The evolution of water-rich asteroids: Linking the mineralogy and spectroscopy of fully hydrated CM carbonaceous chondrites

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Introduction: The C-complex asteroids (which include B, C, F and G-types [1]) are of interest because they are thought to be volatile-rich, and may be able to tell us about the evolution of water and organic compounds in the early Solar System. Additionally, C-complex asteroids likely made a significant contribution to the volatile budget of the terrestrial planets [2,3]. Carbonaceous chondrite meteorites are physical samples of C-complex asteroids; linking laboratory spectra of carbonaceous chondrites to remote sensing observations of asteroids can therefore give insight into the processes, which occur on primitive bodies in the Solar System.

Spectrally, many C-complex asteroids show evidence for aqueous alteration and links with CM and CI carbonaceous chondrites on their surfaces [4–7]. Most spectral links have been between the C-complex asteroids and moderately altered CM2 chondrites. Although there have been limited studies on the association of these asteroids with fully hydrated (“type 1”) chondrites, Clark et al. [8] suggested a possible relationship between more aqueously altered CM and/or CI chondrites and the surface mineralogy of the B-type, OSIRIS-REx target asteroid, Bennu.

The CM1 chondrites are among the most hydrated extra-terrestrial materials available to study; their precursor mineral assemblages have been almost entirely transformed into secondary, hydrated phases. King et al. [9] investigated CM1 and CM1/2 chondrites with the aim of establishing modal mineralogy and examining variations in the extent of aqueous alteration. In this study we collected reflectance spectra from the same powders used by King et al. [9] so that any spectral trends could be put into context of the mineralogy and degree of aqueous alteration for each meteorite sample.

Experimental: The suite of meteorites investigated included six CM1/2 chondrites and four CM1 chondrites. Approximately 100 mg of each sample was ground into a fine powder using an agate mortar and pestle to a particle size of <35 µm. Infrared reflectance spectra of the powders were obtained using a Bruker VERTEX 70v Fourier Transform Infrared (FTIR) spectrometer at the University of Oxford, using a wide range MIR-FIR beam splitter and a room temperature deuterated L-alanine doped tryglycine sulfate (RT-DLaTGS) detector to measure the reflectance between 6000 - 200 cm^{-1} (1.7-50 µm). All observations were obtained under vacuum (~5 hPa), at a resolution of 4 cm^{-1}. In order to remove instrumental effects, spectra were calibrated by dividing each meteorite spectrum with a spectrum of a gold calibration target,

Results & Discussion: Initial observations of the mid-infrared spectra show samples, which are mostly composed of hydrated minerals, particularly serpentine-group phyllosilicates. Upon further investigation of individual spectral regions - the 3 µm band, 6 µm band, Christiansen features (CF: 7.5-9.5 µm), and the transparency features (TF: 10.5-14 µm) - different phyllosilicate compositions and abundances resulted in different, distinguishable spectral features.

The 3 µm band centres are affected by the Fe-cronstedtite abundances in the samples, with higher abundances shifting the feature to longer wavelengths. The 6 µm band features appear to reflect the anhydrous silicate content, with greater band depths for higher olivine contents. The CFs are identified at similar wavelength positions for all samples (8.8 - 8.9 µm) suggesting the meteorites have similar bulk mineralogy. The TFs were affected by the total phyllosilicate abundance, with higher abundances shifting the peaks to shorter wavelengths.

The above conclusions resulted in splitting the meteorites into two groups. Group A samples had larger 6 µm band features, a 3 µm band centre, and TF peak at longer wavelengths (~2.8 µm and ~12.5 µm respectively). Group B samples had smaller 6 µm band features, a 3 µm band centre, and TF peak at shorter wavelengths (~2.7 µm and ~11.6 µm respectively).

Group A samples represent the least altered CM1/2s, which have significant Fe-cronstedtite abundances of 30.8 – 36.9% and anhydrous olivine abundances of 18.2 – 19.6%. Group B samples represent the most altered CM1s, which have significant Mg-serpentine (52.4 – 71.6%) and low olivine abundances (3.6 – 8.0%). This study shows that slight variations in aqueous alteration might be discernible in current and future telescopic and space mission observations of C-complex asteroids.

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