Heated Synthetic Murchison Reflectance Spectra

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Introduction: Several carbonaceous chondrites (CCs) display evidence of thermal alteration [1]. Remote sensing data from the JAXA Hayabusa2 asteroid sample return mission suggests that asteroid (162173) Ryugu's parent body may have undergone internal or impact-generated heating prior to breakup [2]. Furthermore, models of orbital and thermal evolution of Ryugu suggest that the asteroid was likely exposed to surficial heating during close passes to the Sun. [3]. Recently, geomorphological features observed on Bennu's surface indicate alteration of rocks due to thermal fatigue [4]. Constraining the spectral characteristics of heating will aid in identifying the timing and intensity of heating experienced by Ryugu and its parent body, as well as other extraterrestrial bodies which may have also undergone a period of thermal alteration.

Methods: The Centre for Terrestrial and Planetary Exploration (C-TAPE) at the University of Winnipeg conducted a heating experiment on a synthetic Murchison simulant. The synthetic mixture, named WMM, consisted of various major representative phases in CM carbonaceous chondrites as following: 85 wt. % ASB267, a dark serpentinite representative of CM phyllosilicates. 5 wt. % SHU102, shungite, terrestrial organic representative of organic phases. 5 wt. % TRO203, synthetic troilite representative of sulfides, and 5 wt. % MAG200, magnetite. The simulant consisted of <63 µm powders of serpentinite, shungite, and troilite, and ~20 nm sized magnetite that appeared to be maghemite from X-ray diffractometry (likely due to surface oxidation of the nanoparticles). The samples were heated up to 1200°C at 100°C increments. XRD and reflectance spectra were collected prior to heating, and after each temperature increment. A new sample powder was used for each increment, and samples were heated under continuous nitrogen flow. Samples were heated for one week at intervals of 100°C to 1000°C. However, due to the oven's constraints, samples were only heated for 2 hours at 1100°C and half an hour at 1200°C. The reflectance spectrum for 300°C is unavailable due to an accidental sample spill while removing the powder from the oven. The spectra were collected with an Analytical Spectral Devices (Boulder, CO) LabSpec 4 Hi-Res® spectrophotometer between 350 and 2500 nm. Spectra were measured at a viewing geometry of i = 30º and e = 0º with incident light being provided by an in-house 150 W quartz-tungsten-halogen collimated light source. Sample spectra were measured relative to a Labsphere Spectralon® 100% diffuse reflectance standard and corrected for minor (less than ~2%) irregularities in its absolute reflectance.

Results: Heating the Murchison simulant samples resulted in spectral variation across the temperature increments. The spectra show little change up to ~500°C (Figure 1). Beyond 500°C, the spectra display features associated with Fe^{3+} oxyhydroxides, such as low reflectance below ~500nm, a steep red slope in the visible region, and absorption features near 870 nm. Absorption bands associated with serpentine, at 1400 and 2320 nm, are evident up to ~600-700°C. The spectra generally become brighter up to ~800°C, and then darken substantially beyond this temperature. At and above 1100°C, the spectra are generally dark and featureless, with a broad absorption region centered near 1600 nm.

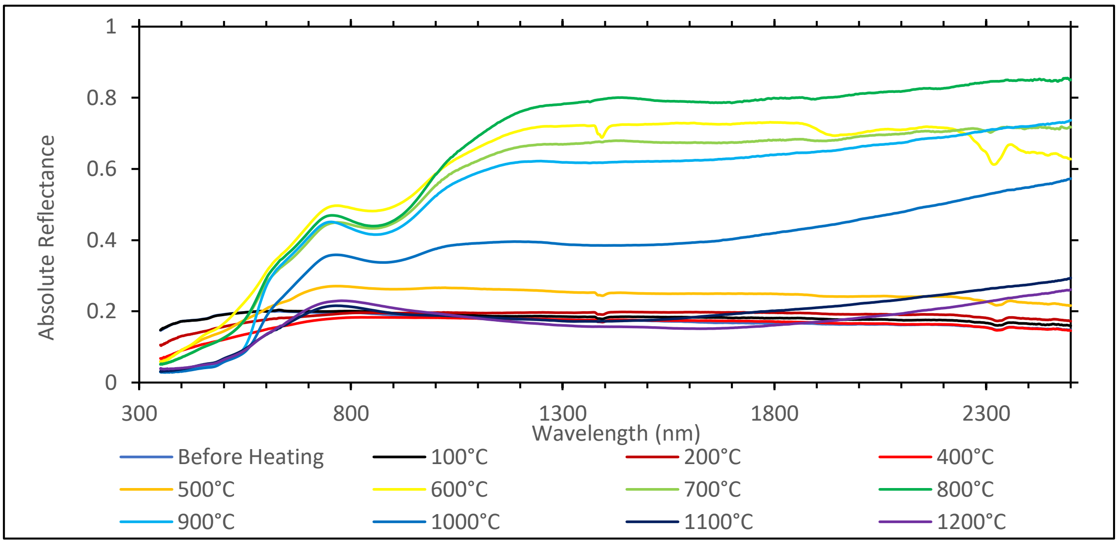

Figure 1. Reflectance Spectra of Simulated Murchison Mixture WMM.

Additionally, we heated end members used to produce the Murchison simulant to better understand the causes of the spectral changes observed. These samples (serpentine, shungite, troilite, and magnetite) were heated under the same conditions as the simulant. Serpentine spectra remained unchanged up to ~200°C, after which the spectra display an increasing red slope below ~700 nm and an absorption feature near 860 nm, both of which are ascribed to Fe^{3+} oxyhydroxides. Furthermore, the OH absorption bands near 1400 and 2320 nm associated with serpentine were evident up to ~700°C. Reflectance generally increased up to ~600°C, and decreased at higher temperatures. Shungite was stable up to ~500°C. However, at 600°C, the organic component of the sample was volatilized. Troilite remained stable up to ~300°C, after which Fe^{3+} oxyhydroxides were evident in its spectra. Fine-grained magnetite remained stable up to ~100°C, after which it also transformed to Fe^{3+} oxyhydroxides.

Discussion: Temperature-induced spectral changes are evident in the Murchison simulant used in this study. XRD measurements confirm that the changes seen in the spectra can be related to the changes in the mineralogy of the samples. The spectral changes occur in multiple wavelength regions, suggesting that various spectral metrics could be robust indicators of temperatures experienced by a serpentine-rich carbonaceous chondrite.

Spectral changes observed in this study are associated with short heating periods (hours to days), and are thus, applicable to short-term heating events such as impact heating. The applicability of these results to long-term heating events, such as internal heating within larger asteroids, is unknown. Furthermore, the dry nitrogen environment under which this heating experiment was conducted only represents one scenario of the conditions which may have prevailed on carbonaceous chondrite parent bodies during any heating events. Nevertheless, the results of our experiments suggest that spectroscopic data in the 350-2500 nm can provide insights into the intensity and duration of heating events affecting carbonaceous chondrite asteroids. It is also worth noting that naturally-heated carbonaceous chondrites show spectral differences associated with changes in mineralogy [1]. We are in the process of relating the results of these experiments to other carbonaceous chondrite heating experiments [5, 6, 7, 8] and naturally-heated carbonaceous chondrites [9] to better understand the full applicability of our results to observational data.

References

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