SMALL-SCALE CONVECTION AND THE GEODYNAMIC ORIGINS OF MARTIAN VOLCANISM J. P. Murphy[1] and S. D. King[2], [1]Virginia Tech Department of Geosciences, Blacksburg, VA [jmurph16@vt.edu], [2]Virginia Tech Department of Geosciences, Blacksburg, VA [sdk@vt.edu].

Introduction: Mars has two major centers of volcanic activity. The largest by far is the Tharsis Rise, a broad dome about 8000 km in diameter and 10 km high centered in the equatorial western hemisphere which contains several large volcanoes [1]. The origin of the Tharsis Rise is generally ascribed to one or more long-lived mantle plumes [2, 3, 4, 5, 6]. While most of the rise was emplaced by the end of the Noachian and the large volcanic shields in the Hesperian, the region has remained volcanically active for most of the planet's history and likely within the past 50-100 Ma [7, 8, 9]. The relatively recent volcanic activity and modeled long-term stability of convection in the Martian mantle indicates that mantle melting is still occurring in the present day [4, 5, 10].

Another major volcanic province, Elysium, is centered ~105 degrees to the west of Tharsis. This region is also marked by a broad dome (2400 km × 1700 km) and volcanoes of similar age [11]. However, geodynamicists have typically focused on Tharsis, since Elysium and its three major volcanoes, while large by Earth standards, are markedly smaller than Tharsis and its volcanoes. Our goal is to explain the volcanism in both provinces and the difference in magnitude between them.

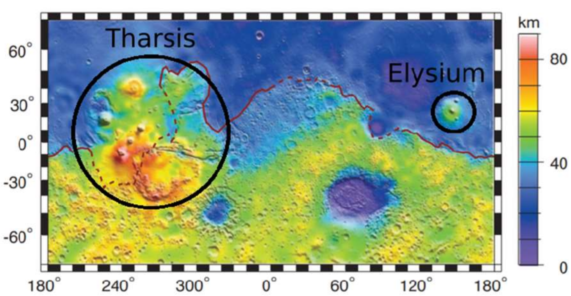

Figure 1. Crustal thickness map adapted from [12]. The locations and approximate extent of Tharsis and Elysium are circled. The red line marks the dichotomy boundary and is dashed where uncertain, in particular beneath Tharsis.

Crustal Dichotomy and Small-Scale Convection: The Tharsis Rise straddles the boundary between the thicker crust of the southern highlands and the thinner crust of the northern lowlands [13]. This boundary also passes near and south of Elysium. The stark contrast between the two hemispheres (zonal degree-1 topography) is referred to as the Martian dichotomy. This feature is apparent in the hypsometry (elevation frequency distribution) of Mars, which has a bimodal distribution with peaks separated by 5.5 km [14, 15]. The maximum elevation difference at the dichotomy boundary is somewhat less, ~3.5 km [16, 17]. Overall the highlands have a much thicker crust than the lowlands; however, the contrast in crustal thickness does not exactly match the topographic boundary of the dichotomy [12].

Like the Tharsis Rise, the dichotomy is one of the most ancient features on the planet. Given the positions and ages of these two large-scale features, the dichotomy may be related to the development of the Tharsis Rise [6, 18, 19, 20, 21, 22]. One proposed mechanism for this link is that Tharsis is the result of small-scale edge-driven convection at the dichotomy boundary [19]. Small-scale convection could explain both the longevity of Martian volcanism and the difference in magnitude between Tharsis and Elysium.

Small-scale edge-driven convection, as described by [23] and [24], occurs at the vertical boundary between thick, stable lithosphere (or crust) and thinner lithosphere. On Earth such an arrangement is found at boundaries between continental cratons and oceanic lithosphere. On Mars a similar situation may occur at the dichotomy boundary where the thick crust of the southern hemisphere meets the thinner crust of the northern hemisphere. When such a boundary, with a thick crustal root on one side and underlain by a mobile mantle, is stable for a long period of geologic time, the base of the crust on either side reaches the same temperature. The vertical boundary therefore has a uniform temperature, an unstable condition that gives rise to small-scale convective flow near the boundary [23, 25]. This continuing movement supplies fresh, hot mantle material from deeper in the mantle to the melting zone, where melting occurs mainly due to pressure release. The melt is then available to produce volcanism such as that associated with the Tharsis Rise, provided the instability can last long enough [19].

Alternative to the classic idea of edge-driven convection, small-scale convection can also develop at a step in crustal thickness due to the insulating effect of the thicker crust. A lower thermal conductivity in the thicker crust can enhance the insulating effect. The warm buoyant material trapped beneath the thicker crust upwells at the boundary. Decompression melting as the warm rock ascends produces or increases melting, providing a source for volcanic activity along and north of the dichotomy boundary.

Model: We investigate the origin and evolution of Martian volcanism and evaluate the potential for small-scale convection at the dichotomy boundary to have produced the Tharsis and Elysium volcanism along and north of the boundary. To do this we construct and analyze 3D spherical shell models of solid-state convection in the Martian mantle using a modified version of the finite element code CitcomS [26, 27, 28], which is designed to solve problems in thermochemical convection in planetary mantles. Modifications include a cooling core boundary condition and decaying internal heating. The dichotomy boundary is currently modeled as a simple degree-1, hemispherical feature. We plan to implement a more realistic dichotomy geometry derived from elevation and gravity data, and potentially the results of InSight.

The largest modification to CitcomS is the calculation of melt production. The equilibrium melt fraction X is computed from pressure and temperature according to the parameterization of [29] for dry peridotite. The instantaneous melt production rate Γ at a point (volume of melting per volume of mantle per time) is equal to the total, or material, derivative of the equilibrium melt fraction (e.g. as in [30]). Negative values are allowed and represent freezing of existing melt. Volume integration of Γ gives the volumetric melt production rate, e.g. in km^3/yr. Thus, the rate of melt production $\dot{M}$ in a given volume V is

$$\dot{M} = \int_V \Gamma \, dV = \int_V \left(\frac{\partial X}{\partial t} + \boldsymbol{u} \cdot \nabla X \right) dV$$

where **u** is the velocity of the solid mantle.

Preliminary Results and Discussion: Our models indicate that of the two small-scale convection scenarios described above, the latter (upwelling from beneath thicker, insulating crust) is most likely. Even with an unrealistically large root at the dichotomy boundary of up to 200 km, edge-driven convection does not develop. However, upwelling and melting occurs immediately north of the boundary (Figure 2). The warm material trapped beneath the southern hemisphere undergoes little or no melting there, unable to ascend to low enough pressures. It upwells from beneath the boundary, concentrating melting in the northern hemisphere, particularly the area along the dichotomy boundary.

Melt production peaks within the first few hundred million years of the model (~4 Ga) and decreases, often rapidly, thereafter. To match observations, models should do this and continue to produce much smaller amounts or pulses of melt for billions of years after peaking.

We aim to explain how volcanism could become concentrated in certain regions such as Elysium, and especially Tharsis. As discussed above, we will incorporate a realistic dichotomy boundary geometry. Variations laterally and vertically from an equatorial, uniform step may produce a scenario where melting is concentrated near specific portions of the boundary.

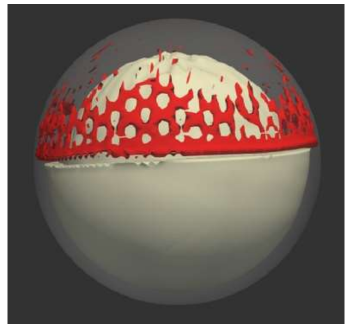

Figure 2. 3D model showing the relatively hot 1800 K isosurface (yellow) and regions of >30% melt (red).

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