Spherical Shock Experiments with Chelyabinsk Meteorite: Reflectance Spectra Changes with Increasing Shock

Tomas Kohout (1), Evgeniya V. Petrova (2), Grigoriy A. Yakovlev (2), Victor I. Grokhovsky (2), Antti Penttilä (1) and Alessandro Maturilli (3)

(1) Faculty of Science, University of Helsinki, Finland (tomas.kohout@helsinki.fi)
(2) Ural Federal University, Ekaterinburg, Russia (evgeniya.petrova@urfu.ru)
(3) Institute of Planetary Research, DLR, Berlin, Germany

Abstract

Spherical shock experiments produced gradual pressure changes from S4 level up to complete melting. At ~50 GPa peak pressure shock darkening of silicates is observed due to troilite melt penetrating silicate grains associated with reduction in intensity of silicate 1 and 2 µm absorptions. This process stops at higher pressures as partial melting of silicates along grain boundaries isolates troilite melt. Darkening occurs again upon material complete melting. In MIR region, spectral trends are similar, however the reststrahlen silicate bands are still resolved in shock-darkened or impact melt zones.

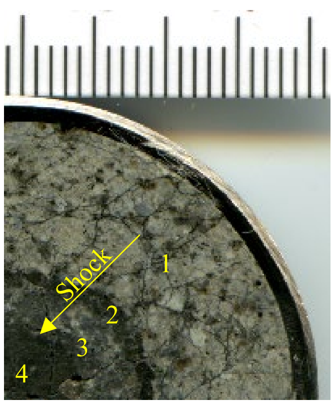

Figure 1: Section of the shocked Chelyabinsk samples with four shock zones. Scale unit is 1 mm.

1. Introduction

Spherical shock experiments with Chelyabinsk meteorite were done at RFNC - VNIITF [1]. The experiment setup allows gradual shock increase from sample rim towards the interior. Altogether 4 zones were observed, corresponding to (1) shock levels S4 at the rim, followed with a (2) sulfide melt rich zone (S5), a (3) zone with extensive silicate melting (S6) and (4) entirely molten phase in the sample interior (Fig. 1).

2. VIS-NIR spectra

The four above mentioned zones are clearly macroscopically distinguishable. The first outer zone resembles original Chelyabinsk light-colored lithology. The light-colored lithology was already shocked up to S3-4 level prior encounter with Earth and thus the experiment-induced shock in this zone is within this initial level. Reflectance spectra (Fig. 2) of this zone resemble also original Chelyabinsk light-colored lithology with prominent silicate absorption bands at 1 and 2 µm [3].

The following second zone is prominent with a sudden and sharp onset of optical darkening. Under the microscope, this zone resembles dark-colored Chelyabinsk lithology with a web of molten troilite veins penetrating silicate grains [2] and acting as darkening agent [3]. The reflected light spectra of this zone are dark and rather flat with only weak silicate absorptions similarly to dark-colored lithology. The corresponding shock stage of this zone is S5 with roughly 50 GPa peak pressure.

The third zone associated with S6 shock level or pressure roughly between 50 and 90 GPa show partial gradual optical brightening compared to dark-colored lithology. Detailed observations under the microscope reveal the onset of extensive silicate crushing and melting along mineral grain boundaries [2]. The extent of the melt increases towards sample interior. The silicate melt along grain boundaries prevents molten troilite to penetrate silicate grains. Troilite is, thus, contained outside silicate grains, and often forms a eutectic mixture with metal. As the silicates are free of troilite melt the material does not darken and its reflected spectra are intermediate between the ones of the first and second zone. The spectra are slightly darker compared to that of light-colored lithology, but silicate absorptions are clearly visible.

The fourth zone is characterized by complete melting and rapid crystallization [2]. This zone is optically dark due to a mixing of silicate, troilite, and metal melts. The reflected light is flat with subdued silicate absorptions. It resembles Chelyabinsk impact-melt lithology [3].

3. MIR spectra

In MIR region, similar darkening trends to VIS-NIR region are observed in the shocked lithologies. The reststrahlen silicate bands, however, are not significantly attenuated and are still clearly distinguishable. No strong shock-induced wavelength shift in the MIR spectra features is observed.

4. Summary and Conclusions

The spherical shock experiments reproduced Chelyabinsk light-colored, dark-colored, and impact-melt lithologies. Surprisingly, new lithology was observed at pressures intermediate between dark-colored and impact melt lithologies. Within this zone, silicate melting along crystal boundaries isolates troilite melt and prevents silicate darkening. This observation implies on narrow pressure conditions responsible for shock darkening of ordinary chondrites. At the onset of silicate melting, shock darkening effects in ordinary chondrites cease and reappear again only upon complete melting.

Acknowledgements

This work was supported by the Ministry of Education and Science of the Russian Federation (The projects 5.4825.2017/6.7, 5.3451.2017/4.6), the Act 211 of the Government of the Russian Federation, agreement no. 02.A03.21.0006, and the Academy of Finland.

References

[1] Petrova E. V. et al.: Spherical shock experiments with Chelyabinsk meteorite: the experiment and textural gradient, EPSC 2018, 16–21 September 2018, Berlin, Germany, 2018.

[2] Kohout T. et al.: Mineralogy, reflectance spectra, and physical properties of the Chelyabinsk LL5 chondrite – Insight into shock-induced changes in asteroid regoliths, Icarus, Vol. 228, pp. 78-85, 2014.

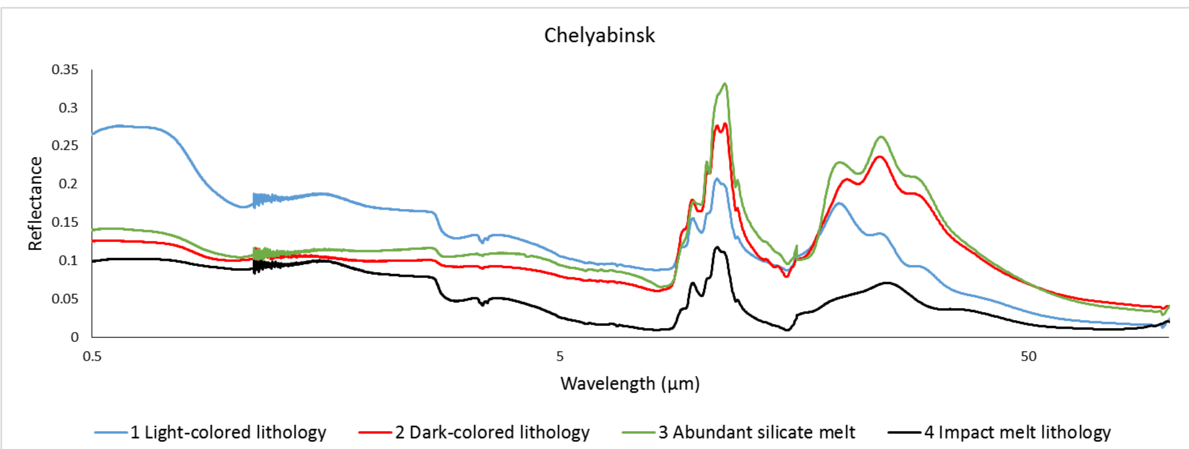

Figure 2: Reflected light spectra of shocked Chelyabinsk meteorite form 0.4 to 100 μm.