CAN WE DISTINGUISH BETWEEN SHOCK-DARKENED AND SPACE-WEATHERED ASTEROIDS?

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Introduction: Both lunar-type space weathering and impact shock darkening are capable of significant darkening of asteroid spectra. Thus, a question arises – are we able to distinguish between these processes from asteroid reflectance spectra?

The Chelyabinsk meteorite represents unique opportunity with delivery of large amount of meteorite material of various shock levels. The basic three lithologies include (1) slightly shocked light-colored lithology, (2) partly molten shock-darkened dark-colored lithology, and (3) entirely molten impact melt lithology [1]. In order to compare shock effects to space weathering, the light-colored lithology was subjected to simulated space weathering (method based on [2]) and the spectral changes were compared to mixtures of the light-colored with impact melt [3] or shock-darkened materials. For comparison, space weathering experiments with olivine [2] and orthopyroxene were done.

Results on olivine and orthopyroxene: Results on both minerals show the 1 µm (in both olivine and orthopyroxene) and 2 µm (in orthopyroxene only) absorption bands progressively reduced. The spectral slope increases in both minerals with the amount of space weathering. In orthopyroxene, both the 1 and 2 µm bands are progressively reduced by a nearly constant ratio. The slope change, however, is more progressive over the 2 µm band. Orthopyroxene is also more resistant to space weathering which is consistent with previous results, e. g. [4] and [5].

Results from the Chelyabinsk meteorite: Results from experiments with the Chelyabinsk meteorite indicate that shocked material shows no significant spectral slope change while both the 1 and 2 µm bands are progressively reduced with a nearly constant depth ratio. This means that shock has the same effect on both the olivine and orthopyroxene present in the Chelyabinsk meteorite.

In contrast, the space weathering causes a strong increase in the spectral slope. Also, the ratio of the 2 µm band depth to the 1 µm band depth is progressively increasing (Fig. 1) with amount of space weathering, most likely due to the higher resistance of pyroxene to space weathering compared to olivine in an olivine-pyroxene mixture. (Note that in pure pyroxenes the reduction in band depth of both bands is constant with increasing space weathering.)

The 2 µm band is caused by the presence of more resistant orthopyroxene only, while the 1 µm band is contributed by both orthopyroxene and olivine. As olivine is more sensitive to space weathering, the combined 1 µm band decreases more progressively.

This is also seen in the principal component analysis (PCA) space using the method of [6] shown in Figure 2. The fresh light-colored lithology plots into the Q-type field. Both space-weathered and shocked materials show reduction in the PC1' component related to the decrease in the 1 µm band depth. However, the addition of shocked material causes significant reduction in the PC2' component related to the decrease in the 2 µm band depth and transition from the Q-type field across the alpha line into the C/X complex. In contrast, space-weathered material shows smaller PC2' component changes and moves along the alpha line towards the S-type field.

Conclusions: The 1 and 2 µm band depth ratio or the PC2'/PC1' ratio together with the spectral slope may be an indicator of shock darkening vs. space weathering in (ordinary chondrite) asteroid spectra. Based on these parameters, it seems that space weathering is not capable of fully obstructing the silicate absorption bands. Shock, however, appears to be fully capable of obstructing the weaker 2 µm pyroxene absorptions which is indicated by the transition into C/X complex in PCA.

References:

[1] Kohout T. et al. (2014) *Icarus, 228,* 78-85. [2] Kohout T. et al. (2014) *Icarus, 237,* 75-83. [3] Reddy V. et al. (2014) *Icarus, 237,* 116-130. [4] Sasaki S. et al. (2002). *Adv. Space Res., 29,* 783-788. [5] Marchi S. et al. (2005) *A&A, 443,* 769–775. [6] DeMeo F. E. et al. (2009) *Icarus, 202,* 160–180.

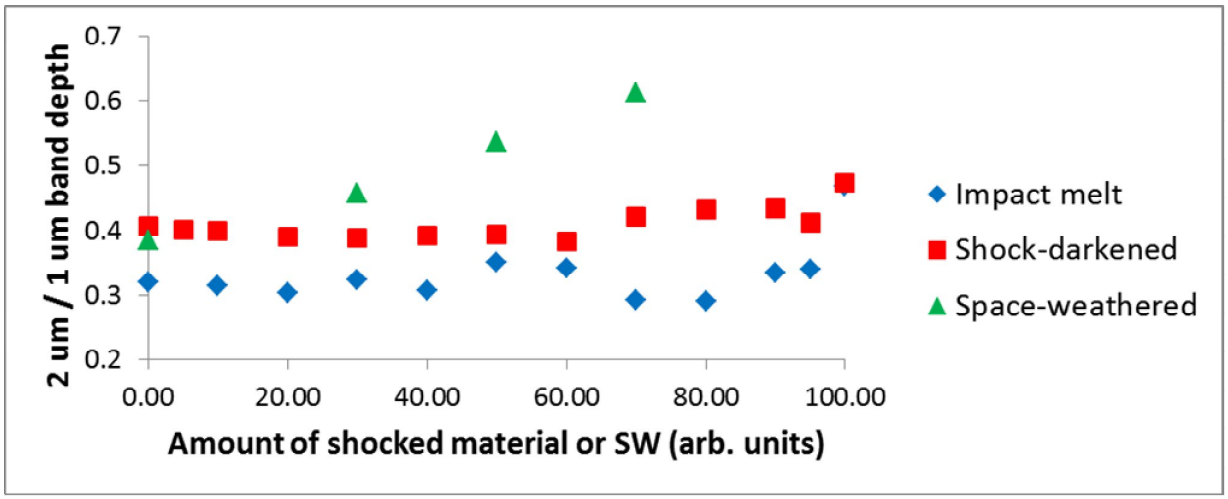

Fig. 1. The ratio of the 2 µm band depth to the 1 µm band depth for the shocked and space weathered Chelyabinsk meteorite.

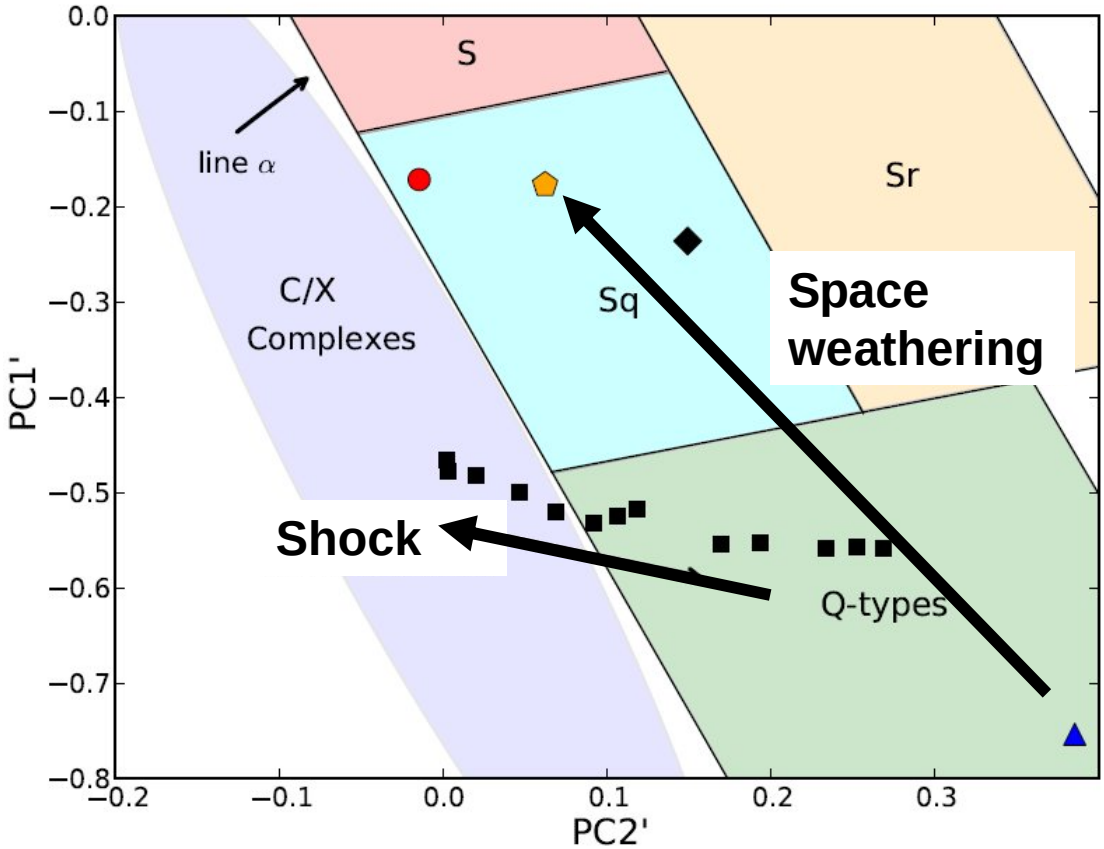

Fig. 2. Shock (black points) and space weathering (color points) trends as seen in the principal component analysis (PCA) space.