

ASYMMETRIC EARLY CRUST-BUILDING MAGMATISM ON THE LUNAR NEARSIDE DUE TO KREEP-INDUCED MELTING POINT DEPRESSION.

S. M. Elardo^{1,2}, C. K. Shearer³, and F. M. McCubbin⁴.
¹Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA. ²Department of Physics, Astronomy, and Geoscience, Towson University, Towson, MD 21252, USA. ³Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA. ⁴NASA Johnson Space Center, Mailcode XI2, 2101 NASA Parkway, Houston, TX 77058, USA. selardo@carnegiescience.edu

Introduction: The lunar magnesian-suite, or Mg-suite, is a series of ancient plutonic rocks from the lunar crust with ages and compositions indicating that they represent crust-building magmatism occurring immediately after the end of magma ocean crystallization [1, 2]. Samples of the Mg-suite were found at every Apollo landing site except 11 and ubiquitously have geochemical characteristics indicating the involvement of KREEP in their petrogenesis [3-5]. This observation has led to the suggestion that the presence of the KREEP reservoir under the lunar nearside was responsible for this episode of crust building [e.g., 5, 6]. The lack of any readily identifiable Mg-suite rocks in meteoritic regolith breccias sourced from outside the Procellarum KREEP Terrane (PKT) seemingly supports this interpretation.

One attractive aspect of including KREEP as a necessary component of Mg-suite formation models, and indeed models of lunar magmatism of many varieties throughout time, is the high abundance of heat-producing elements (e.g., K, Th) in KREEP, which have been proposed to aid in mantle melting. The most primitive Mg-suite rocks contain mafic silicate with Mg#s of ~90 along with plagioclase with An#s of ~96. These compositions indicate mantle source rocks with high melting temperatures, so KREEP involvement presents a convenient heat source for Mg-suite magmatism inside the PKT and its absence outside [5, 6]. However, this model presents a number of issues. Firstly, the absence of Mg-suite magmatism outside the PKT is not a settled issue, and some potential indicators of farside Mg-suite occurrences have been proposed. Prissel et al. [7] suggested that the occurrence of Mg-Al-spinel outside the PKT could be an indicator of the global distribution of Mg-suite plutons. Secondly, given the most reliable ages for Mg-suite rocks are essentially identical to KREEP model ages [2, 8], there may have been insufficient time for radiogenic heat to accumulate and significantly impact the onset of Mg-suite melt production.

In this study, we propose an alternative model by which the presence of KREEP can affect Mg-suite melt production: melting point depression. The KREEP reservoir is thought to be relatively evolved compared to the primitive Mg-suite source rocks and may have had the effect of lowering their melting temperature. Therefore, we have undertaken high-

temperature experiments to test the model that the presence of KREEP resulted in melting point depression of FAN-early LMO cumulate source materials, and to test whether the Mg-suite is inextricably linked to the KREEP reservoir.

Experimental Design: We synthesized an analog for the source materials of Mg-suite magmas using natural and synthetic minerals and oxide powders. The KREEP-free base starting material was a 50:50 mixture of powdered San Carlos olivine and powdered Miyake-jima anorthite. San Carlos olivine has an Mg# of 90, which is very similar to the composition of early LMO dunitic cumulates predicted by Elardo et al. [9], and anorthite megacrysts from the Miyake-jima volcano, Japan have an An# of 96 [10] that is very similar in composition to the lunar anorthositic crust and most Mg-suite troctolites. We also created a synthetic oxide mix with the composition of high-K KREEP from Warren [11]. Six starting materials with 0%, 5%, 10%, 15%, 25%, and 50% of the KREEP mix by weight were prepared by combining the two starting mixes. All mixes were hand ground under ethanol in an agate mortar and pestle.

Experiments were conducted in a Deltech vertical gas mixing furnace at the Geophysical Lab at an fO_2 corresponding to the IW buffer using a CO-CO₂ mixture. Starting materials were suspended from Re-wire loops using a polyvinyl alcohol solution and were allowed to melt and come to redox equilibrium for 2 hours at 1500 °C before being quenched into distilled water, forming a glass. Glass beads were then reintroduced into the furnace at the temperature of interest under controlled atmosphere and were soaked for 4 – 6 days to ensure equilibrium was closely approached.

Analyses: Experimental run products were mounted in epoxy, sectioned, and polished for microbeam analyses. Quantitative WDS analyses of melt and crystalline phases were conducted using the JEOL 8530 field emission electron microprobe at the Geophysical Lab. Analyses were conducted at 15 kV and 20 nA using natural and synthetic mineral standards. The quality of analyses was assessed using stoichiometric constraints. Phase abundances were determined using least-squares mass balance.

Discussion: Our experimental results demonstrate that, as expected, the addition of KREEP to a mixture of crustal anorthosite and deep mantle dunite, which is

the likeliest source rocks for the Mg-suite, depresses the melting temperature of the system relative to a KREEP-free source (Fig. 1). To assess the degree of this effect, we consider only melt-bearing experiments saturated in olivine and plagioclase, but not low-Ca pyroxene. These magmas would produce the primitive troctolites found at multiple landing sites. Melts produced at $1200\text{ }^{\circ}\text{C} < T < 1300\text{ }^{\circ}\text{C}$ satisfy these constraints. Our experiments show that the addition of 5% - 50% KREEP in the source rocks results in an increase in melt production by a factor of 2x – 13x over KREEP-free source rocks at the same conditions. In all of these experiments, the melts are in equilibrium with olivine and plagioclase (+Mg-Al spinel in some cases) with An#s and Mg#s similar to troctolites, showing that even with the addition of 50% KREEP, major element constraints are not violated in our model.

Trace elements, specifically REEs, provide additional constraints on our model. We calculated the REE abundances in our experimentally-produced melts using trace element partitioning parameterizations for olivine and plagioclase from Sun and Liang [12, 13]. For comparison, we modeled the REE abundances of Mg-suite parental magmas using REE contents of troctolite plagioclase [2, 14, 15]. In all cases, REE contents of our experimental melts are lower than or similar to troctolite parental magmas.

These findings strongly suggest that KREEP-induced melting point depression could have had a significant impact on Mg-suite melt production on the nearside vs. the KREEP-free farside. Our findings do not preclude the occurrence of Mg-suite magmatism in the farside crust, but demonstrate that models of Mg-suite petrogenesis should predict far more magmatism on the nearside, perhaps by an order of magnitude or more. This conclusion would only be strengthened if KREEP has a lower Mg# than inferred by Warren [11], and is completely independent of the effects of any radiogenic heat production from KREEP [i.e., 6].

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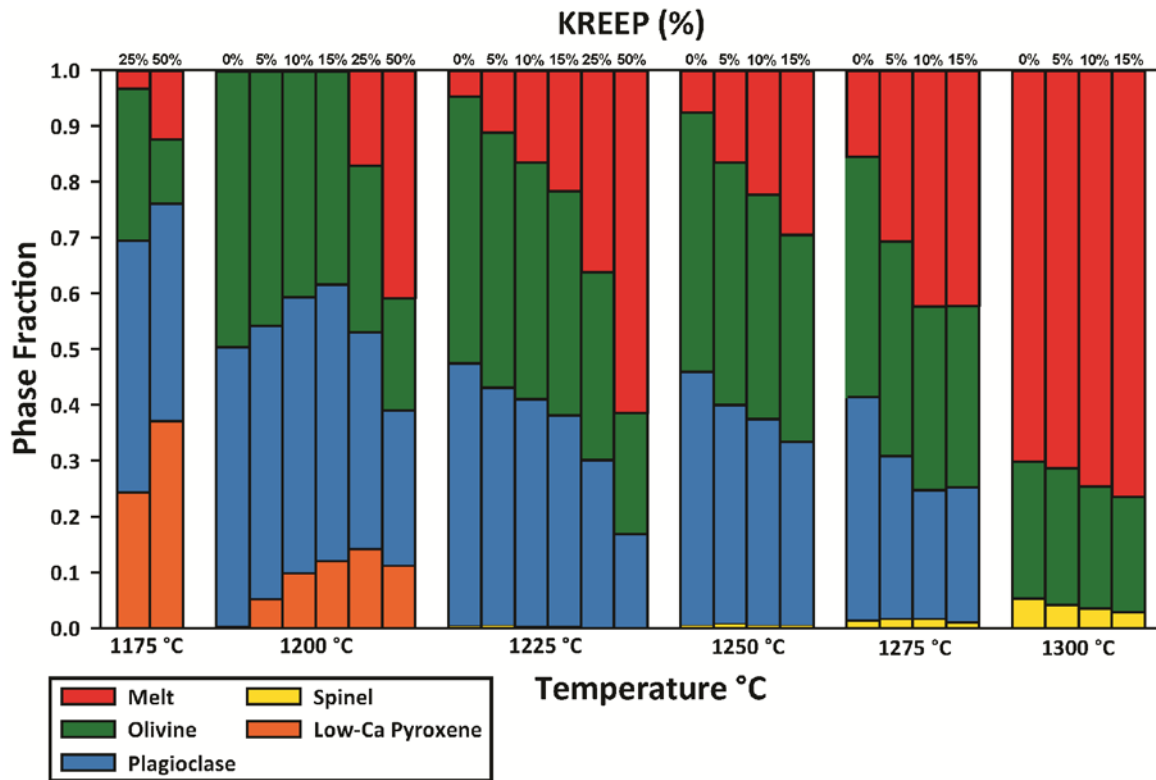


Figure 1: Histogram of phase abundances in analog Mg-suite source region melting experiments.