60035

Polymict Anorthositic Breccia

1052 grams

Figure 1: Photo of 60035 in upside down configuration (zap pits of bottom). NASA # S72-38302. Cube is one cm.

Introduction

60035 is a fine-grained, clast-rich, polymict breccia made up of clasts of ferroan anorthosite, troctolite, troctolitic anorthosite and noritic anorthosite (Ryder 1980, Warner et al. 1980). There are areas that have melted and recrystallized as well as a "matrix" that is somewhat less feldspathic than the clasts. The meteoritic siderophile content is high. It is apparently a highlands breccia, with no mare component (figure 1).

Apparently the surface of this rock was initially completely covered with a black glass coating (figure 2). The top, eroded surface is now covered with micrometeorite pits and thin brown patina (figure 3).

This sample was originally set aside as a "posterity" sample, to be studied at a later date. To date, it remains poorly characterized, and requires further study. Recently, it was dated at 4.09 ± 0.1 b.y. with an exposure to cosmic radiation for about 6 m.y.

Petrography

Warner et al. (1980) performed a survey of several thin sections of 60035. They found that it was clastic in nature, with small recrystallized clasts of troctolitic anorthosite and noritic anorthosite making up about 80% of the rock. Additional clasts of cataclastic anorthosite and troctolite were studied (figure 5).

A variety of textures are observed, from equigranular, granulitic, poikilitic, annealed cataclastic, to recrystallized. All areas are feldspathic. Cushing et

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Mineralogical Mode (from Warner et al. 1980)

Lithology	% plagioclase	Plagioclase	Olivine	Orthopyroxene
Cataclastic ferroan anorthosite	99	An96	Fo35	En50
Recrystallized ferroan anor.	95	An97		En52
Troctolite	57	An96	Fo88	En86
Troctolitic anorthosite	84	An95	Fo79	En78
Noritic anorthosite	81	An95	Fo79	En79
Matrix	75	An95	Fo79	En78

Figure 2: Bottom surface of 60035 showing attached black glass. NASA S72-38301. Cube is 1 cm.

Figure 3: Top side of 60035 showing numerous zap pits. NASA # S72-38300. Cube is 1 cm.

al. (1999) calculated a metamorphic temperature of 1118 deg C from pyroxene pairs and termed the rock a "granulite". Hudgins et al. (2008) included 60035 in their study of granulitic breccias.

A few thin veins of shock glass are reported by Ma and Schmitt (1982) and Warner et al. (1980).

Significant Clasts

Troctolite: At the edge of thin section 60035,21, there is a small clast (4 x 10 mm) of troctolite with mafic minerals including olivine (Fo_{88}), orthopyroxene (En_{86}), chromite and Ni rich metal (Warner et al. 1980).

Ferroan Anorthosite: Two chips from 60035 were found to have Fe-rich pyroxene and were termed ferroan anorthosite by Warner et al. (1980) and Ma and Schmitt (1982).

Mineralogy

Olivine: Ma and Schmitt (1982) found that an "olivine clast" (troctolite?) was strongly enriched in heavy REE and had a high FeO/MnO ratio (104). Hudgins et al. (2008) reported Fo_{76-78}. Warner et al. (1980) reported olivine in a troctolite clast was Fo88.

Plagioclase: Plagioclase is uniformly calcic in composition (An_{92-97}). In some areas, large grains of plagioclase enclose chains of rounded mafic minerals along their boundaries indicating overgrowth.

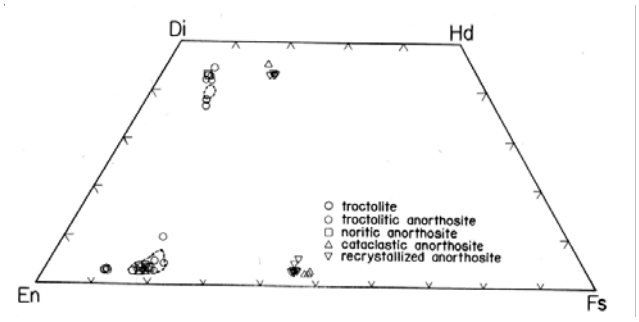


Figure 4: Pyroxene composition of various lithologies in 60035 (figure from Warner et al. 1980).

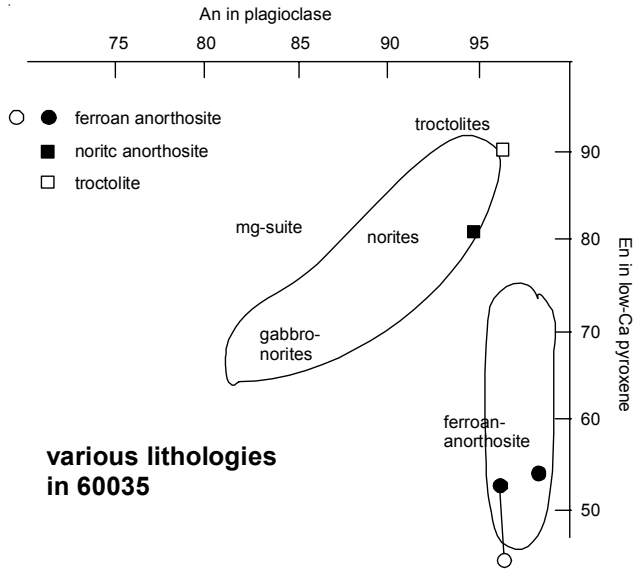


Figure 5: Plagioclase and low-Ca pyroxene diagram (from Warner et al. 1980).

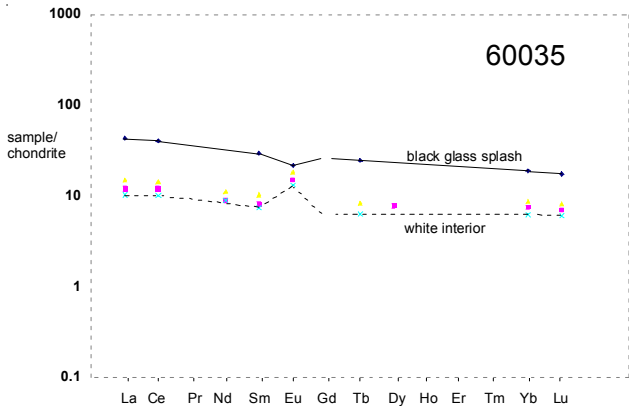


Figure 6: Normalized rare-earth-element diagram for 60035 (data from table).

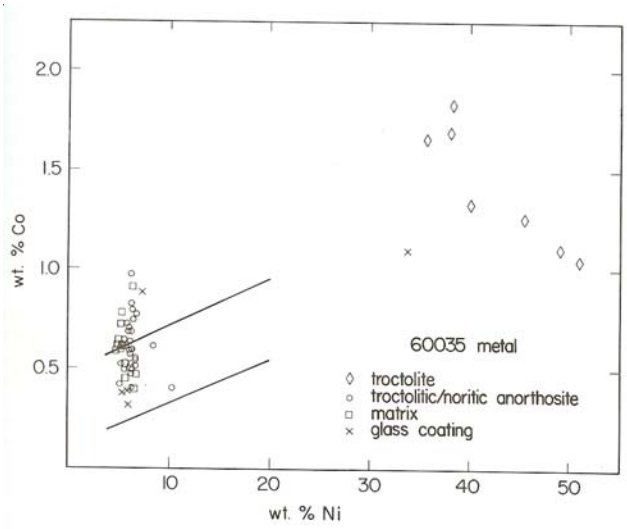


Figure 7: Composition of metal grains in various lithologies of 60035 (from warner et al. 1980).

Pyroxene: The composition of pyroxene in 60035 is given in figure 4 (Warner et al. 1980). Cushing et al. (1999) determined the composition of pyroxene pairs.

Metal: Warner et al. (1980) found high Ni and Co in numerous metal grains in 60035 (figure 6). Hunter and Taylor (1981) reported only minor rust and schreibersite. Hudgins et al. (2008) reported Ni = 4.4 – 6.1 %

Glass: The black glass found attached to the surface of 60035 has been studied by See et al. (1986) and Morris et al. (1986).

Opaques: Ilmenite, chromite and zirconolite were reported by Hudgins et al. (2008).

Apatite: Apatite was reported by Hudgins et al. (2008).

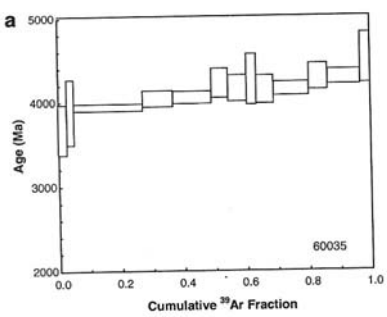


Figure 8: Ar/Ar plateau diagram for 60035 (Hudgins et al. 2008).

Summary of ages for 60035

	Ar/Ar
Hudgins et al. 2008	4.088 ± 0.1 b.y.
New decay constant	

Chemistry

Ma and Schmitt (1982) analyzed the white interior and the black glass and found high Ir indicating meteoritic contamination throughout (table 1). They found similarity of the white interior with materials from North Ray Crater, while the glass was similar to South Ray Crater !? Hudgins et al. (2008) determined duplicate analyses on two additional splits (figure 7).

Radiogenic age dating

60035 has been dated by Hudgins et al. (2008) at 4.088 ± 0.1 b.y. using the Ar/Ar plateau technique (figure 8).

Cosmic ray Exposure Age

Hudgins et al. (2008) determined a cosmic-ray-exposure age of 6.4 ± 0.5 m.y.

Processing

In 1980, a slab was cut through the middle of this large rock (figures 9 - 11). From its appearance, it will prove difficult to break this rock up into its original lithic clasts. A carefully organized consortium study of this posterity sample would yield further understanding of the lunar highland crust. There are currently 10 thin sections.

List of Photo #s

S72-38300-38303	color mug shots
S72-40955	showing zap pits
S72-40962	showing zap pits
S80-35179-35183	reassembled parts
S80-35176	saw cuts
S80-35184	saw cuts

Table 1. Chemical composition of 60035.

	glass coat		glass coat		blk glass	interior	interior						
reference	Morris 86		Warner 80		Ma 82 abs	Ma 82	Ma 82		Hudgins et al. 2008				
weight													
SiO2 %	44.31	(b)	44.1	(b)									
TiO2	0.3	(b)	0.29	(b)	0.3	0.2	0.2	(a)					
Al2O3	28.31	(b)	29	(b)	27.2	26	25.9	(a)					
FeO	5.19	(b)	5.1	(b)	4.9	4	4.3	(a)					
MnO			0.04	(b)	0.059	0.053	0.056	(a)					
MgO	6.47	(b)	6	(b)	5.5	8.4	8.2	(a)					
CaO	15.49	(b)	15.7	(b)	16.3	14.3	14.1	(a)					
Na2O	0.31	(b)	0.26	(b)	0.36	0.379	0.413	(a)					
K2O	0.08	(b)	0.06	(b)	0.058	0.069	0.064	(a)					
P2O5			0.02	(b)									
S %													
sum													
Sc ppm	6.07	(a)			5.5	5.5	5.9	(a)	5.38	5.33	5.58	5.57	(a)
V					15	21	19	(a)					
Cr	696	(a)			691	752	745	(a)					
Co	41	(a)			43	18	19	(a)	21.5	21.8	26	21.5	(a)
Ni	438	(a)			630	180	200	(a)	200	211	292	191	(a)
Cu													
Zn													
Ga													
Ge ppb													
As													
Se													
Rb						2		(a)					
Sr					190	135	190	(a)	174	180	139	140	(a)
Y													
Zr					130	50	50	(a)	50	44	31	38	(a)
Nb													
Mo													
Ru													
Rh													
Pd ppb													
Ag ppb													
Cd ppb													
In ppb													
Sn ppb													
Sb ppb													
Te ppb													
Cs ppm						0.1	0.1	(a)					
Ba	232	(a)			140	40	60	(a)	59	62	40	37	(a)
La	10.04	(a)			8.3	2.8	3	(a)	3.5	3.64	2.42	2.37	(a)
Ce	24.1	(a)			22	7.2	7.3	(a)	8.6	9	6.1	5.9	(a)
Pr													
Nd					14	4	6	(a)	5	5.4	4	3.3	(a)
Sm	4.3	(a)			3.87	1.18	1.33	(a)	1.51	1.6	1.09	1.05	(a)
Eu	1.2	(a)			0.96	0.84	0.9	(a)	1.03	1.05	0.74	0.72	(a)
Gd													
Tb	0.88	(a)			0.68			(a)	0.3	0.33	0.23	0.22	(a)
Dy					4.6	1.9	2.2	(a)					
Ho													
Er													
Tm													
Yb	3.04	(a)			2.72	1.22	1.43	(a)	1.39	1.4	1.01	0.99	(a)
Lu	0.42	(a)			0.37	0.17	0.19	(a)	0.193	0.196	0.144	0.139	(a)
Hf	3.21	(a)			2.8	1	1.1	(a)	1.21	1.26	0.86	0.82	(a)
Ta	0.31	(a)			0.4	0.2	0.2	(a)	0.19	0.21	0.16	0.15	(a)
W ppb													
Re ppb													
Os ppb													
Ir ppb					14	3.8	3.5	(a)	8.8	8.4	8.5	5.6	(a)
Pt ppb													
Au ppb									1.6	1.8	2.2	5	(a)
Th ppm	1.33	(a)			1.38	0.75	0.82	(a)	0.83	0.88	0.65	0.56	(a)
U ppm	0.78	(a)							0.25	0.26	0.19	0.17	(a)
technique	*(a) INAA, (b) microprobe*												

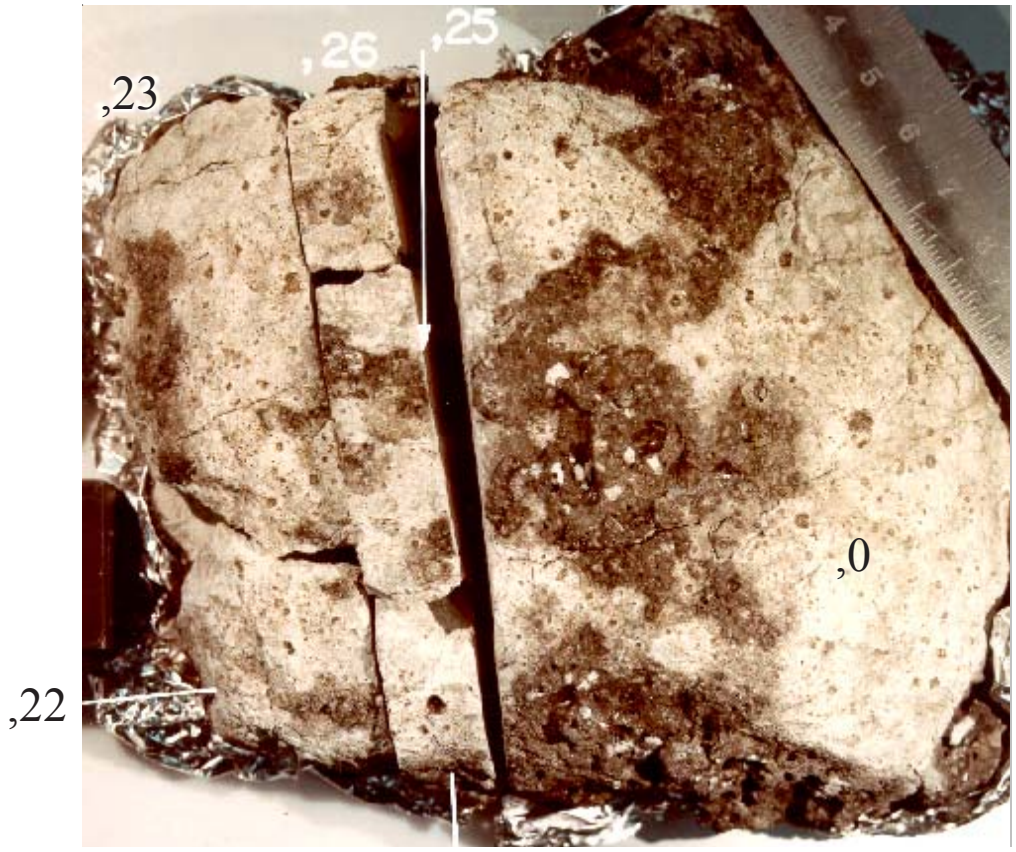
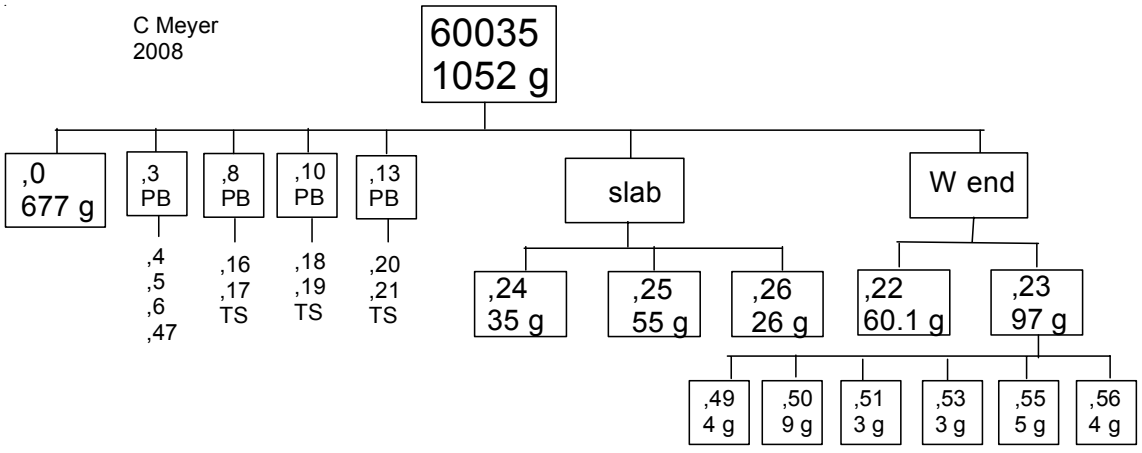


Figure 9: Group photo of 60035 after sawing to create slab. NASA # S80-35183. Scale is in cm.

Figure 10: First saw cut, butt end ,22 and ,23 of 60035. NASA # S80-35176. Scale is in cm.

Figure 11: Second saw cut, butt end ,0 of 60035. NASA # S80-35184. Streaks are from sawblade.



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