MAJOR AND TRACE ELEMENT CONCENTRATIONS MEASURED IN OLIVINE CRYSTALS FROM APOLLO 15 OLIVINE-NORMATIVE MARE BASALTS. Stu Webb[1], Zhuqing Xue[2], Clive R. Neal[1], [1]Department of Civil & Environmental Engineering & Earth Science, University of Notre Dame, Notre Dame, IN 46556, U.S.A., [2]Center of Deep-Sea Research, Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China [cneal@nd.edu; gwebb1@nd.edu; zxue01@foxmail.com]

Introduction: Previous studies of Apollo 15 olivine-normative mare basalt samples (ONBs) have suggested that chemical variation was controlled by olivine that did not accumulate within the samples [1] and quantitatively examined olivine crystals present in the samples [2]. Additionally, major and trace element concentrations have previously been measured in olivine crystals from Apollo 12, 14. and 17 basalts and impact melts and used to show distinct chemical variation among the groups [3]. This study conducts similar major and trace element analyses on olivine crystals within nine Apollo 15 olivine-normative mare basalt thin sections (15529,15, 15545,2, 15547,7, 15555,250, 15557,94, 15622,20, 15647,7, 15676,14, and 15678,7). These samples were selected because they span the range of Apollo 15 ONB whole rock compositions. The two samples with the lowest MgO in Fig. 1 are both from 15556 (,177 & ,178; [1]), which shows this sample exhibits heterogeneity even if ~5g aliquots of sample are homogenized [1]. Therefore, 15556 was not analyzed as part of this study. Whole rock geochemistry has suggested that both CaO and TiO_2 show possible fractional crystallization trends when plotted against MgO content for these basalts [1] (Fig. 1). This study aims to examine the trace element trends present within individual olivine crystals in order to better understand the crystallization history of these basalts.

Methods: Digital photomicrographs of the thin sections were obtained using a Nikon petrographic microscope and 4x objective in plane-polarized, cross-polarized, and reflected light. The images for each thin section were stitched together using *Microsoft Image Composite Editor*© to create complete photomosaics of each sample. These were compared to the thin sections to ensure that no significant distortion/alteration occurred during stitching. Elemental composition maps of the thin sections were then made using the Cameca SX100 Electron Microprobe (EMP) at the University of Notre Dame's Materials Characterization Facility (Fig. 1). The thin sections were carbon coated and the instrument was set to an accelerating voltage of 15 kV and beam current of 25 nA. The elements mapped included Si, Al, Fe, Mg, Ca, K, P, Ti, Na, and Cr.

The same instrument settings were used to acquire major element compositional data of olivine crystals in each sample. These points were recorded on the digital

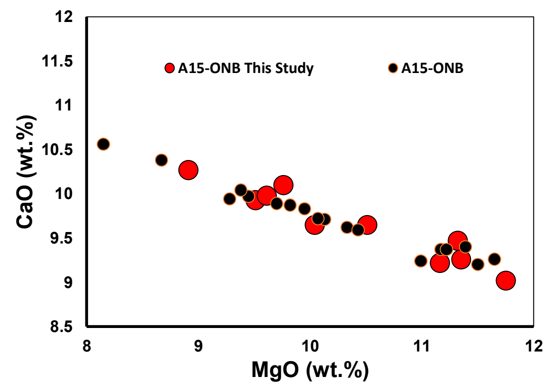

Figure 1: Whole rock geochemistry reported for olivine-normative Apollo 15 basalts [1]. The data forms a linear trend proposed to be due to fractional crystallization. The large red circles are samples that are also represented in this study of olivine geochemistry. The selected samples cover essentially the full whole rock MgO range that has been measured in this suite of samples.

photomosaics of each sample. The elements measured were Fe, Mg, Ca, Al, Ti, Cr, Na, Si, O, and Mn. Oxide weight percentages were calculated and only points whose oxide weight percentages had sums between 98.5 and 101.5 with cation totals of 3.0 were considered viable.

Trace elements (Ca, Sc, Ti, V, Cr, Mn, Co, and Ni) were measured at EMP points using the New Wave UP-213 laser ablation system and Nu Plasma Attom High Resolution Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS) at the University of Notre Dame's Midwest Isotope and Trace Element Research Analytical Center (MITERAC). NIST 610 SRM glass was used as an external standard and EMP manganese abundance was used as an internal standard. The laser ablation system was set to a spot size of 40 µm, repetition rate of 5 Hz, and fluence of ~11 J/cm^2. Helium was used as the carrier gas. Each laser analysis comprised of ~20 sec warm up, ~30 sec background counts, and ~60 sec sample ablation. After each analysis, a 90 second washout was administered before the next data acquisition to avoid sample cross contamination. Measurements of NIST SRM 610 glass were taken at the beginning and end of each analysis set.

GLITTER© software was used to calculate elemental abundances [4].

Results and Discussion: Forsterite percentages within the Apollo 15 olivine crystals ranged from 17% to 71%, which is significantly lower than most of the olivine crystals previously analyzed in [3] and represents a broad range of geochemical evolution (Fig. 2). The Apollo 15 olivines overlap with previously measured samples above ~Fo_{60}, but extend to significantly lower Fo values. When plotted against MgO content some elements from the Apollo 15 olivine crystals (Mn, Ti) appear to form fractional crystallization trends that are consistent with the whole rock trends discussed in [1], although the Ti data exhibit significant scatter beyond the X-Y% uncertainty in each data point. Other elements measured, such as Ni (Fig. 4) and Cr, show broad positive trends, but with significant scatter (again far beyond analytical uncertainty) and correlation between Co, Ca, and V with Fo content show no correlations. Our initial conclusion is that the olivine trace element data are not consistent with simple closed system fractional crystallization. For the range of whole rock compositions covered in this study (Fig. 1), the equilibrium olivine compositions would be $Fo_{74.1\text{-}68.2}$. While it is evident that fractional crystallization occurred in these samples, it appears to have been open system. More details will be presented at LPSC-53. Future work with this dataset will involve calculating equilibrium liquids for these olivines and comparing the chemistry of those liquids to the previously reported whole rock geochemistry data from these samples [1].

Conclusions: The Apollo 15 ONBs contain olivines that have evolved from the equilibrium compositions expected from whole-rock data, and also are generally Fo-poor compared to other lunar basaltic olivines (Fig. 2). Examination of trace element data indicate that some trends are consistent with fractional crystallization trend (e.g., Mn), there is significant scatter in such trends (e.g., Ti, Cr, Ni) or no correlation is apparent (Co, Ca, V). We conclude that the Apollo 15 ONBs did experience fractional crystallization, but that it was open system.

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References: [1] Ryder G. & Schuraytz B.C. (2001) JGR: Planets 106, 1435-1451. [2] Xue, Z. et al. (2020) *51st LPSC* Abstract #1745 [3] Fagan A.L. et al. (2013) GCA 106, 429-445. [4] http://www.glitter-gemoc.com/

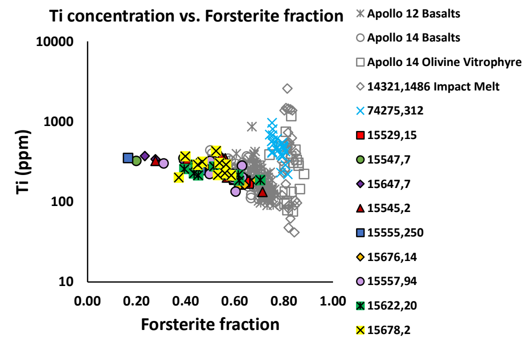

Figure 2: Olivine data from this study compared to data from [3]. The Apollo 15 olivine-normative basalts in this study contain more fayalitic olivine than has been analyzed in previous studies of this type on lunar basalts, with only the most forsteritic olivines in this study overlapping with the most fayalitic olivines from [3].

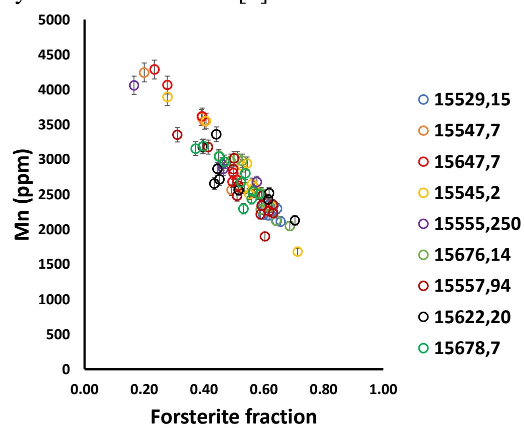

Figure 3: A plot of Mn concentration versus forsterite content for the Apollo 15 olivine crystals in this study. The data forms a clear linear trend, similar to the trends observed in the CaO and TiO whole rock chemistry of these samples [1]. Such trends are frequently indicators of fractional crystallization.

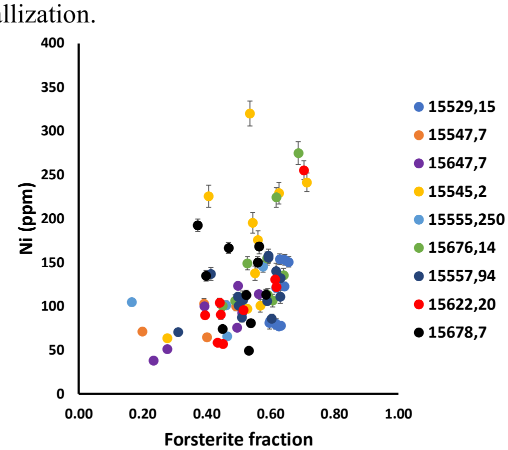

Figure 4: A plot of Ni concentration versus forsterite content for the olivine crystals in this study. The data appears to have a general trend but the spread is much further than can be accounted for by instrument error alone.