60016 FRAGMENTAL POLYMICT BRECCIA 4307 g

INTRODUCTION: 60016 is a friable, medium gray breccia with a porous clastic matrix and abundant light and dark clasts of various sizes (Fig. 1).

The sample was collected 14-15 m southwest of the Lunar Module where it had a poorly developed fillet. Its orientation is known. It is subrounded and zap pits are present on all surfaces.

FIGURE 1. S-78-34417.

PETROLOGY: Johan and Christophe (1974), Haselton and Nash (1975a,b), Takeda et al. (1979), Misra and Taylor (1975) and LSPET (1973) provide limited petrographic information. The rock is polymict with a variety of clast types in a porous, unequilibrated matrix that is essentially free of glass (Fig. 2). Grain size is seriate from several mm downwards. Some rust is present.

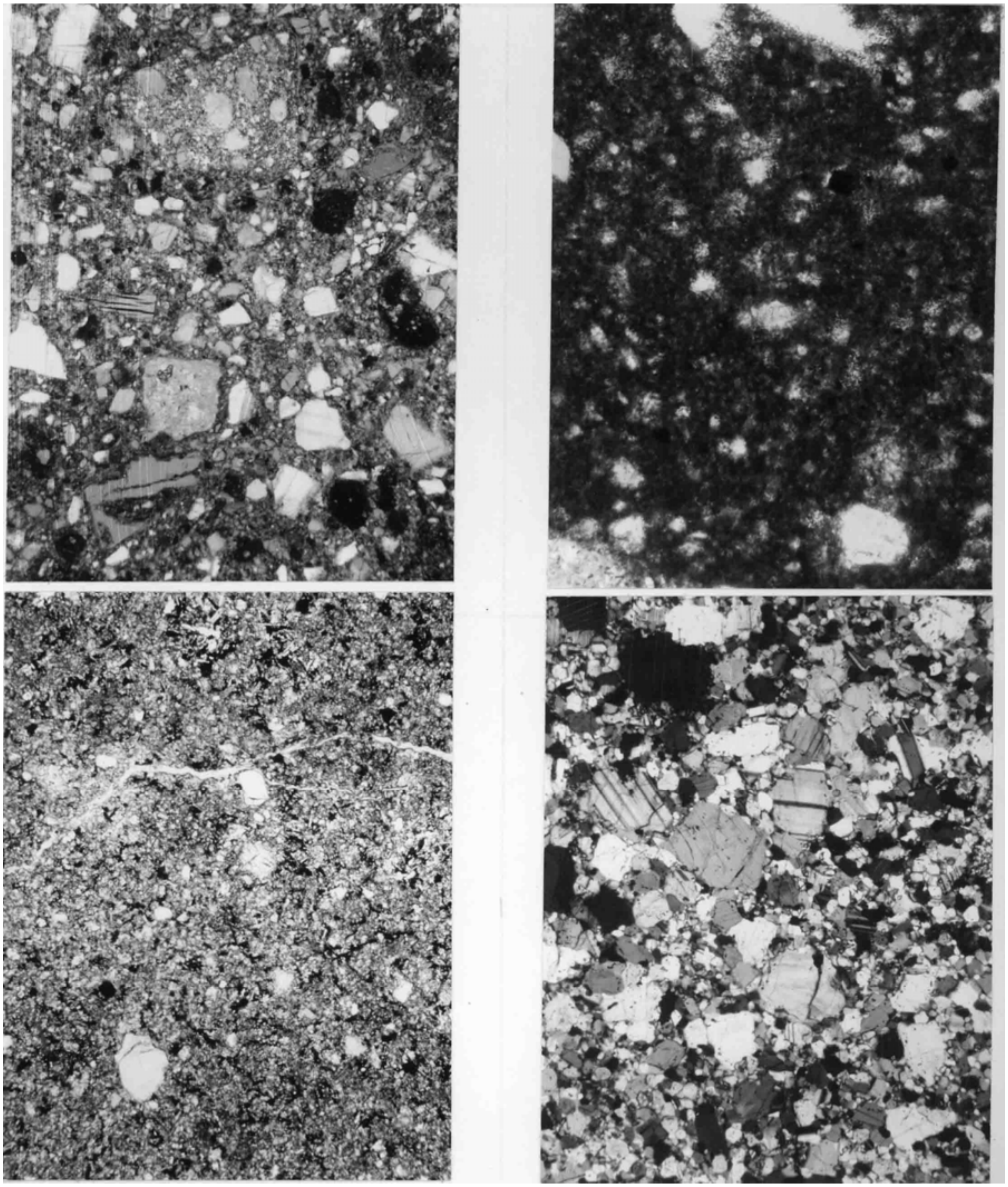

FIGURE 2.
a) 60016,83. general matrix, ppl. width 2 mm.
b) 60016,83. vitric breccia clast, ppl. width 0.5 mm.
c) 60016,86. fine-grained poikilitic melt clast, ppl. width 2 mm.
d) 60016,98. feldspathic granoblastic impactite, xpl. width 2 mm.

Mineral fragments of plagioclase, pyroxene, olivine, spinel and metal are present. Lithic clasts include cataclastic and recrystallized anorthosite, coarse-and fine-grained poikilitic impact melt, granoblastic material, noritic anorthosite with relict cumulate texture, dark-to-vitric matrix breccia and clast-bearing basaltic impact melt. Also present are several types of glass beads and fragments in various stages of devitrification, and rare agglutinates. Most of the clasts show minimal effects of shock or thermal metamorphism.

Plagioclase in mineral and anorthosite clasts is of typical highlands composition (An_{96-98}, low Fe, Mg; Johan and Christophe, 1974). These authors also report systematic variations of Fe, Mg and Na in plagioclase with respect to twin lamellae and associated intergrowths of exsolved pyroxene and silica (Fig. 3). Pyroxene clast compositions are given in Figure 4. One discrete grain of orthopyroxene (En_{79}) with ilmenite lamellae yielded an equilibration temperature of 900-1000ºC based on the coexisting mineral compositions (Fig. 5) (Haselton and Nash, 1975a,b). Metal grains in the matrix that are large enough to analyze by microprobe are homogeneous with 4-6% Ni (Fig. 6) (Misra and Taylor, 1975).

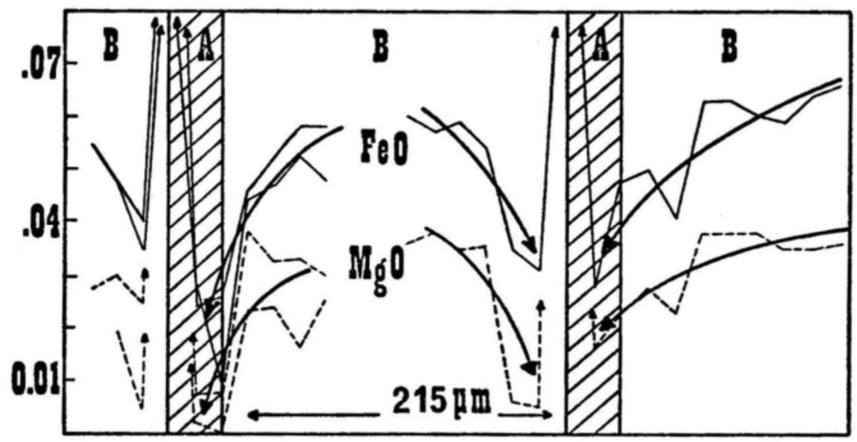

FIGURE 3. Plagioclase; from Johan and Christophe (1974).

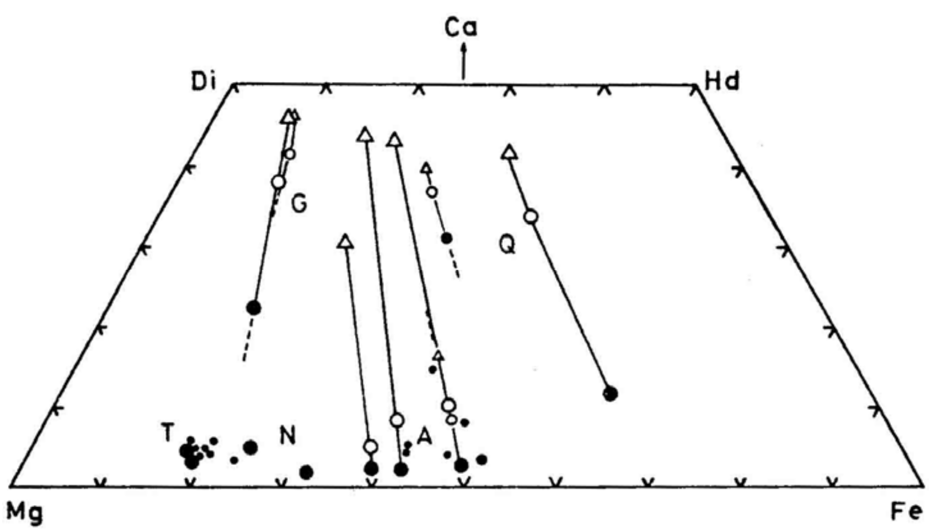

FIGURE 4. Pyroxenes; from Takeda et al. (1979).

Nearly all of the dark clasts (Fig. 1) are aphanitic melts. In thin section they are glassy with an obvious melt texture. Most are packed with abundant plagioclase clasts and could also be called vitric matrix breccias (Fig. 2). Poikilitic clasts occur as both coarse- and fine-grained varieties (Fig. 2). They are very similar to typical Apollo 16 poikilitic rocks such as 60315 and 65015. Macroscopically they appear as pale gray crystalline clasts.

CHEMISTRY: Bulk rock major element analyses are given by Janghorbani et al. (1973) and S.R. Taylor et al.(1974). Bulk trace element data are provided by these authors and Krähenbühl et al. (1973), Ganapathy et al. (1973), Garg and Ehmann (1976), Jovanovic and Reed (1976a,b) and Goel et al. (1975). All of these analyses are of splits of a single sample of chips and fines subdivided at the LCL. Wänke et al. (1975) give major and trace element chemistry on an aphanitic clast, a poikilitic clast and a granoblastic impactite clast. Goel et al. (1975) report nitrogen data on separated light and dark clasts. The bulk rock is compositionally very similar to the local soils, but with slightly lower TiO_2 and Cr_2O_3 (Table 1). Its REE pattern (Fig. 7) and Zr/Hf ratio is typical of a highland breccia with trace element chemistry dominated by KREEP (S.R. Taylor et al., 1974; Garg and Ehmann, 1976). Krähenbühl et a1. (1973) detect an enrichment of volatile relative to involatile elements (e.g. high Tl/Cs and Tl/U) and conclude that the rock is probably enriched in a fumarolic component.

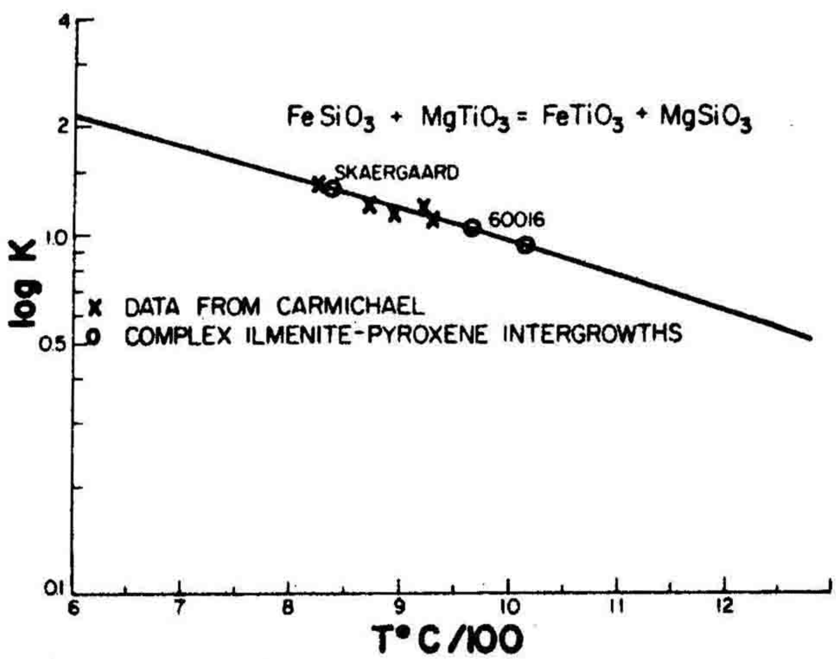

FIGURE 5. Equilibration temperature; from Haselton and Nash (1975b).

Clast analyses by Wänke et al. (1975) are reproduced in Table 1. Both the aphanite and the poikilitic clast are rich in KREEP and in siderophiles indicating a probable impact origin. The granoblastic impactite has low levels of incompatibles and may be low in siderophiles based on Co (Table 1). No other siderophile data are available on this clast.

STABLE ISOTOPES: Clayton et al. (1973) report δO^{18} values, listed in Table 2. The uniform values indicate a dominant plagioclase component in all samples.

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Weber and Schultz (1978) report K-Ar gas retention ages of 3.8 ± 0.1 b.y. for both the poikilitic and the dark aphanite clasts analyzed by Wänke et al. (1975).

RARE GAS/EXPOSURE AGES: Bogard et al. (1973) and Weber and Schultz (1978) provide noble gas data for the bulk rock. The matrix of 60016 contains a large amount of trapped solar gas, probably indicating a significant regolith component.

Noble gas data and ^{21}Ne and ^{38}Ar exposure ages for clasts (Table 3) are also given by Weber and Schultz (1978).

TABLE 1. Summary chemistry of 60016 bulk rock and clasts.

	Bulk rock	,22.4 aphanite	,48.4 poikilitic	,51.4 granoblastic
SiO_2	45.5	43.0	44.7	44.3
TiO_2	0.29			0.27
Al_2O_3	27.4	20.03	15.88	29.48
Cr_2O_3	0.07	0.15	0.21	0.09
FeO	4.8	7.42	11.5	4.0
MnO	0.057	0.09	0.12	0.63
MgO	6.2	7.64	12.45	3.82
CaO	15.2	11.9	10.8	17.2
Na_2O	0.48	0.49	0.60	0.31
K_2O	0.10	0.29	0.33	0.01
P_2O_5				
Sr		160		190
La	13.3	55.9	58.5	0.99
Lu	0.6	2.27	2.46	0.10
Rb	2.3			
Sc	8.2	13.6	15.6	7.43
Ni	300	740	1940	
Co	27	42.3	105	6.19
Ir ppb	5.7	15	36	
Au ppb	5.9	15	36	
C				
N	28			
S				
Zn	7.6			
Cu				

All clast analyses by Wänke *et al.* (1975).
Oxides in wt%; others in ppm except as noted.

MICROCRATERS: 60016 is subrounded in shape with microcraters on all sides. This suggests a complex exposure history that includes tumbling. The surface is probably in cratering equilibrium (Fig. 8) (Morrison et al. 1973; Neukum et al., 1973). Total exposure of the rock after lithification may have been on the order of 15-20 million years, assuming a constant micrometeoroid flux rate (Morrison et al., 1973).

PHYSICAL PROPERTIES: Intrinsic and structure sensitive magnetic parameters and some characteristics of the natural remanent magnetization of 60016 were measured by Nagata et al. (1974,1975) and Cisowski et al. (1975). No significant NRM residue remains in the rock after 250 Oe·rms demagnetization. Therefore there is no magnetic component present which can be attributed to ordinary thermoremanent magnetization although the relatively stable component up to 250 Oe·rms may have some significance for lunar magnetism (Nagata et al., 1974).

The proportions of Fe-bearing phases, the Fe^0/Fe^{2+} ratio and the average composition of the ferromagnetic metal component have also been determined by magnetic and Mossbauer techniques (Huffman et al., 1974; Nagata et al., 1974). Iron metal makes up ~0.33 wt% of the rock. About 71% of this ferromagnetic metal can be attributed to a kamacite component averaging ~5 wt% Ni (erroneously reported as 15 wt% Ni in Nagata et al., 1974). The remainder of the metal is apparently pure iron. This contrasts with the microprobe data of Misra and Taylor (Fig. 6) which show no metal with <4 wt% Ni. Nagata et al. (1975) conclude that this discrepancy can be resolved if the pure iron component exists as micron-size particles too small to analyze by microprobe and possibly forming by subsolidus reduction of oxide and silicate phases. FMR studies show that the metal was annealed at 700-900˚C (Fig. 9) (Tsay and Bauman, 1975).

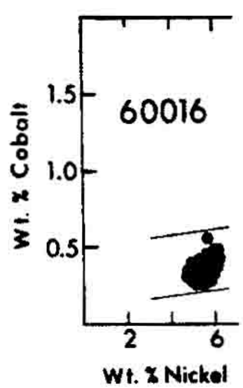

FIGURE 6. Metals; from Misra and Taylor (1975).

TABLE 2. δO^{18} of various portions of 60016.

matrix	5.73
plagioclase	5.78
light clasts	5.62
dark clasts	5.67

The reflectance (albedo) of the 60016 matrix has been measured by Adams and McCord (1973) and Charette and Adams (1977) (Fig. 10). Dollfus and Geake (1975) report polarimetric properties of both the poikilitic and the aphanite clast analyzed by Wänke et al. (1975).

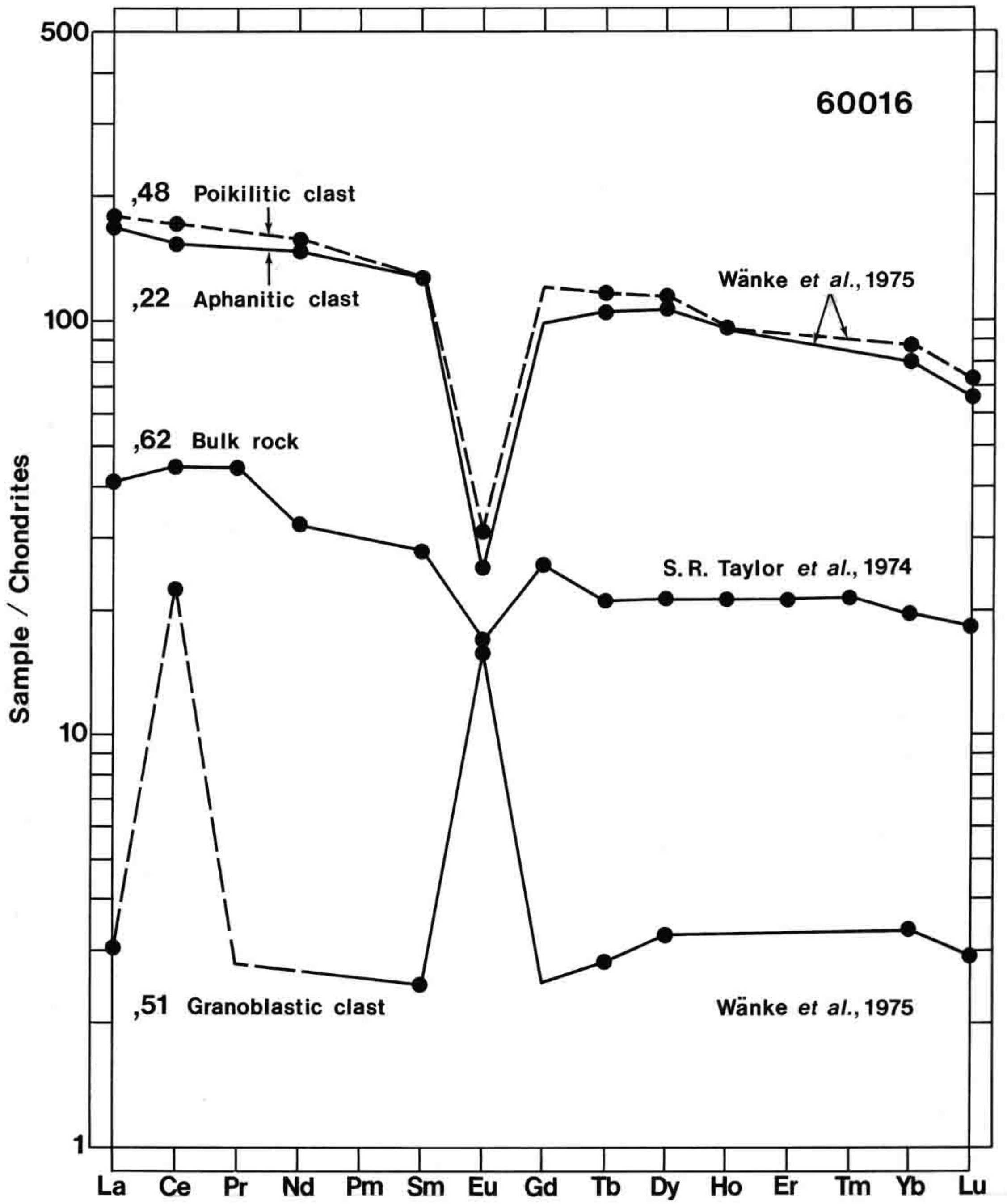

FIGURE 7.

TABLE 3. ^{21}Ne and ^{38}Ar exposure ages (m.y.) of three clasts from 60016.

		^{21}Ne	^{38}Ar
,22.4	aphanite	1.2 ± 0.2	3.0 ± 4.0
,48.4	poikilitic	3.5 ± 0.7	4.0 ± 1.5
,51.4	granoblastic	0.3 ± 0.1	1.2 ± 0.4

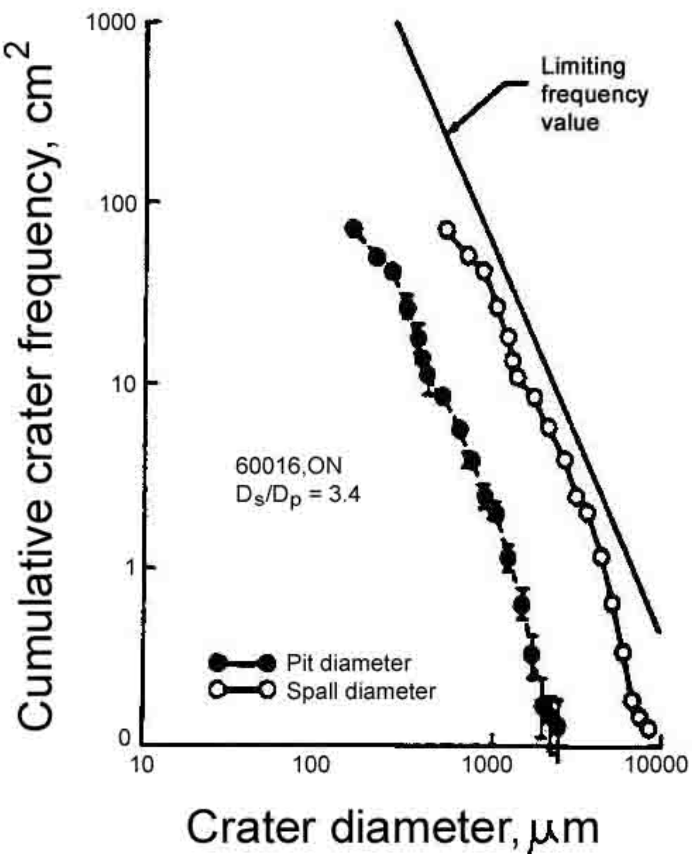

FIGURE 8. Microcraters; from Morrison et al. (1973).

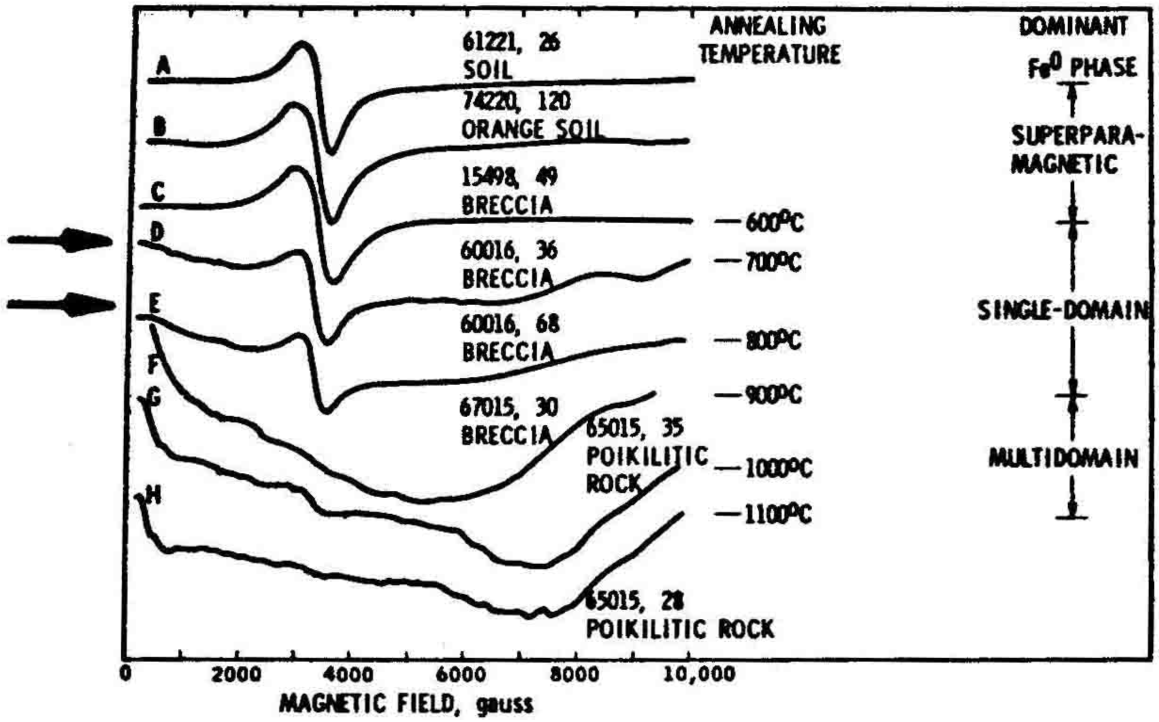

FIGURE 9. Correlation between ferromagnetic resonance and annealing temperature for metal phases; from Tsay and Baumann (1975).

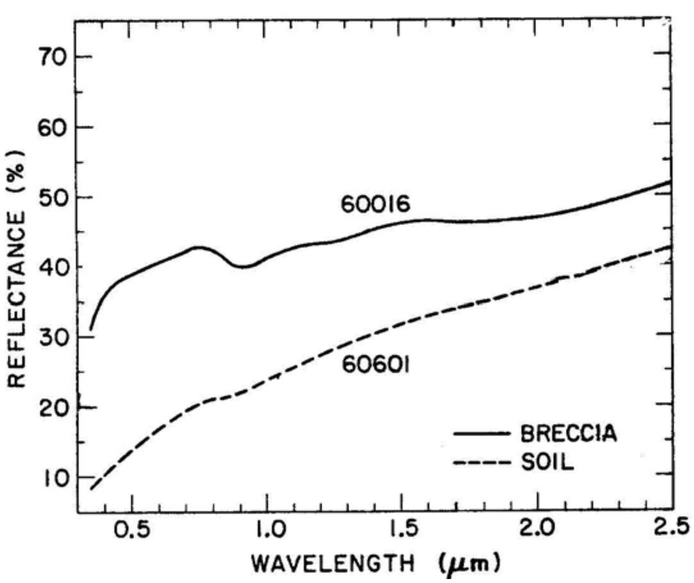

FIGURE 10. Spectral reflectance compared to mature soil; from Adams and McCord (1973).

PROCESSING AND SUBDIVISIONS: In 1972, 60016 was sawn into three main pieces and the slab extensively subdivided and allocated (Fig. 11). All of the various "whole rock" properties published so far were measured on splits of the slab. Bulk chemistry, the oxygen isotopes and rare gases were measured on splits of one undocumented sample of chips and fines (originally ,49—not shown on Fig. 11). The aphanite clast analyzed for chemistry, rare gases, exposure age and polarimetric properties was an interior clast (,48). The poikilitic clast also analyzed for the same properties was a pale gray exterior clast (,22 and ,23). The granoblastic clast was a large white exterior clast (,51 and ,53). Not all splits of the rock are shown in Figure 11.

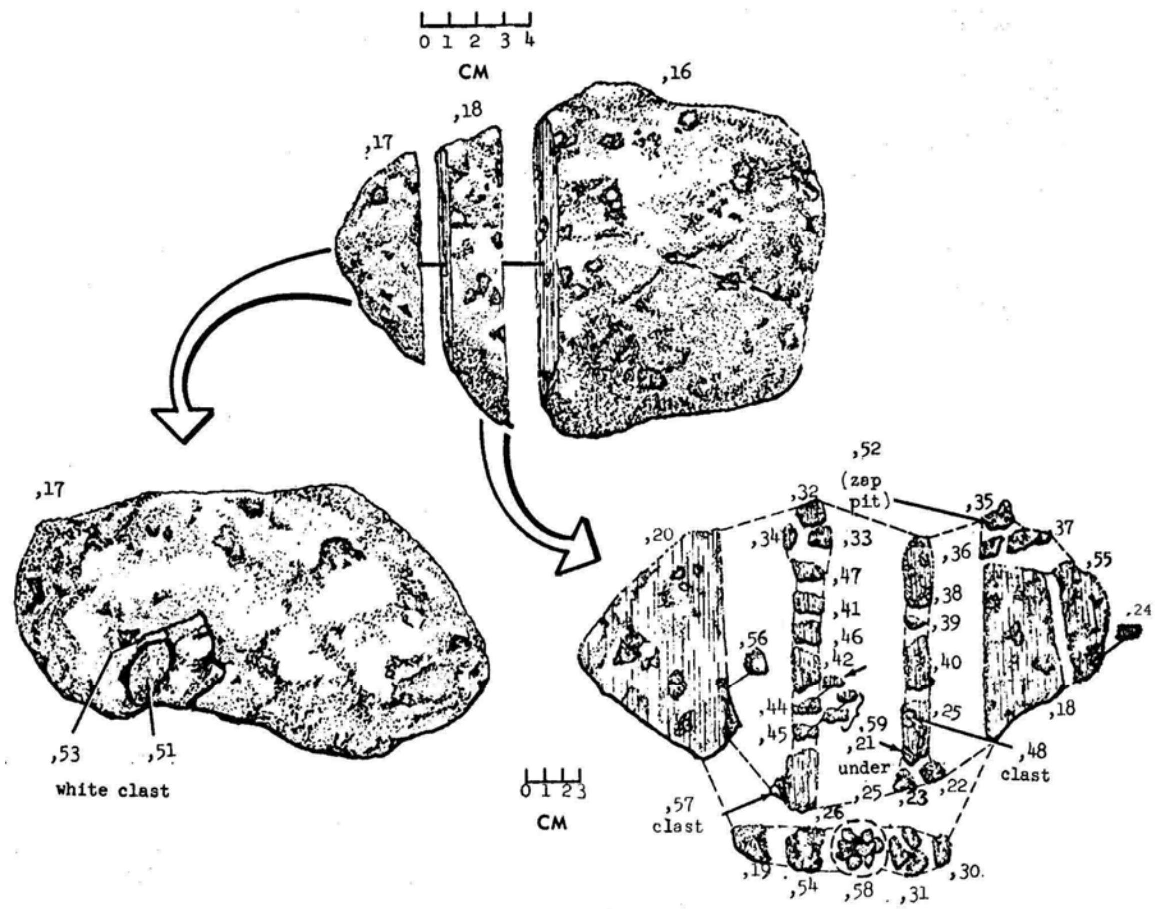

FIGURE 11.