BASALTS: INSIGHTS INTO PLANETARY MAGMATIC PROCESSES FROM THE MOON AND EARTH.

A. Gawronska[1] and C. L. McLeod[1]. [1]Miami University, Dept. of Geology & Environmental Earth Science, 250 S. Patterson Ave, Oxford, OH, 45056, USA. (gawronaj@miamioh.edu)

Introduction: In the fifty years since the Apollo missions, our understanding of the nature and timing of planetary differentiation has continued to improve. Basaltic magmatism is intrinsically linked to the thermal evolution of a planetary body and the process of partial melting fundamentally governs the chemical differentiation and evolution of planetary crusts [1,2].

On Earth, the strategic sampling of basalts from various tectonic regimes (mid-ocean ridges, intra-plate both continental and oceanic, and collisional margins both continental and oceanic) has led to the observation of many distinguishing petrological, elemental, and isotopic characteristics which are widely interpreted as having petrogenetic implications [3,4,5]. For example, the classification of tholeiitic and calc-alkaline basalts, the role of various pressure-sensitive minerals (e.g. garnet) at the depth of basaltic magma generation from observed variations in inter-Rare Earth Element (REE) ratios [6], and attribution of various isotopic characteristics (Sr-Nd-Pb-Hf) to source reservoirs within the mantle, or processes associated with source signature overprinting [7]. From over half a century of work utilizing terrestrial basalts as windows into Earth's differentiation history, the processes which govern their chemistry are well established and therefore provide the best framework possible in which to evaluate the petrogenesis of basalts on other planetary objects (with the operation of plate tectonics acknowledged here).

Basaltic samples appear to represent the largest proportion of returned Apollo material. Lunar volcanism is proposed to be derived directly from the mantle [8], so these samples' chemical compositions (bulk and mineral) have the potential to yield valuable insights into the depth of origin of lunar magmatism and the nature of potential source reservoirs. In order to establish as comprehensive an understanding as possible of the Moon's magmatic history, of course a full, representative range of igneous rocks from the Moon would be required and ideal, if it exists [9, 10]. Given that such a wealth of samples may not be available for some time (although the recent success of the Chang'e 4 mission highlights the potential for future sample return missions to new, previously unexplored regions), the framework from Earth presents an excellent opportunity to compare and contrast the nature of inter-planetary igneous processes. This comprehensive comparison will allow us to characterize similarities and differences between the two planetary bodies, it may aid to close gaps in knowledge, and it may reveal insights to processes not previously considered.

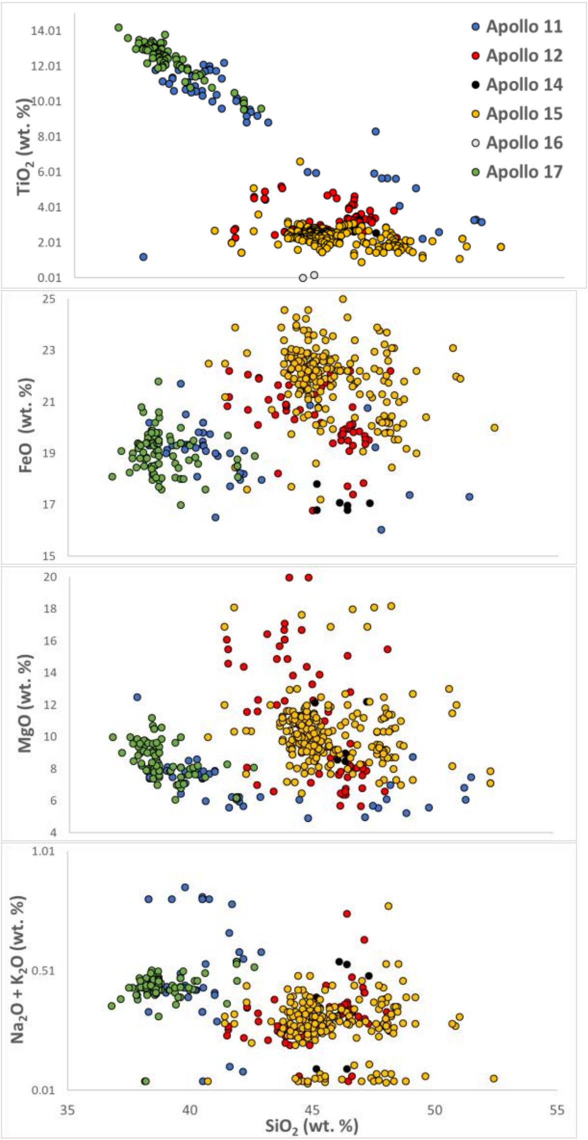

Figure 1. Select major elements plotted against SiO_2 content (Harker diagrams) based on bulk rock data. All color schemes correspond to that of the first graph. Axes on wt. % TiO_2 and TAS plot (lower panel) begin at 0.01 rather than 0 in order to omit analyses which did not measure these elements and plotted at 0.

Methods: For the purpose of the preliminary comparison here, only basalts are considered (glasses, soils, breccias, and basaltic meteorites have therefore been excluded for now). Data was extracted and compiled from the MoonDB database [11]. All Apollo mission basalt samples were chosen for bulk data plotting - no Luna samples or meteoritic basalts were included at this time. Analysis methods chosen for extraction were: atomic absorption, alpha counting, calculated, colorimetric analysis, coulometrical analysis, carbon sulfur analysis, D. C. arc emission spectroscopy, direct reading optical emissions spectroscopy, electron microprobe, emission spectrometry, flame photometry, gamma ray spectrometry, gas chromatography, gravimetry, high-resolution inductively coupled plasma mass spectrometry (ICP-MS), ICP-MS, ICP-MS isotope dilution (ID), IES, ion microprobe, instrumental neutron activation analysis, laser ablation ICP-MS, laser fluorination, magnetically, multicollector ICP-MS, mass spectrometry (MS), MS-ID, neutron activation analysis, optical emission spectrometry, point counting, radioanalytical neutron activation, colorimetry, spark source MS, thermal ionization MS (TIMS), TIMS-ID, titration, wet chemistry, X-ray fluorescence, as well as "unknown" methods. Naturally, all studies were selective in what they measured, and studies which provided 0's for the elements presented here are omitted.

Results: As previously discussed (e. g. [9]), clear chemical similarities and differences exist between basalts from the different Apollo missions (**Fig. 1 & 2**). Apollo 12 and Apollo 15 basalts plot in similar compositional fields in all graphs (> 42 wt. % SiO_2, ~< 4 wt. % TiO_2) as do Apollo 11 and 17 at wt. % SiO_2 < 42, > ~8 wt. % TiO_2). Apollo 17 samples exhibit relatively tightly clustered total alkali silica compositions ($Na_2O + K_2O$) at ~0.31 and 0.51 whereas Apollo 11, 12, 15 (and 14) scatter up to ~0.8. In fig. 2 compositional fields for terrestrial basalts are shown. Apollo basalts are shown to be consistent with a range of tholeiitic signatures. Again, the Apollo 12 and 15 basalts appear similar (at lower TiO_2), while the Apollo 11 and 17 plot almost exclusively in the ocean-island tholeiite field (at higher MnO contents).

Discussion: The formation and emplacement of lunar basalts has often been compared to terrestrial continental flood basalts [12] with calculated output rates comparable to those at Kilauea and Vesuvius [13]. The chemical variation observed throughout the lunar basalt suite (in both major and trace element abundances) has previously been attributed to heterogeneity in the lunar mantle, depth of traversed crust, as well as fractional crystallization, all of which are processes that also affect terrestrial magmas. By comparing across planets, with the help of a well-established terrestrial framework, future work will focus on expanding the comparison in order to evaluate the extent to which similar processes may operate on rocky planetary bodies.

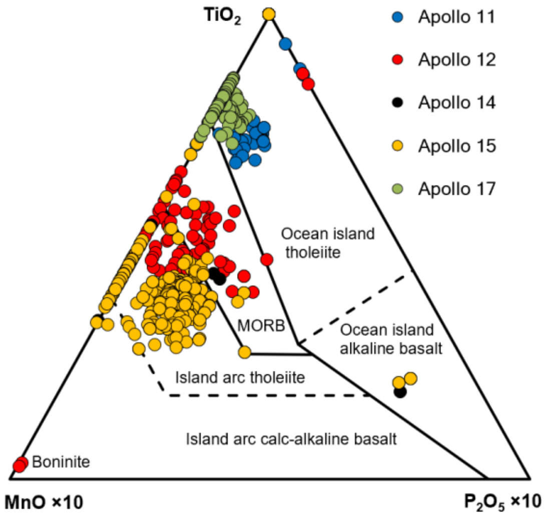

Figure 2. Bulk rock data for Apollo basalt samples as superimposed on a terrestrial source discrimination plot after [14].

References: [1] Lee, C. -T., et al. (2009) *EPSL*, 279; 20-33; [2] Keller, B., & Schoene, B., (2018) *EPSL*, 481; 290-304; [3] Cox K. G. et al. (1979) *The Interp. of Ign. Rocks*, Ch. 2. [4] Le Bas M. J. et al. (1986). *JPet* 27, 745-750 [5] Wilson, M., (1989), *Igneous Petrogenesis, Springer*, 466pp; [6] Davidson, J. P et al. (2007) *Geology*, 35; 787-790 [7] Stracke, A., et al. (2005), G^3, 6:5 [8] Head J. W. (1976) *Rev. Geophys. Space Phys.* 14, 265-300. [9] Warren, P. H., & Taylor, G. J., (2014) *Treat. Geochem.* 2nd edition. [10] Taylor S. R. et al. (2006) *GCA 70*, 5904-5918. [11] MoonDB [12] O'Hara, M. J., (2000), *J. Pet*, 41; 1121-1125; [13] Head, J. W. III & Wilson, L., (1992), *GCA*, 56; 2155-2175. [14] Mullen E. D. (1983) *epsl 62*, 53-62.