Melting induced by Giant Collisions in the Earth-Moon System. L. Manske1,2, N. Güldemeister1,2, K. Wünnemann1,2, 1Museum für Naturkunde, Leibniz Institut für Evolution und Biodiversity Science, 10115 Berlin, Germany, lukas.-manske@mfn-berlin.de, 2Institute for Geological Sciences, Planetary Sciences and Remote Sensing, Freie Universität 12249 Berlin, Germany

1. Introduction: The thermochemical evolution of Earth was heavily influenced by the Moon-forming event and the subsequent bombardment of the Earth Moon system by large cosmic bodies [3]. Besides variations in the compositional budged, such impacts transfer a significant amount of energy as heat to the planet and cause the formation of local magma ponds or even global magma oceans. The determination of the amount of melt generated in the course of these events is key to understand the early evolution of both bodies. We have carried out a series of numerical models to investigate the generation of impact-induced melting during these events. Classical scaling-laws to relate impact energy with melt volume [1,2] fail for the given size scale mostly because of two reasons: first, scaling laws do not account for the interior structure of a differentiated planet and, second, the do not consider the initial temperature or lithostatic pressure of planets interior. These aspects are expected to be not negligible in large scale collisions, in particular if the pre-impact temperature of the target interior is close to the melting point. In addition, scaling laws can neither predict decompression melting nor the post impact location and distribution of melt. By conducting a series of numerical models and determining the volume of impact-induced melt we much more accurately quantify the melt production and locate melting during and right after large-scale impact events. Our results allow for estimating whether a signal giant impact event or the flux of large impactors enable the formation of a global magma ocean or whether they generate local or regional melt ponds instead.

2. Introduction: To model hypervelocity collisions, we use the iSALE shock physics code [4,5] (Version Dellen). The thermodynamic state (EoS) is calculated by ANEOS [6] for basalt/granite, dunite, and iron representing the planetary crust, mantle and core, respectively.

To determine the distribution and volume of impact-induced melting we calculate the local, (post-impact) final temperature $T_f$ via the peak shock pressure method [2,7]; to assess whether the material is (partially) molten or not, we compare $T_f$ with the solidus and liquidus temperature $T_{S/L}$ [8]. A detailed description of the method can be found in [9]. We assume that the lunar crust consists of basalt whereas the Earth’s crust is composed of granite. The planets mantles and the impactors are assumed to consist of dunite. Differentiated impactors are neglected at this stage. We consider two different initial thermal profiles $T_i$ representing young (hot) and old (cold) planets as shown in figure 1. In all models the projectile radius is resolved by 50 cells (50 CPPR).

![Figure 1: Different thermal profiles for Moon and Earth [3] including a solidus function[8].](image1)

3. Results: In our model series, we vary the impactor diameter $L$ and velocity $v$, for different temperature conditions $T_i$ to quantify melt volumes. Additionally, we conducted some preliminary 3D simulations with varying impact angle to address the Moon-forming (c.f. Figure 2.).

![Figure 2: Normalized melt production for hot and cold bodies with classical scaling laws for basalt [1] and dunite [2] (black dashed lines, Moon). Models for different planets are based on hot (dark colors) and cold (light colors) temperature profiles (c.f. figure 1.). Colored dashed lines indicate the 100%/20% of the normalized Mantle volume ($V_{Mantle}/V_{projectile}$) for the Earth (purple) and Moon (turquoise).](image2)
Figure 2 shows the melt volume normalized by the projectile volume as a function of impactor diameter. The models agree with estimates from scaling-laws (dashed lines) for small scale impacts. However, larger events are not well represented. For a given body and thermal profile $T_i$, we find, that when a certain impactor size is exceeded, the normalized melt production ($V_{\text{melt}}/V_{\text{projectile}}$) deviates significantly from estimations of scaling laws. The distinct increase in melt production for impactors larger than 10 km (300 km for cold Moon) in diameter for the hot planet scenarios is caused by the depth-dependence of the $\Delta T_M$, which is given by the difference between $T_i$ and solidus (and liquidus) $T_{\text{L/S}}$. The maximum in normalized melt production usually occurs at a depth corresponding to the bottom of the lithosphere, where $\Delta T_M$ is the smallest [9].

3D simulations of the Moon-forming event show relatively small normalized melt volumes due to the fact, that the projectile volume is relatively big compared to the target. Preliminary melt volume calculations suggest, that after events with impact angles larger than 60° at 12 km/s (~ escape velocity) the entire mantle of the Earth is molten.

Figure 4 show the accumulated amount of melt that is produced in certain time intervals when combining the presented lunar melt production data with the impactor influx after [10] for a fixed 15 km/s impactor velocity and different thermal profiles. The data for the hot thermal profile represent the late accretion phase and the data for the cold profile are shown as reference. We assume a time period right after the solidification of the magma ocean which is best represented by the hot thermal profile. Our results indicate that the bombardment during late accretion was not sufficient to melt large areas of the mantle volume, but it does melt up to 5% of the mantle volume over a time period of 200 Ma.

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