Clast Size Distributions for Lunar Ferroan Anorthosite 60025 Provide Possible Explanation for Age Disparities. J.H.C. De Oliveira[1], M.A. Torcivia[2], and C.R. Neal[3], [1,2,3]University of Notre Dame, Notre Dame IN, 46556; ([1]jdeolive@nd.edu; [2]mtorcivi@nd.edu; [3]cneal@nd.edu)

Introduction: Ferroan anorthosites (FANs) are a suite of plagioclase-rich rocks that are thought to represent flotation cumulates from the lunar magma ocean (LMO) [1]. They are considered to be first cumulates to form the primordial lunar crust. Geochronologic dating of these rocks allow researchers to determine when the first lunar crust formed. Lunar sample 60025 is a FAN that was collected during Apollo 16. It is considered to be a chemically pristine rock [2]. Therefore, this sample has been the subject of many geochronologic studies (e.g., [3,4]). However, analyses of cataclasized anorthosite 60025 have produced 2 Sm-Nd crystallization ages (4.44±0.02 Ga [3] and 4.367±0.011 Ga [4]). The implication of multiple distinct ages could be emblematic of error in dating methodology (unlikely), or of heterogeneity inherent in the sample itself (i.e. the sample is a mixed lithology [5,6]). The context of these ages is incredibly important to our understanding of the evolution of the Moon and will either bolster the LMO hypothesis or weaken it.

Crystal size distributions (CSDs) are a nondestructive quantitative petrographic analysis method that can reveal the crystallization history of igneous rocks [7-9]. However, size distributions of clasts within impact breccias have also been used to distinguish shocked and unshocked populations in terrestrial samples [10]. CSDs are produced by imaging a thin section and then tracing out individual crystals or clasts. The purpose of this project is to use CSDs across two distinct thin sections (60025,21 and ,130) as an analytical method to determine whether the clast distribution within brecciated 60025 is homogenous or heterogenous, which will help provide context for the geochronologic dating results and the implications about the evolution of the Moon.

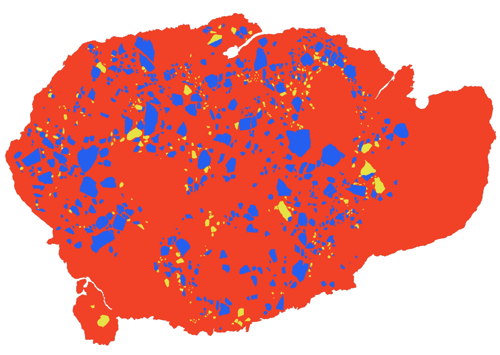

Figure 1. Trace for thin section 60025,21. Blue and yellow colors were used during tracing process to increase contrast.

Methods: A number of protocols were employed throughout the tracing process to differentiate plagioclase clasts in the two thin sections. The two thin sections were first imaged in cross polarized (XPL) and plane polarized light (PPL). Photomicrographs of each thin section were stitched together using Microsoft's Image Composite Editor, and then traced by hand in Adobe Photoshop© (see figures 1 and 2 for traces of thin sections as well as the XPL image of 60025,130). Unlike true crystal size distributions, individual crystals were not traced. For this study, only the individual clasts were traced primarily through recognition of differences in coloration along clean, well-defined borders in the XPL image. For grains/clasts in extinction in the image, tracing was used in conjunction with the sample loaded on a petrographic microscope and rotated so that extinction could be eliminated allowing determination of the boundaries of the clast. In clasts that maintained consistent birefringence colors, but contained multiple cracks, twinning and the presence of undulose extinction were used to determine whether the clast would be considered as a whole or several separate clasts. If there was noticeable offsetting in the twinning, which was seen most frequently in the largest clasts, then the clast was divided along the offset borders. Undulose extinction, as examined through the petrographic microscope, was used to differentiate particularly large, shocked sections of 60025,130. If

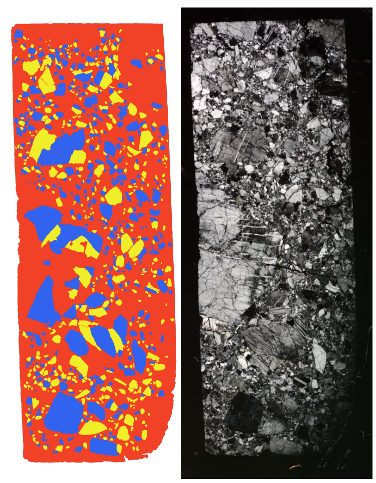

Figure 2. Trace (left) and XPL image of thin section 60025,130 (right) for comparison.

there was a moment during rotation of the thin section where a distinct portion of the clast went into extinction when other sections of the larger clast did not, then that section was traced as a single clast. If there was not noticeable offsetting and the coloration was consistent, regardless of the number of cracks, the grain was traced as one single clast. Traces were processed using the program ImageJ to determine clast area and dimensions and then those data were run through CSDSlice [8] and CSDCorrections [9] software packages.

Results and Discussion: A total of 928 clasts were traced for thin section 60025,21 and 730 clasts were traced for thin section 60025,130. The CSDs performed on thin sections 60025,130 and 60025,21 reveal graphs with a great deal of commonality with similar y-intercepts (3.62 for 21 and 3.34 for 130), concave up orientation (denoting an accumulation of larger clasts), and marked kinks (two kinks per thin section, resulting in three distinct slopes for each thin section; Fig. 3). Kinks, or abrupt changes in CSD slope, define distinct populations of clasts/crystals. The kinks in these two thin sections can be interpreted as the mixing of distinct clast populations that have experienced different impact histories and potentially different provenances. As with the samples used in the geochronology studies that produced distinct Sm-Nd ages, the two thin sections studies here were taken from different portions of 60025. Because of this, there is reason to rethink the pristine/homogenous status of this FAN. The distinct ages could have depended upon which area of the sample and clast population that was used in the individual studies [3,4]. However, it remains to be seen whether kinked clast-size distributions are observed across other 60025 thin sections.

Conclusion(s): The results of the two CSDs indicate that lunar sample 60025 is a heterogenous rock made up of at least two separate, distinct clast populations. This could explain the disparities in ages gathered from this particular sample and supports the conclusion that 60025 appears to be a rock containing mixed lithologies [5,6]. Further research will be conducted with the method described here to determine whether these multiple clast populations are represented across several other 60025 thin sections.

References: [1] Toksöz M. & Solomon S. (1973) *EMP* 7, 251-278. [2] Warren, P. (1993) *Am. Min.* 78, 360-376. [3] Carlson, R. & Lugmai, G. (1988) *EPSL* 90, 119-130. [4] Borg et al. (2011) *Nature* 477, 70. [5] James O.B. et al. (1992) PLPSC 21, 63-87. [6] Torcivia M.A. & Neal C.R. (2018) *LPSC 49*, #1331. [7] Marsh, B. D. (1988) *Cont. to Min. & Pet.* 99, 277–291. [8] Morgan D. J., & Jerram D.A. (2006) *JVGR* 154, 1-7. [9] Higgins M.D. (2000) *Am. Min.* 85, 1105-1116. [10] Pitarello L. & Koerbel C. (2013) *MaPS* 48, 1325-1338.

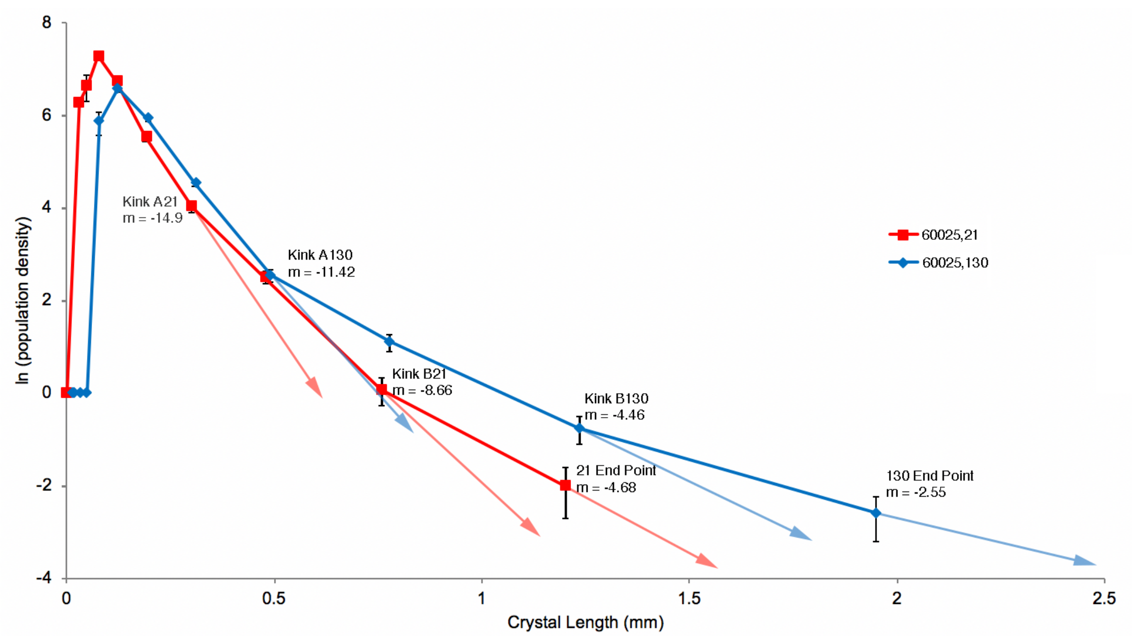

Figure 3. CSD profiles for thin sections 60025, 21 and 60025, 130 along with trend lines for slope segments