76015

Vesicular Micropoikilitic Impact Melt Breccia

2819 grams

Figure 1: Exposed surface of 76015. Note the micrometeorite craters and broken vesicles. Cube is 1 cm. NASA S73-18777B. Note deep "pencil holder" vug near center this face.

Introduction

Sample 76015 was chipped off of the top corner of Block 5 of the big boulder at Station 6 (Wolfe et al. 1981). It is a sample of lithologic unit B of the big boulder and is similar in color (green-grey) and texture to 76215 spalled from the top of adjacent boulder half.

One surface of 76015 was protected from micrometeorite bombardment and developed a thick patina from glass splashes on opposing, adjacent boulder surfaces. The deep vugs and good photographic documentation allow study of direction of micrometeorite bombardment.

location of large porous clast

Figure 2: Exposed surface (left) and partially protected surface (top, center) of 76015 showing thick patina. Cube is 1 cm. NASA S73-18773.

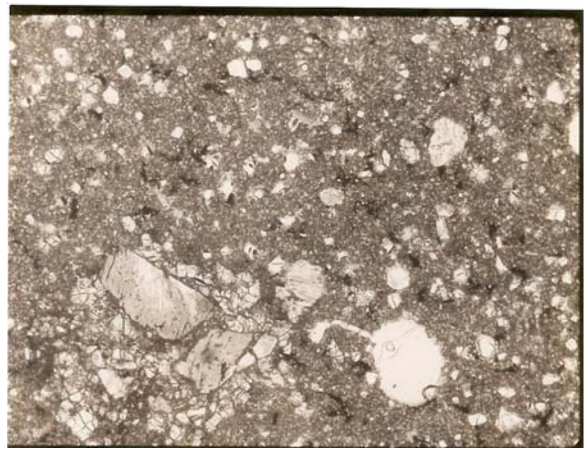


Figure 3: Low magnification photo of thin section of 76015 showing crystalline matrix.

Figure 4: Close-up photo of exposed surface showing numerous micrometeorite craters - some glass-lined, with obvious spall zones surrounding pits. Scale is in mm on left. NASA S87-28994.

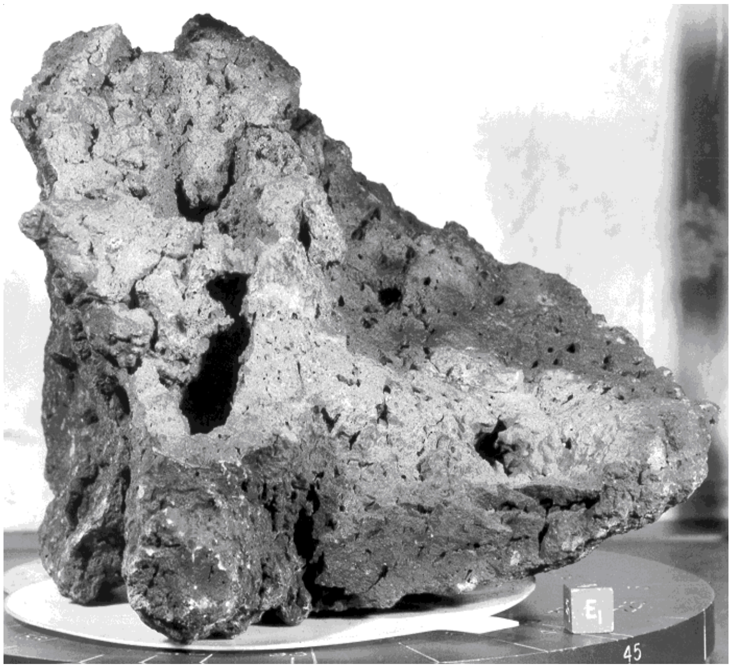


Figure 5: Freshly broken surface of 76015 showing large vugs and vesicles. Cube is 1 cm. NASA S73-18768B.

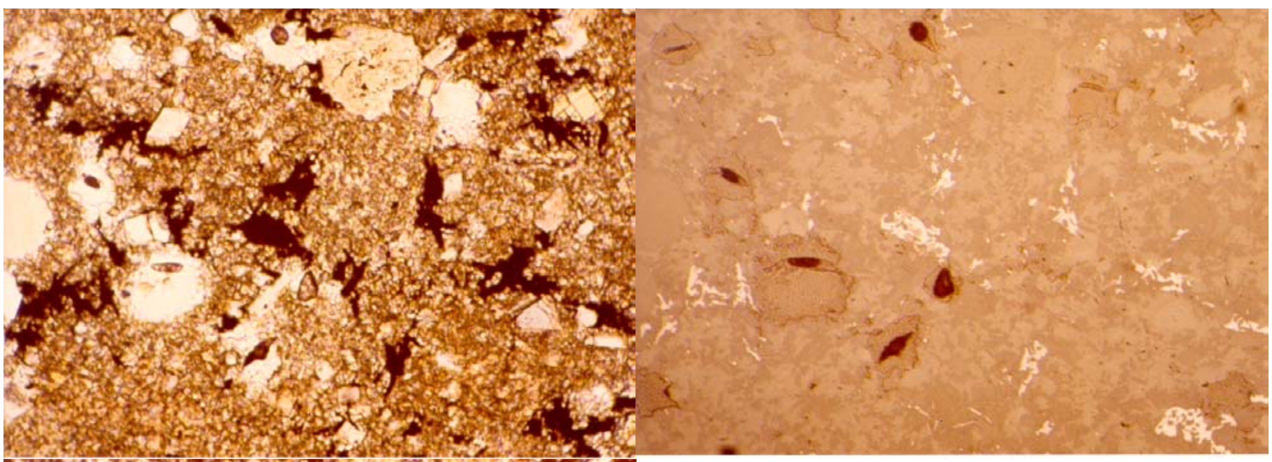
The crystallization age of 76015 is ~3.9 b.y. and it has been exposed to cosmic rays for ~17.5 m.y.

Petrography

Sample 76015 is a very vesicular, crystalline-matrix breccia with <0.1 mm to 5 cm long irregular vesicles that compose about 20% of the rock by volume (figures 1-4). Some of the vugs and cavities are quite large (figure 5).

Simonds (1975) describes the poikilitic matrix of 76015 as a continuous network of interlocking pigeonite oikocrysts enclosing tabular plagioclase (10-50 microns) and rounded olivine chadocrysts. Small amounts of small augite grains (20 mcirons) are found both within the pigeonite and between grains.

a) c)



b)

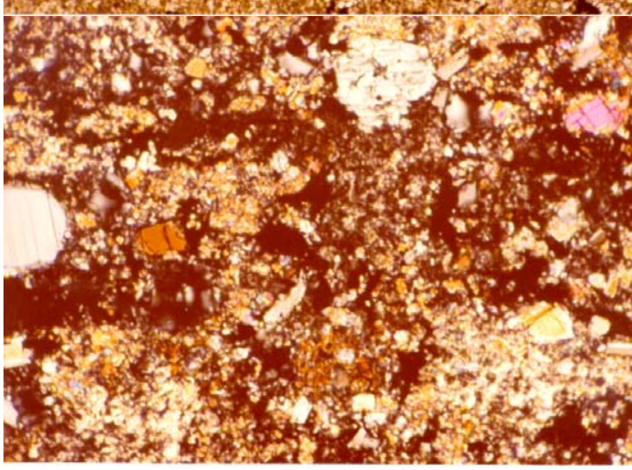


Figure 6: a) Plane-polarized light photomicrograph of thin section of 76015,9, b) cross-polarized light and c) reflected light - all same area. Field of view is about 1.2 mm. NASA S79-27396, 397, 395 respectively. Note the poikilitic texture, especially ilmenite.

Both poikilitic ilmenite and armalcolite grains up to 200 microns long, with spinel and rutile lamellae, are concentrated between the pyroxene oikiocrysts (figure 3 and 6).

The modal mineralogy of the matrix is about 50% plagioclase, 40% low-Ca pyroxene, with minor amounts of olivine, high-Ca pyroxene, ilmenite, armalcolite and metallic iron. Mineral and lithic clasts make up about 5-15% of the rock (Simonds 1975). They are predominantly granoblastic or poikilitic in texture with 70-80% plagioclase and often appear partially "digested."

Blandford et al. (1974) studied the thick patina on 76015, finding that it is made of glass splashes.

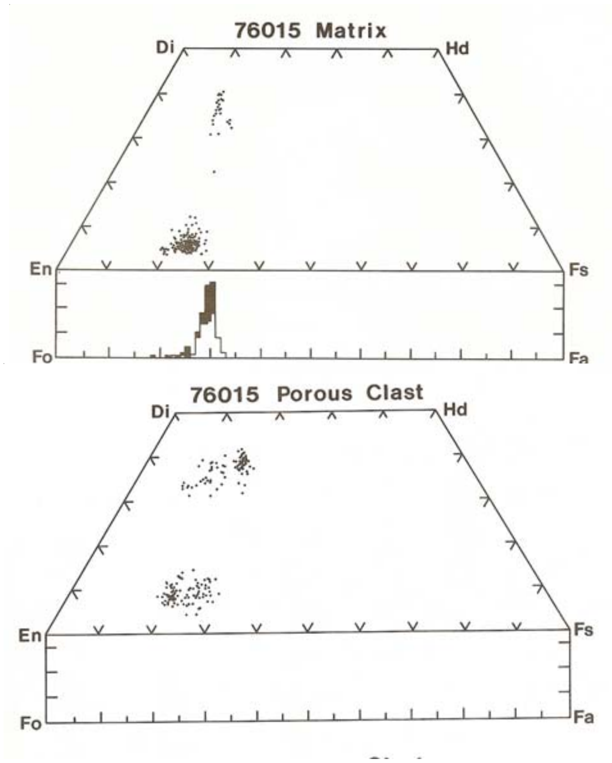


Figure 7: Pyroxene and olivine composition in matrix of 76015 and porous clast (Phinney 1981).

Wentworth et al. (1999) found the patina on 76015 was due to "space weathering".

Vugs in 76015 and 76215 contain euhedral crystals of troilite and metallic iron with crystal growth steps (Carter et al. 1975). Phinney (1981) reported that large apatite crystals are found to be doubly terminated and loosely adhering to cavity walls. Large beta-cristobalite crystals and wiry and dendritic metallic Cu are also reported in these cavities!

Spudis and Ryder (1981) summarize the arguments that this boulder is from the melt sheet or ejecta blanket from the Serenitatis impact event. Simonds et al. (1976) and Onorato et al. (1976) provide a comprehensive thermal model for the lithification of impact melt breccias based on their detailed study of the textures of samples from the station 6 big boulder.

Mineralogy

Pyroxene: There is more low-Ca pyroxene than high-Ca pyroxene in 76015 (figure 7). Takeda et al. (1976) studied the crystal structure.

Olivine: Phinney (1981) reports that olivine in 76015 is Fo_{70}.

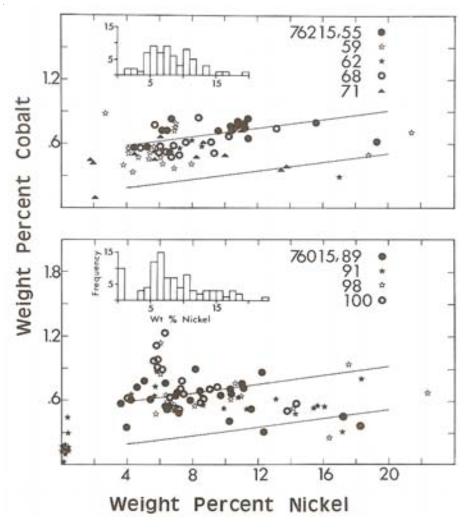


Figure 8: Ni and Co content of metal grains in 76015 and 76215 (Misra et al. 1976).

Plagioclase: Plagioclase in the matrix is An_{85}, while clasts are An_{95}.

Metallic Iron: Misra et al. (1976) found the Ni and Co composition of iron grains in 76015 and 76215 were of similar distribution (figure 8).

Significant Clasts

Large Porous Clast: ,42

Simonds (1975) and Phinney (1981) describe a large (2 cm) porous basalt clast in 76015 with intersertal texture (figure 9). The composition of pyroxene in this clast is shown in figure 7b. There is no olivine and plagioclase is An_{80}. Otherwise, this clast has not been studied as an entity.

Chemistry

Rhodes et al. (1974), Hubbard et al. (1994) and Wiesmann and Hubbard (1975) found that four seperate splits of 76015 were similar to one another and to the matrix of the other samples of this big boulder (figure 10). Higuchi and Morgan (1975), Palme et al. (1978) and Norman et al. (2002) determined siderophile and volatile elements (Ni, Ir and Au are very high in analysis by Palme). The large porous clast has apparently not been analyzed.

Analyses for carbon and sulfur in 76015 are given in Gibson and Moore (1974) and Phinney (1981). Analyses for U, Th and Pb by Silver (1974) are given in Phinney (1981).

Figure 9: Photomicrograph of thin section 76015,91 showing texture of "porous clast". Field of view 5 mm.

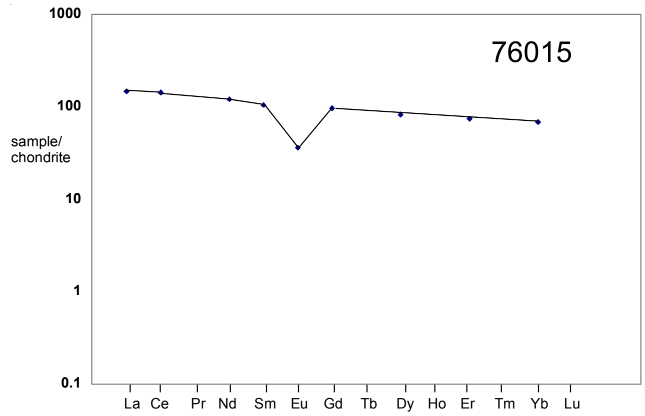


Figure 10: Normalized rare-earth-element diagram for 76015 (data by IDMS). This pattern is typical for all samples of station 6 boulder.

Radiogenic age dating

Cadogen and Turner (1976) used the Ar/Ar plateau technique to get the age of 76015. They studied both the martix and two plagioclase separates getting 3.93 b.y., 3.92 b.y. and 3.96 b.y. respectively. Nyquist et al. (1974) reported Rb and Sr isotope studies.

Cosmogenic isotopes and exposure ages

Crozaz et al. (1974) reported a ^{81}Kr-Kr exposure age of 17.5 ± 0.5 m.y. Cadogen and Turner (1974) determined 14 m.y. for matrix and 20 m.y. for plagioclase using ^{38}Ar. This is mysteriously less than the value from 76315 (22 m.y.), possibly due to some erosional effect.

Vugs

76015 has numerous vugs and cavities with well-known lunar orientation (Wolfe et al. 1981). Morrison and Zinner (1975) used two of these cavities to study the possible directional variations in the flux of micrometeorites and solar flare particles. Studies by Morrison and Zinner (figure 12) and by Blanford et al. (1975)(figure13) found no evidence for aniotropy in the flux of micrometeorites between the north direction and the eclyptic. However, Morrison and Clanton (1979) have apparently determined some directional differences and an elongated vug (that would have made a great pencil holder) has been prepared for additional studies (figures 22 and 23).

Other Studies

Crozaz et al. (1974) reported Kr isotopes while Hohenberg et al. (1980) reported the Xe isotopes. Bogard (1974) also collected data on rare gases.

Crozaz et al. (1974) studied cosmic ray tracks in 76015. The solar flare track exposure age (18 m.y.) is found to be concordant with the galactic proton age (17 m.y.) – but these ages appear young when compared with other exposure ages for this boulder.

Wentworth et al. (1999) studied the patina on 76015 due to "space weathering".

Pearce et al. (1974) and Gose et al. (1978) have carefully studied the remanent magnetization of 26 subsamples of the big boulder, including 76015. The direction of magnetization of clast-free samples from unit B (including 76015) cluster fairly well after partial demagnetization by alternating field scrubing. Gose et al. proposed that the natural remanent magnetization of impact melt breccias is the vector sum of two magnetization, a pre-impact magnetization combined with a partial thermoremanence acquired during breccia lithification.

Delano (1976) experimentally determined the depth-temperature phase relations for 76015 (figure 14), but these may not be relavent because the sample appears to be a mixture of components.

Charette and Adams (1977) have compared the refectance spectra of 76015 with other samples, but one wonders about the effects of patina on specta obtained from orbit. Specta of the thick patina on surfaces of 76015 and 76215, should be compared with spectra of fresh brokne surfaces.

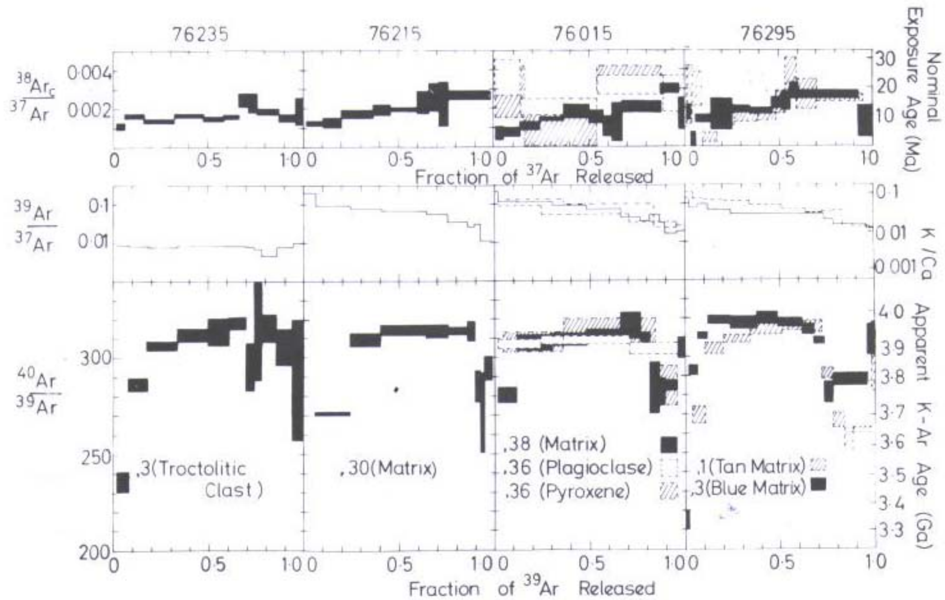


Figure 11: Argon release diagrams of 76015 etc (Cadogen and Turner 1976).

Summary of Age Data for 76015

	Ar/Ar
Cadogen and Turner 1976	3.93 ± 0.04 b.y.
	3.92 ± 0.04
	3.96 ± 0.06

Caution: Decay constant - -

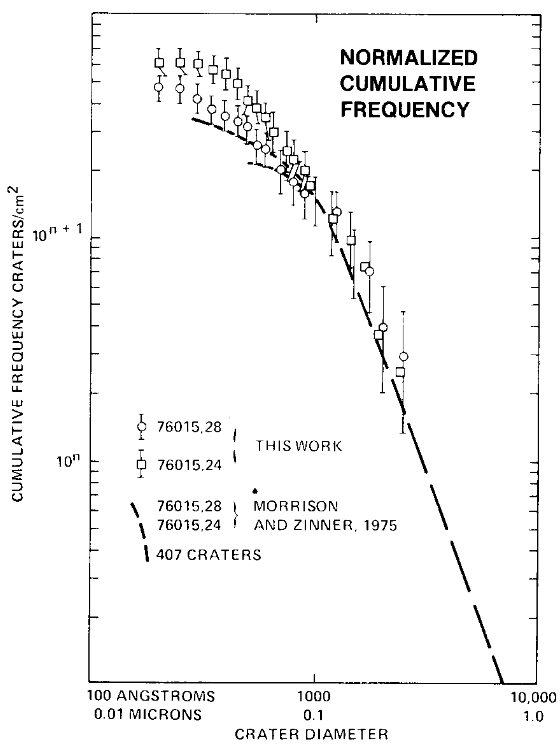


Figure 12: Micrometeorite crater density distribution for 76015 extended to smallest size (from Morrison and Clanton 1979).

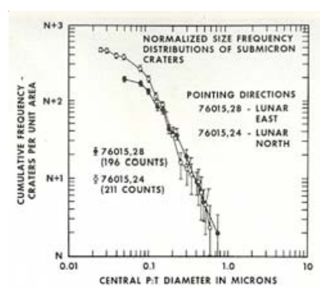


Figure 13: Micrometeorite density distribution for 76015 (Blandford et al. 1974).

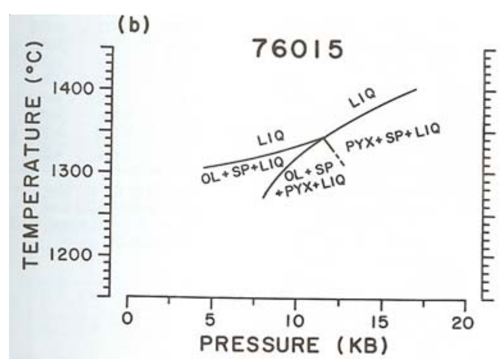


Figure 14: High pressure phase relations for 76015 determined by experiments by Delano (1977).

Table 1. Chemical composition of 76015.

reference	Rhodes74					Hubbard 74 Wiesmann75					Palme78	Higuchi75		Norman2002		Silver 74 Phinney1981	
weight	,25	,37	,41	,64		,25	,37	,41	,64								
SiO2 %	46.16	46.38	46.38	46.59	(b)						46.52		(b)	45.6	(f)		
TiO2	1.52	1.55	1.53	1.48	(b)						1.54		(b)	1.47	(f)		
Al2O3	17.17	17.78	17.77	18	(b)						17.86		(b)	18.5	(f)		
FeO	9.81	9.65	9.07	9.1	(b)						8.08		(b)	8.2	(f)		
MnO	0.13	0.13	0.12	0.12	(b)						0.11		(b)	0.12	(f)		
MgO	13.03	12.4	12.67	12.43	(b)						12.57		(b)	11.9	(f)		
CaO	10.77	11.13	11.11	11.1	(b)						10.99		(b)	11.1	(f)		
Na2O	0.7	0.72	0.69	0.75	(b)	0.52	0.53	0.52	0.53	(a)	0.68		(b)	0.67	(a)		
K2O	0.26	0.26	0.26	0.29	(b)	0.27	0.28	0.27	0.29	(a)	0.24		(b)	0.27	(a)		
P2O5	0.27	0.29	0.29	0.28	(b)						0.28		(b)				
S %	0.09	0.06	0.08	0.08	(b)						*0.39*		(b)				
sum																	
Sc ppm											16.7			17.2	(e)		
V														43	(e)		
Cr						1316	1099	1188	1226	(a)	1300			1298	(e)		
Co											90.2			22.8	(e)		
Ni											1140	135		190	(e)		
Cu														11.8	(e)		
Zn												2.8		14.7	(e)		
Ga														5.2	(e)		
Ge ppb												164	(d)				
As																	
Se												76	(d)				
Rb						6.41	6.67	6.57	7.46	(a)		5.77	(d)	7.3	(e)		
Sr						172	178	177	174	(a)	180		(c)	191	(e)		
Y											112		(c)	123	(e)		
Zr						490	515	507	484	(a)	480			533	(e)		
Nb														35.9	(e)		
Mo																	
Ru														19.1	(e)		
Rh																	
Pd ppb														19.4	(e)		
Ag ppb												1.02	(d)				
Cd ppb												3.2	(d)				
In ppb																	
Sn ppb																	
Sb ppb												1.02	(d)				
Te ppb												2.7	(d)				
Cs ppm												0.266	(d)	0.26	(e)		
Ba						348	362	358	354	(a)	340		(c)	344	(e)		
La							34.3	33.4	29.9	(a)	33.8		(c)	29.8	(e)		
Ce						83.3	85.9	84.9	78.4	(a)	89.2		(c)	77.4	(e)		
Pr														10.47	(e)		
Nd						52.8	54.4	54	49.3	(a)	54		(c)	48.4	(e)		
Sm						14.9	15.3	15.2	14	(a)	14.11		(c)	13.8	(e)		
Eu						1.94	2.02	1.99	1.97	(a)	1.99		(c)	1.9	(e)		
Gd						18.7	19	18.9	17.6	(a)	18.1		(c)	15.3	(e)		
Tb											3.04		(c)	2.72	(e)		
Dy						19.5	20	19.9	18.3	(a)	19.9		(c)	17.1	(e)		
Ho														3.7	(e)		
Er						11.5	11.8	11.7	10.9	(a)				10.54	(e)		
Tm																	
Yb						10.6	11	10.8	10	(a)	11.43		(c)	9.47	(e)		
Lu						1.58		1.3	1.5	(a)	1.55		(c)	1.37	(e)		
Hf						12.4	12.7			(a)	11.81		(c)	10.56	(e)		
Ta											1.62		(c)	1.53	(e)		
W ppb														0.56	(e)		
Re ppb												0.315	(d)	1.01	(e)		
Os ppb																	
Ir ppb											*43*	3.41	(d)	10.7	(e)		
Pt ppb														23	(e)		
Au ppb											*18*	1.89	(d)				
Th ppm						5.44	5.64	5.56	5.41	(a)	4.18			5.61	(e)	5.11	(a)
U ppm						1.46	1.59	1.96	1.48	(a)	1.2	1.49	(d)	1.47	(e)	1.5	(a)

technique: (a) IDMS, (b) XRF, (c) INAA, (d) RNAA, (e) ICP-MS, (f) fused-bead, e-probe

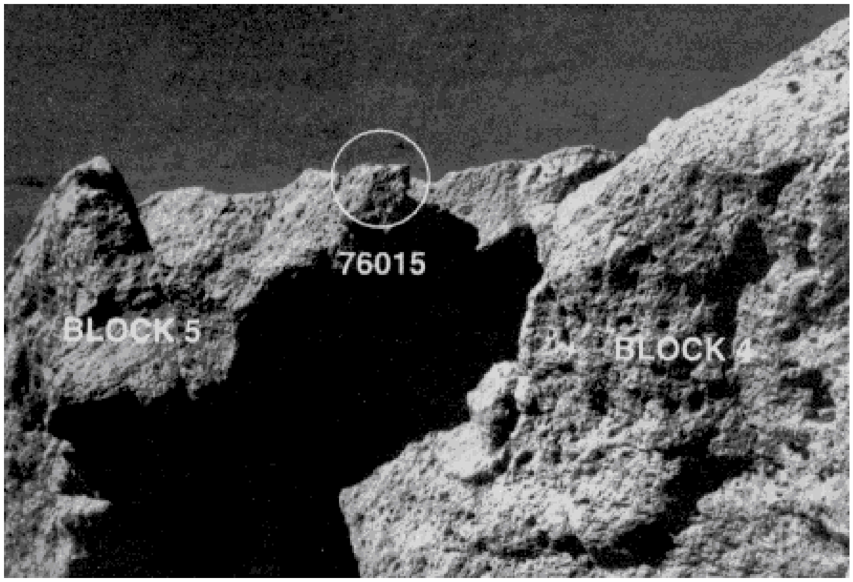


Figure 15: Location of 76015 on top of block 5 of station 6 boulder. AS17-14-21411.

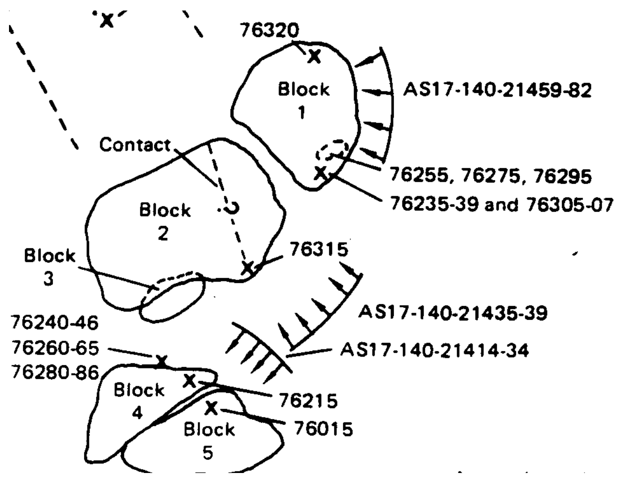


Figure 16: Sketch of large boulder at Apollo 17, Station 6 showing sample numbers and photograph numbers (taken from Wolfe et al. 1981).

Processing

A slab (,20) and a column were cut from the center of this rock (figures 17 and 21). A second slab and column (,148) were cut at right angles to the first slab (figures 18-20). The column (,148) was cut such as to capture the deep "pencil holder" vug which was cut and quartered to open up the inside for J.A. McDonnell (figure 22 and 23). There are 36 thin sections of 76015.

A large sample of 76015 is on public display in Germany (figure 24).(see nice essay by Eric Jones)

Meyer (1994) and Phinney (1981) included discussion of 76015 in their catalogs.

References for 76015

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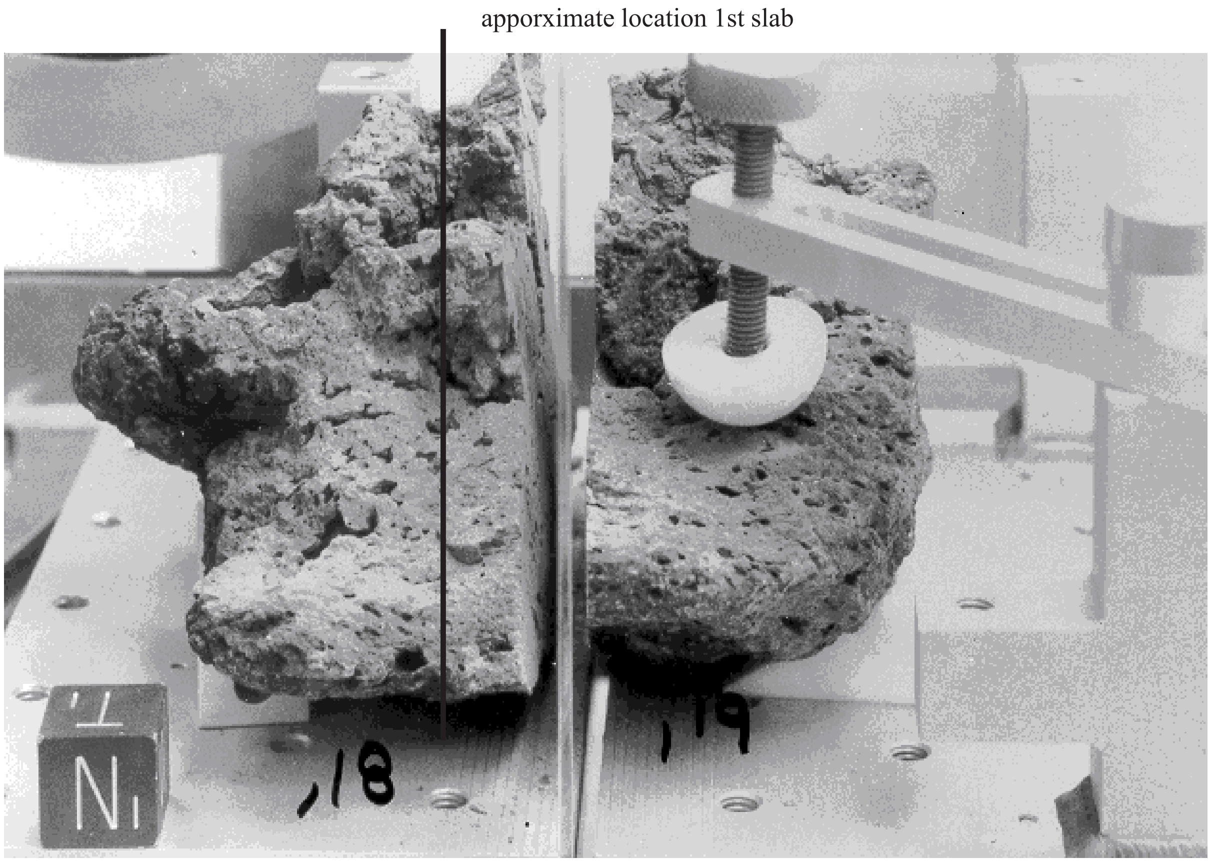


Figure 17: Processing photo for 76015. S76-21672. Cube is 1 inch.

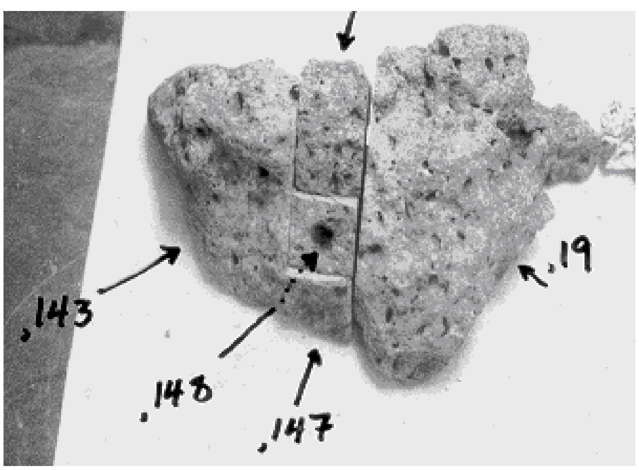


Figure 18: Processing photo for 76015,19 showing position of second slab and column ,148 with deep vesicle "pencil holder".

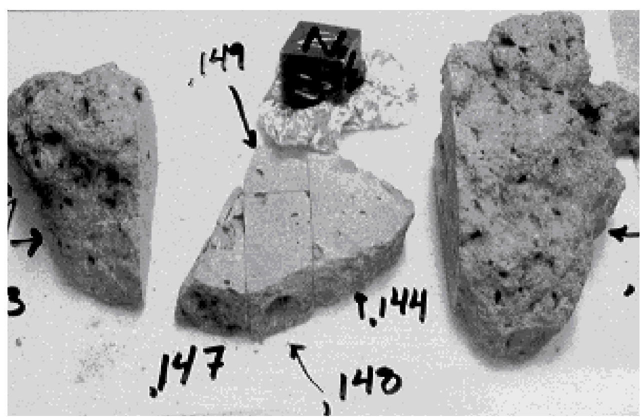


Figure 19: Second slab cut from 76015. Cube is 1 inch.

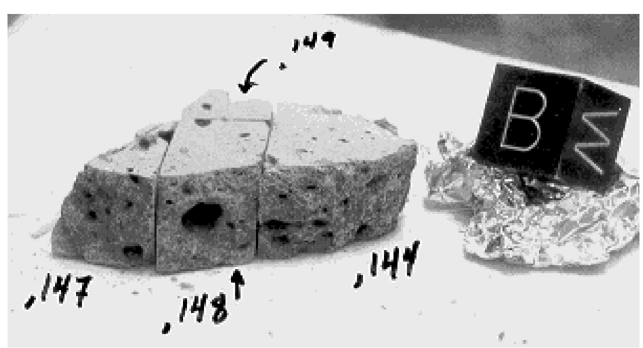


Figure 20: Second slab cut from 76015. Cube is 1 inch.

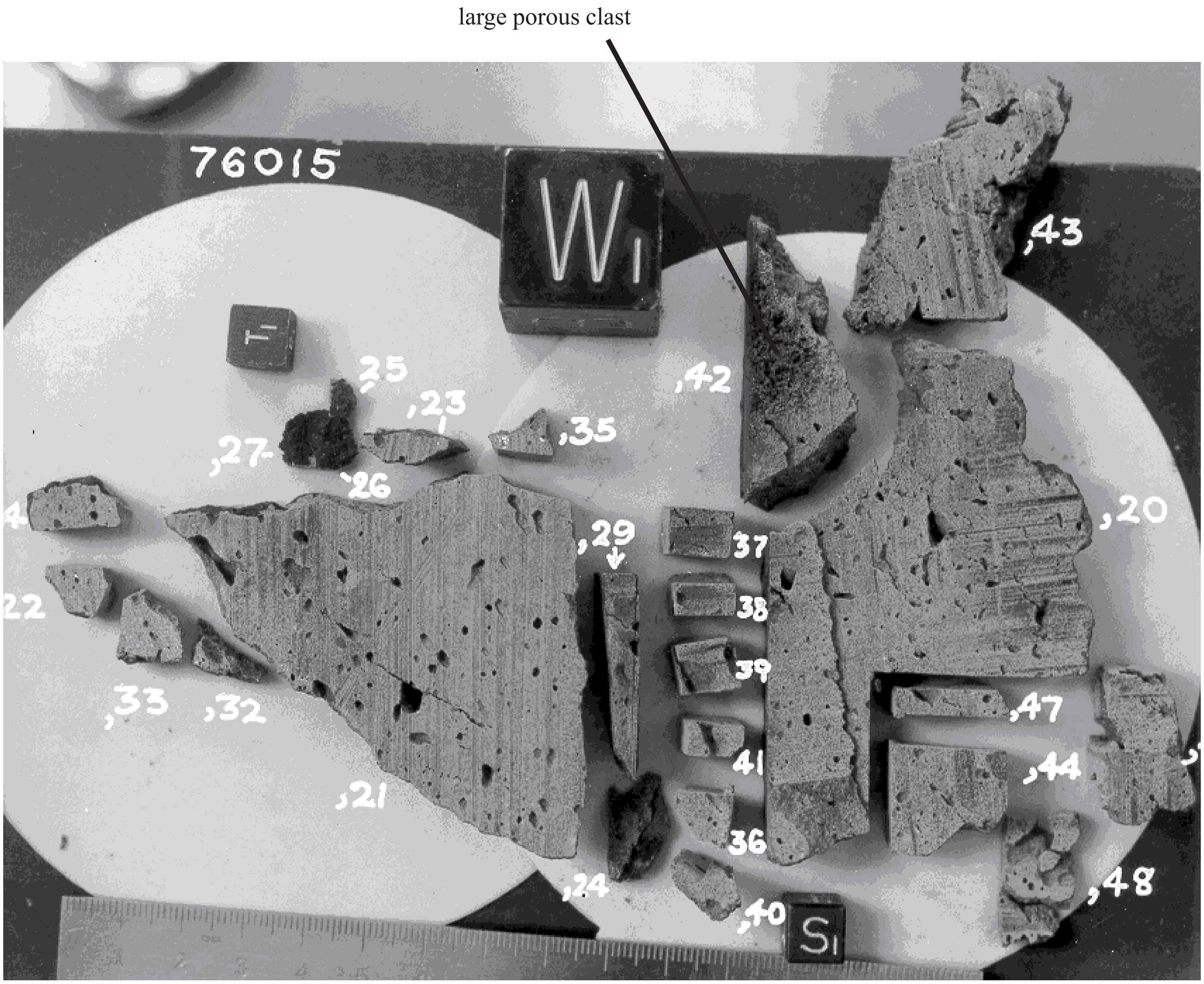
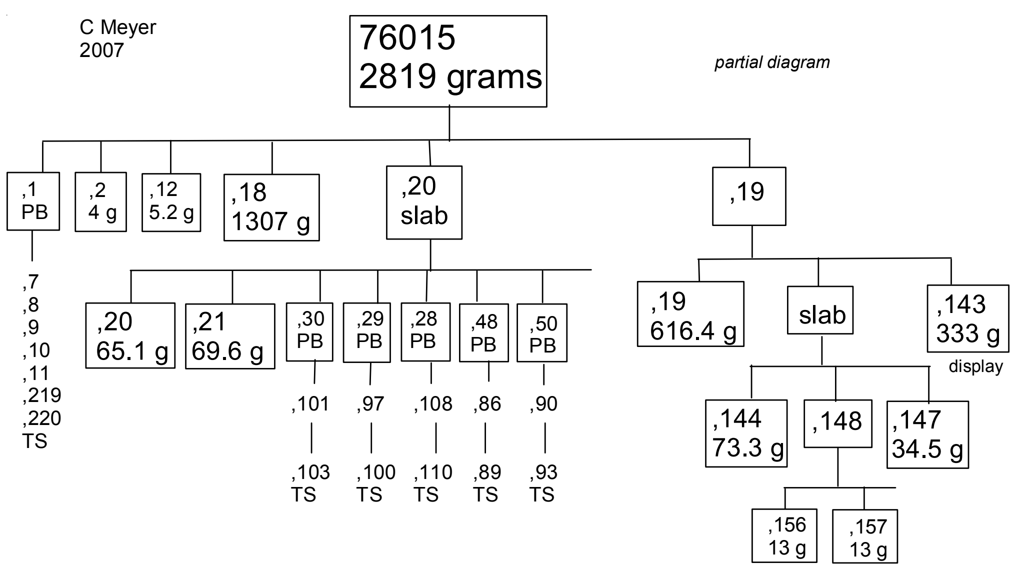


Figure 21: Exploded parts diagram of thin slab (,20) cut from 76015 (see flow diagram). Small cube is 1 cm; large is 1 inch. NASA S74-15090.



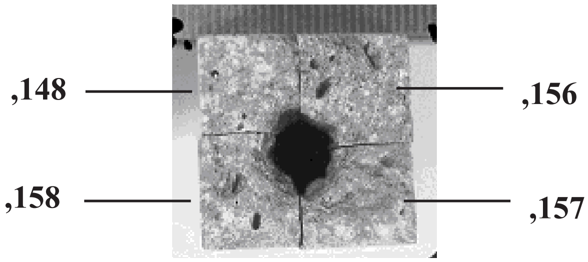


Figure 22: Surface photo of deep "pencil holder" vug on 76015,148. Scale in mm at top. Sample is about 2.3 cm across.

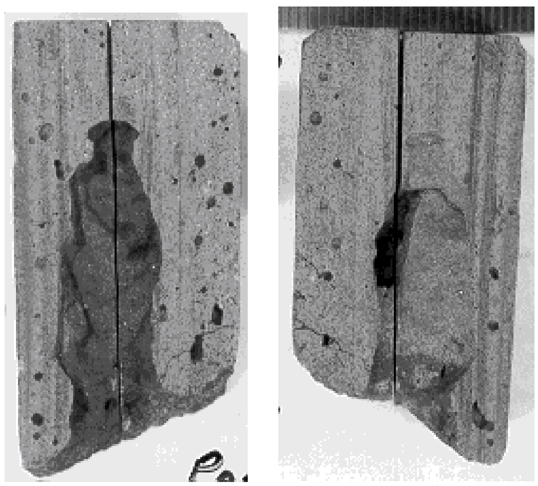


Figure 23: Lengthwise splits of 76015,148. Scale is mm at top. Left to right samples are ,157, ,156, ,148 and ,158.

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Figure 24: Three views of public display sample 76015,143 showing micrometeorite cratered surface, protected patina from within large vug and sawn surface showing vuggy interior. NASA S87-34949, 948 and 860. About 4 inches high.

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