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Numerical modeling of giant collision events implications for the heat budget of planetary interiors

M. Bierhaus (1), K. Wünnemann (1), D. Elbeshausen (1) and G. S. Collins (2)
(1) Museum für Naturkunde - Leibniz-Institut an der Humboldt-Universität zu Berlin, Germany, (2) Impacts and Astromaterials Research Centre, Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, UK
(Michael.Bierhaus@mfn-berlin.de)

1. Introduction

The evolution of the solar system and planets is heavily affected by collision events. The Moon, for example, is thought to have been formed as a result of the impact of a Martian-sized planetesimal on the early Earth; the heavy bombardment by asteroids and comets may have caused a complete melting of the early crust of planets. Accordingly, a large amount of energy that is transferred by an impact event may have affected dynamic processes in the planet's interior. Impacts generate shock waves that travel through the entire planetary body and distribute thermal energy deep into the planet [e.g. 1] . Therefore, it has been suggested [3-6] that it is feasible that giant impact events caused the cessation of the Martian geodynamo or triggered mantle convection processes. We present dynamic numerical models (hydrocode modeling) of giant collision events to quantify the amount of heat that is deposited into a planet by an impact process. We use the iSALE [6,7,8] code in 2D for this study.

2. Scaling laws for Impacts on a planar surface

In most hydrocode models pressure is calculated much more precisely than temperatures. The temperature rise as a result of shock compression after unloading can be calculated from the peak shock pressure of the target material and specific material parameters [e.g. 2,3].
Figure 1 shows the post shock temperature distribution (a) and profiles of the decrease of post shock temperature as a function of depth for different impact velocities (b). The so-called isobaric core is indicated by a zone where post-shock temperature is almost constant (or changes only slightly, dashed lines). Outside the isobaric core the temperature decreases according to a power law [9,10].

$$T(r) = T_{IC} * r^n \quad (1)$$

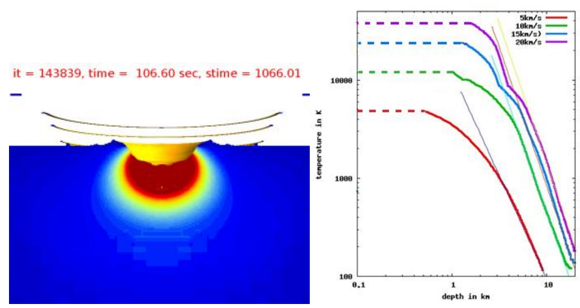

Figure 1: Two dimensional simulation of an impact of a 1km projectile on a homogenious planar surface with a velocity of 15km/s. a) Temperature difference from 0K (blue) to >200K (red) b) Temperature vs. depth profile for different impact velocities.

The exponent n in Eq. 1 depends on the impact velocity. For the different velocities we find n=-2.11 for v_{imp}=5 km/s, n=-2.74 for v_{imp}=10 km/s, n=-2.82 for v_{imp}=15 km/s and n=-2.84 for v_{imp}=20 km/s.

3. Giant impacts on Mars

3.1 Interior structure of Mars

To represent Mars in our models we assume a planet radius of 3400 km, a dense iron core of 1700 km radius, followed by a 1660 km dunite like mantle and a 40 km granite like crust. The surface gravity is 3.7 m/s, the surface temperature 220 K. The core is set to a constant temperature of 2000 K and the temperature gradient in the mantle is chosen to represent a convective mantle. Figure 2 summarizes the initial setup of our Mars model showing pressure, temperature, and density profiles from the surface to the center.

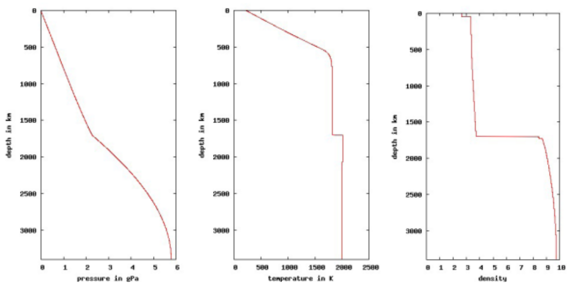

Figure 2: Setup of the assumed Mars model: pressure (a), temperature (b) and density (c) as a function of depth.

3.2 Deposition of shock wave induced heat in Mars interior

Figure 3 shows a comparison of the distribution of post-shock temperatures (temperature above the initial temperature) after the decay of shock waves between our 2D numerical models of a giant impact on Mars and scaling laws derived from impacts on planar surfaces (see section 1). Apparently the heating of planetary interior is significantly underestimated by the scaling approach. In particular a large increase in temperature can be observed antipodal to the point of impact.

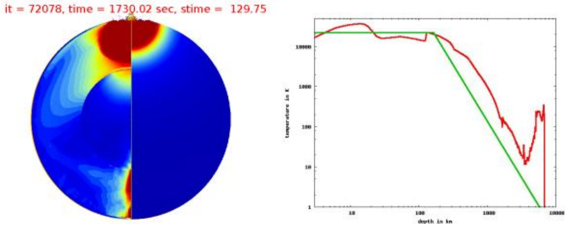

Figure 3: distribution of post shock temperature after an impact of a 200km projectile at 15km/s. a) Temperature difference from 0K (blue) to >200k (red). The left hand side shows the numerical model results, on the right hand side the temperature distribution was calculated with the scaling laws (see section 1). b) profile along the symmetry axis through the planet of temperature as a function of depth resulting from numerical models (red) and scaling laws (green).

4. Conclusions

Our numerical models of giant impacts on a Mars-like planet show some new features that can not be observed at impacts on planar surfaces. Apart from a slightly different post-shock temperature distribution in the near field due to reflections from the curved free surface, most striking is the of shock waves at the rear side (antipodal to the point of impact) of the planet. The models demonstrate that in previous studies dealing with the consequences of giant impacts on the thermal budget of planetary interior [e.g. 3,4] the deposition of heat was underestimated.

In our models we get a temperature increase of more than 100K at the core-mantle-boundary for a 200km impactor at 15km/s. This temperature increase is enough to change the heat flux through the core-mantle-boundary and thus may be enough to cease a geodynamo [4]. The complex structure of our heat distribution leads to problems comparing the results, because it still has to be determined in how far the structures we found are neutralized in a convecting mantle or core. We plan to couple our model results with geodynamo and mantle convection codes to further study these effects.

Acknowledgements

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