PETROLOGIC MODELING OF MAGMATIC EVOLUTION IN THE ELYSIUM VOLCANIC PROVINCE ON MARS

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Introduction: The Elysium Volcanic Province (EVP) on Mars is a massive expanse of land made up of many hundreds of lava flows of various ages [1]. The variable surface ages within this volcanic province have distinct elemental compositions based on the derived values from the Gamma Ray Spectrometer (GRS) suite [2]. Without seismic data or exposed crustal sequences on Mars, the compositions of lavas on the surface provide some of the only information to study the properties of the interior of the planet. The Amazonian surface age and isolated nature of the EVP in the northern lowlands of Mars make it ideal for analyzing the mantle beneath Elysium during the most recent geologic era on Mars.

The MELTS algorithm is one of the most commonly used programs for simulating compositions and mineral phases of basaltic melt crystallization [3]. It has been used extensively for both terrestrial applications [4] and for other planetary bodies [3,5]. The pMELTS calibration of the algorithm allows for higher pressure (10-30 kbars) regimes, and is more appropriate for modeling melt compositions and equilibrium conditions for a source within the martian mantle. We use the pMELTS program to model how partial melting of the martian mantle could evolve magmas into the surface compositions derived from the GRS instrument, and how the mantle beneath Elysium has changed over time. =By performing these simulations with varying initial conditions and comparing the results to geochemistry of the surface of three sub-regions of variable age within the volcanic province (NW, Central, and SE), this work models how the mantle beneath Elysium has changed over time and makes predictions for how martian volcanic provinces evolve globally.

Methods: This work uses a range of initial pressure conditions which correspond to possible thicknesses of the martian lithosphere. For the pMELTS simulations, we use a pressure range of 10-30 kbars, with steps of 2 kbars, and a temperature range from 2000˚C down to 1000˚C in increments of 10˚C. The small temperature increments provide results with enough resolution to select liquid compositions as a function of partial melting at melt fractions of 3%, 5%, 10%, 20%, 30%, 40%, and 50%. Each of these temperature-pressure regimes were repeated three times with a different H_2O value estimated by previous work for the martian mantle (39 ppm, 185 ppm, 1800 ppm). The oxygen fugacity pathway 3 log units beneath the quartz-fayalite-magnetite buffer (QFM-3), was found to be optimal for martian basalts [6] and is used in our work.

After using pMELTS to find the pressure and degree of partial melting for compositions most consistent with surface compositions derived from the GRS instrument, the depth at which the melt formed within the martian mantle is calculated using the pressure conditions for each sub-region, the gravitational constant for Mars ($3.711\ m/s^2$), and the average density of martian crust. A density of $3300\ kg/m^3$ was used for this work [7]. The equilibrium temperature of the source, the degree of partial melting, and an adiabatic gradient calculated for the martian mantle, was then used to calculate the mantle potential temperatures for each sub-region. To calculate the potential temperature of the martian mantle, the average equilibrium temperature had to be corrected to surface pressure conditions (~0 bars) by subtracting the effects of an adiabatic gradient of 0.18°C/km [8] and adding the latent heat of fusion for the melt. The latent heat of fusion (T_{fus}) was calculated using the expression $\Delta T_{fus}=F*(H_{fus}/C_P)$, where F is the degree of partial melting, H_{fus} is the heat of fusion of the mantle ($6.4\times 105\ J*K^{-1}*kg^{-1}$) [9], and C_P is the heat capacity at a constant pressure ($1200\ J*K^{-1}*kg^{-1}$) [8,9].

Results: The results reveal how the oxide composition of the liquid component vary with pressure, degree of partial melting, and H_2O concentration. The mass fraction of each oxide: TiO_2, Al_2O_3, FeO, MgO, CaO, and K_2O is compared with that of SiO_2 in terms of degree of partial melting and pressure. Each plot includes 11 melt curves which show the composition of oxides as a function of degree of partial melting from 3-50%. Each curve corresponds to a pMELTS trial with a unique initial pressure ranging from 10 kbars to 30 kbars with an interval of 2 kbars. All of these melt curves together form a pressure continuum, which are used to determine mantle pressures at the melt source for the EVP. The average GRS derived values for each of the three Elysium sub-regions have also been included on each plot. Their location relative to the pressure curves is used to determine a possible range of pressures and degrees of partial melting for the magma source beneath the EVP.

The results show that H_2O content of the parental magma does not greatly affect the liquid composition trend, especially at the two lower concentrations 39 and 185 ppm, which are nearly indistinguishable.

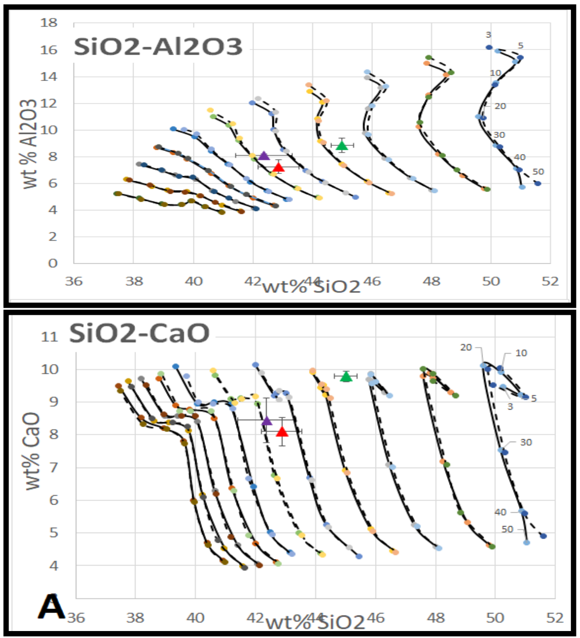

Figure 1: *The compositions for select oxides in the melt in terms of degree of partial melting, for low H_2O content. The 10kbars curve is furthest to the right and progress to the left with increasing pressure up to 30kbars. The numbers (3, 5, 10, 20, 30, 40, 50) are degrees of partial melting for each trial. Compositions are each sub-region are represented by triangles SE (green), Central (Purple), and NW (red).*

The SE Elysium sub-region consistently shows the lowest pressure conditions for equilibrium in the magma source. The NW and the Central sub-regions show much more comparable pressures, but the Central tends to be slightly higher across the oxide pairs. A visual approximation places the SE data points in between the 14 kbar and 16 kbar melt curve for nearly every oxide. The NW and Central sub-regions show slightly more variation, but most of the oxides show them plotting between the 18 kbar and 20 kbar melt curves with variations as high as 21 kbars and as low as 17 kbars.

The mantle pressure and the degree of partial melting increase from the Late Hesperian NW sub-region to the Early Amazonian Central sub-region. The pressure and partial melting then decreases from the Central Elysium sub-region to the Late Amazonian SE region. SE Elysium has a lower mantle pressure than the NW sub-region, however the degree of partial melting is between the level of the NW and the Central sub-regions. Central Elysium has the highest mantle potential temperature of any of the three sub-regions, with temperatures of roughly 1470°C. The NW and SE have similar temperatures to one another, around 1420°C. The NW sub-region has a crustal heat flow of ~35 mWm^{-2}, the Central sub-region is ~34 mWm^{-2}, and the SE sub-region is ~42 mWm^{-2}.

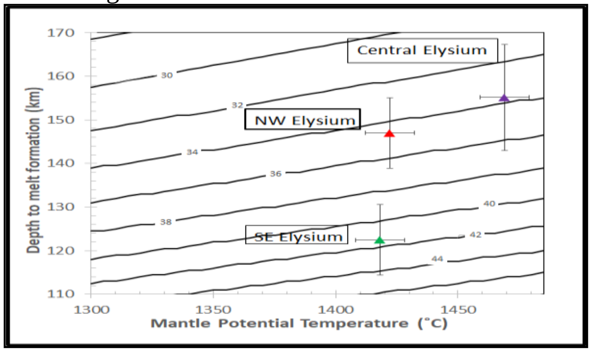

Figure 2: *Depth to melting (km) plotted against mantle equilibrium temperature (°C). Heat flow contour lines in milliwatt per square kilometer are shown.*

Interpretation: These estimations are consistent with the interpretation the melt zones calculated by this study are located at the base of the elastic lithosphere in the upper mantle. This interpretation supports the conclusions by Susko et al. [2] that the GRS-derived compositions within the EVP represent primary magmatism generated from the partial melting of the martian mantle. The results from the modeling support the hypothesis that the variation in surface geochemistry of the Elysium Volcanic Province is largely dependent on a change in depth of melt formation. The oldest exposed resurfacing took place during the Hesperian in the NW Elysium sub-region. As eruptions proceeded to build up the Elysium Rise, the pressure on the mantle beneath the volcanic province increased and the elastic lithosphere began to flex [10]. This shutdown melt formation at shallower depths and during the Early Amazonian. During the Late Amazonian, mantle pressure became so high that melt formation was shut down at its original source and forced to shift to the southeast, where it initiated eruptions and resurfacing in the SE sub-region.

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