LUNAR CRUSTAL DIFFERENTIATION TRENDS PRODUCED BY SECONDARY MAGMATISM FROM A COMMON SOURCE. S. M. Elardo. The Florida Planets Lab, Department of Geological Sciences, University of Florida, Gainesville, FL 32611, USA. selardo@ufl.edu.

Introduction: The distinction between primary lunar magma ocean (LMO) derived crustal rocks and those produced by post-LMO secondary magmatism was established by the recognition of apparent differences in major element differentiation trends [e.g., 1]. These differing trends are clearly observed in the oft-reproduced plot of the Mg# in mafic minerals vs. An# in plagioclase (Fig. 1). Geochemical analyses of crustal lithologies have shown that ferroan anorthosites (FANs) and the secondary crustal rocks of the Mg- and alkali-suites define different crystallization trends in Mg# vs. An#. These trends are thought to be the product of the different formation settings for these lithologies [e.g., 2]. As nearly pure anorthosite floatation cumulates, the near-vertical trend in Mg# vs. An# observed in FANs is likely the result of crystallization of mafic minerals from trapped intercumulus melt, wherein the cumulus plagioclase composition remains constant as the Mg# of intercumulus mafic minerals decreases with crystallization or the timing of formation from the LMO. Conversely, as intrusive plutonic rocks, the simultaneous decrease in both Mg# and An# in Mg- and alkali-suite rocks is likely an igneous fractional crystallization trend produced by removal of plagioclase and mafic silicates. Together these differing trends are widely cited as evidence for the formation and building of the crust through different types of early magmatism.

The continued discovery and analysis of feldspathic lunar meteorites, which presumably sample a much larger swath of the crust than did the Apollo missions, have added complexity to crustal petrogenetic models. Whereas the compositions of Mg-suite samples and FANs are distinct in Mg# and An#, rock clasts in feldspathic meteorites overlap with the high Mg#s of the Mg-suite while also showing little variation in An#, thus overlapping the compositions of FANs [3 and refs therein] and also extending a wider range in Mg#. Assigning provenance to these magnesian anorthosite samples, however, is difficult. As primarily small clasts in meteoritic breccias, the representativeness of their modal abundances is questionable and radiogenic isotopic ages and compositions are often difficult or impossible to obtain. Although some clasts are likely to represent primary igneous rock fragments of either LMO-derived crust or secondary magmatism [e.g., 3], it is possible others are impact-derived mixtures of different lithologies [e.g., 4] and it is not always straightforward to separate igneous from non-igneous examples. This naturally complicates the use of magnesian anorthosites in constraining the origin and evolution of the lunar crust and the diversity in igneous rock types found within it.

In this work, I have approached this problem from the standpoint of the Mg-suite, specifically modeling the igneous differentiation trends of possible Mg-suite parental melt compositions that were produced in a previous experimental study [5]. In that study, experiments were conducted that simulated equilibrium partial melting of Mg-suite source regions consisting of dunite and anorthosite with variable amounts of KREEP from 0% to 50%. Here I examine the differentiation of those partial melts and the implications for the lunar crust.

Modeling and Results: The Mg-suite parental melts experimentally produced by Elardo et al. [5] served as the starting compositions for this study. Since those experiments were conducted at ambient pressure in a controlled-atmosphere furnace in which alkalis are commonly lost, the Na_2O and K_2O contents of these liquids were calculated using the compositions of the starting materials and the melt fraction assuming incompatible enrichment. These compositions were then used for fractional crystallization calculations using the rhyolite-MELTS algorithm (v.1.2.0) in the alphaMELTS front end [6, 7]. Calculations were conducted at a pressure of 1 bar beginning at the liquidus temperature of each composition, which was calculated using MELTS. The fO_2 of each starting composition was set at the iron-wüstite buffer at the beginning of the calculations, but was allowed to vary during the calculations. Solid phases were fractionated every 2°C until the calculations terminated.

The results of a select number of calculations are shown in Fig. 1. Elardo et al. [5] used the Mg# of the equilibrium olivine in each experiment and the calculated REE pattern of each melt to constrain which experiments and source region compositions produced partial melts that reasonably approximated the parental melts of Apollo 14 and 17 troctolites [8, 9]. The results of fractional crystallization calculations for those experiments are shown in Fig. 1, along with the results for a high-degree partial melt of a farside-analogous KREEP-free source. The portion of each calculation where there are two roughly parallel trends plotted for a single experiment is where the MELTS algorithm predicts two stable pyroxenes. Each of the compositions also crystallized variable amounts of dunite before plagioclase saturation.

Interpretations: The most striking and interesting observation from the results of this modeling is that both of the major igneous differentiation trends observed in lunar crustal rock suites can be produced by Mg-suite parental magmas derived from a similar source region. The only differences in the formation conditions of these magmas are the KREEP content of their source and the degree of partial melting (related to both source composition and temperature).

The Mg-suite to alkali-suite trend is reproduced by fractional crystallization of melts produced by high degrees partial melting of anorthosite-dunite sources with substantial KREEP contents on the order of ~25 – 50%. These melts would also reproduce the high REE contents inferred for Apollo 14 and 17 troctolite parental magmas [5, 8, 9]. Melting of similar KREEP-free sources, however, results in a low-alkali melt (at least at high degrees of partial melting) that upon undergoing fractional crystallization reproduces the near-vertical trend in Fig. 1 defined by magnesian anorthosites from feldspathic meteorites and FANs. The high-Mg#'s of meteoritic magnesian anorthosites are reproduced along with the trend in Mg# at near-constant An#. The slight increase in An# of the plagioclase with differentiation may be an artifact of the calculation rather than a real effect; however the near-vertical trend is undoubtedly real due to the low alkali contents of the melts.

These results suggest that at least some magnesian anorthosites, and possibly even some FANs, may be the product of secondary (i.e., post-LMO) crustal magmatism produced from KREEP-free Mg-suite source rocks. This formation mechanism obviates the need to invoke LMO alternatives such as serial magmatism to explain these lithologies. Detailed trace element and/or isotopic studies of individual samples would likely be required to differentiate between an LMO origin vs. a KREEP-free Mg-suite secondary magmatism origin. The global extent of Mg-suite magmatism is unclear and KREEP-rich Mg-suite magmatism is likely far more common than KREEP-free Mg-suite magmas [5]. However, these results demonstrate that the near-vertical differentiation trend in Mg# vs. An# is not necessarily attributable solely to lithologies produced in the LMO and could, at least in part be the result, of other processes.

References: [1] Warner et al. (1976) *7th Lunar Sci. Conf.*, 915-917. [2] Shearer et al. (2015) *Am. Min.* **100** 294 – 325. [3] Gross et al. (2014) *EPSL* **338**, 318-328. [4] Cahill et al. (2004) *MaPS*, **39,** 503-529. [5] Elardo et al. (2020) *In Review.* [6] Ghiorso and Sack (1995) *Cont. Min. Pet.* **119,** 197-212. [7] Smith and Asimow (2005) *G³*, **6,** Issue 2, 1-8. [8] Papike et al. (1996) *GCA*, **60**, 3967-3978. [9] Shervais and McGee (1998) *GCA*, **62,** 3009-3023.

Acknowledgements: S. M. E. acknowledges NASA Solar System Workings grant 80NSSC19K0752.

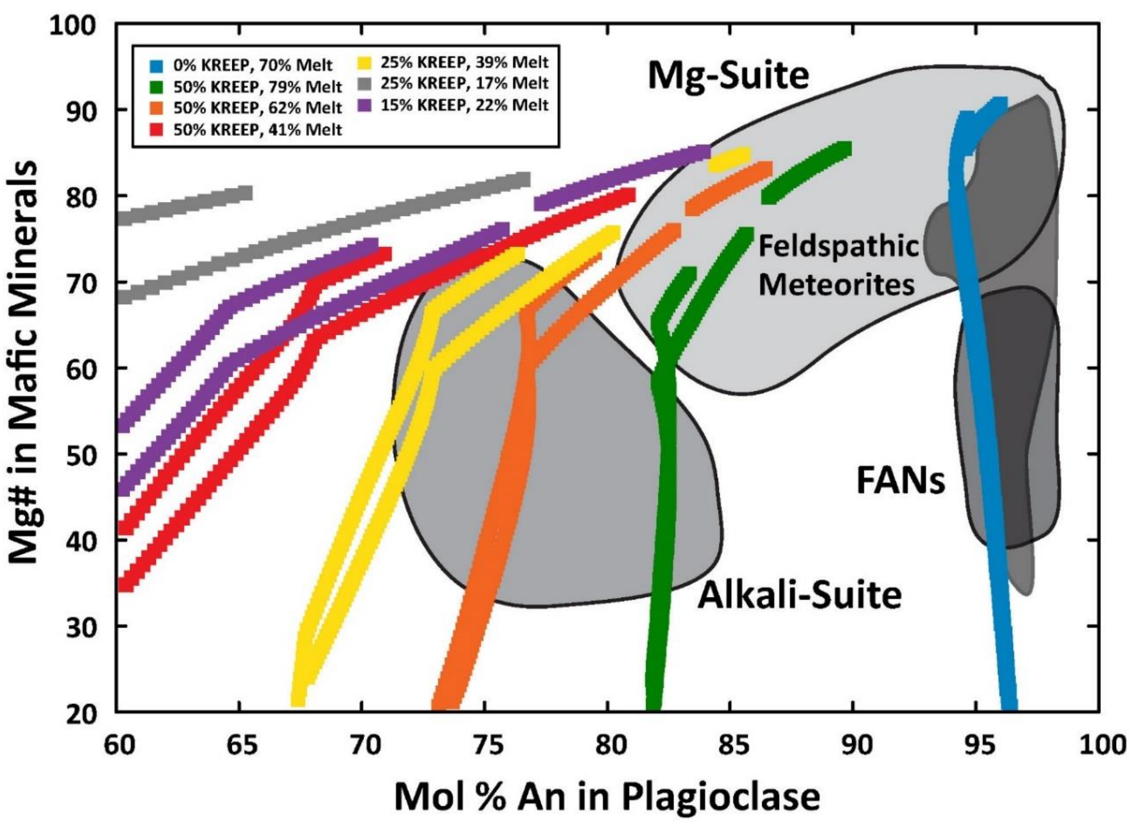

Figure 1: Plot of Mg# of mafic minerals vs. An# in plagioclase for lunar crustal rock suites (gray fields) and for the results of fractional crystallization modelling of possible Mg-suite parental magmas produced experimentally by Elardo et al. [5] (lines).