PETROLOGY OF THE CENTIMETER-SIZE IMPACT MELT CLASTS IN ANCIENT REGOLITH BRECCIA 60016. Takafumi Niihara[1,2] David A. Kring[1,2]. [1]Center for Lunar Science and Exploration, Lunar and Planetary Institute, Houston, TX. 77058 (niihara@lpi.usra.edu), [2]NASA Lunar Science Institute.

Introduction: Early impact bombardment dramatically affected the evolution of the Moon's surface. It has been hypothesized that the basin-forming epoch occurred in a cataclysmic spike of impactors [1–3] that are dominantly from the asteroid belt [4, 5]. Data remain scarce, however, and the hypothesis requires additional tests. In particular, it is still necessary to compare the impact age distributions among different populations of impact melt. We are, thus, examining fragments of melt that survive in cm-size clasts within the 60016 ancient regolith breccia. This rock was classified as a B2-type ancient regolith breccia and was assembled ~3.74 Ga [e.g., 6], meaning the melts within it were produced during the final phases of the basin-forming epoch or earlier.

Samples and Analytical Procedure: We have been allocated six clasts (Clasts 1-6) in 60016 that are 1-2 cm in size. Here we report petrological analyses of five of six clasts: Clast 1 (,319), Clast 2 (,320), Clast 3 (,324), Clast 4 (,322), and Clast 5 (,323). We utilized an optical microscope, backscattered-electron (BSE) detectors on a Scanning Electron Microscope (SEM; JEOL JSM-5910LV), and a Field Emission Gun-SEM (JEOL JSM-7600F). Major-element analyses were made with an Electron Probe Micro Analyzer (EPMA; CAMECA SX-100) using a 15 kV accelerating voltage 20 nA beam current, and <1 μm beam diameter. Defocused beam (20 μm diameter) analyses (DBA) of representative areas for each clast were performed to determine bulk major element compositions.

Results: *Clast 1, a clast-rich poikilitic melt,* contains ~45 % relict grains of plagioclase (An_{97-95} $Or_{0.6-0}$; 39 %), olivine (Fo_{79-69}; 5 %), and pyroxene ($En_{77-58}Wo_{5-2}$; 1 %). Plagioclase relicts are euhedral to anhedral with slightly Na-rich ~2 μm-wide overgrowths. The Na-rich rims contain small Fe-Ni droplets (< μm in diameter). Interstitial materials consists of pyroxene ($En_{82-46}Wo_{42-3}$), plagioclase (An_{95-83} $Or_{1.7-0.3}$), Fe-Ni metal (Ni ~6 wt.%: Co ~0.4 wt.%), troilite, ilmenite and glass. Pyroxene encloses fine-grained euhedral to subhedral plagioclase and round-shaped olivine. Fe-Ni metal-rich droplets (~44 μm) are fine-grained aggregates of metal with some P-bearing material.

Clast 2, a clast-poor poikilitic melt, contains ~15 % relict grains of olivine (Fo_{82-73}; 12 %), plagioclase (An_{97-93} $Or_{0.4-0}$; 2 %), and pyroxene ($En_{84-78}Wo_{4-3}$; 1 %). Plagioclase relicts have euhedral to anhedral morphologies with slightly Na-enriched rims. The Na-rich rims contain small Fe-Ni droplets (< 1 μm in diameter). Olivine and pyroxene are irregular to round in shape. This clast has up to 2 mm pyroxenes ($En_{83-49}Wo_{41-3}$) that encloses fine-grained euhedral plagioclase (An_{96-84} $Or_{1.3-0.2}$) and are embedded in an olivine- and feldspar-bearing mesostasis. Opaques in this clast are Fe-Ni metal (Ni ~7 wt.%: Co ~0.5 wt.%), troilite, and armalcolite. Fe-Ni metal droplets (~180 μm) have eutectic textures with schreibersite (Ni 18 wt.%) and surrounded by rims of troilite.

Clast 3, a clast-rich poikilitic melt, contains ~40 % relict grains of plagioclase (An_{97-82} $Or_{2.6-0.1}$; 29 %), olivine (Fo_{83-74}; 8%), and pyroxene ($En_{78-75}Wo_{5-4}$; 3 %). Relict plagioclase rims are, again, slightly enriched in Na. This clast has up to 1 mm pyroxenes ($En_{82-50}Wo_{40-3}$) enclosing euhedral plagioclase (An_{97-88} $Or_{0.9-0.3}$) and are embedded in an olivine- and feldspar-bearing mesostasis. Other constituent materials are phosphate, Fe-Ni metal (Ni ~5 wt.%: Co ~0.4 wt.%), troilite, armalcolite, and glass. Fe-Ni metal droplets (~80 μm) are fine-grained aggregates, but do not contain schreibersite or phosphorous materials.

Clast 4, a clast-rich porphyritic melt, contains ~47 % relict grains of pyroxene ($En_{81-78}Wo_{5-4}$; 29 %), plagioclase (An_{96-88} $Or_{1.4-0.1}$; 10 %), and olivine (Fo_{79-78}; 8 %), and show irregular to rounded morphologies. Fine-grained melt products of plagioclase (An_{96-85} $Or_{1.9-0.3}$), Fe-Ni metal (Ni ~8.9 wt.%: Co ~0.4 wt.%), troilite, and glass are located in the interstitial of relict materials. Fe-Ni droplets (~136 μm) have P-bearing materials in mesostasis. Fine-grained Fe-Ni metal droplets (< 1 μm) make dark bands across the thin section.

Clast 5, a clast-rich porphyritic glassy melt, contains ~34 % relict grains of plagioclase (An_{97-82}; 34%) and a trace of olivine (Fo_{94-91}; less than1 %). Plagioclase relicts have a thin overgrowth along their rims. Melt products of plagioclase (An_{97-93}), Fe-Ni metal (Ni ~4 wt.%: Co ~0.5 wt.%), and sulfides are embedded in glass. Fe-Ni metal droplets (~68 μm) are fine-grained aggregates of kamacite and schreibersite (Ni 10 wt.%).

DBA data: Bulk chemical compositions, which were calculated by averaging >200 DBA analyses per clast, are plotted on Fig. 1. The melt clasts in 60016 have narrow range of K_2O (0.3-0.5 wt.%) and P_2O_5 (0.4-0.5 wt.%) concentrations and a wide range of Mg# (69-78 mol.%). On the other hand, FeO+MgO (10-23 wt.%) and Al_2O_3 (16-26 wt.%) concentrations are widely distributed.

Discussion: Clasts 1, 2, and 3 have similar poikilitic textures. Moreover, Clasts 2 and 3 both have poikilitic pyroxenes enclosing plagioclase and are embedded in a relict olivine- and plagioclase-bearing mesostasis. However, the constituent materials and their abundances are different between all clasts. Clasts 4 and 5 do not have poikilitic textures but have porphyritic textures similar to (but different in detail) from Clast 6 described elsewhere [7].

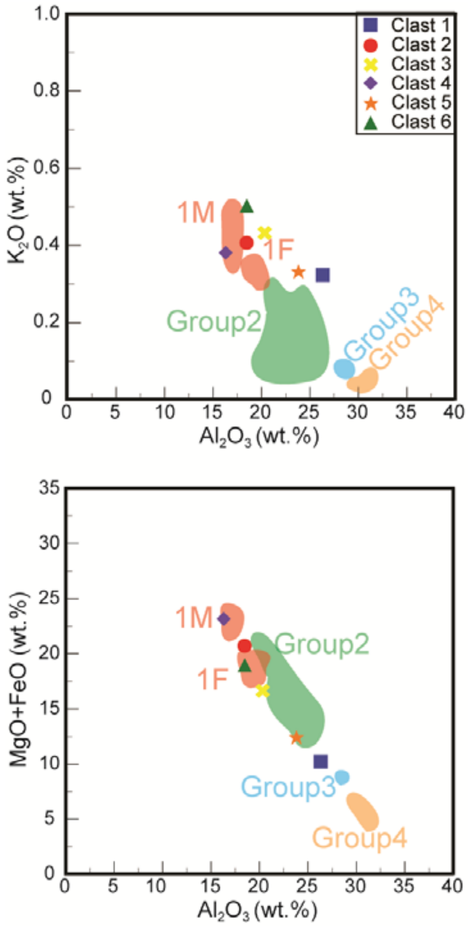

Fig. 1. Averaged DBA data for impact melt clasts in 60016. Data of clast 6 comes from Schaffer et al. (2012) [7]. Reference values for impact melt groups are obtained from Korotev (1994) [8] and reference therein.

We interpret all of these clasts as impact melts, because they entrain meteoritic metal and have relict silicate textures. Korotev [8] established a classification of Apollo 16 impact melt rocks based on Sm and Sc concentration. We plotted the major element composition of previously classified Apollo 16 impact melt rocks [e.g. 8] and compared them with melt clasts in 60016 (Fig. 1). K_2O and P_2O_5 concentrations are similar to Group 1 melt rocks [8], but Al_2O_3 contents are higher than Group 1 in Clasts 1 and 5. We could not find correlation between petrolographic texture and bulk major element compositions of melt clasts.

Fe-Ni metal droplets are found in all of the melt clasts although the abundances are different. Metal droplets in clasts 2 and 5 (probably clasts 1 and 4 also) have eutectic textures with schreibersite. Schreibersite is the main P-phase in those melt clasts. Clast 5 does not contain schreibersite, but instead contains phosphate. Every melt clast has a similar P_2O_5 concentration, but there is no correlation with the abundance of metal. Thus, the phosphorous component is possibly derived from the lunar target rock [10]. The high K and P concentration in these melt clasts could have derived from KREEP component.

Relict plagioclase and olivine grains are found in all of the samples. The composition of relict plagioclase in clasts 1, 2, and 5 are homogeneous while, on the other hand, that of plagioclase in clasts 3 and 4 are heterogeneous. The plagioclase that crystallized from impact melt in clasts 1, 2, 4, and 5 have slightly Na-enriched compositions comparted to that of relict plagioclase. Most of olivine grains have rounded shapes and are sometime surrounded by pyroxene. Relict olivine grains in Clast 5 have more magnesian compositions than other melt clasts in 60016. Relict pyroxene grains in Clast 1 have bimodal ($En_{77-72}Wo_{4-2}$ and $En_{68-58}Wo_{5-2}$) and Fe-rich compositions compared to others. The existence of relict pyroxene grains reflects a difference in melting degree of precursor material at the time of impacts. Additionally, compositional differences in relict minerals (e.g., Fo_{94-91} in Clast 5 vs Fo_{79-69} in Clast 1) imply that these melt clasts have different origin.

Conclusion: All of the melt clasts contain KREEP contents. Four clasts have poikilitic textures, but their mineral abundances and chemical composition are different from each other. Collectively, the petrological texture and mineral compositions data suggest these clasts in 60016 possibly represent five different types of impact melts. Further Ar-Ar age analyses and highly siderophile element analyses would be give us the detailed information on the origine of the melt clasts.

Acknowledgements: Samples are allocated from Astromaterials Acquisition and Curation Office at JSC. We are grateful to D. K. Ross, C. N. Achilles, and A. H. Peslier for support on laboratory works.

References: [1] Turner G. et al. (1973) Proc. LPSC IV, 1889–1914. [2]Tera et al. (1974) EPSL 22, 1–21. [3] Cohen B.A. et al, (2000) Science 290, 1754–1756. [4] Kring D.A. and Cohen B.A. (2002) JGR 107, E2, 5009. [5] Strom R.G et al. (2005) Science 309, 1847–1850. [6] Joy K.H. et al. (2011) GCA. Doi: 10.1016/j.gca.2011.09.018 (in press). [7] Schaffer L.A. et al. (2012) LPS XLIII (this volume). [8] Korotev R.L. (1994) GCA 58, 3931–3969. [9] Goldstein J.I. and Yakowitz H. (1971) Proc. LPSC II, 177–191. [10] Gooley R.C. et al., (1973) Proc. LPSC IV, 799–810.