EPSC Abstracts,
Vol. 4, EPSC2009-393, 2009
European Planetary Science Congress,


# A possible internal origin of the Martian crustal dichotomy and Tharsis: New insights from numerical modelling of mantle convection and crust formation

T. Keller and P. J. Tackley

Institute of Geophysics, ETH Zurich, Switzerland (keller@erdw.ethz.ch)

## Introduction

The Martian crust displays two equally stunning features: the crustal dichotomy expressed as a contrast in elevation, crustal thickness and surface age between the northern and the southern hemisphere, and Tharsis, the massive crustal pile of volcanic origin located at the dichotomy boundary. In order to find a possible explanation for both of these features, a number of recent papers have examined the effect of layered viscosity on the evolution of a degree-1 mantle convection, e.g. [1] and [2]. It was found that a mid-mantle viscosity jump in the Martian mantle, combined with highly temperature- and depth-dependent viscosity, are effective in developing a degree-1 convection within 200-300 Million years of core formation. Such a layered viscosity profile could be justified by Martian mineralogy, where both the olivine to spinel and garnet/pyroxene to majorite transitions occur below a mantle depth of 1000 km. All of these high-pressure mineral phases show higher strength than their corresponding upper mantle phases and thus a higher viscosity might be expected [3]. Only recently, it was possible to demonstrate the actual effect of a low-degree convective planform on the crustal thickness distribution by means of numerical modelling [4]. These first results indicate that a significantly thicker crust due to enhanced crustal production would form above the hemisphere of mantle upwelling. Thus, the evolution of low-degree mantle convection inside the planet Mars is reflected on its surface in terms of its low-degree crustal thickness distribution. The general shape of the dichotomy, however, is not symmetrically hemispherical. A simple one-plume origin for the dichotomy is therefore not adequate, as it would produce a spherical patch of thick crust instead of the elongated, roughly elliptical shape of the dichotomy. Another convective planform, however, satisfies the constraints of an elongated upwelling geometry. In numerical models using realistic Mars-like parameters, a so-called one-ridge convection, where a hemispherical ridge-shaped upwelling evolves, can be established already as early as 150 Myr after core formation and is thereafter sustained over several hundred Myr.

## Method

This study involves full planet-scale modelling of the crustal patterns produced by 3D-spherical models of Martian mantle convection. All results are computed using the finite-volume multigrid code StagYY [5]. By using tracer particles to track composition, a self-consistent treatment modelling melting and chemical differentiation has been added to models of thermal convection. This allows us to obtain model maps of the crustal thickness distribution as it evolves with time on the whole planetary surface due to underlying convection patterns. To obtain rapid reduction of convective degree, a strongly depth- and temperature-dependent rheology is applied with additional viscosity jumps at each mineralogical phase transition. This is to reflect the increased strength of the Martian lower mantle mineral phases like wadsleyite, ringwoodite and majorite.

## Results and Discussion

Due to expensive computational costs (3.5 Million gridpoints, 50 Million tracer particles), the parameter range for this study is kept rather narrow. The results of the model runs display a number of consistent features appearing over the examined range of Rayleigh numbers (3.0e+7 to 9.0e+7) and initial temperatures (1500 K to 1700 K). The results indicate that the initially random convection geometry rapidly (<200 Myr) evolves into a pattern of very low degree. The obtained convective planform is not of spherically symmetrical one-plume geometry (l = 1), but rather like what we call one-ridge convection where the upwelling has the form of a ridge-shaped feature covering a variable angle around the CMB. A closer look at this feature reveals that it consists of two plumes at each end, interlinked by a sheet-like upwelling region of lower intensity. Thus, it represents a stable transition state between l = 1 and l = 2 convection. Additionally, differencial rotation of the upwelling feature against the lithosphere can lead to a situation, where the location of the center of magmatic acitivities shifts towards the boundary of older crustal patches. This behavior has recently been described by [6] and offers a possible combined origin

EPSC Abstracts,
Vol. 4, EPSC2009-393, 2009
European Planetary Science Congress,


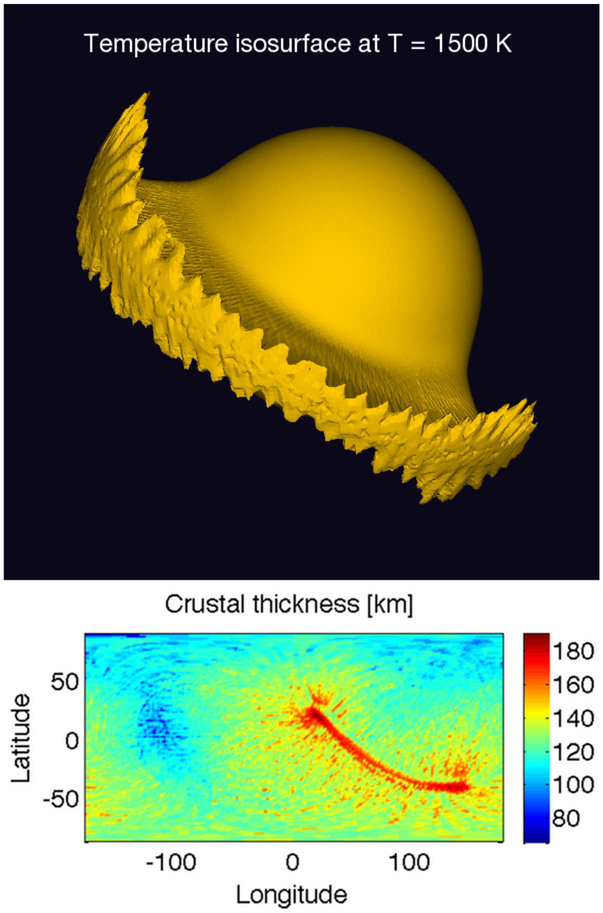


Figure 1: Best fit model at the age of 1 Gyr in model time. Temperature isosurface at 1500 K is shown on top and below, the corresponding crustal thickness map. The shape of the one-ridge upwelling is reflected on the surface as region of thickest crust.

of both the dichotomy and Tharsis from the same kind of mantle feature but resulting from subsequent stages of its evolution. Most melt in our model runs is generated above the major ridge-shaped upwelling region and thus crustal thickness distribution reflects to a first order the large-scale upwelling pattern in the mantle. Additional melting occurs where small-scale convection occurs underneath the rigid lid. Due to this effect, the hemisphere of downwelling is covered by crust as well, but it is remarkably thinner than above major upwellings. Most of the crustal production in our models takes place during the first 1 Gyr, thus satisfying the constraints given by surface stratigraphy on Mars [7]. To analyze the crustal structure of our model runs, we compare histograms of crustal thickness distribution to a model Martian crust obtained by inverting Mars Orbiter Laser Altimetry (MOLA) topography and gravity data collected by the Mars Global Surveyor spacecraft [8]. We find that the relative crust distribution of our best fit model still shows intriguing similarity to the MOLA model.

**Conclusions**

Although many questions still remain, the obtained results demonstrate that it is indeed possible to form a crustal dichotomy as a consequence of very low degree (l=1 to l=2) mantle convection very early in the planet's history and, furthermore, that some of the observed patterns also show intriguing first order similarities to the general non-spherical shape of the Martian dichotomy. In all of our models, the region of thick crust comes to be located over the region of mantle upwelling, whereas crustal thinning above upwellings seems to be a minor effect. The region of upwelling itself proves not to be strictly hemispherical, but is rather a ridge-like structure spread over more or less one half of the planets body. Differential rotation of the upwelling region against the lithosphere leads to a relocation of the main magmatic center towards the boundary of previously produced patches of thick crust, reminiscent of the location of Tharsis relative to the dichotomy. This study demonstrates how important it is to model closely linked processes like thermal convection and magmatism in an integrative and self-consistent way to gain more insight into terrestrial planetary evolution. Furthermore, the timeframe of these processes only shortly after core formation renders it necessary to investigate the thermal initial condition resulting from terrestrial planetary differentiation, an issue that is currently subject of ongoing research.

**References**

[1] Roberts, J. H. and Zhong, Sh. (2006) JGR, 111 (E06013).

[2] Yoshida, M. and Kageyama, A. (2006) JGR, 111 (B03412).

[3] Meade, Ch. and Jeanloz, R. (1990) Nature, 348, pp. 533-535.

[4] Keller, T. and Tackley, P. J. (2009) Icarus, in press.

[5] Tackley, P. J. (2008) PEPI, 171 (1-4), pp .7-18.

[6] Zhong, S. (2009) Nature Geosci., 2, pp. 19-23.

[7] Werner, S. C. (2009) Icarus, 201, pp. 44-68.

[8] Neumann, G. A. et al. (2004) JGR, 109 (E08002).