SHOCK-DARKENING IN ORDINARY CHONDRITES: PRESSURE-TEMPERATURE p-T CONDITIONS STUDY BY IMPACT MODELLING. J. Moreau[1], T. Kohout[1,2] and K. Wünnemann[3], [1]Department of Physics, University of Helsinki, Finland (julien.moreau@helsinki.fi), [2]Institute of Geology, The Czech Academy of Sciences, Prague, Czech Republic, [3]Museum für Naturkunde, Berlin, Leibniz Institute for Evolution and Biodiversity Science, Berlin, Germany.

Introduction: Shock-darkening in ordinary chondrites is the partial melting of metals and iron sulphide in a network of melt into veins and the silicate cracks, remaining solid themselves. With the recent fall of the

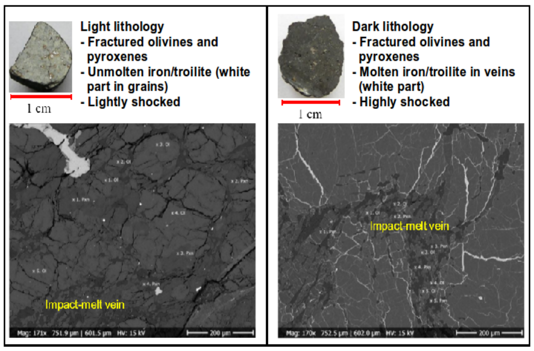

Fig 1. Chelyabinsk meteorite samples and their electron microscope snapshots.

Chelyabinsk LL5 meteorite, such features has been studied in [1] and can be seen in Fig. 1. It is a cause for the changes in the reflectance spectra of these meteorites, making their classification more difficult ([2], [3]). In such cases, S-type asteroids (chondritic silicate composition) spectra look like C-type asteroids (associated with carbonaceous chondrites).

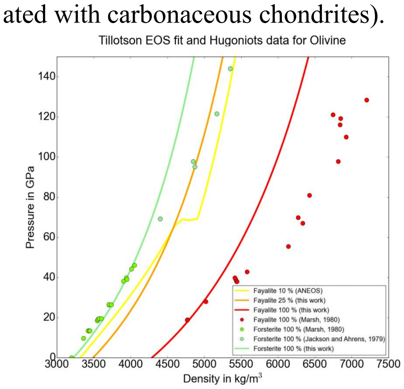

Fig 2. Hugoniots data for the olivine solid-solution (from Tillotson EOS, ANEOS and literature) given for density and pressure.

Methods: To study the pressure and temperatures p-T conditions at which this process occurs, we use the shock physics code iSALE [4]. In the parameters we include materials typical of ordinary chondrites:

- olivine (Fa_{25} or Fa_{10}) at ~96%
- iron grains and or/troilite (approximated in the models with a pyrrhotite material)

Olivine has a porosity of 6%. These settings are consistent with an LL5 ordinary chondrite with a composition dominated by olivine Fa_{27}, iron metal and troilite.

Equations of state (EOS). An equation of state describes a material behavior under shock-pressure. It can be compared to shock experiment Hugoniots data. We used either a Tillotson EOS [5] or an analytical EOS (ANEOS). Both EOS require a number of material-specific input parameters such as:

- the density
- the bulk modulus
- the internal energy
- the compression

In Fig. 2 and Fig. 3, the Hugoniots data from the Tillotson EOS, ANEOS and literature for different material including olivine Fa_{25} [adapted from 6] and Fa_{10} (ANEOS) can be seen. One issue is the limitation of the Tillotson EOS not accounting for phase changes in olivine.

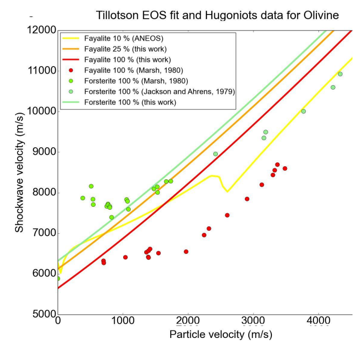

Fig 3. Hugoniots data for the olivine solid-solution (from Tillotson EOS, ANEOS and literature) given for particle and shock-wave velocities.

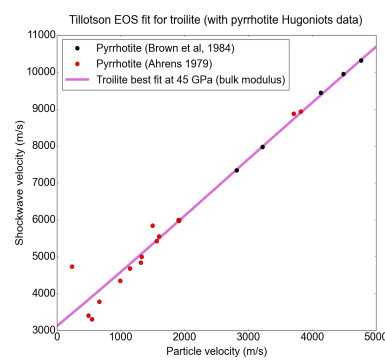

Fig 4. Hugoniots data for pyrrhotite to which a Tillotson EOS for troilite is fit to be used in the modelling. The bulk modulus was one of the only parameters that needed to be changed from the Tillotson EOS parameters to fit the data points.

Low pressures phases are well fitted in the first graphic (Fig. 2) but is an issue in the second (Fig. 3, important for the post-shock temperatures calculation). In Fig. 4 a good fit for the Tillotson EOS of Troilite to pyrrhotite iron sulphide can be seen.

Porosity and strength. In iSALE, porosity is considered in two ways: finely dispersed in the material (as a material parameter, distension $\alpha = 1 / (1-\Phi)$ where Φ is the porosity fraction [4]) or in resolved individual pores. In the models we use the distension α. Concerning the strength model, the material is defined either as hydrodynamic or perfect plastic (Von Mies model, using the yield strength as the only parameter).

Post-shock temperatures (PST's). To study the melt fraction, we defined the post-shock temperatures relative to the peak-shock pressures. After the shock-wave, pressures drop to 0, residual energy is translated to post-shock temperatures (Fig. 5). We used a linear relationship existing in the Hugoniots data (see Fig 3 and Fig. 4) giving $U = C + S.up$, with up – particle velocity and U – shock-wave velocity. [7,8,9]

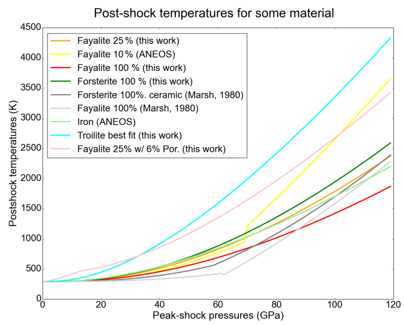

Fig 5. Graphic evolution of the post-shock temperatures at different peak-shock pressures. Note: peak-shock pressures reached by the materials depend on their Hugoniots data.

Results: Using tracers, we can study the peak-shock pressures in a material to compute the PST's. The melt fraction of the material is then assessed. In Fig. 6 can be seen a theoretical example of post-shock results using a mesoscale model with a 50 cells thick flyer plate (over the 0 mm mark in the first panel) hitting a 450 cells thick sample plate made of non-porous and hydrodynamic olivine Fa10 (ANEOS) and sub-mm iron grains (ANEOS).

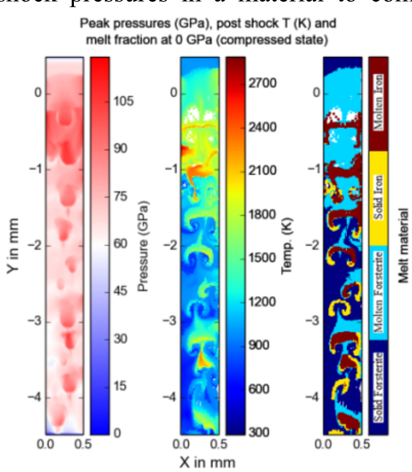

Fig 6 Theoretical results on a 50x500 cells model with a flyer plate hitting at 5 km/s a 450 cells thick sample made of olivine Fa10 where sub-mm iron grains are randomly resolved. The iron behaviour made it reflecting the shock-wave back to the forsterite, heating it. The iron is also subject to higher peak-shock pressures (as seen in the red circled zone of the first panel). Post-shock temperatures in the second panel allow us to compute the melt fraction in the third panel where the material is distinguished.

Conclusion: The key result of our study is the behaviour of the material under shock pressures (EOS'). Using PST's and material melting temperatures, we obtained a good approximate for which material melts first. Furthermore, troilite seems to be the best candidate for a complete melt with an unmolten or partially molten silicate phase. We also noticed the strong dependence of the material and the associated EOS' and Hugoniots data. A propagating shock-wave will cause reflections on the iron grain boundaries with olivine where the peak-shock pressures attained will depend on the material and how well it reflects the shock-wave. Such shock-wave reflection will heat the surrounding material (olivine) due to higher reflected peak-shock pressures.

Future Work: From constraining the material EOS, the strength model and porosity, the next step is to implement a mesoscale model [10] with olivine, iron and troilite grains included (separately or together). Completing this study will help us to get the best p-T conditions at which shock-darkening occurs and therefore leading to experiments with real samples.

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