THE SHAPE OF THE 3 µm ABSORPTION BAND LINKED TO THE ALTERATION HISTORY? LABORATORY INVESTIGATIONS ON CARBONACEOUS CHONDRITES AND APPLICATIONS TO AKARI, Hayabusa2 AND OSIRIS-REx SPECTRA

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Introduction: the two space probes Hayabusa2 and OSIRIS-REx are currently orbiting their respective targets, the Near-Earth Asteroids (NEAs) Ryugu and Bennu. The reflectance spectra of these small bodies are drastically different, showing a strong blue slope and well-defined 3 µm hydration band for Bennu [1], while Ryugu presents a very low reflectance value and a tenuous 3 µm band [2]. To explain this difference despite small bodies experienced heating during their lifetime, we propose to investigate the effect of thermal alteration on the reflectance spectra of carbonaceous chondrites. Our conclusions will then be applied to Main Belt asteroids (MBAs) and the two NEAs observations.

Samples and methods: Reflectance spectroscopy has been performed on 12 powdered carbonaceous chondrites (10 CM, 1 CR and 1 CI) using the SHADOWS spectro-gonio radiometer [3] coupled with the environmental cell MIRAGE [4]. This setup enables reflectance measurements over the visible-near IR spectral range while keeping the sample under asteroid-like environment: secondary vacuum (10^{-6} to 10^{-7} mbar) from room temperature to 523 K. The spectra were measured with a nadir illumination and observation at 30°. A first spectrum was acquired as a reference at room temperature. The sample was then heated to 523 K and kept at this temperature during 90 min and cooled down to room temperature. Another spectrum was then measured after this heating cycle. The experiment is fully automatized and never breaks the vacuum inside the cell.

Results: Fig. 1 presents the reflectance spectra before and after the heating cycles for 2 samples.

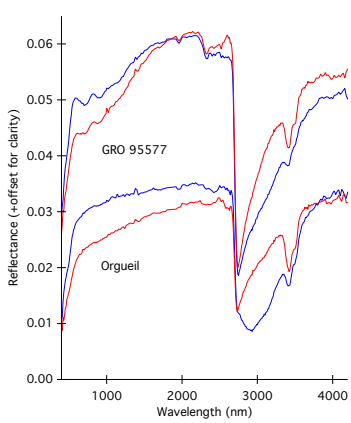

Fig. 1: Normalized reflectance spectra of the CR1 GRO 95577 and the CI1 Orgueil before (blue) and after heating at 523 K (red). Offsets for clarity.

The heating experiment strongly affects the whole spectrum: the continuum become redder and darker and the absorption bands in the visible range reduce and shift towards shorter wavelengths. Focusing on the 3 µm feature, the hydration band becomes fainter and thinner, the position of the minimum shifts towards shorter wavelengths and the global shape of the band drastically changes and become much sharper.

The 3µm is due to oscillation of –OH groups, in oxidized minerals, or/and in water molecules. The feature is so a convolution of several components, that can be separated to better understand the effect of heat on the mineralogy and hydration of the sample. As an example, Fig. 2 presents the hydration feature of Orgueil (before heating) separated into 3 components, using the model and algorithm described in [5]. Two Gaussian profiles are added to model the detected stretching modes of CH_2 and CH_3 groups between 3400 and 3600 nm.

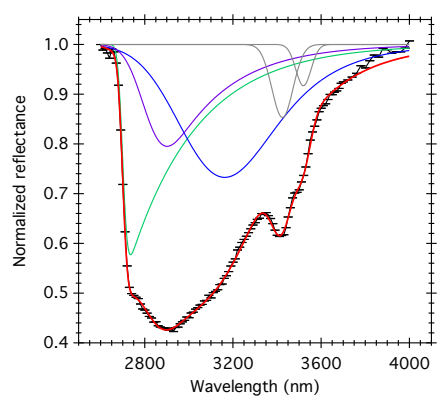

Figure 2: Spectral modelling of the 3µm band of Orgueil, before heating. Black: measured spectrum, Red: modeled spectrum, Green, Purple, Blue: components of the 3 µm band, Grey: organic features.

The components of the -OH absorption band have been previously described [6, 7] and are directly linked to the alteration history and relative humidity of the sample:

- the first component (green in Fig. 2) around 2750 nm is due to stretching vibrations of –OH groups in oxidized minerals, such as phyllosilicates.

Abundance and chemistry of phyllosilicates will vary with the extent of aqueous alteration. In particular, the metal-OH component will deepen and shift towards 2700 nm with increasing aqueous alteration [8]. The thermal cycle has no effect on this spectral component. This is expected as the dehydration of phyllosilicates occurs over 400°C while the heating in our experiment is at 250°C.

- the second component (blue in Fig. 2) around 3200 nm is due to –OH stretching vibartions within bulk water molecules. The amplitude and position of this component directly depends on the number of water molecules trapped between phyllosilicates sheets. With decreasing number of trapped water molecules, this component faints and shifts towards shorter wavelengths [9].

- the third component (purple in Fig. 2) around 2900 nm is due to –OH vibrations in adsorbed or mesopore water molecules, minimized thanks to acquisition under vacuum.

All studied samples showed the metal-OH and bulk water components/molecules. Half of them also presented traces of adsorbed water. The modification of the shape of the 3 µm band with temperature (see Fig. 1), from rounded to sharp, is explained by the disappearance of the adsorbed water component and the decrease and shift of the bulk water band, revealing the sharp and asymmetric shape of component related to -OH in oxidized minerals.

Application to asteroids observations: reflectance spectra of 11 C-complex MBAs were selected from the AKARI AcuA survey [10]. The spectra of the two NEAs Ryugu and Bennu were digitalized from [2] and [1], respectively. Their 3 µm bands were processed similarly to those from chondrites. When comparing the position and amplitude of the different components, we found that all considered C-complex asteroids are consistent with hydrated surfaces similar to type 1 and 2 carbonaceous chondrites, as we expected. Some of the asteroidal spectra reveal the presence of bulk water molecules on the surface, other present signs of adsorbed water. Our analysis also showed that asteroids from the same type (C-, Ch-, Cgh-,…) present metal-OH and water components of similar amplitudes and positions.

Ryugu: the reflectance spectrum of Ryugu shows a tenuous metal-OH component centered at 2720 nm, reflecting a heavy aqueous alteration of the surface. This is consistent with Ryugu being formed from an ice-covered parent body [11]. However, no water molecules, bulk or adsorbed, are detected on the spectrum. Given also the small amplitude of the metal-OH component, this would suggest a high-temperature episode (above 400°C) occurring after the heavy aqueous alteration, removing any water molecules however strongly trapped to the surface, and dehydrating the minerals.

Bennu: the reflectance spectrum of Bennu presents a metal-OH component consistent with strongly altered type 1 chondrites. This is in agreement with Bennu supporting affinity with CI and CM chondrites [12]. The 3 µm band also suggests traces of water molecules adsorbed to the surface of the small body. This adsorbed water could be linked to the newly discovered activity of the surface, as a cause or consequence.

Conclusion: Process at high temperature can strongly alter the reflectance spectra of surfaces, and drastically change the shape of the 3 µm absorption band. Laboratory measurements on meteorites under asteroid-like environment highlight the link between the different components of this feature and the aqueous alteration history of the sample. The same interpretation can be applied to asteroid telescopic observations to explain the strong difference between the 3 µm band detected on Ryugu and Bennu.

References: [1] Hamilton, V.E. et al. (2019), *Nature Astronomy,* 3, 332-340. [2] Kitazato, K. et al. (2019), *Science,* 7, eaav7432. [3] Potin, S. et al. (2018), *Applied Optics, 57,* 8279-8296. [4] Potin, S. et al. (2019), *Icarus, 333,* 415-428. [5] Potin, S. et al. (subm.), *Icarus.* [6] Bishop, J. et al. (1994), *Clays and Clay Minerals, 42,* 702-716. [7] Frost, R. et al. (2000), *Thermochimica Acta, 346,* 63-72. [8] Beck, P. et al. (2010), *Geochimica and Cosmochimica Acta, 74,* 4881-4892. [9] Schultz, J. (1957), *PhD thesis*. [10] Usui, F. et al. (2019), *Publications of the Astronomical Society of Japan,* 7, 1-41. [11] Sugita, S. et al. (2019), *Science,* 364, eaaw0422. [12] Lauretta, D. et al. (2019), *Nature, 568*, 55-60