CONSTRAINING VISCOSITY LAYERING ON MARS USING GEOID AND TOPOGRAPHY FROM MANTLE CONVECTION MODELS. Pavithra Sekhar[1] and Scott D. King[2], Virginia Polytechnic Institute and State University (4044 Derring hall (0420), Blacksburg, VA 24061; pav06@vt.edu[1]; sdk@vt.edu[2]).

Introduction: A number of studies have used gravity and topography to understand the Martian lithosphere [1-3] and determine crustal thickness [4]. Mars Orbiter Laser Altimeter (MOLA) [5] and Mars Global Surveyor (MGS) [6] provide global topographic and gravity data which can be used to study the interior and thermal evolution of Mars. The gravity and topographic data from Mars Global Surveyor showed that the present day crustal thickness is approximately 50-120 km [4]. The Martian areoid (geoid) is dominated by two large highs, one over Tharsis and the other approximately 180 degrees away [6]. The most prominent long-wavelength topographic structures are due to the Tharsis Rise and the crustal dichotomy [7], where the Tharsis rise may be associated with a deeper mantle component [8-9]. According to Kiefer et al. [9], a significant fraction of the topography and geoid, up to spherical harmonic degree 10, is supported by mantle convection. Kiefer et al. [9] specifically note that degrees 2 through 4 of the geoid and topography are inconsistent with a model that requires deep mantle structure. The anti-Tharsis geoid high may be due to elastic deformation of the crust, which in turn may be due to the load created by Tharsis [10] as expected by the topographic loading on a spherical elastic shell [11]. While Martian surface topography is dominated by the hemispherical dichotomy and Tharsis rise [12] by construction, gravity models have no degree 1 component. Due to the non-uniqueness of gravity, there is a tradeoff between Moho topography and internal structure of the mantle.

Modeling: In this work, mantle convection simulations are performed using finite element program CitcomS [13-15] to model thermal convection calculations in a 3D spherical shell. The numerical model consists of a global mesh with 12 caps in full spherical mode. Thermal convection models are governed by equation of conservation of mass, energy and momentum. The computation work was carried out on HESS (for High – performance Earth System Simulator), a powerful supercomputers at Virginia Tech, using 216 cores. The calculations in this work are performed in a 3D spherical shell with a cold free-slip upper boundary and a free-slip core mantle boundary. We use time-dependent, stagnant lid, incompressible convection calculations with a temperature-dependent Newtonian rheology based on the creep properties of olivine [16] and a layered viscosity structure that includes a viscosity increase by a factor of 8 and 25 at a depth of 996 km [17]. This depth corresponds to the pressure of the phase transition between olivine and spinel and the pressure at which a viscosity increase on Earth is needed to explain the long wavelength geoid [18]. Due to the lower gravity Mars, this phase transition occurs in the mid-mantle in comparison to the upper mantle on Earth. Hence a viscosity jump might be expected at this depth [17].

Results: We have compiled numerous temperature-dependent viscosity calculations using different radial viscosity structures including both uniform viscosity with depth and layered viscosity cases. We also have decaying radiogenic heat sources implemented in our calculations.

In the calculations with a uniform viscosity with depth there is a strong drop in the power spectrum of the geoid for low harmonics ($l < 5$) and a clear flattening for the higher harmonics. On the other hand, in the calculations with a layered viscosity structure there is less steep drop in the power spectrum for the low harmonics and the power appears to drop almost linearly even for higher harmonics.

For calculations with varying Rayleigh number, a lower Rayleigh number ($Ra < 10^7$) produces the maximum geoid for low harmonics and the geoid contribution continues to be large for higher harmonics as well. As we increase the Rayleigh number, the geoid becomes smaller. The Rayleigh number reported here is based on the planetary radius, and not on mantle depth, consistent with the scaling used in CitcomS.

For low Rayleigh numbers, not only is the mantle geoid unacceptably large, the mean mantle temperature is very high producing widespread and extensive melting, observed from our previous study [19]. The amount of melt produced depends on the thickness of the stagnant lid and the average mantle temperature [19].

In the case of decaying heat sources, the effect of internal heat produces a flat geoid spectrum for lower harmonics ($l < 7$). Varying the partitioning of radiogenic elements between the mantle and the crust produces a very small variation in geoid calculation for lower harmonics.

Kiefer et al. [9] showed that degrees 3 and 4 of the Martian geoid and topography are not well correlated with topography and go on to show that these are consistent with the deep mantle structure. The poor correlation between topography and geoid for degrees 3 and

4 remains the case in the most recent gravity and planetary shape models for Mars.

Discussion: There is a significant power in the long-wavelength geoid harmonics for calculations with no increase in viscosity with depth. This would indicate that a significant fraction of the observed geoid of Mars is due to internal mantle structure and is inconsistent with previous investigations of gravity and topography of Mars [e.g., 4]. However, for calculations with a viscosity jump of either 8 or 25 in the lower mantle, there is a continuous drop in power continuing for short wavelengths (l< 20) and the geoid due to internal mantle convection beyond degree 10 is small. We observe that a significant fraction of the topography and geoid, up to spherical harmonic degree 10, may be supported by mantle convection, consistent with Kiefer et al [9].

On Earth, the slope of the power spectrum as a function of spherical harmonic degree, l, or Kaula's law, has been used to constrain mantle structure. Following Kaula's rule of thumb [20], the slope for low degree harmonics (l< 5) depends on the viscosity of the lower mantle and this provides a constraint on viscosity layering of the lower mantle.

References:

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