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Numerical modelling of the thermal state of Earth after giant impact events

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1. Introduction

Planetary collisions play an important role in the compositional and thermal evolution of the planetary system. The final stage of planet formation is characterized by collisions of large bodies. The Moon-forming impact event is thought to be Earth's last giant collision event, marking the end of the main accretion phase of the Earth. This large event (re)set the conditions for the subsequent thermochemical evolution of both bodies, Earth and Moon. Large parts of proto-earth are thought to melt as a consequence of the impact. To constrain the initial conditions of proto-Earth, to investigate the subsequent thermochemical evolution after the impact of a Mars-size object, and to quantify the volume of melt production, we carried out numerical simulations of giant impact events on the scale of the collision scenarios.

2. Methods

Previously, the Moon-forming giant impact has mostly been modeled with mesh-free so-called smoothed particle hydrodynamics (SPH [1, 2, 3]). In contrast, our new models are based on an ALE (Arbitrary-Langrangian-Eulerian) code with a fixed grid in space which tend to be more accurate in the description of thermodynamics and shock waves. The two-dimensional (2D) and three-dimensional (3D) iSALE code [4, 5] is used to model giant collisions of large objects with proto-earth. iSALE accounts for multi-material and strength. In the simulations we assume two different cases, (1) the impactor and proto-earth are differentiated into an iron core and dunitic mantle and (2) homogeneous materials (dunite) for both bodies (primitive bodies). Although the latter scenario is somewhat unrealistic we use it as a reference for better comparison with estimates from existing simple scaling laws. In addition such scenarios may be relevant for collisions of planetary embryos during the main accretion phase. The core of the differentiated bodies is represented by the Analytical Equation of State (ANEOS, [6]) for iron and the mantle by an ANEOS for dunite. We take into account an initial thermal profile for the impacted body. In 3D we also carry out a series of oblique impacts with different impact angles (30, 45 and 60°). The impact velocity for all cases was 12 km/s. In order to quantify the volume of impact-induced melt, we use the so-called peak-shock pressure approach (*'Tracer method'*) that has been used in several modeling studies [7] and is described in more detail by [8]. It is based on the assumption that the shock wave-induced increase in temperature is proportional to the maximum shock pressure the material experiences. For the 3D cases, instead, we directly use the final temperatures to quantify the amount of melt (*'No tracer method'*). Note, on the one hand the tracer method does not account for plastic work, which is usually considered to contribute little to the heat budget in smaller-sized impacts, but may play a significant role in giant impacts. On the other hand this methods is a lot less numerically diffusive and we expect it to provide more accurate results.

3. Results

Simulations in 2D (head-on collisions, cen-tral-gravity) show that the volume that is fully or partially molten after the impact event significantly depends on the distribution of material, if the bodies are primitive or differentiated. Figure 2 shows the degree of melting, where red represents partially and orange fully molten areas of the impactor and impacted body. For the case of primitive bodies, the volume of material that is partially or completely molten is 5.3 times the projectile volume. The complete mantle is molten. In contrast only 1.1 of the projectile volume is molten which corresponds to 20% of mantle material in case of differentiated bodies. 3D modeling allows for simulating oblique impacts. Figure 3 shows the development of pressure during the early stage and melt production after the moon-forming event considering an oblique impact angle (30°) where a dunitic impactor strikes a dunitic proto-Earth. The melt volume is about 5.5 times the projectile volume for such shallow impact angle. Further, the simulations show a decrease of pressures and temperatures and consequently less melt production with an increase of the impact angle. We note that different methods have been used to determine the amount of melt in 2D and 3D simulations to test the importance of contribution of plastic work to the melt production.

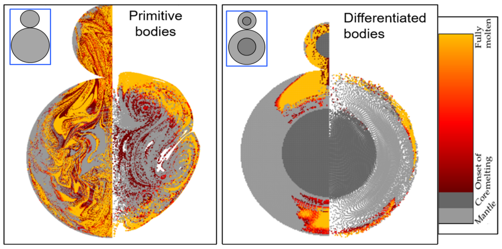

Figure 1: Melt distribution including the degree of melting after the impact of a Mars-size object with proto-earth with an impact velocity of 12 km/s considering homogeneous dunitic material (left) and primitive bodies (right). On the left of each plot, the used tracers have been mapped back to the initial position. On the right of each plot, the final positions of the tracers are shown.

4. Conclusion

Numerical simulations of Moon-forming-like impact events allow for quantifying the melt production as a function of impact angle, velocity, initial thermal, and differentiation state. In all our simulations giant impact events of the size of the Moon-forming impact scenario produce a global magma ocean. It could be shown that melt production is significantly affected by the presence of a proto-earth core. The melt volume decreases with impact angle. Only steep impact angles allow for a complete melting of the mantle. There are still large differences in melt production using either the tracer method or the final temperature method. The temperature method overestimates the melt production due to the contribution of plastic work. The tracer method is more accurate in comparison to previous model approaches that are based on the final temperature although the consideration of plastic work is lacking. Future work will include the implementation of a self-gravity routine in iSALE3D and the estimation of possible mixing of core material of the impactor with the mantle and core material of the proto-earth.

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References

[1] Nakajima M. and Stevenson D. J.: Melting and Mixing States of the Earth's Mantle after the Moon-Forming Impact. EPSL, 427, 286-295, 2015.

[2] Canup, R. M., Barr, A. C., and Crawford, D. A.: Lunar-forming impacts: High-resolution SPH and AMR-CTH simulation. ICARUS 222, 200-219, 2013.

[3] Monaghan, J.J.: Smoothed particle hydrodynamics, Annu. Rev. Astron. Astrophys. 30, 543–574, 1992.

[4] Collins, G. S., Melosh, H. J., and Ivanov, B. A.: Modeling damage and deformation in impact simulations. Meteoritics & Planetary Science, 39, 217–231, 2004.

[5] Wünnemann, K., Collins, G. S., and Melosh, H. J.: A strain-based porosity model for use in hydrocode simulations of impacts and implications for transient crater growth in porous targets. Icarus, 180, 514–527, 2006.

[6] Thompson, S. L.: ANEOS Analytical Equation of State for Shock Physics Codes Input Manual. Technical Report SAND89-2951 UC-404, Sandia National Laboratories.76 pages, 1990.

[7] Pierazzo, E., Vickery, A. M., and Melosh, H. J.: A Reevaluation of Impact Melt Production. ICARUS 127, 408-423, 1997.

[8] ManskeL., Wünnemann K., Nakajima M., Plesa A.-C.: Impact-Induced Melting by Giant Impact Events. 49th LPSC, abstact# 2269, 2018.

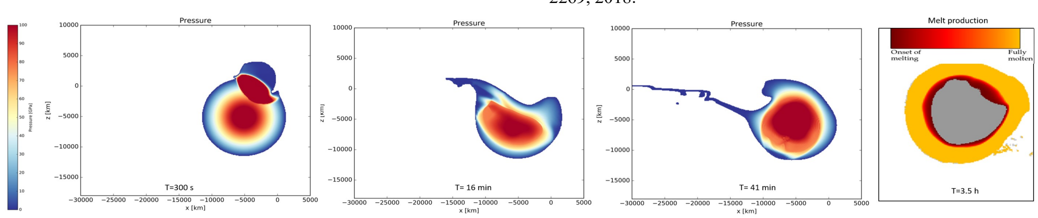

Figure 2: Pressure development and melt production for an oblique impacts (mars-size object impacting onto proto-earth with a velocity of 12 km/s and an impact angle of 30°).