THE INFLUENCE OF INTERIOR STRUCTURE AND THERMAL STATE ON IMPACT MELT GENERATION IN TERRESTRIAL PLANETS. L. Manske[1,2], A.-C. Plesa[3], T. Ruedas[1,3] and K. Wünnemann[1,2], [1]Museum für Naturkunde, Leibniz Institut for Evoluton and Biodiversity Science, Berlin, Germany, (lukas.-manske@mfn.berlin), [2]Institute for Geological Science - Freie Universität, Berlin, Germany, [3]German Aerospace Center (DLR), Berlin, Germany.

Introduction: The production of melt and vapor is an important process during impact cratering events. We revisit the impact-induced melt generation during large scale impacts onto generic terrestrial planets.

Traditionally, so called scaling laws are used to estimate the amount of melt as a function of different impact parameters such as the impactor diameter $\boldsymbol{L}$ and velocity $\boldsymbol{v}$ as well as the densities of impactor $\boldsymbol{\rho_i}$ and target $\boldsymbol{\rho_t}$ and the internal energy of melting $\boldsymbol{E}$. These scaling laws are derived from semi-analytical models and parameterized results from hydrocode simulations that account for melt generation due to the impact-induced shock (e.g., [1,2]).

However, there are two major issues with this approach; (i) The impactor and target density $\boldsymbol{\rho_i}$, $\boldsymbol{\rho_t}$ and internal energy of melting $\boldsymbol{E}$ are assumed to be constant. While this is a valid assumption for small impacts, which encounter an essentially homogeneous target, scaling laws will fail if impact-related length scales such as the depth of penetration or the size of the shocked volume approach the length scales on which the properties of the target ($\boldsymbol{\rho}$, $\boldsymbol{E}$, $\boldsymbol{T}$, $\boldsymbol{p}$, etc.) change substantially (e.g., [4,5]). (ii) The other issue is, that besides the melt generation that is caused by shock-heating throughout the impact process (considered in scaling laws), heating due to plastic work and decompression due to uplift may also contribute significantly to melt production. The latter mechanism is particularly efficient if the change of target properties with increasing depth is substantial (e.g., the target temperature approaches the solidus [5]). The contribution of plastic work to melting also promotes melt production, which is proposed to be significant in impact scenarios with impactor speeds lower than 15 km/s [6,7].

Methods: We quantify impact-induced melt production using a set of generic models of terrestrial planets. Thereby we examine a broad set of interdependencies between certain target planet properties and impact parameters (see figure 1.) as well as the different sources of impact melt production (mentioned above, see figure 2b.). The thermal structure of the target planet is calculated by employing parameterized thermal evolution models. These account for partial melting of the mantle and crustal growth [8,9] and consider the heat transport in both stagnant lid and plate tectonics regimes. The resulting heterogeneous planetary gradients are evaluated at different times to cover a broad range of the planetary evolution. These data are used as initial condition for the target in the impact melt quantification models.

The fully dynamical impact models are performed by the iSALE shock physics code (e.g., [10,11]). To accurately quantify impact-induced melt volumes, we developed a Lagrangian tracer-based method that accounts for the impact-induced melt production by shock-heating, decompression, and plastic work as a consequence of the shock, material deformation and displacement in the course of crater formation.

We investigate the dependence of melt production on impactor size $\boldsymbol{L}$ (10 – 1000 km) and velocity $\boldsymbol{v}$ (10 – 20 km/s) in vertical impacts ($\boldsymbol{\alpha}$ = 90°). The latter choice is a limitation required by our use of 2D models in order to reduce computational costs. The target size varies from 0.5 – 1.5 Earth radii while the temperature $\boldsymbol{T}$ is derived from the thermal evolution models, which in turn depends on the planet's thermal history and size, specifically on the mantle thickness $\boldsymbol{d}$ and gravity $\boldsymbol{g}$. The latter in turn is a function of the mass of the target planet, which also influences the impact velocity and thus the depth of penetration of the impactor. While the models are derived for generic planets ranging in size from Moon-sized objects to super-Earths, they are also applied to planets of our Solar System, in particular Mars.

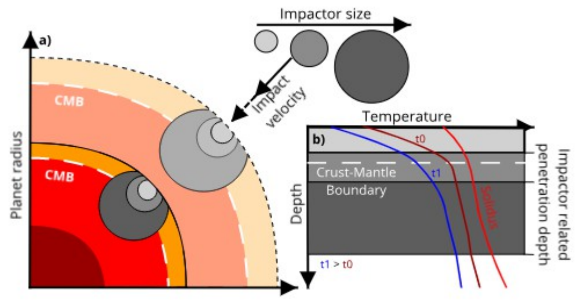

Figure 1: Schematic overview illustrating (a) the area experiencing impact-induced melting (gray areas) depending on the impactor diameter ***L*** and impact velocity ***v*** and (b) the evolution of the planet's thermal gradient for different time steps. The dark red line indicates a thermal profile for early, and the blue line for a late planet. The different gray colors indicate up to which penetration depth melt is generated depending on the impactor properties ***L***, ***v*** (c.f. (a)).

Results: Our preliminary results indicate that impact-induced melting is not only sensitive to shock-heating, which is the basis of most of the impact melt scaling laws, but also to decompression by uplifted material and heating due to plastic deformation. Figure 2 indicates the melt fraction (a) and the source mechanism of melt generation (b). Both panels show the melt at an identical time step. The left panel displaying the resulting melt distribution and the right panel the provenance of that melt.

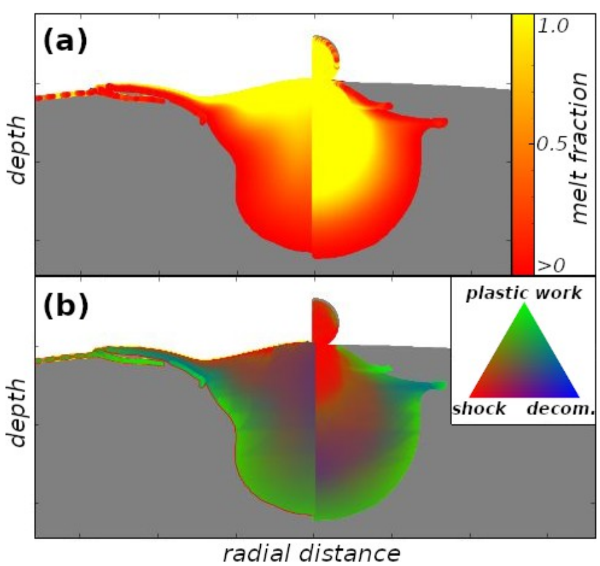

Figure 2: Schematic melt distribution (left) and provenance (right) for an impactor diameter of few tenth km, 15 km/s and an hot thermal profile. The melt fraction (a) and the source of the dominant mechanism responsible for melting (b) is displayed.

Indicated by the schematic example in figure 2, melting in the area close to the contact point (isobaric core) is dominated by shock-heating. However this effect decreases with the distance over which the peak shock pressures decay. Decompression melting only affects material that was initially placed at greater depth and gets uplifted in the course of crater formation. It is strongly dependent on the impactors penetration depth and the planets thermal and pressure profile. Melting due to plastic work is related to small melt fractions and dominates melting close to the interface between melt and incipient melting. It strongly depends on strength parameters and additional properties like the thermal softening model and melt viscosity.

The ultimate goal is to find a comprehensive representation of these complex interdependencies for a broad range of impact and target properties. Furthermore, we aim at narrowing the parameter ranges where scaling laws represent melt production satisfactorily and indicate in which scenarios target heterogeneities or melting due to decompression or plastic work affects the overall melt production significantly.

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