SHOCK-DARKENING IN ORDINARY CHONDRITES: MESOSCALE MODELING OF THE SHOCK PROCESS AND COMPARISON WITH SHOCK-RECOVERY EXPERIMENTS. J. Moreau[1], T. Kohout[1,2] and K. Wünnemann[3], [1]Department of Geosciences and Geography, University of Helsinki, Finland (juulia.moreau@helsinki.fi), [2]Institute of Geology, The Czech Academy of Sciences, Prague, Czech Republic, [3]Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science – Freie Universität, Institute of Geological Sciences, Berlin, Germany.

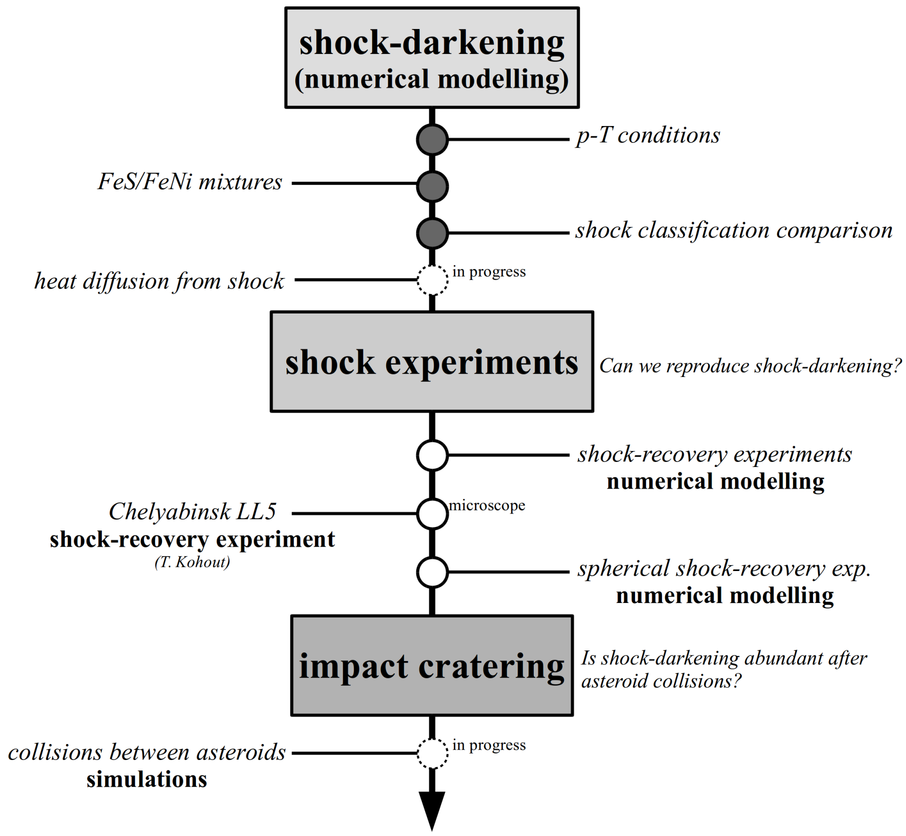

Fig 1. General overview of the project with published or submitted researches (dark circles), additional research results (white circles) with a few research in early stage of investigation (dashed circles)

Introduction: Shock-darkening in ordinary chondrites is a shock process featuring melting of metals and iron sulfides spreading into a network of tiny melt veins in cracks between silicates and inducing darkening of the lithology [1-5]. The darkening alters the reflectance spectra of meteorites by removing silicate absorption bands [5]. Because asteroids are classified using reflectance spectra [6], S-complex asteroids (hosting ordinary chondrites) affected by shock-darkening will have reflectance spectra similar to those of C-complex asteroids, introducing an eventual mismatch in the distribution of asteroids in the Main Belt.

This project aims to:

(1) estimate and understand the pressure and temperature conditions at which shock-darkening is likely to occur in ordinary chondrites.

(2) understand shock-recovery experiments in more details to decide which technique from the reverberation [7,8] or the spherical shock [9] is best to reproduce shock-darkening in experimentally shocked ordinary chondrites to support the previous research topic results

(3) investigate asteroid collisions to estimate the amount of material shocked at pressures to produce shock-darkening, a first step to estimate the amount of shock-darkened materials in the Main Belt.

In Fig. 1 is shown the general flow of the research in which are also carried out microscope observations of experimentally shocked ordinary chondrites and first investigation of heat diffusion in numerically shocked ordinary chondrites.

Methods: To carry out most of the research topics (points 1, 2, and 3 of the introduction) we used the shock physics code iSALE [10] to setup:

(1) mesoscale models to enable shock compression of multi-phase samples containing, in various amounts: olivine, iron, troilite, albite, or open pores [11-13]
(2) mesoscale models reproducing the shock conditions for shock-recovery experiments using either the reverberation or the spherical shock technique
(3) large scale impact models to reproduce collisions between asteroids with projectiles, and spherical or planar targets, of various porosities and impact velocities.

Results and discussion: First, using the mesoscale models for compression of ordinary chondrites, we draw the main conclusions [11-13] that:

(1) Shock-darkening, dominated by iron sulfide melting, is characteristic of the 40–60 GPa shock pressure range.

(2) Impedance contrasts between phases cause heterogeneous distributions of peak shock pressures and post-shock temperatures in ordinary chondrites.

(3) Eutectic melting, strong shock wave interactions, or pore crushing, are conditions that can lead to melting of metals.

(4) The shock classification of ordinary chondrites [14] is strongly dependent on the precursor porosity and pre-heating conditions.

Second, by comparing the two techniques for shock-recovery experiments, we showed that reaching shock entropy for shock-darkening in ordinary chondrites is difficult using the reverberation technique [15]. A reverberated shock will not amount to the entropy of a single shock necessary to melt iron sulfides and/or metals. Therefore, the spherical shock technique should be used instead because this technique generates shock compression in a wide range of pressures in one sample, without reverberations asides from the diverging shock wave. A couple of researches [16,17] succeeded to produce shock-darkening in shock-recovered ordinary chondrites, but at different degrees of achievement: very few zones of shock-darkening with the reverberation technique at pressures ~40 GPa [16] or whole area shock-darkening with the spherical shock technique at pressures ~50 GPa [17].

Finally, most recent results demonstrate that the amount of material shocked between 40 and 60 GPa can be one half to third times the projectile volume in 10 km/s asteroid impacts on asteroidal targets of various porosities (Fig. 2).

Conclusions: This project demonstrated the use of numerical modeling, from the millimeter scale to the kilometer scale, with one common thread that is shock-darkening. Our results may show that shock-darkening is a rather common process in the evolution of the Main Asteroid Belt, but which still needs further studies using appropriate shock-recovery experiments and more extensive investigation of asteroid collision modeling and statistics.

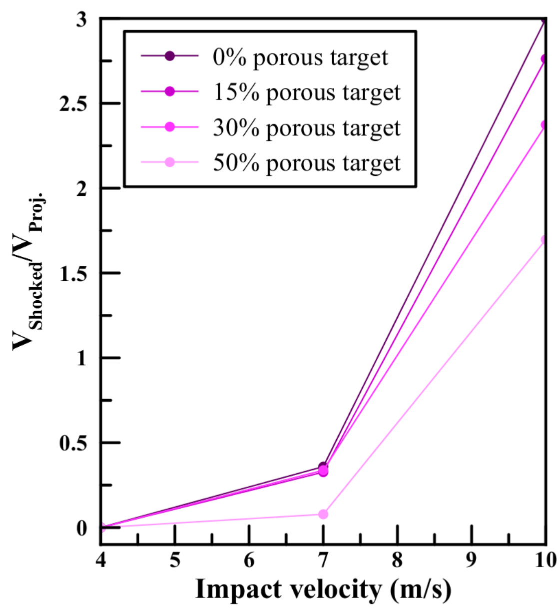

Fig 2. Volumes of material shocked at 40–60 GPa in simulations of collisions between asteroids in function of impact velocity and porosity on planar targets. Projectile size was 0.8 km, 30% porous, with dunite material used for both projectile and target. The simulation resolution was 80 CPPR (cells per projectile radius). Strength properties were used but didn't vary with porosity.

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References: [1] Heymann D. (1967) *Icarus*, 6, 189-221. [2] Britt D. T. et al. (1989) Proc. *19th LPSC*, 537-545. [3] Britt D. T. and Pieters C. M. (1989) Proc. *20Th LPSC*, 109-110. [4] Britt D. T. and Pieters C. M. (1994), *Geochim. Cosmochim. Acta*, 58(18), 3905-3919. [5] Kohout T. et al. (2014) *Icarus*, 228, 78-85. [6] DeMeo F. E. and Carry R. P. (2014) *Nature*, 505, 629-634. [7] Langenhorst F. and Deutsch A. (1994) *Earth Planet. Sc. Let.*, 125, 407–420. [8] Langenhorst F. and Hornemann U. (2005) *EMU Notes Mineralog.*, 7(15), 357-387. [9] Kozlov E. A. and Sazonova L. V. (2012) *Petrology*, 20(4), 336-346. [10] Wünnemann K. et al. (2006) *Icarus*, 180, 514-527. [11] Moreau J. et al. (2017) *Meteorit. Planet. Sci.*, 52(11), 2375-2390. [12] Moreau J. et al. (2018a). *Phys. Earth Planet. In.*, 282, 25-38. [13] Moreau J. et al. (2018b). *Icarus*, submitted. [14] Stöffler D. et al. (1991). *Geochim. Cosmochim. Acta*, 55(12), 3845-3867. [15] Moreau J. et al. (2018) *EPSC 2018*, vol. 12, abstract #212. [16] Schmitt R. T. (2000) *Meteorit. Planet. Sci.*, 35, 545-560. [17] Kohout T. et al (2018) *EPSC 2018*, vol. 12, abstract #827.