SPECTRAL REFLECTANCE (0.3-2.5 µm) PROPERTIES OF CARBONACEOUS CHONDRITES - RELEVANCE TO BENNU AND RYUGU.

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Introduction: The carbonaceous chondrite (CC) group of meteorites is diverse and includes a wide range of petrologic types (1-6) as well as members with more complex histories that include both aqueous alteration (leading to lower petrologic grades [1]), and subsequent thermal metamorphism (leading to a higher petrologic grade in this scheme).

Bennu, the target asteroid for the OSIRIS-REx mission and Ryugu, the target asteroid for the Hayabusa-2 mission have both been spectrally characterized by a number of investigators. While the various studies have not always produced consistent results, it appears that both asteroids are dark and devoid of absorption bands in the 0.3-2.5 µm region, or display, at best, weak absorption bands [e.g., 2, 3, 4]. Here we review the 0.3-2.5 µm spectral reflectance properties of various CCs with an emphasis on the most spectrally featureless ones.

Featureless CC reflectance spectra: In a series of papers on the 0.3-2.5 µm reflectance spectra of ureilites [5] and various classes of CCs [6-13], it was found that absorption bands that can be attributed to various phases that are present in different CC groups, specifically hydrous and anhydrous mafic silicates, and Fe-bearing components in calcium aluminum inclusions, are nearly ubiquitous, but that band depths are highly reduced compared to pure end members, due to the presence of fine-grained dispersed opaque phases, such as carbonaceous compounds, metal, magnetite, and sulfides. Ubiquitous, or nearly so, absorption bands that could be attributed to constituent minerals were found in reflectance spectra of ureilites [5], CM [7], CO [9], CV [11], CK [12], CH [13], and a number of ungrouped CCs [13]. In some cases, these bands were weak, on the order of 1% deep. Some of these results are worth discussing in detail.

CI1 meteorites: Of the various CC groups, the CI1s showed the largest number of featureless reflectance spectra [6], but also diversity in that the spectra of some subsamples showed absorption bands, while others did not. The lack/presence of absorption bands may be because CIs can be heterogeneous at sub-gram scales [14].

ATCC meteorites: These are CCs that were aqueously altered and subsequently thermally metamorphosed. In all cases, they were found to exhibit mafic silicate-associated absorption bands when sufficiently high SNR spectra were acquired (bands were as shallow as 1% deep). Laboratory heating of CM2 and CI1 chondrites showed that these meteorites can have a temperature "window" (~600-800ºC) in which hydrated mafic silicates presumably become amorphous and silicate absorption bands are shallowest; at higher temperatures, the silicates begin to recrystallize, largely as olivine.

CR meteorites: The CR group is mineralogically diverse, with members ranging between petrologic grades 1 and 3. They are generally characterized by low-Fe content silicates, which should lead to weak absorption bands. In spite of absorption features associated with terrestrial weathering, it appears that CR chondrites do exhibit absorption bands (as weak as 1% deep) attributable to hydrated mafic silicates (lowest petrologic grades) and/or mafic silicates (higher petrologic grades).

"Outlier" meteorites: Some CCs have been spectrally characterized and seem to exhibit no silicate-associated absorption bands or possibly bands that are too weak given the signal to noise (SNR) of the data to be reliably identified. In some cases, newer spectra of previously measured samples [15] with higher SNR show the presence of absorption bands [11, 12], that were not seen in earlier data. For obviously brecciated meteorites (e.g., Kaidun), spectra of only some subsamples show absorption bands [13].

Implications for Bennu and Ryugu: Reflectance spectrometers aboard OSIRIS-REx and Hayabusa-2 can acquire data with much higher SNR than Earth-based observations. Laboratory investigations suggest that with sufficiently high SNR, we expect to see mineralogically diagnostic absorption bands in almost all cases [16]. Truly featureless reflectance spectra are, or may be, associated with the following possibilities:

- some CI1 carbonaceous chondrites
- assemblages with spectrally-featureless opaque abundances in excess of those seen in any CCs
- some form of space weathering, not yet reproduced in the lab, which effectively amorphizes or otherwise "hides" mafic silicates
- aqueously altered CCs that have been heated to the amorphization window (~600-800ºC) of hydrated mafic silicates, and perhaps with additional mechanisms to hide the mafic silicates

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