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Formation of the lunar highlands Mg-suite as told by spinel

Tabb C. Prissel[1,*], Stephen W. Parman[1], and James W. Head[1]

[1]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, Rhode Island 02912, U.S.A.

Abstract

Two competing hypotheses suggest lunar Mg-suite parental melts formed: (1) by shallow-level partial melting of a hybridized source region (containing ultramafic cumulates, plagioclase-bearing rocks, and KREEP), producing a plagioclase-saturated, MgO-rich melt, or (2) when plagioclase-undersaturated, MgO-rich melts were brought to plagioclase saturation during magma-wallrock interactions within the anorthositic crust. To further constrain the existing models, phase equilibria experiments have been performed on a range of Mg-suite parental melt compositions to investigate which composition can best reproduce two distinct spinel populations found within the Mg-suite troctolites—chromite-bearing ($FeCr_2O_4$) troctolites and the more rare pink spinel ($MgAl_2O_4$ or Mg-spinel) troctolites (PST).

Phase equilibria experiments at 1 atm pressure were conducted under reducing conditions (log f_{O_2} ~IW-1) and magmatic temperatures (1225–1400 °C) to explore the spinel compositions produced from melts predicted by the models above. Additionally, the experimental data are used to calculate a Sp-Ol, Fe-Mg equilibrium exchange coefficient to correct natural spinel for sub-solidus re-equilibration with olivine in planetary samples: Sp-Ol $K_D^{Fe-Mg} = 0.044Cr\#_{sp} + 1.5$ ($R^2 = 0.956$). Melts from each model (≥50% normative anorthite) produce olivine, plagioclase, and Mg-spinel compositionally consistent with PST samples. However, chromite was not produced in any of the experiments testing current Mg-suite parental melt compositions. The lack of chromite in the experiments indicates that current estimates of Mg-suite parental melts can produce Mg-spinel bearing PST, but not chromite-bearing troctolites and dunites. Instead, model calculations using the MAGPOX equilibrium crystallization program predict chromite production from plagioclase-undersaturated melts (<20% normative anorthite). If so, experimental and model results suggest chromite in Mg-suite crystallized from plagioclase-undersaturated parental melts, whereas Mg-spinel in the PST is an indicator of magma-wallrock interactions within the lunar crust (a mechanism that increases the normative anorthite contents of initially plagioclase-undersaturated Mg-suite parental melts, eventually producing Mg-spinel). The constraints for magmatic chromite crystallization suggest Mg-suite parental melts were initially plagioclase-undersaturated. In turn, a plagioclase-undersaturated Mg-suite parent is consistent with mantle overturn models that predict Mg-suite parent magmas resulted from decompression melting of early ultramafic cumulates produced during the differentiation of a global lunar magma ocean.

Keywords: Mg-suite, lunar highlands, spinel, petrogenesis, magma-wallrock interactions