77017

Poikilitic Anorthositic Gabbro
1730 g, 17 x 12.5 x 9 cm

INTRODUCTION

Sample 77017 is a large, annealed, feldspathic breccia set in a frothy black glass matrix (Fig. 1). A photograph of a slab through this rock reveals how the anorthositic portion has been incorporated in the black glass matrix (Fig. 2). The feldspathic portions all appear to be the same, with uniform chemistry and mineral composition. The anorthositic portion has high siderophiles with an age of about 4 b.y., while the glassy matrix is basaltic with a fusion age of about 1.5 b.y. (see below). The petrogenetic history of this rock was well-described by Helz and Appleman (1974).

Various names have been given to the feldspathic portion of this rock:

Crushed anorthositic gabbro - Butler (1973), Helz and Appleman (1974)

Poikilitic anorthositic gabbro - McCallum et al. (1974)

Feldspathic granulitic impactite -- Warner et al. (1977)

Olivine gabbro breccia - Wolfe and others (1981)

Poikilitic anorthositic norite - Lindstrom and Lindstrom (1986).

PETROGRAPHY

The feldspathic portion of Apollo 17 sample 77017 is an olivine-bearing, anorthositic gabbro with a relatively coarse-grained poikilitic texture (McCallum et al., 1974; Helz and Appleman, 1974; and Ashwal, 1975). The mineral composition of 77017 is ~75% plagioclase (An_{94-97}), ~5% olivine (Fo_{60-65}), ~10% augite ($Wo_{37}En_{46}Fs_{17}$), and ~10% pigeonite ($Wo_8En_{62}Fs_{30}$). It contains relict lithic clasts of annealed troctolitic anorthosite and anorthosite. Mineral clasts of plagioclase, olivine, pink spinel, and opaque minerals are enclosed within

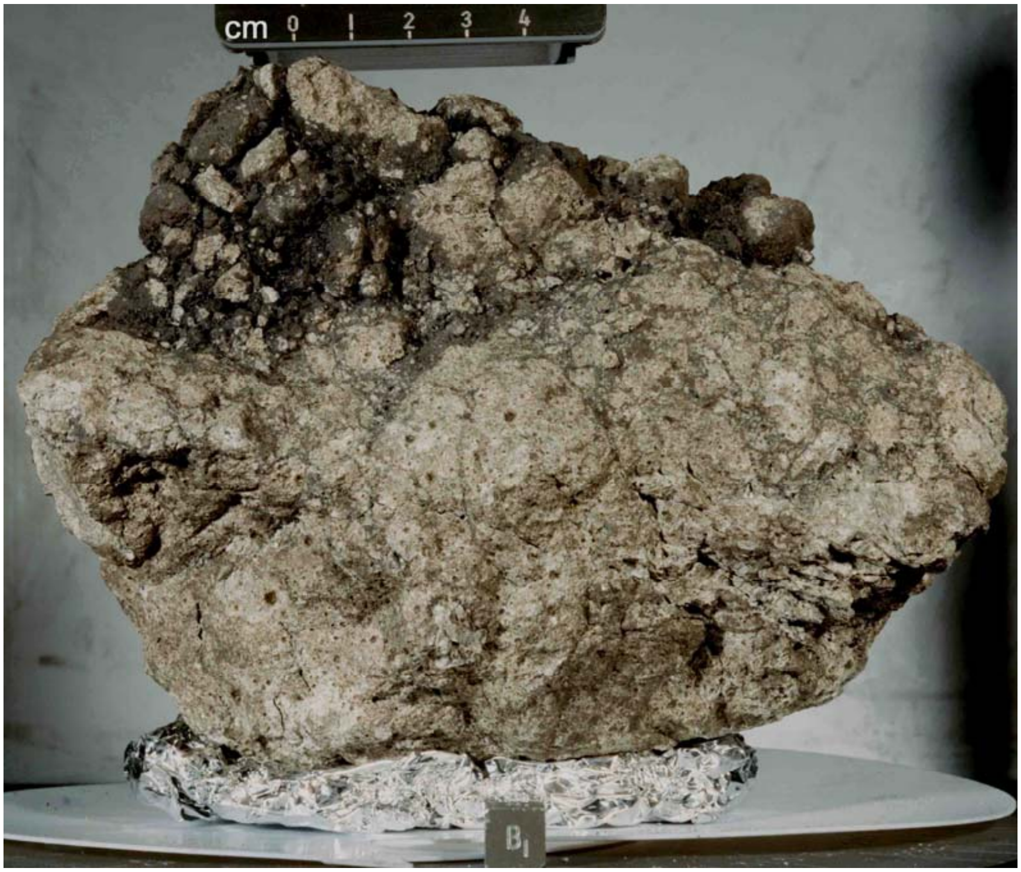

Figure 1: Photograph of lunar sample 77017. Cube is 1 cm. S73-17772.

Figure 2: Slab surface of 77017. Cube is 1 inch. S75-34250.

pigeonite and augite oikocrysts. All minerals show a restricted compositional range.

A late shock event has caused partial granulation, producing a fine-grained cataclastic matrix. The proportions and compositions of minerals in the crushed areas are the same as in the uncrushed, indicating that the cataclasis was not accompanied by any significant transfer of material. Shock features are common: undulose extinction, shock-induced twinning, mosaicism, and partial to complete vitrification of plagioclase. Minor amounts of clear glass in the interior of the rock were produced by this late shock.

The plagioclase in the relict anorthosite and troctolitic anorthosite lithic clasts has well-developed polygonal grain boundaries indicative of extensive subsolidus annealing. Pyroxene oikocrysts (up to 1 mm) occur as both pigeonite and augite; sometimes found epitaxially intergrown (McCallum et at., 1974). Both pyroxenes show well-developed exsolution lamellae: up to 2 µm wide. The pyroxenes are homogeneous in composition and show a well-defined compositional gap (Fig. 5). Anhedral olivine: grains occur in the troctolitic anorthosite and are included in the pyroxene oikocrysts. Ilmenite oikocrysts enclose plagioclase and mafic minerals.

Temperatures calculated from the pyroxene pairs indicate a temperature of equilibration between 1050 and 1100 °C, which is estimated to be about 100 °C below the solidus for a rock of this composition (McCallum et al. 1974). One interpretation could be that this represents the Apollonian metamorphism proposed by Stewart (1975). However, the abundant amount of trace siderophiles leads one to consider the impact model of Simonds et al. (1975). Warner et al. (1977) propose that 77017 formed in the period after the consolidation of the lunar crust but before the final bombardment when "still hot impactite sheets could have been buried by layers of younger ejecta that were themselves hot." Helz and Appleman (1974) and Lindstrom and Lindstrom (1986) interpret the clasts in 77017 to represent a plutonic anorthositic norite lithology that was breeciated and metamorphosed to produce the poikiloblastic texture. Cushing et al. (1993) and James (1993) have recently discussed the relationship of 77017 to the "granulitic suite."

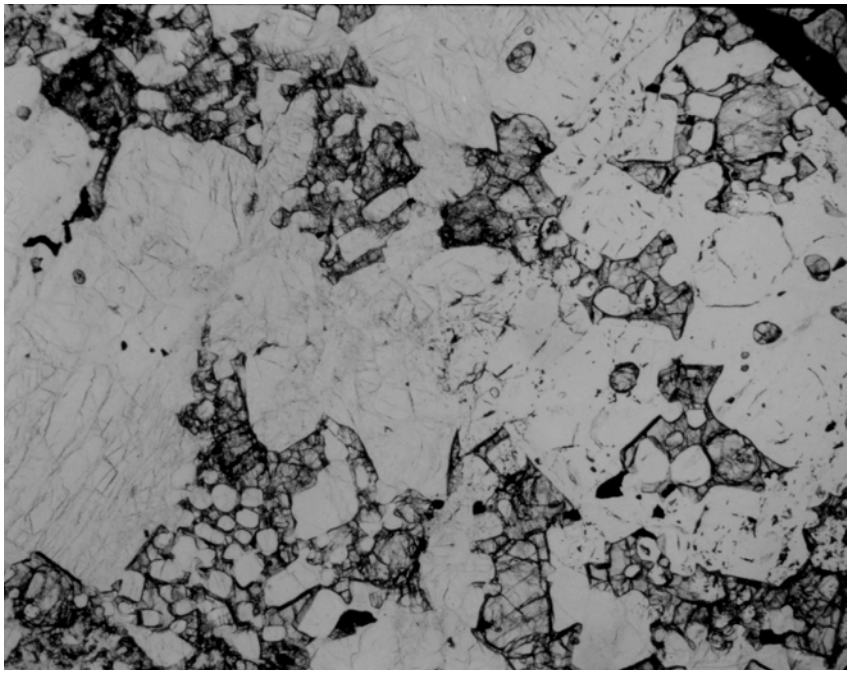

Figure 3: Photomicrograph of a thin section of the feldspathic portion of thin section 77017,65, showing coarse poikilitic texture. Field of view is 3 x 5 mm.

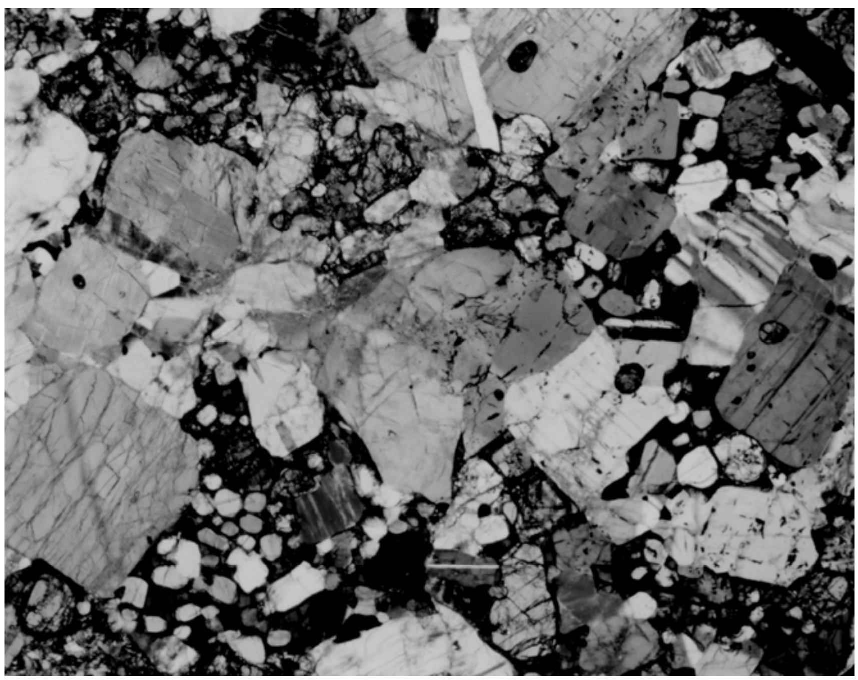

Figure 4: Photomicrograph of the same feldspathic portion of 77017,65 using partially crossed polarizers to show the granulitic texture on the plagioclase grains with 120 deg triple junctions. Field of view is 3 x 5 mm.

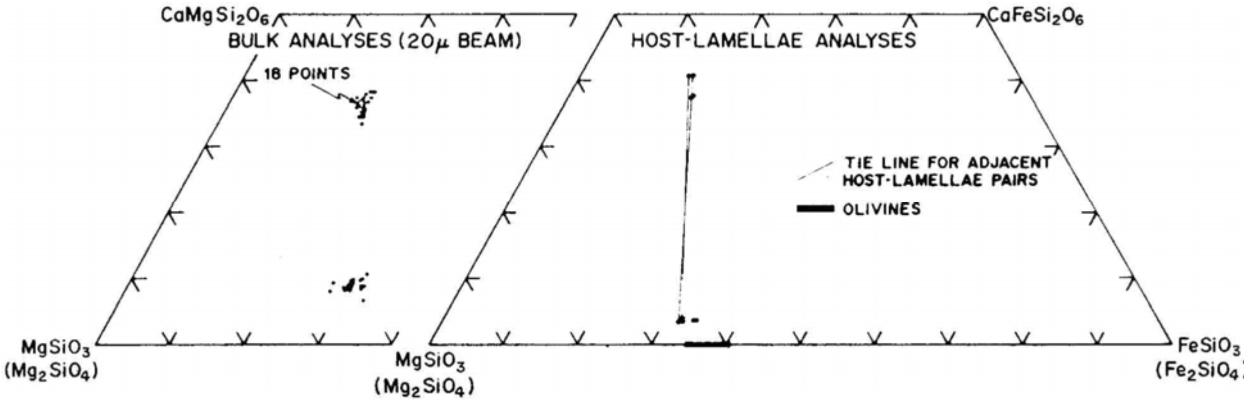

Figure 5: Pyroxene and olivine compositions in 77017. Data from McCallum et al. (1974).

Finally, the anorthositic portion of this rock was caught up in the black matrix, which has a high mare component. This is best seen in the saw cut of the slab (Fig. 2).

Bence et al. (1974) have studied a small fragment 78503,7,1, which they claim is the equivalent of 77017.

MINERAL CHEMISTRY

The composition of olivine, plagioclase, and pyroxene is relatively homogeneous in the feldspathic portion of 77017 (Helz and Appleman, 1974 and McCallum et al., 1974). Fig. 6 shows that 77017 falls in the field of ferroan anorthosite even though the minerals have "equilibrated" composition. This indicates that the precursor of 77017 may have been a ferroan anorthosite.

Taylor and Williams (1974) and Hewins and Goldstein (1975) have studied the compositions and phases of the metallic particles (Figs. 7 and 8). Metal grains in the poikilitic facies of 77017 are chemically homogeneous, containing 15 to 20% Ni, while grains in the shocked portion of 77017 show exsolution.

McCallum et al. (1974) present x-ray diffraction data for pyroxenes.

WHOLE-ROCK CHEMISTRY

Hubbard et al. (1974), Laul et al. (1974), and Lindstrom and Lindstrom (1986) have determined the rare earth element contents of 77017 (Table 1). The feldspathic portion of the rock is very low in trace elements (Fig. 9). The incorporation of abundant siderophiles without the addition of ;a significant amount of rare earth elements by mixing with KREEP-rich rocks is thought to be an important constraint to when KREEP was present on the lunar surface (Warner et al., 1977).

Morgan et al. (1974) have determined the siderophile and volatile element composition of 77017' (Table 2). They found extremely high Ir, Re, and Au (Fig. 10). The data by Lindstrom and Lindstrom (1986) also confirm the extremely high siderophile content of this rock. Hertogen et al. (1977) and James (1994) have reviewed the siderophile and volatile element data.

SIGNIFICANT CLASTS

Helz and Appleman (1974) and McCallum et al. (1974) describe relict feldspathic clasts with apparent cumulate texture. Lindstrom and Lindstrom (1986) attempted to analyze several relict clasts, but found that their samples all had basically the same composition (Fig. 11). However, the feldspathic portion of this large rock has not been fully explored.

STABLEISOTOPES

Mayeda et al. (1975) have studied the oxygen isotope fractionation of 77017. Two olivine separates have different isotopic compositions, and the plagioclase-olivine fractionation is larger than for other lunar rocks. Muller et al. (1976) attempted to determine the nitrogen in 77017.

RADIOGENIC ISOTOPES

Phinney et al. (1975) dated 77017 as 3.97 ± 0.02 b.y. by the Ar-Ar plateau technique (Fig. 12). Kirsten and Horn (1974) determined 4.05 t 0.05 b.y. for the white mineral fraction of their sample and 1.5 ± 0.3 b.y. for the black glass vein within it (Fig. 13) using the Ar-Ar technique.

Nunes et al. (1974) and (1975) have studied the U-Th-Pb systematics of 77017 (Table 3), but could not determine an internal isochron or an age for this rock. Nyquist et al. (1974) obtained Rb-Sr data for 77017 (Table 4).

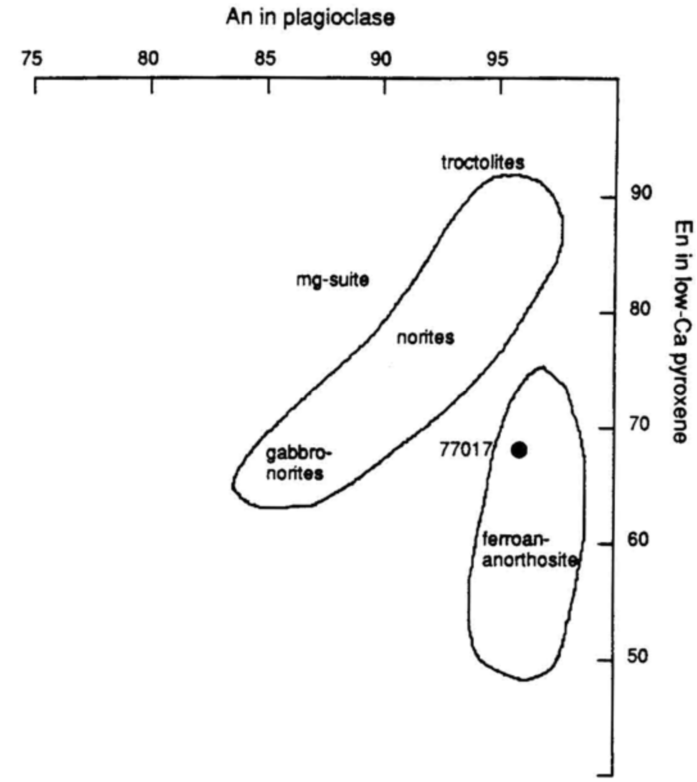

Figure 6: 77017 falls in the field of "ferroan anorthosite" even though the minerals have a metamorphic origin. Boundaries of rock types from James and Flohr (1983).

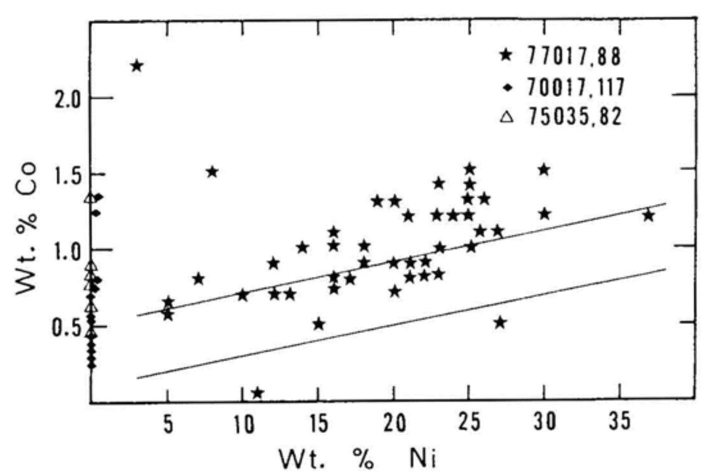

Figure 7: Composition of metal grains in 77017. From Taylor and Williams (1974).

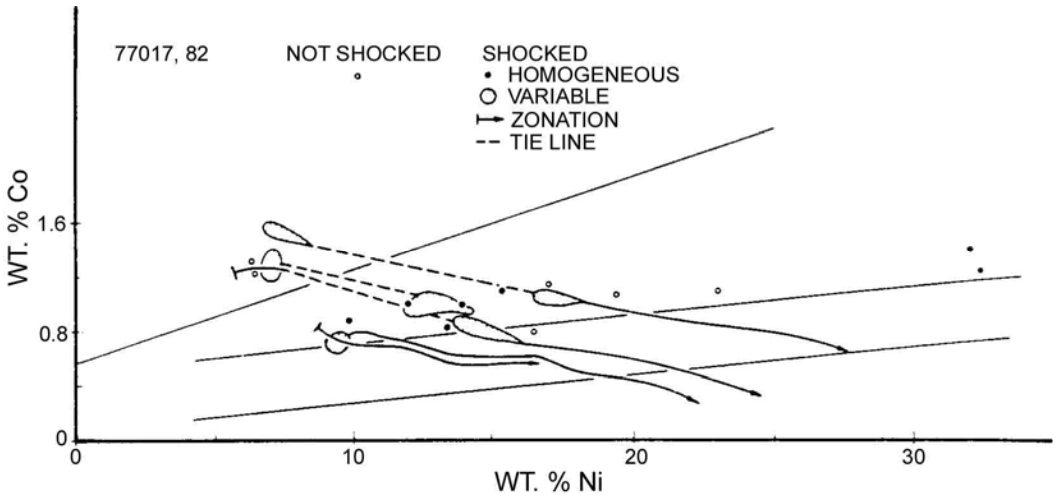

Figure 8: Composition of metal grains in 77017. From Hewins and Goldstein (1975).

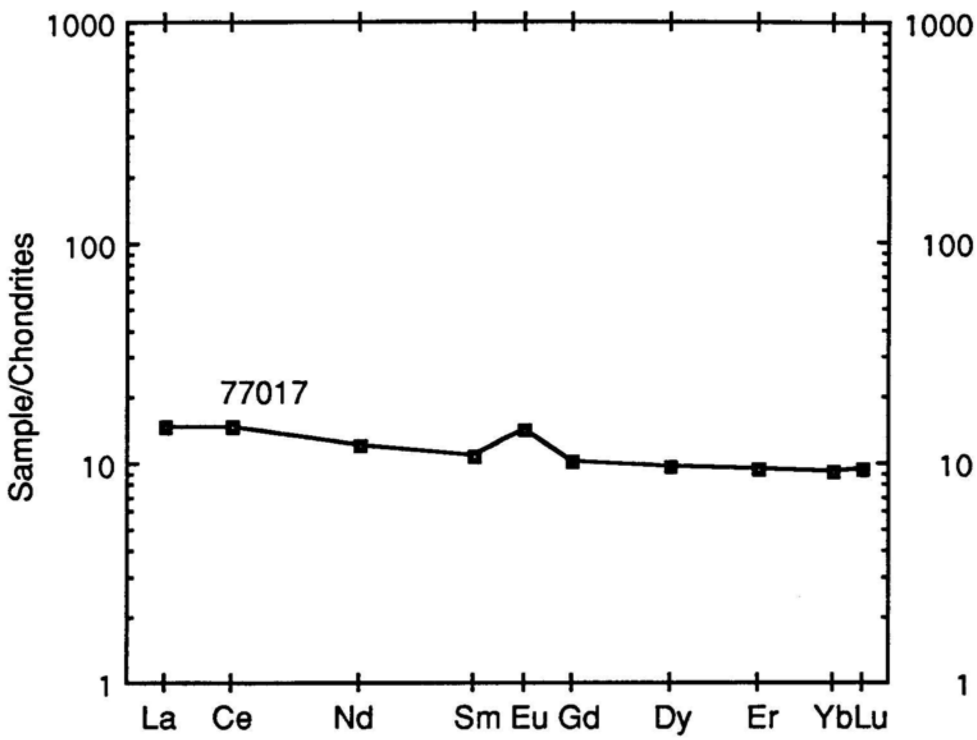

Figure 9: Normalized rare earth element diagram for 77017. Data from Hubbard et al. (1974).

COSMOGENIC RADIOISOTOPES AND EXPOSURE AGES

Phinney et al. (1975) determined an exposure age of 224 ± 20 m.y., while Kirsten and Horn (1974) determined one of 80 ± 10 m.y.

MAGNETIC STUDIES

Brecher et al. (1974), Nagata et al. (1974 and 1975), Pierce et al. (1974), and Cisowski et al. (1983) have studied the remanent magnetization of 77017. Huffnan et al. (1974) and Brecher et al. (1975) studied the distribution of Fe by Mbssbauer spectroscopy (Fig. 14).

Mizutani and Osako (1974) have studied the elastic wave velocity, thermal diffusivity, and thermal conductivity of 77017 (Fig. 15). According to Horai and Winkler (1976), the thermal diffusivity of 77017 is the lowest among the solid rock samples (Fig. 16).

SURFACE STUDIES

Adams and Charette (1975) and Charette and Adams (1977) determined the spectral reflectance of 77017 and compared it with other anorthositic gabbros (Fig. 17).

PROCESSING

Sample 77017 has 32 thin sections. The largest piece is 1053 g.

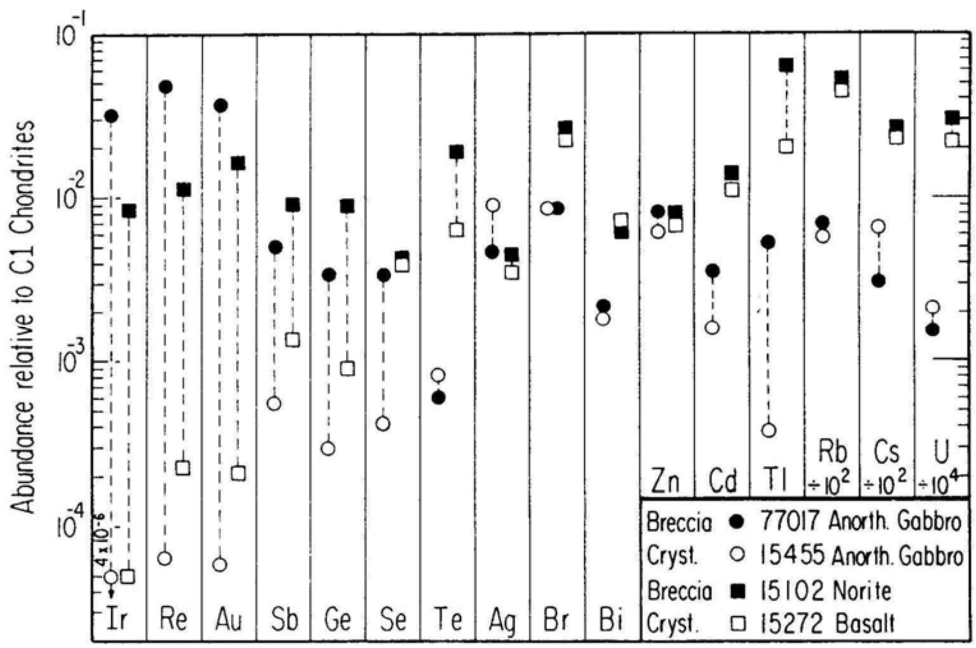

Figure 10: Trace element data for 77017 compared with other rocks. Sample 77017 has elevated siderophiles. From Morgan et al. (1974).

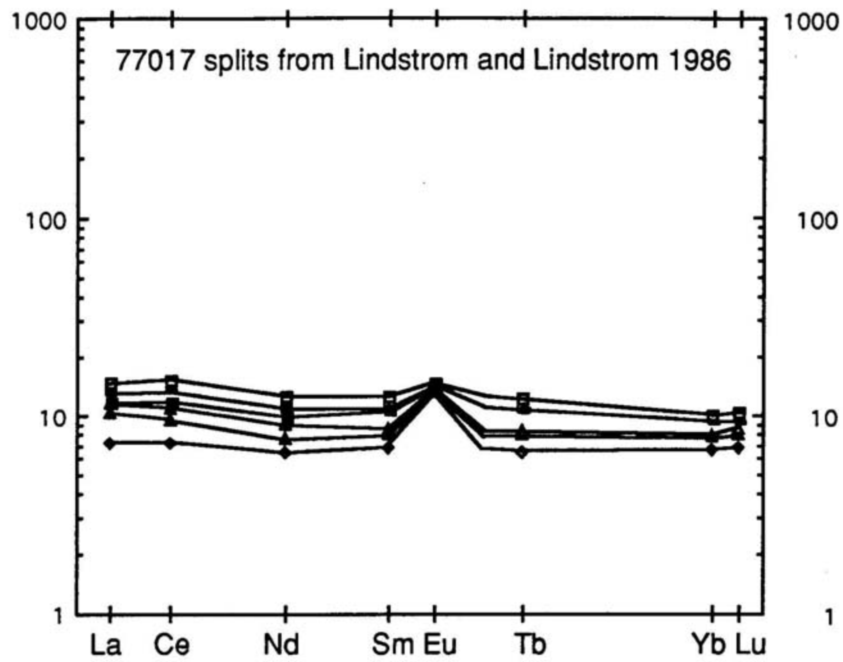

Figure 11: Normalized rare earth element diagram for multiple splits of 77017. Data from Lindstrom and Lindstrom (1986).

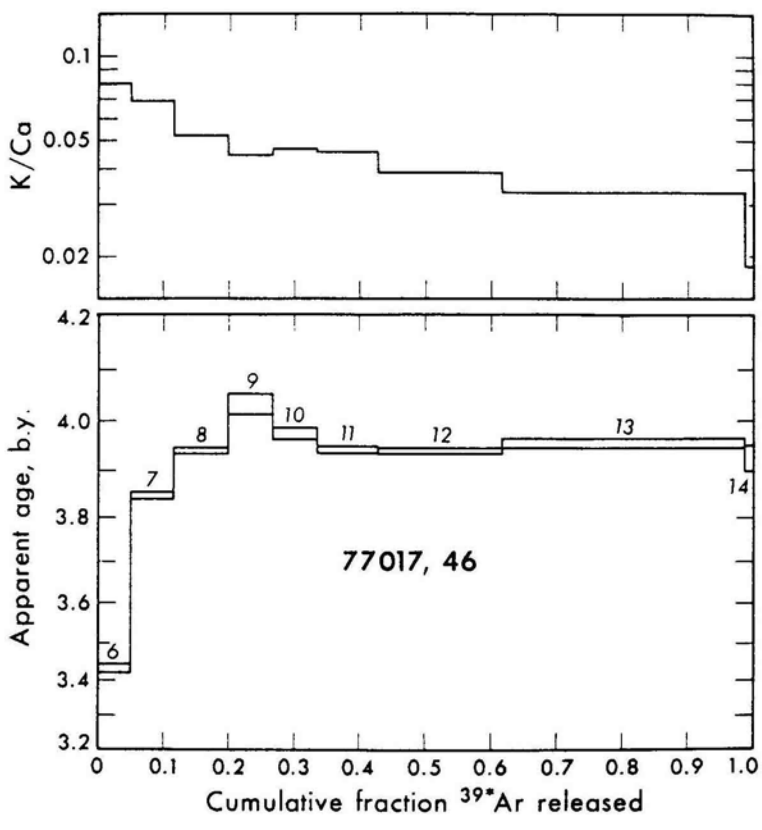

Figure 12: ^{39}Ar-^{40}Ar release patterns and apparent K/ Ca ratios for anorthositic breccia 77017,46. From Phinney et al. (,V5).

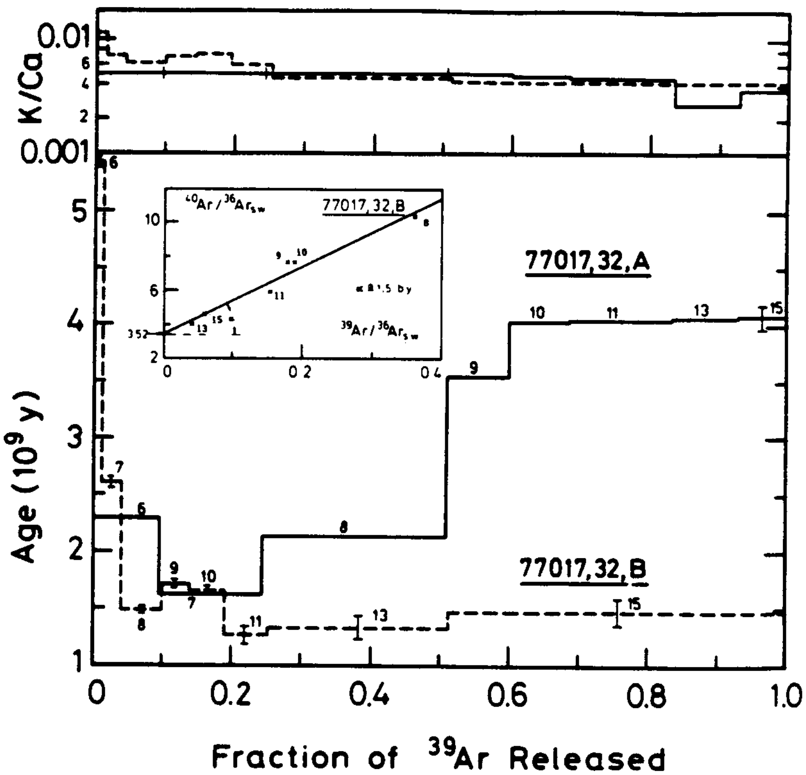

Figure 13: ^{39}Ar-^{40}Ar release patterns and apparent K/Ca ratios for anorthositic breccia 77017,32A and for a black glass vein penetrating the breccia 77017,32B. From Kirsten and Horn (1974).

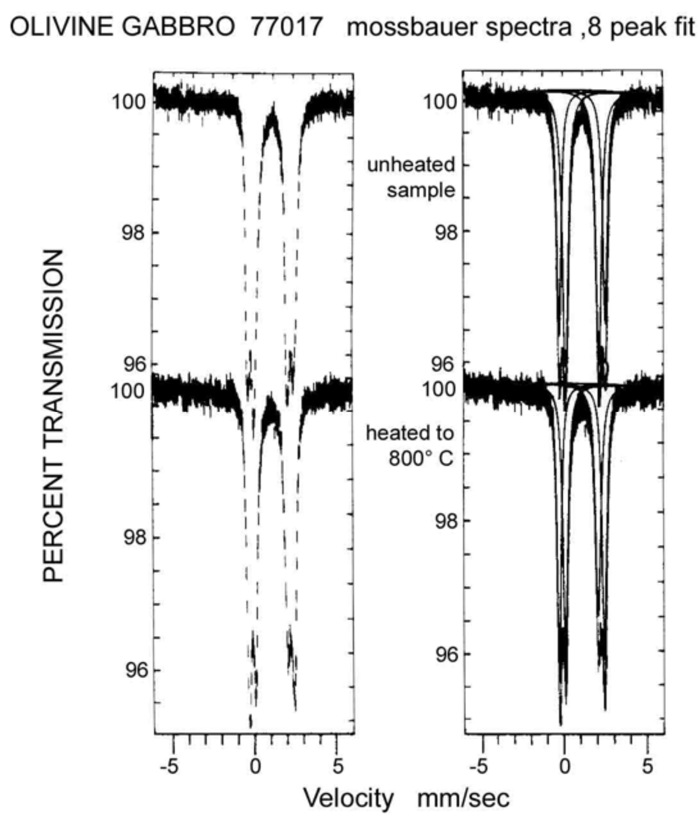

Figure 14: Mossbauer spectra of 77017. From Brecher et al. (1975).

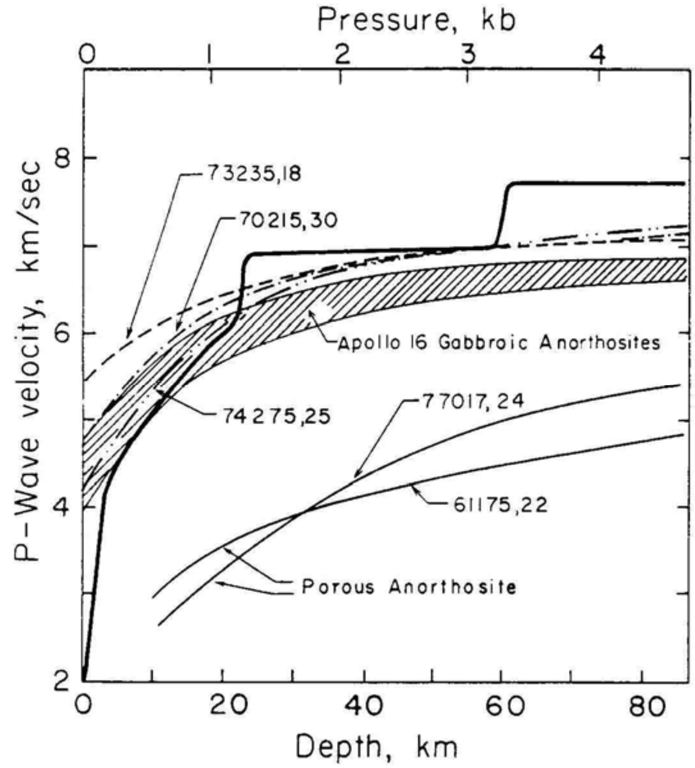

Figure 15: Elastic wave velocity as function of pressure. From Mizutani and Osako (1974).

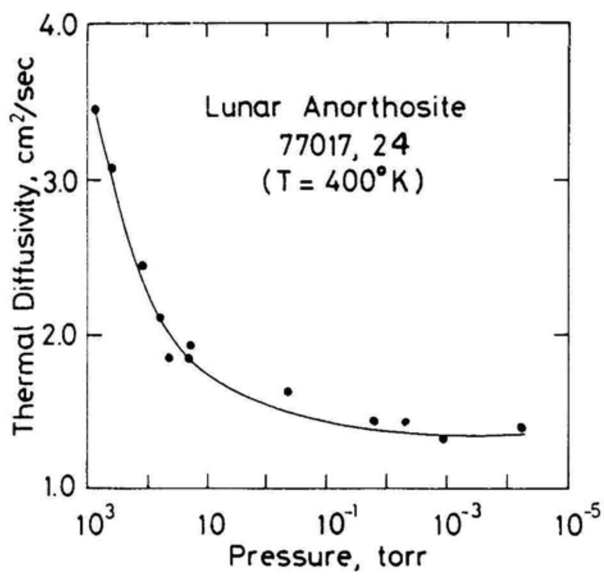

Figure 16: Thermal diffusivity of 77017. From Mizutani and Osako (1974).

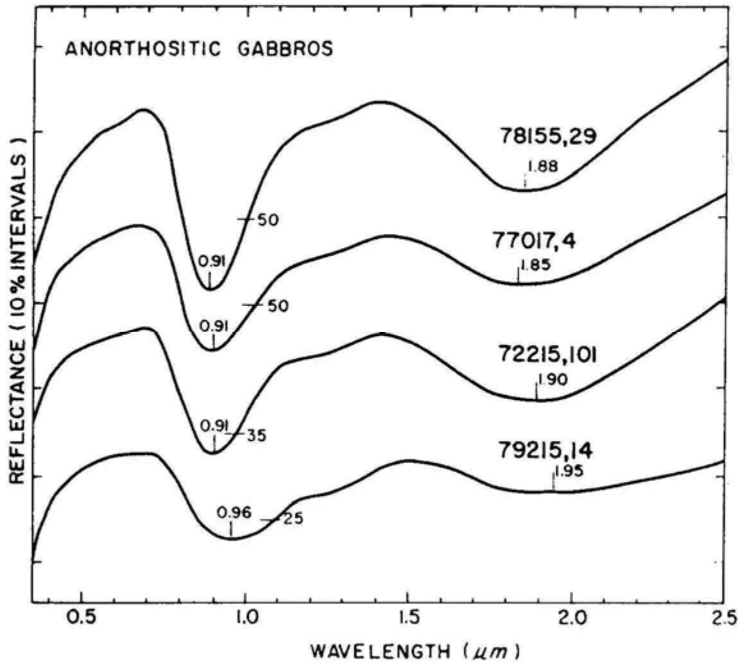

Figure 17: Reflectance spectra of 77017 compared with other anorthositic gabbros. From Adams and Charette (1975).

Table 1: Whole-rock chemistry of 77017.
a) LSPET; b) Hubbard et al. (1974); c) Wiesmann and Hubbard (1975); d) Laul et al. (1974)

Split Technique	,2 (a, b, c) XRF, ID	,57 (d) INAA	matrix (d) INAA	grey fragment (d) INAA
SiO_2 (wt%)	44.09			
TiO_2	0.41	0.75	5.3	0.35
Al_2O_3	26.59	26.0	18.9	27.1
Cr_2O_3	0.13	0.14	0.29	0.126
FeO	6.19	6.2	12.1	5.7
MnO	0.08	0.085	0.155	0.077
MgO	6.06	6	8	6
CaO	15.43	14.5	11.7	15.7
Na_2O	0.30	0.31	0.39	0.36
K_2O	0.06	0.05	0.10	0.076
P_2O_5	0.03			
S	0.15			
Nb (ppm)	4.1			
Zr	59		200	
Hf	1.6	1.5	4.9	1.0
Ta		0.22	0.85	0.14
U	0.22	–	–	–
Th	–	0.4	0.6	–
Y	14			
Sr	142			
Rb	1.31			
Li	4.4			
Ba	49	30	70	40
Zn	4			
Ni	95	290	290	300
V		40	70	40
Co		24	27	23
Sc		12	36	9.8
La	3.48	3.3	6.4	3.6
Ce	8.9	9	22	10
Nd	5.56	5	18	5
Sm	1.6	1.5	5.9	1.7
Eu	0.794	0.78	1.42	0.81
Gd	2.01			
Tb		0.3	1.3	0.3
Dy	2.34	2.4	9	2.4
Er	1.50			

Table 1: (Continued).

Split Technique	,2 (a, b, c) XRF, ID	,57 (d) INAA	matrix (d) INAA	grey fragment (d) INAA
Yb	1.50	1.6	5.1	1.4
Lu	0.23	0.21	0.66	0.18
Ge (ppb)				
Ir		10	9	10
Au		3	3	3

Table 1: (Continued).
From Lindstrom and Lindstrom (1986).

Split Technique	,151g INAA	,151 INAA	,152 INAA	,153 INAA	,154 INAA	,155 INAA
SiO_2 (wt%)						
TiO_2	1.17	0.70		0.41		
Al_2O_3	24.9	24.7		24.9		
Cr_2O_3	0.15	0.16	0.12	0.14	0.14	0.12
FeO	6.34	5.99	6.18	6.21	6.02	6.02
MnO						
MgO	6.2	6.5		6.1		
CaO	15.5	14.9	15.3	15.4	14.9	15.0
Na_2O	0.36	0.33	0.34	0.34	0.34	0.33
K_2O						
Nb (ppm)						
Zr	40	30	38	50	32	48
Hf	1.57	0.8	1.10	1.27	0.89	1.16
Ta	0.28	0.103	0.112	0.152	0.128	0.148
U	0.11	0.05	0.18	0.17	0.13	0.06
Th	0.47	0.52	0.52	0.72	0.84	0.71
Sr	165	155	170	147	151	150
Ba	45	34	45	46	47	50
Ni	360	300	312	297	296	290
Co	28.5	24.8	27	25.2	24.9	24.6
Sc	15.2	13.4	12.0	13.1	11.8	11.5
La	2.76	1.68	3.17	3.46	2.69	2.4
Ce	7.1	4.3	8.3	9.2	6.6	5.7
Nd	4.5	2.9	5.0	5.7	4.0	3.4
Sm	1.61	0.984	1.621	1.824	1.258	1.164

Table 1: (Continued)

Split Technique	,151g INAA	,151 INAA	,152 INAA	,153 INAA	,154 INAA	,155 INAA
Eu	0.835	0.75	0.765	0.762	0.74	0.745
Gd						
Tb	0.41	0.235	0.403	0.44	0.29	0.295
Dy						
Er						
Yb	1.57	1.06	1.60	1.61	1.26	1.28
Lu	0.237	0.163	0.24	0.248	0.193	0.203
Ge (ppb)						
Ir	15	14	13	13	13	13
Au	6.2	4.1	4.8	3.5	7.9	3.5

Table 2: Trace element data for 77017. Concentrations in ppb.
From Morgan et al. (1974).

	Sample 77017,48
Ir	17
Os	
Re	1.7
Au	5.65
Pd	
Ni (ppm)	443
Sb	0.72
Ge	110
Se	68
Te	1.9
Ag	0.87
Br	35
In	
Bi	0.22
Zn (ppm)	2.5
Cd	9
Tl	0.77
Rb (ppm)	1.34
Cs	61
U	137

Table 3: U-Th-Pb for 77017.
From Nunes et al. (1974).

wt (mg)	94.7	79.8
U (ppm)	0.2699	0.4147
Th (ppm)	1.025	1.489
Pb (ppm)	0.5733	0.8663
$^{232}Th/^{238}U$	3.92	3.71
$^{238}U/^{204}Pb$	643.0	863.0

Table 4: Rb-Sr composition of 77017.
Data from Nyquist et al. (1974).

	Sample 77017,2
wt (mg)	68.4
Rb (ppm)	1.310
Sr (ppm)	141.5
$^{87}Rb/^{86}Sr$	0.0268 ± 3
$^{87}Sr/^{86}Sr$	0.70072 ± 6
T_B	4.22 ± 0.20
T_L	4.40 ± 0.20

B = Model age assuming I = 0.69910 (BABI + JSC bias)
L = Model age assuming I = 0.69903 (Apollo 16 anorthosites for T = 4.6 b.y.)