HYDROCODE MODELLING OF MELT PRODUCTION IN PLANETESIMAL COLLISIONS Thomas M. Davison[1], Gareth S. Collins[1] and Fred Ciesla[2], [1]Department of Earth Science and Engineering, Imperial College London, London, SW7 2AZ, United Kingdom. (E-mail: thomas.davison02@imperial.ac.uk) [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington, DC 20015-1305, USA.

Introduction: Planetesimal collisions were important events during the early evolution of the solar system. Not only were these collisions responsible for the growth of the planetary embryos and eventually the planets that we see today, but these collisions have also been invoked to explain the heating of planetesimals, the shock effects seen in meteorites, the compaction and lithification of the earliest generation of planetesimals, and even the formation of the chondrules which populate the most primitive meteorites in our collections [1,2]. While a large amount of effort has been devoted to studying the low velocity, accretionary impacts [e.g. 3], the higher velocity collisions that may be responsible for this latter set of processes are not well understood [e.g. 1]. We have begun a thorough numerical investigation of the detailed physics and consequences of planetesimal collisions to help constrain models of solar system evolution. Here we present preliminary results that quantify the effects of target properties, such as porosity, on melt production in planetesimal collisions. Our results have implications for chondrule formation by planetesimal collisions.

Simulations: To quantitatively assess the volume of melt produced in impacts between similar sized, km-scale, spherical dunite bodies we used the iSALE hydrocode [4]. In addition to the effect of impact velocity and planetesimal size, the effect of pore space closure on shock attenuation and heating was investigated using the epsilon-alpha porous compaction model [4,5]. This parameterization relates the reduction in volumetric strain in each cell during compression to a reduction in bulk porosity, and can be used in combination with any equation of state (for the solid matrix material) to describe the bulk thermodynamic behaviour of a porous material. Importantly, the scale of pore spaces considered by the model must be smaller than the computational cell size, which in our simulations is $\sim 1/500$ times the radius of the planetesimal (~ 10 m). The sensitivity of our model results to numerical resolution and the epsilon-alpha model parameters were quantified; the uncertainties in our results due to these factors are in the range of $1 - 10\%$.

Results: Our numerical models so far assess the effect on melt volume production of (a) porosity; (b) the relative size of the bodies to one another; and (c) impact velocity.

Porosity: Target porosity ϕ (void volume/bulk volume) is known to increase impact melt production due to the large amount of energy (PdV work) expended during the crushing of pore space [6,7]. The efficient energy absorption of porous materials increases their shock attenuation relative to nonporous materials, but at the same time greatly lowers the critical shock pressure required to melt the material [5]. To quantify the effect of porosity on melt production in planetesimal collisions we simulated the impact of two 10-km diameter dunite planetesimals at a relative velocity of 5 km s^{-1}, with different initial porosities in the range $0 \leq \phi \leq 0.75$. We used the ANEOS equation of state for dunite [8] to represent the solid material.

At 5 km s^{-1} the volume of material melted is very low when porosity is low (i.e. for $0 \leq \phi < 0.2$), but increases rapidly above a porosity of 0.2. Melt volume increases by a power law up to a porosity of 0.4 (approximately 28% of the initial volume is melted in this case), where it then increases less rapidly, and linearly with porosity (see Figure 1). However, since the mass of a given size planetesimal decreases with increasing porosity, the absolute mass of impact melt actually reaches a maximum ($\sim 30\%$ initial mass) between $0.4 < \phi < 0.6$, before falling off for even higher porosities (see Figure 2).

Relative body size: For collisions between identical spherical bodies of a given material the impact melt volume, when normalised by the planetesimal volume, depends only on impact velocity, not on planetesimal size. Thus, provided the assumption implicit in our porosity model remains valid (i.e. that pore spaces are small compared to the cell size), the results presented in Figs. 1 and 2 should be independent of body size. However, as the *relative* size of each body varies, the propagation of

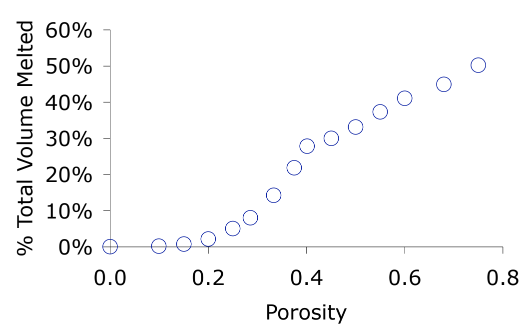

Figure 1: *Percentage of the total initial volume of the two bodies that is shocked to a sufficient pressure to melt material.*

the shock wave and the generation and propagation of release waves within the colliding bodies will change and affect melt production.

To quantify how the relative size of the colliding bodies affects the volume of melt produced, we varied the volume of the two bodies but kept the total volume of the system equal. Our results demonstrate that melt production is most efficient when the colliding bodies are of equal volume. As the difference between the volume of the two bodies increases, the volume of melt produced decreases. When the ratio of volumes between the two bodies is approximately 0.5, the volume of melted material is reduced by almost 20% (for $\phi = 0.5$) of the value when the bodies are the same size (see Figure 3). This reduction in melt volume is less pronounced for lower porosity cases (there is only a 12% reduction for when $\phi = 0.33$). As shown in figure 2 the melt mass reaches an optimum value above $\phi = 0.4$. This behaviour is also seen when the relative body size changes — the melt mass for $\phi = 0.4$ and $\phi = 0.5$ are approximately the same, and also significantly higher than for $\phi = 0.33$.

Velocity, impact angle and other target properties: Numerical models are currently being performed to quantify the coupled effect of impact velocity and porosity on melt production. Future investigations of impact angle and other target properties such as composition and strength are planned.

Discussion: The results of our models indicate that porosity and the relative size of the impacting bodies greatly affect the amount of melt produced in collisions between planetesimals. The collision of moderate-to high-porosity, similar-sized planetesimals can melt a substantial fraction of both objects, even at relative impact velocities below 5 km s^{-1}. The production of large volumes of melt in such collisions could be important in considering the origin of chondrules — the millimetre-sized, igneous particles that dominate the textures of chondritic meteorites. An impact origin for these objects has been suggested before [e.g. 9], but had been largely rejected, in part due to the belief that melt production is inefficient in such collisions, as has been shown to be the case in collisions of non-porous planetesimals of significantly different sizes [6,10], and because collisional velocities were expected to be low. Recently, it has been shown that early planetesimals could attain a velocity of many kilometres per second [11]. In light of our new results and the recent proposal that impacts are responsible for the young and unique chondrules in the CB chondrites [12], we suggest that a new look at chondrule formation in planetesimal collisions is warranted.

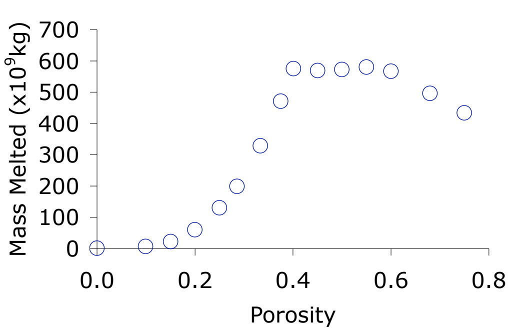

Figure 2: *Total mass that is shocked to a sufficient pressure to melt material. Note the maximum mass of melt is reached for porosity of 0.4 - 0.6*

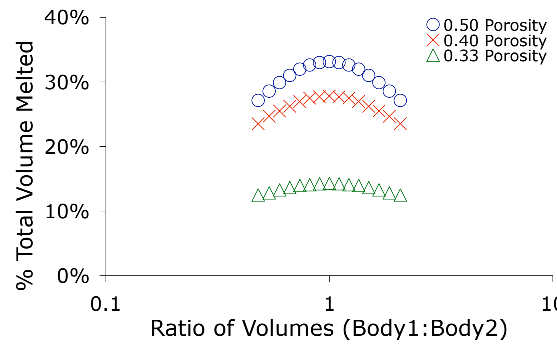

Figure 3: *Percentage of the total initial volume melted. The melt volume increases with porosity, and decreases as the relative difference in size of the bodies increases.*

References: [1] Consolmagno, G. and Britt, D. T. (2004) *Planetary and Space Science, 52*, 1119-1128. [2] Scott, E.R.D. (2002) In *Asteroids III* (Bottke et al. eds.), 697-709. [3] Benz, W. (2000) *Space Science Reviews, 92*, 279-294. [4] Wünnemann, K. et al. (2006) *Icarus, 180(2)*, 514–527. [5] Wünnemann, K. et al. (2007) Submitted to *Earth and Planetary Science*. [6] Taylor, G. J. et al. (1983). In *Chondrules and their origins* (A85-26528 11–91). Houston, TX, Lunar and Planetary Institute, 262-278. [7] Hörz, F. et al. (2005) *Meteoritics and Planetary Science, 40 Nr9/10.* 1329–1346. [8] Benz, W. et al. (1989) *Icarus, 81*, 113–131. [9] Fredricksson, K. et al. (1973) *The Moon, 7*, .475–482. [10] Keil, K. et al. (1997). *Meteoritics and Planetary Science, 32*, 349–363. [11] Weidenschilling, S. J. et al. (1998) *Science, 279*, 681–684. [12] Krot A. N. et al. (2005) *Nature, 436*, 989-992.