INVESTIGATING THE LUNAR MAGMA OCEAN HYPOTHESIS WITH ANORTHOSITE 15415 AND TROCTOLITE 76535. K. M. O'Sullivan[1], C. R. Neal[1], and A. Simonetti[1] [1]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA (kosulli4@nd.edu, neal.1@nd.edu, simonetti.tony@gmail.com)

Introduction: In this pilot study we chose two samples from the highlands region on the Moon to test the lunar magma ocean (LMO) crystallization hypothesis; Ferroan Anorthosite 15415, and Mg-Suite troctolite 76535.

Ferroan Anorthosite (FAN) 15415. 15415 is considered a pristine anorthosite [1]. This sample contains offset twining in some plagioclase crystals, which is evidence of mild shock, probably due to the impact that placed it upon the lunar surface (Figure 1a). It is comprised of 98% plagioclase with minor pyroxene, ilmenite, and silica [2].

Mg-Suite Troctolite 76535. 76535 is comprised of 35% olivine, 60% plagioclase, 5% orthopyroxene, and trace amounts of other minerals (baddeleyite, apatite, Cr-spinel, and metal; [3] (Figure 1b). Lunar troctolites, such as Apollo 17 sample 76535, present an interesting conundrum: How can you generate a partial melt from the plagioclase-poor lunar mantle that will co-crystallize olivine and plagioclase? [e.g., 4] The petrogenesis of troctolites and their relationship to the lunar magma ocean remains a major question 40 years after samples were returned from the Moon. Models proposed for troctolite petrogenesis include the following: Involvement of a Mg-rich parent magma crystallizing after the primary crust from the crystallization of a magma ocean (represented by Apollo 15 sample 15415). This Mg-rich magma is derived from the re-melting of the lunar interior [e.g., 5, 6]. On the other hand, [4] showed that such models cannot account for the extremely Mg-rich nature of the parent magmas. He presented two alternatives to form these parental magmas: mechanical mixing of anorthositic crust and olivine enriched upper mantle from impact or partial melting of an Al-rich lherzolitic source.

In this investigation we used crystal stratigraphy to explore the petrogenesis of the "genesis rock" FAN 15415 and the Mg-Suite troctolite. Major and trace elements were used to determine equilibrium liquids from plagioclase compositions. This allowed an investigation of the models of FAN and Mg-Suite formation. If FANs are formed from the crystallization of the LMO, the equilibrium liquid compositions should be consistent with those calculated for LMO crystallization (e.g., [7]). The compositions determined from the Mg-Suite troctolite can be used to test if it was formed by re-melting of the interior [e.g., 5, 6] or from partial melting of a lherzolitic source [4]. If the liquids can not be related to either of these, then the troctolites must be derived from some other source/mechanism, possibly mechanical mixing during an impact [4].

Methods:

Major Element Analysis. Major element concentrations were obtained using a JEOL JXA-8200 Electron Microprobe (EMP) at Washington University. EMP points were obtained for plagioclase in both samples, and olivine in 76535. EMP points were obtained using a 25nA beam current, a 5-10 micron spot size and a 30 second count time on each element peak. Data were reduced using *Probe for Windows* software.

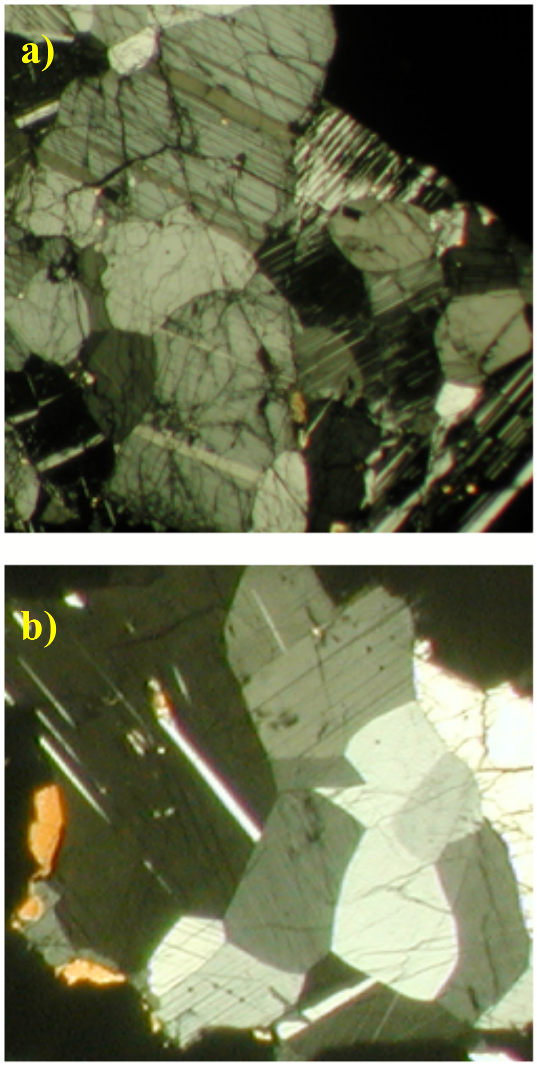

Figure 1. Cross polarized view of (a) 15415 and (b) 76535. Each image is 4 mm across.

Trace Element Analysis. In-situ trace element analysis was conducted using Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS); an

Element 2 high resolution ICP-MS combined with a *New Wave* 213nm Nd:YAG laser ablation system was used at the University of Notre Dame. Laser spots were chosen to correspond to the EMP points, using CaO as the internal standard. NIST 612 glass was used as the external standard. Data were reduced using the *Glitter* software [8].

Crystallization Modeling. We calculated parental liquid compositions by dividing the elemental concentration by the respective partition coefficient. Partition coefficient values are therefore very important and must be chosen with care. The values were taken from studies using undoped crystals with major element compositions similar to those in this study. We then modeled plagioclase rim zones using the parental liquids derived from the cores, using equilibrium, in-situ, and fractional crystallization schemes. 15415 parental liquids are then compared to those calculated for LMO crystallization [7].

Results:

Olivine Major Element Analysis. All olivine crystals are relatively homogeneous: MgO ranges from 46.7-47.7%, and FeO ranges from 12-12.5%. Plagioclase major element analyses were also quantified, although not reported here.

Plagioclase Trace Element Analysis. Plagioclase Sr and Ba concentrations are shown in Figure 2. 76535 has higher Sr and Ba concentrations than 15415. The chondrite normalized rare earth element abundances for 15415 (blue) and 76535 (red) are in Figure 3. Only three plagioclase analyses for 15415 are reported due to the thickness and the limited number of crystals in the thin section.

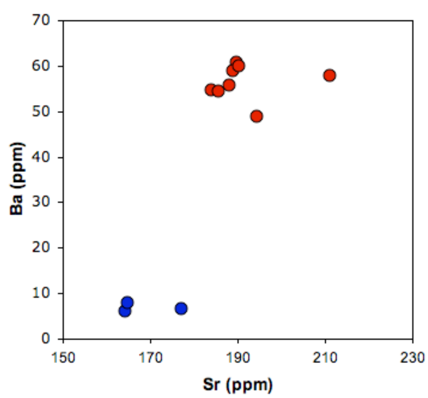

Figure 2. Ba vs. Sr for plagioclase in 15415 (blue) and 76535 (red).

Crystallization Modeling. Parental liquid compositions of 15415 and LMO liquids [7] are plotted in Figure 4. Parental liquids for 15415 exhibit a positive Eu anomaly, and are less enriched in heavy REE than the liquid compositions reported by [7]. Discrepancies could be due to partition coefficients, especially for Eu. Another possibility is that the LMO elemental abundances should be revised. However, additional plagioclase analyses will need to be conducted in order to verify this hypothesis.

Crystallization modeling for 76535 will presented at LPSC 42.

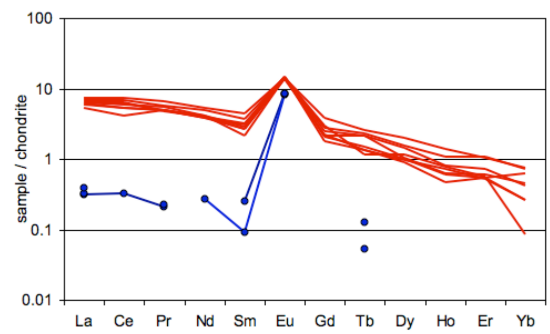

Figure 3. Chondrite normalized rare earth element profiles for plagioclase in 76535 (red) and 15415 (blue).

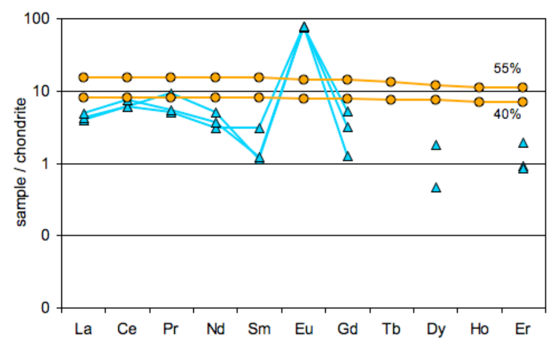

Figure 4. Chondrite normalized rare earth element profiles for parental liquids of 15415 (light blue) and LMO liquids at 40 and 55% total crystallization (orange) [7].

Conclusions: Determining the parental compositions for 15415 can test the crystallization hypothesis for the LMO. Because only three plagioclase analyses were obtained for 15415, we have requested an additional thin section. Preliminary results suggest that the LMO liquid compositions may need to be revised. Crystallization modeling of 76535 will be reported at LPSC 42.

References: [1] Warren P.H. (1993) Am. Min. 78, 360-376; [2] Stewart D.B. et al (1972) *Proc. Lunar Sci. Conf.* **3rd**, 726-729. [3] Gooley R. et al (1974) *Geochim. Cosmochim. Acta.* **38**, 1329-1342. [3] Hess P.C. (1994) *J. Geo. Res*. **99**, 19083-19093. [4] James O.B. (1980) *Proc. Lunar Planet. Sci. Conf.* **11th**, 365-393. [5] Norman M.D. and Ryder G. (1979) *Proc. Lunar Sci. Conf.* **10th**, 531-559. [6] Snyder et al. (1992) GCA 100, 9365-9388; [8] Simon Jackson, Macquarie University <http://www.glitter-gemoc.com/>.