MINERALOGY, REFLECTANCE SPECTRA, AND PHYSICAL PROPERTIES OF THE CHELYABINSK LL5 CHONDRITE — INSIGHT INTO SHOCK-INDUCED CHANGES IN ASTEROID REGOLITHS

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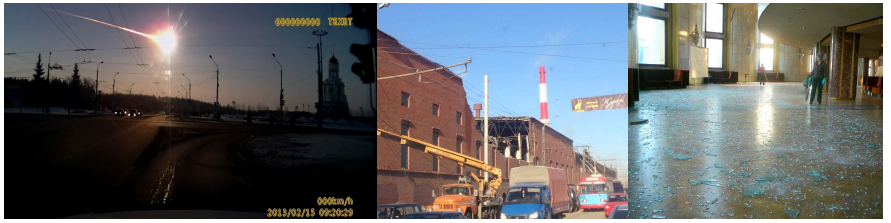
Introduction

On February 15, 2013, at 9:22 am, an exceptionally bright and long duration fireball was observed by many eyewitnesses in the Chelyabinsk region, Russia. A large-sized object with a relatively low mass-loss rate and shallow atmospheric entry angle led to a very long trail. The event was recorded by numerous video cameras from the ground and was also imaged from space by the Meteosat and Fengyun satellites. A strong shock wave associated with the fireball caused significant damage including broken windows and partial building collapses in Chelyabinsk and the surrounding territories.

Two days later the first fragments of the Chelyabinsk meteorite were reported to be found around Pervomaiskoe, Deputatsky, and Yemanzhelinka, located approximately 40 km south of Chelyabinsk. In total three lithologies, the light-colored, dark-colored, and impact melt lithologies, were found within the recovered meteorites.

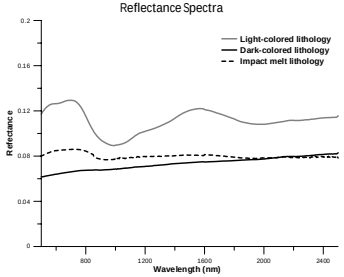


Physical Properties

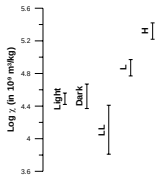
Bulk and grain density and porosity of both light- and dark-colored lithology match values typical for LL chondrites. Magnetic susceptibility, however, is in intermediate L/LL range. Thus, compared to a typical LL chondrite, Chelyabinsk meteorites are richer in metallic iron. No significant difference related to shock-darkening is observed among light- and dark-colored lithology or impact melt rich clasts. Thus, shock does not have a significant effect on the material physical properties.

The reflectance spectrum of the light-colored lithology is typical for an LL ordinary chondrite with the presence of 1 and 2 µm olivine and pyroxene absorption bands. Such a spectrum is similar to fresh S or Q type asteroids. In contrast, the shocked dark-colored or impact melt lithologies are darker and the silicate absorption bands are almost invisible. Thus, the shock history affects the reflectance and the depth of the absorption bands of chondrite material in a way similar to space weathering. However, unlike space weathering (or at least unlike its lunar type form with the presence of nanophase iron in the surface coatings of silicate minerals) there is no change in the spectral slope observed due to the increased shock.

Reflectance Spectra



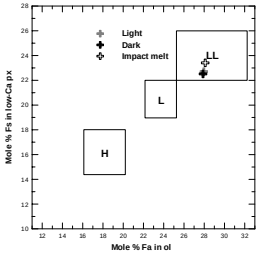
Magnetic Susceptibility



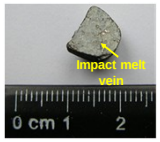
	Light-colored	Dark-colored
Bulk density (g/cm³)	3.32 (s.d. 0.09)	3.27 (s.d.0.08)
Grain density (g/cm³)	3.51 (s.d. 0.07)	3.42 (s.d. 0.10)
Porosity (%)	6.0 (s.d. 3.2)	5.7 (s.d. 1.7)
Magnetic susceptibility (log in 10⁻⁹ m³/kg)	4.49 (s.d. 0.07)	4.52 (s.d. 0.15)

Mineralogy

- The light colored lithology is a LL5 ordinary chondrite shocked to S4 level.
- The dark colored lithology is of identical LL5 composition. However, it is shocked to higher level (shock-darkened). The silicate grains are mechanically crushed. Partial melting occurred and is limited mainly to metal and sulfides. Molten metal and sulfide-rich melt formed a dense network of fine veins impregnating the inter- and intra-granular pore space within crushed silicate grains. Thus, high pressure loads and moderate temperature rise is characteristic for shock darkening
- The impact melt lithology is a breccia of crushed mineral grains with various amounts of silicate melt. It derived from similar LL5 source material and is present as inter-granular veins within both light-colored and dark-colored lithologies, or as a matrix supporting larger ~mm to ~ cm-sized clasts in brecciated meteorites. In comparison to shock darkening the impact melting requires higher temperatures to reach melting point of the silicates.

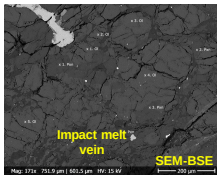


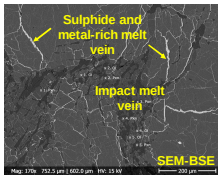
Light-colored Lithology

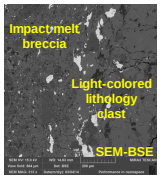


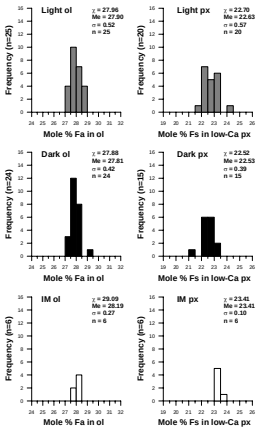
Dark-colored Lithology

Impact Melt Lithology









Conclusions

The Chelyabinsk fireball with an almost instant recovery of a large number of fresh meteorites is one of the most spectacular meteorite fall events in the recent history. Three lithologies, light-colored, dark-colored, and impact melt, were found within the recovered meteorites. All three are of LL5 composition. The dark-colored lithology is being shocked to a higher level (shock darkening). The silicate grains are mechanically crushed and partial melting, limited to metal and sulfides, occurs. The impact melt lithology experienced higher temperatures during the shock and is made of crushed mineral grains with a silicate melt.

Based on the magnetic susceptibility, the Chelyabinsk meteorites are richer in metallic iron as compared to other LL chondrites (in the intermediate range between LL and L chondrites). The measured bulk and grain densities and the porosity closely resemble other LL chondrites. Shock darkening does not have a significant effect on the material physical properties.

However, changes in reflectance spectra are observed in the highly shocked lithologies. A decrease in reflectance and suppression of the silicate absorption bands is observed in both shock-darkened and impact melt lithologies. This is similar to the space weathering effects observed on asteroids. However, no spectral slope change similar to space weathering is observed. Thus, it is possible that some dark asteroids with invisible silicate absorption bands may be composed of relatively fresh shock-darkened or molten chondritic material. The main spectral difference between shock darkening and space weathering of asteroid surfaces is the presence of the spectral slope change (reddening) in the latter case.

Acknowledgments

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