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Silicic lunar volcanism: Testing the crustal melting model

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Abstract

Lunar silicic rocks were first identified by granitic fragments found in samples brought to Earth by the Apollo missions, followed by the discovery of silicic domes on the lunar surface through remote sensing. Although these silicic lithologies are thought to make up a small portion of the lunar crust, their presence indicates that lunar crustal evolution is more complex than originally thought. Models currently used to describe the formation of silicic lithologies on the Moon include in situ differentiation of a magma, magma differentiation with silicate liquid immiscibility, and partial melting of the crust. This study focuses on testing a crustal melting model through partial melting experiments on compositions representing lithologies spatially associated with the silicic domes. The experiments were guided by the results of modeling melting temperatures and residual melt compositions of possible protoliths for lunar silicic rocks using the thermodynamic modeling software, rhyolite-MELTS.

Rhyolite-MELTS simulations predict liquidus temperatures of 950–1040 °C for lunar granites under anhydrous conditions, which guided the temperature range for the experiments. Monzogabbro, alkali gabbronorite, and KREEP basalt were identified as potential protoliths due to their ages, locations on the Moon (i.e., located near observed silicic domes), chemically evolved compositions, and the results from rhyolite-MELTS modeling. Partial melting experiments, using mixtures of reagent grade oxide powders representing bulk rock compositions of these rock types, were carried out at atmospheric pressure over the temperature range of 900–1100 °C. Because all lunar granite samples and remotely sensed domes have an elevated abundance of Th, some of the mixtures were doped with Th to observe its partitioning behavior.

Run products show that at temperatures of 1050 and 1100 °C, melts of the three protoliths are not silicic in nature (i.e., they have <63 wt% SiO_2). By 1000 °C, melts of both monzogabbro and alkali gabbronorite approach the composition of granite, but are also characterized by immiscible Si-rich and Fe-rich liquids. Furthermore, Th strongly partitions into the Fe-rich, and not the Si-rich glass in all experimental runs.

Our work provides important constraints on the mechanism of silicic melt formation on the Moon. The observed high-Th content of lunar granite is difficult to explain by silicate liquid immiscibility, because through this process, Th is not fractionated into the Si-rich phase. Results of our experiments and modeling suggests that silicic lunar rocks could be produced from monzogabbro and alkali gabbronorite protoliths by partial melting at $T < 1000$ °C. Additionally, we speculate that at higher pressures ($P \geq 0.005$ GPa), the observed immiscibility in the partial melting experiments would be suppressed.

Keywords: Moon, silicic volcanism, crustal melting, partial melting experiments, silicate liquid immiscibility