CRUSTAL RELAXATION AND ITS IMPLICATIONS FOR THE MARTIAN CRUSTAL DICHOTOMY. James H. Roberts, *Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder CO 80309-0391, USA, (jhr@anquetil.colorado.edu)*, Shijie Zhong, *Department of Physics, University of Colorado, Boulder CO 80309-0390, USA, (szhong@spice.colorado.edu)*.

Introduction

The crustal dichotomy is one of the oldest features on Mars [1,2]. Both exogenic [3,4] and endogenic models [5] have been proposed to explain the origin of this feature. We propose that regardless of the formation mechanism, convective forces may be required to maintain the dichotomy over geologic time.

Studies from MGS topography and gravity data suggest that the crust must be at least 50 km thick on average [6]. The crustal dichotomy appears to have formed during the early Noachian [2], when the planet was still relatively hot and the elastic layer was substantially thinner [7,8]. The warm lower crust would have been able to flow. Stress relaxation studies suggest that the topography may relax relatively quickly in the absence of a degree-1 mantle convective force [9-11], and would remove the pole-to-pole variation seen on Mars.

Crustal Temperature and Viscosity

The rate at which the crustal topography relaxes is highly dependent upon the crustal viscosity, which is largely controlled by the temperature within the crust. Assuming heat is transferred conductively through the crust, we solve for the vertical temperature profile of the crust. We assume a surface temperature of 220 K and a bulk heating rate of 2.4*10^{-11} W/kg [12], and that half of the radiogenic elements are in the 50 km thick crust [13]. Our lower boundary condition is the heat flux from the mantle. The minimum heat flux from the mantle should equal that required to remove the heat produced by radioactive decay. For our internal heating rate and distribution, a minimum of 44 mW/m^2 must flow out of the mantle (Fig. 1, black curve). For secular cooling of the core and mantle, the moho heat flux should be higher (Fig. 1, red and green curves).

The crust may of course, be thicker than this geophysically determined minimum [6,10]. We therefore deveoped a set of thermal profiles for a 70 km thick crust. Conduction of heat is slower across a thicker layer. The moho temperatures increase for a thicker crust. A 70 km thick crust requires a minimum moho temperature of 1800 K compared to 1300 K for a 50 km crust. The distribution of radioactive heating will control the thermal structure of the crust. While the fraction of radioactive elements in the crust is not well known, it may be as high as 75%, especially if the crust is thick [13]. A smaller quantity of heating in the mantle drops the minimum moho heat flux to only 22 mW/m^2. For a 50 km thick crust, the moho temperature may be as low as 1150 K.

The strength of the upper crust is controlled by Byerlee's law. For the lower crust, we assume a diabase rheology, with a reference strain rate of 10^{-15} s^{-1} [14]. Using the temperature profile from Fig. 1 we determined the crustal viscosity profile for both a wet and a dry crust (Fig. 2).

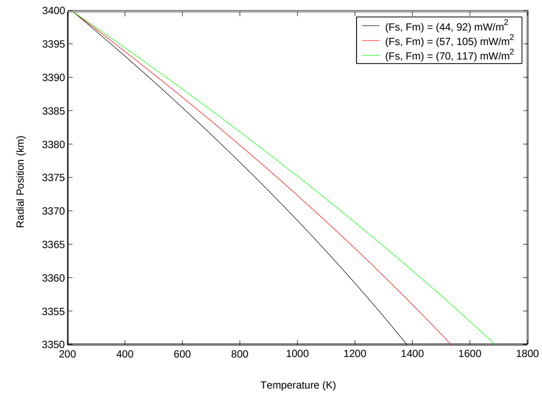

Figure 1: Heat conduction profiles through a 50 km thick crust. Values are given for the surface and moho heat flux. The bulk heating rate is 2.4*10^{-11} W/kg and half of the heating is in the crust.

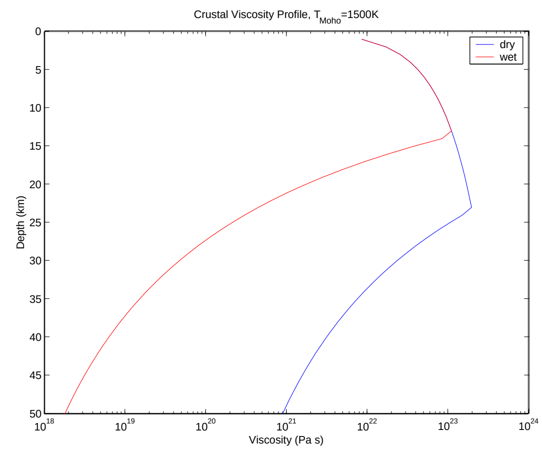

Figure 2: Crustal Viscosity profile for the case when Fm=105 W/m^2. The presence of water is expected to weaken the crust by a factor of 50.

Viscoelastic Relaxation

Assuming a wet rheology (the likely case for Mars), the viscosity in the lower crust may be less than 10^{19} Pa s. A crust with such low viscosity can flow quite easily. Using a propagator matrix method [8], we imposed a topographic load upon the crust, which lay over a mantle with a viscosity of 10^{19} Pa s. When the crustal viscosity is 10^{19} Pa s, we find that the topography relaxes very quickly. Longer wavelengths will survive for longer times, but even the degree-1 component has largely relaxed within a few hundred Myr (Fig. 3), which is the characteristic time (Fig. 4). The characteristic times for

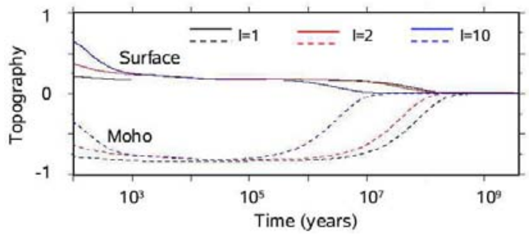

Figure 3: Evolution of the surface and moho topography over time. η_{lower}=10^{19} Pa s, η_{upper}=10^{23} Pa s

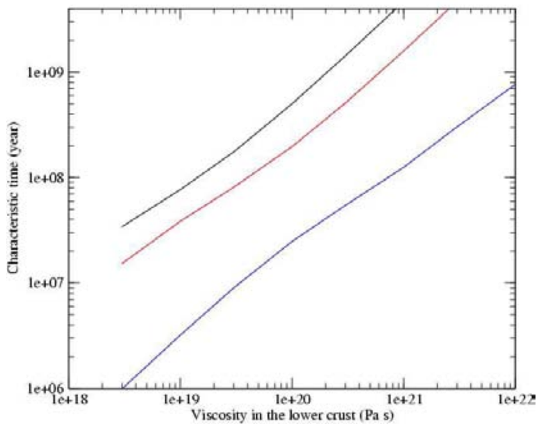

Figure 4: Characteristic times for degrees 1 (black), 2 (red), and 10 (blue) as a function of crustal viscosity.

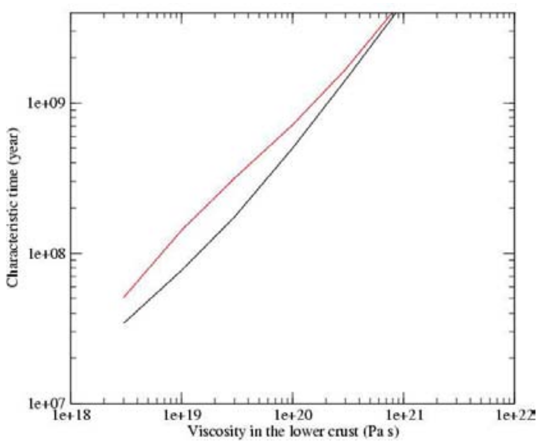

Figure 5: Degree-1 characteristic time for mantle viscosity of 10^{19} Pa s (black) and 10^{20} Pa s (red) as a function of crustal viscosity.

shorter wavelengths are even shorter; a higher crustal viscosity will be needed to maintain those.

The viscosity of the mantle have some effect on the relaxation time if the lower crust is weak. However, increasing the mantle viscosity by a factor of 10 increases the characteristic time by less than a factor of 2 (Fig. 5). The characteristic time is thus largely insensitive to the mantle viscosity. The crustal viscosity is a much stronger control. It is difficult to maintain the crustal dichotomy over geologic time when the crustal viscosity is less than about 3*10^{19} Pa s.

Discussions

Given a relatively thick crust (50-70 km), topography created in the early Noachian would have largely relaxed within a few hundred Myr. Whether the crustal dichotomy was produced by exogenic or endogenic processes, it could not have survived to the present day unless some continuous force was in place to support it dynamically during the Noachian. Once the lithosphere had thickened, it could support the dichotomy elastically.

Degree-1 mantle convection can provide the forces necessary to support the crustal dichotomy dynamically [15,16]. The inclusion of layering in the viscosity profile to lower the viscosity of the upper mantle by a moderate amount, causes a degree-1 convective pattern to develop under a range of rheology [16]. Since convection appears to be necessary for the maintenance of the dichotomy it is the likeliest mechanism to explain the origin of the dichotomy as well.

References

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