CLUSTER ANALYSIS OF APOLLO BASALT WHOLE ROCK COMPOSITONS. A. J. Gawronska[1], M. R. Hughes[2], C. L. McLeod[1], [1]Department of Geology and Environmental Earth Science, Miami University, Oxford OH, [2]Statistical Consulting Center, Miami University, Oxford OH. (gawronaj@miamioh.edu)

Introduction: The application of statistical methods to datasets is a powerful approach to assess the extent to which differences and similarities exist within a sample suite (or suites). With a large enough sample set (depending on the statistical method used), relatively minute differences in sample composition may be utilized to investigate broader questions regarding a sample set. Within the context of magmatic petrogenesis, bulk compositional information can be utilized to investigate and constrain the processes occurring during the crystallization of a magma as it cools and ascends from its source region. Degree of partial melting, differentiation, assimilation, magma mixing, fractional crystallization lead to compositional variation which may be used to quantitatively compare and contrast final rock composition. In this work, we specifically apply cluster analysis in order to statistically evaluate the extent of compositional differences throughout the Apollo lunar basalt suite(s) [e.g. Fig. 1]. Through this work we will evaluate the extent to which the current approach to grouping sample suites is appropriate (i.e. are the groups statistically validated). We will also evaluate whether the physical sampling location of a mission is a component to consider when assessing how to best classify lunar basalts (and the extent to which this variable statistically correlates to compositional characteristics).

Apollo basalt major element oxide characteristics: Based on current Apollo basalt data, the largest bulk compositional differences with respect to major element oxides are the abundance of Ti, Al, and K [e.g. 1; Fig. 1]. These differences are due to the presence of the high Ti basalts at Apollo 11 and 17 sites and low Ti basalts at Apollo 12 and 15 sites; high Al basalts at the Apollo 14 site; high K basalts at the Apollo 14 and 11 sites; and KREEP (potassium, rare earth elements, phosphorus) at the Apollo 15 site. The variations of the major element oxide compositions of these basalts may be explained by the depth of melting, degree of partial melting, incorporation of ilmenite, and assimilation/fractional crystallization processes [1-6]. Historically, the Apollo basalts across the six missions can be split into a minimum of 22 individual groups based on compositional differences alone [e.g. 1-3].

Methods: Major element oxide compositions for the Apollo basalt suite were evaluated in this study. Data from 234 studies was extracted and compiled from the MoonDB lunar sample analysis database [7]; an additional 47 studies were included to supplement

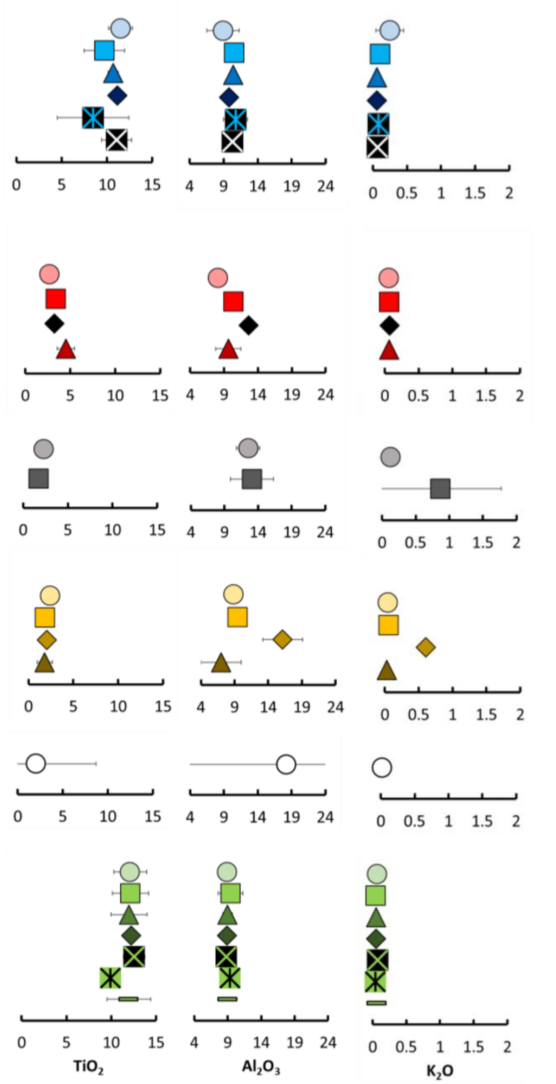

Fig. 1. The variation in TiO_2, Al_2O_3, and K_2O across the Apollo groups shown through Caltech plots. These oxides were proposed by [1] as good discriminants to assign the Apollo samples into groups based on their chemistry. In the above plots, blue is Apollo 11, red is Apollo 12, gray is Apollo 14, yellow is Apollo 15, white is Apollo 16, and green is Apollo 17 samples. Different symbols in the above plots correspond to different groups within the mission sample suite. In each plot, the mean group composition is represented by the symbol, and error bars are 2σ. From these plots, it is easy to visualize some of the compositional differences – e.g. the high-Ti nature of Apollo 11 and 17 samples in comparison to the other mission suites. Moreover, it is clear that some individual groups within the mission suites may be similar as well. It is the goal of this study to investigate this.

missing information regarding Apollo 14 and 16 samples.

Statistical analysis: Hierarchal cluster analysis (an unsupervised statistical learning technique, e.g. [9]) will be carried out at Miami University's Statistical Consulting Center. Various cluster aggregation methods will be performed and evaluated, and optimal obtained cluster classifications for the samples will be evaluated for goodness of fit to known mission and/or group classifications. Whole rock major element compositions will be compared across the samples for the oxides MgO, FeO, SiO_2, TiO_2, Al_2O_3, K_2O, Na_2O, MnO, CaO, Cr_2O_3, P_2O_5. Trace element data was also compiled from the MoonDB, but will not be considered at this time. This complementary suite of chemical information may form the basis of future work, however. These analyses will be performed using R statistical software [10].

Results and Discussion: Results from cluster analysis of the compiled samples will be used to evaluate the extent to which samples are statistically chemically similar and/or different. By considering each sample independent of each other, and outside of the context of which mission they were collected in, we may be able to make broader connections regarding the evolution of magmas within and on the Moon in general. As products of partial melting, the compositions of lunar basalts can be utilized as probes of not only the chemical make-up of the lunar interior but also as a window into post-lunar magma ocean (LMO) differentiation processes [4]. We anticipate that this work will corroborate the inferences made by previous authors [1-6], that samples from Apollo 12 and 15 as well as those from the Apollo 11 and 17 sites are similar compositionally. The chemical differences that occur between samples from different groups (e.g. Fig. 1) already suggest that processes operating to differentiate lunar magmas may be relatively wide-spread and planetary-wide. Understanding these processes across missions may further allow us to investigate the extent of LMO products, and their imposed effects (i.e. the generation of source regions at depths). Additionally, by defining where significant differences lie between samples, this study may aid in matching basaltic clasts in meteorites and those collected during Apollo 16 samples [e.g. 8] to their potential locations of origin based on the maria currently sampled.

Future work will involve consideration of the bulk rock trace elements in these samples. Many sample groups are also defined by their trace element variations and arguably, trace elements are more sensitive to magmatic processes than major elements. By considering trace element signatures this will allow us to investigate the extent to which previously defined (and potentially new) basalt groupings are significantly different as well.

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