FLEXURE AND THE TOPOGRAPHY OF THE DICHOTOMY BOUNDARY ON MARS.

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Introduction: In the eastern hemisphere of Mars, the dichotomy boundary is expressed by a significant change in elevation (>2 km) (Fig 1). Tectonic features are also associated with the dichotomy boundary in the eastern hemisphere [1]. The dichotomy boundary in this hemisphere is marked by fault-controlled fretted valleys and extensional troughs in the lowlands and lobate scarp thrust faults in the adjacent highlands [2, 3]. Extensional and compressional deformation along the boundary appears to have occurred during the late Noachian to early Hesperian [2, 3]. This suggests that tectonism played a role in the formation of the dichotomy boundary. The population of ancient buried impact basins in the northern lowlands suggests that the northern lowlands crust and the crustal dichotomy formed in the early Noachian [4, 5]. A number of lines of evidence suggest that the present-day boundary is the result of tectonic, depositional and erosional modification of the ancient dichotomy boundary [1, 6].

Long Wavelength Topography: The long wavelength topography along the length of an ~2100 km section of the dichotomy boundary in northern Terra Cimmeria has been examined (Fig. 1). We find that the dichotomy boundary along much of its length consists of an arching ramp flanked by a broad rise. Topographic profiles across the boundary show that the broad rise is followed by a relatively steep ramp that slopes downward into the lowlands (Fig. 2). Slopes reach a maximum on the ramp and the scarp that marks the dichotomy boundary and slopes on the back rise are low and dip away from the boundary.

Flexure of Weakened and Continuous Lithosphere: Lithospheric flexure results in long wavelength topography with a distinct deflection profile. The downward deflection of the lithosphere is accompanied by a flanking upwarp or bulge [see 7, 8]. We model lithospheric flexure of an elastic plate overlying an incompressible fluid subjected to a line load for both a weakened and a continuous plate (in a parallel effort, flexure is being modeled using finite element methods [9]). The most pronounced difference between the deflection of a continuous or infinite elastic plate and a weakened or semi-infinite plate supporting a line load is in the amplitude of the deflection. For a given load the maximum height of the rise is larger for a weakened plate than for a continuous plate [see 7, 8]. In addition to a smaller height of the bulge, the slope of the downward deflection or ramp is less for a continuous lithosphere. Two well-preserved areas of the dichotomy boundary in northern Terra Cimmeria (eastern and western sections of the study area) have been modeled. Deflection profiles were generated for a range of the maximum amplitude of the deflection w_0 and the flexural parameter α for a continuous plate. The maximum downward deflection and ramp slope in eastern (Fig. 3) and western (Fig. 4) Terra Cimmeria can be obtained for reasonable parameter values (east: α=115 km, w_0=130 m; west: α=95 km, w_0=118 m). However, in both cases the height of the rise is underestimated. Better fits are obtained for a weakened plate (Fig. 3, 4) (east: α=155 km, w_0=220 m; west: α=154 km, w_0=387 m), consistent with the results obtained modeling flexure of an elastic plate subjected to end load [1]. The model fits correspond to an elastic thickness of ~30 km, assuming the mean density of the highland of 2900 kg·m^{-3}, a density of the martian mantle of 3400 kg·m^{-3} and a Young's modulus of the lithosphere of E = 100 GPa [see 1]. Flexure of the highlands may be the result of late Noachian-early Hesperian vertical loading from the emplacement of volcanic material in the northern lowlands [1].

Implications of a Weakened Lithosphere: The analytical model fits (Fig. 3, 4) favor a weakened lithosphere at the dichotomy boundary. A weakened lithosphere could have been formed in an early stage of plate tectonics [10] where the dichotomy boundary in the eastern hemisphere is analogous to a terrestrial passive margin [see 1]. Another possibility is that the dichotomy is the result of early transport of crustal material by degree-one mantle convection which thinned and thickened the crust above zones of upwelling and downwelling [11, 12]. However, new evidence indicates the crust of Mars formed very soon after planet formation, suggesting there may not have been sufficient time for early plate tectonics or convection driven subcrustal transport to have formed the northern lowlands crust [13]. The crystallization of an early magma ocean could result in a gravitationally unstable mantle that rapidly overturned [14]. If the scale of mantle overturn was hemispheric, the crustal dichotomy could have formed by very early subcrustal transport. The fiber stresses for a semi-infinite load from the removal of 3.5 km of lowlands crust reach a near-surface maximum >400 MPa assuming values for the flexural parameter and elastic thickness consistent with those obtained from the flexural models ($\alpha \cong 154$ km, T_e = 30 km, ρ_c = 2900 kg m^{-3}, ρ_m = 3400 kg m^{-3}) (Fig. 5). These stresses are sufficient to cause significant extension along the early Noachian dichotomy boundary and may have resulted in a weakened lithosphere.

References: [1] Watters T.R. (2003a) *Geology, 31*, 271-274. [2] McGill G.E. and Dimitriou A.M. (1990) *JGR, 95*, 12595-12605. [3] Watters T.R. (2003b) *JGR, 108*, 5054. [4] Frey H.V. et al. (2002) *GRL, 29*, 1384. [5] Frey H.V. (2004) Hemispheres Apart, LPI, #4012. [6] Irwin R.P. et al. (2004) *JGR, 109*, E09011. [7] Turcotte D.L. and Schubert G. (2002) Cambride Univ. Press, Cambridge. [8] Watts A.B. (2001) Cambride Univ. Press, Cambridge. [9] McGovern P.J. and Watters T.R. (2004) Hemispheres Apart, LPI, #4034. [10] Lenardic A. et al. (2004) *JGR, 109*, E02003. [11] Zhong S. and Zuber M. (2001) *EPSL, 189*, 75-84. [12] Zhong S. et al. (2004) (2004) Hemispheres Apart, LPI, #4019. [13] Solomon S.C. (2004) Hemispheres Apart, LPI, #4024. [14] Elkins-Tanton L.T. et al. (2004) Hemispheres Apart, LPI, #4009.

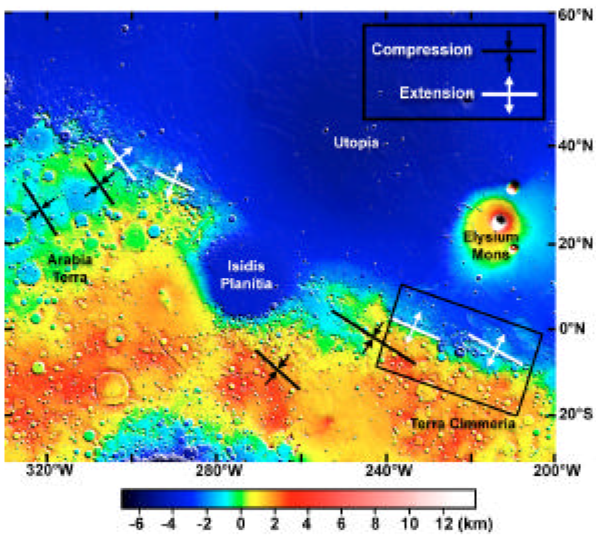

Figure 1. Location of extensional (troughs) and compressional (lobate scarps) tectonic features along dichotomy boundary in the eastern hemisphere overlaid on a color-coded digital elevation model (DEM) combined with a shaded-relief map derived from MOLA $^{1}/_{32}$ degree per pixel resolution gridded data. Black box shows the approximate location of the study area in northern Terra Cimmeria.

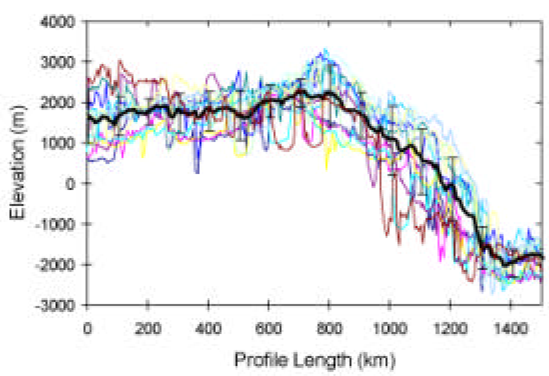

Figure 2. Long wavelength topography of the dichotomy boundary in northern Terra Cimmeria. The black line is the mean of 13 profiles across this 2,100 km segment with ± 1 standard deviation error bars. Vertical exaggeration is ~136:1.

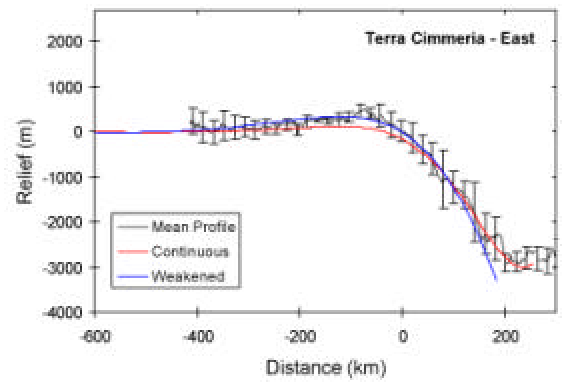

Figure 3. Topographic profile across dichotomy boundary in eastern Terra Cimmeria compared to deflection profiles for a continuous and weakened plate. Topographic profile (black curve) is the mean of the 4 profiles with ±1 standard deviation error bars. Vertical exaggeration is ~85:1.

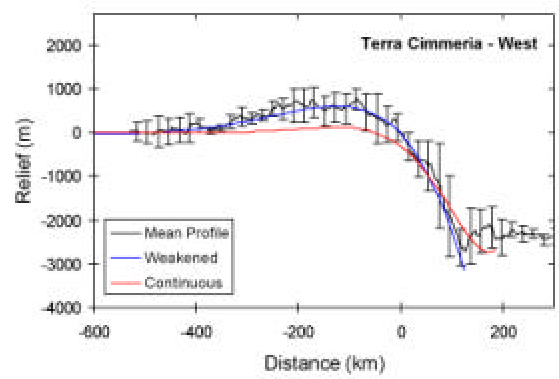

Figure 4. Topographic profile across dichotomy boundary in western Terra Cimmeria compared to deflection profiles for a continuous and weakened plate. Topographic profile (black curve) is the mean of the 7 profiles with ±1 standard deviation error bars. Vertical exaggeration is ~85:1.

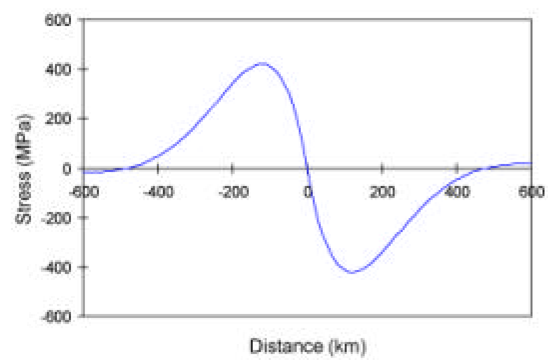

Figure 5. Near-surface fiber stresses due to subcrustal transport of 3.5 km of lowlands crust. Extensional stresses (positive) reach a maximum in the highlands (x<0) and compressional (negative) reach a maximum in the lowlands (x>0).