

LINKING MINERALOGY AND SPECTROSCOPY OF HYDRATED CM CARBONACEOUS CHONDRITES IN PREPARATION FOR PRIMITIVE ASTEROID SAMPLE RETURN MISSIONS. H. C. Bates^{1,2}, A. J. King¹, K. L. Donaldson Hanna², N. E. Bowles² and S. S. Russell¹, ¹Dept. of Earth Sciences, Natural History Museum, London, UK, SW7 5BD (h.bates@nhm.ac.uk), ²Atmospheric, Oceanic and Planetary Physics, University of Oxford, Oxford, UK, OX1 3PU.

Introduction: The C-complex asteroids (which include B, C, F and G-types [1]) are of interest because they are volatile-rich, and may 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]. Carbonaceous chondrite meteorites are hypothesized to be samples of C-complex asteroids; linking laboratory analyses of carbonaceous chondrites to remote sensing observations of asteroids can therefore provide insight into the processes which occur on primitive bodies in the Solar System.

Spectrally, C-complex asteroids show evidence for aqueous alteration and links with CM and CI carbonaceous chondrites [3-5]. Most studies have focused on the relationship between these asteroids and partially altered CM2 (~70 vol% phyllosilicate) chondrites, but few have investigated the fully hydrated (>80 vol% phyllosilicate) CM1 chondrites. Recently, Clark et al. [6] suggested a possible relationship between CM1 and/or CI chondrites and the surface mineralogy of the B-type, OSIRIS-REx target asteroid (101955), Bennu. This potential relationship necessitates further study of these meteorites, particularly investigating the infrared (IR) spectra of a suite of well-characterised samples, for comparison with asteroid observations.

King et al. [7] measured the modal mineralogy of a suite of CM1 and CM1/2 chondrites and examined variations in their extent of aqueous alteration. In this study we collected reflectance spectra from nine of the same powders characterised by [7] so that observed spectral trends could be put into context with the mineralogy and degree of aqueous alteration for each meteorite sample. These types of lab measurements will help in the selection of OSIRIS-REx's sampling site and placing the returned sample into geologic context.

Methodology: The suite of meteorites investigated here include five CM1/2 chondrites and four CM1 chondrites. Approximately 100 mg of each sample was ground into a powder (particle size of <35 μm) using an agate mortar and pestle. IR reflectance spectra of the powders were obtained using a Bruker VERTEX 70v Fourier Transform Infrared (FTIR) spectrometer in a bi-directional reflectance geometry at the Planetary Spectroscopy Facility within the University of Oxford, using a wide range mid to far IR (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 (~2 hPa) at a spectral resolution of 4 cm^{-1} . To remove instrumental effects, each meteorite spectrum was divided by a spectrum of a gold calibration target.

Results & Discussion: Initial IR spectral measurements corroborate results from King et al. [7], that these samples are composed primarily of serpentine-group phyllosilicates. Upon further investigation of individual spectral regions including the 3 μm band (which is caused by absorption of H_2O and OH, and so is linked to hydration [eg. 8]), 6 μm band, Christiansen feature (CF: 7.5-9.5 μm), and transparency feature (TF: 11-14 μm), we find that different phyllosilicate compositions and abundances result in different, distinguishable spectral features.

Based on the reflectance spectra (see Figs. 1 and 2), the suite of samples were split into 3 groups. Group A contains LAP 031214 and MCY 05231 (both CM1/2), group B contains MIL 090288 and LAP 031166 (both CM1/2), and group C contains NWA 8534 (CM1/2), GRO 95645, LAP 02277, MIL 05137 and MIL 07689 (all CM1).

Group A: Near-IR spectra have rounded 3 μm features, with band centres at longer wavelengths (2.81-2.82 μm , Fig. 1). This is likely due to the high Fe-cronstedtite abundances in these samples (>30 vol% [7]), and is consistent with results from Takir et al. [8]. The presence of the heavy Fe cations slow vibrational frequencies, resulting in features at longer wavelengths. Group A spectra have 6 μm features with spectral contrast of ~9 % (MCY 05231) and ~12 % (LAP 031214) above the continuum. This could reflect the high anhydrous silicate content (~20 vol% [7]), although further evaluation is needed to examine the constituents which might contribute to this feature. The CFs were identified near 8.9 μm in both samples spectra. The MCY 05231 spectrum has a TF minimum near 12.4 μm , which is consistent with the TF peak identified by McAdam et al. [9] in CM2 chondrites with high anhydrous silicate contents. The LAP 031214 spectrum has a shorter wavelength TF minimum near 11.7 μm , which could be due to its higher Mg-serpentine content when compared to MCY 05231 (40 vol% compared to 36 vol%). These two samples were suggested to be reclassified as CM2 chondrites by [7] and these results support that finding.

Group B: Near-IR spectra have a steep downward slope at the beginning of the 3 μm feature (between 2.6-2.7 μm), compared to the rounded, shallow slope in group A sample spectra and is followed by a relatively flat shaped band. The 6 μm features have spectral contrasts of $\sim 7\%$ (MIL 090288) and $\sim 9\%$ (LAP031166). This spectral contrast is similar to the group A samples, but they have much less anhydrous silicate (4-5 vol% [7]). This suggests this feature is caused by a number of factors, and further evaluation is needed. The CFs in both sample spectra are identified near 8.9 μm . The TFs have minima near 11.5-11.9 μm , which is consistent with the Mg-serpentine standards (see lizardite spectrum in Fig. 2) and is expected as the group B samples have high Mg-serpentine contents ($\sim 65\%$ vol% [7]). These results corroborate the samples classification of CM1/2.

Group C: Near-IR spectra have a steep downward slopes between 2.6-2.7 μm , followed by a relatively sharp 3 μm feature, with band centres near 2.73 μm . The short wavelength band centre is expected due to the removal of the heavy Fe cations, speeding up vibrational frequencies and showing features at shorter wavelengths, and corroborates work by [8]. The shape of the feature is consistent with the Mg-serpentine standards (see lizardite spectrum in Fig. 1). These samples have low Fe-cronstedtite abundances (20-32 vol%) and high Mg-serpentine abundances (52-71 vol%) [7]. GRO 95645 and MIL 07689 spectra have a different, steeper slope in the mid-IR when compared to the other group C samples and have significant 6 μm features (contrasts of $\sim 19\%$ and $\sim 16\%$ respectively). They also appear to have the strongest 3 μm features. These two samples are the most weathered of the whole suite [10, 11], and it could be that these features are due to the presence of terrestrial alteration. As with the other groups, however, further evaluation is needed to establish the contributing mineralogy, especially in the 6 μm region. The other group C spectra have weak features near 6 μm . The CFs identified in the C spectra are between 8.8-9.0 μm . As with group B, the TF minima identified in group C spectra are between 11.6-11.8 μm , which is likely due to the high Mg-serpentine contents. All samples in group C are classified as CM1 chondrites, excluding NWA 8534, which is the CM1/2 with the highest phyllosilicate reported by [7]. These classifications are consistent with the IR spectra.

This study shows that variations in mineralogy related to the degree of aqueous alteration are discernible in the IR spectra of CM meteorites, which is relevant to the interpretation of future telescopic and space mission observations of C-complex asteroids.

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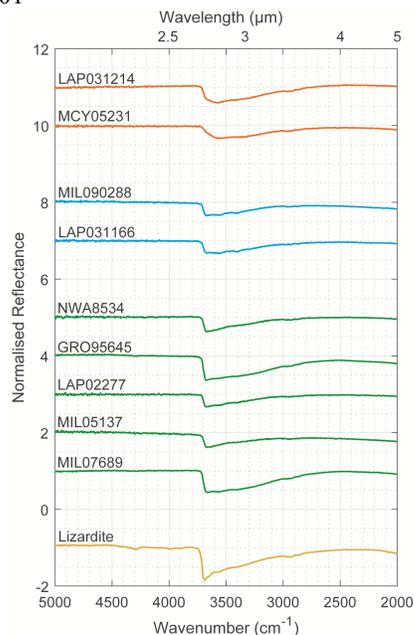


Figure 1: Near-IR spectra of CM1 and CM1/2 chondrites and lizardite. Group A is in red, group B in blue and group C in green.

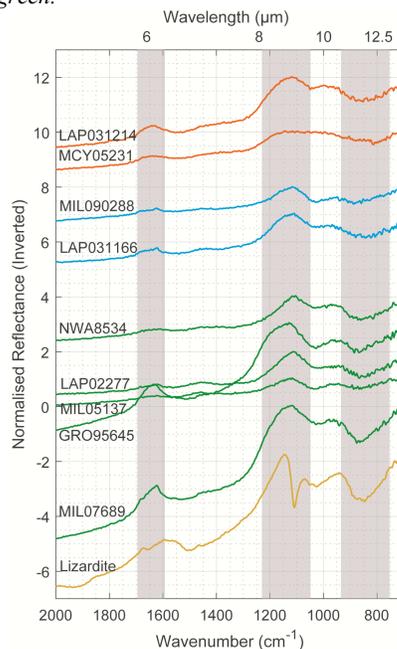


Figure 2: Mid-IR spectra of CM1 and CM1/2 chondrites and lizardite, with areas of interest in grey.