PETROLOGY AND DISTRIBUTION OF U-PB AGES IN LUNAR METEORITE BRECCIA MILLER RANGE (MIL) 13317. Barry J. Shaulis[1,3], David A. Kring[1,3], Thomas J. Lapen[2,3], and Minako Righter[2]. [1]Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, Texas 77058, USA (shaulis@lpi.usra.edu): [2]University of Houston, Houston, Texas, 77204, USA: [3]NASA Solar System Exploration Research Virtual Institute.

Introduction: Lunar meteorites potentially sample portions of the lunar surface that were not visited during the Apollo and Luna missions to the Moon and can provide new insights into the impact history of the Moon [1]. Miller Range (MIL) 13317 is a newly classified lunar anorthositic breccia that was collected during the 2013 ANSMET Expedition [2]. The meteorite is a single stone weighing 32.2g and is partially covered by fusion crust. The interior is a dark gray breccia with numerous clasts up to 1 cm in size [2]. Here we present an integrated petrologic and U-Pb geochronologic study of thin section MIL 13317,5.

Analytical Methods: For each thin section an X-ray element map was produced using a JEOL JXA-8530F HyperProbe following the procedures of [3] but adapted to this machine (Fig. 1). BSE images of target locations were then generated using a JEOL 5910LV SEM to assess mineral assemblages. Quantitative analyses of minerals in the thin sections were conducted using a Cameca SX100 using standards appropriate to the minerals being analyzed. All three instruments are located at NASA JSC

Lastly, *in situ* analyses of zircon, baddeleyite (>7 μm), and Ca-phosphate phases (> 25 μm) were analyzed by LA-ICPMS using a Varian 810 Quadrupole Mass Spectrometer coupled with a Photon Machines Analyte.193 Excimer Laser Ablation System at the University of Houston [4]. All reported ages are given with 2σ uncertainties.

Petrography: The meteorite is composed of numerous clasts in a comminuted matrix (Fig. 1). The clasts consist of fine-grained feldspathic clasts, coarse-grained mare basalt clasts, and mineral fragments. The clasts are aligned and flattened, producing a structural fabric.

Olivine and Pyroxene: Olivine in lithologic clasts that contain apatite and merrillite are Fe-rich and have a composition of $Fa_{93.0-97.5}$ (Average $Fa_{95.9}$; Mg# = 4). Isolated olivine fragments (bright green in Fig. 1) are Mg-rich $Fo_{78.9-83.5}$ (Average $Fo_{81.6}$; Mg# = 81.6).

Pyroxene varies in composition $Wo_{3-34}En_{1-76}Fs_{20-84}$ (Mg# = 1-79). A large pyroxene crystal near the center of the section (Fig. 1) is zoned from a Mg-rich core ($Wo_{13}En_{46}Fs_{41}$; Mg# = 53) to a Fe-rich rim ($Wo_{27}En_{9}Fs_{63}$; Mg# = 15).

Phosphate: Apatite and merrillite were identified (Fig. 2). Both typically occur in Fe-rich clasts. Apatite contains appreciable F (~2.23 wt%) and Cl (~0.75 wt%) and has an average composition of 40.26 wt% P_2O_5; 53.25 wt% CaO; 1.0 wt% SiO_2; 0.05% TiO_2; 1.27 wt% FeO; 0.43 wt% Y_2O_3; <0.2 wt% La_2O_3; <0.5 wt% Ce_2O_3; and <0.1 wt% SmO.

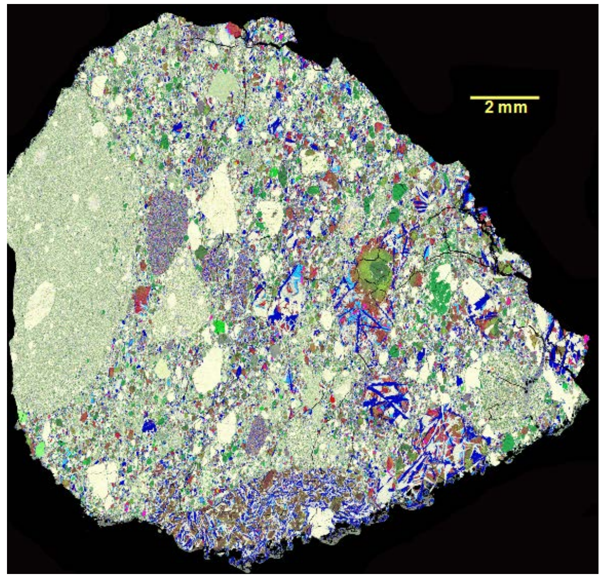

Figure 1: *False color element map of lunar anorthositic breccia MIL 13317,5 where Fe = red, Mg = green, Si = blue, Al = white, Ti = magenta, K = cyan, and Ca = yellow.*

Merrillite, conversely, is devoid of F and Cl and is REE-rich. The average composition of merrillite is: 41.68 wt% P_2O_5; 39.63 wt% CaO; 0.5 wt% SiO_2; 0.06% TiO_2; 3.84 wt% FeO; 1.41 wt% MgO; 2.61 wt% Y_2O_3; 1.32 wt% La_2O_3; 3.19 wt% Ce_2O_3; and 0.45 wt% SmO. In the preliminary analysis of merrillite, not all of the REEs were accounted for, so total REE may be 4-7 wt% higher than the sum of Y, La, Ce, and Sm oxides measured.

Baddeleyite and Zircon: Baddelyite is found in four distinct petrologic contexts: (i) associated with symplectite regions, (ii) within pyroxene grains, (iii) isolated within the breccia matrix, and (iv) within a melt-vein. Zircon was only observed with symplectite regions which are typically found within mare basalt clasts.

Tranquillityite and Zirconolite: Small grains of tranquillityite are typically found along the grain boundaries of pyroxene crystals and are often found occurring with baddeleyite, silica, and plagioclase. Several large crystals of tranquillityite (up to ~50 μm in longest dimension) were also found in a single mare basalt clast.

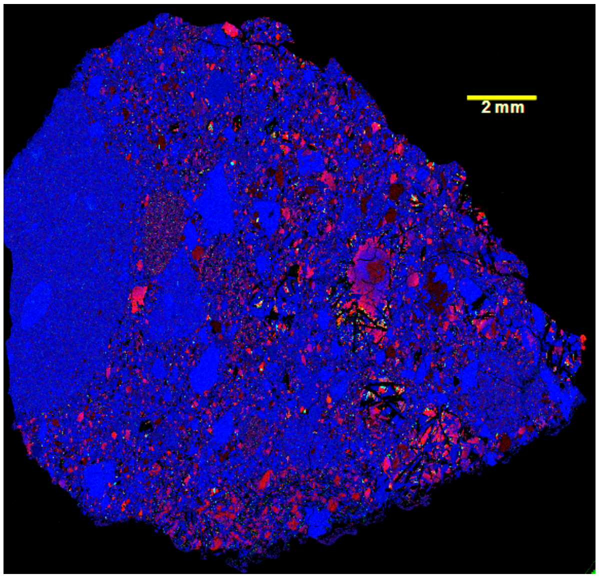

Figure 2: *False color map of MIL 13317,5 where Fe = red, P = green, and Ca = blue, used to identify zircon (green), apatite (cyan), and sulfide (yellow) minerals. Small apatite and zircon grains can be seen in several areas of the meteorite.*

Zirconolite is rare and occurs as either a small crystal in larger symplectite regions of hedenbergite, fayalite, and silica or as larger grains (up to ~40 µm) in contact with olivine and baddeleyite.

Geochronology: Baddeleyite, like zircon, has a high closure temperature (>900°C) with regards to the U-Pb system [5]. Apatite, and likely merrillite, has a much lower closure temperature (~450-550°C) [6].

Baddeleyite grains found within symplectite regions, pyroxene, and the matrix will likely date the time of crystallization for the clasts in which they are found. The relationship of baddeleyite, apatite, and merrillite grains in symplectite regions provide an opportunity to determine the ages of crystallization and any later thermal event(s) within the same clast. Symplectites form from the breakdown of pyroxferroite during cooling or from shock-induced heating [7,8].

A total of 39 U-Pb analyses were performed on 21 baddeleyite grains, 11 Ca-phosphate grains, and a single tranquillityite grain in MIL13317,5. The U-Pb baddeleyite ages are similar within error and yield a $^{207}Pb/^{206}Pb$ weighted average of 4270±24 Ma (Fig. 3). The Ca-phosphate and tranquillityite yield $^{207}Pb/^{206}Pb$ weighted average of 4351.8±8.7 Ma (Fig. 3). There were only two locations in which baddeleyite and Ca-phosphate were analyzed in the same symplectite region. Location A yielded a baddeleyite age of 4207±81 and a merrillite age of 4276±27 Ma, while location B yielded a baddeleyite age of 4339±94 Ma and an apatite age of 4357±12 (5 analyses on a single grain). Ca-phosphate ages in other symplectite regions yield an average age of 4352±14 Ma while two more Ca-phosphate grains found in the matrix yielded ages of 4338±19 Ma and 4276±32 Ma. A single tranquillityite grain yielded an age of 4339±17 Ma which is similar to the age of apatite and merrillite. A single baddeleyite located in the matrix, yielded an age of 4368±89 Ma. Five other baddeleyite grains in the matrix yield an average age of 4235±39 Ma and a lone baddeleyite found in a melt vein yielded an age of 4273±145 Ma.

The ages of baddeleyite and Ca-phosphate located together in two different symplectite regions, plus the ages of individual grains in the matrix, suggests two mare basalt lithologies with primary crystallization ages of ~4350 Ma and ~4270 Ma. The similar ages within the symplectites suggests that symplectite likely formed from the breakdown of pyroxferroite during rapid cooling as opposed to shock-induced heating. This is further supported by the presence of pyroxferroite in the meteorite which can exist metastably at low pressures as the result of rapid cooling from a melt [9].

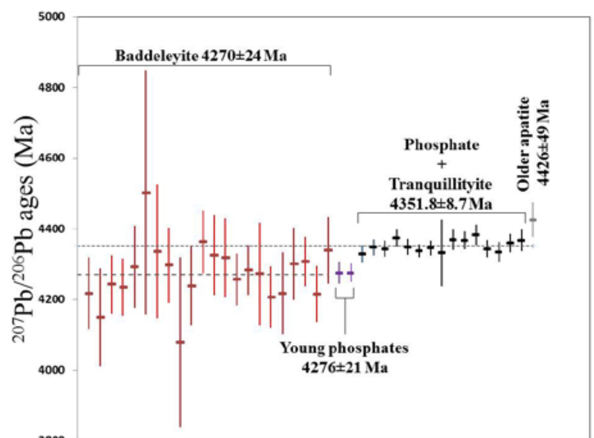

Figure 3: *Pb-Pb ages of baddeleyite, Ca-phosphate phases of apatite and merrillite, and tranquillityite. The dashed line represents the weighted average age of baddeleyite (4270±24 Ma) and the dotted line represents the weighted average age of phosphate and tranquillityite (4351.8±8.7 Ma).*

References: [1] Cohen B. A. et al. (2000) *Science*, 290, 1754-1756. [2] Satterwhite C. and Righter K. (2015) *AMN*, 38-2, 12. [3] Joy K. et al. (2011) *LPSC XLII*, Abstract #2103. [4] Shaulis et al. (2010) *GGG*, 11. [5] Heaman and LeCheminant (2001) *Chem. Geol.*, 172, 77-93 [6] Schoene and Bowring (2007) *GCA*, 71, 165-185. [7] Lindsley et al., (1972), *LPSC*, 3, 483-485. [8] Liu et al., (2009), *MAPS*, 44, 261-284. [9].Lindsley D. H. et al (1972) *LPSC III*, 483-485.