Heat Diffusion in Shocked Chondrites
Towards a Better Understanding of Shock Melting Features

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Shock-darkening in the **Chelyabinsk LL5 ordinary chondrite** (back-scattered electron microscope image)

INTRODUCTION

Current numerical models of shock heating in ordinary chondrites [1-4] fail to reproduce the extensive melting of iron metal leading to shock-darkening (darkening of the lithology by the formation of iron metal and sulfide melt veins). One reason for this is that the numerical models did not consider heat diffusion, even though shock waves produce strong temperature contrasts among neighboring grains in chondrite textures. We model shock heating and post-shock heat diffusion in ordinary chondrite textures in order to reproduce observed degrees of iron metal and sulfide melting.

METHODS

We designed several 2-D multi-phase models representing typical textural features of ordinary chondrites and simulated shock heating in these models using the iSALE shock physics code [1], assuming shock pressures of 40-60 GPa (the typical pressure range for shock-darkening). Resulting post-shock temperature maps were used as input for a heat diffusion code with integrated thermal diffusivity and melting models for all considered phases (olivine, iron, troilite, albite, pyroxene and eutectic iron-troilite mixtures). Using this code we simulated the progressive relaxation of temperature contrasts among neighboring grains and concurrent melting or crystallization of individual phases.

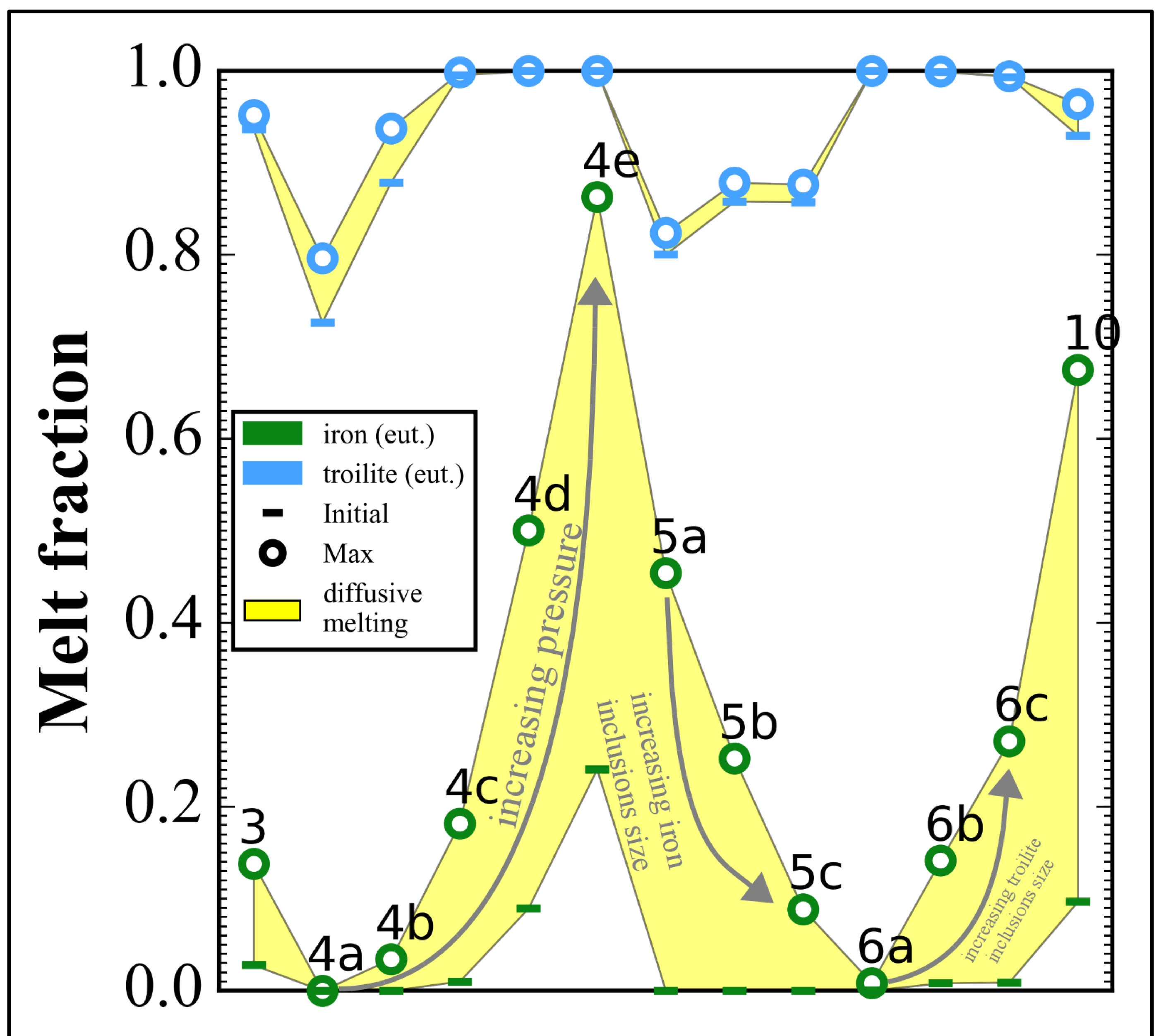

Fig. 2. Contribution of shock heating and heat diffusion to melting in models simulating different textures (labeled 3-10) featuring intergrown iron and troilite grains. The models simulate contacts between two equal sized adjacent grains (models 4, 10), iron grains with troilite inclusions of different sizes (models 3, 6, 10) or troilite grains with iron inclusions (model 5). Data points corresponding to the same model are placed at the same level on the x-axis. Model variations are indicated by labels a-e and the type of variation is specified by the descriptions on the gray arrows. Colored dashes indicate the initial melting of iron and troilite by shock, while open circles indicate the total fraction of the phase that has experienced melting during the runtime of the model. The difference between these values is highlighted by the yellow shading and represents the contribution of heat diffusion to the total degree of melting.

RESULTS

At shock pressures typical for shock-darkening (40-60 GPa), modeled iron metal grains are not sufficiently heated by direct absorption of shock wave energy to explain the high degrees of iron metal melting observed in experiments and natural samples (Figs. 1, 3). However, diffusion of heat from strongly shock heated adjacent phases (e.g. troilite or albite) into iron grains can induce substantial degrees of melting (Figs. 1-3). This strong contribution of heat diffusion to the degree of iron melting (see Fig. 2) can likely explain the formation of shock darkening metal veins. Post-shock heat diffusion can also explain local intermixed melting of iron, albite and olivine observed in ordinary chondrite textures (Fig. 3). In addition, pre-shock porosity was found to strongly influence local shock heating and melting (Fig. 3).

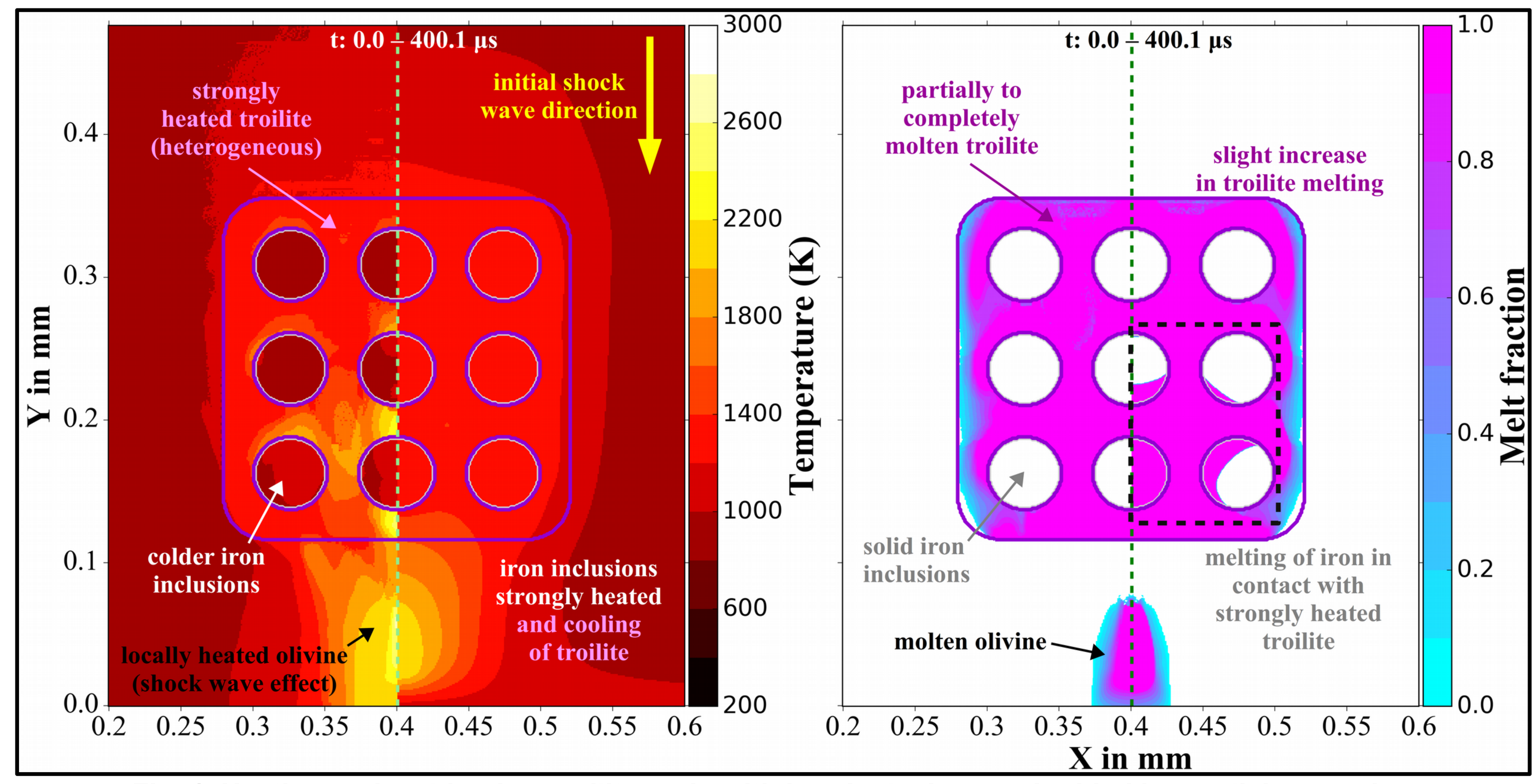

Fig. 1. Heating and melting in a troilite grain with iron inclusions embedded in an olivine matrix. Left diagram: Post-shock temperatures before (left side of the diagram) and after (right side of the diagram) 400µs of heat diffusion. Right diagram: Local melt fractions before (left side of the diagram) and after (right side of the diagram) 400µs of heat diffusion. The strong initial temperature contrast between iron and troilite leads to heating and melting of iron by heat diffusion.

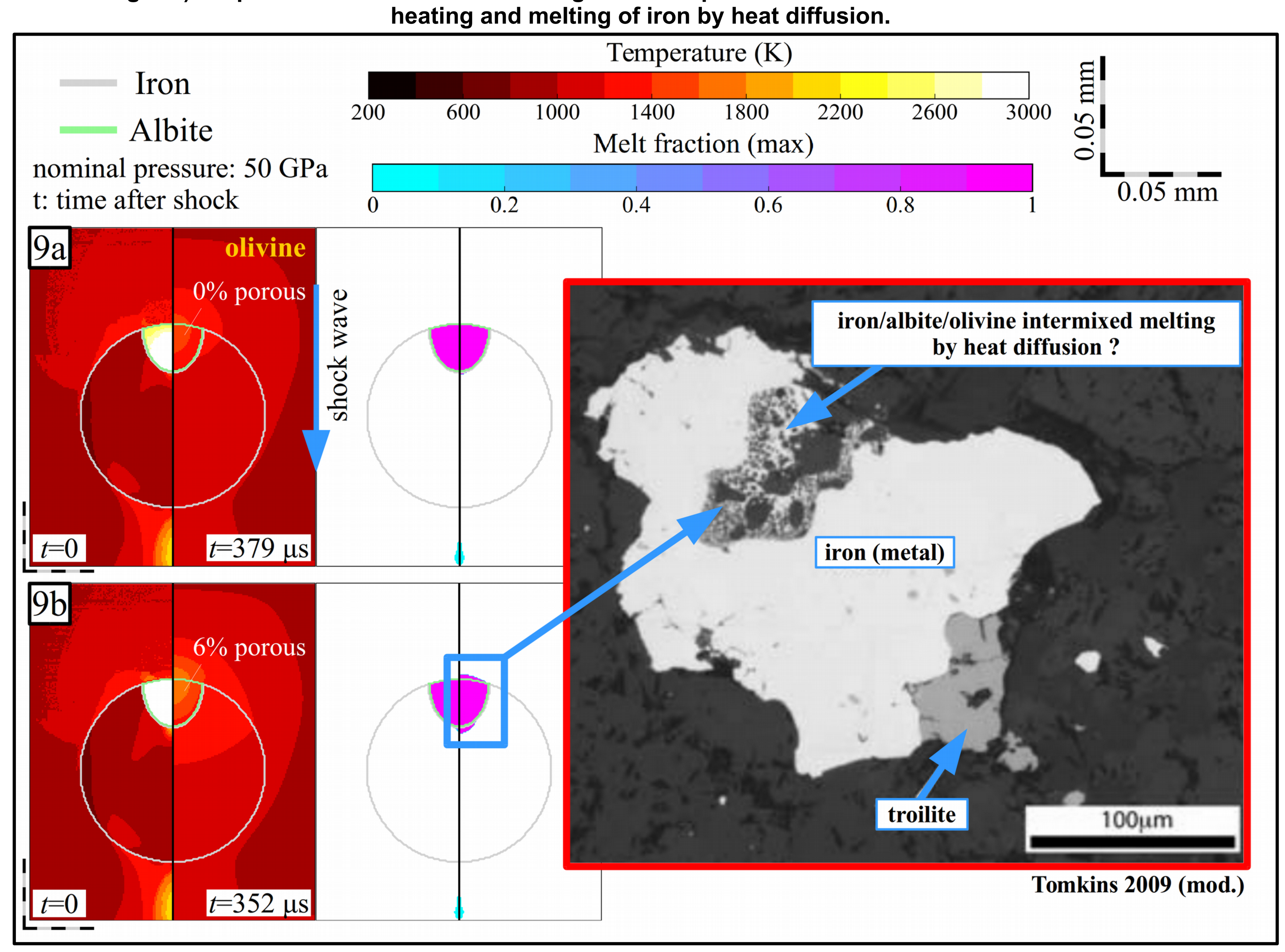

Fig. 3. Intermixed melting of metal and silicates in models (left) and observed chondrite textures (right). The diagrams on the left illustrate temperatures and melt fractions immediately after shock (t=0) and after a specified time of heat diffusion. The porosity of the albite grain is assumed to be either 0 % (model 9a) or 6 % (model 9b), which notably affects initial shock heating.

PROCESS	DURATION
collisions between asteroids (km-size)	100-1000 ms (shock pulse)
reverberation shock-recovery experiments	<1 µs (shock pulse)
thermal equilibration (grain scale)	0-500 µs (grain size and phase dependent)

DISCUSSION & CONCLUSIONS

Our results demonstrate that simulating heat diffusion on the grain scale is crucial for our understanding of shock melting features in ordinary chondrites (e.g. localized intermixed melting and melting of iron-troilite mixtures required for shock-darkening). In this study we simulate shock events with short shock pulse durations (< 1µs) characteristic for reverberation shock-recovery experiments. In such a setup the timescales of post-shock thermal equilibration on the grain scale are larger than the shock pulse duration. This justifies our approach of simulating shock heating and post-shock diffusion in consecutive modeling steps. In natural impact scenarios shock pulse durations can significantly exceed the typical timescales of local thermal equilibration (see table on the right). Hence, simulating heat diffusion during, not after, passing of the shock wave might provide further insights in the formation mechanisms of observed melting features and allow a quantitative reproduction of melt fractions in naturally shocked chondrites.

Acknowledgements

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