American Mineralogist, Volume 104, pages 370–384, 2019

Spinel-anorthosites on the Moon: Impact melt origins suggested by enthalpy constraints

Allan H. Treiman[1,*], Michael J. Kulis[2], and Allen F. Glazner[3]

[1]Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Boulevard, Houston, Texas 77058, U.S.A. Orcid 0000-0002-8073-2839
[2]Extreme Environments Laboratory, NASA Glenn Research Center, 2100 Brookpark Road, Cleveland, Ohio 44135, U.S.A.
[3]Department of Geological Sciences, University of North Carolina, Chapel Hill, North Carolina 27599, U.S.A. Orcid 0000-0002-3111-5885

Abstract

Magnesium aluminate spinel, $(Mg,Fe)Al_2O_4$, is uncommon in lunar rocks but petrologically significant. Recent near-infrared spectra of the Moon have delineated regions where spinel is the only ferromagnesian mineral; the rock is inferred to be spinel anorthosite. One hypothesis is that significant pressure is required for spinel formation; another is that spinel-bearing rocks form by low-pressure assimilation of highlands anorthosite into olivine-rich basaltic (i.e., picritic) magmas. Here, we evaluate the heat (i.e., enthalpy) required for this assimilation process. Magma compositions are the picritic Apollo 14 B green glass and an estimation of the magma parental to Mg-suite cumulate rocks. From calculated enthalpy-composition phase diagrams, assimilation of anorthite into either magma cannot produce spinel anorthosite unless the anorthite is already hotter than ~1300 °C. For cooler anorthosite, assimilation will produce olivine- and/or pyroxene-bearing rocks. Such hot anorthite could be produced by the nearby passage of large volumes of magma, but this is not obviously consistent with occurrences of spinel far from outcrops of basaltic rocks. Hot anorthosite could also be produced by global tidal flexure; that mechanism could have only been efficient early in lunar history when a solid anorthosite crust floated above an evolved magma ocean, and it is not clear how picritic magma could pass through the magma ocean to interact with anorthite in the crust. On the other hand, spinel-bearing anorthosite can form directly upon cooling of superliquidus melts of anorthite-rich composition. Such superliquidus melts can be generated by impact events; this mechanism seems likely, given the Moon's ubiquity of impact craters, abundance of impact-metamorphosed lunar rocks, and common presence in lunar regolith of impact glasses (quenched superliquidus impact melts) of appropriate compositions. High pressure does stabilize spinel in basaltic and peridotitic systems, but available models do not permit quantitative evaluation of the effects of pressure on the enthalpy required for assimilation. Near the lunar surface, the most likely process of spinel formation is rapid crystallization of impact melts of anorthosite + picrite or peridotite compositions. The presence of spinel anorthosite on the walls and central peaks of impact craters results from rapid cooling and partial crystallization of superliquidus melts produced in the impacts, and not from uplift of deep material to the Moon's surface.

Keywords: Moon, spinel, assimilation, enthalpy, troctolite, impact melt