BASIN-FORMING IMPACTS ON MARS: CONSEQUENCES ON MANTLE DYNAMICS

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Introduction: The existence of large impact basins testify to giant collision events on all planetary objects. Besides the surficial remnants of such events giant collisions may have also affected the thermodynamic evolution of the planets. Shock waves generated by basin forming impacts are strong enough to travel through the whole planet and deposit a significant amount of heat deep in the planetary interior. It has been suggested that the heat input as a consequence of the formation of large basins, such as Hellas and Argyre on Mars, may have significantly affected mantle and core convection processes, plate tectonic, volcanism, and the generation of an intrinsic magnetic field of planets [1-6]. In this study we combine numerical models of the impact process using the iSALE-3D hydrocode coupled with ANEOS [7,8] and the 2D/3D mantle convection code GAIA [6,9] to quantify the impact-induced heat input and model the long time consequences regarding mantle convection. We focus on a Mars-like planet as target and impactors in a size range of about 200 km and impact angles between 10° and 90° and an impact velocity of 15 km/s. For the mantle convection models we assume an olivine silicate mantle and treat the beginning of thermal evolution of Mars by employing Earth-like parameters for rheology and internal heat sources. The aim of this study is to systematically investigate the long time consequences of asteroid impacts on the Martian interior and constrain impact energies required to sustainably change Martian mantle convection processes.

Shock heating: The temperature rise as a result of shock compression and unloading can be calculated from the peak pressure the material was exposed to and specific material properties [e.g. 10-12]. We use tracer particles to record the peak shock pressure in our simulations and work out the heat input subsequently. When calculating the temperature rise from peak shock pressure it is important to account for phase transitions the material experiences during shock compression (as it is the case for the dunitic mantle) [13]. Otherwise post-shock temperatures are overestimated. For the mantle convection model temperatures are limited to the melt temperature of the material.

Impact model: To model impacts on a Mars-like planet we choose a target body with a radius of 3450 km. The planet is differentiated featuring a dense iron core of 1725 km radius and a dunitic mantle. We assume central gravity to iteratively determine starting pressure, density and gravity profiles for a given temperature profile. This approach enables the construction of a self-consistent and stable planetary target. The temperature profile represents a slowly convecting mantle with an upper crust-mantle boundary temperature of 220 K and a lower core-mantle boundary temperature of 2000 K. The core temperature is assumed to be constant (2000 K). The amount of total thermal energy brought into the planet is highly dependent on the impact angle. For moderately oblique impacts the energy transferred to the planet is nearly proportional to the sinus of the impact angle, for shallower impacts even less thermal energy is delivered to the planetary interior. The radial distribution of thermal energy (Fig. 2) shows that not only the total amount of thermal energy deposited in the planet is dependent on the impact angle but also the depth to where it is deposited. For very shallow impacts up to 15°-20° the shock wave is not strong enough to cause a visible pressure increase at the bottom of the mantle or in the core region. For moderately oblique impacts (>20°) regions of increased shock pressure occur inside the core and at the rear side of the mantle. Nevertheless the resulting post shock temperatures inside the core region are very low due to the high densitiy of the iron core and the low compressibility of iron. The pressures at the rear side of the planet are only in the range of some GPa, leading to a post shock temperature rise below 20K and are negligible in the convection models.

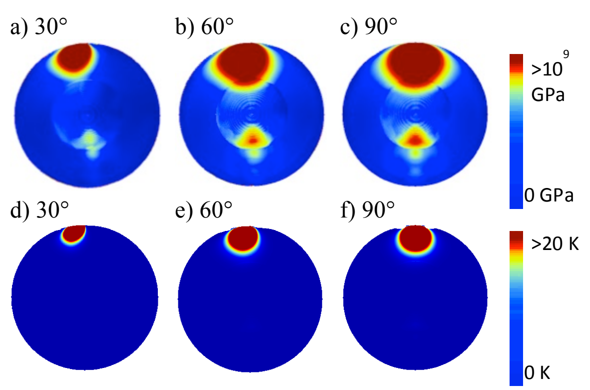

Fig 1. Oblique impact of a 200 km projectile with 15 km/s at different impact angles into a Martian sized planet. Shown are the peak pressures reached in the target (a-c) and the temperature rise (d-f).

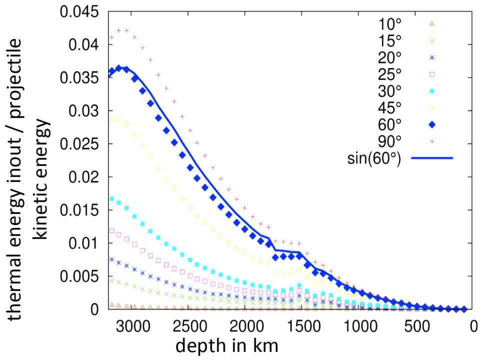

Fig. 2: Radial energy distribution after the impact of a 200 km projectile with 15 km/s into a Martian sized planet. The input of thermal engery (y-axis) is scaled by the total kinetic energy of the impactor.

Effects on mantle convection: We use both 2D and 3D models to investigate the influence of an impact-induced heat input on mantle convection for different impact angles. Directly after the impact occurred the temperature anomaly in the upper mantle leads to partial melting in the lithosphere and underneath (Fig. 3). The impact angle induces an angular plume and a melt region beneath the impact crater, both of which are still active after more than 200 Myr.

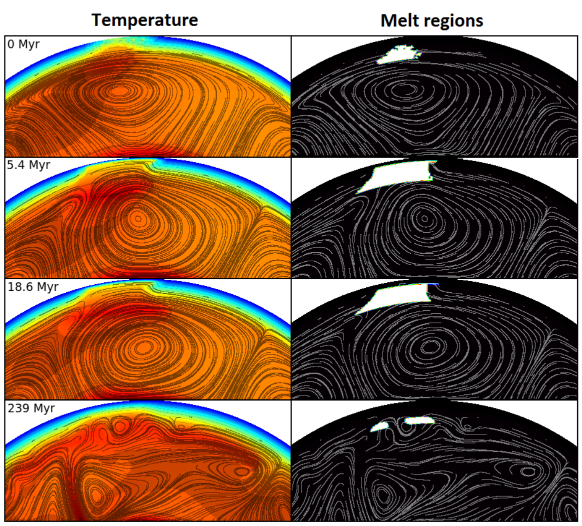

Fig. 3: 2D mantle convection simulation after an impact of a 200 km projectile at 15 km/s at an angle of incidence of 30° into a convecting mantle. The left column shows the temperature distribution and the right column the amount of melt at different points in time.

Conclusions and outlook: Our combined model approach to quantify the heat input to planetary interior by a basin forming impact and its effect on mantle convection on Mars shows that very large impacts have been able to influence the dynamic of the mantle for a long period of time. Basin forming impacts generate a large amount of melt below the impact structure giving rise to a thinner lithosphere that is preserved for hundreds of Myr. The asymmetric heat distribution after an oblique impact affects the early convection patterns in the mantle leading to tilted plumes at the edge of the impact-induced temperature anomaly for the first few Myr.

For very shallow impacts the temperature rise is too small and too close to the surface to affect mantle convection. For the future we plan to run models for even larger impactors striking the planet at different impact angles. In particular we want to investigate the effect of the asymmetric temperature distribution caused by oblique impacts and how these asymmetries change the long term temperature distribution patterns. Higher impact energies lead to higher post shock temperatures at the antipode of the planet which further increases the degree of asymmetry in the heat distributiopn and, thus, affects mantle convection processes sustainably.

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