The Tharsis province of Mars is 6000 km in diameter and contains four major shield volcanos and a number of smaller volcanic structures. It is approximately 7 to 9 km higher than the plains to the north and west and has a peak geoid anomaly of 1.5 km [1,2]. The Elysium province is a smaller scale version of Tharsis, with a peak uplift of 3 to 4 km, a peak geoid anomaly of 300 m (omitting the Tharsis dominated degree 2), and three main volcanic structures. Cratering statistics indicate that volcanic activity in both regions occurred over most of the age of the Solar System and continued into the Upper Amazonian [3,4]. Existing models of Tharsis and Elysium have generally treated these regions in terms of either isostatic or flexural models [e.g., 5-8]. However, the uplifted topography, geoid anomalies, large horizontal length scales, and the volume of volcanic materials are all consistent with convective upwellings being important in these regions. Dynamic support for the topography of Tharsis and Elysium has sometimes been rejected on the grounds that it cannot be maintained for a significant fraction of Martian history [5,6]. However, Mars is sufficiently large that mantle heat transport currently must be dominated by convection. In the absence of plate tectonics, the Tharsis and Elysium volcanic provinces could stay over mantle upwellings indefinitely. Observations of young volcanism [3,4] are consistent with currently active convective upwellings in these areas.

Only two prior models explicitly treated the role of convection in forming Tharsis and Elysium [9,10]. In one model [9], Tharsis and Elysium overlie regions of broad-scale upwelling caused by the internally-heated component of convection in the mantle of Mars. Within these broad upwellings, a number of mantle plumes are formed by the bottom-heated component of convection. These plumes feed the various shield volcanos. The concentration of plumes within the Tharsis and Elysium regions is reminiscent of the situation on Earth, where hotspots show a pronounced bimodal distribution [11].

A number of parameters affect the magnitude of the geoid anomaly and topographic uplift associated with convection [e.g., 12]. One of the most important is the variation of viscosity with depth. The viscosity structure of Mars depends on a number of poorly constrained parameters, such as the average grain size in the mantle and the concentration of volatiles. Models of long-wavelength geoid anomalies indicate that viscosity in the Earth increases by several orders of magnitude from the asthenosphere to the lower mantle, whereas on Venus the mantle viscosity appears to be only a weak function of depth [13,14]. Because of the relatively small gravitational acceleration on Mars, structural models of its interior suggest that the pressure at the base of its mantle are no larger than at 670 km depth on Earth [15], implying that Mars lacks the perovskite phase that dominates the Earth’s lower mantle mineralogy. Mars therefore probably does not have as large a variation of viscosity with depth as is observed on Earth, although some increase of viscosity with depth cannot be ruled out. Scaling recent isoviscous, spherical axisymmetric convection models [16] to likely Mars conditions gives geoid anomalies of as much as 900 m and topographic uplifts of up to 10 km. The geoid and topography amplitudes will vary with time due to the time-dependence of the mantle thermal structure [16]. The magnitude of the convective geoid and topography are increasing functions of the aspect ratio of the convection [12]. The smaller horizontal scale of Elysium relative to Tharsis suggests a smaller aspect ratio for the convection at Elysium, which might account for the different geoid and topography amplitudes of the two features. These results suggest that mantle convection could be a significant contributor to the geoid and topography of Tharsis and Elysium, although isostatic and flexural processes undoubtedly also play a role. The predicted amplitude of the convective geoid and topography would be decreased if Mars does have a low viscosity layer in its upper mantle.

An important consideration in assessing the amount of convective uplift on Mars is the extent to which the elastic lithosphere can flexurally resist uplift. Based on models of deformation associated
with volcanic loading, elastic lithosphere thicknesses were estimated to be about 20 km at Arsia, Ascraeus, and Pavonis Mons, at least 150 km at Olympus Mons, and about 50 km at Elysium Mons [17]. Although these estimates apply to the time at which the volcanic loads were emplaced, a similar range of thicknesses could be maintained at present if convective upwelling is presently occurring under central Tharsis and Elysium. Prior models of Tharsis and Elysium have typically assumed a constant thickness elastic lithosphere. Including lateral variations in the elastic lithosphere’s thickness may allow greater convective uplift in the center of the upwelling than would be predicted by models with a uniform thickness lithosphere. Efforts are currently underway to quantify this effect.

The proposed convective upwellings will also impose horizontal normal stresses at the base of the elastic lithosphere. If these stresses are large enough to produce near-surface faulting, the expected pattern is radially oriented normal faulting near the upwelling, surrounded by a narrow zone of strike-slip faulting, followed by concentric thrust faulting at greater distances from the upwelling [14]. This pattern appears to be generally consistent with the observed distribution of graben and ridges around Tharsis [18-20]. Boundary layer instabilities will cause the mantle thermal structure to vary with time [16], leading to episodic variations in the magnitude of the convective stresses. These variations, in combination with stresses from a monotonically increasing volcanic load, could lead to complex time variations in the tectonic history of the surface, as required by the observed geology [18,20].

References


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