# 70019

## Soil Breccia - Agglutinate
## 159.9 g, 13 x 6 x 6 cm

### INTRODUCTION

70019 is a dark-gray soil breccia with a brownish tint and an irregular shape. It is weakly coherent and variably brecciated. It is a glass-bonded agglutinate with a mass of 160 g collected from the bottom of a 3m crater near the Apollo 17 lunar module (Pearce and Chou, 1977). The appearance of the sample is controlled by a flattened rhomboidal, penetrative fracture pattern. The overall texture appears to be homogeneous and fine-grained. The entire surface possesses a glass coating of variable extent: T is finely hackly with a 20% glass coating broken by rhomboidal fracturing; S has a 70% glass coating over partially rounded fragments. Small amounts of fine dark dust adhere to smooth surfaces of the glass. The glass contains 10% vesicles of 0.5 mm diameter and 20-30% angular voids in the glass cemented between fragments of soil breccia at the W end, where fragments are present as a loosely packed aggregate (Fig. 1), and external faces are glass coated. The closely packed fragments are slightly disrupted at the E end of the sample. No zap pits are present. 70019 was collected between the Lunar Module and Station 5.

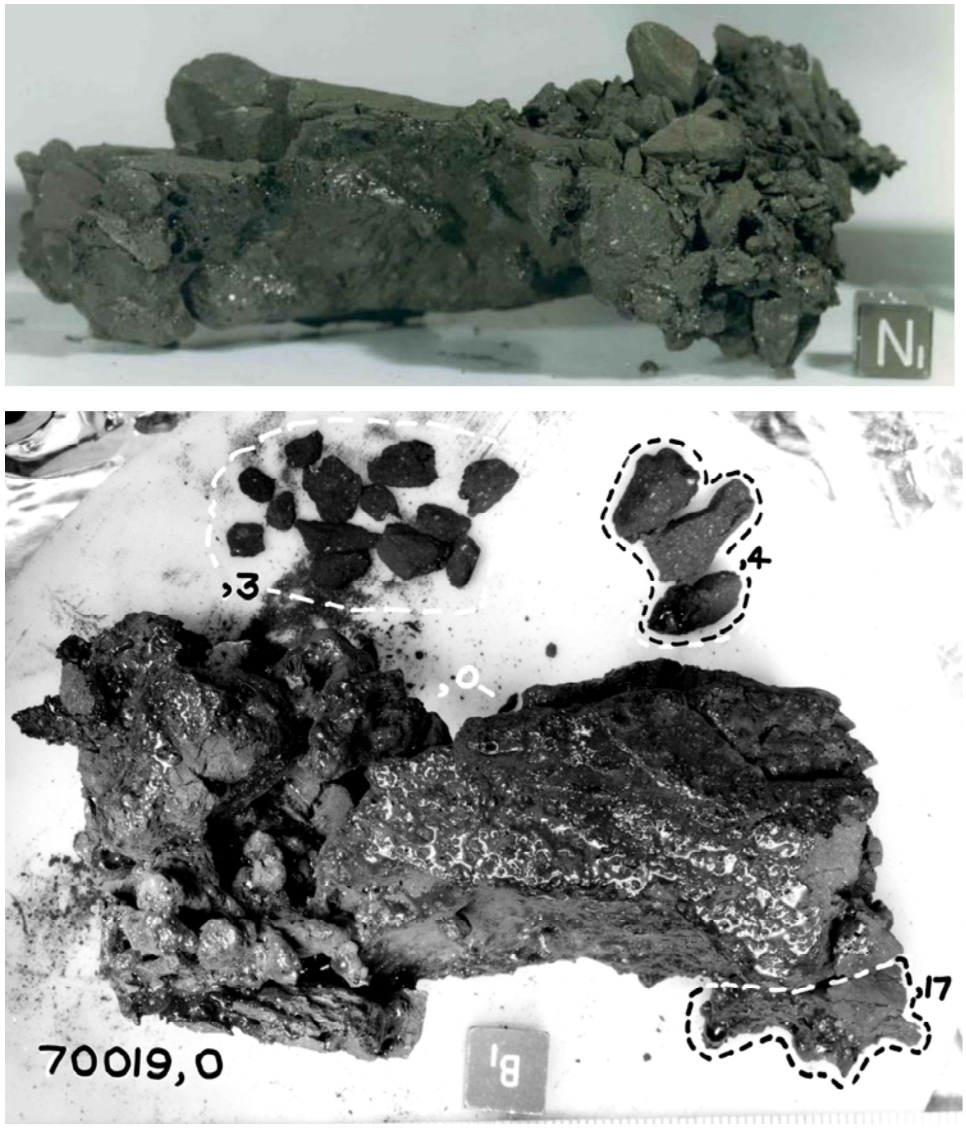


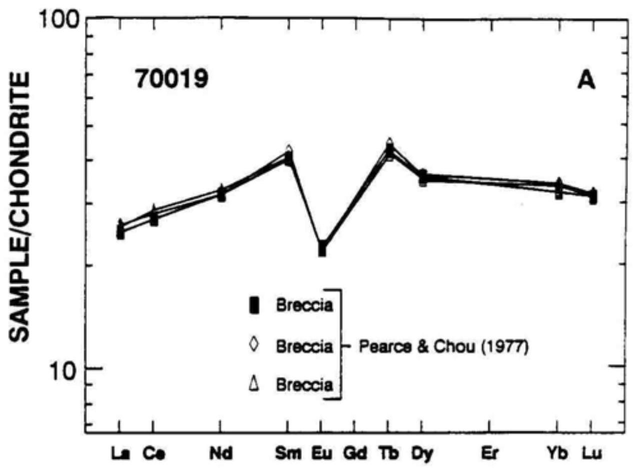

Figure 1: Hand specimen photograph of 70019.

## PETROGRAPHY

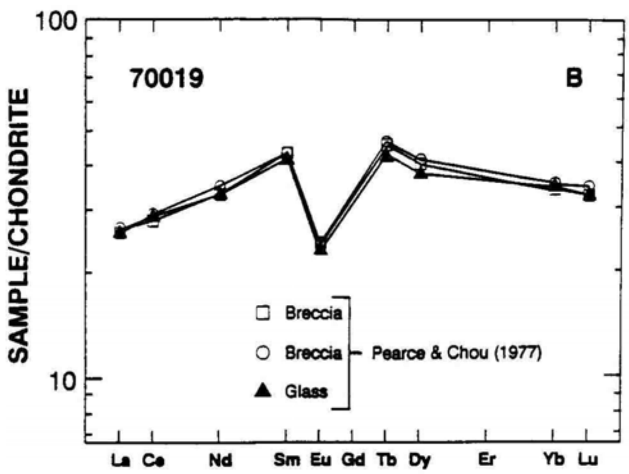
No petrographic descriptions have been reported in the literature for 70019.

## WHOLE-ROCK AND GLASS CHEMISTRY

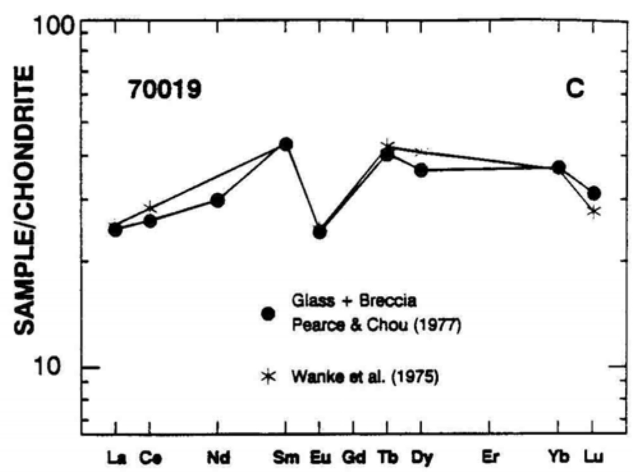
Wanke et al. (1975) used the whole-rock chemistry of 70019 in their study of the presence of "primary matter" in the lunar highlands; this determination of the REE abundances is shown in Fig. 2. This pattern is similar to that of Apollo 17 basalts, in that 70019: 1) is LREE-depleted; 2) contains MREE which reach 35 times chondritic abundances; and 3) contains a negative Eu anomaly ($[Eu/Eu^*]_N = 0.63$). Pearce and Chou (1977) reported whole-rock compositions for 5 breccia samples, 1 glass sample, and 1 breccia/glass mixture from 70019. REE patterns are similar for each and to the profile of Wanke et al. (1975) (Fig.2 a-c). A negative Eu anomaly is present ($[Eu/Eu^*]_N = 0.60$-$0.65$), and the REE profiles have a convex-upward appearance with maximum abundances at either Sm or Tb (Fig. 2 a-c). These authors also concluded that the compositional similarity between the breccia and the glass (Table 2, Fig. 2) indicates that the glass was generated from material almost identical to the rock and soil components of the breccia.




*2a: Breccia matrix.*




*2b: Two profiles of breccia matrix + one of glass.*




*2c: One glass + breccia profile and one whole-rock profile.*

Figure 2: Chondrite-normalized rare-earth element profiles of 70019

Jovanovic and Reed (1975ab, 1980) used C1/Br and $Cl/P_2O_5$ ratios to determine whether or not 70019 represented early, primordial lunar crust. However, in light of the revealing study of Taylor and Hunter (1983), use of these data for such conclusions is not valid.

Light-element concentrations of 70019 have been reported by Petrowski et al. (1974), Leich et al. (1974), and Filleux (1977, 1978). Petrowski et al. (1974) reported C, N, S, $Fe^0$, and He of 142 ppm, 70 ppm, 999 ppm, 0.7 wt%, and 34 ppm, respectively (Table 1). However, no distinction between the glass and soil breccia was made. Leich et al. (1974) reported H and F abundances from the exterior and interior of 70019, noting that the exterior contained more H and F (up to 400 ppm H and 235 ppm F) than the interior (10-40 ppm H and 40-75 ppm F), concluding that the differences were due to the effect of the solar wind. Filleux (1977, 1978) reported the C abundance in 70019 using a nuclear depth profiling technique and quoted reliable abundances of 176±30 ppm and 165 ± 30 ppm.

Fredriksson et al_ (1974) reported three glass compositions (Table 2) and one bulk composition (Table 1) and used these analyses to compare lunar impact glasses with those from the Lonar Meteorite Crater. Their conclusions indicated that the glass from 70019 is comprised of two main components: A - local soil; and B - local basalts to which have been added more exotic varieties. They suggested that 70019 contains the products of several impacts on a variety of targets.

The glass chemistry of 70019 was also reported by Mao et al. (1975) in a study of the chemical reduction in lunar regolith samples from the Apollo 17 site (Table 3). These authors identified trapped bubbles of gas (inferred to be hydrogen) quenched into an orange glass and concluded that these samples are more reduced than any other previously identified.

## STABLE ISOTOPES

Norris et al. (1983) reported both C and N isotopic ratios (Table 4) and defined a correlation between isotopically light carbon and nitrogen, implanted by ancient solar wind activity. Petrowski et al. (1974) reported a $s^{15}N$ composition of 70019, noting that this is one of the lightest samples analyzed from the Moon. Their result is substantially different from that of Norris et al. (1983). Petrowski et al. (1974) also reported a $s^{34}S$ composition for 70019 (Table 4). A similar study of N isotopes was also undertaken by Becker and Clayton (1975), who determined the N isotopic composition on two splits of 70019, 10 (Table 4). The results are approximately midway between the values of Petrowski et al. (1974) and Norris et al., (1983). Becker and Clayton (1975) concluded that the N isotopic ratio has increased by ~15% over the last 4.5 x $10^8$ yr due to nitrogen being implanted into the lunar regolith. This may have been due to a change in the N isotopic ratio of the solar wind with time, or it may be due to outgassing and subsequent reimplantation of an isotopically light indigenous lunar nitrogen from the lunar interior during the early history of the Moon.

A study by Grossman et al. (1974) reported the oxygen isotopic composition of 70019 (Table 4) and concluded that the Moon could not be a mixture of ordinary chondrites and Allende inclusions, nor could it be derived by fractionation of such a mixture.

## RADIOGENIC ISOTOPES

Nunes (1975) and Church and Tilton (1975) noted that a substantial amount of Pb loss occurred during the agglutinization of 70019. Nunes (1975) reported Pb isotope analyses from glassy and non-glassy samples of 70019 (Table 5). Glass formation by impact, less than 200 Ma, at the Apollo 17 site was accompanied by substantial loss of Pb relative to U. The analyses of non-glassy samples of 70019 indicated that initial lead isotopic compositions, distinctly different from that defined by KREEP, are present on the Moon. Nunes (1975) further concluded that the U and Th concentrations of 70019 demonstrate that it was a mixture of comminuted mare basalt and highland material. Church and Tilton (1975) reported the Pb isotope composition of 70019,24B (Table 5). These results were used to demonstrate the presence of initial radiogenic $^{207}Pb/^{206}Pb$ ratios of 1.32, which are distinctly different from the "cataclysm lead" ratio of 1.45.

**Table 1: Whole-rock analysis of 70019.**

| Ref. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | ,29 | ,28 | ,7 | | | ,17 | ,17 | ,17 | ,10 | |
| $SiO_2$ | 41.5 | 40.66 | | | | | | | | 41.4 |
| $TiO_2$ | 8.22 | 8.26 | | | | | | | | 7.24 |
| $Al_2O_3$ | 12.1 | 12.38 | | | | | | | | 12.8 |
| $Cr_2O_3$ | 0.44 | 0.43 | | | | | | | | 0.46 |
| FeO | 16.6 | 16.38 | | | | | | | | 16.3 |
| MnO | 0.22 | 0.24 | | | | | | | | 0.26 |
| MgO | 9.61 | 9.50 | | | | | | | | 9.95 |
| CaO | 11.4 | 11.03 | | | | | | | | 10.6 |
| $Na_2O$ | 0.40 | 0.47 | | | | | | | | 0.28 |
| $K_2O$ | 0.08 | 0.09 | | | | | | | | 0.15 |
| $P_2O_5$ | 0.07 | 0.07 | 0.08 | 0.084 | | | | | | $<0.10$ |
| S | 0.11 | 0.10 | | | | | | | | |
| Nb | | | | | | | | | | |
| Zr | | | | | | | | | | |
| Hf | 6.94 | | | | | | | | | |
| Ta | 1.25 | | | | | | | | | |
| U | | | 0.29 | | | | | | | |
| Th | 0.68 | | | | | | | | | |
| W | | | | | | | | | | |
| Y | | | | | | | | | | |
| Sr | 200 | | | | | | | | | |
| Rb | | | | | | | | | | |
| Li | | | 9.8 | | | | | | | |
| Ba | 95 | | | | | | | | | |
| Cs | | | | | | | | | | |
| Be | | | | | | | | | | |
| Zn | | 42 | | | | | | | | |
| Pb | | | | | | | | | | |
| Cu | | | | | | | | | | |
| Ni | 140 | 154 | | | | | | | | |
| Co | 31.3 | | | | | | | | | |
| V | | | | | | | | | | |
| Sc | 60.4 | | | | | | | | | |
| La | 8.44 | | | | | | | | | |
| Ce | 25 | | | | | | | | | |
| Nd | | | | | | | | | | |
| Sm | 7.87 | | | | | | | | | |
| Eu | 1.70 | | | | | | | | | |

**Table 1: (Concluded).**

| Ref. | 1 ,29 | 2 ,28 | 3 ,7 | 4 | 5 | 6 ,17 | 7 ,17 | 8 ,17 | 9 ,10 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Gd | | | | | | | | | | |
| Tb | 2.00 | | | | | | | | | |
| Dy | 14.0 | | | | | | | | | |
| Er | | | | | | | | | | |
| Yb | 7.30 | | | | | | | | | |
| Lu | 0.95 | | | | | | | | | |
| Ga | | | | | | | | | | |
| F | | | | | | 60-235 | | | | |
| Cl | | | 15 | 15 | | | | | | |
| C | | | | | 142 | | $330 \pm 30$ | $165 \pm 30$ | | |
| N | | | | | 70 | | | 60 | | |
| H | | | | | 39.5 | | | | | |
| He | | | | | 34 | | | 13.3 | | |

References: 1 = Wänke et al. (1975); 2 = Rhodes et al. (1974); 3 = Javanovic and Reed (1975); 4 = Javanovic and Reed (1980); Petrowski et al. (1974); 6 = Leich et al. (1974); 7 = Filleux et al. (1977); 8 = Filleux et al. (1978); 9 = Becker and Clayton (1975); 10 = Fredriksson et al. (1974).

**Table 2: Elemental concentrations in glass and breccia fractions of 70019**
(in ppm except for CaO, $TiO_2$, and Fe %).
Data from Pearce and Chou (1977a). Analyses by INAA.

| | 5-1 | 5-2a | 5-2b | 5-3 | 5-4 | 5-6 | 5-7 |
|---|---|---|---|---|---|---|---|
| Na | 3100 | 3080 | 3220 | 2730 | 3090 | 3180 | 3110 |
| K | 860 | 720 | 680 | 600 | 740 | 740 | 660 |
| CaO | 12.7 | 11.4 | 10.3 | 13.7 | 9.34 | 11.1 | 10.4 |
| Sc | 57 | 60 | 57 | 58 | 61 | 59 | 59 |
| $TiO_2$ | 8.00 | 8.16 | 8.25 | 8.72 | 9.08 | 8.48 | 8.46 |
| V | 88 | 82 | 89 | 112 | 102 | 90 | 86 |
| Cr | 3130 | 3190 | 3230 | 3180 | 3370 | 3220 | 3230 |
| Mn | 1740 | 1800 | 1770 | 1840 | 1860 | 1840 | 1870 |
| Fe | 12.8 | 13.1 | 13.1 | 12.9 | 13.7 | 13.0 | 13.0 |
| Co | 32 | 35 | 33 | 32 | 34 | 33 | 33 |
| Ni | 113 | 163 | 123 | 157 | 170 | 141 | 141 |
| Zr | --- | 270 | 240 | 240 | 300 | 290 | 270 |
| Ba | --- | --- | 120 | --- | --- | 105 | --- |
| La | 7.9 | 8.3 | 8.2 | 8.3 | 8.2 | 8.3 | 8.2 |
| Ce | 22.7 | 23.5 | 24.1 | 23.1 | 24.4 | 23.8 | 23.1 |
| Nd | 19.4 | 19.4 | 20.0 | 20.0 | 21.3 | 19.9 | 18.9 |
| Sm | 7.9 | 8.3 | 8.0 | 8.4 | 8.5 | 8.1 | 8.0 |
| Eu | 1.68 | 1.66 | 1.65 | 1.79 | 1.77 | 1.66 | 1.69 |
| Tb | 1.93 | 2.02 | 1.90 | 2.04 | 2.11 | 1.92 | 1.91 |
| Dy | 11.9 | 12.6 | 11.7 | 13.2 | 13.6 | 12.4 | 12.5 |
| Yb | 6.9 | 7.3 | 7.2 | 7.2 | 7.5 | 7.3 | 7.4 |
| Lu | 1.02 | 1.04 | 1.02 | 1.05 | 1.12 | 1.05 | 1.07 |
| Hf | 6.7 | 7.0 | 6.8 | 7.1 | 7.2 | 6.9 | 7.2 |
| Ta | 1.3 | 1.4 | 1.3 | 1.3 | 1.4 | 1.3 | 1.3 |
| Th | 0.85 | 0.83 | 0.93 | 0.95 | 0.94 | 0.89 | 0.84 |

5-1, 5-2a, 5-2b, 5-4, and 5-6 = whole-rock analyses; 5-3 = glass analysis; 5-7 = mixture of soil and glass.

**Table 3: Glass compositions from breccia 70019. Oxides in percent; others in ppm.**

| Ref. | 1 | 1 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 40.0 | 38.4 | 33.3 | | | 40.32 |
| $TiO_2$ | 8.26 | 8.65 | 8.12 | | | 8.24 |
| $Al_2O_3$ | 13.2 | 6.74 | 17.2 | | | 12.36 |
| $Cr_2O_3$ | 0.46 | 0.71 | 0.40 | | | 0.50 |
| FeO | 17.3 | 22.2 | 14.6 | | | 15.18 |
| MnO | nd | nd | nd | | | 0.27 |
| MgO | 10.1 | 15.3 | 11.6 | | | 10.20 |
| CaO | 10.9 | 7.15 | 13.4 | | | 10.69 |
| $Na_2O$ | 0.31 | 0.35 | 0.10 | | | 0.18 |
| $K_2O$ | 0.11 | 0.19 | $<0.10$ | | | 0.02 |
| $P_2O_5$ | nd | nd | nd | 0.24 | 0.24 | |
| Cl | 7.8 | 7.8 | | | | |
| Br | 93 | | | | | |
| Li | 7.6 | | | | | |
| U | 0.26 | | | | | |

References: 1 = Fredriksson et al. (1974); 2 = Jovanovic and Reed (1975); 3 = Jovanovic and Reed (1980); 4 = Mao et al., (1975).

**Table 4: Stable isotope analyses of 70019.**

| Ref. | 1 | 2 | 3 | 3 | 4 |
|---|---|---|---|---|---|
| C (ppm) | 142 | 116 | | | |
| $S^{13}C$ o/oo PDB | +11.6 | +10 | | | |
| N (ppm) | 70 | 70 | 62 | 57 | |
| $S^{15}N$ o/oo AIR | -8.5 | +49 | +21.7 | +22.1 | |
| S (ppm) | 999 | | | | |
| $S^{34}S$ o/oo CDT | +7.6 | | | | |
| $S^{18}O$ o/oo SMOW | | | | | +5.53 |
| $S^{17}O$ o/oo SMOW | | | | | +3.7 |

References: 1 = Petrowski et al. (1974); 2 = Norris et al. (1983); 3 = Becker & Clayton (1975); 4 = Grossman et al. (1974),

**Table 5: Pb isotope analyses from 70019.**

| NUNES (1975) | U | Th | Pb | $^{206}Pb/^{204}Pb$ | $^{207}Pb/^{204}Pb$ | $^{208}Pb/^{204}Pb$ |
|---|---|---|---|---|---|---|
| Non-glassy | | | | | | |
| P | --- | --- | --- | 184.5 | 141.6 | 186.4 |
| Cl | 0.2735 | 0.9819 | 0.9007 | 147.0 | 113.0 | --- |
| C2* | 0.2612 | 0.9158 | 0.7889 | 123.7 | 88.99 | --- |
| Glass Concentrate | | | | | | |
| P | --- | --- | --- | 169.2 | 128.4 | 173.4 |
| C | 0.2737 | 0.9824 | 0.5349 | 159.2 | 120.9 | --- |

| NUNES (1975) | $^{207}Pb/^{206}Pb$ | $^{208}Pb/^{206}Pb$ | $^{232}Th/^{238}U$ | $^{238}U/^{204}Pb$ |
|---|---|---|---|---|
| Non-glassy | | | | |
| P | 0.7671 | 1.010 | --- | 135 |
| Cl | 0.7691 | --- | 3.71 | 107 |
| C2* | 0.7197 | --- | 3.62 | 96 |
| Glass Concentrate | | | | |
| P | 0.7592 | 1.025 | --- | 209 |
| C | 0.7600 | --- | 3.71 | 196 |

P = Composition run; C = Concentration run. All samples corrected for analytical blank.

| CHURCH & TILTON (1975) | U | Th | Pb | $^{204}Pb/^{206}Pb$ | $^{207}Pb/^{206}Pb$ | $^{208}Pb/^{206}Pb$ |
|---|---|---|---|---|---|---|
| 70019,24B | --- | --- | --- | 0.00827 | 0.7684 | 1.0758 |
| 70019,24B | 0.258 | 0.852 | 0.917 | 0.00877 | 0.7582 | --- |

| MODEL AGES (m.y.) | $^{206}Pb/^{238}U$ | $^{207}Pb/^{206}Pb$ |
|---|---|---|
| 70019,24B | ---- | ---- |
| 70019,24B | 5451 | 4811 |

## COSMOGENIC RADIONUCLIDES & EXPOSURE AGES

Cosmic ray studies have been conducted on 70019 by Keith et al. (1974a,b) and Fruchter et al. (1978a,b). Keith et al. (1974a,b) analyzed natural and cosmic ray induced radionuclides in 70019 by non-destructive gamma-ray spectroscopy (Table 6). These authors conclude that 70019 is unsaturated in $^{26}$Ai, probably because of its friability. No exposure age was reported by these authors.

Fruchter et al. (1978a,b) also used gamma-ray spectroscopy to determine the $^{26}$A1 and $^{53}$Mn abundances from 70019,48 (51.9 ± 3.4 dpm/kg samples and 245 ± 25 dpm/kg Fe, respectively). Saturation of 70019 in these isotopes has also been calculated by these authors. According to their calculations, 70019,48 is 86% saturated in $^{26}$A1 and 82% saturated in $^{53}$Mn. The $^{26}$A1 exposure age for 70019 is 2.2 ± 1.0 Ma and that for $^{53}$Mn is 9 ± 2 Ma.

## MAGNETIC STUDIES

Pearce et al. (1977) and Pearce and Chou (1977) reported the magnetic hysteresis properties of seven fractions of 70019,5 (Table 7). These authors noted that the saturation magnetization for both glass and breccia samples is remarkably similar (~5%). The similarities between these properties for the glass and whole-rock breccia, coupled with the whole-rock data also presented by Pearce and Chou (1977) (see above), suggested a common source material.

Sugiura et al. (1979a,b) used a new technique of encapsulation (Taylor, 1979) of 70019,49 (glass) for Thellier-Thellier paleointensity determination. This glass sample gave a paleointensity of about 2500 nT by such a method. Sugiura et al (1979a,b) suggested that this field was due either to local anomalies created by strongly magnetized rock or possibly to enhancement of local fields by the shock process which produced the glass. These results for 70019,49 are reproduced in Sugiura and Strangway (1980). Also, the magnetic data of 70019 was reported by Cisowski et al. (1983) on a plot of absolute paleointensity versus normalized remanent intensity,

## EXPERIMENTAL

Oxygen fugacity experiments have been conducted on 70019,4 by Sato (1976a) who reported that 70019 exhibited a noticeable shift of the log $fo_2$ - 1/T trace towards more reduced values during the first heating cycle at temperatures above 1000 °C (a decrease in the average -log $fO_2$ from 16.1 at 1000 °C to 13.4 at 1200 °C).

Uhlmann et al. (1975) used 70019 in an experiment to determine the formation of lunar breccias. These authors used viscous sintering in a stress-free environment to mimic breccia formation and assumed that crystallization and sintering were concurrent, competing processes. Their experiment made it possible to estimate the rate of breccia cooling and the minimum temperature at which the breccia particles came into contact. Uhlmann et al. (1975) presented their model, but no quantitative results, concluding that 70019 cooled on the surface of the Moon in its present form, rather than being buried in an ejecta blanket. Uhlmann and Onorato (1979) presented the results from the above model for 70019. These authors concluded that the glass on 70019 cooled at a rate of 1.8 °C/sec.

**Table 6: Gamma-ray analysis of 70019.**
Data from Keith et al. (1974).

| | |
|---|---|
| **Type** | Breccia |
| **Subtype** | Agglutinate |
| **Sample** | 70019 |
| **Weight (g)** | 128.0 |
| **Comments** | from crater floor |
| Th (ppm) | 1.03 ± 0.10 |
| U (ppm) | 0.23 ± 0.02 |
| K (%) | 0.0692 ± 0.0012 |
| $^{26}Al$ (dpm/kg) | 45 ± 3 |
| $^{22}Na$ (dpm/kg) | 110 ± 8 |
| $^{54}Mn$ (dpm/kg) | 166 ± 12 |
| $^{56}Co$ (dpm/kg) | 240 ± 30 |
| $^{46}Sc$ (dpm/kg) | 59 ± 5 |
| Th/U | 4.5 |
| K/U | 3000 |

**Table 7: Magnetic hysteresis data for 70019,5 from Pearce and Chou (1977).**

| Sample | $J_s$ (emu/g) | $X_p * 10^6$ (emu/g) | $J_{rs}/J_s$ | $H_c$ Oe | $Fe^o$ (%) | FeO (%) |
|---|---|---|---|---|---|---|
| 70019,5-1 | 1.455 | 30.5 | 0.060 | -- | 0.67 | 18.0 |
| 70019,5-2 | 1.442 | 30.7 | 0.063 | 41 | 0.66 | 18.1 |
| 70019,5-2 | 1.439 | 28.5 | 0.067 | 40 | 0.66 | 16.5 |
| 70019,5-3 | 1.425 | 24.0 | 0.019 | 43 | 0.65 | 14.1 |
| 70019,5-4 | 1.446 | 29.9 | 0.067 | 45 | 0.66 | 7.6 |
| 70019,5-6 | 1.495 | 31.1 | 0.067 | 40 | 0.69 | 18.3 |
| 70019,5-7 | 1.473 | 31.3 | 0.064 | -- | 0.68 | 18.4 |