Investgating the Cooling Regimes of Apollo 11 Basalts. Welsh, D.F.[1], Neal, C.R.[1], Burney, D.[1], Cronberger, K.[1], Torcivia, M.A.[1]. [1]Department of Civil and Environmental Engineering and Earth Science, University of Notre Dame, Notre Dame, IN 46556, USA [dwelsh1@nd.edu; cneal@nd.edu].

Introduction: Apollo 11 was the first human mission to the Moon, and the samples that were collected are still providing important information regarding the nature of the lunar mantle and ages of lunar volcanism. The Apollo 11 mission returned high-Ti basalts (e.g., [1]) which have been divided into three general groups – A, B, and D [2,3]. Over 70 mare basalt fragments have been analyzed since the return of these first lunar samples in 1970. Group A basalts are the only high-K (K_2O > 0.2 wt.%) high-Ti basalts returned from the Moon and are enriched in incompatible trace elements (ITEs). Group B basalts are low-K (K_2O <0.1 wt.%) and are subdivided into 3 subgroups – B1, B2, B3 (based on composition and texture [2,3]. Groups B1 and B3 are similar texturally and form a continuum of compositions, with B3 being the most primitive. Group B2 basalts are enriched in ITEs and Al_2O_3, with lower TiO_2 than Groups B1 and B3 basalts [4]. Group D basalts are also low-K, but have REE abundances similar to the Group A basalts [4].

This project examines thin sections of Apollo 11 basalts in order to investigate the cooling regimes of the different Apollo 11 magma types [4]. Plagioclase crystal size distributions (CSDs) are constructed and the data are compared with those previously reported [5]. Three Apollo 11 thin sections were examined in this initial study and the plagioclase CSDs are reported here. Samples analyzed are 10003,185 (low-K, Group B2), 10092,10 (low-K, Group B3), and 10057,33 (high-K, Group A). More information on the Apollo 11 samples can be found in the lunar sample compendium [6]. CSDs are the quantification of the mineral textures present in a thin section, and through comparison of CSDs of samples from different groups, information can be gathered about the crystallization of various magma batches. The texture of samples, and therefore the CSDs, are related to emplacement mechanisms, cooling rates, and bulk composition. Therefore, they can be used to define the origin (for example an impact melt or a flow due to endogenic volcanism) [5] as well as the type of flow (A'a or Pahoehoe) from which the sample was derived [7].

Method: In order to place the Apollo 11 samples in context with the other high-Ti basalts returned by the Apollo 17 mission, CSDs for plagioclase were created. The method used is described in detail in Neal et. al. [5] To summarize, each thin section was photographed using a 4x objective, and these images were stitched together using the Microsoft *Image Composite Editor*© to create a digital photomosaic (Fig. 1).

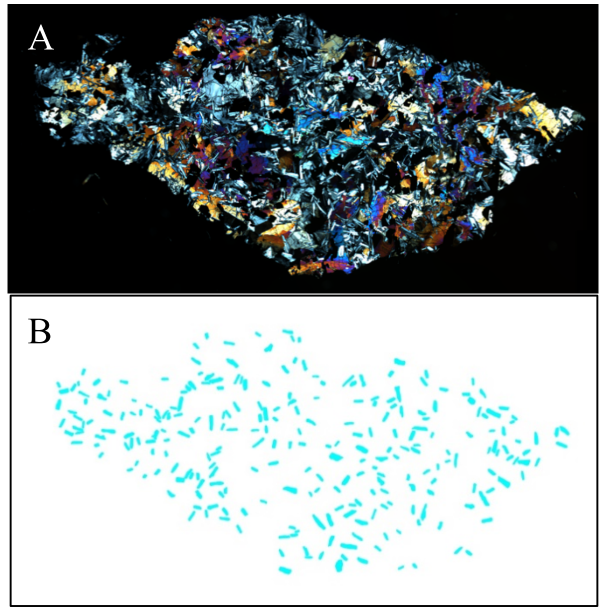

Figure 1: A: Stitched photomicrograph of sample 10003,185 in cross polarized light. B: The traced plagioclase crystals.

The stiched images of the sample were generated on a petrographic microscope in reflected light, plain polarized light, and cross polarized light.. In each of the images, there was a ratio of 1000 pixels for every millimeter. Then in *Adobe Photoshop*©, the crystals of interest – in this case plagioclase – were traced using a tablet PC (e.g. Figure 2a plagioclase traces) (Fig 1). Also needed to calculate accurate CSDs is the outline of the entire sample. A minimum of 250 plagioclase crystals were traced for each sample which is needed for the CSD to be statistically viable [5]. The layers used for the crystal tracings were then imported into *ImageJ*© [8]. Multiple trace layers are necessary in cases where crystals are overlapping each other- a single trace layer would erroneously record these crystals as one. *ImageJ* does a pixel analysis to the imported layers, and applies a best-fit ellipse to each crystal to determine a major and minor axis, as well as the precise area of each crystal. The same *ImageJ* is applied to the sample trace layer to determine modal percentage. Major and minor axes of the crystals are then exported to *CSDSlice* [9] and all data to *CSDCorrections* [10]. The former determines the approximate shape (e.g. rounded, oval, tabular, etc.) of the 2D traced crystals in three dimensions, and the latter sorts the crystals based on the length of the major axes and plots these in size bins based on the number of crystals present versus the natural log (ln) of the population.

Once created, the linear portion of the CSD that represents crystals that are >0.3mm is used for analyses as there is a drop off in crystal population due to limitations in visual resolution. The intercept and slope of each individual CSD could then be compared with the respective values from other samples to find relations in the crystallization of the various magma batches.

Results and Discussion: The three samples reported here represent preliminary data for the Apollo 11 basalts suite (Fig. 2). Sample 10092,10 has the largest error bars due to its small size and therefore smaller plagioclase population to trace (Fig 2). The slope and intercept of each calculated CSD plot in Fig 3 have been plotted with plagioclase CSDs previously made from Apollo 12, 14, 16, and 17 basalts [5] (Fig. 3) Although more data are needed, the three Apollo 11 high-Ti basalts are distinct from the high-Ti basalts from Apollo 17. The two Group B basalts (10003,185 and 10092,10) have plagioclase CSDs that are within error of each other, but the Group A basalt is distinct. Even though they plot in a different area, the three Apollo 11 basalts CSDs show a sublinear trend to the Apollo 14 high-Al basalts. This similarity in trends indicates that both samples went through similar crystal nucleation and crystal growth. Both Apollo 11 and Apollo 14 samples show a larger population of smaller crystals than other Apollo sample suites (Fig 3). This lack of larger crystals shows that these samples went through a more rapid quenching process which can be seen terrestrially on thinner basalt flows, or the quenched margins of thicker flows.

These data also plot definitively outside of the impact melt field (Fig. 3). It can be said with certainty that these Apollo 11 high-Ti basalts, and any subsequent data derived from them, represent endogenous melts that are sourced from the lunar interior.

Conclusion: The Apollo 11 basalts studied here are endogenous melts from the lunar mantle as they plot well away from the impact melt field in Figure 4. The similarity to Apollo 14 high-Al basalts indicates that the samples lack large plagioclase crystals suggesting they were derived from the chilled margins of thick flows or basalts present at the Apollo 11 and 14 sites and were a series of thin flows. More data will be collected in order to further examine these relationships.

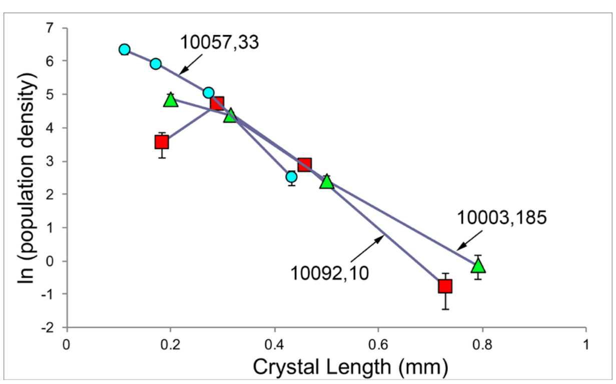

Figure 2. Plagioclase CSD profiles for 10003,185, 10057,33, and 10092,10

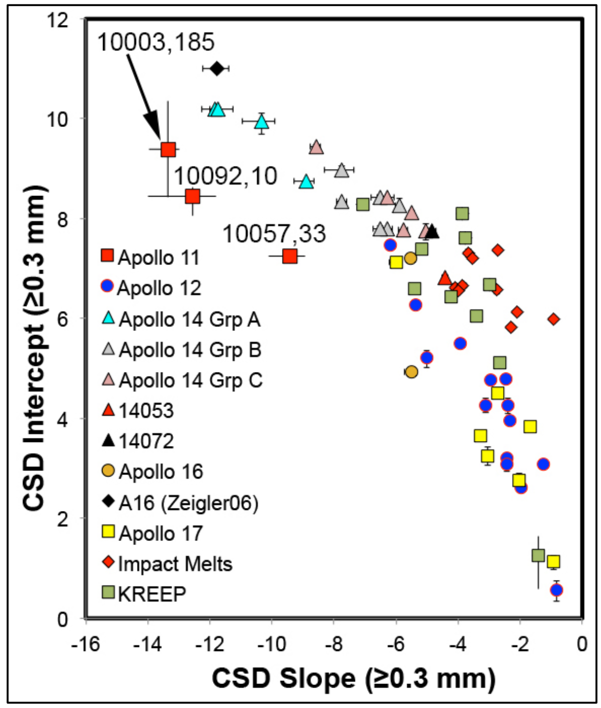

Figure 3. A11 samples compared with impact melts and basalts from other missions using plagioclase CSDs. Shows the plot of CSD Intercept against CSD Slope for plagioclase with errors calculated from CSDCorrections shown for each data point. If error bars are not visible, they are within the size of the symbol.

References: [1] Neal C.R. & Taylopr L.A. (1992) GCA 56, 2177-2211. [2] Beaty D.W. & Albee A.L. (1978) PLPSC 9, 359-463. [3] Beaty D.W et al. (1979) PLPSC 10, 41-75. [4] Jerde E. A. (1993) GCA 58, 515-527. [5] Neal C. R. et al. (2015) GCA 148, 62-80. [6] Lunar Sample Compendium http://curator.jsc.nasa.gov/lunar/compendium.cfm. [7] Neal C.R. et al. (2015) LPSC 46, abstract #1299. [8] Schneider C.A., et al., (2012). Nature Methods, 9(7). [9] Morgan D. J., & Jerram D.A. (2006) JVGR 154, 1-7. [10] Higgins M.D. (2000). Amer. Min. 85, 1105-1116.