IMPACT EFFECTS ON COOLING RATES OF IRON METEORITES. R. J. Lyons[1], T. J. Bowling[1], F. J. Ciesla[1], T. M. Davison[2], G. S. Collins[2], [1]The Department of the Geophysical Sciences, The University of Chicago, Chicago, Illinois, USA (rjlyons@uchicago.edu), [2]Impacts & Astromaterials Research Centre, Department of Earth Science & Engineering, Imperial College London, London, UK.

Introduction: Iron meteorites come from the cores of differentiated planetesimals. The cooling rates of these samples provide valuable insight into the thermal evolution and structures of their parent bodies. Haack et al. [1] simulated the thermal evolution of differentiated bodies using a one-dimensional conductive thermal model. They found that a core would cool uniformly and that the cooling rate was a function of the planetesimal size. However, for many iron meteorite groups, the measured cooling rates exhibit values that range over orders of magnitude. For example, IVA iron meteorites have measured cooling rates from 100 to 6600 K/Myr [2]. Additionaly, [1] inferred the parent body sizes for iron meteorites would be <100 km in radius. This is at odds with the idea that asteroids are "born big," with initial sizes from 100 - 1000 km [3].

The Haack et al. [1] model did not allow for collisions to occur as the body cooled. However, during the first 100 Myr of solar system evolution, planetesimals would have experienced frequent and energetic collisions [4]. Ciesla et al. [5] found that an impact onto a radiogenically heated body could uplift material at depth, bringing it closer to surface, where it would cool more quickly than expected for where it originated. Similarly, it has been shown that hit-and-run collisions could strip large planetesimals of their mantles, expose the cores, and produce the non-uniform cooling rates found for iron meteorite groups such as the IVA's [2,6]. However, hit-and-run impacts in the first 100 Myr would be much less frequent than collisions between smaller bodies. Therefore, it is useful to investigate the effect small, energetic impacts would have.

Here we report preliminary results of our investigation of whether energetic collisions in the early Solar System could produce scatter in metallographic cooling rates throughout the core of a differentiated body. To do so we follow a planetesimal as it is heated, differentiates, is impacted, and subsequently cools.

Differentiation Model: Our modeling pipeline starts with a cold purely chondritic body and is then heated by Al^{26}. Thermal evolution is found by solving the 1D heat equation, assuming spherical symmetry [1]. The thermal properties of the materials and heat production rates are taken from [7].

When regions of the planetesimal reach temperatures of 1673 K (the midpoint between the assumed liquidus and solidus) differentiation occurs, forming a core and molten silicate mantle. The size of the iron core is determined from the metal fraction in the original chondritic material and the volume of the molten region. Additional melting of the planetesimal would lead to further growth of the core. In the models reported here, the cores are 44 km in radius for fully differentiated 100 km radius bodies.

The molten mantle is assumed to convect when the temperature is above the 50% partial melt threshold, producing a roughly isothermal region [7]. The rapid heat transfer in a convecting mantle is modeled by increasing the thermal diffusivity of the hot silicate material by three orders of magnitude [8,9].

Impact Model: Using the iSALE-2D [10-12] shock physics code, we modeled 10 km radius dunite impactors colliding head-on into the 100 km radius differentiated target planetesimals formed simultaneously with CAIs (t=0) at 3 and 6 km/s at various points in their evolution (10, 50, and 88 Myr after formation). All models assume a cylindrically symmetric geometry and have a spatial resolution of 666 m. Material thermodynamics are addressed using the ANEOS equation of state package [13]. The mantle is treated as a visco-elastic-plastic solid [14], with flow laws appropriate for the terrestrial mantle [15], and a temperature dependent yield strength with a melting point of 1436 K. In the 10 Myr scenario, the entire core is above the melt temperature of most iron alloys and is assumed to be a fluid with viscosity η=100 Pa s. For the 50 Myr scenario the core has an initial temperature of ~1200 K, and depending on composition, could reasonably be either entirely molten or entirely crystallized before impact. As such, we consider both liquid (η=100 Pa s) and solid cores; in the latter case assuming a strain- and temperature-dependent yield strength [16] appropriate for metals and a melt temperature of 1300 K. For the 88 Myr scenario, the temperature of the core is ~750 K and is treated as a solid for all impact scenarios. These simulations were also used to investigate the mixing of silicate and metal during impacts [17].

Thermal Evolution: The cooling of the post-impact planetesimals is calculated using a 2D, cylindrically symmetric heat equation. Cooling rates at the metallographic closure temperature of the iron core, 773 K, are recorded throughout the body.

Figure 1a shows the initial conditions for a simulation of a 100 km body impacted head-on with a 10 km impactor at 6 km/s 50 Myr after its formation. The core was assumed to be solid. The colors denote the temperature profile of the planetesimal as calculated using our differentiation model. The black line marks the core-mantle boundary. Figure 1b shows the same body about 7 hours post-impact. The iron core has been disturbed slightly, with the silicate mantle experiencing some erosion and thinning.

Figure 2 shows cooling rates near the impact zone. Only material with temperature exceeding 773 K post impact had cooling rates recorded. The gray regions are parts of the mantle that remained at T<773 K after the impact occurs, and thus retain their onion-shell cooling rate. The black line marks the core-mantle boundary. The mantle near the impact site cools very quickly as it is now closer to the surface than before the impact. The core, however, still cools uniformly at a rate of ~10 K/Myr which is the same as a non-impacted body. We explored impacts at 10, 50, and 88 Myr after formation with a 10 km impactor at 3 and 6 km/s. All simulations show similar outcomes, the cores cool at the same rate as an unimpacted body. A more energetic impact would likely excavate even more mantle, reducing the size of the insulating silicate layer at the impact cite. This would lead to faster cooling in the core. Such simulations are now being performed.

Future Plans/Discussion: We are currently running a suite of simulations of more energetic collisions, varying time of impact, impactor size, and impact velocity. If we continue to find that disturbing the cooling rates of the core is difficult in this scenario, it would suggest that more rare low velocity, hit-and-run collisions among large bodies were the dominant mechanism for producing spread among the iron meteorite cooling rates. However, if more energetic collisions involving small impactors can also enhance cooling, this would suggest that these meteorites possibly are sampling the high velocity impacts predicted in planetary accretion simulations [4,18]. Either way, this research will constrain the dynamical evolution of meteorite parent bodies in the early Solar System.

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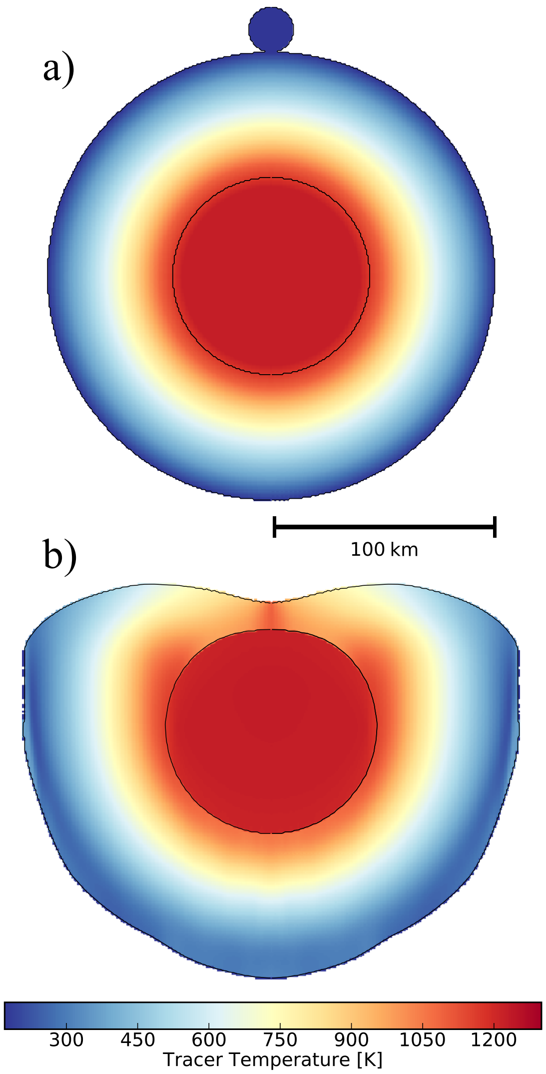

Figure 1: An impact onto a differentiated planetesimal occurring 50 Myr after formation with a 10km impactor at 6 km/s head-on. The black line marks the location of the core. The mantle at the impact site is displaced bringing the core closer to the surface.

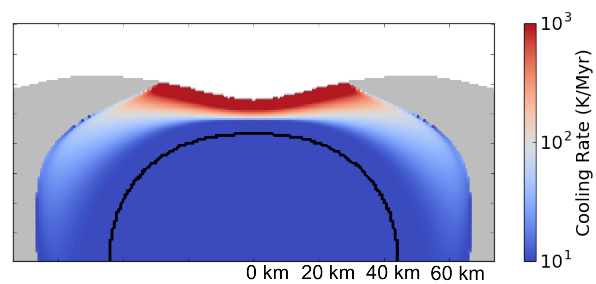

Figure 2: The cooling rate of the above impacted body near the impact site. The gray regions are mantle that were not hotter than 773 K post-impact. The core is outlined in black. The core cools uniformly at ~10 K/Myr while the uplifted hot mantle cools very quickly at the surface.