THERMAL ALTERATION OF CI AND CM CHONDRITES: LINKS TO PRIMITIVE C-TYPE ASTEROID SURACES

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Introduction: In the meteorite collection there are >30 CI and CM carbonaceous chondrites that experienced low temperature (<150°C) aqueous alteration followed by short-lived thermal metamorphism (300 – 1000°C) [1]. As the surfaces of many low albedo C-type asteroids are likely to be a mixture of hydrated and dehydrated materials, and with C-type asteroids the focus of several current space missions (e.g. Dawn, Hayabusa-2 and OSIRIS-REx), it has become important to systematically characterize the spectral properties of heated CI and CM chondrites. We have previously investigated the bulk modal mineralogy and H_2O contents of 16 heated CI and CM chondrite powders (~50 mg) using X-ray diffraction (XRD), thermogravimetric analysis (TGA) and transmission mid-infrared (IR) spectroscopy [2]. Thermal metamorphism results in distinct mineralogical and chemical changes that can be used to constrain the alteration history of these meteorites. Here, we present visible, near- and mid-IR reflectance spectra collected from the same meteorite powders. Our aim is to directly relate characteristic features in the spectra to the known properties and alteration history of the heated CI and CM chondrites in order to support remote sensing observations and accurately interpret the surface mineralogy of primitive C-type asteroids.

Experimental: The spectroscopic measurements were made at the Planetary Spectroscopy Laboratory (PSL) of DLR in Berlin with two identical FTIR Bruker Vertex 80V evacuated to ~.1 mbar and equipped with two pairings of detector+beamsplitter to cover the spectral range from 0.45 to 16 µm. One of the spectrometers has internal optics optimized for measurements from the UV to the VNIR spectral range; this instrument was used to cover the VIS spectral range (0.45 to 1.1 µm), mounting a Si Diode detector coupled with a CaF_2 beamsplitter. The second spectrometer is best suited for covering from the VNIR to the FIR spectral range; the IR spectral range (1 to 16 µm) was covered using an MCT (HgCdTe) detector coupled to a KBr broadband beamsplitter [3].

Each sample was packed into a black PFTE 10 mm diameter diffuse reflectance sampling cup and measured for illumination angles i=e spanning from 13° to 70° (i=incidence, e=emerging angle) by using an automatic and computer controlled accessory optical unit (Bruker A513). To prevent the light source projection exceeding the sample surface dimension, an aperture of 1 mm was chosen as a standard for all the measurements. The reference targets (measured under the same instrumental and illumination conditions) were spectralon for the VIS spectral range (0.45 to 1.1 µm) and gold sandpaper for the IR region (1 to 16 µm). The illumination source was an external Wolfram 24V lamp for the VIS spectral range, and an internal Globar lamp for the IR spectral range.

Results & Discussion: One of the most diagnostic features in CI and CM chondrite IR spectra is the 3 µm band, which is attributed to the -OH/H_2O in the phyllosilicates and Fe-(oxy)hydroxides. The measurements were made under ambient conditions so the 3 µm band is observed in all spectra of the heated CI and CM chondrites. Nevertheless, the shape and intensity of the 3 µm band varies with the extent of thermal metamorphism. For example, the depth of the 3 µm band is correlated with the H_2O abundance of the meteorites, and both features decrease with increasing peak metamorphic temperature due to the dehydration of the phyllosilicates. Exceptions are PCA 91008 and PCA 02010, which are both heavily weathered and have deep, broad 3 µm bands.

The 0.7 µm feature is often linked to Fe^{2+}-Fe^{3+} charge transfer in phyllosilicates and oxides, and has been detected for several C-type asteroids [e.g. 4] and in CI and CM chondrites [5]. We only observe the 0.7 µm feature in the heated CM chondrites that experienced the lowest peak metamorphic temperatures (<300°C). This suggests that thermal metamorphism led to a reduction of Fe^{3+} in the phyllosilicates. Preliminary analyses also indicate that with increasing metamorphism up to ~500°C the spectral slope (2.4/0.56 µm reflectance ratio) becomes greater before an overall flattening is observed in the meteorites heated >500°C.

We identify weak absorption bands in the 0.8 – 1.3 µm region, which likely result from both phyllosilicates and silicates. More prominent features from these phases occur in the mid-IR. In the least heated CM chondrites (<300°C) we observe a broad feature at ~9 µm from Mg-rich phyllosilicates, whereas in CM chondrites heated to >500°C this becomes a doublet due to presence of olivine. This reflects dehydration of the phyllosilicates back into anhydrous silicates and is consistent with XRD data showing that these meteorites contain high abundances (>20 vol%) of fine-grained and/or poorly crystalline olivine.

Our initial findings demonstrate that reflectance spectra of well characterized meteorite samples can be used to understand remote sensing observations and assess the degree of aqueous alteration and thermal metamorphism on the surfaces of C-type asteroids.

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