GRAVITY MODELS OF THE HEMISPHERIC DICHOTOMY IN EASTERN MARS: LITHOSPHERIC THICKNESS AND SUBSURFACE STRUCTURE.

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Introduction The hemispheric dichotomy of Mars is one of the most prominent topographic structures on the planet, with a typical offset of 4 km between the southern highlands and the northern lowlands [1,2]. Various mechanisms have been proposed for forming the dichotomy, including both internal processes related to mantle convection [3-5] and external processes related to one or more large impacts [6,7]. Gravity and topography observations provide clues that can help to constrain the mechanisms which produced the dichotomy. For example, these observations can constrain the lithospheric thickness and hence the heat flux at the time of lithospheric loading. They can also reveal the presence of possible buried structures.

In this work, I focus on the dichotomy boundary in eastern Mars between 50° and 155° East longitude. In this region, the dichotomy boundary has a roughly linear planform, striking NW-SE, except where the boundary is affected by the Isidis impact basin. The topographic offset across the dichotomy in this part of Mars is relatively scarp-like, with 3 to 4 km of vertical relief occurring across a narrow transition zone between the southern highlands and the northern lowlands [1]. The results reported here are based on the highest resolution gravity model currently available from the Planetary Data System, JGM95I-01 [8], and include spherical harmonic degrees 2-60 (half-wavelength resolution 180 km).

Nepenthes Mensae (110° – 130° longitude) Nepenthes Mensae is the portion of the dichotomy boundary immediately east of the Isidis impact basin. I have estimated the lithospheric thickness in this region by comparing models calculated using elastic flexure of a thin spherical shell [9] with the observed gravity anomaly and minimizing the RMS misfit in the region 105° to 130° East longitude and 10° South to 15° North latitude. The models assume a global mean crustal thickness of 50 km [10], a mantle density of 3400 kg m^{-3} [11], and a crustal density between 2600 and 2900 kg m^{-3} (brecciated or vesicular basalt versus intact basalt). Regardless of crustal density, the RMS misfit requires a lithospheric thickness of less than 5 km, corresponding to a very high heat flow, > 200 mW m^{-2} at the time the dichotomy boundary formed. This study region, and hence the inferred lithospheric thickness, is dominated by the high topography on the south side of the dichotomy boundary. Based on fitting flexure models to topographic profiles in the dichotomy boundary zone, Watters [12] estimated an elastic thickness of 31-36 km in this region. Nimmo [13] used gravity admittance modeling to estimate a lithospheric thickness of 61 km in a study region that includes regions both north and south of the dichotomy boundary. He interpreted the large elastic thickness as an average between thin, southern lithosphere and thicker lithosphere in the north. The combined results of this study and the earlier work of Nimmo and Watters are quite consistent with such a pattern. This implies a strong decrease in heat flux from south to north across the dichotomy at the time that these structures formed.

Numerical convection modeling shows that a type of small-scale convection known as edge-driven convection can develop in regions with a pre-existing step discontinuity in the crustal thickness [14]. On Earth, this type of convection may occur in association with continental rifting and the formation of new ocean basins, with hot convective upwelling occurring on the thin crust side and cold downwelling along the transition between thin and thick crust. This is consistent with seismic tomography observations of the south Atlantic margins of both Africa and South America [14]. On Mars, the dichotomy boundary might serve as a nucleation point for edge-driven convection [15]. The pattern of decreasing heat flux to the north across the dichotomy in this region could be the signature of edge convection, although the lowest heat flux and strongest convective downwelling is inferred to occur north of the dichotomy rather than along the dichotomy as expected from the numerical models. If edge-driven convection occurred in this region, it does not necessarily require a purely internal origin for the dichotomy boundary. Rather, the edge-driven convection could be a secondary process induced by whatever mechanism is the primary cause of the dichotomy.

Figure 1 shows the residual gravity anomaly after removing the contributions of both the surface topography and the subsurface compensation associated with a 5 km thick elastic lithosphere. In most places, the residual anomaly is quite small, demonstrating the general success of the lithospheric compensation model. However, there is a strong residual anomaly along the northern part of the study region, just to the north of the dichotomy boundary in this region. The northern edge of this residual anomaly is basically along the northern edge of Figure 1, with the gravity anomaly decreasing rapidly toward zero further north. The peak amplitude of the residual anomaly is 52 mGal, well above the noise level in the gravity data.

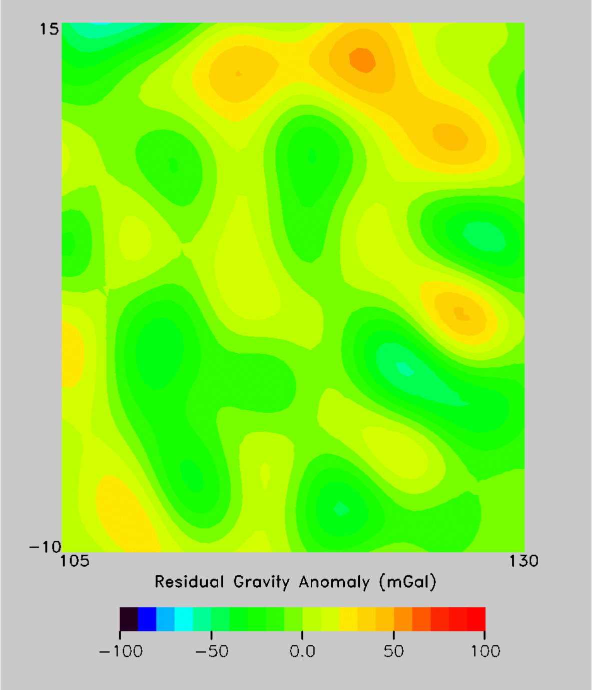

Figure 1: The residual gravity anomaly for the Nepenthes Mensae portion of the dichotomy boundary after removing the contributions of surface topography compensated with a 5 km thick elastic lithosphere.

The residual anomaly is roughly 1000 by 250 km in size. The anomaly is slightly north of the dichotomy boundary scarp, in a region of little topographic relief. Thus, the anomaly must be due to a buried, high-density load. Possible causes include buried volcanic cumulates, thinned crust with super-isostatic uplift of the crust-mantle interface, or cold, dense material in the mantle. Treating the anomaly as a sheet mass with a maximum likely density contrast of 1000 kg m^{-3} (crust of brecciated basalt, 2600 kg m^{-3} [16], intrusive load of Chassigny-like olivine, 3600 kg m^{-3} [17]), the minimum thickness of a volcanic intrusion would be 1.2 km. However, there is no associated evidence of significant surface volcanism along the hypothetical intrusion. If edge-driven convection did occur, the cold downwelling could produce the observed positive residual gravity anomaly. The required temperature anomaly depends on the assumed depth range for the convective flow. A significant concern about this type of model is its possible longevity, which may be much less than the likely 4 billion year age of the dichotomy. Perhaps the most likely cause is variations in crustal thickness along the dichotomy boundary. Quantitative constraints on the required mass distributions for both the crustal thinning model and the cold mantle model are currently being developed using the three-dimensional modeling method of Kiefer [16].

Aeolis Mensae and Protonilus Mensae Similar residual anomalies are seen along other parts of the dichotomy in eastern Mars. In Aeolis Mensae (130° – 155° longitude), the residual gravity anomaly is 1300 km by 350 km. As in Nepenthes, the residual anomaly is elongated along the dichotomy boundary and located on the northern (lowland) side of the topographic scarp. The peak residual anomaly is 120-130 mGal in Aeolis, roughly 2.5 times the amplitude observed in Nepenthes. Nimmo [13] previously recognized the importance of buried loads in both Aeolis and Nepenthes, but his admittance model could not identify the spatial location or amplitude of the buried load.

In Protonilus Mensae (50° – 70° longitude), the residual anomaly is 700 to 1000 km long by 300 km wide, located in the fretted terrain along the northern (lowland) side of the topographic scarp. The peak amplitude of the residual anomaly is about 80 mGal. Additional modeling of this structure was recently presented by Smrekar et al. [18].

These high-density buried loads probably represent a common process that operated over a substantial segment of the dichotomy boundary. This pattern of positive residual anomalies along the dichotomy boundary in eastern Mars contrasts with the typically negative gravity anomalies along the dichotomy boundary in Arabia, and correlates with a difference in boundary topography, scarp-like in the regions discussed here versus a gradual slope in Arabia.

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