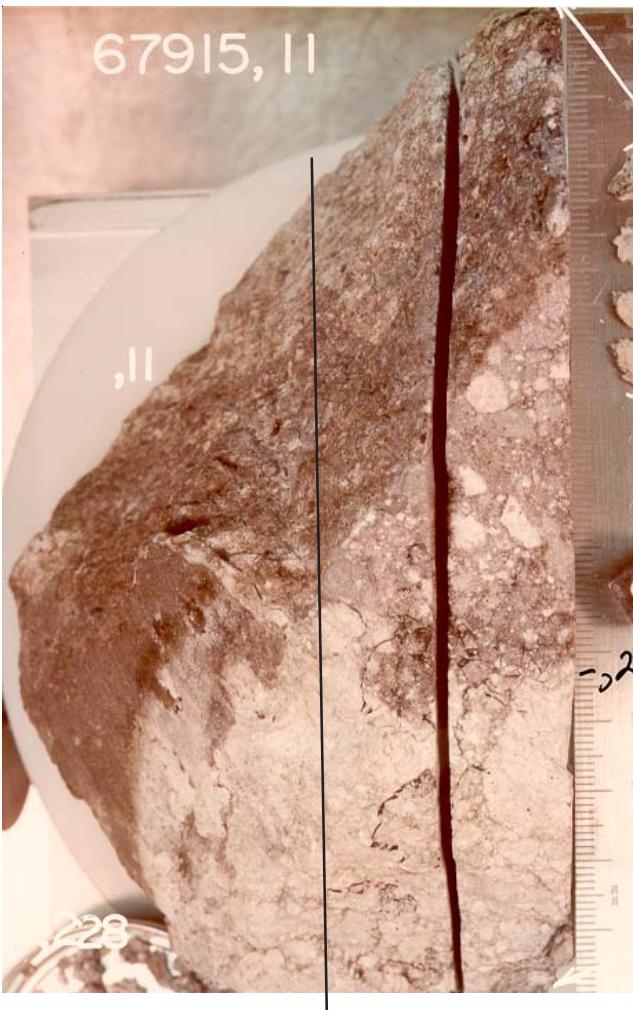
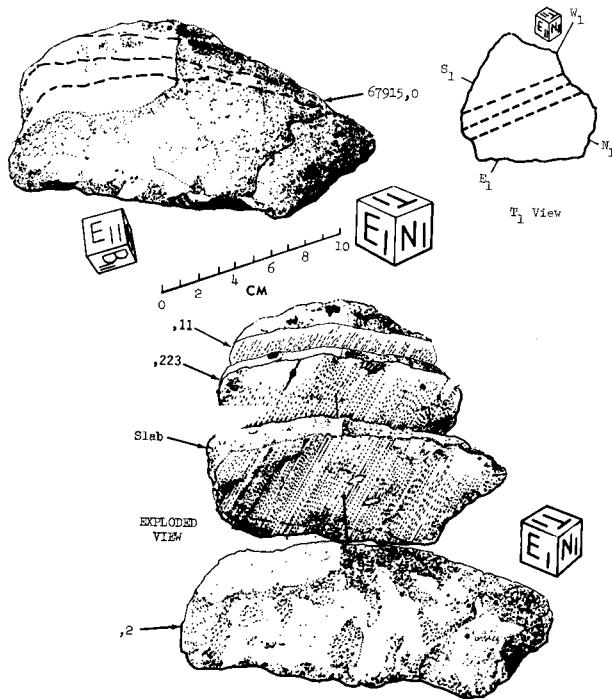
**Table 1b. Chemical composition of clasts in 67915.**

reference weight SiO <sub>2</sub> %	Taylor 80		Marti 83		SFG ave.	,26		,67		Ebihara 92 clast	
	SFG clast	SFG clasts				pristine troc. anor.	granulitic troc. anor.	clast	clast		
TiO <sub>2</sub>	6	(b) 6	5.3	4.6	5.2	0.2	0.2	(b)			
Al <sub>2</sub> O <sub>3</sub>	8.4	(b) 8.4	11.9	11.9	11.5	28.6	30.4	(b)			
FeO	13.6	(b) 13.6	12.3	12.3	12.4	7.1	2.6	(b)			
MnO	0.2	(b) 0.2	0.15	0.15	0.16	0.077	0.027	(b)			
MgO	3.8	(b) 3.8	3	3.5	3.2	4.7	5.1	(b)			
CaO	8.9	(b) 8.9	9.4	9.2	9.3	17.2	18.2	(b)			
Na <sub>2</sub> O	1.35	(b) 1.35	1.3	1.25	1.29	0.3	0.52	(b)			
K <sub>2</sub> O	0.46	(b) 0.46	0.52	0.52	0.51	0.026	0.067	(b)			
P <sub>2</sub> O <sub>5</sub>											
S %											
sum											
Sc ppm	34	(b) 34	31	31	32	1.9	1.2	(b)			
V	10	(b) 10	3	2	3	12	10	(b)			
Cr		232	191	191	198	157	178	(b)			
Co	6.6	(b) 6.6	5.5	9.5	6.6	14.2	7.1	(b)			
Ni							58	33	55	(d)	
Cu							6.2	11.2	3.6	(d)	
Zn											
Ga											
Ge							21	35	22	(d)	
As											
Se							1.19	0.068	0.01	(d)	
Rb							3.8	0.53	0.78	(d)	
Sr		320	250	270	260	113	160	(b)			
Y											
Zr	320	(b)	300	300	300			(b)			
Nb											
Mo											
Ru											
Rh											
Pd ppb							9	1.7	1.3	(d)	
Ag ppb							6	1.1	1.7	(d)	
Cd ppb							41	12	3	(d)	
In ppb							1.5	0.5	0.67	(d)	
Sn ppb											
Sb ppb							2.7	1.1	1	(d)	
Te ppb							12	18	10	(d)	
Cs ppm							0.135	0.028	0.07	(d)	
Ba	390	(b) 390	330	350	340		80	(b)			
La	26.7	(b) 26.7	21.5	24	22.7	0.4	5.1	(b)			
Ce	62	(b) 62	50	59	54	0.7	11	(b)			
Pr											
Nd	45	(b) 45	35	38	37		7	(b)			
Sm	13.1	(b) 13.1	10.4	11.6	11	0.13	1.9	(b)			
Eu	2.45	(b) 2.45	2.4	2.5	2.42	0.83	1.15	(b)			
Gd											
Tb	2.85	(b) 2.9	2.1	2.2	2.2		0.32	(b)			
Dy	19	(b) 19	14	15	15		2	(b)			
Ho			3.1	3.2	3.1			(b)			
Er											
Tm			1.4	1.6	1.5			(b)			
Yb	11.2	(b) 11.2	8	8.5	8.5	0.072	0.93	(b)			
Lu	1.58	(b) 1.58	1.2	1.3	1.27	0.01	0.13	(b)			
Hf	9.6	(b) 9.6	8.4	8.8	8.6		1.2	(b)			
Ta	2.9	(b) 2.9	2.2	1.9	2.2		0.5	(b)			
W ppb											
Re ppb							2.31	0.014	0.05	(d)	
Os ppb							0.164	0.198	0.93	(d)	
Ir ppb							0.022	0.057	0.79	(d)	
Pt ppb											
Au ppb			44					1.01	0.657	1.16	(d)
Th ppm	4.7	(b) 4.7	3.7	4	3.9		2.1	(b)			
U ppm	1.3	(b) 0.8	1	1.1	1		0.4	(b)	0.95	0.005	
technique:	(b) INAA, (d) RNAA								0.01	(d)	

**Table 2. Chemical composition of clasts in 67915.**

reference	Rose et al. 1975				Taylor 80	
weight	1	2	3	4	SFG ave.	
SiO <sub>2</sub> %	43.92	43.37	44.44	44.36	(a) 56.7	(b)
TiO <sub>2</sub>	0.26	0.15	0.29	0.26	(a) 4.7	(b)
Al <sub>2</sub> O <sub>3</sub>	32.16	29.21	31.38	27.16	(a) 11.1	(b)
FeO	2.71	5.99	3.04	3.63	(a) 12.8	(b)
MnO	0.02	0.05	0.03	0.05	(a) 0.2	(b)
MgO	2.28	4.79	2.58	8.98	(a) 3	(b)
CaO	17.9	15.94	17.58	14.95	(a) 8.9	(b)
Na <sub>2</sub> O	0.57	0.38	0.44	0.38	(a) 1.1	(b)
K <sub>2</sub> O	0.06	0.04	0.04	0.07	(a) 0.6	(b)
P <sub>2</sub> O <sub>5</sub>	0.02	0.02	0.03	0.04	(a) 0.1	(b)
S %						
sum				99.23		

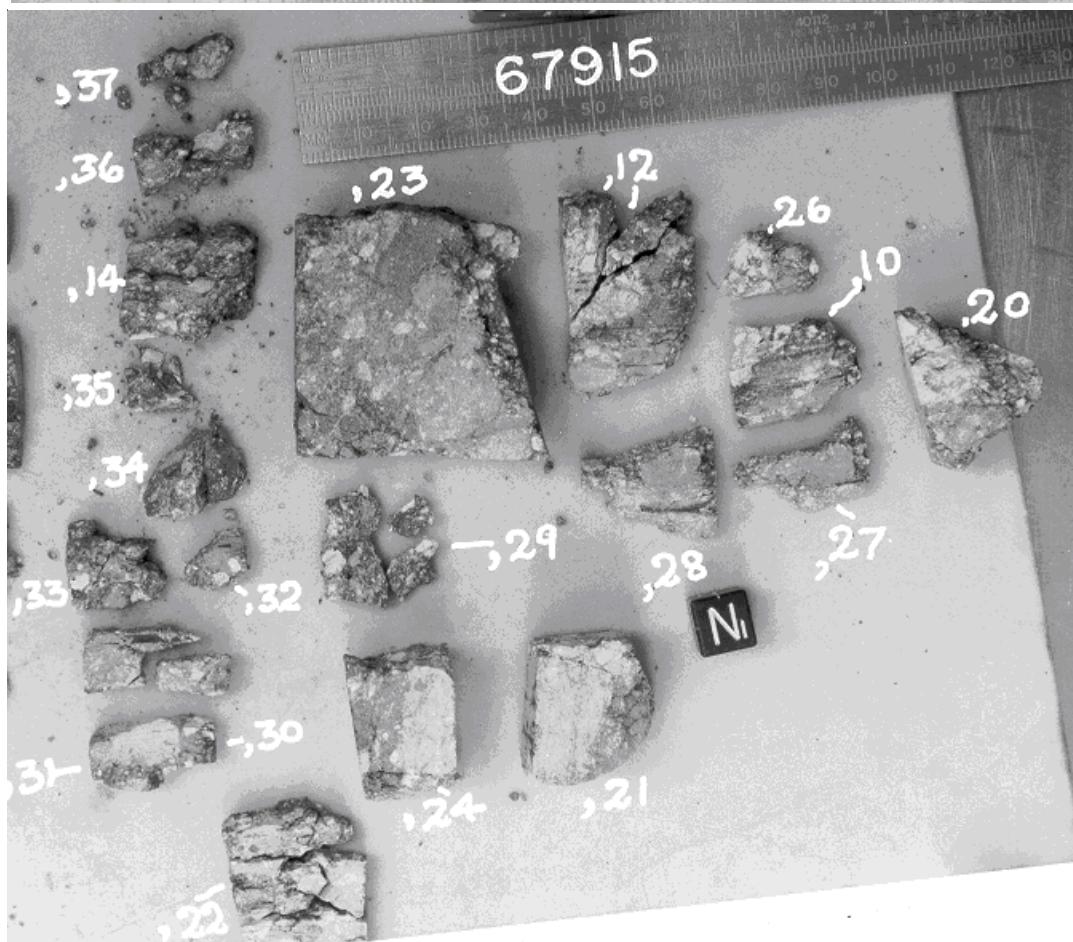
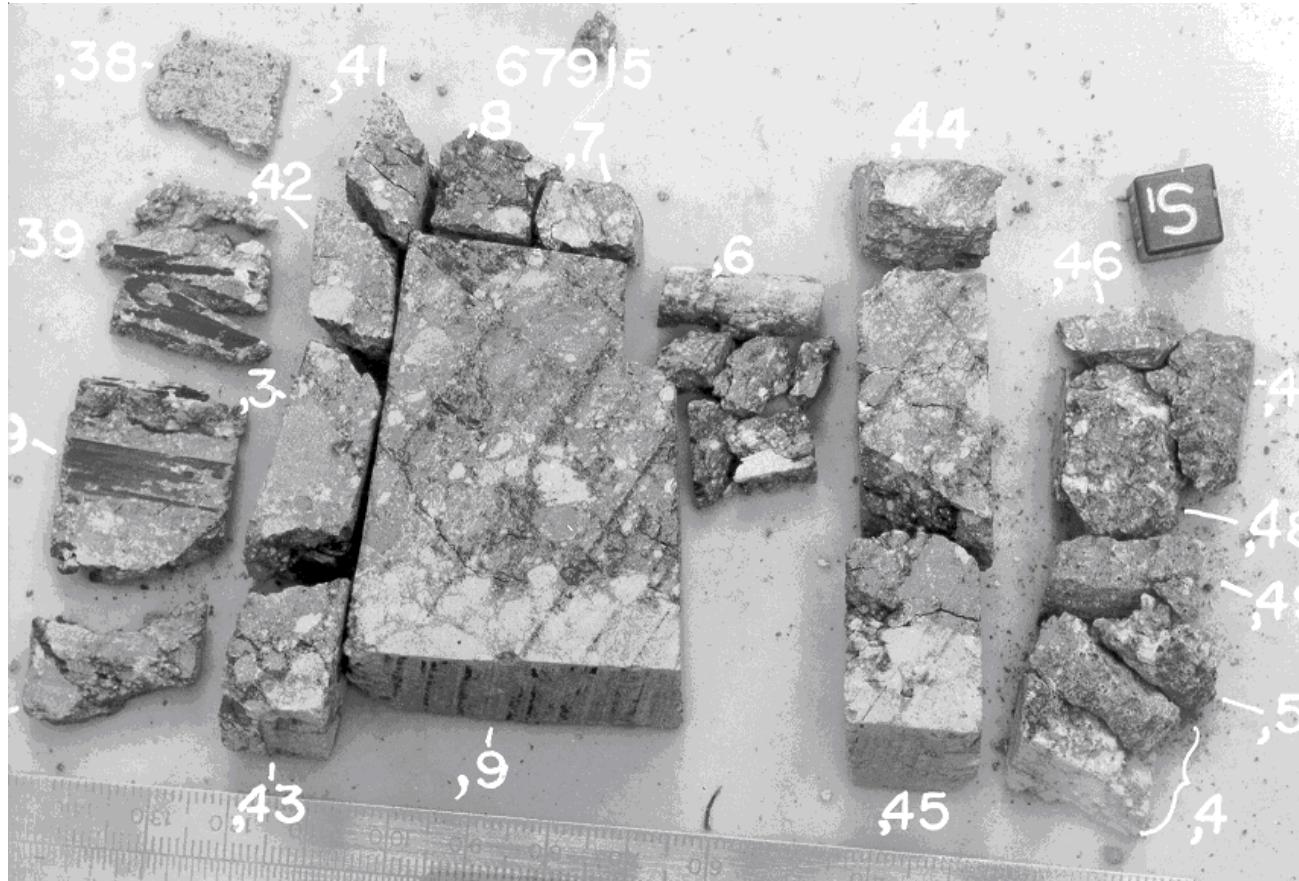
technique: (a) combined "microchemical", (b) ave.



*Figure 15: Second slab (,223) cut from 67915,11. NASA S79-33377. Thickness of slab about 1 cm. The line represents the planned cut in 1997, to prepare a large end piece for display at the Smithsonian. This third slab (,11) has not been studied.*



Figure 16:  
Sawn surface  
of 67915.11  
showing saw  
marks. Note  
large white  
clast (WB  
lithology?).  
Cube is 1 cm.  
NASA photo  
S79-33376.



Figures 17 and  
18: Group  
photos of pieces  
cut from first  
slab. NASA S72-  
53858 and  
53924. Small  
cube is 1 cm.

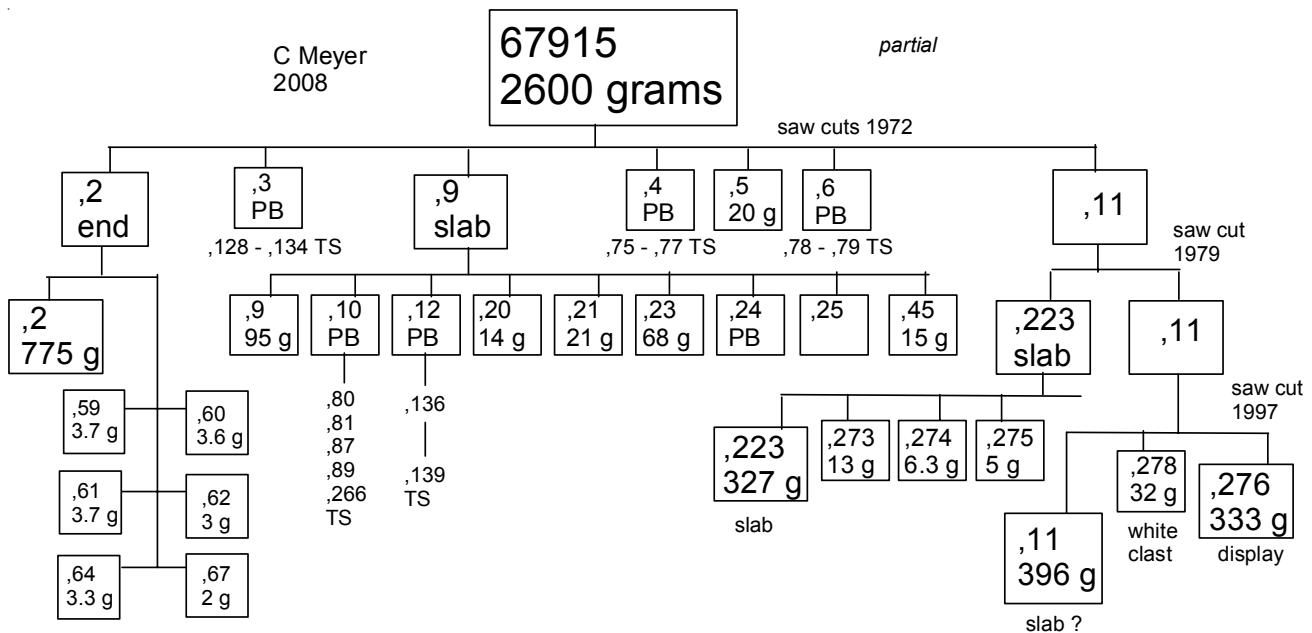
67915, 11



Figure 18: Sawn surface of 67915, 11. Photo number S79-32232. Scale is metric.



Figure 20: Sawn surface of slab 67915, 223. Photo number S79-33378. Cube is 1 cm.



*Note: This is only a partial diagram - see Taylor and Mosie for complete diagram.*

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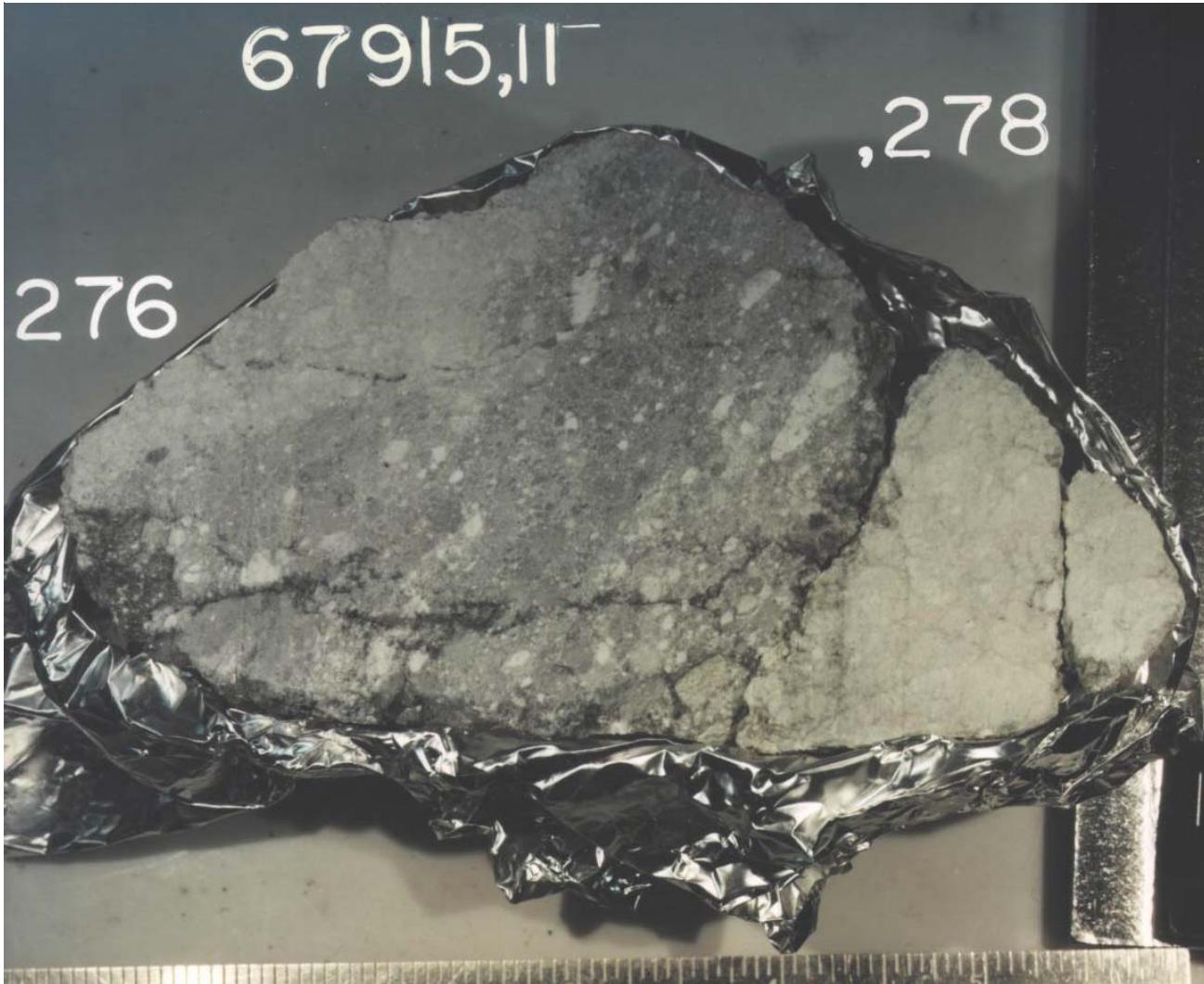
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*Figure 21: Sawn surface of end piece of 67915 used for display at Smithsonian. The white clast was preserved as ,278. NASA S96-09092. Scale is metric.*



*Figure 22 : Sample 67915 showing external surface and saw cut, ready for display at US National Museum, Smithsonian Institution, Washington DC.*

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