67016 FRAGMENTAL POLYMICT BRECCIA 4262 g

INTRODUCTION: 67016 is a friable, light gray breccia with abundant light and dark clasts (Fig. 1). It was collected just outside the southeast rim of North Ray Crater; lunar orientation is known. Zap pits are present on all sides, with preserved exterior surfaces indicating a rather complex exposure history.

PETROLOGY: 67016 is a polymict breccia dominated by two types of lithologies; granoblastic lithic fragments and clast-rich, dark, aphanitic melt breccia as abundant mineral clasts are also present. The matrix is fragmental but bonded by a small amount of glass.

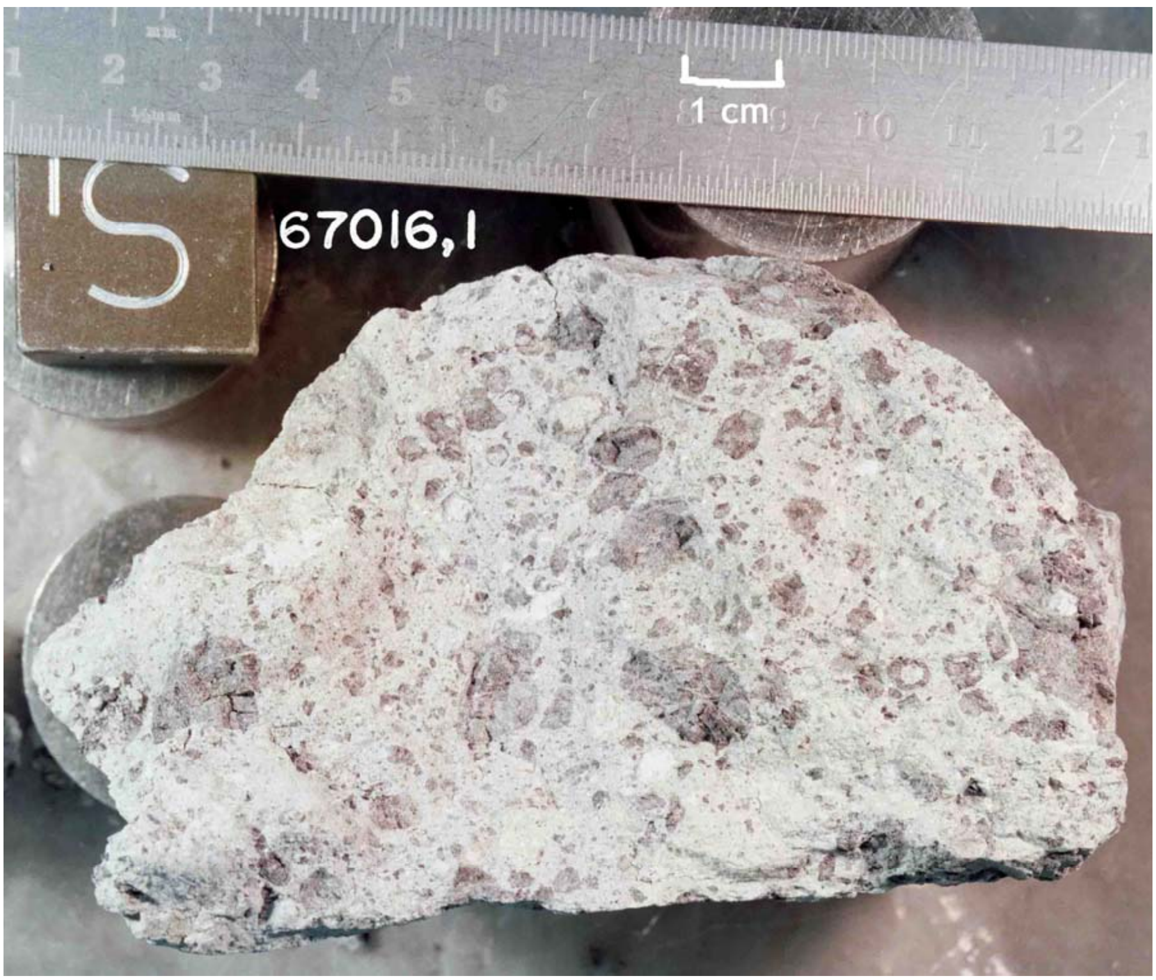



FIGURE 1. S-75-32783.

The matrix of 67016 is mostly fine-grained plagioclase with minor pyroxene, olivine, ilmenite, metal and spinel. Nord et al. (1975) note the presence of several small (< 0.1 mm) clasts of silica-potassium feldspar intergrowths. All of these "granitic" clasts have thin reaction rims of pyroxene. Nord et al. determined that the matrix is bonded by a small amount of glass at grain contacts and conclude that this rock could have been lithified by the North Ray event.

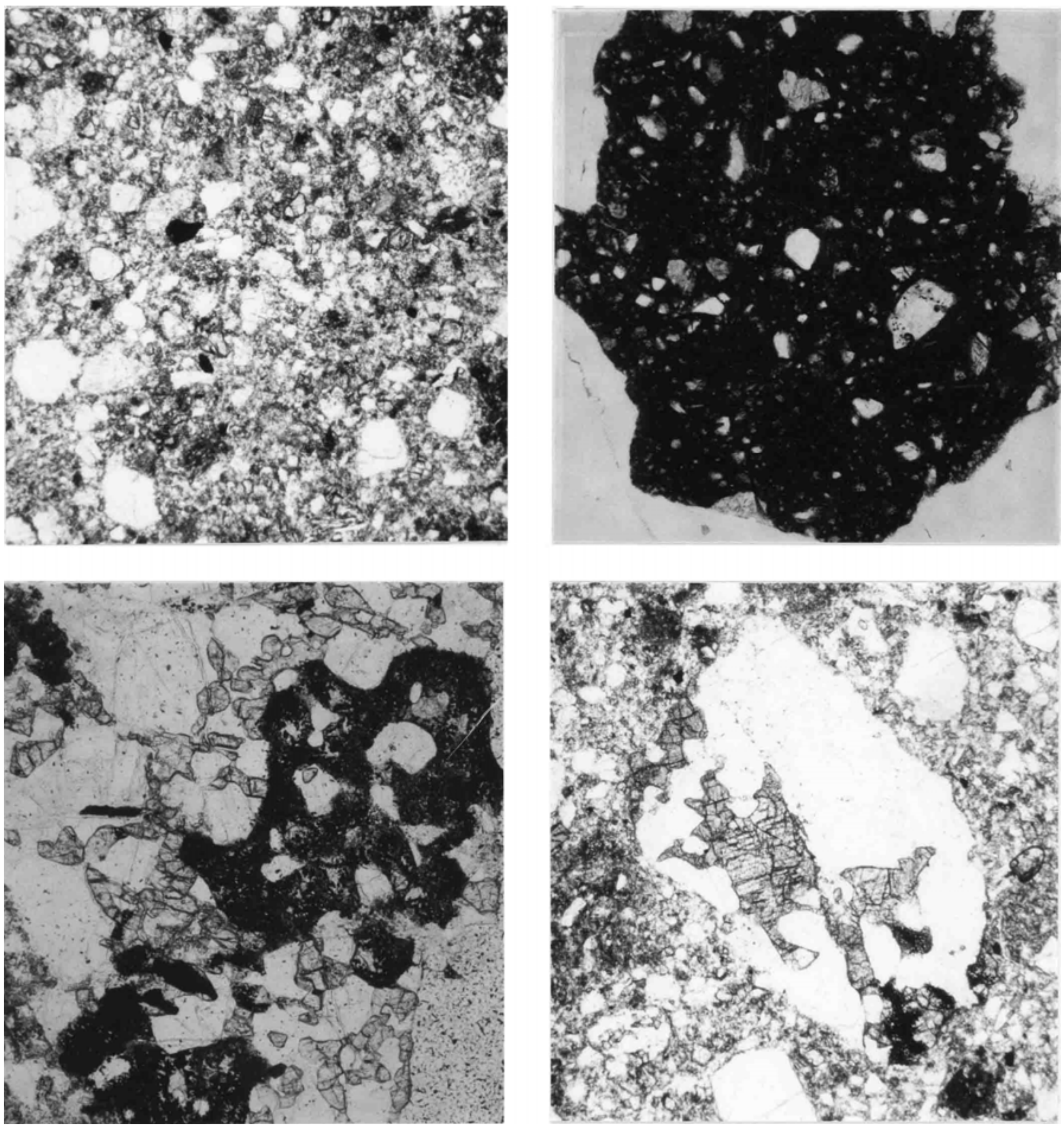


FIGURE 2.
a) 67016,111. Matrix, ppl. Width 2 mm.
b) 67016,189. Dark clast, analyzed by Hertogen et al. (1977), ppl. Width 2 mm.
c) 67016,111. Granoblastic clast with troilite-rich intergrowths replacing mafic minerals, ppl. Width 1 mm.
d) 67016,104. Possible ,cumulate clast, ppl. Width 2 mm.

The dark aphanitic melt clasts are packed with angular fragments, most of which are plagioclase grains (Fig. 2). In an electron microscopy study, Nord et al. (1975) found that the dark matrix was completely crystalline with blocky to anhedral plagioclase and interstitial pyroxene in a microsubophitic texture. The grain size of this dark matrix is on the order of a few microns.

Granoblastic lithologies include noritic, troctolitic and possibly gabbroic anorthosites. Mafic minerals are generally small (< 0.1 mm), rounded grains interstitial to larger, anhedral plagioclases (Fig. 2). Occasionally gradations to a coarser, more cumulate-appearing texture can be found. A fine-grained intergrowth rich in troilite (Fig. 2) appears to be replacing the mafic minerals in several granoblastic clasts.

Other clasts retain what may be a cumulate texture. These fragments show irregular mafic minerals interstitial to granoblastic plagioclase (Fig. 2). These clasts have generally not been affected by cataclasis.

A single 8-mm fragment of cataclastic anorthosite was found with rare pyroxene (?) as intra-crystalline rods and stringers and interstitial grains. Plagioclase up to 4 mm long is preserved in a relict granoblastic texture.

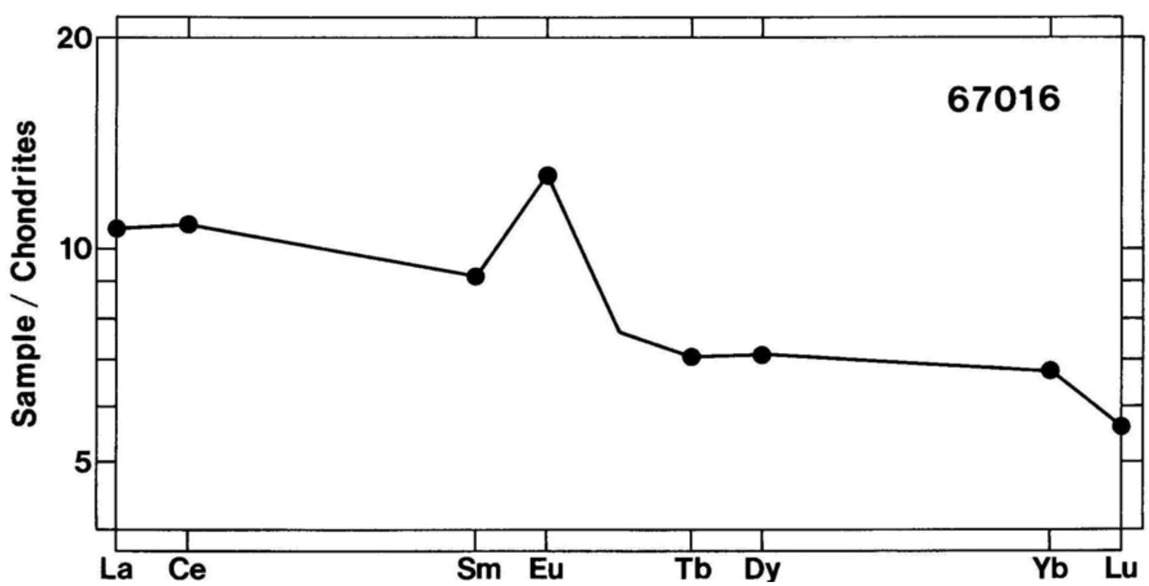



FIGURE 3. Rare earths, from Wanke et al. (1976).

CHEMISTRY: Several chemical analyses on 67016 are available; references are given in Table 1.

67016 is one of a number of highly aluminous ($Al_2O_3$ ~30%) polymict breccias from the North Ray Crater area that are characterized by low levels of incompatibles and a relatively high Fe/Mg (Table 2, Fig. 3). Overall 67016 is compositionally very similar to the North Ray soils. The low total C, N and other light gases indicate no substantial solar wind component in the rock (Fig. 4). Nitrogen was the only gas detected by Gibson and Andrawes (1978) upon crushing to 25 tons. Gibson and Chang (1974) note that the low temperature evolution of $CO_2$ may indicate the presence of a "carbonate-like phase" in 67016.

TABLE 1. Chemical studies of 67016 (all bulk rock or matrix except as noted).

| REFERENCE | SPLIT ANALYZED | ELEMENTS ANALYZED |
|---|---|---|
| Duncan et al. (1973) | ,47 | majors and traces |
| Brunfelt et al. (1973) | ,86 | majors and traces |
| S.R. Taylor et al. (1974) | ,63 | majors and traces |
| Janghorbani et al. (1973) | ,78 | majors |
| Wänke et al. (1976) | ,173 | majors, traces, siderophiles |
| Wänke et al. (1977) | ,173 | V |
| Garg and Ehmann (1976) | ,78 | Zr, Hf, Fe, Co, Sc, Cr, REEs, Th |
| Hertogen et al. (1977) | ,167,170,172* | meteoritic siderophiles and volatiles |
| Jovanovic and Reed (1973) | ,64 | halogens, Li, U, Te, $P_2O_5$ |
| Eldridge et al. (1975) | ,2 | K, U, Th |
| Moore et al. (1973) | ,90 | C |
| Cripe and Moore (1974) | ,90 | S |
| Moore and Lewis (1976) | ,90 | C, N |
| Gibson and Andrawes (1978) | ,88 | N by crushing |
| Flory et al. (1973) | ,81,91 | Organogenic gases |
| Gibson and Moore (1975) | ,88 | Volatile gases |
| Gibson and Chang (1974) | ,88 | Volatile gases |

(*aphanitic melt clast, granoblastic clast and bulk rock respectively).

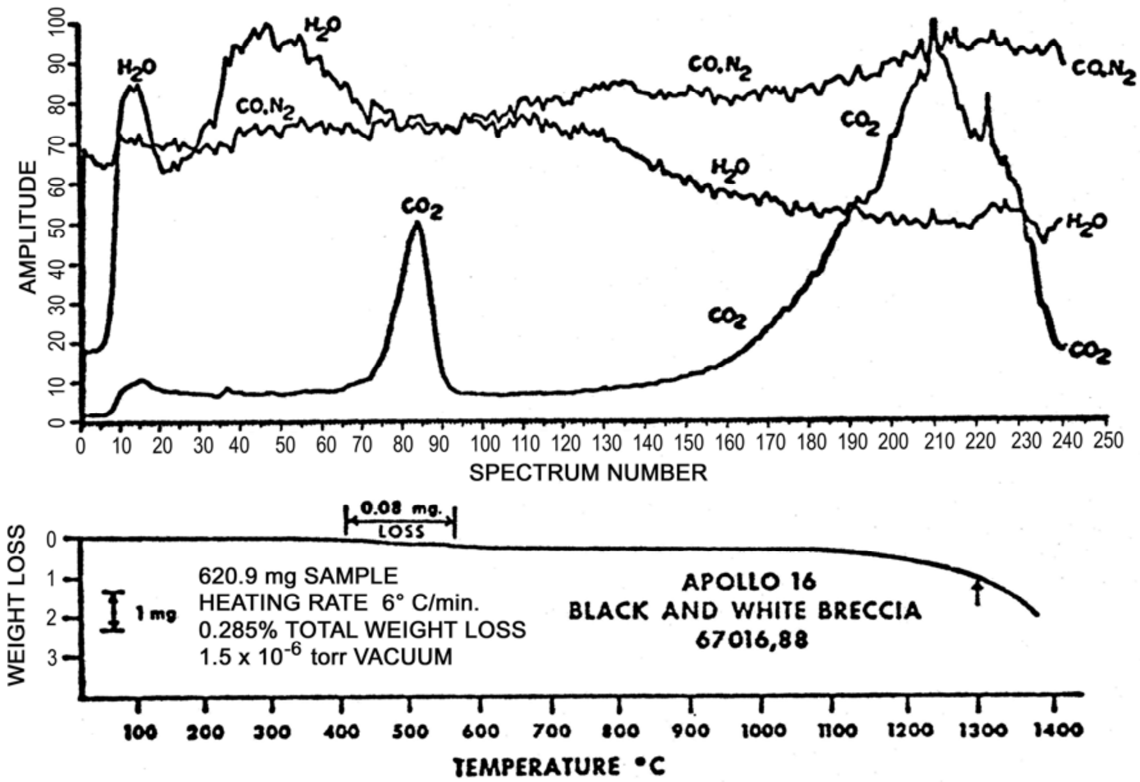
The only chemical analyses of clasts are provided by Hertogen et al. (1977) who report meteoritic siderophiles and volatiles for a typical dark matrix breccia clast (Fig. 2), and a very fine-grained granoblastic clast. Both of these lithologies were found to be very low in both siderophiles and incompatibles (Table 2).

STABLE ISOTOPES: Gibson and Chang (1974) report the $\delta^{13}C$ and $\delta^{18}O$ of $CO_2$ from 67016 in an attempt to characterize a possible "carbonate-like phase" (Table 3). These isotopic data are outside the ranges of meteoritic carbonates and terrestrial atmospheric contamination.

TABLE 2. Summary chemistry of 67016 lithologies.

| | Bulk Rock | Granoblastic clast | Dark aphanitic melt clast |
|---|---|---|---|
| $SiO_2$ | 44.5 | | |
| $TiO_2$ | 0.34 | | |
| $Al_2O_3$ | 29.6 | | |
| $Cr_2O_3$ | 0.07 | | |
| FeO | 3.7 | | |
| MnO | 0.051 | | |
| MgO | 4.1 | | |
| CaO | 16.4 | | |
| $Na_2O$ | 0.52 | | |
| $K_2O$ | 0.05 | | |
| $P_2O_5$ | 0.03 | | |
| Sr | 174 | | |
| La | 3.8 | | |
| Lu | 0.23 | | |
| Rb | 1.0 | 0.66 | 0.34 |
| Sc | 7.7 | | |
| Ni | 80 | 182 | 14 |
| Co | 10 | | |
| Ir ppb | 2.3-10 | 2.90 | 1.14 |
| Au ppb | 0.5-4.8 | 1.01 | 0.08 |
| C | 35 | | |
| N | 20 | | |
| S | ~175 | | |
| Zn | ~6 | 5.59 | 0.75 |
| Cu | ~2 | | |

Oxides in wt%; others in ppm except as noted.




Gas release pattern for light-matrix breccia 67016,88. Note the carbon dioxide evolution betwee 450-550° C.

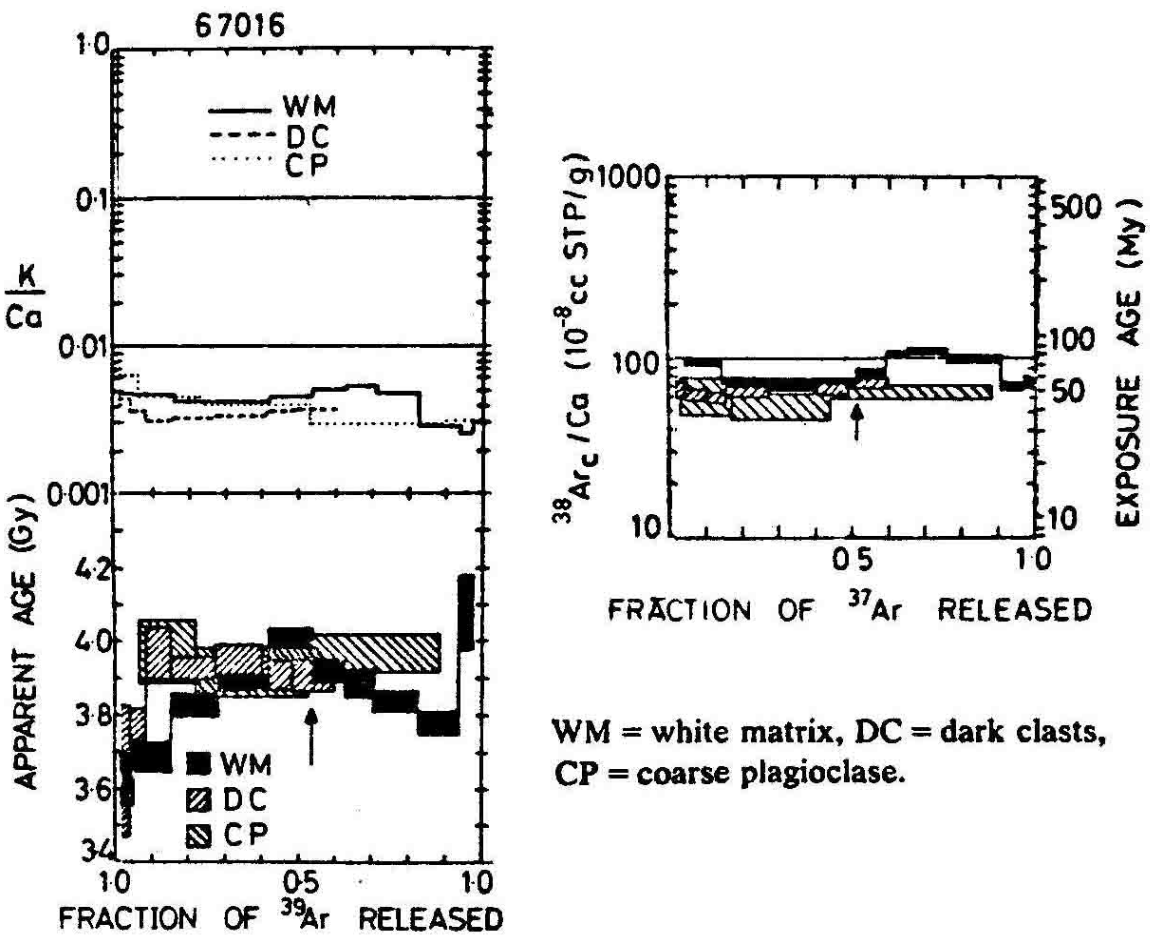
FIGURE 4. Gas releases, from Gibson and Chang (1974).

RADIOGENIC ISOTOPES/GEOCHRONOLOGY: Ar isotopic data are given by Turner and Cadogan (1975). The release patterns are shown as Figure 5. A sample of "white powdery matrix" yielded a complex release pattern with no plateau. The total Ar age of 3.88 b.y. places a lower limit on the age of 67016 (Turner and Cadogan 1975). A dark clast yielded a good plateau age of 3.95 ± 0.05 b.y. Since the rock must be younger than any clasts within it, the age of this clast is an upper limit to the age of 67016. Thus 67016 is constrained to be 3.88-4.00 b.y old. A coarse plagioclase separate also yielded a plateau age of 3.95 ± 0.07 b.y.

RARE GASES/EXPOSURE AGES: Turner and Cadogan (1975) provide Ar isotopic data on a split of matrix, a dark clast and a coarse plagioclase separate. All three splits yield Ar exposure ages of 40-50 m.y.

Bhandari et al. (1973)give surface exposure ages of 1 m.y. and 1.2 m.y. for two surface chips and a subdecimeter age of 15 m.y. from an interior chip, based on particle tracks. From the track gradient on opposite faces of the rock Bhandari et al. (1973 )also conclude that 67016 has been exposed in at least two orientations on the Moon. (Horz et al., 1975, quote a subdecimeter age of 15 m.y. by Lal, pers. comm., for a rock listed as 67015. The data are actually for 67016 and are the same as that given by Bhandari et al., 1973).

Cosmogenic radionuclide abundance data indicate that 67016 is unsaturated in $^{26}Al$ (Eldridge et al., 1973).

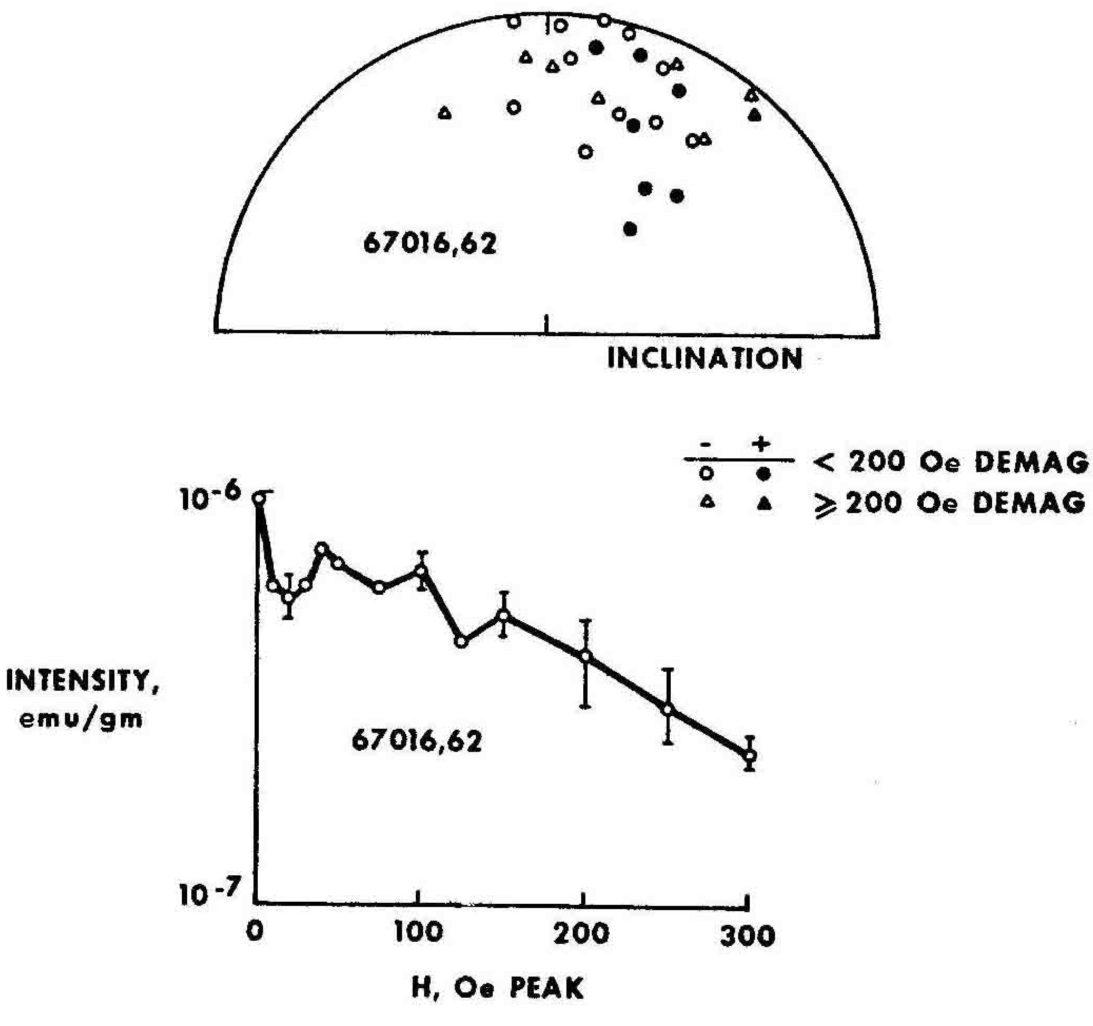



**WM = white matrix, DC = dark clasts, CP = coarse plagioclase.**

FIGURE 5. Ar releases, from Turner and Cadogan (1975).

PHYSICAL PROPERTIES: Pearce et al. (1973) find that 67016 contains one component of magnetization which is fairly stable against AF demagnetization (Fig. 6). This rock does not possess the FMR intensity characteristic of lunar fines (Housley et al., 1976).

PROCESSING AND SUBDIVISIONS: 67016 has been extensively split and widely allocated. Due to its friable nature 67016 was never sawn but was chipped into several smaller pieces in 1972 (Fig. 7). Most of the allocations were taken from ,2 with a few from ,3 and ,10.




AF demagnetization of 67016,62. No systematic changes in direction were observed above 200 Oe.

FIGURE 6. From Pearce et al. (1973).

TABLE 3. Isotopic composition Of $CO_2$ in 67016,88 (Gibson and Chang, 1974).

| Extraction method | $\delta^{13}C$ | $\delta^{18}O$ |
|---|---|---|
| Acid hydrolysis | -32.83 | -16.57 |
| Vacuum pyrolysis | | |
| 150-550°C | -12.53 | -33.41 |
| 550-1200°C | -14.08 | -31.03 |

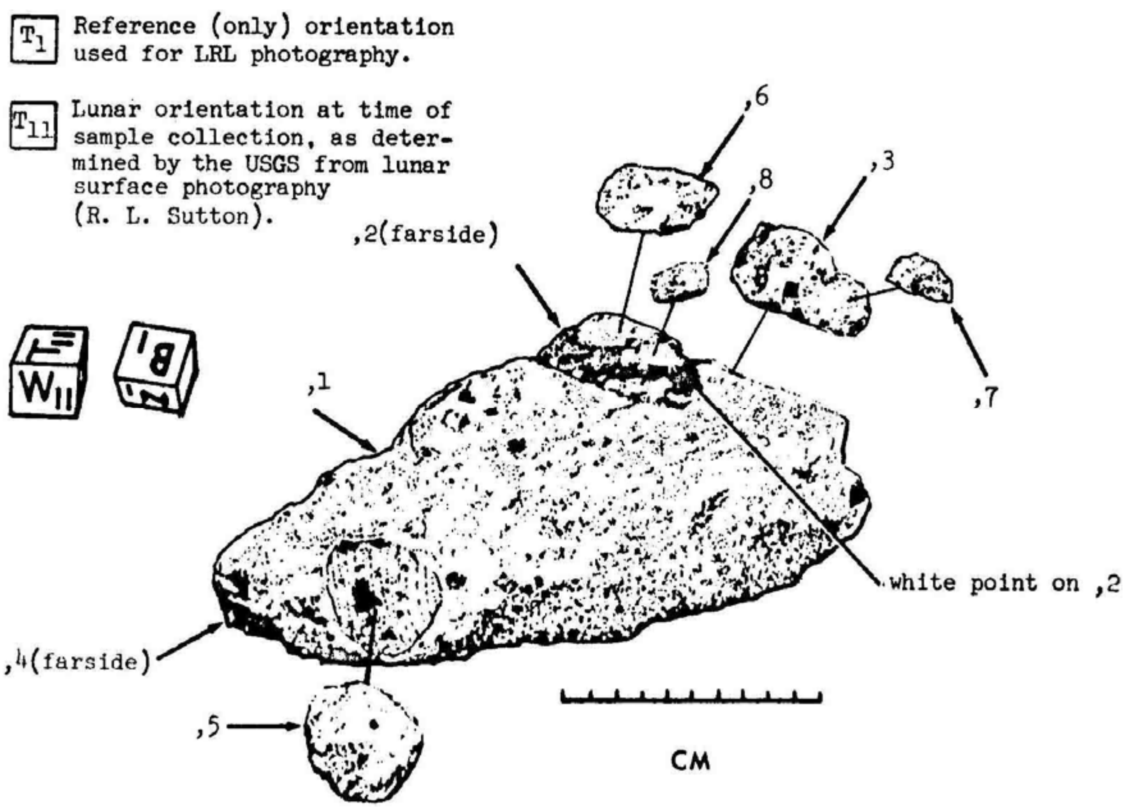



FIGURE 7. Major subdivisions of 67016.