COMBINED IMPACT AND RADIOGENIC HEATING OF EARLY PLANETESIMALS.
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Introduction: The source of heating in early planetesimals has been the subject of study for decades. Numerical models have shown that the decay of short-lived radionuclides (SLRs) could have produced enough energy to heat planetesimals to the temperatures needed for differentitation or thermal metamorphism. In fact, these thermal models have been shown to match the thermal chronometry data of many meteorite types, constraining the sizes and times of accretion of their parent bodies [e.g 1-3].

It has also been argued that impacts contributed to the thermal evolution of planetesimals. As collisions between planetesimals were frequent and energetic events during the formation of planets, their effects would have been seen throughout the same period of time that planetesimals were being heated by SLRs. Recently, we have shown that the thermal evolution of localized regions of a planetesimal where impacts took place would be similar to that caused by global heating by SLRs, and that such events are important on the scale of meteorite samples [4].

To date, the combined effects of impacts and SLRs have not been considered. Radiogenic thermal models assume planetesimals remain isolated and undisturbed for periods of ~100 Myr. Models show that it is unlikely bodies escaped impacts of any sort over this time [e.g. 5]. In fact, impacts are needed to fully explain the thermal chronometry of the H-chondrite parent body [3]. Thus we are carrying out a quantitative investigation of how impacts and SLRs combined to thermally process materials in the early Solar System.

Modeling Approach: Given the range of planetesimal sizes and accretion times to explore, we begin our investigation with the H-chondrite parent body. Recently, [3] compiled the available thermal chronometry data of all H-chondrite meteorites and used a thermal model to determine that the radius of the parent body was 100 km and that it accreted ~2.2 Myr after CAIs. In their work, they found that a perfectly undisturbed body (which would have resulted in an onion-shell structure) was unable to fit all data, and that non-catastrophic impacts likely were responsible for those data which did not fit the onion-shell model predictions. We focus on this body in order to compare our model predictions to meteorite data, but stress that our methods and results are general and applicable to all bodies, including achondrites.

Our approach was to model the thermal evolution of a body as described by [3], and at a given instant model the effect of a sub-catastropic impact on that body using results from iSALE hydrocode simulations. The initial target thermal structure in the iSALE simulations was thus chosen to be appropriate for the time of impact. The simulation accounts for (a) the additional heat produced by the impact and (b) the redistribution of (heated) material on the surviving planetesimal. Once the impact-related motions on the surviving planetesimal were completed, we continue to model the thermal evolution of the body, tracking how heat from both the impact and the decay of short-lived radionuclides are lost with time. For the sake of simplicity, we focused on vertical impacts, but are developing the same routines to understand the consequences of oblique impacts [6].

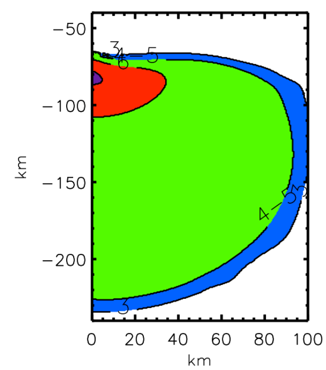

Figure 1: *Surviving planetesimal, color coded by petrologic type (3-blue, 4/5-green, r6-red, 7-purple). Impact was normal, directed from top of plot.*

Results: Figure 1 shows the surviving planetesimal after the collision of 10 km radius impactor with a 100 km radius heated, onion-shell H-chondrite-like parent body target 1 million years after that body formed.

Figure 2 shows the thermal evolution of the the entire surviving body, with the bottom panel showing the amount of mass of the surviving body that reaches a given temperature (normalized to the mass of the target). For reference, the ranges of temperature for different petrologic types as defined by [3] are shown, and the portions of mass coming from the impactor vs target identified. The top panel shows the amount of mass that experiences given cooling rates (at 773 K), separated by petrologic type and by impactor and target material. For comparison, Figure 2 also shows the results for a pure H-chondrite onion-shell body.

The impact clearly resulted in increased heating in parts of the planetesimal as increases in the peak temperatures of materials can be seen by comparing the bottom panels of Figures 2. While the onion-shell body reaches a maximum temperature of ~1150 K throughout much of its interior, the peak temperature in the impacted planetesimal is ~1300 K. Although the hottest material appears to come from the impactor, closer examination shows that ~1-2% of the target's mass (M_t) is heated beyond the expected peak temperature from an onion-shell model. The increased heating is also seen at lower temperatures, as the amount of mass that reaches 800 K is ~1% M_t in the impacted planetesimal, while only ~0.3% M_t in the onion-shell model. In fact, the amount of mass that reaches temperatures between 400-1000 K is higher in the impacted planetesimal than the pure onion-shell model.

Despite this, the top panels below clearly show that the onion-shell model produces more type-6 petrologic types than the impacted planetesimal. That is, a larger amount of mass reaches a higher petrologic type in the onion-shell model than the impacted planetesimal. This counter-intuitive result is because after the impact, even though much of the planetesimal continued to warm from the decay of SLRs, the shape of the planetesimal had been altered by the impact, increasing the surface area/volume ratio of the planeteimal over that of the spherical onion-shell. As a result, heat was lost from the planetesimal more easily, reducing the peak temperatures of material distal to the impact site. The net effect is that the peak temperatures reached in that region are ~30-50 K less than expected in the onion-shell model. For the choice of parameters here, this is the difference between reaching type 4-5 and type 6.

Discussion: Our simulations show that the collateral effects of an impact are not limited to heating a localized region, and can have implications for the global thermal history of a parent body. Assuming a spherical shape for a parent body when calculating its thermal history may lead to a mischaracterization of the body, and perhaps an over-estimate of the heating capability of SLRs. This also has implications for the thermal history of asteroids that have sustained a large shape altering impact, such as Vesta. We are examining plausible impact scenarios based on impact probabilities and impactor size distributions from planetary accretion simulations [7], including the differences in impact histories for those bodies that accreted to form the planets and those that remain in the asteroid belt.

Our results allow us to quantitatively evaluate the roles impacts played in shaping planetary building blocks and meteorite parent bodies, and to possibly constrain the impact histories of such bodies. Our next steps will be to compare the specific temperature-time histories of regions of the planetesimal with the thermochronometry data of H-chondrites as done in [3] to determine (1) what scenarios allow a parent body to produce local thermal histories consistent with the available data and (2) the amount of this heating that is due to impacts vs SLRs. We are also exploring implications for achondrites.

References: [1] Elkins-Tanton L. T. et al. (2011) *EPSL, 305,* 1-10. [2] Henke S. et al. (2011) *A&A, 537,* A45. [3] Harrison K. P. and Grimm R. E. (2010) *GCA, 74,* 5410-5423. [4] Davison T. M. et al. (2012) *GCA,* Submitted. [5] Davison T. M. (2011) *PhD Thesis*. [6] Davison T. M. et al. (2012). *This Meeting.* [7] O'Brien D. P. et al. (2006) *Icarus, 184,* 39-58.

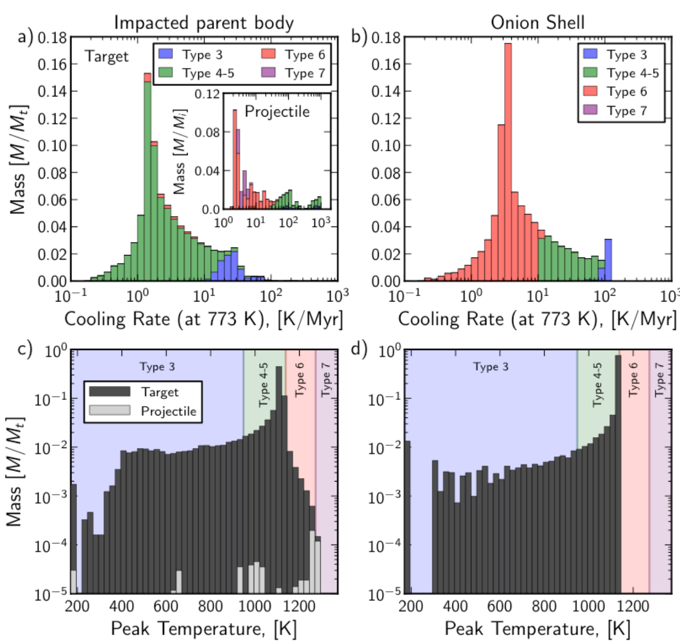

Figure 2: *Top panels: Mass of surviving planetesimal which experiences given cooling rates, color coded by petrologic type for the impacted onion-shell body (left) and the pure onion-shell (right). Bottom panels: Mass of surviving planetesimal which reaches given peak temperatures, with boundaries of petrologic type given. Masses were normalized to the mass of the target/onion-shell body everywhere, except for the inset in the upper left panel. There the cooling rates of projectile material are shown, normalized to the mass of the impactor. All differences are attributed to the heat deposited during impact and physical restructuring of the target, which affects subsequent heat transport.*