MAGMATIC EVOLUTION OF IMPACT INDUCED MARTIAN MANTLE PLUMES AND THE ORIGIN OF THARSIS.
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Introduction. Tharsis is one of the most prominent features on Mars. Volcanism and tectonism associated with the plateau by far exceed the levels of activity in other areas of the planet. This monopolar distribution of tectonism and volcanism led to the suggestion that the planform of mantle convection on Mars is dominated by a single, long-lived, thermal plume originating at the core-mantle boundary similar to a terrestrial plume but much larger [1].

Although the plume model explains some features of Tharsis, there are both observational and theoretical reasons to consider alternatives. First, the plume model has not reproduced Tharsis development on timescales consistent with observations [2]. Second, constructional volcanism seems to be a major contributor to Tharsis elevation [3]. A thermal plume contributes only a fraction to the present-day topography and areoid [4]. Third, the plume hypothesis implies an actively convecting mantle and a sufficiently large heat flux from the Martian core. However, in the absence of plate tectonics, convection in the Martian mantle is likely to be sluggish or absent [5] and mantle heating shuts off any core heat flux and associated plume activity [6]. Finally, large variations in Sm/Nd and Lu/Hf ratios among shergottites suggest a heterogeneous mantle which retains an isotopic signal of initial differentiation [7]. This also argues against vigorous convective mixing.

An alternative hypothesis is that Tharsis could be associated with a large impact early in Martian history. Geodynamical consequences of this hypothesis were investigated in [5]. It was shown that impact-induced plumes can survive for the entirety of planetary evolution and can contribute to the present-day areoid. Production of Tharsis by such a long-lived, impact-related plume requires neither globally occurring convection nor generation of plumes at the core-mantle boundary. In the present study, we explore if this hypothesis can also explain the magmatic evolution of Tharsis.

Model. To model evolution of impact-induced thermal and compositional heterogeneity we use the spherical shell code TERRA in which compositional information is carried by particles. The region heated by the impact shock wave, isostatic adjustment, and core formation is assumed to be hemispherical with radius R left as a model parameter. Heating is assumed to be uniform with ΔT = 300 K while upper mantle temperatures quickly drop to the solidus temperature. Because any core heat flux was probably short lived the bottom boundary is assumed to be insulating throughout evolution. Melting results in a decrease of residual mantle density and an associated compositional buoyancy. Exponential temperature-dependent viscosity is considered.

Results and discussion. Initial, localized upwelling results in decompression melting and additional depletion buoyancy producing an extended period of magmatism the duration of which depends on interior mantle viscosity (Fig. 1). Depleted material spreads out at the bottom of the viscous lid. For all cases, melt production decays with time from an initial maximum to very low levels. As interior viscosity decreases, the decay rate and total melt volume decrease and increase, respectively. In all cases, widespread volcanism is suppressed by lid thickening, and volcanism is concentrated in the thermochemical plume region. For low interior viscosities, there are two spatial scales in the distribution. The outer scale is that of the impact plume. The inner scale is associated with localized, small scale convection within the plume.

The quantity of melt generated by large impacts can be sufficient to obliterate evidence of the initial crater. Scaling laws suggest that the ratio of crater volume to retained melt volume produced by the initial impact shock wave increases with transient crater radius For Mars, the ratio reaches ~ 1 when the transient crater radius is $\sim$ 2000 km. If it is assumed that the initial thermochemical anomaly region corresponds to shock wave pressure $\geq$ 50 GPa (corresponding to $\sim$ 20 % partial melting at the boundary if molten silicate entropy scales linearly with melt fraction) then for initial anomaly radius on the order of half the mantle thickness, $R \sim \Delta r/2$, the initial retained melt volume is $\sim$ 1/2 the crater volume. Additional melt volume produced during the extended period of magmatism can result in a total melt volume (initial shock melting plus extended decompression melting) equal to the crater volume if the interior viscosity is sufficiently low. For $R \sim \Delta r$, the initial retained melt volume $\sim$ crater volume. In this case, additional decompression melting associated with the impact plume can result in volcanic construction.

The topography and material contained within a depression due to Tharsis loading and lithospheric flexure correspond to $\sim 3 \times 10^8$ km^3 of igneous material [8]. While the $R \sim \Delta r/2$ case is only capable of producing a total melt volume $\sim$ initial crater volume, for $R \sim \Delta r$, all of the melt produced subsequent to initial shock melting is available for igneous construction. Decompression melt volumes for interior viscosities $\eta_i \leq 10^{22}$ are on the order of the observed volume of Tharsis igneous material. The duration of large scale melting for all cases is < 1 Gyr which is approximately the time by which Tharsis was emplaced [8].

References. 1. Harder, H., and U.R. Christensen, *Nature, 380*, 507-509, 1996. 2. Zuber, M. T., *Nature, 412,* 220-227, 2001. 3. Solomon, S. C., and J. W. Head, *J. Geophys. Res., 82*, 9755-9774, 1982. 4. Zhong, S., and J. H. Roberts, *Earth Planet. Sci. Lett., 214*, 1-9, 2003. 5. Reese, C. C., et al., *J. Geophys. Res., 107,* 10.1029/2000JE001474, 2002. 6. Nimmo, F., and D. Stevenson, *J. Geophys. Res., 105,* 11969-11979, 2000. 7. Albarède, F., et al., *Nature, 404*, 488-490, 2000. 8. Phillips, R. J., et al., *Science, 291,* 2587-2591, 2001.

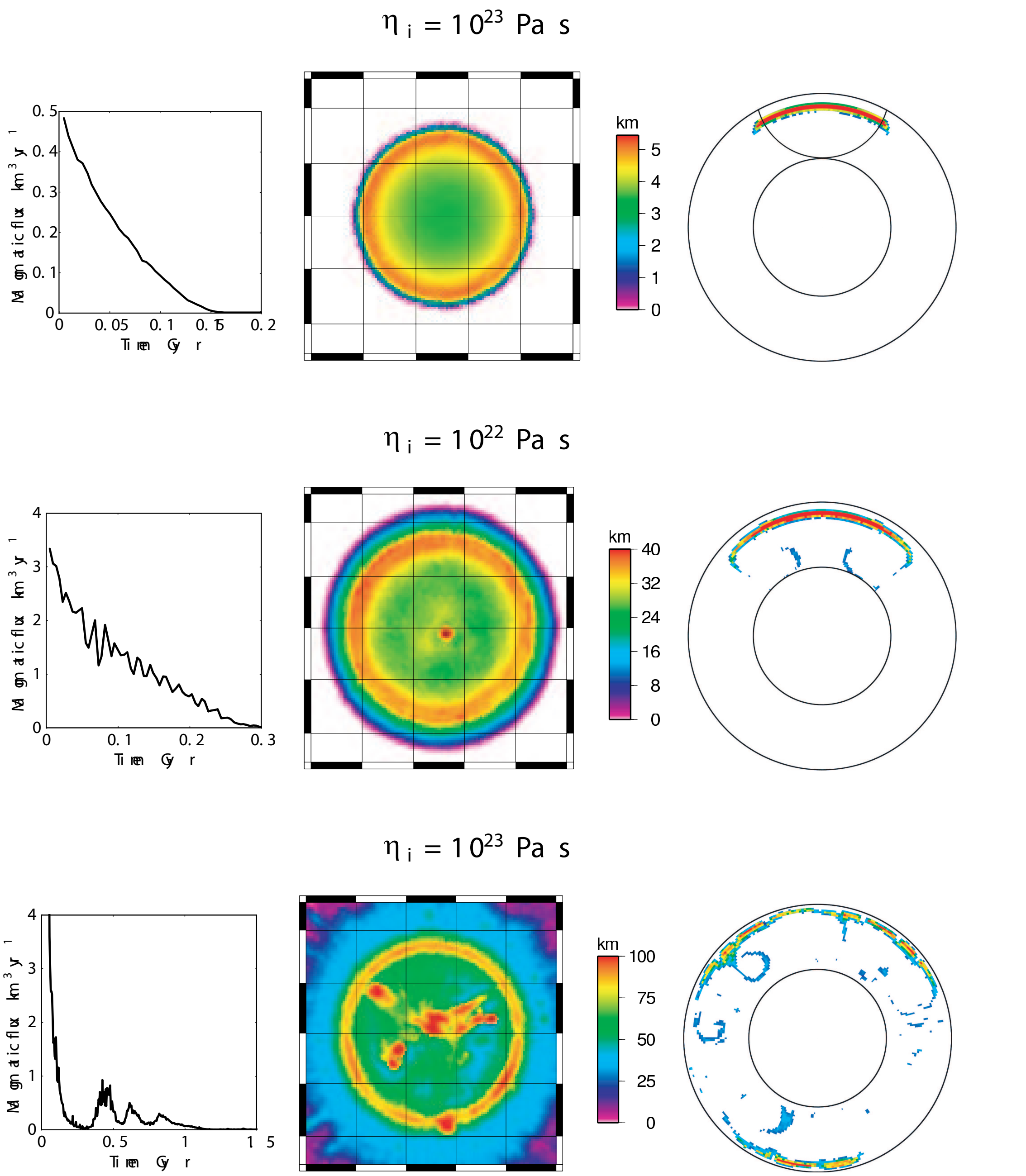

Figure 1: Magmatic evolution of impact-induced thermochemical anomalies for the case R = 1500 km. Total magmatic rate as a function of time (left). Cumulative spatial distribution of magmatism (center). Final distribution of depleted mantle material along a cross section passing through the hemispherical anomaly axis (right). Color (white through red) indicates degree of depletion and the solid line indicates the initial radius of the hemispherical anomaly.