Shock-darkening in Ordinary Chondrites: Pressure-Temperature p-T Conditions Study by Impact Modelling

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INTRODUCTION

Shock-darkening is a shock process associated with partial melting of metal and iron sulphide observed in various ordinary chondrites (e.g. Chelyabinsk LL5 meteorite [1], figure 1). It alters meteorite reflectance spectra from S-type asteroids (chondritic silicate composition) to look like C-type asteroids (generally associated with carbonaceous chondrites [2], [3]).

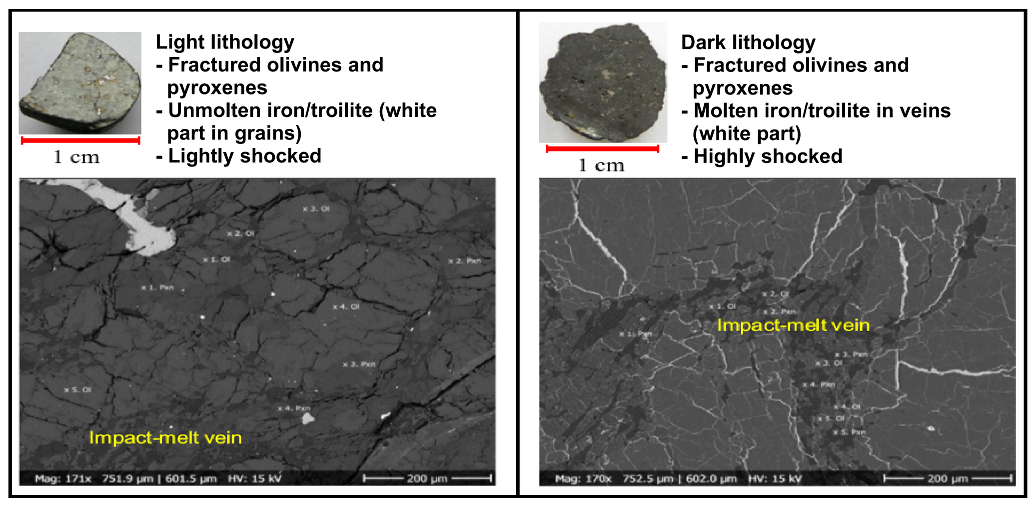

Fig 1. Chelyabinsk meteorite samples and their electron microscope snapshots.

METHODS

For the study, we use the shock physics code iSALE [4], applying different materials with equations of state (material behaviour under shock-pressure conditions):

- olivine (either $Fa_{18\text{-}29}$ or Fa_{10})
- iron and/or troilite grains (troilite is approximated by a pyrrhotite material as seen in figure 2 for the pressure/density and shock-wave and particles velicities ranges)

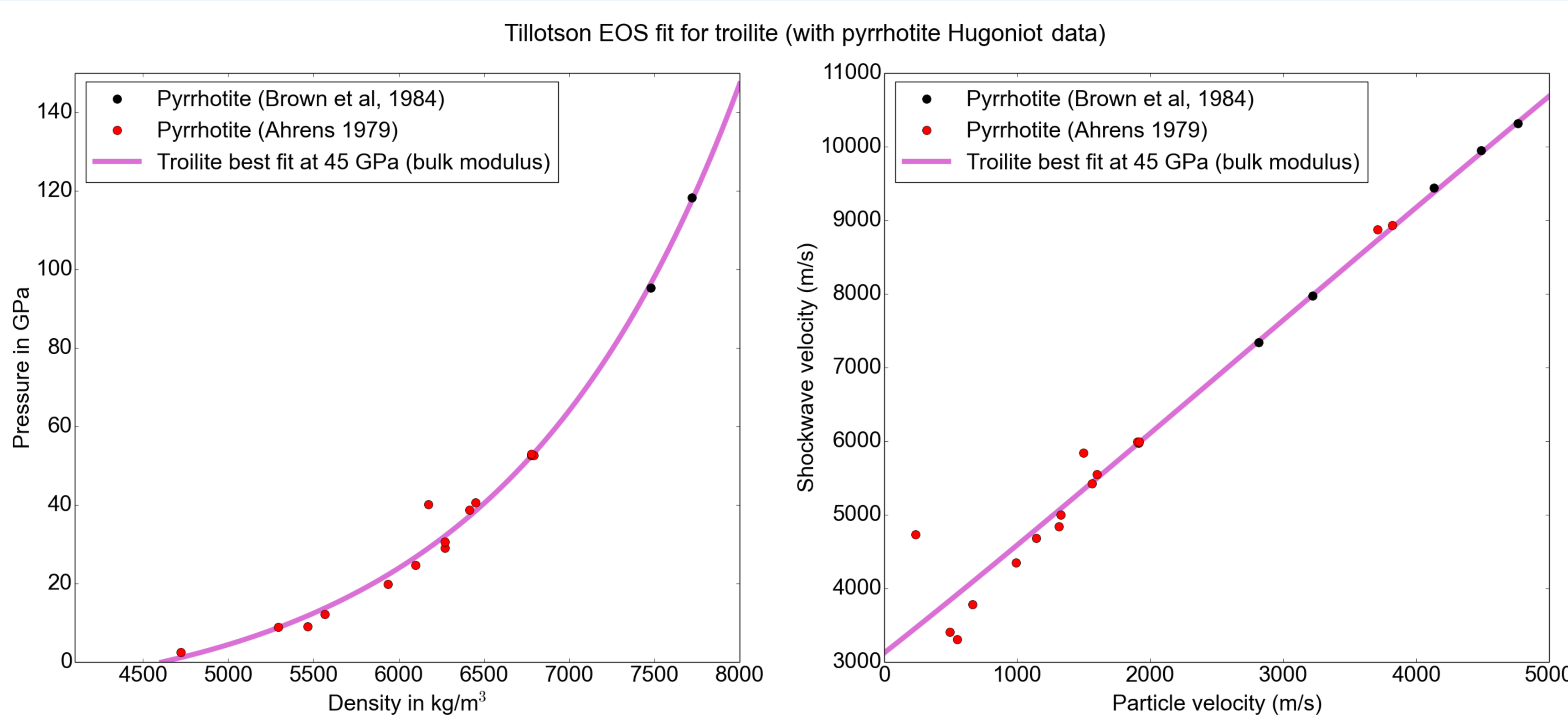

Fig 2. Hugoniot data for pyrrhotite to which a Tillotson equation of state (EOS) [5] for troilite is fit to be used in the modelling.

MODELS SETTING AND RESOLUTION

The models we used are composed of different layers [6]:

- a thick flyer-plate (olivine)
- a upper buffer plate (olivine)
- a sample plate (olivine and grain particles)
- a lower buffer plate (olivine).

In figure 3 can be seen a cartoon of the models setting in relative cell size. Our resolution is based on grains resolution and ranges between 24 to 72 cells per grain diameter.

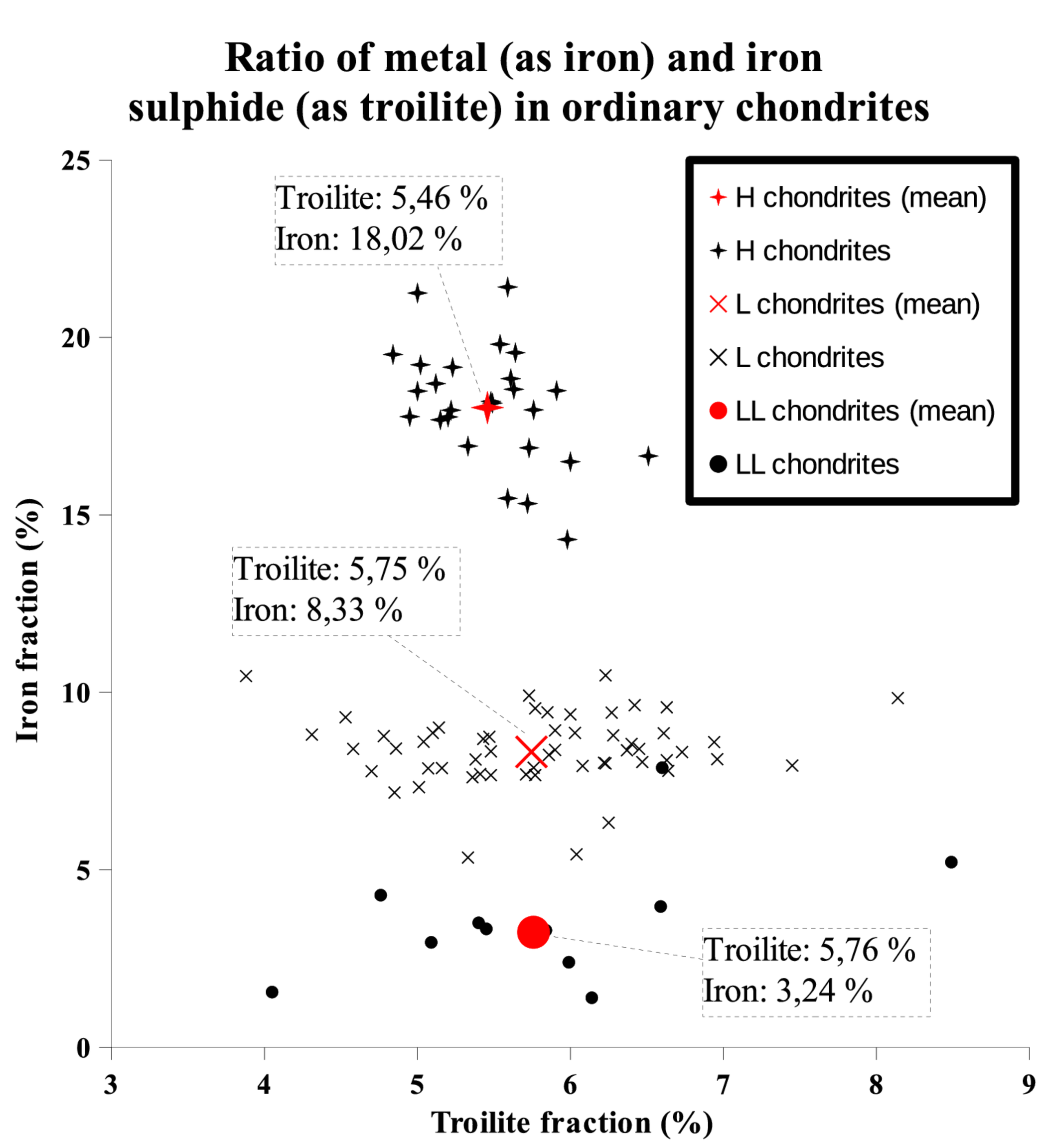

Fig 4. General composition of iron and troilite in ordinary chondrites.

CHONDRITES: COMPOSITION, PARTICLES DISTRIBUTION (IRON AND TROILITE)

To know the particles distribution in our models, we used the data from [7], as seen in figure 4, to model H, L and LL chondrites (red dots are the average distributions). We assigned thermal properties typical for each type of meteorite for olivine with 6% porosity.

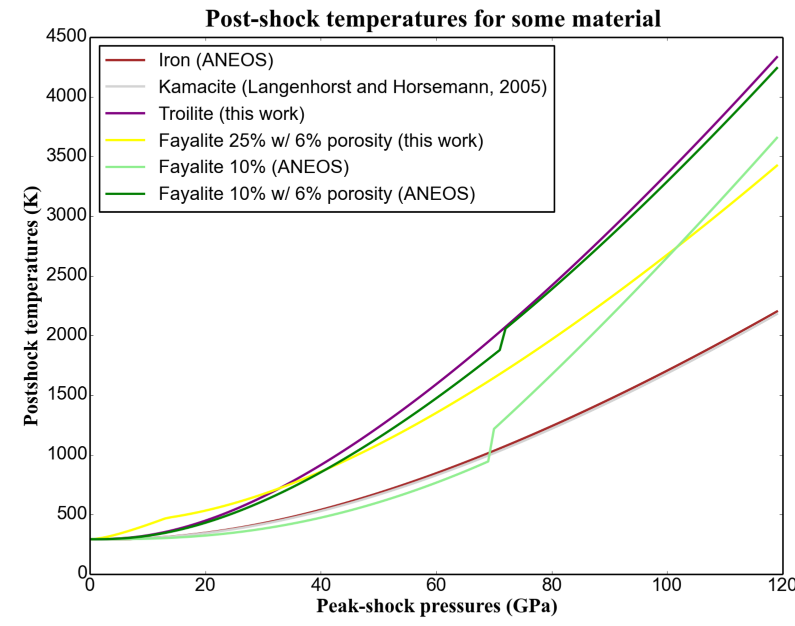

Fig 5. Graphic evolution of the post-shock temperatures at different peak-shock pressures. Note: peak-shock pressures reached by the materials depend on their Hugoniot data.

POST-SHOCK TEMPERATURES (PST's)

To study melt fractions, we defined post-shock temperatures relative to peak-shock pressures [8,9,10]. After pressures drop to 0, residual energy is translated to heating (figure 5). Using material heat capacity c_p ($J.kg^{-1}.K^{-1}$) with parameters of a linear relationship (figure 2, right) $U = C + S.u_p$, (u_p – particles velocity, U – shock-wave velocity), PST's can be assessed:

$$\Delta T = \frac{1}{c_p}\left(\frac{u_p^2}{2} - \left(\frac{C}{S}\left(u_p + \frac{C}{S}\ln\left(\frac{C}{U}\right)\right)\right)\right) \quad (1)$$

RESULTS

Getting peak-shock pressures in the material, we assess the melt fractions by calculating PST's. In figure 6 is a compilation of three different models results: 4% of iron, 4% of troilite and H chondrite composition. In figure 7 can be seen an example of post-shock results in mesoscale models representing H ordinary chondrites.

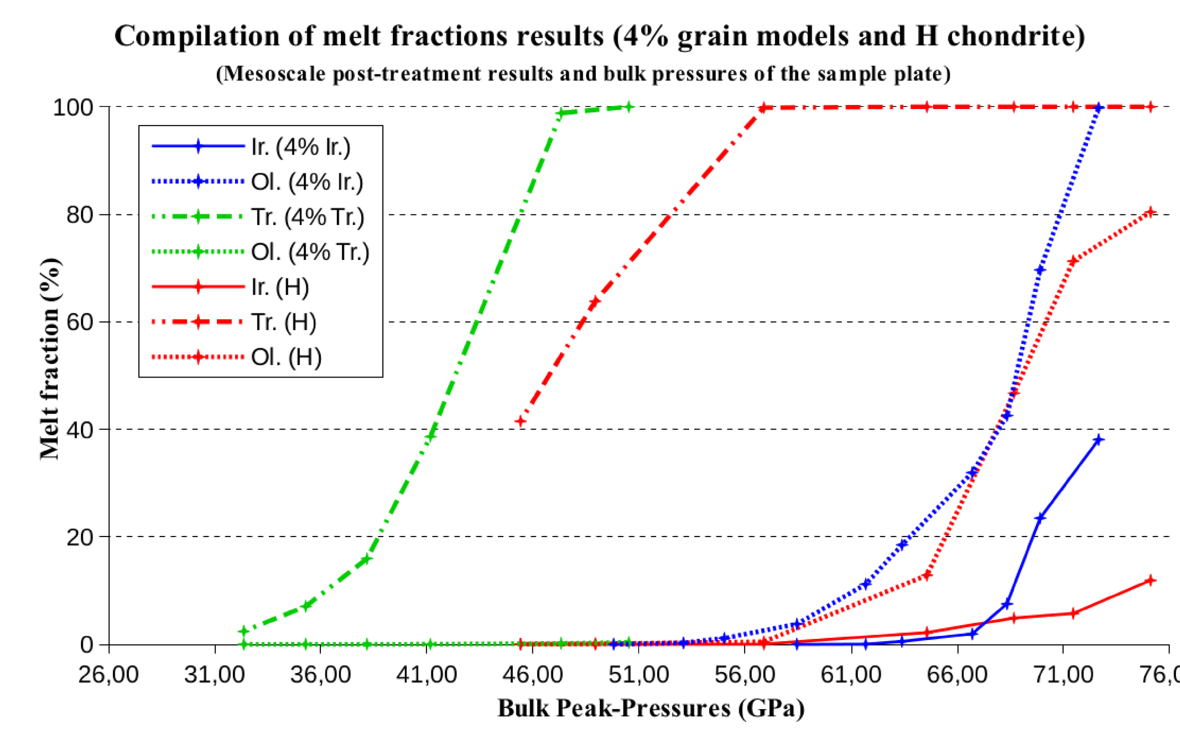

Fig 6. Mesoscale post-treatment results for models with either 4% of iron grains or 4% of troilite grains in olivine (with thermal properties of olivine Fa_{25}) and H chondrite composition (based on figure 4 distribution).

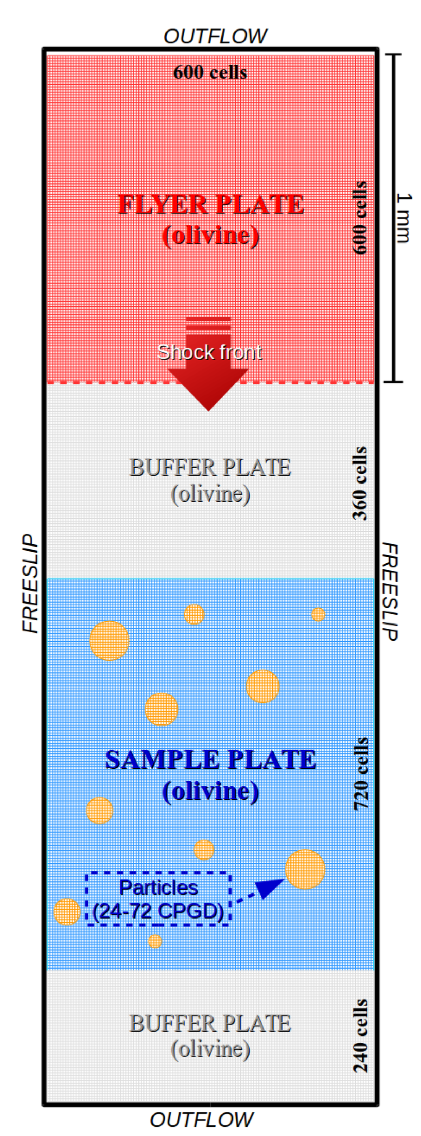

Fig 3. Mesoscale model conception.

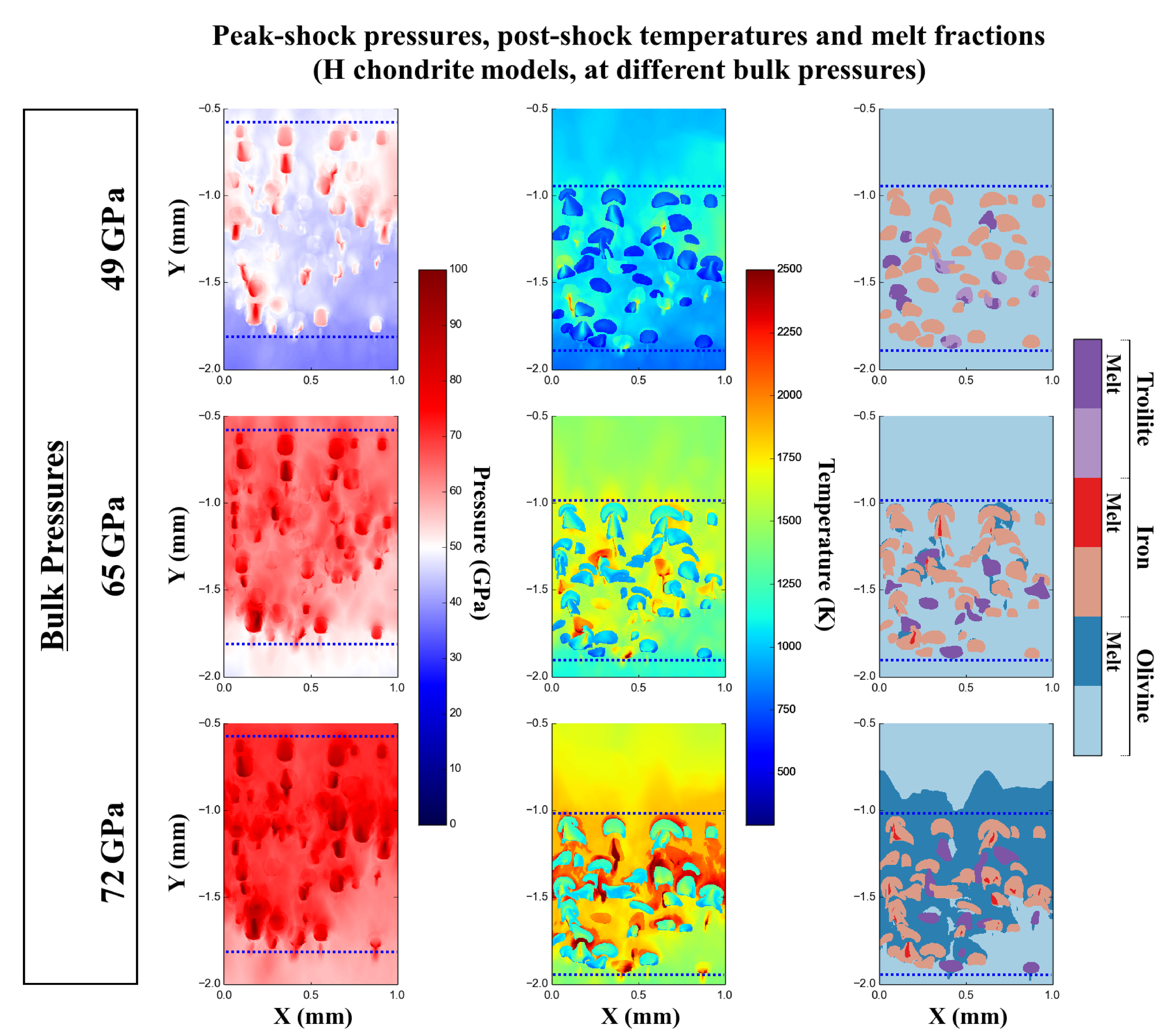

Fig 7. H chondrite mesoscale models post-treatment of the post-shock temperatures and the melt fraction with peak-shock pressures. The models are in compressional stage for the temperature and melt panels. Dashed lines delimit the sample plates.

CONCLUSIONS

Troilite melts at lower bulk pressures than iron (with an already partially molten silicate phase). By looking at figure 4, we can suspect different melt fractions for different compositions due to the iron grains abundance. The key is the behaviour of material under shock-pressures and how the material can be heated under specific shock pressures. Future models will help us to understand and assess the melt fractions for different compositions. Results from these numerical experiments will help us to determine the best p-T conditions for shock-darkening to occur.

ACKNOWLEDGEMENTS

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[1] Kohout *et al.* (2014), [2] DeMeo *et al.* (2009), [3] DeMeo and Carry (2014), [4] Wünnemann *et al.* (2006), [5] Tillotson (1962), [6] Bland *et al.* (2014), [7] McSween *et al.* (1991), [8] Artemieva and Ivanov (2004), [9] Fritz *et al.* (2005), [10] Watters et al. (2009)