RELAXATION OF THE MARTIAN CRUSTAL DICHOTOMY BOUNDARY IN THE ISMENIUS REGION. A. Guest and S. E. Smrekar, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA; alice.slancova@jpl.nasa.gov, ssmrekar@jpl.nasa.gov.

Introduction: The origin of the Martian crustal dichotomy remains a puzzle that when solved can provide an insight to the geological and geophysical evolution of Mars. In this study we model crustal relaxation in order to better constrain the original topographic shape, rheology, and temperature of the Martian crust. Our approach is to model the detailed geologic history of the Ismenius region of Mars, including slope, strain, and timing of faulting [1]. This region may contain the best preserved section of the dichotomy boundary as it is relatively unaffected by large impacts and erosion. So far the only study Martian crustal relaxation [2] suggests that the original topographic shape of the dichotomy is preserved. However, in this area strain from faulting implies at least some relaxation [1].

Martian Dichotomy: The Martian dichotomy is a nearly global boundary between the more heavily cratered southern highlands and the smoother northern plains. The difference in elevation is typically 2-4 km. The topographical change occurs over a distance of several 100s km to as much as 1300 km [3, 4]. The boundary is modified in some places by relatively young volcanism, and where unmodified, is transitional or consists of a single scarp or a series of eroded fractures [5]. The Ismenius region seems to be the best-preserved section of the dichotomy boundary. The boundary consists of a steep scarp with an elevation of 2.5 km and a slope 20-23 degrees as well as a series of fractures. Strain across the boundary is at least 3.5% [1]. The location of graben near the plateau rim, the small extensional strain estimates, and the presence of wrinkle ridges in the plains generally parallel to the dichotomy boundary are consistent with models of plateau relaxation [6].

Previous Works: Nimmo and Stevenson [2] modeled relaxation of the Martian dichotomy. They argue that the topographic boundary is not relaxed and that the boundary can be preserved for a crustal thickness of 80 km or less. Their model uses viscous rheology, assumes a dry diabase flow law [7], and compares the predicted topographic relaxation to 10 evenly spaced (excluding Tharsis) profiles across the dichotomy, averaged along track. The focus of their study was on constraining crustal thickness and the amount of crustal heat production.

Model: We present an elasto-visco-plastic finite-element model for the relaxation of the Martian dichotomy boundary. We will explore a range of possible parameters for temperature, crustal thickness, rheological laws and initial geometry as discussed below. The starting model presented here has the following parameters: The highlands in our model (Fig. 1) are 5km higher than the lowlands. Assuming a crustal density of 2900 kg/m3, a mantle density of 3500 kg/m3, we include a 24.17 km thick crustal root below the plateau to produce an isostatic compensation [8]. The width of the dichotomy boundary is 143 km and the average slope, smoothed using a cosine function, is 2 degrees. We use diabase [7] and dunite [9] as a representative for the rheological behaviour of the crust and mantle, respectively. We use a Mohr-Coulomb criterion for plasticity, with cohesion of 14 MPa and friction of 40 degrees. The temeperature in our model is linear from a surface temperature 220K to 1400K (~ 15 K/km) at 69 km. After this depth, the temperature remains constant. The size of our mesh is 2500 km horizontally by 2000 km vertically and contains about 2800 elements. The bottom of the box is fixed, the sides have fixed horizontal displacement and zero vertical shear stress, and the top is a free surface. The initial condition is hydrostatic pressure.

The elasto-visco-plastic models tend to predict greater amounts of relaxation than a purely viscous model [10]. When the viscosity is constant, plastic strains tend to be negligible, as the topographic stresses driving relaxation generally don't exceed the yield stress. As temperature increases with depth, elastic and plastic deformations become more significant – the material at depth becomes more inviscid and less able to support the driving stresses as effectively. Topography does not correspondingly relax, because it sits atop of a cooler, more sluggish surface layer. The plasticity then can have a significant effect.

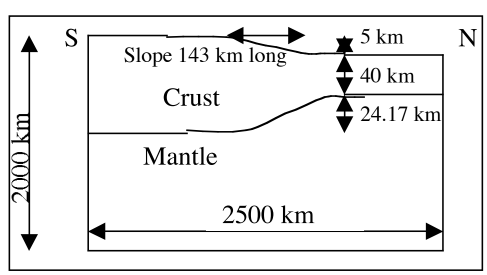

Fig. 1: Sketch of the model. Not to size.

Results: For this set of parameters, our model does not produce any significant relaxation of the topography after 1 Gyr, similarly to the Nimmo and Stevenson [2] model. On the surface, the maximum vertical displacement located around the top of the slope is around 11 m downward, and around the bottom of the slope 15 m upward. The maximum horizontal displacement located in the center of the slope equals 370 m to the north. Such a displacement over 143 km gives about 0.2% of strain, which is less than the observation. All plastic strain is located 100 km south of the plateau rim. Interestingly, there is an unstrained area in the center of the slope, where is never any deviatoric stress.

Even though we used relatively high temperature gradient for our starting model, the model did not predict relaxation of the dichotomy boundary. The primary factor is likely to be the very stiff crustal rheology we have assumed for comparison with past work [2]. In the following we explore the limits of our model parameters.

Parameter Space: Zhong and Zuber [11] and Nunes and Phillips [12] (and others) studied crustal relaxation considering various viscosities of a crust and mantle. They conclude from constant viscosity cases that short wavelength topography features are relaxed in the crust whereas long wavelengths topography features are relaxed in the mantle. In an isoviscous case where viscosity is 10^24 Pas in the crust and mantle, short wavelength features relax faster than the long wavelength features and the resulting shape is smoothed. If viscosity in the crust is 10^24 Pas and in the mantle 10^20 Pas, the original shape is preserved but the plateau height is relaxed. If the viscosity in the crust is 10^26 and more, and whatever value in the mantle, the original shape of the dichotomy will be preserved. Because our crustal viscosity is very high due to a low surface temperature, using a weaker wet crustal rheology may significantly help to relax the dichotomy boundary. The average crustal thickness is still debated and estimates range from 40 to 175 km. The main argument against a thick crust is that the crustal thickness of 100 km could not sustain the inferred low order crustal thickness variations over the planet's history, unless the viscosity of the lower crust was larger than 10^22 Pa s. Crust 50 km thick can be maintained for more than 10^8 years if viscosity is larger than 10^20 Pas [8]. The viscosity of the lower crust is dependent on the temperature in the lower crust during the time of relaxation, and the rheological laws and parameters considered. The temperature distribution in Mars at time of dichotomy formation (4. Gyr-3.5 Gyr ago [2, 5]) is unknown. There are a variety of models calculating the thermal evolution of Mars [13] that give an idea about the mantle temperature, lithosphere and crustal thicknesses in early Mars by relating the creation of the crust mainly to the vigor of mantle convection and to the concentration of the crustal component in the mantle [13]. However, the change of the initial temperature in the mantle about 200 K changes the resulting thicknesses significantly. According to these models, the thermal gradient range in the early lithosphere is 8-20 K/km, with the crustal thicknesses of 40-140 km (thinner crust for higher temperature gradients). The "stagnant lid model" suggests a crustal thickness of 70-140 km at the time of probable dichotomy formation, and the "lithosphere growth model" suggests a thickness of 40 km [13].

Mantle convection models also restrict the variation of temperature gradient with time. The models that have higher temperature gradients in early history of Mars loose the heat faster and the time available for relaxation is shorter. The models with lower temperature gradients may allow for significantly longer relaxation times [13]. Similarly, if there is a plume activity beneath the northern plains [14], the lateral temperature gradient may ease the relaxation of the dichotomy boundary.

Conclusion: More models exploring the possible parameter space are necessary for a better understanding of the crustal rheology and dichotomy modification on Mars. Future models will examine a different surface temperature due to presence of an early atmosphere [15], thicker crust, a wet diabase rheology, and higher thermal gradients, and the time and lateral variations of temperature gradient.

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