THE THERMAL HISTORY OF CI AND CM CHONDRITES AND THEIR RELATIONSHIP TO PRIMITIVE ASTEROID SURFACES

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Introduction: The CI and CM carbonaceous chondrites are products of low temperature (<150°C) aqueous alteration on asteroids during the early history of the Solar System. Among known meteorites, there are also a small number (~30 samples) of CI and CM chondrites that experienced post-hydration thermal metamorphism at temperatures >300°C. Evidence for heating comes from dehydration of the phyllosilicates and recrystallization back into olivine, variations in elemental and isotopic compositions, and the destruction and modification of organics [e.g. 1].

Reflectance spectra suggest that the CI and CM chondrites are derived from low albedo C-type asteroids [2], which are the focus of several current space missions (e.g. Dawn, Hayabusa-2 and OSIRIS-REx). However, the surfaces of C-type asteroids are expected to contain a mixture of both hydrated and dehydrated materials. It has therefore become important to constrain the extent of alteration and the spectral characteristics 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 infrared (IR) spectroscopy [3]. Here, we now present visible, near- and mid-IR reflectance spectra collected from the same powders. Our aim is to directly relate spectral features to the known properties and alteration history of the heated CI and CM chondrites and accurately interpret the surface mineralogy of C-type asteroids.

Experimental: Spectroscopic measurements were made at the Planetary Spectroscopy Laboratory (PSL) at the DLR, Berlin, with two identical FTIR Bruker Vertex 80V spectrometers evacuated to ~0.1 mbar. One spectrometer covered the visible spectral range (0.45 to 1.1 µm) using a Si diode detector coupled with a CaF_2 beamsplitter; the other covered the near- to mid-IR (1 to 16 µm) using an MCT detector coupled to a KBr beamsplitter. Each sample (grainsize <50 µm) was packed into a black PFTE 10 mm diameter diffuse reflectance sampling cup, and to prevent the light source projection exceeding the sample surface dimension, an aperture of 1 mm was chosen as a standard for all measurements. The illumination source and reference targets were an external Wolfram 24V lamp and spectralon for the visible range, and an internal Globar lamp and gold sandpaper for the near- and mid-IR.

Results & Discussion: We identify only weak absorption bands from phyllosilicates and silicates in the visible and near-IR region. The 0.7 µm feature is associated with Fe^{2+}-Fe^{3+} charge transfer in phyllosilicates and oxides, and has been detected in some CI and CM chondrites [4] and C-type asteroids, including Ryugu, the target for the Hayabusa-2 spacecraft [5]. We find that the 0.7 µm feature is absent from spectra of heated CI and CM chondrites, suggesting that thermal metamorphism led to a reduction of Fe^{3+} in the phyllosilicates. Thermal metamorphism up to ~500°C also increases the spectral slope (2.4/0.56 µm reflectance ratio) before a flattening is observed in CI and CMs heated to >500°C.

A typical feature in CI and CM chondrite spectra is the 3 µm band, which is attributed to -OH/H_2O bound in phyllosilicates and Fe-(oxy)hydroxides. We observe the 3 µm band in all of the heated CI and CM chondrite spectra; however our powders were not dried and the measurements were made under ambient conditions so this is at least partly due to adsorbed terrestrial water. Nevertheless, we note that except for the heavily weathered meteorites (PCA 91008 and PCA 02010), the position and intensity of the 3 µm band is correlated with the H_2O content measured by TGA and the inferred peak metamorphic temperatures.

In the mid-IR the CI and CM chondrites that experienced temperatures of <500°C have a broad feature at ~9 µm from Mg-rich phyllosilicates. In the CI and CM chondrites heated to >500°C we also see minima at ~10 µm and ~12 µm that are attributed to the presence of olivine. This reflects dehydration of phyllosilicates back into anhydrous silicates and is consistent with XRD data showing that these samples contain high abundances (>20 vol %) of fine-grained and/or poorly crystalline olivine.

Conclusion: The heated CI and CM chondrites are likely to be excellent analogues for the types of materials that will be encountered by the Hayabusa-2 and OSIRIS-REx missions. We are now using reflectance spectra collected from well characterized naturally heated CI and CM chondrite powders to interpret the surface mineralogy of C-type asteroids. Features in the mid-IR are particularly diagnostic of the anhydrous and hydrous silicate mineralogy and can be used to remotely infer the extent of aqueous and thermal processing on these primitive bodies.

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