60019

Ancient Regolith Breccia

1887 grams

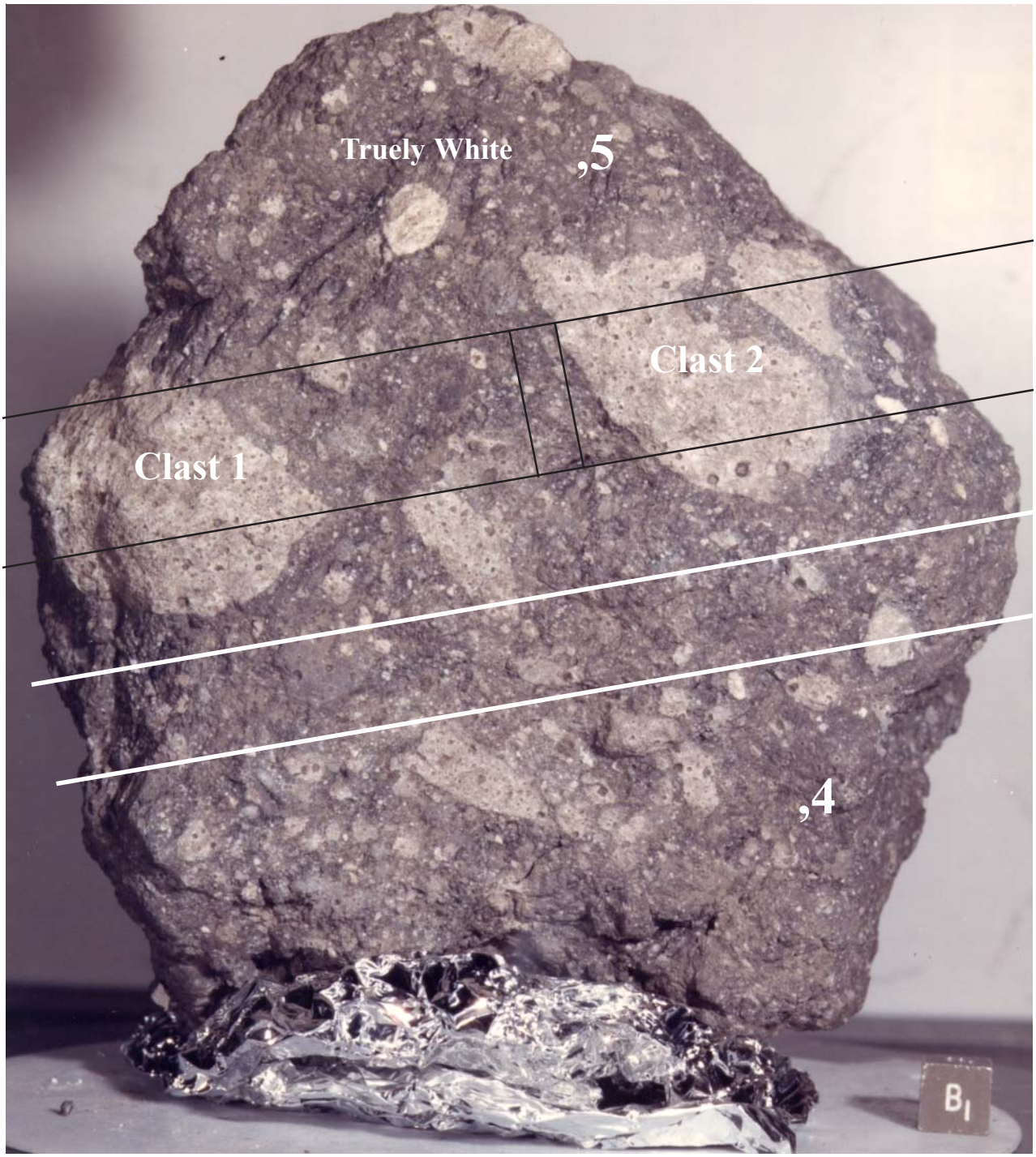


Figure 1: Photo of top surface of lunar breccia 60019. Note the abundance of micrometeorite craters. S72-42574. Cube is 1 cm. Approximate position of first slab and column indicated by thin black lines and position of two additioanl slabs by white lines.

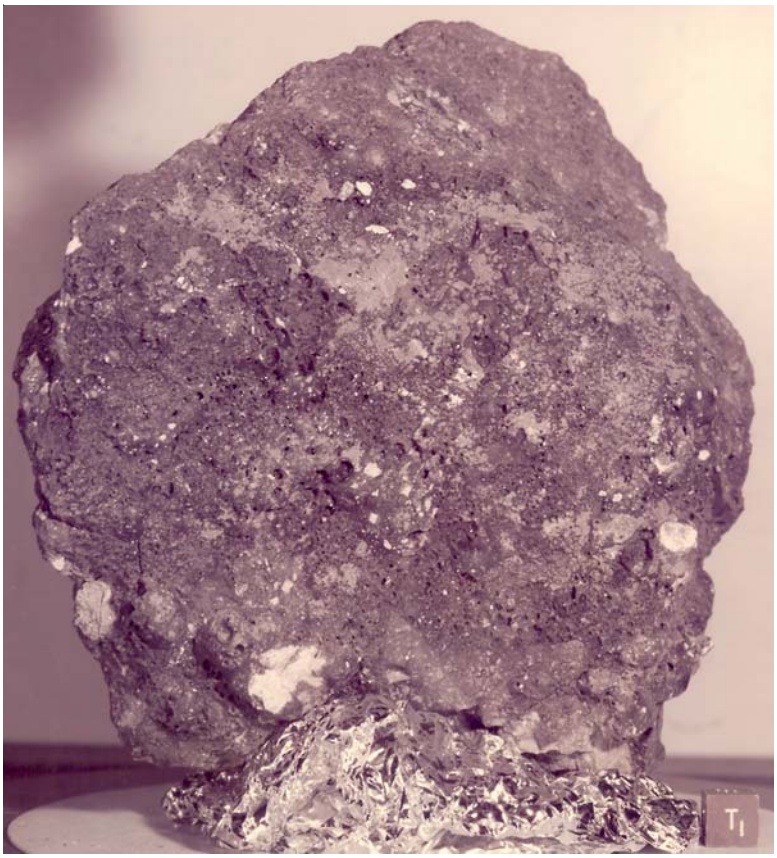


Figure 2: Photo of bottom surface of 60019, showing coating with vesicular glass. S72-42578. Cube is 1 cm. for scale.

Introduction

Lunar sample 60019 is a dark glassy-matrix breccia with several large white clasts. It is found to have high $^{40}Ar/^{38}Ar$ and excess fission Xe, so it has been classified as an "ancient regolith breccia" (McKay et al. 1986), although there is no date given.

One side (the top) of 60019 has numerous micrometeorite craters (figure 1). The other side of 60019 was covered with a thick vesicular glass coat and apparently protected from meteorite bombardment (figure 2). It may have been a glass-covered bomb.

Petrography

Lunar sample 60019 is a clast-rich coherent regolith breccia (Ryder and Norman 1980, Fruland 1983). The maturity is low (Is/FeO = 0.2 (McKay et al. 1986)). However, Bernatowitz et al. (1978) and McKay et al. (1986) found it to have high concentrations of rare gases, with excess ^{129}Xe.

McKay et al. (1986), Simon et al. (1988), Korotev (1996), Takeda et al.(1988) and Pieters and Taylor (1989) have all given descriptions of the matrix of 60019. Simon et al. noted that it contained brown glass.

Mineralogy

Mineral compositions (plagioclase, pyroxene and olivine) can be found in Takeda et al. (1988) and in Pieters and Taylor (1989). Trace element analyses for plagioclase and pyroxene were reported by Steele et

Mineralogical Mode for 60019
(from Simon et al. 1988)

	20-90 micron	90-1000 micron
Matrix < 20 micron	50.9 %	
Mare basalt	0	0.7 %
KREEP basalt	0	0
Feldspathic basalt	0.1	0
Plutonic rock frag.	0	6.2
Granulite	0	3.4
Poik. rocks	1	6.8
Impact melts	0.3	7.2
Regolith brec.	0	1.5
Agglutinate	0.2	1.7
Plagioclase	6.3	6.1
Olivine	0.5	0.2
Pyroxene	1	0.4
Opaques	0	0
Glass	4.4	4.5

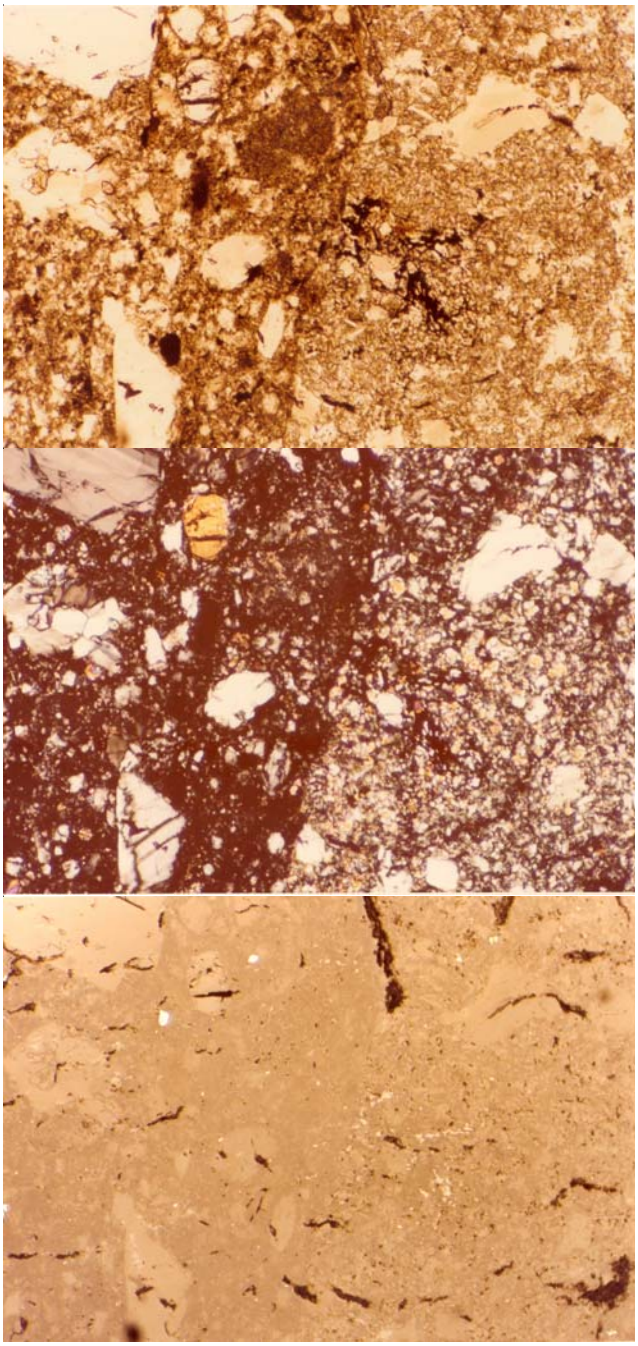


Figure 3: Photomicrographs of thin section 60019,82 (field of view 1.3 mm). Top is plane polarized S79-27699; middle is crossed polarized S79-27700; bottom is reflected light S79-27698. A portion of clast 1 (WC-1) is on the right, matrix on the left.

al. (1980) and Takeda et al. (1988). A minor amount of "rust" is reported by Hunter and Taylor (1981).

Significant Clasts

60019 has numerous large white clasts which were nicely mapped and described by Galindo (1985). Takeda et al. (1987, 1988) have reported on several of the smaller clasts (termed WF-1, WF-4 and WC-1). They are feldspathic and poikilitic in texture. In addition, Galindo (1985) identified two small basalt clasts.

Pieters and Taylor (1989) have also studied small clasts in 60019 (by combined mineralogy and spectroscopy). They were mostly feldspathic "impact melts", with various proportions of minerals (termed clasts A, B, D, G and R).

Clast 1 (WC-1)(about 3 cm)

According to Ryder and Norman (1980) the large white clast seen in figures 1 and 12 has a poikilitic texture and is made up of "granoblastic impactites, cataclastic anorthosite and aluminous basalt". Rose et al. (1975) reported the chemical composition (table 1), which does not appear to be greatly different from that of the matrix of the bulk breccia. Takeda et al. (1988) reported pyroxene and plagioclase compositions. Thin section numbers of this clast include ,77 ,78 ,81 ,82 and ,207. A portion of this rock can be seen in figure 3.

Clast 2 (WC-2)(about 4 cm)

Figures 1 and 8 show that this clast is probably several clasts adjacent to each other. They have not been studied.

Clast III:

See figure 17. TS ,79 ,80

Clast IV:

See figure 17. TS ,83 ,84

Ba-2: Basalt

A small basalt clast is illustrated in figures 7 and 12. Takeda et al. (1987) reported analyses of the pyroxene (figure 8) and plagioclase (An_{95-98}) in this clast.

Truly White

See figure 1. This 5 mm truly white clast (dedicated to Paul Warren) on butt end ,5, needs to be studied (by him).

Chemistry

Rose et al. (1975), McKay et al. (1986), Simon et al. (1988) and Korotev (1996) obtained similar results (table 1). The glass coating is also similar (figure 9).

Figure 5: Thin section of clast 1, 60019. Field of view is 3 mm.

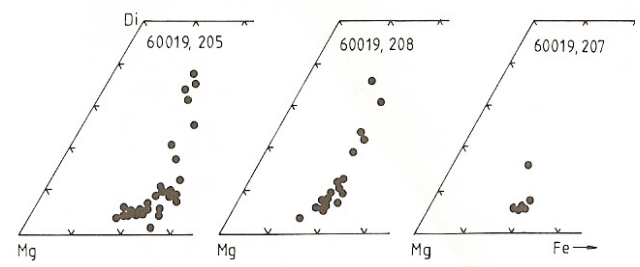


Figure 6: Pyroxene composition of white clasts in 60019 (from Takeda et al. 1988). Analyses of ,207 are from WC-1.

Moore and Lewis (1976) reported high carbon and nitrogen contents for the matrix of 60019 (162 ppm and 56 ppm) and one clast (110 ppm and 28 ppm) respectively (figure 10). It also has high Ni, Ir and Au (Simon et al 1988). All this data indicates that 60019 should be considered as a soil breccia.

Other Studies

Rare gases are reported in McKay et al. (1986) and Bernatowitz et al. (1978). This sample has excess ^{129}Xe from extinct ^{129}I., as well as "excess fission Xe" and high ^{40}Ar/^{38}Ar (indicators of implantation of an ancient component).

Processing

Three slabs were cut through the middle of 60019 (see figures 1 and 11). The first slab was cut in 1974 and the other two in 1984 (Galindo 1985). Butt end (,4) fell to pieces (figure 16). There are 43 thin sections of 60019. The study of clasts in 60019 has not been well coordinated. Few have been analyzed and none have been dated.

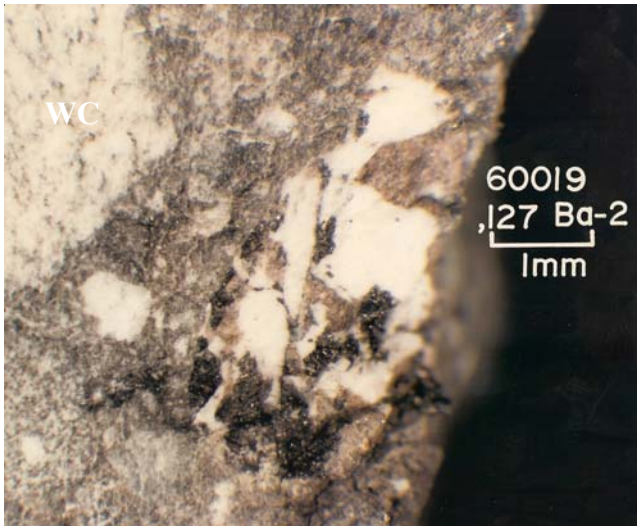


Figure 7: Mare basalt clast Ba-2 in 60019 (see figure 9).

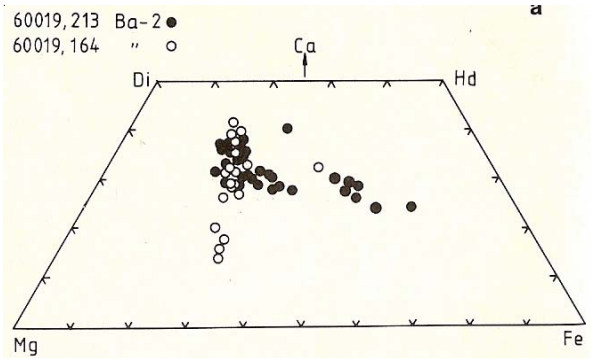


Figure 8: Pyroxene composition in basalt clast Ba-2 in 60019 (Takeda et al. 1977).

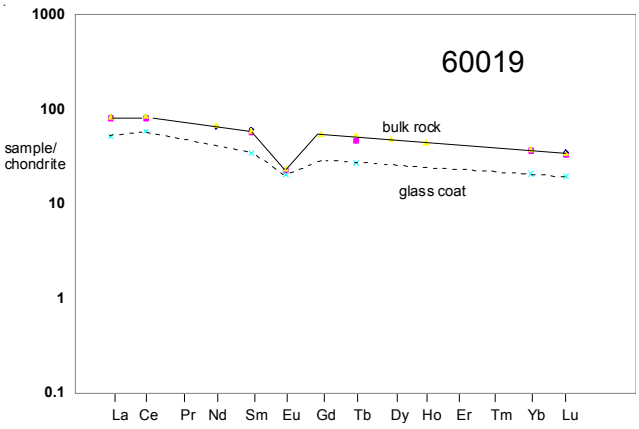


Figure 9: Normalized rare-earth-element diagram for 60019 (data from McKay et al. 1986, Simon et al. 1988, Korotev 1996 and Morris et al. 1986).

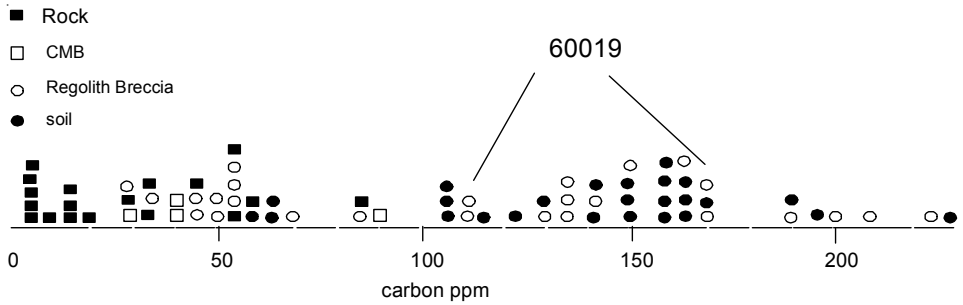


Figure 10: Carbon content of 60019 compared with Apollo 14, 15, 16 and 17 samples.

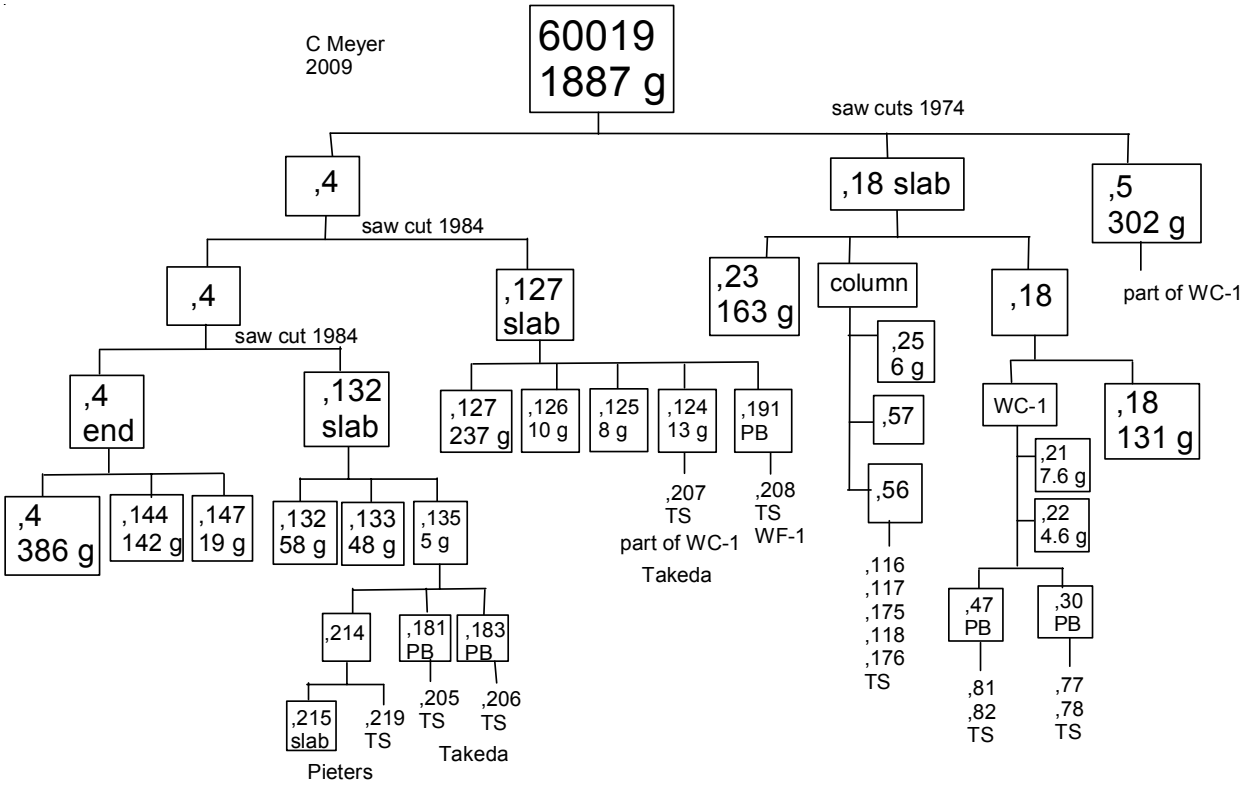
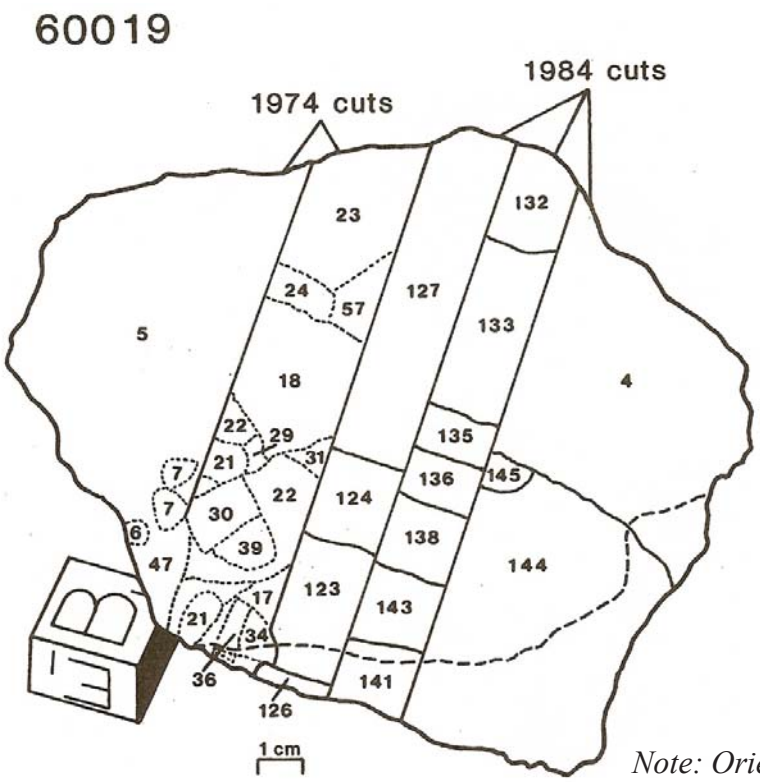


Table 1. Chemical composition of 60019.

reference	Rose75			McKay86	Korotev96	Simon88		See86			Morris86	
weight	*matrix*	*clast 1*						glass	interior		glass	
SiO2 %	45.25	45.26	(b)					44.95	45.25	(c)		
TiO2	0.59	0.77	(b)			0.66	(a)	0.43	0.35	(c)		
Al2O3	26.34	23.15	(b)			27.7	(a)	28.13	26.31	(c)		
FeO	5.3	6.88	(b)	5.32	5.33	5.46	(a)	4.89	5.3	(c)	4.98	(a)
MnO						0.074	(a)	0.1	0.06	(c)		
MgO	6.73	9.5	(b)			6.7	(a)	5.56	6.79	(c)		
CaO	14.93	13.57	(b)	14.9	15	15.1	(a)	15.81	14.93	(c)		
Na2O	0.46	0.48	(b)	0.441	0.475	0.51	(a)	0.45	0.47	(c)	0.46	(a)
K2O	0.14	0.18	(b)			0.152	(a)	0.08	0.14	(c)		
P2O5	0.18	0.27	(b)									
S %												
sum												
Sc ppm	11	11	(b)	8.92	8.7	9.4	(a)				6.15	(a)
V	26	22	(b)			14	(a)					
Cr				782	771	742	(a)				682	(a)
Co	49	45	(b)	27.7	30.3	28.4	(a)				45	(a)
Ni	795	810	(b)	412	439	430	(a)				687	(a)
Cu												
Zn	13		(b)									
Ga	5.1	3.4	(b)									
Ge ppb												
As												
Se												
Rb	3.1	4.2	(b)			2.5	(a)					
Sr	131	136	(b)	176	174	170	(a)					
Y	78	86	(b)									
Zr	266	315	(b)	250	268	260	(a)					
Nb	17	30	(b)									
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb												
Te ppb												
Cs ppm				0.29		0.28	(a)					
Ba	220	320	(b)	191	187	180	(a)				120	(a)
La	20	26	(b)	19.7	18.83	19.8	(a)				12.15	(a)
Ce				51	48.5	51.4	(a)				35.8	(a)
Pr												
Nd				30		31.1	(a)					
Sm				9.06	8.49	8.9	(a)				5.11	(a)
Eu				1.285	1.27	1.35	(a)				1.16	(a)
Gd						10.8	(a)					
Tb				1.68	1.71	1.95	(a)				0.99	(a)
Dy						12.1	(a)					
Ho						2.5	(a)					
Er												
Tm												
Yb	8.2	9.9	(b)	6	5.98	6.2	(a)				3.49	(a)
Lu				0.86	0.81	0.84	(a)				0.48	(a)
Hf				6.75	6.44	6.5	(a)				3.61	(a)
Ta				0.76	0.72	0.77	(a)				0.36	(a)
W ppb												
Re ppb												
Os ppb												
Ir ppb				8.4	11.2	5.5	(a)					
Pt ppb												
Au ppb				9	9	1.4	(a)					
Th ppm				3.35	3.12	3.05	(a)				1.59	(a)
U ppm				0.86	0.86	0.9	(a)				0.68	(a)

technique: (a) INAA, (b) microchemical, (c) elec. Probe



Note: Orientation reversed

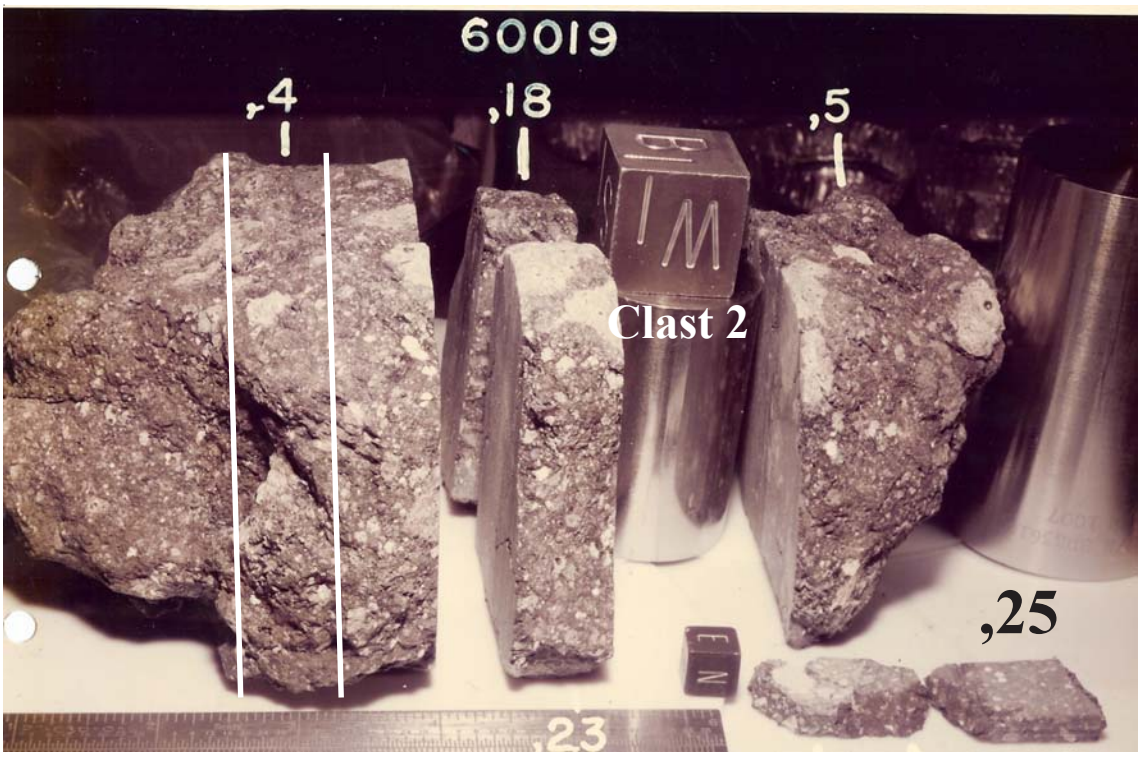


Figure 11: Processing photo of 60019 showing initial thick slab (,18). The pieces on their side are the thin column (,25) cut from the middle of slab (,18). S74-32514. Small cube is 1 cm. Note that two additional slabs were cut from ,4 in 1984.

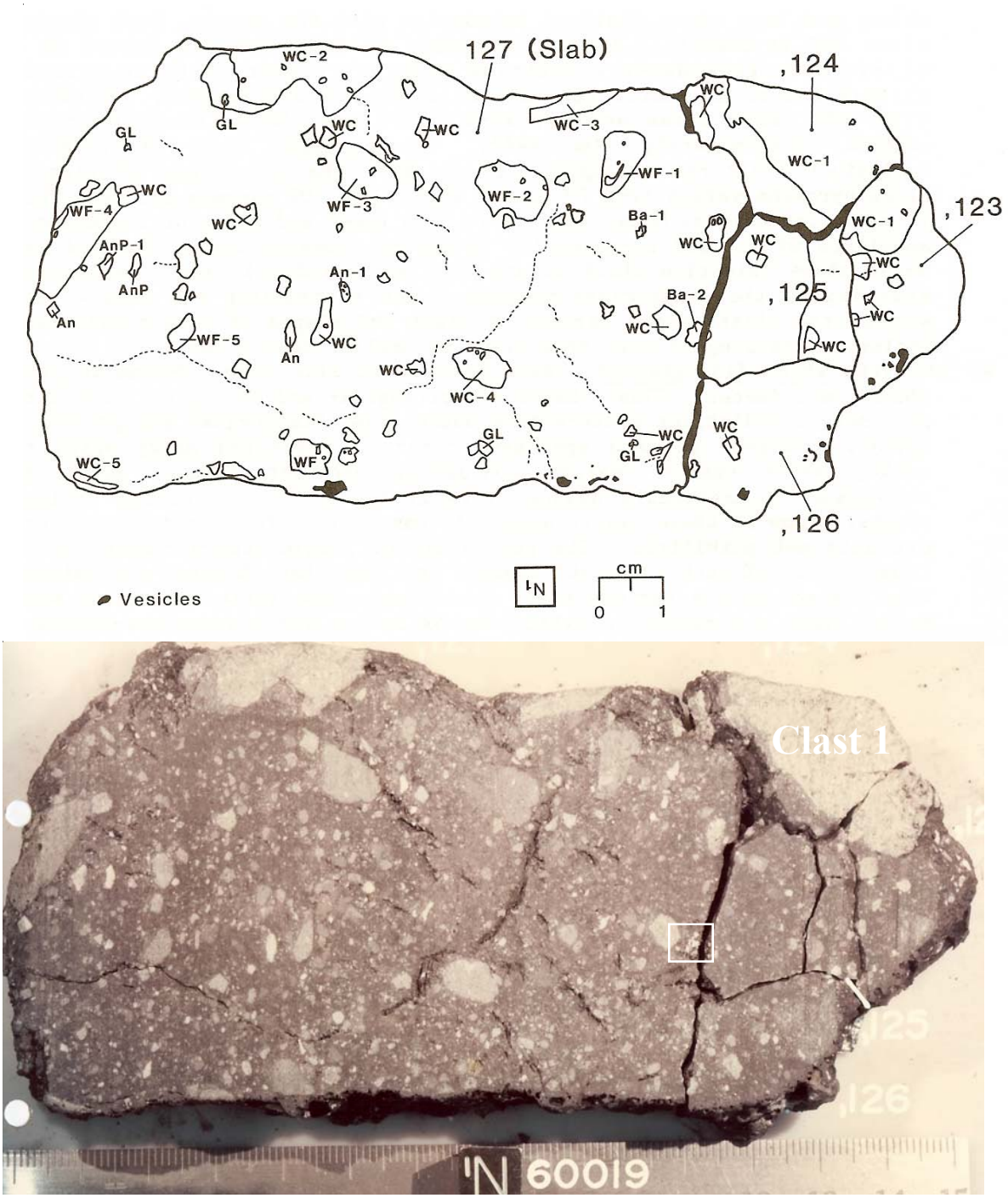
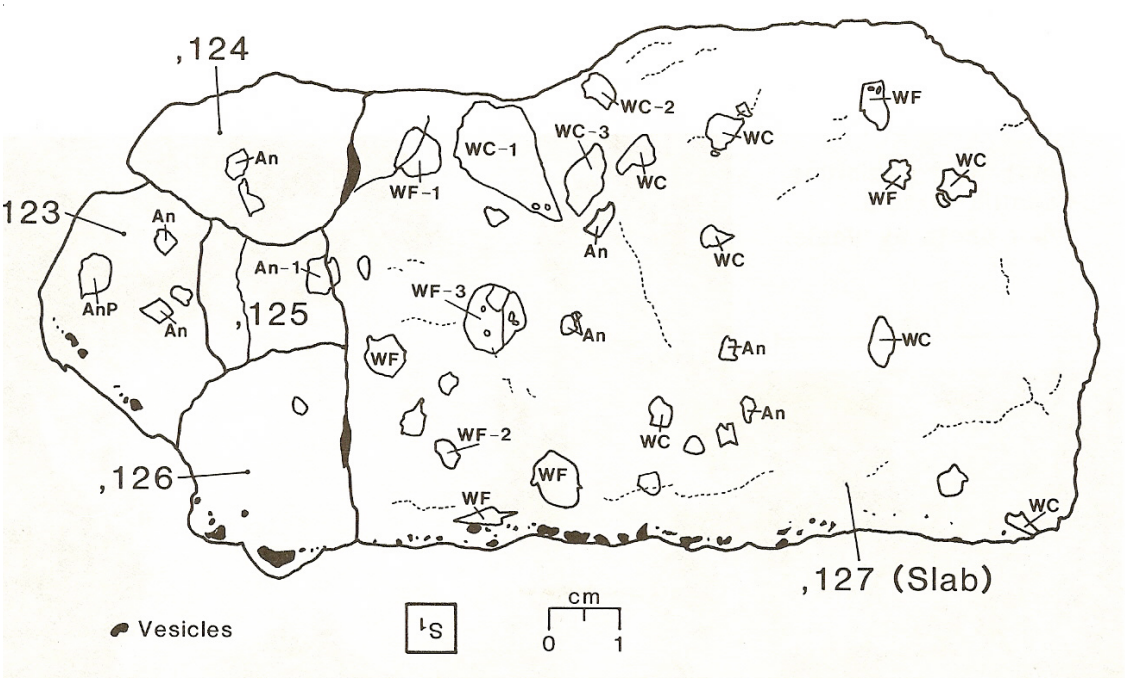


Figure 12: Photo and map of N1 side of slab (,127) of 60019 from Galindo (1985). S84-46294. Cube is 1 cm. White box is approximate location of mare basalt clast (figure 6).



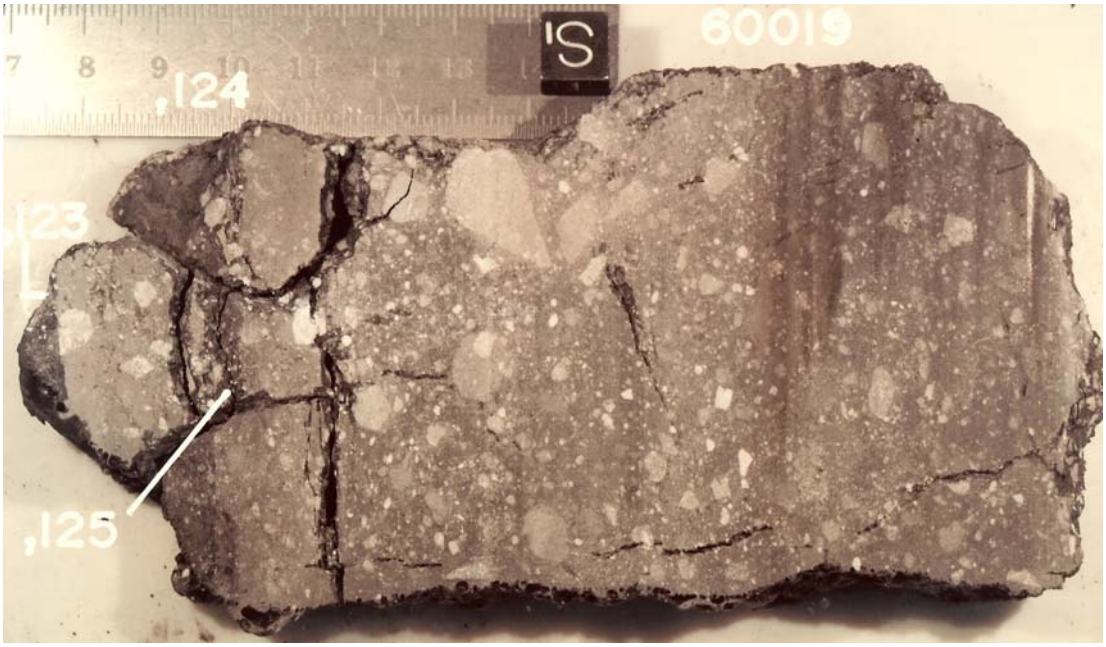


Figure 13: Photo and map of S1 side of slab (,127) of 60019 from Galindo (1985). S84-46297. Cube is 1 cm.

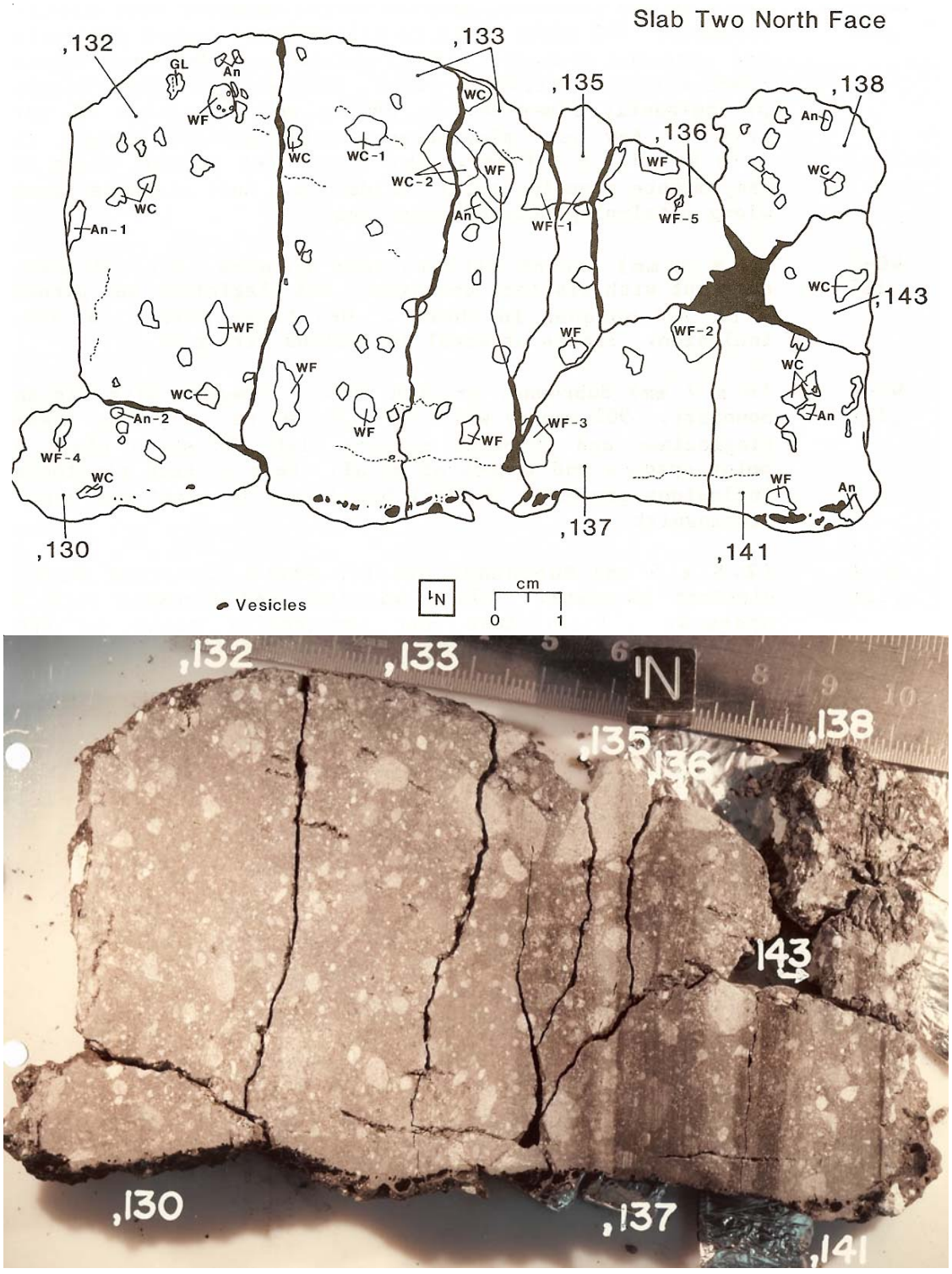


Figure 14: Photo and map of N1 side of slab (,132) of 60019. S84-46302. Cube is 1 cm.

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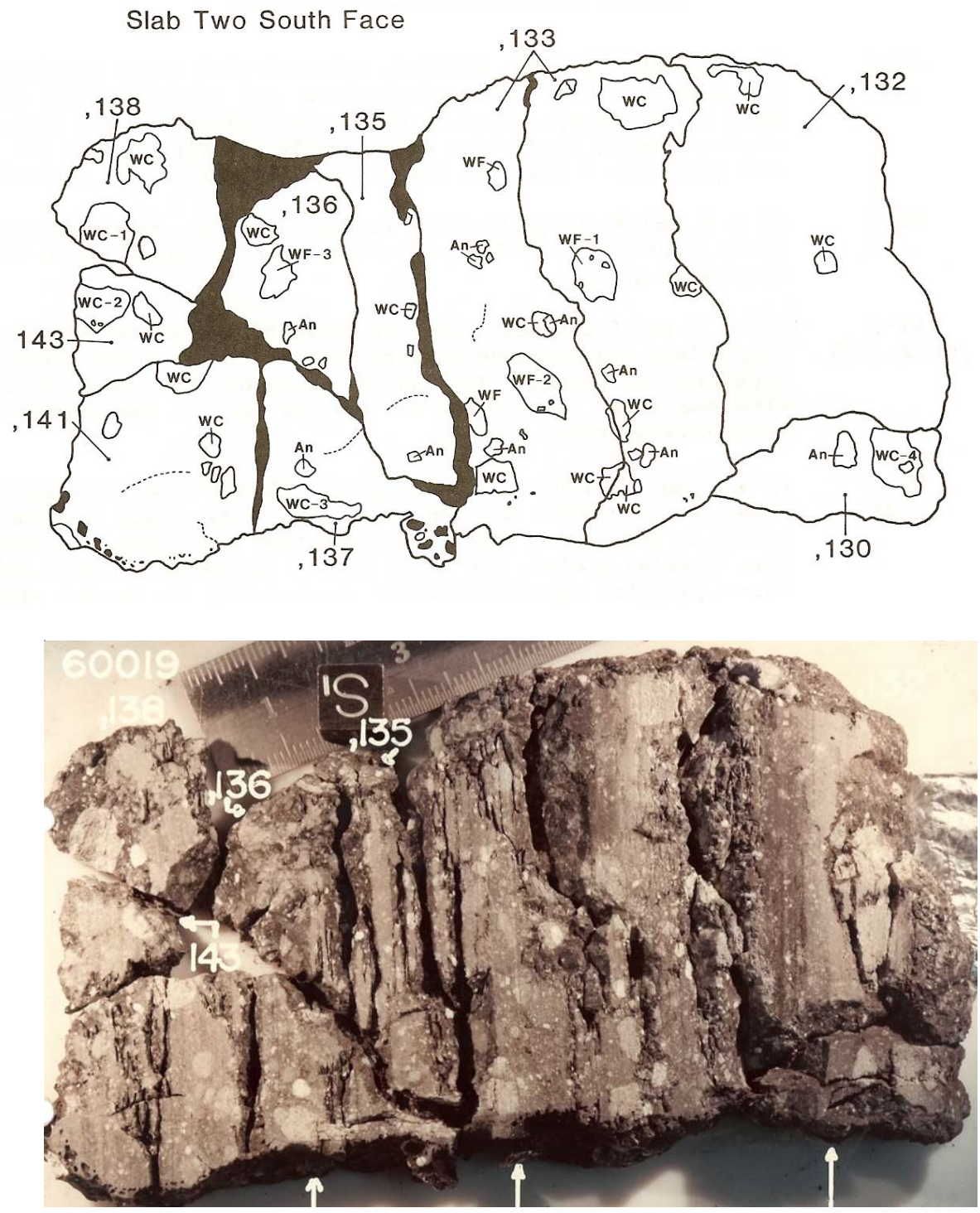

Figure 15: Photo and map of S1 side of slab (,132) of 60019. S84-46300. Cube is 1 cm.

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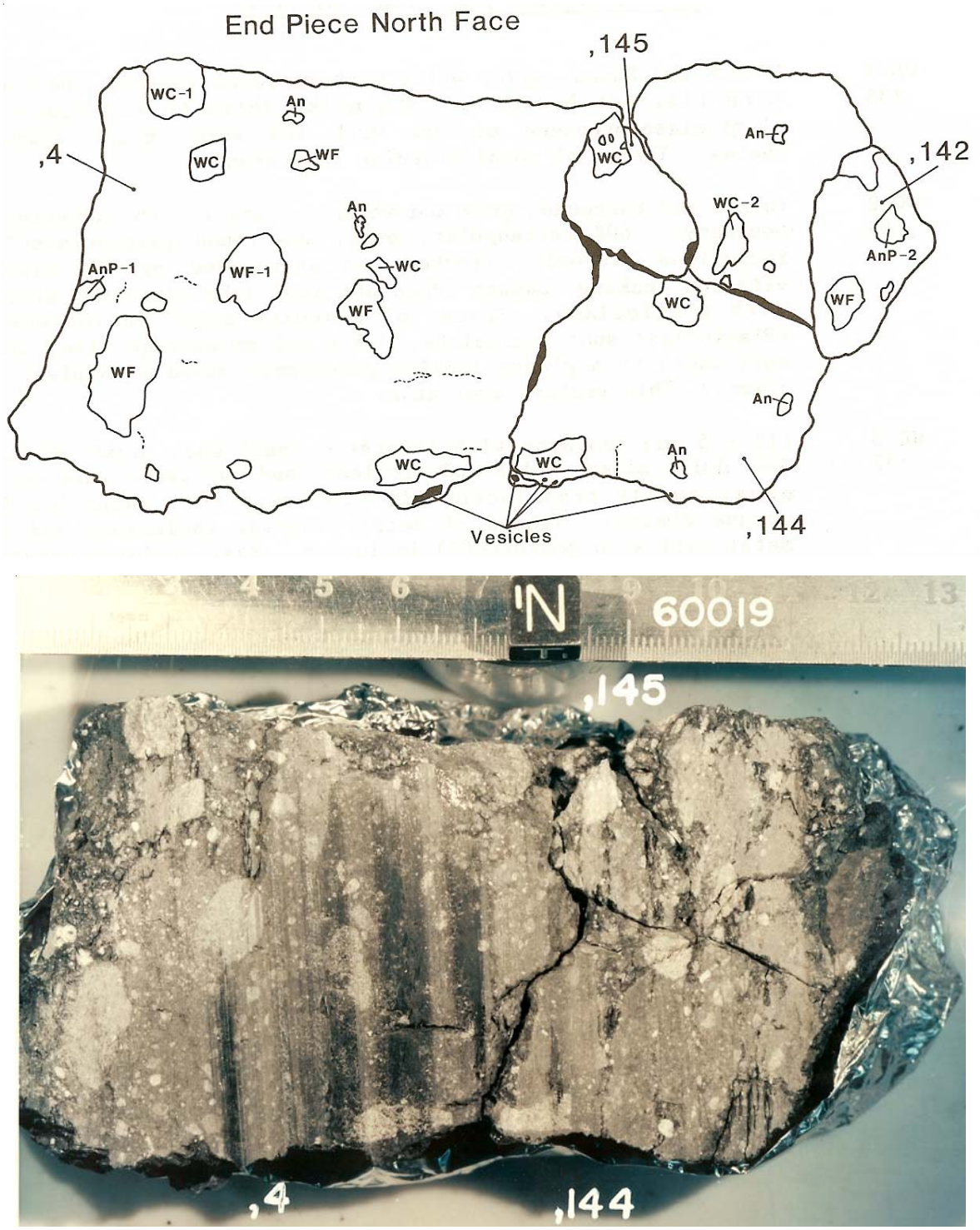

Figure 16: Photo and map of N1 side of end piece (,4) of 60019. S84-46298. Cube is 1 cm. Saw marks are visible.

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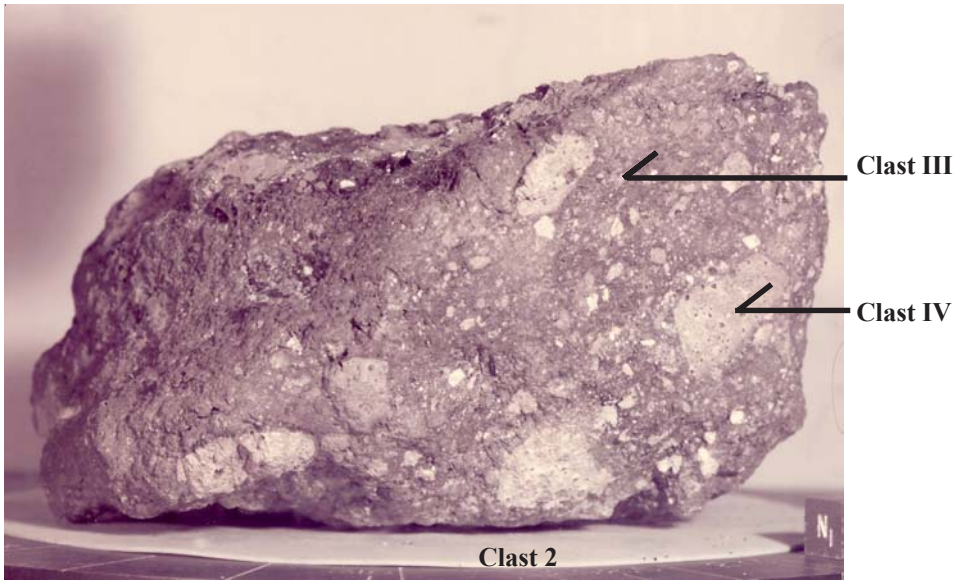

Figure 17: More clasts exposed on the surface of 60019 (W1 face). S72-42573B

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