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Shock-darkening in ordinary chondrites: Modeling of the pressure-temperature conditions

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Abstract

Shock-darkening in ordinary chondrites is the melting of iron sulfides and metals into a network of veins rendering the lithology darker. Using the shock physics code iSALE [7, 8] we determined the shock-darkening pressure range to be 40-50 GPa for the melting of iron sulfides. Modeling and thermal effect uncertainties are also discussed in our work.

1. Introduction

Shock-darkening in ordinary chondrites is the partial melting of metals and iron sulfides filling cracks within silicate grains [5]. It leads to optical darkening and makes asteroid classification more difficult [2, 3]. In such cases, S-type asteroids (chondritic silicate composition) spectra look like C-type asteroids (associated with carbonacaeous chondrites).

2. Methods

To study the pressure and temperature conditions at which this process occurs, we used the shock physics code iSALE [7, 8]. In our mesoscale models of a planar shock wave in 2D we study the complex interaction of shock wave with different mineral phases. We employ a model setup analogous to the setup in experiments: a flyer plate impacts a top buffer plate, which transmits the generated shock wave into the sample plate. A buffer plate at the bottom avoids boundary problems. All layers are composed of olivine. The pressure in the buffer plate is considered as nominal pressure. The sample plate contains also iron and troilite grains to mimic ordinary chondrites type H, L and LL composition.

The thermodynamic behaviour of olivine is described by ANEOS (analytical equation of state) with a porosity of 6% ([8], ε-α compaction model). Iron is described by ANEOS and Troilite by the Tillotson EOS (using pyrrhotite [1]).

To study melting, we use the peak shock pressures recorded in tracers, which can be translated into post-shock temperatures [4]. This approach assumes a constant heat capacity and heat of fusion is neglected. The total amount of melting is approximated by the ratio of tracers in a material reaching temperatures above the solidus and all tracers. This technique provides reasonable temperature estimates but suffers from several uncertainties (e.g. a positive ~10% error in pressure to reach melting point in troilite).

3. Results

We conducted models with each type of ordinary chondrites (H, L and LL). The iron/troilite particles distribution are according to data from [6]. Fig. 1 shows profiles of the tracer fractions reaching melt temperatures in the materials. We observe that:

- The onset of melting of troilite tracers occurs at ~40 GPa. At 52 GPa of nominal pressure all tracers reach melting point. It is a consequence of shock wave-induced increase in entropy (pure shock melting). This is only slightly influenced by reflexions when reaching peak shock pressures.

- In iron, only a few percents of tracers reach melting point at 58 GPa of nominal pressure. It is mainly due to strong reflections and specific disposition of the iron particles.

- Olivine tracers reach melting point at ~50 GPa of nominal pressure. This is due to strong reflexions of the shock wave at iron grains boundaries, ramping up the peak shock pressures and, thus, post-shock temperatures.

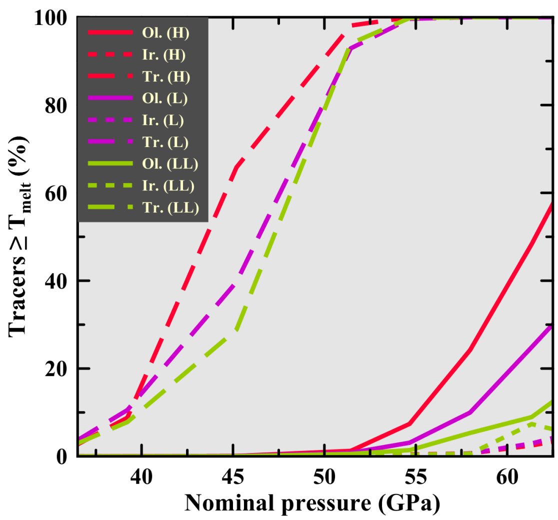

Figure 1: Results of the mesoscale models with porous olivine showing fractions of tracers reaching melting point in all materials after pressure release in each ordinary chondrite type. Each ordinary chondrite type is represented by its abbreviation and phases are Ir.: iron, Tr.: troilite, Ol.: olivine.

4. Discussion

Our results show that shock-darkening likely happens at pressures from 40 GPa to 50 GPa with almost all tracers in troilite reaching the melting point. Fractions of olivine start to reach melting point at 50 GPa. We observe that the influence of iron is important for the melting of olivine. The shock-darkening agent is only composed of troilite. In our models we did neither consider heat transfer nor the Fe-FeS eutectic point (unshocked petrologies show only few Fe-FeS mixtures) - melting temperatures for the materials were therefore high. No shearing between grains was considered. In general, the thermal and mechanical effects that are not taken into account in the modeling would eventually balance out with the uncertainties in estimating the post-shock temperature of the material (constant heat capacity and assuming that peak shock pressures represent single shocks).

5. Conclusions

Based on numerical modeling, the shock-darkening process in ordinary chondrites starts at ~40 GPa up to ~50 GPa. In each ordinary chondrite type, all troilite material reaches the melting point at ~52 GPa and is considered to be the darkening agent. Despite uncertainties in assessing the post-shock temperature giving a positive ~10% error in the required melt pressures estimate for troilite, heat transfer, shearing between grains, pores crushing, and the eutectic point are important aspects that we intend to investigate further in future.

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