THE SPECTRAL EFFECTS OF DISPERSED OPAQUES IN OPTICALLY ALTERED ORDINARY CHONDRITES. D.T. Britt and C.M. Pieters. Department of Geological Sciences, Brown University, Box 1846, Providence, RI, U.S.A..

Introduction: Meteorites are an invaluable source of information and insight into a myriad of solar system processes. Some are especially useful as a record of the effects of the space environment on the surface material of atmosphereless bodies; i.e. regolith processes on asteroids and moons. A thorough understanding of these effects is important for the interpretation of imaging and spectroscopic data from a whole suite of future missions and current telescopic observations. Regolith processes tend to be dominated by shock. The optically altered black chondrite meteorites can provide significant clues to the effects of shock processes in the space environment on common rock-forming minerals. Black chondrites are, as the name implies, ordinary chondrites that exhibit significantly lower reflectance than normal ordinary chondrites. In addition they are characterized by very subdued absorption bands in their reflectance spectra, low gas-retention ages, and pervasive brecciation and shock features [1]. About 13% of ordinary chondrite falls can be classified as black [2]. Black chondrites have been shown to have strong spectral similarities to the spectra of some low-albedo C-class asteroids [3]. In this study we will analyze the structure of the opaque components in two black chondrites, Farmington (L5) and Pervomaisky, (L6) and model the optical effects of these materials on the spectral characteristics of normal ordinary chondrites.

Meteorite Samples: The meteorites chosen for this initial study represent the two major morphologies seen in black chondrites. Farmington shows darkening throughout the entire meteorite, although, as discussed below, there is significant variation in the degree of optical alteration at the chondrule scale. Pervomaisky exhibits the light and dark macrostructure common in many black chondrites: large areas of light, unaltered material co-existing with large areas of darkened, optically altered material. The spectra of samples from light and dark portions of Pervomaisky are shown in **Figure 1.** These samples were taken from areas less than a centimeter apart and the bulk chemistry of the two areas are identical [4]. The spectrum of the dark portion exhibits a strong attenuation of both albedo and absorption features while the light portion shows a spectrum similar to normal ordinary chondrites of the same petrologic type [5]. In thin section the light portion of Pervomaisky is characterized by broken chondrules and fragments of chondrules ranging between 70 μm to 1 mm in diameter. Opaques are irregular blebs of troilite and Fe-Ni metal 100-200 μm in diameter and some veins of the same material. Average particle size is approximately 200 μm for the chondrules and 150 μm for the opaques. In the dark portion of Pervomaisky the chondrules exhibit the same basic structure and size, but the form of the opaque component is dramatically different. In contrast to the large blebs seen in the light portion, opaques in the dark portion are drawn out into a network of fine, thin veins and veinlets. The veins are generally 1-5 μm thick and are often surrounded by a cloud of minute opaque particles with diameters of < 0.5 μm. Examination of thin sections shows veins are directly associated with areas opaque to transmitted light and appear to be primarily composed of troilite. To estimate vein density a series of random traverses 100 μm in length were examined in thin section. The average number of veins crossing the traverses were 5.4, indicating that optical path lengths of greater than 20 μm would be strongly attenuated by the veins. The total abundance of opaque components estimated from chemical analysis are 6.4 wt.% FeS and 9.18 wt.% Fe-Ni [4].

In thin section Farmington is characterized by broken chondrules and fragments of chondrules ranging from 20 to 400 μm in diameter. Transparent and opaque chondrules are randomly intermixed with about 70% of the chondrules showing at least some opacity. In contrast to Pervomaisky, the opaque fraction of Farmington consists of relatively few irregular clumps of Fe-Ni metal and troilite 50-100 μm in diameter, and a pervasive dusting of finely dispersed droplets ranging from 5 to < 0.5 μm in diameter. It is thought that these "dusty" opaques were dispersed as a result of shock processes [5]. These finely dispersed droplets are primarily composed of troilite and are directly associated with the opaque chondrules [6]. Chemical analysis reports the total abundance of opaques as 4.79 wt.% FeS and 7.46 wt.% Fe-Ni [6]. To estimate the particle density of the droplets a series of areas 100 x 100 μm in opaque material were examined in reflected light and the numbers of droplets were counted. Average droplet population was approximately 400 droplets per 10,000 sq. μm area. With this density of droplets, a photon would have an 0.21% probably of traversing 100 μm of this material without encountering an opaque particle. The average path length through this material would be 11.6 μm.

Spectral Mixture Modelling: To examine the optical effects of the distribution of the opaque material we used a two-component intimate mixture program [7] based on the reflectance model of Hapke [8]. The end-members for this mixture are the spectrum of normal ordinary chondrite material such as the light material of Pervomaisky and the spectrum of a troilite separate from the iron meteorite Munbrabilla [9]. The spectrum of these end-members are shown in **Figure 1.** Photometric scattering properties for this material were assumed for purposes of this study to be similar to those measured for magnetite [7]. Although the scattering properties of troilite are almost certainly not the same as magnetite, the effect of the forward or backward scattering properties is probably secondary to the effect of particle size on photon path length. For all simulations the density of the ordinary chondrite material was set at 3.0 g/cm^3 and for troilite was 4.5 g/cm^3. The weight percent of troilite was fixed at 6% to simulate the approximate concentration reported by chemical analysis. Average particle diameter was set at 100 μm for the ordinary chondrite material and varied for the shock darkened portion to determine the effect of particle size on the optical properties of the mixture.

Discussion: Shown in **Figure 2** are the results of three simulations run with ordinary chondrite and troilite end-members. The first simulation fixed troilite particle size at 100 μm. This is similar to the distribution of opaques in normal ordinary chondrites and the light portions of Pervomaisky. In this case the effect of the opaque end-member on the mixture spectrum is very modest. Simulation number two reduced the troilite particle size by an order-of-magnitude to 10 μm. The effect on the mixture spectrum is now more pronounced as the smaller particle size increases the optical effectiveness of the opaque component. The final simulation is with a troilite particle size of 1 μm, within the actual range of opaque particle sizes seen in thin sections of optically altered material. The spectrum of this simulation shows that small particle size in opaques strongly attenuates the albedo and absorption bands of normal ordinary chondrite material, producing a spectrum very similar to the attenuation seen in optically altered black chondrites.

Conclusions: In thin section fine structures of small-diameter (< 5 μm), shock dispersed opaques are pervasive throughout darked portions of optically altered ordinary chondrites. These structures tend to be composed primarily of troilite and are directly associated with optical opacity in the chondrules and matrix. The process or processes that mobilizes, disaggregates, and disperses this material into the silicate fraction of the meteorite is a key in understanding the conditions for optical alteration on asteroidal surfaces and will be a focus of future work. Intimate mixture modelling using realistic parameters confirms the importance of opaque particle size in the attenuation of albedo and absorption bands. A two (or more) order-of-magnitude difference in particle sizes between the silicate and opaque phases in optically altered ordinary chondrites allows a very small component of opaque material to dominate the optical properties of these meteorites.

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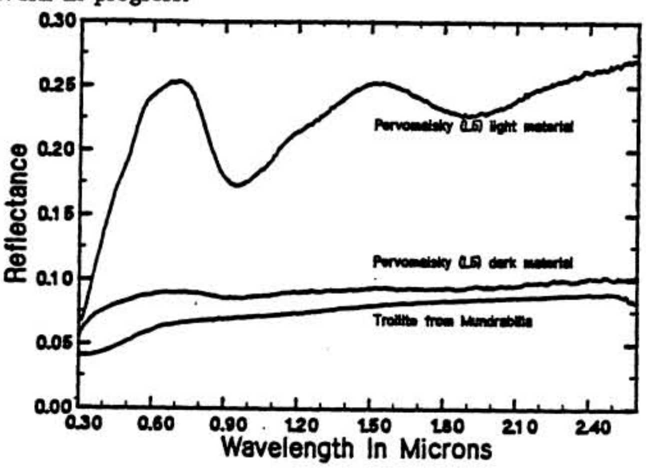

Figure 1: Bidirectional reflectance spectra of dark and light portions of the L6 ordinary chondrite Pervomaisky and troilite separates from the iron meteorite Mundrabilla. In mixing simulations described in the text the spectra of the light portion of Pervomaisky and troilite from Mundrabilla were used as end-members.

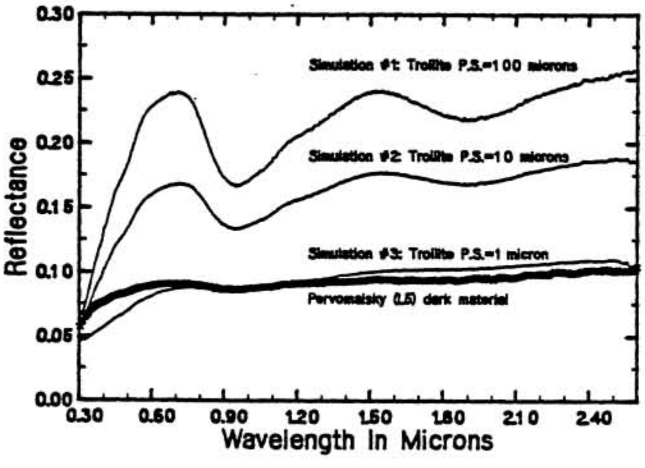

Figure 2: The results of three spectral mixing simulations compared to the spectra of the dark portion of Pervomaisky. The spectra of the light portion of Pervomaisky and troilite from Mundrabilla were used as end-members.