MESOSCALE NUMERICAL MODELING OF COMPACTION OF PRIMITIVE SOLAR SYSTEM SOLIDS IN LOW-VELOCITY COLLISIONS T. M. Davison[1], G. S. Collins[1] and P. A. Bland[2]. [1]Impacts and Astromaterials Research Centre, Department of Earth Science and Engineering, Imperial College London, London, SW7 2AZ, United Kingdom (E-mail: thomas.davison@imperial.ac.uk). [2]Department of Applied Geology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia.

Introduction: Previous numerical studies of impact processing (e.g., compaction, heating) of primordial solids [e.g. 1,2] have estimated 'bulk' pressure-temperature conditions over large (planetesimal) scales. However, primordial solar system solids accumulated as bimodal mixtures of mm-scale zero-porosity inclusions (chondrules) surrounded by highly porous, sub-μm dust particles (matrix). The fine-scale response of such mixtures to shock has not previously been modeled, despite the fact that these mixtures were the precursors to all solar system materials. Here we describe a novel method of quantifying the meteorite-scale response of primordial solar system mixtures to shock compaction in low-velocity impacts. Our results provide an important link between meteoritic evidence and the bulk thermal and compaction histories of meteorite parent bodies.

Modeling: A suite of "mesoscale" numerical planar impact simulations were performed using the iSALE shock physics code [3–5], in which shock waves were propagated through a bimodal mixture of explicitly resolved non-porous disks (the chondrules) surrounded by a highly porous matrix. Chondrules were placed with random sizes (in the range 0.3–1 mm) and spacing within the computational mesh until the desired matrix-to-chondrule volume ratio was reached. An ANEOS-derived equation of state table for forsterite [6] was used to describe the thermodynamic response of both the non-porous disks and the solid component of the matrix. Compaction of porosity and material strength were modeled using the methods described in [4,5]. The chondrules were given a high cohesive strength (1 GPa), whereas the porous matrix was assumed to be very weak, with a cohesive strength of a few kPa. Simulations spanned a range in impact velocity (v_i = 0.75–3 km/s), initial matrix volume fraction (30–70%) and initial matrix porosity (60–80%), with an initial temperature of 300 K. Lagrangian tracer particles recorded the peak- and post-shock state of the matrix and chondrule material, from which the bulk state was determined.

Results: A typical simulation is shown in Figure 1. The first panel on the left shows the initial conditions of the model, in which a flyer plate impacts a cover plate at the prescribed velocity (in this case, 1 km/s). Chondrules and matrix are coloured grey and brown in this panel, respectively. The cover plate is used to allow the shock wave to reach a steady state before entering the sample plate. To prevent a release wave being generated at the rear edge of the sample, a buffer plate was placed behind the sample plate. All plates (flyer, cover, sample and buffer) were assigned the same material compositions (matrix fraction and porosity), to prevent any shock impedance mismatches. In the second panel, the shock wave is seen propagating into both the cover and flyer plates. By 12 μs, the shock wave has reached the sam-

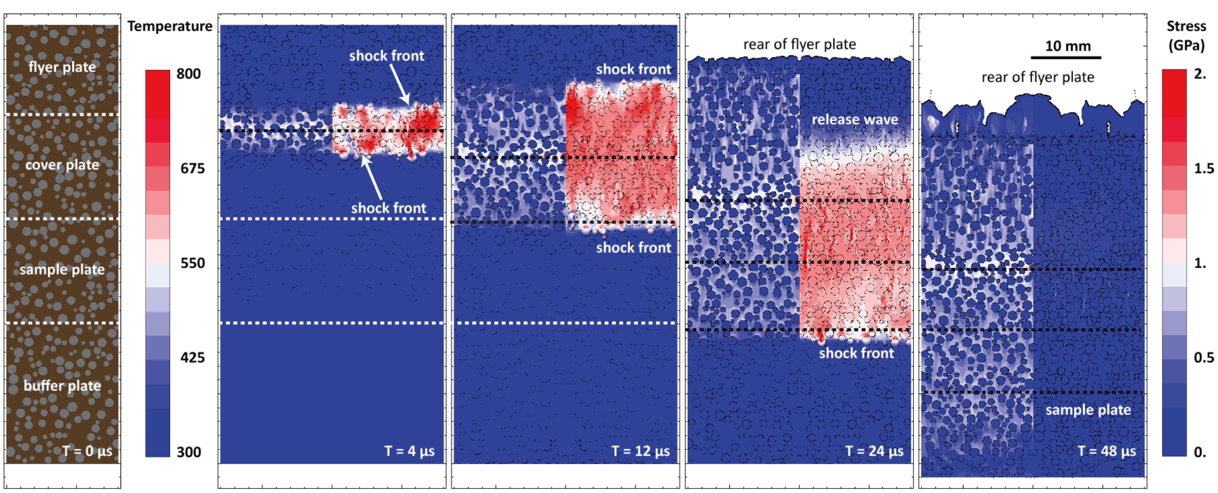

Figure 1: *Time sequence (from left to right) of a typical mesoscale simulation of a nominally planar shockwave propagating through a bimodal mixture of explicitly resolved non-porous chondrules surrounded by a high-porosity matrix. The colour-scale for the right panel denotes the instantaneous longitudinal stress; the colour-scale for the left panel denotes temperature. The impact velocity was 1 km/s, and the initial matrix fraction was 0.7.*

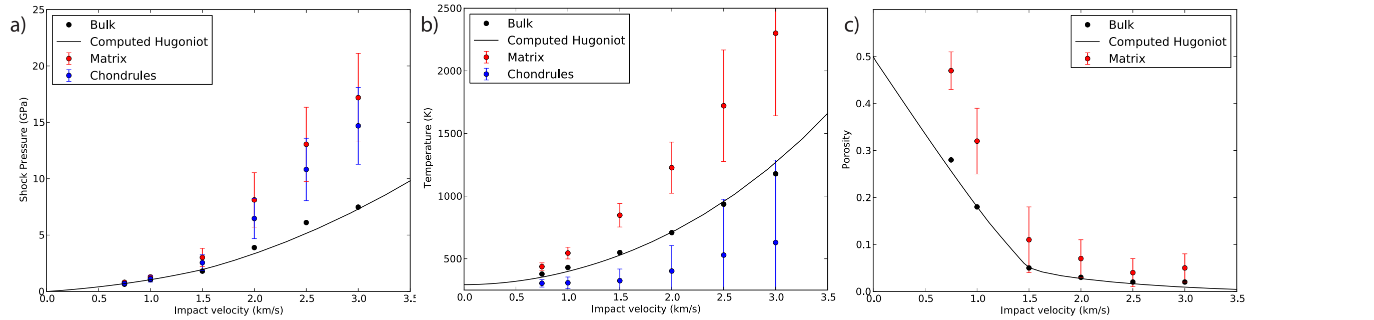

Figure 2: *Shock pressure (left), peak-shock temperature (middle) and post-shock porosity (right) as a function of impact velocity for a matrix volume fraction of 70%. Black symbols show bulk values of the state quantity, averaged over the entire sample region; red and blue symbols (and error bars) show mean (and standard deviation) of the state variable in the matrix and chondrule fraction, respectively.*

ple. By 24 μs, the shock wave has propagated through the sample plate, and a release (rarefaction) wave has been generated at the free-surface at the rear edge of the flyer plate, and is travelling through the flyer plate towards the cover and sample plates. Values of post-shock temperature and porosity were recorded just after the release wave had passed through the sample mixture (e.g. 48 μs in Figure 1).

The bulk (volume averaged) shock pressure, temperature and porosity of the mixture simulated using our new mesoscale model is consistent with previous macroscale models (using the bulk values as the initial conditions [e.g. 2]) and Hugoniot curves created with the $\varepsilon - \alpha$ porous compaction model (Figure 2a–c). The post-shock state of the mixtures can be compared with meteoritic evidence. For the simulation shown in Fig. 1, the final bulk porosity (18%; Figure 2c) and matrix fraction (54%) are consistent with the measured properties of carbonaceous chondrites [e.g. 7,8]. For a corresponding simulation with an initial matrix fraction of 30%, the final bulk porosity (4%) and matrix fraction (16%) are similar to measurements from ordinary chondrites [e.g. 7,8].

Resolving at the finer mesoscale, our simulations reveal a complex, heterogeneous response to shock within the mixture. While peak pressures are similar in the chondrules and the matrix, for $v_i > 1.5$ km/s they are ~ 2 times higher than the average bulk pressure recorded (Figure 2b); this is a consequence of the mesoscale structure, which creates resonant oscillations about the steady wave amplitude, the peaks of which are recorded in the chondrules and matrix. This behaviour has been observed in laboratory experiments and numerical models of granular materials and porous rocks [9–11].

Moreover, there is a large dichotomy between the temperatures recorded in the matrix and the chondrules: The massive difference in compressibility between the porous matrix and the nonporous chondrules results in much greater energy deposition in the matrix. Consequently, while the chondrules record only a modest temperature change, well below the bulk temperature increase, the post-shock temperature increase in the matrix is much larger (several hundred K) than in the bulk and highly variable. The juxtaposition of hot matrix and cold chondrules imply that the temperature difference is short-lived: the chondrules act as a heat sink, equilibrating the mixture to the bulk post-shock temperature in seconds.

Conclusions: For a range of impact velocities and initial matrix fractions, our mesoscale simulations can produce final materials with meteorite-group-like properties (porosity, matrix abundance) from low-velocity impacts on primordial solid materials. Even at low velocities, transient temperature excursions in the matrix can be much higher than the bulk temperature. Using this method to model specific scenarios (specific rocks, compositions and mixtures of components), and matching them to meteorite groups allows, for the first time, a full quantitative analysis of the shock evolution of primitive materials, and thus enables a firm link between numerical modeling and measurements of meteoritic samples.

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