CONSTRAINTS ON THE NATURE AND THE DEGREE OF AQUEOUS ALTERATION IN OUTER MAIN BELT ASTEROIDS.

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Introduction: Carbonaceous chondrites (CCs) are important meteorites because they contain some of the most pristine matter known. CM (Mighei-like) and CI (Ivuna-like), which are believed to have been altered on their parent asteroids (e.g., [1]), are two groups of CCs that exhibit evidence of fluid-assisted alteration to varying degrees (e.g., [2]). Here, we investigate the geochemical/petrological parameters (i.e., Mineralogical Alteration Index: MAI, petrological subtype) and the spectral properties (e.g., band shape, band depth) of 10 CM/CI CCs (Table 1). Meteorite infrared (IR) reflectance spectra were measured under dry conditions to remove adsorbed water and mimic space conditions. Serpentine (lizardite) and saponite spectra were also measured under dry conditions. [3] measured IR transmission spectra of heated CM/CI CCs. However, this investigation includes IR reflectance spectra of heated CM/CI CCs that were measured for direct comparison with reflectance spectra of asteroids. Laboratory analyses of meteorites have the potential to provide important hints to the nature and the degree of aqueous alteration of outer Main Belt asteroids spanning the 2.5 < a < 4.0 AU region, placing crucial constraints on how, when, and where this alteration occurred.

Table.1. CM/CI carbonaceous chondrites analyzed in this study and their spectral parameters.

Meteorites	Class	3-µm Band Depth (%)	Band Center (µm)	Band Area (μm^{-1})
Cold Bokkeveld	CM2	34.34	2.78	0.22
LAP 03786	CM2	30.26	2.77	0.18
Bells	C2-ung.	26.01	2.75	0.10
MAC 02606	CM2	14.87	2.76	0.13
QUE 99038	CM2	13.10	2.86	0.08
Ivuna	CI1	14.10	2.71	0.08
MET 00639	CM2	9.22	2.68	0.04
QUE 97990	CM2	8.99	2.68	0.03
LAP 02277	CM1	7.70	2.68	0.02
MIL 07700	CM2	6.24	2.68	0.02

Methodology: The MAI [4] and the petrological subtype [5] were determined applying two different published alteration scales. Polished thin sections were examined with a petrographic microscope, in both transmitted and reflected light. Compositions of matrix material were analyzed with the CAMECA SX-100 electron microprobe at the University of Tennessee, using 2-µm beam size, a 10-nA beam current, and a 15-keV accelerating voltage. Counting times for all elements were generally 20-30s. The IR reflectance spectra of CM/CI chondrites were measured at the USGS Spectroscopy Laboratory, using two spectrometers, an Analytical Spectral Devices (ASD) portable field spectrometer (model FR)[1] covering the range from 0.35 to 2.5 µm, and a Nicolet Fourier transform infrared (FTIR) Interferometer Spectrometer[1] covering the range from ~1.3 to 15.5 µm [5]. The samples were measured at ambient conditions and at higher temperatures (up to 450 K) and low pressure (down to 0.01 torr; e.g., Figure 1). High-quality spectra of outer Main Belt asteroids spanning the 2.5 < a < 4.0 AU region were measured, using SpeX spectrograph/imager at the NASA Infrared Telescope Facility (IRTF) [6].

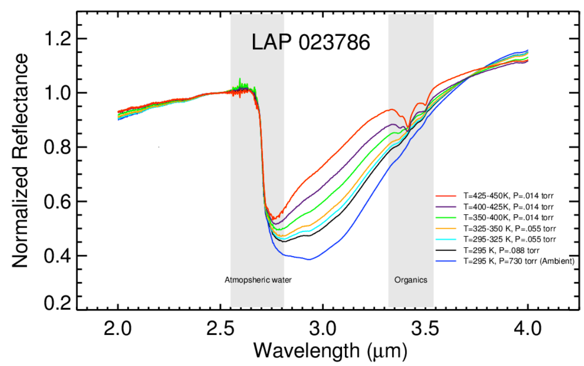

Figure.1. IR reflectance spectra of LAP 03786 at different temperatures and pressures. Several spectra were averaged for each temperature bin.

Results: Figure 2 summarizes the results of our investigation. IR reflectance spectra of heated meteorites (up to 450 K) in low pressure have revealed an interesting classification. The first group consists of four CM chondrites: MIL 07700, LAP 02277, QUE 97990, and MET 00639. This group is characterized by a small band depth (6.24-9.22 %), a small band area (0.02-0.04 μm^{-1}), a narrow and sharp feature centered at ~2.68 µm, and a metal-OH feature at ~2.2 µm. The second group consists of five CM chondrites: QUE 99038, MAC 02606, Bells, LAP 03786, and Cold Bokkeveld. Unlike the first group, this group is characterized by a deeper band depth (13.10-34.34 %) and larger band area (0.08-0.22 μm^{-1}). The second group does not exhibit a 2.2-µm feature, but it has a C-H feature (organics) at ~3.4-3.5-µm. Ivuna, which is the only CI chondrite analyzed in this study, is characterized by an intermediate band depth and band area, a 2.2-µm feature, and a C-H feature ~3.4-3.5-µm.

Discussions: Spectra of the second group and serpentine's spectrum have a similar 3-µm band, suggesting that serpentine-group phyllosilicates are the product of aqueous alteration in this group. However, spectra of the first group do not match serpentine's spectrum (Figure 3). This finding suggests that aqueous alteration in the first group may have been distinct from that in the second group. It is interesting to note that the first group exhibits a 2.2-µm feature, and does not exhibit organic features seen in the second group. For the first group, there is a good correlation between the MAI of [4] and the 3-µm band depth and area, except for LAP 02277, which is a CM1. The petrological subtype of [5] in this group ranges from 2.3-2.6. For the second group, there is a good correlation between the MAI and both the 3-µm band depth and area, except for MAC 02606, which contains high concentrations of carbonates. The petrological subtype in this group ranges from 2.2-2.3. It appears, from the occurrence of organics in the second group but not the first, that the production of high concentrations of organics may be associated with serpentine-group phyllosilicates.

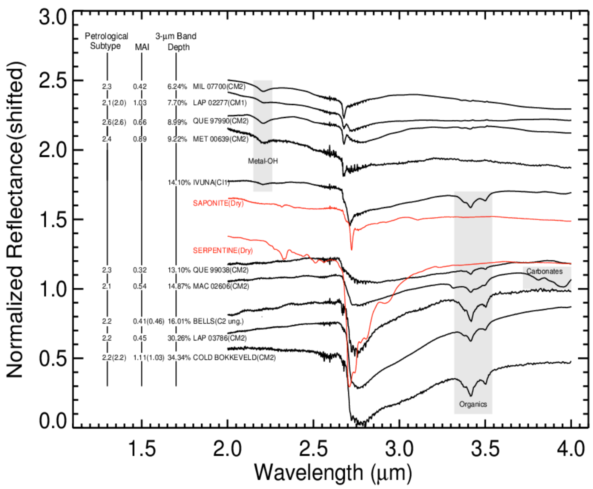

Figure.2. Shifted IR reflectance spectra of CM/CI carbonaceous chondrites measured under dry conditions. The MAI and the petrological subtype were determined applying the alteration scales of [4] and [5], respectively.

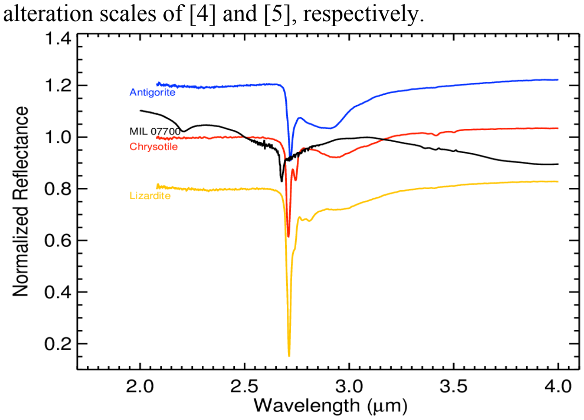

Figure.3. Shifted IR reflectance spectra of antigorite, chrysotile, and lizardite ([7]) and a spectrum of MIL 07700 (first group).

Implications: Asteroids that are observed by ground-based telescopes are affected by strong absorptions of telluric water vapor, especially in the region between 2.5 and 2.8 µm (e.g., [6]). Laboratory spectra of meteorites can be used to analyze the 3-µm band and hence constrain the nature and the degree of aqueous alteration in outer Main belt asteroids. Figure 4 illustrates plots of asteroid 54 Alexandra (C-type) and the CM chondrite Bells. On the basis of the 3-µm shape, we can constraint the MAI (0.41) and the petrological subtype (2.2) for 54 Alexandra, as well as the band depth and band area.

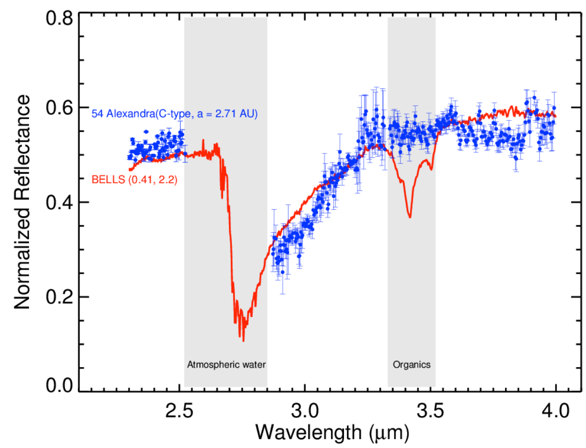

Figure.4. IR reflectance spectra of the dry CM meteorite Bells (second group) and asteroid 54 Alexandra. Bells has an MAI of 0.41 and a subtype of 2.2.

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References: [1] McSween H. Y. (1979) *Rev. Geophys. Space Phys.* 17, 1059–1078. [2] McSween H.Y.Jr. (1979) *Geochim. Cosmochim. Acta*, 43, 1761-1170. [3] Beck P. et al. (2010) *Geochim. & Cosmochim. Acta*, 74, 4881-4892. [4] Browning L.B. et al. (1996) *Geochim. Cosmochim. Acta*, 60, 2621-2633. [5] Rubin A. E. et al. (2007) *Geochim. Cosmochim. Acta,* 71, 2361-2382. [6] Takir D. and Emery J. P. (in review). *Icarus*. [7] Salisbury J.W. et al. (1991) Johns Hopkins Univ. Press, Baltimore, 267pp.

[1] Any use of trade names is for descriptive purposes only and does not constitute endorsement by the authors institutions.