INVESTIGATING LUNAR CRUSTAL MELTING THROUGH THERMODYNAMIC MODELING: IMPLICATIONS FOR THE GENESIS OF SILICIC VOLCANISM ON THE MOON.
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Introduction: Granitic fragments returned by the Apollo missions, as well as the recent discovery of silicic domes on the lunar surface have provided evidence for the presence of SiO_2-rich lithologies on the Moon [1]. This type of rock, though very common on Earth, is considered rare on the Moon. Crustal melting is proposed as a possible model for explaining how silicic lithologies may have formed on the Moon [e.g., 1]. A significant amount of petrologic and experimental data exists for producing granites via crustal melting in terrestrial environments [2-4]. Low pressure crystallization experiments have been performed on lunar microgabbros [5], although further experiments are required to test whether crustal melting can explain the presence of silicic volcanism on the Moon. Our goal is to test this model by performing a series of partial melt experiments using compositions of expected lunar protoliths and determine whether such rocks can produce a melt similar to lunar granite compositions. As a complementary step to these experiments, we have investigated likely protoliths and melting conditions using the thermodynamic modeling software of Rhyolite-MELTS [6].

Computer simulations of lunar melting conditions and protoliths: For the purpose of this study, gabbronorite, norite, monzodiorite and KREEP basalt are considered likely protoliths for lunar granites. In deciding which rock types are the most appropriate to use in partial melt experiments, partial melt compositions were explored using Rhyolite-MELTS [6]. This program allows the composition of a liquid to be estimated in a partially molten bulk rock system at a given temperature, pressure, and oxygen fugacity. The goal of this computer modeling is to determine likely conditions that will produce a partial melt matching lunar granite compositions as well as a potential protolith composition.

Simulations were also run using MELTS [7]. At higher temperatures (≥950 °C) both MELTS and Rhyolite-MELTS yield similar results. Given this and the fact that, at lower temperatures, Rhyolite-MELTS has been optimized for saturation of quartz and potassium feldspar [6], the results of modeling using the latter program are reported here.

Investigation of lunar granite liquidus temperatures. The liquidus temperatures of three lunar granite compositions (e.g., 14004,94, 14321,1027, and 12033,507) were modeled using Rhyolite-MELTS. These samples were chosen because of their SiO_2 contents represent the range of lunar granite compositions returned from the Apollo missions. Granite 1 (12033,507) has the lowest amount of silica, 65 wt%, and the highest content of refractory elements. Granite 2 (14004,94) has an intermediate composition with 69 wt% SiO_2. Lastly, Granite 3 (14321,1027) is the most evolved sample, having 74.2 wt% SiO_2 and the highest amount of K_2O (8.6 wt%) compared to other lunar granites.

The Moon has an oxygen fugacity (fO_2) one log unit below iron-wüstite (IW -1) [8,9]. Therefore, simulations were run under QFM -5 fO_2 conditions. Previous experimental data suggest that melting conditions for formation of granitic melts are at low pressures in the upper crust, below 1 kbar [10,11]. Three different isobaric simulations using Rhyolite-MELTS were run, 1, 0.5, and 0.2 kbars (**Figure 1**).

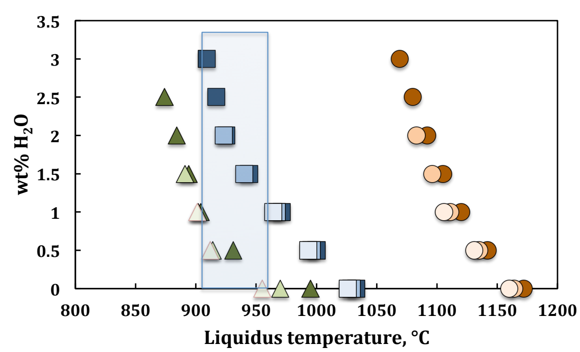

Figure 1. Variation in liquidus temperature of three lunar granites with water content and pressure as determined using Rhyolite-MELTS. Sample 14321,1027 (74.2 wt% SiO_2) are green triangles, sample 14004,94 (69 wt% SiO_2) are blue squares, and sample 12033,507 (65 wt% SiO_2) are orange circles. Darkest shading is 1 kbar, then 0.5 kbar, and lightest shading is 0.2 kbar. The transparent box represents the temperature range of 900-950°C.

Temperatures expected for lunar granites are estimated to be 900-950°C [1,10], and are highlighted in **Figure 1**. Water content was varied to investigate its depression of liquidus temperatures. It is believed that the Moon is relatively anhydrous [9], compared to the Earth, so an extreme upper limit of 3 wt% H_2O was applied to the simulations.

Modeled pressures do not significantly affect liquidus temperatures. Under anhydrous conditions, Granites 2 and 3 (14004,94 and 14321,1027) have liquidus temperatures ranging from 955-1033°C, somewhat higher than previously estimated. With the addition of water, these same granites have liquidus temperatures within the 900-950°C range for water contents of <2 – 3 wt%, and generally <1.5 wt%. Granite 1 (12033,507), the least evolved, has liquidus temperatures in excess of >1050°C for water contents of ≤3 wt.% H_2O.

By calculating the liquidus temperatures for lunar granites under anhydrous conditions, constraints on the temperature range for partial melt experiments can be made.

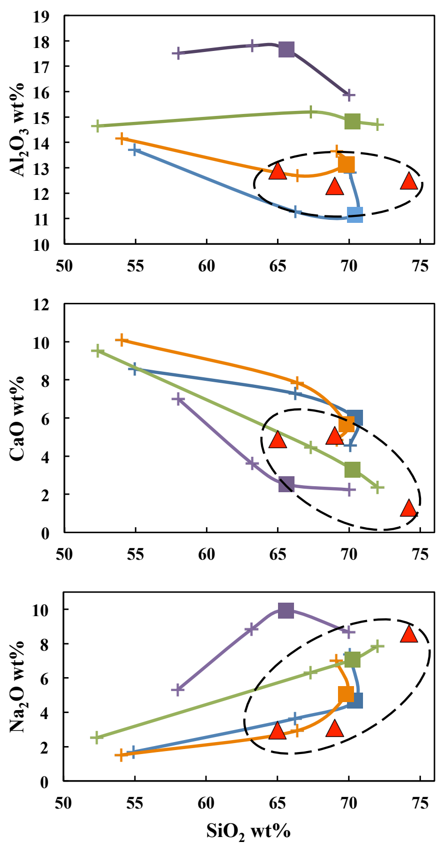

Figure 2. Variation diagrams showing melting curves for different lithologies obtained using Rhyolite-MELTS at 1 bar pressure, under anhydrous conditions. Plus symbols correspond to melt compositions at 1100°C, 1000°C, and 900°C (from left to right). Square symbols represent melt compositions at 950°C. Red triangles are lunar granite compositions. Orange curve is KREEP basalt, blue is monzodiorite, purple is gabbronorite, and green is norite.

Investigation of experimental starting compositions. A series of compositions consisting of monzodiorite, KREEP basalt, and two other lunar rock types have been modeled to test whether such lithologies can produce partial melts similar in composition to lunar granites. Given the shallow and relatively anhydrous conditions appropriate to the granites, experiments at atmospheric pressure are planned; extrapolating results at these conditions to the inferred natural pressures of melting will likely have only minor consequences. Computer simulations were thus carried out at 1 atm and performed over the temperature range of 900-1300°C, at 25°C increments. Equilibrium melt compositions are plotted on variation diagrams in **Figure 2**, where they are compared to the compositions of lunar granites. At 950°C, prospective experimental compositions of monzodiorite and KREEP basalt yield melt compositions closest to those of lunar granites.

Limitations of Rhyolite-MELTS for lunar melting. Rhyolite-MELTS is a useful program for obtaining important preliminary experimental constraints for the proposed work, but ultimately cannot provide the necessary answers that only experiments can produce. The reliance of MELTS and Rhyolite-MELTS on results for terrestrial conditions may not accurately represent lunar conditions or compositions.

Conclusions and future work: By performing preliminary computer simulations using Rhyolite-MELTS, we have placed constraints on future partial melt experiments. Based on these results, partial melting experiments will be performed on synthetic compositions equivalent to those of lunar monzodiorite and KREEP basalt. These appear to yield the closest matches for partial melt compositions reflecting lunar granites. Experiments will be performed using a 1-atm gas-mixing Deltech furnace, under IW -1 *f*O2. Experimental temperatures will be at conditions ranging from 900-1100°C, with 25°C iterations. Experimental results will then be presented at LPSC. Such experiments will ultimately determine the validity of the crustal melting model for the production of lunar granites and rhyolites.

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