PETROLOGY OF AN IMPACT MELT CLAST FROM LUNAR REGOLITH BRECCIA 60016.

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Introduction: The collisional evolution of the inner solar system is uniquely preserved on the Moon, where impact craters have been accumulating for 4.5 billion years. One of the intriguing observations made thus far is a cluster of impact melt ages around 3.9 to 4.0 Ga [*e.g.*, 1, 2]. It has been suggested that these melts were produced during a brief period of heavy bombardment that resurfaced much of the Moon and created many of the impact basins that currently dominate the lunar surface [*e.g.*, 1, 3, 4, 5, 6]. Many large-volume impact melt samples have been studied and placed into compositional- and age-based melt groups, but smaller volume samples have remained largely unstudied. By examining small-volume melts such as those in regolith breccia 60016, we can begin to determine if these small clasts represent the same suites as the larger melts, or if different impacts are represented.

Sample and Analysis Methods: Sample 60016 is a light grey regolith breccia that contains a large variety of both light- and dark-colored clasts and metal [7]. A ~1 cm diameter dark-colored clast (#6 in our study) was sampled to produce a thin-section (,321). The petrology of the clast was assesssed using transmitted- and reflected-light optical microscopy that was augmented with backscattered-electron (BSE) images taken with a scanning electron microscope (SEM; JEOL JSM-5900LV). Elemental maps were created with a field emission gun-SEM (JEOL JSM-7600F) and an energy-dispersive spectrometer system. Major element compositions were determined with an electron microprobe (EPMA; Cameca SX100) using a 15 kV, 20 nA, and 1μm diameter beam for silicates, oxides, sulfides, and metals. A series of 452 defocused (20μm diameter) beam analyses (DBA) were made to estimate bulk chemical composition.

Results: *Petrography*. 60016,321 (Clast 6) is a crystallized impact melt, composed of olivine (18.5 %), pyroxene (47.8 %), plagioclase (31.0 %), Fe-Ni metal (2.2 %), troilite and schreibersite (0.5%). It has a porphyritic texture (Fig. 1) with phenocrysts (up to 200 μm) of olivine and plagioclase in a finer-grained (less than 60 or 70 μm) groundmass. Minor clots of phenocrysts produce a subtle glomeroporphyritic texture. A small fraction (~15 %) of the olivine and plagioclase phenocrysts are anhedral, fractured, contain groundmass along fractures, and are relict grains. Some of them also have rim overgrowths. On the other hand, the majority of phenocrysts are finer-grained, euhedral to subhedral, and appear to have crystallized from the melt. The groundmass is composed mainly of dendritic microcrystalline pyroxene crystals with smaller amounts of elongate plagioclase laths and interstitial glass. These laths create a seriate texture that ranges from microcrystalline to ~8μm, at which point they become less elongate and more similar in shape to the blockier plagioclase phenocrysts. There is one small (~100 μm long) relict lithic fragment embedded in this sample. It is composed of anhedral anorthite grains with a small amount of pyroxene groundmass. Half of the metal grains are smaller than 4 μm, and a quarter of the grains are smaller than 1μm. Most metal droplets (4 to 160 μm in diameter) have rounded shapes and are a fine-grained mixture of Fe-Ni metal (up to 5 μm) and schreibersite (up to 16 μm in size) with rims of troilite (5-10 μm).

Major element compositions of constituent materials. Of the 32 olivine grains analyzed, only 5 are zoned. Three of them (20 and 30 μm in size) crystallized from the impact melt, while the other two are larger relict grains. The average olivine core composition for all grain sizes is Fo_{86}, and the rims of zoned grains range between Fo_{82}-Fo_{84}. Plagioclase relicts and melt products have similar compositional variation of An_{90-97}, although most of relict plagioclase grains have the composition of An_{95-97}. Overgrowths around relict plagioclase have slightly Na-rich compositions (An_{92-94}). Individual phases in the groundmass of sample 60016, 321 are comparable in size to the electron beam of EPMA, so X-ray contamination from adjacent phases is difficult to avoid. None of the analyzed areas in the ground-mass are stoichiometrically balanced, but are compositionally similar to pyroxene that is contaminated by surrounding plagioclase and glass. Composition of Fe-Ni metal droplets (Fe ~94.7 wt.%, Co ~ 0.5 wt.%, and Ni ~ 4.8 wt.%) is typical of lunar impact melts and imply a meteoritic origin. Schreibersite contains up to 11 wt.% Ni.

Bulk rock composition: major and minor elements. Bulk chemical compositions are estimated from DBA analyses of this clast. Clast 6 has higher K_2O concentration (0.50 wt.%) and similar Mg# (=73), compared to other melt clasts in 60016 [8].

Discussion: The classification system most commonly used to distinguish between Apollo 16 impact melts was proposed by Korotev using trace element compositions (Sm and Sc concentrations)[9]. When compared the major element composition of Clast 6 with other Apollo 16 impact melt rock [*e.g.*, 8, 9, and reference therein], the sample shares chemical signatures with Apollo 16 mafic KREEP-bearing impact melts. However, as shown in Figure 2, it's composition lies in between sub-groups 1M and 1F of Korotev [9]. To accurately compare Clast 6 to these groups would require trace element data, however we can use other properties to see if the clast is at least consistent with either of the two sub-groups.. Both 1M and 1F samples and Clast 6 have high metal contents and mafic compositions. However, one of the other distinctive characteristics of all previously studied group 1 rocks is a poikilitic texture [9], which this impact melt clearly lacks. The Mg# of Clast 6 is slightly high to be placed in group 1F, and contains less aluminum than samples classified as group 1M. The K_2O concentrations in this split are higher than other Apollo 16 impact melts as well. The KREEP signatures found in this sample suggest the melt is from an impact event that occurred in the Procellarum KREEP terrain [10].

Conclusion: The impact melt (Clast 6) that was extracted from 60016 seems to have a major element composition similar to that in the samples of group 1 impact melt rocks. It is interesting that the poikilitic texture associated with these sub-groups is absent, but it is possible that the cm-size clast in our study is not representative of the parent rock texture [9, 11]. Thus, without trace element data or a radiometric age, the melt clast is tentatively classified as a group 1 melt, and is likely from the Imbrium impact event or another event that impacted the Procellarum KREEP terrain.

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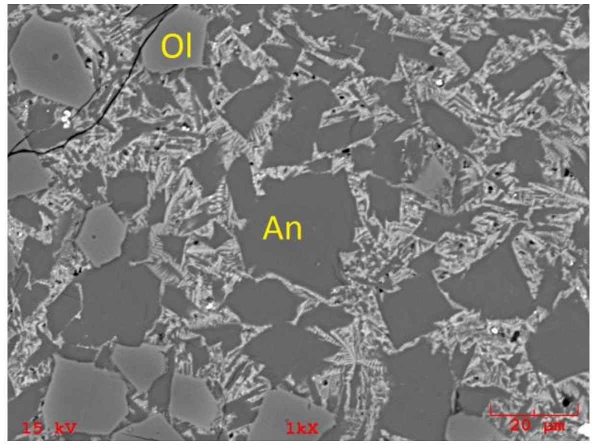

Figure 1. A backscattered electron image of clast 6. Olivine and plagioclase grains that have crystallized from the melt are surrounded by dendritic pyroxene and interstitial glass. Several small metal grains (tiny white dots) are visible in this field of view. Ol: olivine, An: anorthite.

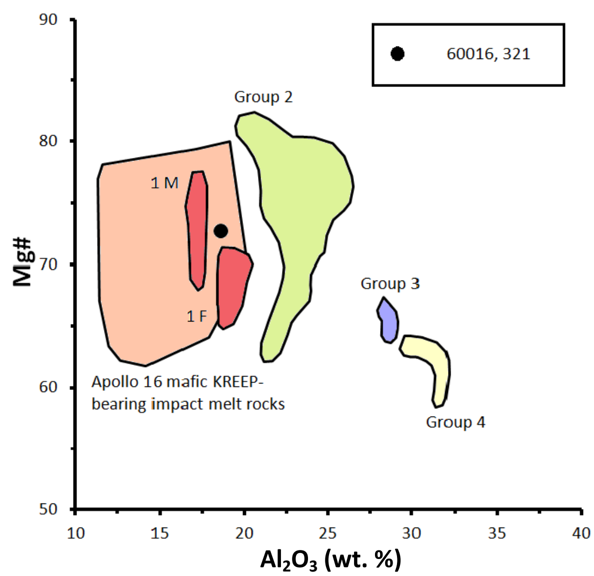

Figure 2. Al_2O_3 vs. Mg# plot for bulk composition of 60016, 321. Reference major element values for impact melt groups are from [9, 12, 13, 14, 15, 16, 17, 18]. KREEP-bearing impact melt rock field is described by Cohen [19].