ESTABLISHING NEW CO-MAGMATIC TRENDS AMONG THE LUNAR HIGHLANDS. T.C. Prissel[1,2,3], J. Gross[3]. [1]Lunar & Planetary Institute, Houston, TX 77058. [2]Astromaterials Research & Exploration Science Division, NASA Johnson Space Center, Houston, TX 77058. [3]Department of Earth & Planetary Sciences, Rutgers University, Piscataway, NJ 08854. (contact: tabb.c.prissel@nasa.gov; tprissel@lpi.usra.edu; tcprissel@gmail.com).

Premise: Several key aspects concerning the primary differentiation and large-scale magmatic evolution of the Moon are constrained by the petrogenesis of pristine lunar sample suites. Recent modeling has relaxed the commonly applied "Mg# problem" to petrogenetic hypotheses, which posits that equilibrium crystallization of mantle-derived melts cannot explain the high forsterite content of lunar troctolites [1]. Note however, that there are two types of pristine lunar troctolites as distinguished by spinel chemistry: "common" lunar troctolites +/- chromite, and the volumetrically minor pink spinel-bearing troctolite clasts (PST). [1] demonstrate that the lower overall forsterite contents of common lunar troctolites (Mg# < 90) can be explained via > 45% equilibrium crystallization from mantle-derived and plagioclase-undersaturated liquids derived from primordial mantle cumulates produced during LMO (lunar magma ocean) crystallization. Additionally, the generally higher forsterite contents of PST require early plagioclase-saturation and production of pink spinel, and are therefore reconciled when considering the same Mg-suite primary melt interacting with anorthositic crust (Fig. 1).

If the Mg-suite primary melt is derived solely from primordial LMO ultramafic cumulates, and only later modified through interaction with anorthositic crust or KREEP, or both, several ramifications follow including:

a) crystallization ages of Mg-suite samples may be used to constrain the onset and duration of cumulate mantle overturn (CMO). CMO provides a mantle convection mechanism for initially deep-seated primordial cumulates to reach the surface, and simultaneously can explain high-degree (> 30%) pressure-release melting of said cumulates in producing Mg-suite primary melts [2-5].

b) the simplified Mg-suite equilibrium crystallization model presented here precludes the more complicated petrogenetic model of, and processes required to form and later re-melt, hybridized source regions [2,4,5] (Fig. 1).

c) crystallization modeling of melts derived from ultramafic LMO cumulates supports the hypothesis that gabbronorites are not co-genetic to troctolites and norites [6,7]. If so, the differentiation trends and diversity of lunar highlands lithologies needs to be redefined.

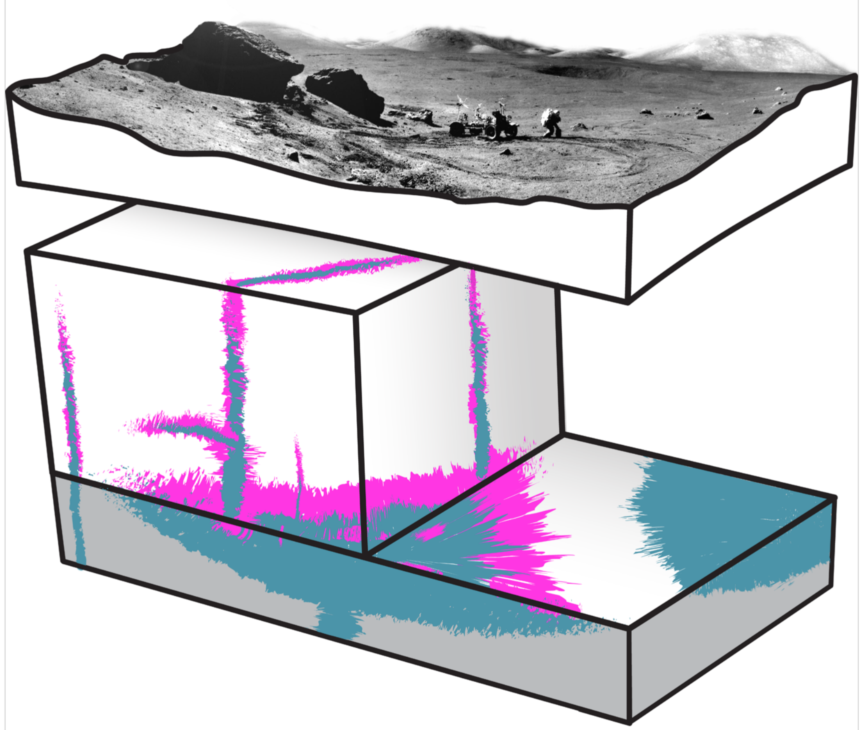

Fig. 1. Illustrating potential intrusions of Mg-suite primary melts (blue-green) ponding at the base of the lunar crust (white = crust; gray = mantle) with possible dikes and interaction with the crust, creating contaminated regions (pink) of a given intrusion capable of yielding pink spinel and PST. The slow diffusion rate of Al in basaltic melts may restrict crustal contamination to the margins of a given intrusion or dike, resulting in a small total volume of PST-bearing melt regions. The expected small volume of PST-bearing liquids during magma-wallrock interactions is consistent with the small total volume of PST clasts in the sample collection, and also the small total volume of pink spinel-bearing lithologies detected by orbital remote sensing.

Below, we review the classical differentiation trends among the non-mare lunar highlands lithologies, and detail results from our crystallization modeling. In contrast to modern classification, we argue that model results establish new co-magmatic trends in the context of the simplified Mg-suite petrogenetic model above, which exclude most gabbronorite samples, but include ferroan norites [7,8]. Additionally, our redefined Mg-suite differentiation trend is capable of explaining the production of some magnesian anorthosites and magnesian troctolitic clasts within the meteorite collection [8,9].

Classical Differentiation Trends: Traditionally, the pristine igneous highlands lithologies are comprised of ferroan anorthosites (FAN), magnesian anorthosites (MAN), magnesian-suite plutonic rocks (Mg-suite: troctolites, PST, norites, and possibly gabbronorites), KREEP basalts (enriched in K, rare earth elements, P), and the alkali-suite [2]. Each highlands rock type above, and associated co-magmatic trends, are most commonly distinguished in composition by the anorthite content of plagioclase (An#=molar [Ca/(Ca+Na+K) x 100] and Mg# of coexisting mafic silicates (molar [Mg/(Mg+Fe)] x 100) (Fig. 2).

Modeled Crystallization Sequence of Mg-suite Primary Liquids: We have modeled the crystallization sequence and resulting mineralogy of newly estimated Mg-suite parent magmas [1] (in equilibrium with liquidus olivine of Mg#~95) using the SPICEs (Simulating Planetary Igneous Crystallization Environments) matlab crystallization code [10]. The Mg-suite primary melt yields Fo89.1 olivine and An97.5 plagioclase (+ chromian spinel) after ~53% olivine fractionation. The resulting troctolite assemblage is consistent with the most primitive, commonly found lunar troctolites in the Apollo collection. Continued pure equilibrium crystallization results in only minor variation in Mg# and plagioclase with An# ~92 due to the initially low bulk Na_2O content of the starting composition (~0.12 wt.%). On the other hand, continued pure fractional crystallization results in a dramatic decrease in Mg# (< 30), whereas the An# of plagioclase decreases to ~92 (Fig. 2).

The possible mineralogy resulting from the combined equilibrium and fractional crystallization model of Mg-suite primary liquids is inconsistent with a majority of gabbronorite samples (Fig. 2). However, the crystallization model is consistent with Apollo troctolites, Apollo 15, 17 norites, as well as the relatively understudied ferroan norites from [6] (Fig. 2), representing a redefinition of the Mg-suite co-magmatic trend [7]. Additionally, the crystallization trend is consistent with some MAN and magnesian troctolite data from the meteorite collection [9], which have yet to be definitively classified among current differentiation trends. In light of the redefined

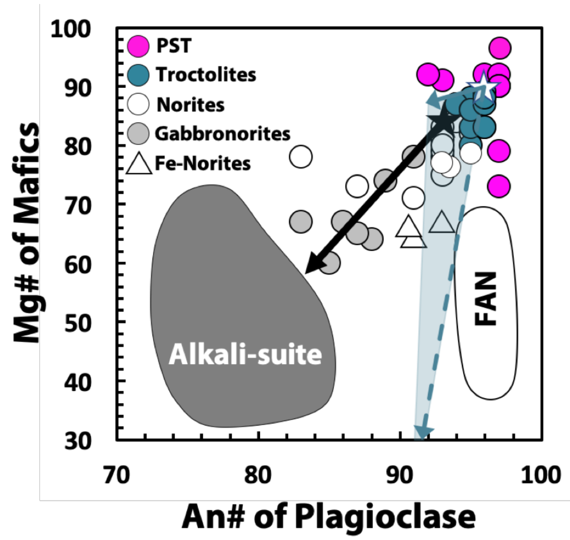

Fig. 2. Lunar highlands lithologies relative to the Mg# of mafic silicates vs. An# of co-existing plagioclase. Legend provided, and FAN = ferroan anorthosite suite. PST contain the most forsteritic olivine compositions among all lunar troctolites and Mg-suite samples. Black star and arrow represent crystallization trend of primitive KREEP basalt, and white star with blue-green arrows represent equilibrium (solid arrow) and fractional (dashed arrow) crystallization models. Taken together, the modeled equilibrium and fractional Mg-suite trends do not appear to reproduce gabbronorite mineralogy, but do include ferroan norites (triangles) [all data from [2,6] and references therein].

Mg-suite co-magmatic trend presented here, the primitive KREEP basalt crystallization sequence from [11] appears consistent with some norites and the gabbronorite samples excluded from the Mg-suite primary crystallization trend defined in Fig. 2.

Conclusions: The simplified Mg-suite equilibrium crystallization model of [1] dramatically shifts the classical interpretation of the lunar highlands, and can potentially explain the production of presently unclassified meteorite data not grouping within current differentiation trends. If so, the co-magmatic trends and diversity of lunar highlands lithologies may need to be redefined. Experimental investigations are underway to substantiate or refine the model results.

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