EPSC Abstracts
Vol. 12, EPSC2018-709-1, 2018
European Planetary Science Congress 2018

Spherical shock experiments with Chelyabinsk meteorite: the experiment and textural gradient

Evgeniya V. Petrova (1), Victor I. Grokhovsky (1), Tomas Kohout (2), Razilia F. Muftakhetdinova (1), and Grigoriy A. Yakovlev (1)
(1) Institute of Physics and Technology, Ural Federal University, Ekaterinburg, Russia (evgeniya.petrova@urfu.ru)
(2) Faculty of Science, University of Helsinki, Finland (tomas.kohout@helsinki.fi)

Abstract

Shock experiment with loading by spherically converted shock waves on the Chelyabinsk meteorite sample was performed. A shock pressure and temperature have been increased from the outer to the inner part of the shocked sphere. As the result, a wide range of textural changes in the material from the surface to the center of the sphere was revealed from the microscopic observations.

1. Introduction

The Chelyabinsk chondrite (fall, 2013, Russia) was classified as LL5 S4 W0. Its complex structure with different lithologies was described before in [1-4]. Light-colored and dark-colored lithologies of Chelyabinsk LL5 are supposed to be of identical LL5 composition mostly [1], but they are slightly different. There are few explanations of different lithologies formation from the initial substance [5].

Different lithologies could be observed in the large samples and in the main mass fragments recovered from Chebarkul Lake. However, small samples mostly possessed a single type of lithology. Relatively large sections (up to the 150 cm^2) of the massive Chelyabinsk meteorite fragments look like impact melt breccia from the impact craters described in [6]. It was supposed that Chelyabinsk meteoroid was formed at the similar mechanism as suevite because it appears as the fragments of the host rock were mixed with the impact melt and were partly re-heated. [5, 7]. In this study, the intensive shock impact on the initial material of the light-colored lithology of Chelyabinsk LL5 meteorite was experimentally performed.

2. Samples and Methods

The method of spherically converging shock waves is a useful technique for modeling of the effect of wide ranges of pressure and temperature on studied materials. Several meteorites (the Saratov chondrite; the Chinga ataxite; Sikhote-Alin octahedrite) were affected by the spherically converging shock waves previously [8, 9]. In the current experiment, the individual fragment with light-colored lithology was used. A sample was prepared in the shape of the sphere of 40 mm in diameter. This sphere was put into vacuumed steel container and loaded by the spherically converted shock waves. Details of the spherical shock experiments were reported in [8]. The peak pressures and temperatures reached in the center of the ball can be estimated to be about 100 GPa and more than 2000ºC, respectively. Changes in reflectance spectra of shocked Chelyabinsk LL5 for the four textural zones are presented in [10].

After the shock loading of the ball sample, it was cut in half and then removed from the steel container. The diametric section was polished, while the thin section was prepared from another. An optical observation was performed using AxioVert 40 MAT (Carl Zeiss) and Laboval 2 (Carl Zeiss Jena), electron microscopy was done by using of scanning electron microscope ΣIGMA VP (Carl Zeiss) with an X-max energy dispersive spectroscopy device (Oxford Inst.).

3. Results and Discussion

From the naked eye observation of the diameter section of the experimentally shocked Chelyabinsk sample four visually different zones were distinguished (fig.1 in [10]). Under the microscope, the outer region of the circle section showed light-colored lithology material, which resembles initial material with a number of thick impact veins in the material texture. Some of the troilite inclusions were found partly melted. In the transmitted light weak mosaicism of olivine grains was noted, that corresponds to the shock stage S4. This zone spreads from the sample edge to the 0.45 of the ball sample radius (R).

The second zone is situated from the 0.45R to the 0.4R. It looks like a dark-colored ring. Moreover, its texture appears to have the same features as found in the dark-colored lithology of Chelyabinsk [4]. For example, troilite melt is filling in small cracks within silicates. There was not found pristine troilite grains in this region, while large metal grains and moderate chromite grains are still present. This zone corresponds to the shock stage S5. Silicate grains have smooth edges and they are almost opaque under the transmitted light microscope.

The third zone is sulfide melt-rich zone corresponds to the S6. It situated from the 0.4 R to 0.25 R. Its texture contains clasts of heated material embedded into the melt, where abundant vesicles with the small metal and troilite particles were observed. A few newly formed silicate crystals were found in this region.

The fours zone is an entirely molten phase in the sample interior, which corresponds to the impact melt. It appears as entirely melted and recrystallized material in the inner region. There are presented newly grown crystals of olivine in the shape of cross-oriented bars, which intersperse with a rich of vesicles glass. New crystals show a sharp extinction in the polarized transmitted light. Several metal-troilite eutectic grains were observed in the central region. Some of them was relatively large. It was noted that every metal+troitite droplet were associated with a vesicle. Only a few small chromite grains were oed in melted material sample center.

4. Summary and Conclusions

A possibility of various lithologies formation in one sample has been demonstrated during converging shock waves experiment. The four visually different zones obtained from the spherical shock experiment on the light-colored lithology of Chelyabinsk LL5 were studied by optical and electron microscopy: shock melt, dark-colored, brighter-dark-colored and light-colored material. All possible higher shock stages were revealed in the experimentally shocked sample: from the S4 of the initial material up to the impact melt, which presented a completely melted material.

Acknowledgements

This work was supported by the Ministry of Education and Science of the Russian Federation (Projects 5.4825.2017/6.7, 5.3451.2017/4.6); the Act 211 of the Government of the Russian Federation, Agr.# 02.A03.21.0006, and the Academy of Finland.

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