

CONSTRAINTS ON EARLY MARS EVOLUTION AND DICHOTOMY ORIGIN FROM RELAXATION MODELING OF DICHOTOMY BOUNDARY IN THE ISMENIUS REGION. A. Guest¹ and S. E. Smrekar¹,

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Introduction: The Martian dichotomy is a global feature separating the northern and southern hemispheres. The 3.5-4 Gyr old feature [1,2] is manifested by a topographic difference of 2-6 km and crustal thickness difference of ~15-30 km between the two hemispheres [3,4,5]. In the Ismenius region, sections of the boundary are characterized by a single scarp with a slope of ~20°-23° and are believed to be among the most well preserved parts of the dichotomy boundary. The origin of the dichotomy is unknown. Endogenic hypotheses do not predict the steep slopes (scarps) of the dichotomy boundary. Exogenic models for forming the northern lowlands by impact cratering, associate the scarps along the dichotomy boundary with craters' rims [6], but are not globally consistent with the topography and gravity [5]. In order to better understand the origin of the Martian dichotomy, it is necessary to know if the steep scarps along the boundary represent the original shape of the dichotomy.

Smrekar et al. [7] presented evidence showing that the boundary scarp in Ismenius is a fault along which the highland crust was down faulted [8]. We test whether the relaxation process could produce faulting along the dichotomy boundary and examine the crustal and mantle conditions that would allow for faulting to occur within 1 Gyr and preserve the long wavelength topography over another 3 Gyr. We approach the problem by a combination of numerical and semi-analytical modeling. We test different viscosity profiles and crustal thicknesses by comparing our modeled magnitude, location and timing of plastic strain and displacements to detailed geologic observations in the Ismenius region.

Previous Works: Nimmo and Stevenson [9] 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 [10], 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.

Numerical Model: We construct a visco-elasto-plastic finite-element model to predict the relaxation of the topography over time. The model is 1500 km wide and 1000 km deep, and consists of two materials, the crust and the mantle. We test two

different crustal thicknesses (35, 80 km) and a plateau elevation 5 km. The width of the dichotomy boundary is 143 km and the average slope, smoothed using a cosine function is 2°. 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 [10]. In the equation, the total strain is defined as a sum of elastic, viscous and plastic strains [11]. We use wet diabase [10] and wet dunite [12] as a representative for the creep strain of the crust and mantle, respectively. We use a Mohr-Coulomb criterion for plasticity, with cohesion of 9 MPa and friction of 40°. The temperature in our model is represented by an error function connecting a surface temperature of 220 K, a temperature 1400 K (assumed to be the base of the lithosphere) at 60 km depth, which gives a thermal gradient of ~20 K/km, and a mantle temperature 1600 K or 2150 K.

Semi-analytical Model: Assuming an incompressible viscous fluid, the equilibrium and constitutive equations can be solved semi-analytically in the frequency domain [13]. The horizontal variations of the stress and velocity are transformed using a FFT allowing us to numerically integrate the equilibrium and constitutive equations only along the vertical axis. The vertical velocity at the surface is then converted to the change of topography over time. The numerical integration allows for variations of viscosity with depth. The viscosity variations are input in the model a priori and represent the effective viscosity in the given depth.

Results: First, we run the finite-element model till relaxation slows significantly, and then we continue the calculations by semi-analytical solution.

The evolution of the topographic relief for a model with 80-km thick crust and 1600 K mantle temperature is shown in Fig. 1. The relaxation is focused into a few hundred km thick belt along the dichotomy boundary. After 30 years the topography changes by 1 km. The plastic strain develops in four locations: 1) 200-300 km south of the dichotomy boundary (tension), 2) 200-300 km north of the boundary (compression), 3) along the bottom of the slope of the boundary (tension) and 4) along the top slope (compression). The model with 35-km thick crust and 1600 K mantle temperature behaves similarly, only relaxation occurs more slowly.

Our semi-analytical solutions match the finite-element solutions assuming a simple two-layered

constant-viscosity profile. Continuation of the finite-element calculations by semi-analytical modeling shows that 80-km thick crust relaxes too fast to preserve the long topographic wavelengths over 3 Gyr, even if cooling of the Martian interior is considered. If we assume plausible cooling rates, the 35-km thick crust will allow the preservation of long wavelengths while relaxing the 300-500 km wavelengths.

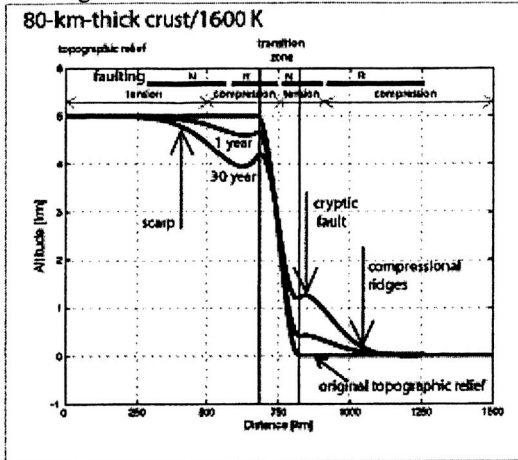


Fig. 1: Topographic relaxation, plastic strain (faulting), and stress distribution on surface of the finite-element model.

In order to preserve the long topographic features (10,000 km) over 3 Gyr and relax the 300-500 km wavelengths within 0.5 Gyr, the contrast of effective viscosity between the upper and lower crust must be 4-6 orders and a lower crustal channel of 10 km thickness must develop. The viscosity of the lower crust of 10^{19} Pa s for 35-km thick crust, or 10^{21} Pa s for 80-km thick crust, averaged over 30 Myr, (Fig. 2) provides a reasonable viscosity estimate that satisfies both criteria. The viscosity is one order higher if we average over 300 Myr time. If cooling rates are taken into account, lower viscosities will be allowed.

Conclusion: Our finite-element model predicts relaxation of the topography within several hundreds km along the dichotomy boundary. The relaxation, and the faulting associated with the relaxation, matches the geologic observations in the Ismenius region. The faulting, located 200-300 km south from top slope of the boundary, probably results in a steep scarp. Thus relaxation of a gently sloped boundary, as predicted by many formation models [14] can result in the steep slopes observed in many areas today. The deformation of the boundary is dependent on the lower crustal rheology, which is dependent on the crustal thickness and temperature. From our finite-element modeling, the temperature gradients of 20 K/km 4 Gyr ago provides the best fit to the

geologic observations. This gradient is consistent with those inferred from elastic thickness estimates [15].

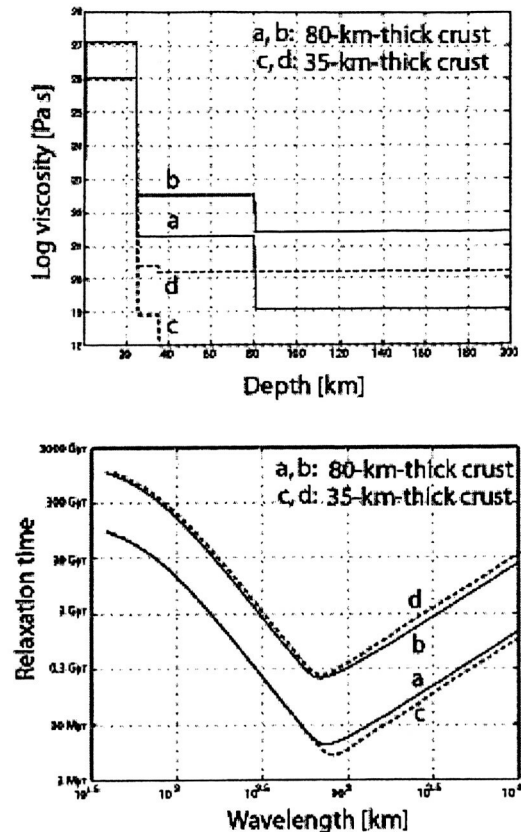


Fig. 2: The viscosity profiles (top) and relaxation curves (bottom) that will preserve 10,000 km features over 3 Gyr and relax 300-500 km features in 0.5 Gyr. Curves a and c average viscosity over time 30 Myr, curves b and d average viscosity over 300 Myr.

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