60017 VARIOLITIC IMPACT MELT BRECCIA 5574 g

INTRODUCTION: 60017 is a crystalline, medium to dark gray, vesicular melt rock, containing clasts which are mainly dark melt breccia and macroscopically indistinct (Fig. 1). The melt, which has a variolitic texture, contains ~30% $A1_2O_3$.

Despite its number, 60017 was collected from Shadow Rock at Station 13 but its precise location on the boulder is unknown. Because it was broken from the boulder, one surface (B) is fresh while the others are subrounded. Few zap pits occur even on the surfaces that were exposed on the lunar surface.

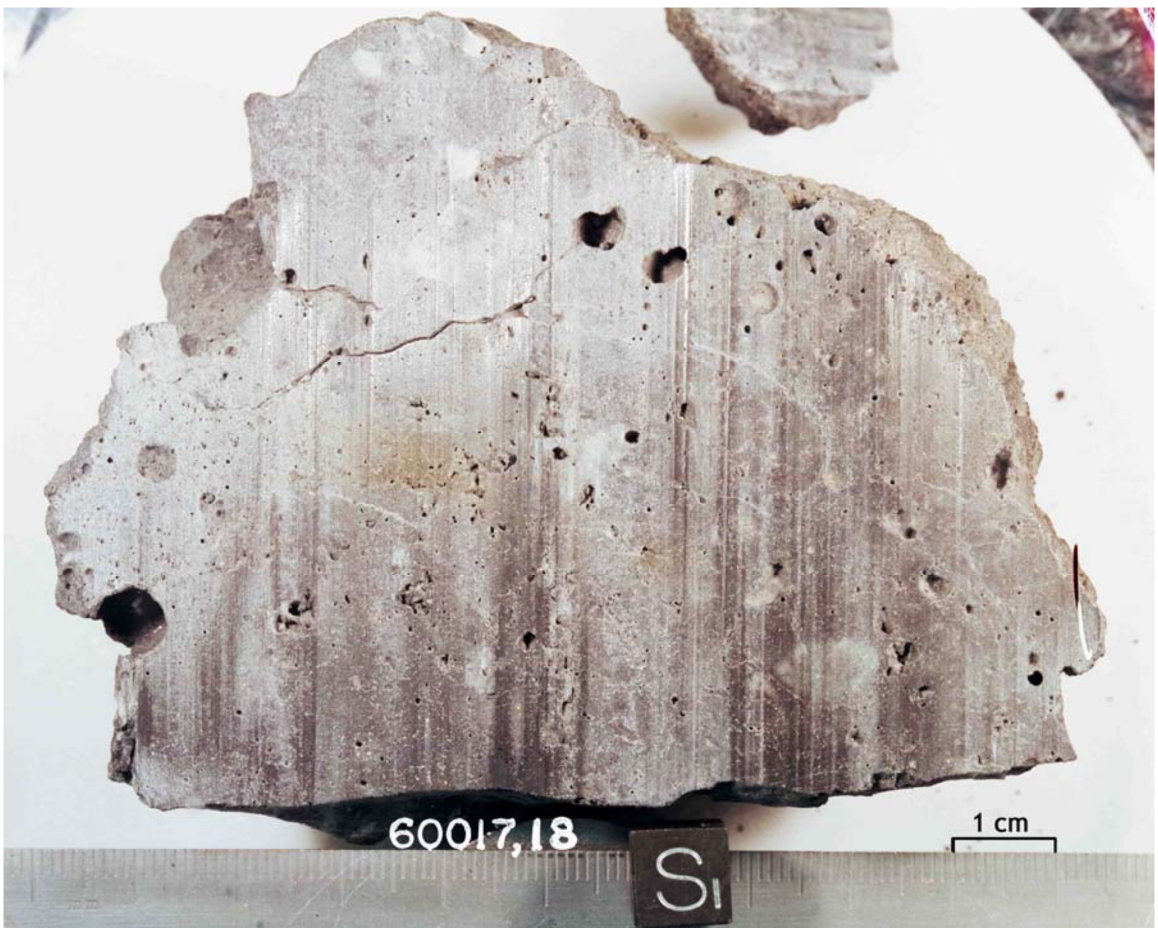

FIGURE 1. Saw-cut face. S-75-33756.

PETROLOGY: The rock contains two dominant lithologies: ~70% variolitic melt and ~30% dark aphanitic clasts (Fig. 2). The rock is heterogeneous at the thin section scale such that some thin sections contain only variolitic melt whereas others contain very little of it. Petrographic information of various thin sections is provided by Kridelbaugh et al. (1973), Nord et al. (1975), Misra and Taylor (1975), Ganapathy et al. (1974), and Engelhardt (1979). Cadenhead and Brown (1976) provide some details of a surface chip.

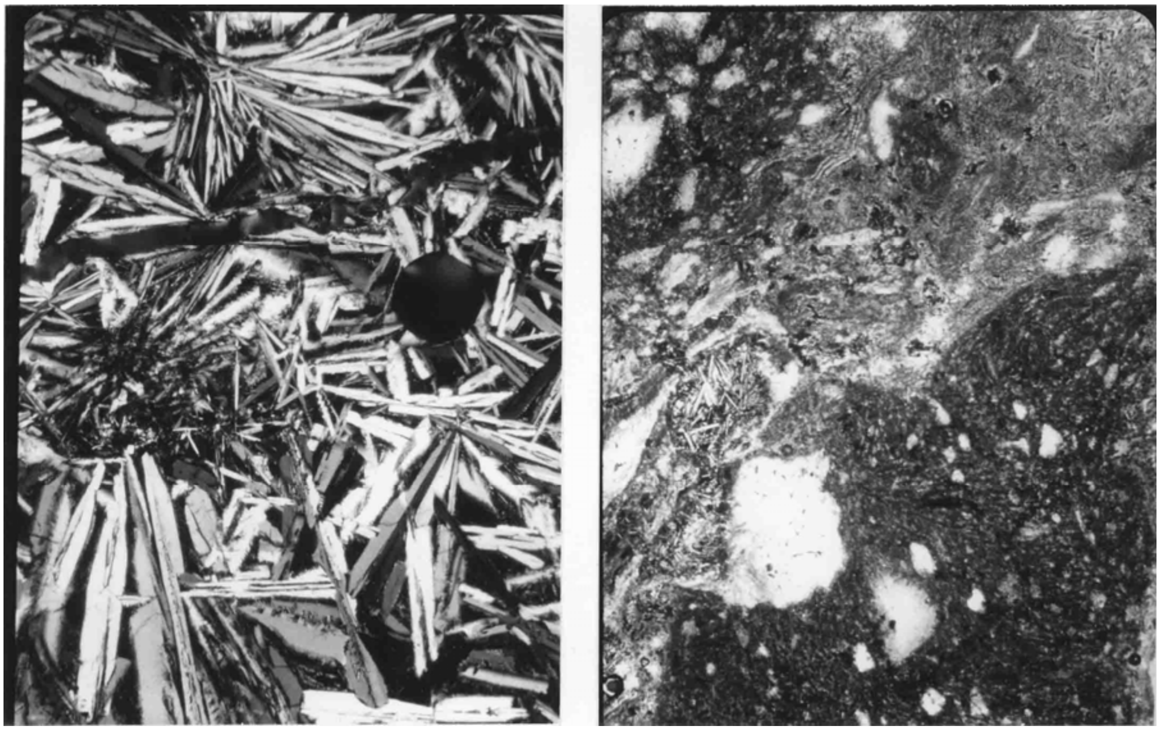

FIGURE 2.
a) 60017,116. variolitic melt, xpl. width 2 mm.
b) 60017,119. aphanitic melts, ppl, width 2 mm.

The variolitic melt consists of plagioclase laths with interstitial mafic minerals, minor ilmenite and Fe-metal, and very rare troilite and cryptocrystalline material. Although referred to as “devitrified glass” by Kridelbaugh et al. (1973) and Misra and Taylor (1975) the evidence leading to this conclusion is not stated. The typical textures are shown in Figure 2. The plagioclase laths which are up to ~2mm long have compositions of $An_{93\text{-}95}$ (Kridelbaugh et al., 1973). They are frequently skeletal and mainly untwinned. Spherulites are often cored by plagioclase xenocrysts. Analyses of mafic minerals by Kridelbaugh et al. (1973) show only olivine (Fo_{68}), although Nord et al. (1975) and Engelhardt (1979) refer to the mafic mineral as pyroxene. Analyses of metal by Misra and Taylor (1975) have an average of 5.7% Ni, 1.3,% Co, 0.05% P and 0.01% S. Co shows a wide scatter and is mainly out of the meteoritic range (Fig. 3). Nord et al. (1975), in a high voltage electron microscopy study, found no glass or evidence of deformation.

The variolitic melt is generally finer-grained towards the dark breccia clasts, and contains rare xenocrysts of pink spinel and a few small lithic clasts, including dunitic material.

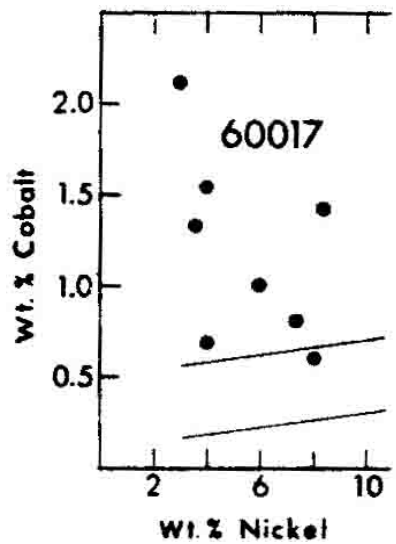

FIGURE 3. Metals; from Misra and Taylor (1975).

The dark breccia clasts are brown, aphanitic and inhomogeneous melt breccias. In places they are flow banded and deformed (Fig. 2). They are plagioclase-rich (>85%) and contain numerous plagioclase-rich xenocrysts and xenoliths which have various reaction rims. Petrographic descriptions are given by Kridelbaugh et al. (1973) and Nord et al. (1975). The former in particular note the bulk composition of "gabbroic anorthosite" and the variety of xenoliths, including shocked, recrystallized anorthosite (An_{94-96}) and small "anorthositic gabbro" (actually basalt-textured) clasts (?) which have plagioclase laths (An_{95}), interstitial olivine (Fo_{62-74}) and thin dark rims. Nord et al. (1975) note the presence of some isotropic material and deformation with low dislocation densities within the dark breccia material.

The boundary between the variolitic melt and the dark breccia clasts is generally distinct, but in places it is diffuse and irregular, suggesting considerable digestion of the clasts. Cadenhead and Brown (1976) describe the characteristics of a surface chip (,43) using various methods. The petrography of the chip is not known but they find it to be heterogeneous, not porous at sub-micron scales, and of low density (2.78 g/cc). The surface is enriched in volatiles and surface iron is reduced more than the interior.

CHEMISTRY: Major and trace element analyses of bulk rock (Table 1) are presented by Janghorbani et al. (1973), Rose et al. (1973), Laul and Schmitt (1973), Laul et al. (1974), Morrison et al. (1973) and S.R. Taylor et al. (1973). Krahenbuhl et al. (1973) and Ganapathy et al. (1974) report siderophile and other trace elements, Garg and Ehmann (1976) report trace elements, Tera et al. (1974) report U, Th, and Pb abundances, and Flory et al. (1973) report hydrocarbon and light element abundances. The latter suggest the presence of indigenous lunar methane. MacDougall et al. (1973) give a U abundance (~0.2 ppm) from fission track mapping. These are probably mainly analyses of variolitic melt.

Although Morrison et al. (1973) state that they received and analyzed a white chip, photodocumentation demonstrates that they received a dark vesicular chip. Nonetheless their analysis is significantly different from other analyses, in particular being lower in alumina and higher in magnesia. Krahenbuhl et al. (1973) and Ganapathy et al. (1974) give incorrect split numbers; they actually analyzed ,80.

60017 is significantly more aluminous than local soil compositions and has a positive Eu anomaly (Fig. 4). It is similar to Sample 63335 taken from the same boulder. The trace siderophiles are low (although not at indigenous levels) as are many North Ray Crater samples. The siderophile element ratios place the sample in meteoritic Group 6 of Ganapathy et al. (1974). Rose et al. (1973) obtained higher Ni and Ni/Co than other analysis.

Defocussed beam microprobe analyses of the dark breccia and their included "anorthositic gabbro" clasts are reported by Kridelbaugh et al. (1973). The dark breccia is similar in composition to the bulk breccia analyses, while the "anorthositic gabbro" clasts are much less aluminous (Table 1).

RADIOGENIC ISOTOPES AND GEOCHRONOLOGY: Murthy and Coscio (1977) and Murthy (1978) report $^{87}Sr/^{86}Sr$ for two hand-picked plagioclase clasts, which extrapolate to values close to BABI at 4.6 b.y. (Table 2).

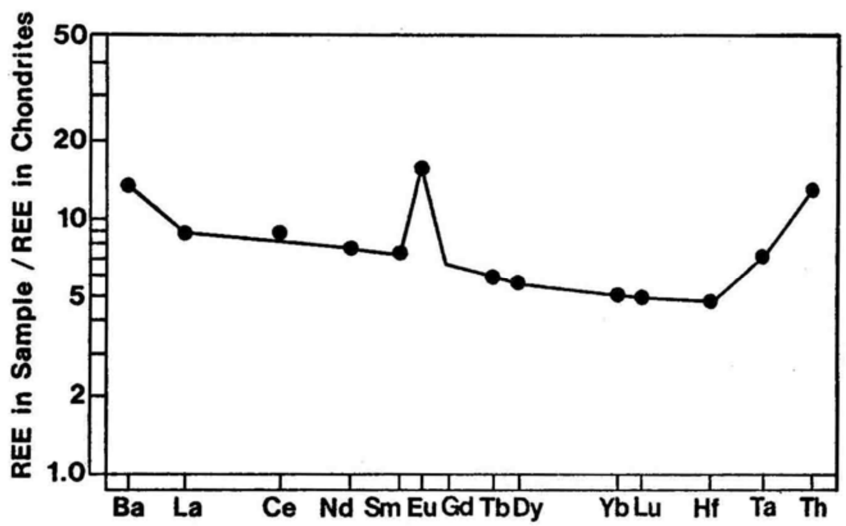

FIGURE 4. Rare earths; from Laul and Schmitt (1973).

Tera et al. (1974) report U, Th and Pb isotopic data for 60017,72, a bulk rock sample. The sample contains predominantly initial radiogenic lead rather than in situ-produced lead. The sample falls off a reference isochron which encompasses most other highlands samples on a $^{207}Pb/^{206}Pb$ v. $^{238}U/^{206}Pb$ evolution diagram (Fig. 5). The departure can be accounted for by assuming that the sample formed at ~4.0 b.y, from a source ~4.4 b.y. old or formed at ~3.9 b.y. from a source 4.5 b.y. old.

TABLE 1. Summary chemistry of 60017.

	Bulk rock or variolitic melt	dark breccia*	"anorthositic gabbro"*
SiO_2	44	46	46
TiO_2	0.3	0.2	1.1
Al_2O_3	31.0	31.2	22.9
Cr_2O_3	0.06		
FeO	3	3.3	9.2
MnO	0.04		
MgO	3	2.4	6.4
CaO	17.0	17.4	14.0
Na_2O	0.53	0.03	0.76
K_2O	0.07	0.43	0.05
P_2O_5	0.02	0.02	0.06
Sr	140 ?		
La	3.0		
Lu	0.16		
Rb	0.8		
Sc	6		
Ni	50		
Co	7		
Ir ppb	1.4		
Au ppb	0.4 ?		
C	30-105		
N	7-24		
S	120		
Zn	5		
Cu	2		

Oxides in wt%; others in ppm except as noted
*from DBA, Kridelbaugh et al.(1973)

TABLE 2. $^{87}Sr/^{86}Sr$ for plagioclase clasts in 60017,56.

$^{87}Sr/^{86}Sr$ for plagioclase clasts in 60017,56

	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr$ at 4.6 b.y*
I	0.69933 ± 5	0.69900 ± 5
II	0.69928 ± 5	0.69899 ± 5

* adjusted for bias by subtracting 0.00006 to be equivalent to Caltech data

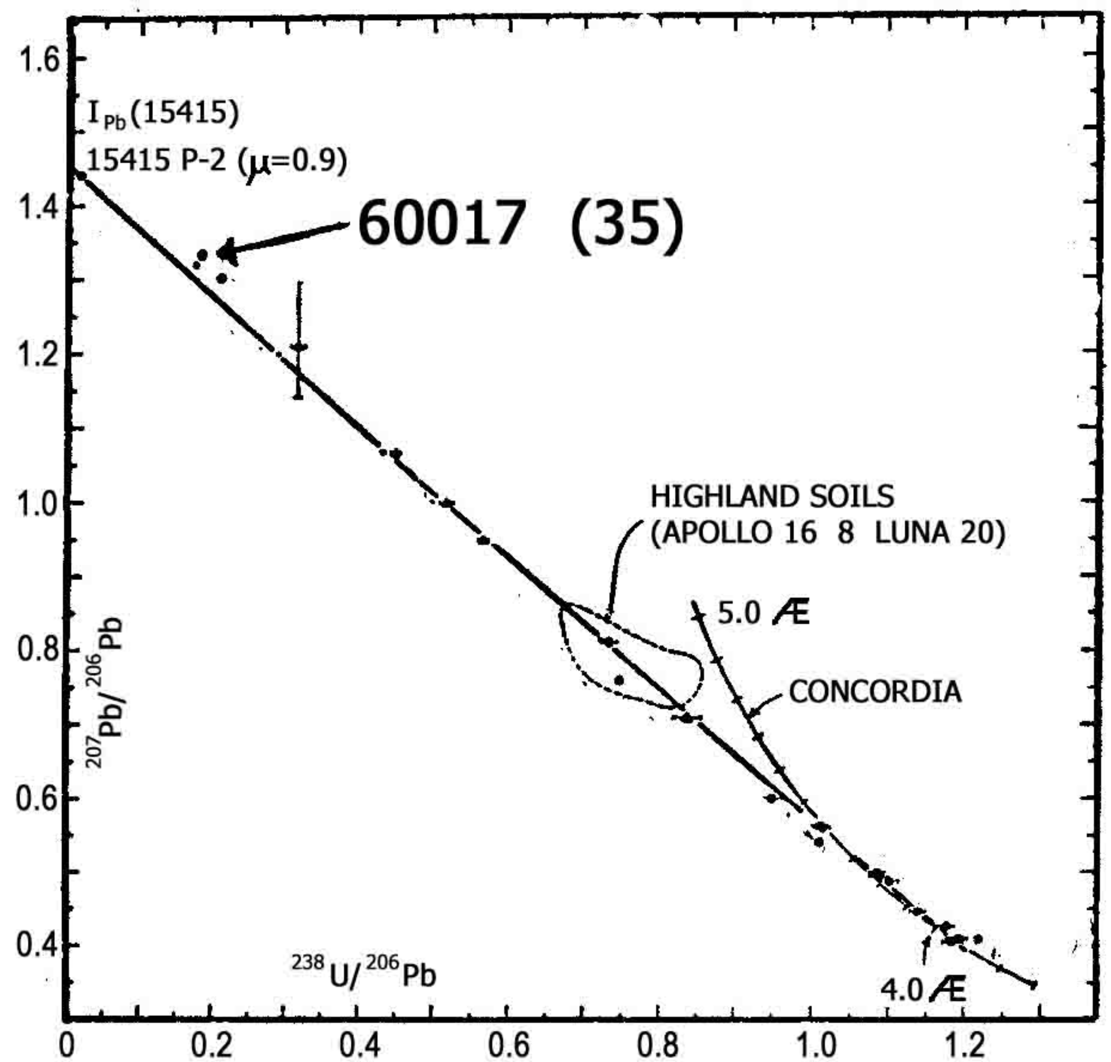

FIGURE 5. U-Pb evolution diagram.
Reference isochron passes through total rock and plagioclase for rock 68415.
Number in parentheses is μ value; from Tera et al (1974).

TRACKS AND RELATED STUDIES: MacDougall et al. (1973) measured the U content from fission tracks, but found no solar flare tracks in olivine or feldspar. Fireman et al. (1973) report count rates for ^3H, which is less abundant in the interior than the surface.

PHYSICAL PROPERTIES: Housley et al (1976) found that 60017,84 (bulk rock) has a very weak ferromagnetic resonance and is thus unlike either soils or soil breccias. Gold et al. (1974, 1975,1976a) used 60017 for calibration in Auger electron spectroscopy of samples. They found that the albedo (0.5) of 60017 does not decrease to highland soil albedo levels merely by crushing.

PROCESSING AND SUBDIVISIONS: A few small fragments were chipped off the samples prior to its sawing in late 1972. During sawing several fragments were produced (Fig. 6). The two largest pieces ,18 and ,52 and several small pieces are preserved intact. Slab A was dissected as shown in Figure 7, and ,17 was dissected to give splits ,53 through ,88 (Fig. 6). Most allocations have been made from the subdivisions of ,17.

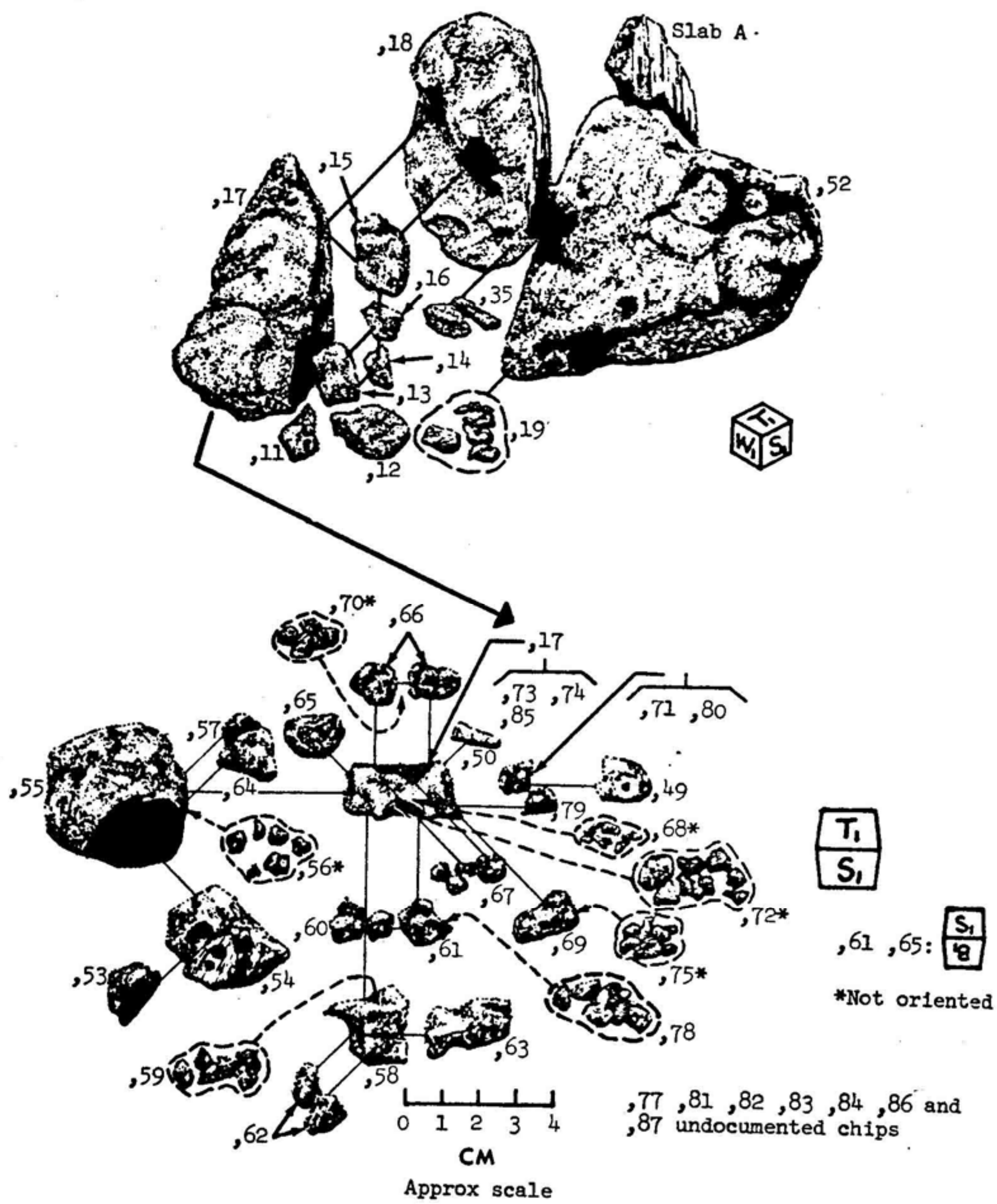

FIGURE 6. Cutting diagram.

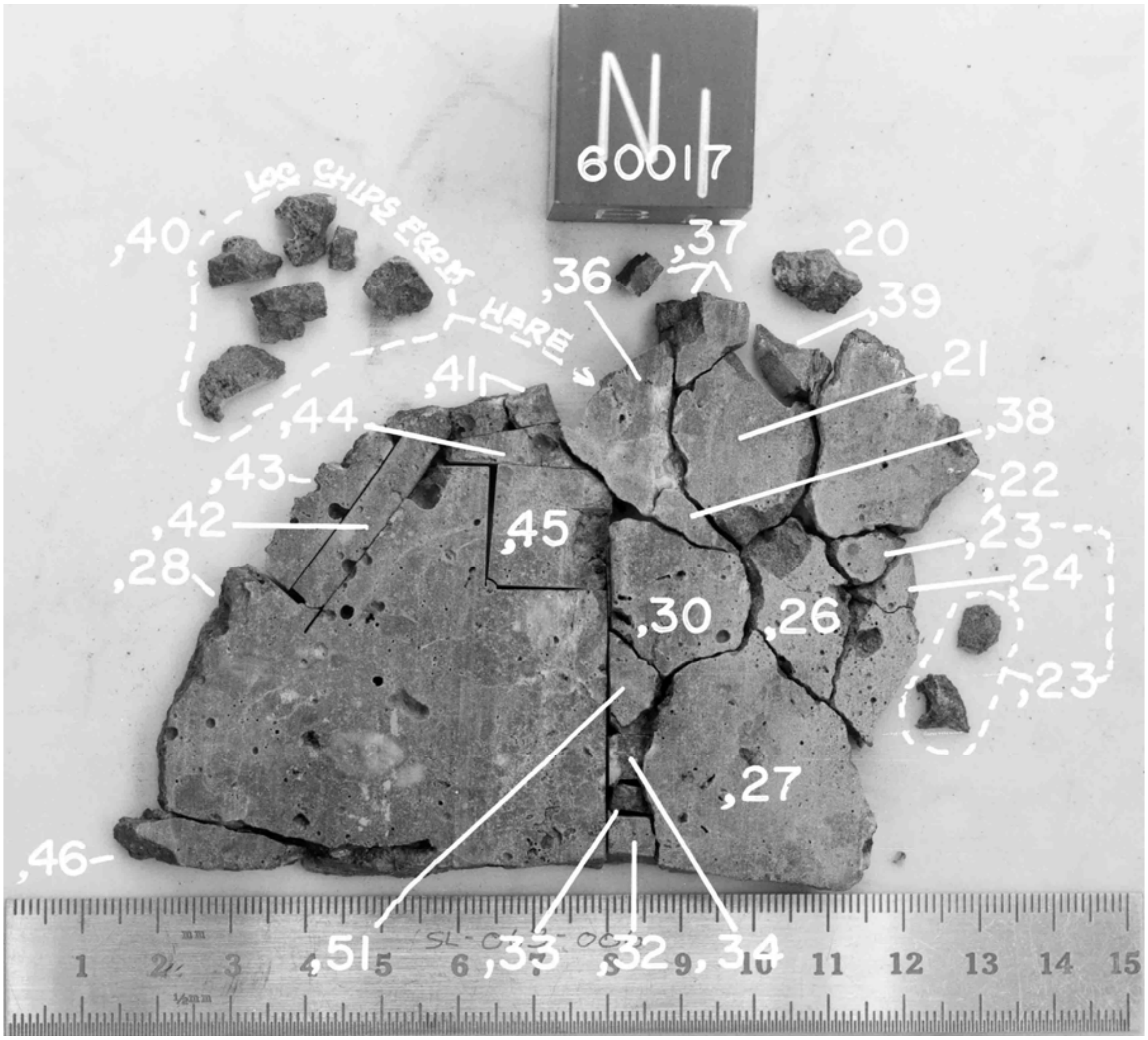

FIGURE 7. Subdivision of slab. S-73-21544.