MODERATELY VOLATILE ELEMENTS IN LUNAR BASALTS: IMPLICATIONS FOR THE LUNAR VOLATILE BUDGET. D. Burney[1], C.R. Neal[1], and A. Simonetti[1]. [1]University of Notre Dame, Notre Dame IN, 46556; dburney@nd.edu.

Introduction: The formation of the Moon through an energetic collision of a Mars-sized planetesimal with the proto-Earth requires that the Moon be depleted in volatile elements due to the very high temperatures.. Early analyses of Apollo lunar material generally demonstrated that the Moon was volatile depleted [1,2]. Recently, however, newer analytical methods (e.g., Fourier transform infrared spectroscopy (FTIR), nano-SIMS) have quantified trace volatile elements in olivine-hosted melt inclusions, volcanic glasses, and apatite grains [1-3]. These studies demonstrate that endogenous water is present within the lunar interior. While modifications to the Giant Imapct hypothesis have been suggested to account for the new data (e.g., [4,5]), gaps in the lunar geochemical database mean that definitive tests of the model using a large suite of volatile elements cannot be made.

Moderately volatile elements (MVEs) that have a condensation temperature ~750 K (e.g., Zn, Se, Rb, Ag, Cd, In, Tl, Bi, Pb, and Sb) would have condensed later than commonly measured refractory elements, and earlier than highly volatile elements (e.g., Cl, S, O, H, etc.). The MVEs provide insight into fractionation events that occurred early in the Moon's formation.

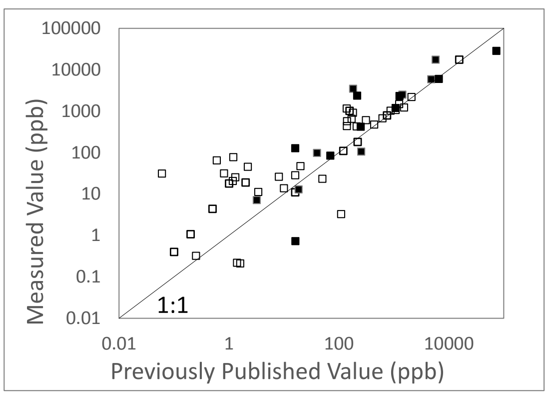

***Fig. 1**: Previously published MVE values [7-21] vs. the values measured here. Analyses are split into high-Ti (solid symbols) and low-Ti (open symbols) samples.*

Methods: 11 lunar basalts were analyzed using solution mode ICP-MS [6]. Those analyzed include 4 high-Ti, and 7 low-Ti. The high-Ti consist of 2 high-K (10017 & 10057), and 2 Type-C (74245 & 74255) basalts. The 7 low-Ti are two high-Al (14053 & 14072), one feldspathic (12038), and four olivine basalts (12002, 12008, 12009, & 15555). Due to low concentrations of many MVEs, isolating and quantifying all major interferences in the method used here is of the upmost importance;see [6] for full details. Interference solutions were analyzed with reference materials and lunar samples in order to properly quantify any intereferences into a counts per ppb value that could then be subtracted from the element of interests signal [6]. Two reference materials (BIR & BHVO) were used to validate the method and resulting data. The result is an interference-corrected accurate value for the low concentration MVEs.

Results and Discussion: The analyzed reference materials are compared with the GeoRem recommended and informational values, indicating the promise of this method [6]. The analyses of the 11 lunar samples show relative agreement with sparse previously published values (**Fig. 1**) [7-21]. Of note, the abundance of published values for a given element can vary greatly. For example, the published Zn abundances for basalt 12009 range from 0.9 to 9.7 ppm. The lack of reproduced published data shows the need for precise quantification of interferences. MVEs tend to be generally enriched in

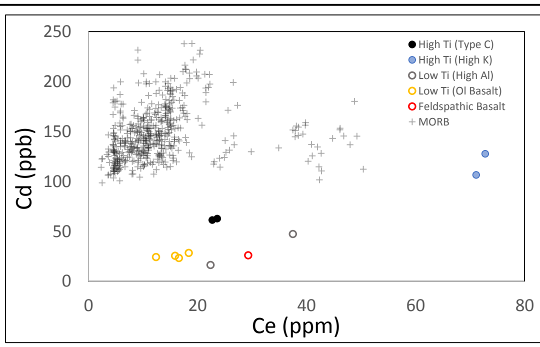

***Fig. 2**: Values measured in this study compared to MORB values [22] comparing Ce, a refractory element to Cd, a MVE.*

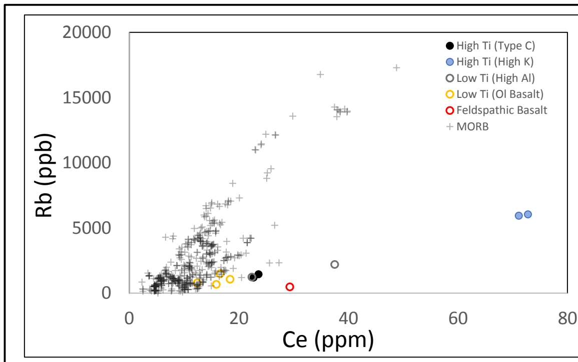

***Fig. 3**: Ce, a refractory element vs. Rb, a MVE, to Ce was taken from an average of analyses from [7-21].*

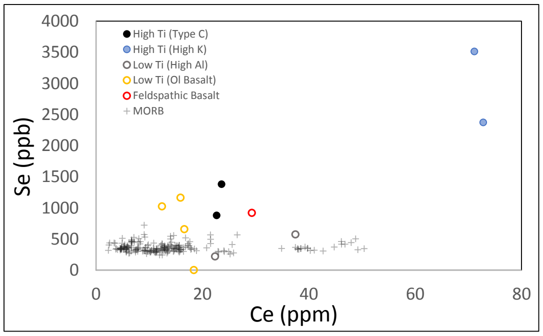

***Fig. 4**: The enrichment of Se (MVE), relative to Ce (refractory) with respect to MORB's.*

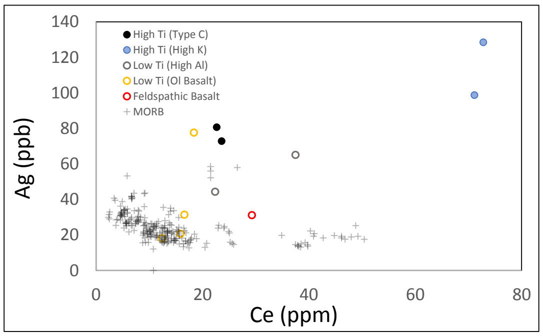

***Fig. 5**: The enrichment of Ag (MVE), relative to Ce (refractory) with respect to MORB's.*

high-Ti samples relative to low-Ti samples (**Figs. 2 - 5**, solid vs. open symbols).

A comparison of MVEs vs. a refractory element (Ce) shows a more complicated enrichment pattern relative to MORBs (**Figs. 2-5**). The large impact hypothesis posits that MVE's should be depleted with respect to MORBs, however these data show that this is not the case for all MVEs. There is an expected depletion of Cd and Rb with respect to MORBs (**Figs. 2 & 3**), but Ag and Se are unexpectedly enriched relative to MORBs (**Figs. 4 & 5**). This indicates more complex relationships occurring within the MVEs, and shows that they are not fractionating equally under the early conditions of lunar formation. These data also indicate that not all samples are enriched or depleted equally, some samples (low Ti – Olivine basalts) tend to fall within the MORB field with Cd as an exception, while the high Ti – high K basalts demonstrate the most extreme enrichment. All samples exhibit a positive linear trend with respect to Ce, indicating that there is a relationship between MVEs and refractory elements during early lunar forming events, as described by [23].

Within these data there are not only depletions, but enrichments relative to MORBs. The current data set suggest that Ag and Se are enriched relative to MORB, and Cd and Rb are depleted. Data will continue to be gathered on lunar basalts using these methods that have

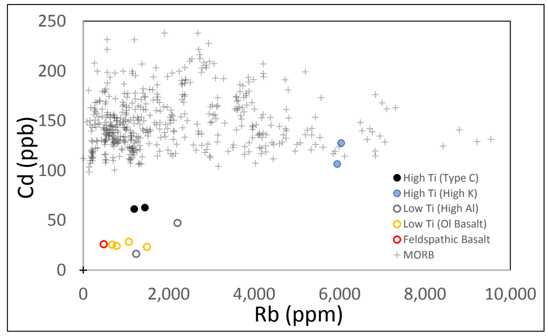

***Fig. 6**: The depletion of Rb & Cd (MVEs) relative to MORBs.*

shown to yield accurate data. A larger database will help define the observed enrichments and depletions relative to MORB. If confirmed, these relationships will need to be evaluated against the giant impact theory and subsequent lunar magma ocean (LMO) hypothesis. Critical in this evaluation will be the MVE partition coefficients for LMO phases. These data will be used to understand the events occurring during early stages of lunar formation, and to refine current models (such as the large impact theory) of lunar formation.

References: [1] Hauri E. et al. (2011) *Science*, *333*, 213-215. [2] McCubbin, F. M. et al (2015) *Amer. Mineral. 100*, 1668–1707. [3] Saal A. E. et al. (2008) *Nature 454*, 192-195. [4] Nakajima M. & Stevenson D.J. (2014) *Icarus 233*, 259-267. [5] Nakajima M. & Stevenson D.J. (2015) *EPSL 427*, 286-295. [6] Burney et al. (2016) *LPSC 47*, Abstract# 1514. [7] Wolf R. et al. (1979) *PLSC 10th*, 2107-2130. [8] Ganapathy R. et al. (1973) *PLSC 4th*, 1239-1261. [9] Baedecker P.A. et al. (1971) *PLSC 2nd*, 1037-1061. [10] Morgan J.W. et al. (1972) *PLSC 3rd*, 1377-1395. [11] Brunfelt A.O. et al. (1971) *PLSC 2nd*, 1281-1290. [12] Neal C.R. (2001) *JGR Planets 106*, 27. [13] Anders E. et al. (1971) *PLSC 2nd*, 1021-1036. [14] Warren P.H. et al. (1986) *PLSC 16th* in *JGR 91*, D319-D330. [15] Ganapathy R. et al. (1970) *PLSC 1*, 1117-1142. [16] Morrison G.H. et al. (1970) *PLSC 1*, 1383-1392. [17] Morgan J.W. et al. (1972) *PLSC 3rd*, 1361-1376. [18] Brunfelt A.O. et al. (1972) Elemental composition of Apollo 15 samples. In T*he Apollo 15 Lunar Samples* (Chamberlain J.W. and Watkins C., eds.), 195-197. [19] Willis J.P. et al. (1971) *PLSC 2nd*, 1123-1138. [20] Snyder G.A. et al. (1997) *GCA 61*, 2731-2747. [21] Rose H.J. et al. (1975) *PLSC 6th*, 1363-1373. [22] Jenner F.E., & O'Neill, H.S.C. (2012). *GGG 13(2), doi:10.1029/2011GC004009*. [23] Taylor G.J. et al. (2016) *LPSC 47*, This Conference.