EPSC Abstracts
Vol. 13, EPSC-DPS2019-1447-2, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Global Thermochemical Convection after Mars' Giant Impact: Numerical Models

Kar-Wai Cheng (1), Antoine B. Rozel (1), Gregor J. Golabek (2), Harry Ballantyne (3), Martin Jutzi (3), Paul Tackley (1)
(1) ETH Zürich, Switzerland, (2) University of Bayreuth, Germany, (3) University of Bern, Switzerland
(karwai.cheng@erdw.ethz.ch)

Abstract

To investigate the formation of the martian crustal dichotomy and its possible link to Tharsis volcanic region, several sets of numerical simulations are presented. They mainly focus on the effect of various melt and crustal production parameters on the long-term mantle convection subsequent to a giant impact. Diagnostics comparable to observational data including topography, crustal thickness and surface heat flux are computed.

1. Introduction

The crustal dichotomy is one of the most prominent characteristics of Mars, featuring a ≈5.5 km contrast in topography and ≈25 km difference in crustal thickness between the southern highlands and the northern lowlands [1], and is thought to have formed within the first 400-500 Myr of martian history [2]. However, it remains unclear how the dichotomy was formed. While some workers suggested an excavation of crust in the northern hemisphere by a giant impact forming the Borealis basin [3], others suggested that impact-induced melting and subsequent crustal production creates the highlands in the southern hemisphere [7, 8].

On the other hand, the Tharsis volcanic region is another dominating feature, and is emplaced throughout late Noachian and early Hesperian period [2]. Numerous models suggest a degree 1 upwelling to explain Tharsis volcanism, involving an endogenic origin where a viscosity jump in mid-mantle facilitates the formation of such an upwelling [5, 6], and the presence of a thick and radiogenically enriched crust on one side of the planet that attracts and gathers plumes into a single upwelling [8, 10].

Several studies suggested the linkage between the crustal dichotomy and the emplacement of Tharsis [4, 8, 10]. Here we investigate the feasibility of creating both a crustal dichotomy and a long-lived volcanic region as the consequence of a single giant impact using thermochemical models.

2. Methods

We use the thermochemical convection code StagYY [11] in 2D spherical annulus and axisymmetric geometry. Phase changes relevant to Mars and temperature- and pressure-dependent viscosity are considered.

A parametrized impact is imposed as a thermal anomaly, whose size and amplitude follow standard methods of impact scaling [12]. Melting of silicates causes compositional buoyancy and can affect geodynamic processes, and therefore related parameter, such as melt densities, are systematically studied.

The presence of crust in Mars' early geological history already at ≈4.547 Ga was suggested [13]. To account for this, primordial crust of various extent and thickness is imposed at the beginning of the simulation. Heat producing elements are preferentially partitioned into the crust, leaving the mantle relatively depleted.

3. Results

Initial models show that compositional buoyancy of melt causes the impact induced magma pond to rise and spread, forming a degree 1 convection pattern for at least 1 Gyr after the impact (Fig. 1a). During this time crust production occurs preferentially at the impact side and spreads to the whole surface of the planet as a higher degree convection pattern develops (Fig. 1b).

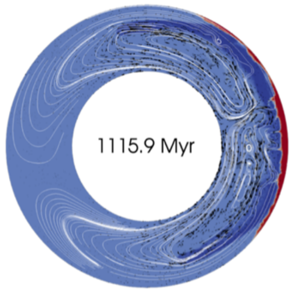

Fig. 1a: Compositional field at ≈1.11 Byr after the imposed impact. Red - basalt, dark blue - depleted harzburgite, light blue - pyrolite. Overlaid by velocity field as black arrows and streamlines in white. Crust production preferentially at impact side (on the right), with a degree 1 convective pattern.

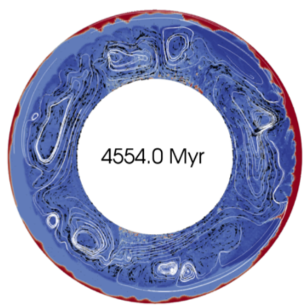

Fig. 1b: Compositional field at ≈4.55 Byr. Crust production observed on non-impact side, on top of high degree convection cells.

Additional simulations with varying melt density and rheology, and primordial crust of different extents will be presented.

4. Future work

Smoothed particle hydrodynamics (SPH) simulations can give insights into different impact scenarios [9], other than the less likely head-on collisions considered here. Results from SPH models will be used as initial conditions for long-term thermochemical evolution of Martian mantle to study the preservation and evolution of impact signatures.

Acknowledgements

This project is supported by the Swiss National Science Foundation under grant 200021_175630.

References

[1] Watters, T., McGovern, P., & Irwin III, R. (2007). Hemispheres Apart: The Crustal Dichotomy on Mars. *Annual Review Of Earth And Planetary Sciences*, *35*(1), 621-652.

[2] Taylor, S., & McLennan, S. (2009). *Planetary crusts*. Cambridge, UK: Cambridge University Press.

[3] Andrews-Hanna, J., Zuber, M., & Banerdt, W. (2008). The Borealis basin and the origin of the martian crustal dichotomy. *Nature*, *453*(7199), 1212-1215.

[4] Zhong, S. (2008). Migration of Tharsis volcanism on Mars caused by differential rotation of the lithosphere. *Nature Geoscience*, *2*(1), 19-23.

[5] Keller, T., & Tackley, P. (2009). Towards self-consistent modeling of the martian dichotomy: The influence of one-ridge convection on crustal thickness distribution. *Icarus*, *202*(2), 429-443.

[6] Roberts, J., & Zhong, S. (2006). Degree-1 convection in the Martian mantle and the origin of the hemispheric dichotomy. *Journal Of Geophysical Research*, *111*(E6).

[7] Reese, C., Orth, C., & Solomatov, V. (2011). Impact megadomes and the origin of the martian crustal dichotomy. *Icarus*, *213*(2), 433-442.

[8] Golabek, G., Keller, T., Gerya, T., Zhu, G., Tackley, P., & Connolly, J. (2011). Origin of the martian dichotomy and Tharsis from a giant impact causing massive magmatism. *Icarus*, *215*(1), 346-357.

[9] Golabek, G., Emsenhuber, A., Jutzi, M., Asphaug, E., & Gerya, T. (2018). Coupling SPH and thermochemical models of planets: Methodology and example of a Mars-sized body. *Icarus*, *301*, 235-246.

[10] Citron, R., Manga, M., & Tan, E. (2018). A hybrid origin of the Martian crustal dichotomy: Degree-1 convection antipodal to a giant impact. *Earth And Planetary Science Letters*, *491*, 58-66.

[11] Tackley, P. (2008). Modelling compressible mantle convection with large viscosity contrasts in a three-dimensional spherical shell using the yin-yang grid. *Physics Of The Earth And Planetary Interiors*, *171*(1-4), 7-18.

[12] Monteux, J., Coltice, N., Dubuffet, F., & Ricard, Y. (2007). Thermo-mechanical adjustment after impacts during planetary growth. *Geophysical Research Letters*, *34*(24).

[13] Bouvier, L., Costa, M., Connelly, J., Jensen, N., Wielandt, D., & Storey, M. et al. (2018). Evidence for extremely rapid magma ocean crystallization and crust formation on Mars. *Nature*, *558*(7711), 586-589.