The Crustal Dichotomy and Edge Driven Convection: A Mechanism for Tharsis Rise Volcanism? S. D. King[1] and H. L. Redmond[2], [1&2]Department of Earth and Atmospheric Sciences, 550 Stadium Mall Drive, Purdue University, West Lafayette, IN 47907-2051, [1]sking@purdue.edu, [2]redmondh@purdue.edu

Introduction: A vertical wall of constant temperature is a convectively unstable geometry and drives convective motion in the fluid near the wall. This is the essence of the edge-driven convection hypothesis [1]. On Earth small-scale convection could be triggered from the vertical step in the thermo-chemical boundary at cratonic keels [1] and continent-ocean boundaries [2]. Seismic evidence supporting EDC has been observed under the African cratons [3].

The spatial correlation of the crustal dichotomy boundary and Tharsis rise is intriguing and a relationship between these features has been suggested by a number of investigators. The lack of correlation between the areoid and the dichotomy boundary (Figure 1) indicates that there is topographic relief on the crust-mantle boundary (Moho), similar to passive margins or cratonic keels on Earth [4]. The question is whether this step is large enough to initiate a small-scale convective instability and whether this small-scale instability will survive long enough to produce the volcanism needed to create Tharsis rise.

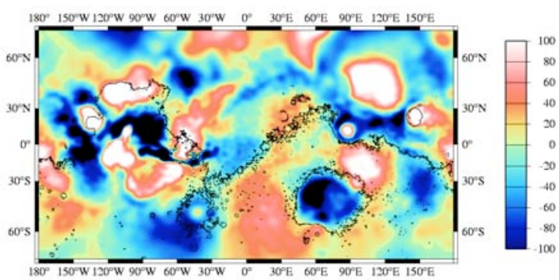

Figure 1. Spherical harmonic degrees 5-60 of the areoid. The black line is the zero contour of the topography, a proxy for the crustal dichotomy.

If an EDC mechanism is responsible for the small, late-stages of volcanic activity, it is possible that it could be observable in the present areoid and topography. Figure 2 shows the residual areoid from degrees 5-60 after the best fitting isostatic areoid, in a least-squares sense, has been removed. The best fitting isostatic model has a crustal thickness of 110 km and a crustal density of 2800 kg/m^3 and the result is relatively insensitive to the low-end harmonic cut off. The linear relative areoid highs in the residual that parallel the dichotomy (red) could represent mantle structures paralleling the crustal feature.

This paper will examine whether the long, linear features paralleling the dichotomy boundary in the residual areoid (Figure 2) are robust and whether these have possible mantle origins. These appear to be the most promising evidence for edge-driven convection in the present-day areoid. However, the absence of present day edge-driven convection does not rule out edge-driven convection as a possible mechanism for the formation of Tharsis rise, the bulk of which formed in the Late-Noachian to Early-Hesperian period. This will be examined using numerical models of edge-driven convection, mapping out the minimum crustal thickness necessary to develop long-lived edge-driven convection instabilites.

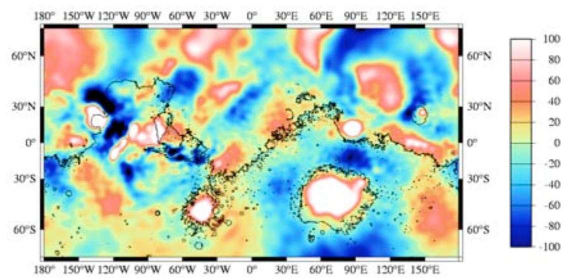

Figure 2. Spherical harmonic degrees 5-60 of the residual areoid, computed by removing the best fitting isostatic areoid (crustal thickness of 110 km and a crustal density of 2800 kg/m^3), in a least-squares sense. The black line is the zero contour of the topography, a proxy for the crustal dichotomy.

The presence or absence of edge-driven convection depends on the differential crustal thickness and the gradient of the transition in crustal thickness between the northern and southern hemispheres. If we assume a crustal density of 2900-3000 kg/m^3, a mantle density of 3300-3500 kg/m^3, and an average dichotomy height of 4 km, an isostatic balance predicts a differential crustal thickness of 20-40 km. This alone would be insufficient to nucleate a small-scale instability. If the process that formed the southern hemisphere led to the development of a deep, depleted layer beneath the southern hemisphere, similar to a cratonic keel on Earth, then the difference in 'crustal' thickness between the northern and southern hemispheres would be much larger than indicated by an isostatic balance. In this case it would be reasonable to expect small-scale instabilities to form.

Cratering studies demonstrate that Martian northern plains are similar in age to the southern hemisphere [5-6]. Thus, the dichotomy boundary is an old feature and at the time of formation, the lithosphere was not as thick as it is today. While the process of craton formation on Earth is poorly understood, cratonic roots are nearly as old as the cratons they underlie and appear to be stable, resisting deformation almost as soon as they form [7]. Thus, since the dichotomy boundary formed at a time when the lithosphere was thinner than it is today, this compositional boundary would appear to be ideal to nucleate edge-driven convective instabilities.

Numerical experiments of small-scale convection show that an edge-driven convective instability can last for 50-100 million years and is limited by the erosion of the step in the boundary [1]. If edge-driven convection produced the volcanism comprising Tharsis rise in the Late-Noachian to Early-Hesperian period, the same instability would not remain today.

Maintaining stable continental keels on Earth requires that the keel be buoyant relative to normal sublithospheric mantle and relatively viscous [8]. Thus, keel material is envisioned to be cold, depleted, and dehydrated. There is yet no evidence for a depleted, dehydrated region of the Martian mantle. Without seismology, our best hope for additional constraints on Martian crustal structure will be thermobarometric studies of xenolith inclusions in lavas and/or discovery of kimberlites.

An edge-driven instability continuously draws new (unmelted) mantle material through the melting zone, and melting occurs dominantly by pressure release. King and Anderson [1] estimated that an edge-driven convective instability could produce the volume of volcanic material observed at flood basalt provinces such as the Parana basalts of South America. Tharsis rise is 10-30 times the volume of volcanic material of typical flood basalt provinces on Earth. Gravity on Mars is roughly one third of that on Earth; therefore, the growth time for edge driven instabilities will be approximately three times as long on Mars as Earth. The time period edge-driven instabilities is reasonably consistent with the time period for the major phase of Tharsis volcanism. It is possible that a series of edge-driven type instabilities along the dichotomy boundary together formed Tharsis rise. It is intriguing that Tharsis forms in a concave section of the dichotomy boundary. Thus small-scale instabilities could nucleate from a nearly 5,000 km arc along the boundary and upwell beneath the Tharsis swell.

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