HEAT DIFFUSION IN SHOCKED CHONDRITES: TOWARDS A BETTER UNDERSTANDING OF SHOCK MELTING FEATURES.

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Introduction: The reflectance spectra of ordinary chondrites, which are commonly used as reference data to interpret asteroid spectra, can be significantly altered by darkening of the lithology caused by localized shock melting of metals and iron sulfides. To improve our understanding of this shock-darkening process, several studies have employed numerical modeling with the iSALE shock physics code [1] in order to investigate the pressure and temperature conditions of localized shock melting in ordinary chondrites [2–4]. However, these simulations failed to reproduce melting of pure metals and metals in eutectic mixtures with iron sulfides, or the intermixed melting of metals with silicates, all of which are commonly observed features in shocked ordinary chondrites. The main reason for the lack of metal melting lies in the impedance properties of the iron grains that tend to reflect rather than absorb shock wave energy and hence experience very little heating by shock compared to adjacent sulfide or silicate grains.

Differences in the shock wave impedance properties on the grain scale lead to high contrasts of post-shock temperatures between iron sulfides, or silicates, and metals (>400 K [3,4]). Such temperature contrasts on the µm scale can be expected to be leveled quickly by heat diffusion. However, the process of heat diffusion is not implemented in the iSALE code and hence has not been considered in previous studies. To obtain a more realistic model of shock melting in ordinary chondrites, we simulated post-shock heat diffusion on the grain scale using 2-D post-shock temperature maps produced by the iSALE code as initial conditions [5]. To reproduce observed melting features, we implemented simplified textural models with different grain configurations typical of textural features in ordinary chondrites. In addition we systematically investigated the effects of shock pressure, porosity, grain size and grain orientation relative to the direction of the shock wave on the degree of shock melting.

Methods: We set up 12 textural models and used the iSALE code to determine 2-D-maps of post-shock temperatures, following the procedure described in [3,4]. These maps were further processed using a 2-D heat diffusion code that exerts a finite difference solution for multi-phase meshes and heterogeneous thermal diffusivities with Dirichlet boundary conditions, update of phase thermal diffusivities according to current local temperatures and consideration of partial melting with change of state.

For simplification, the code only considers:

- post-shock heat diffusion, without consideration of heat diffusivity change with pressure
- even-spaced nodes of different materials (identical to the uncompressed state of the iSALE meshes)
- simplified eutectic properties (melting temperatures of 1261 K for iron or troilite phase in mixtures).

The distribution of temperatures, melt fractions and thermal diffusivities was recorded for each timestep of the diffusion model in order to track the change of these properties with time.

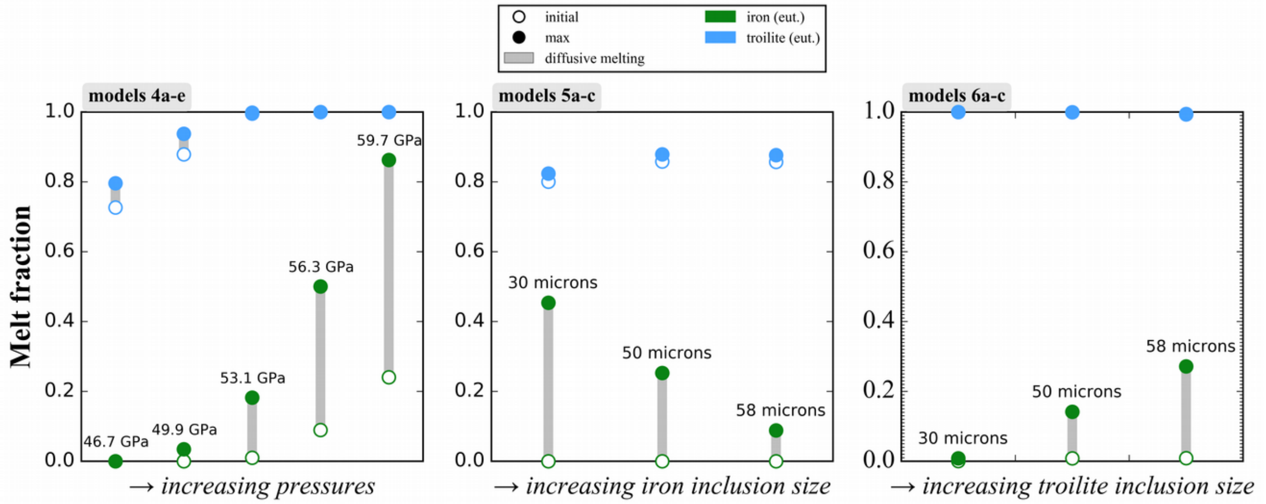

Fig 1. Melt fractions in iron (green) and troilite (blue) grains before (plain circles) and after (open circles) heat diffusion, illustrating the effects of a) increasing pressures (models 4a-e), b) the size of iron inclusions in troilite (models 5a-c), and c) the size of troilite inclusions in iron (models 6a-c). Results corresponding to the same model are aligned at the same position along the horizontal axis. The values for the corresponding parameters in each model are indicated by black labels. The continuous gray bars between data correspond to the contribution of heat diffusion to the total melt fraction observed in the respective phase. [1, modified]

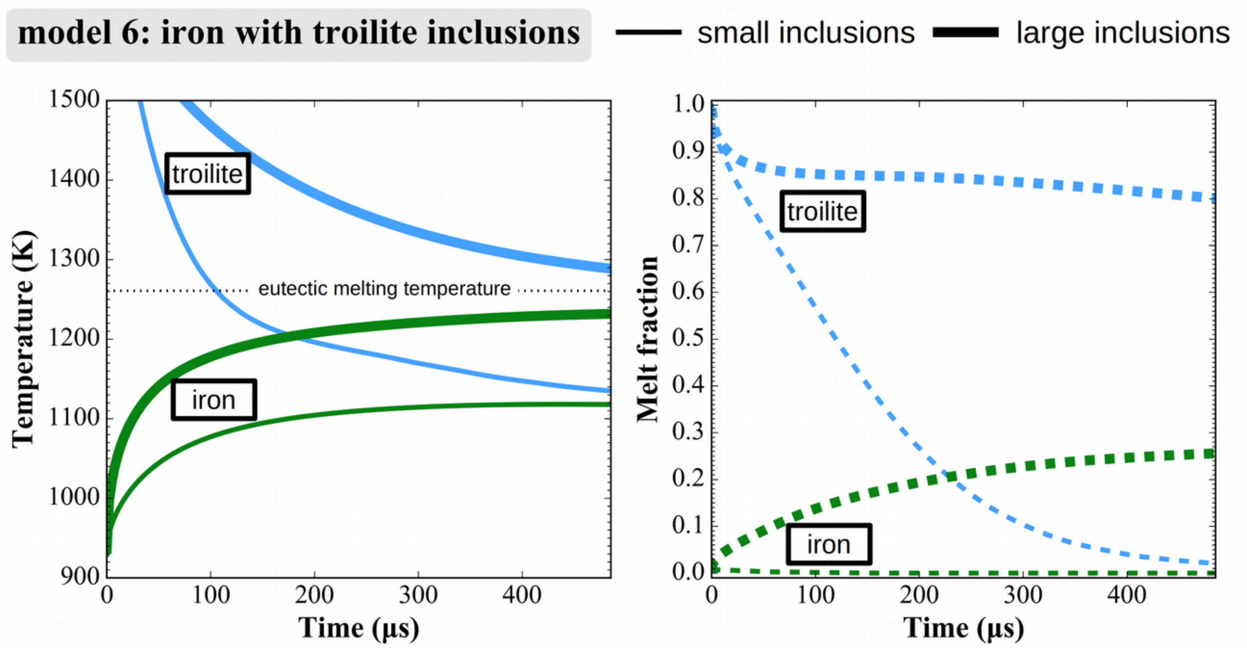

Fig 2. Temperatures and melt fractions as functions of diffusion time for two models of iron grains (240 μm diameter) with larger (58 μm diameter, thick lines) or smaller (30 μm diameter, thin lines) troilite inclusions. When shock heated troilite inclusions are larger, more heat is transferred into the iron grain which leads to the partial melting of iron. [1, modified]

Results: The consideration of heat diffusion has a significant effect on the modeled post-shock heat distribution and the resulting degrees of shock melting experienced by individual phases. In Fig. 1 we compile results of models representing mixtures of iron and troilite. Similar to previous studies, we find that individual phases experience different degrees of heating by the shock wave due to their different shock wave impedances. Most notably, troilite is strongly heated and easily melted by shock, while shock heating of iron is limited. However, if iron is intergrown with strongly shock heated phases like troilite, as it is often observed in ordinary chondrite textures, iron can melt from the heat transfered by diffusion from neighboring grains, especially if those grains are larger, and hence provide more heat for melting iron (Fig. 2).

Discussion and conclusions: Our results indicate that iron melts not by initial shock heating but by diffusion of heat from adjacent, strongly shock heated phases. This is consistent with textural observations in ordinary chondrites like intermixed melting of iron and shock heated albite and the presence of iron metal in shock melt veins. Our work also illustrates the importance of the time scales of shock heating and heat diffusion for the formation of shock melt features. For example, shock-darkening might not occur if any of the phases cool down and solidify before opening of the silicate cracks upon release of the shock wave. Hence, the shock wave duration and consideration of heat diffusion during the shock wave might be important for the understanding of shock melt migration in natural samples. In shock recovery experiments the time scale of the shock pulse is typically <1μs [6], so that the time scale of the shock pulse never exceeds the time scales relevant for heat diffusion. However, large scale impacts like asteroid collisions involve shock pulse durations of 100-1000ms [7], which exceeds the time scales of heat diffusion by several orders of magnitude. Hence, a better understanding of the formation conditions of melt features in ordinary chondrites requires further study considering heat diffusion and the associated changes in heat distribution during shock.

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