

IRREVERSIBLE METAMORPHISM OF WARM C-TYPE NEAR-EARTH ASTEROIDS INVESTIGATED WITH CARBONACEOUS CHONDRITES. S. Potin¹, P. Beck¹, P. Vernazza², and B. Schmitt¹, ¹Institut de Planétologie et Astrophysique de Grenoble (IPAG, Université Grenoble Alpes, CNRS), 414 rue de la Piscine, 38400 Saint-Martin d'Hères, France. ²Laboratoire d'Astrophysique de Marseille (LAM), 38 rue Frédéric Joliot-Curie, 13388 Marseille, France. (sandra.potin@univ-grenoble-alpes.fr)

Introduction: Spectral signatures of hydration are detected on a majority of Main-Belt Asteroids (MBAs) corresponding to C-types asteroids [1], while they seem scarce in the Near-Earth Asteroids (NEAs) population [2,3]. The origin of this difference remains to be understood.

Signatures of aqueous alteration can be recorded in the optical properties of primitive meteorites, corresponding to the Fe²⁺ and Fe³⁺ bands around 700 nm and 900 nm, and the -OH vibration band typical of phyllosilicates at 2700 nm. These tracers of hydration are also detected in reflectance spectra of C-type asteroids [4].

The effects of the increase of temperature on the absorption features of meteorites in the visible range have already been investigated [5]. We propose to analyze the spectral variations occurring over a wider spectral range, during a cycle of heating and cooling, and in a temperature range relevant for NEAs [6]. This method simulates on the laboratory timescale the temperature history of a rotating NEA.

Methods: Meteorites of different petrologies and alteration histories have been chosen to perform the experiment. Among them, 11 water altered CM chondrites are used to investigate the processes responsible for the apparent dryness of NEAs. Reflectance spectroscopy were conducted using the spectrogonioradiometer SHADOWS [7], coupled with the home-made environmental cell MIRAGE.

SHADOWS. The spectro-gonio radiometer generates a monochromatic light between 340 nm and 5000 nm and illuminates the sample under a given direction (incidence angle). Two detectors measure the reflected light under another given direction (emergence angle). We did not focus our experiment on the bidirectional reflectance behavior of the meteorites, so we fixed the geometry at nadir illumination (incidence angle of 0°) and an emergence angle of 30°. The reflectance of the sample is calculated at each wavelength relative to measurements of calibrated Spectralon[®] and Infragold[®] targets.

MIRAGE. Standing for “Mesures en InfraRouge sous Atmosphère Gazeuse et Étuvée”, MIRAGE is composed of a circular chamber closed on the top with a sapphire window. This cell enables reflectance spectroscopy measurements with SHADOWS while controlling the temperature of the sample placed in it,

from room temperature up to 523K. A volume of 38mm³ (around 40 mg) of material is needed to fill the sample holder.

Measurements. The cell was put under secondary vacuum (10⁻⁶ mbar) to remove the adsorbed terrestrial water molecules and to prevent any oxidation of the sample at high temperature. We intentionally did not fill the cell with gaseous nitrogen (which ensures a good thermalization of the sample) in order to avoid overheating of the interior of the cell. To ensure thermalization of the small amount of material, we kept it at the desired temperature during 30 minutes before starting the acquisition of a spectrum.

Impacts on the 2.7 μm and organic features. We first study the variations of the phyllosilicate absorption band around 2750 nm and of the organic features detected on some samples around 3400 nm. During this study, reflectance spectra are acquired under vacuum at room temperature before and after setting the sample at 523K for 1h30. After the first spectrum and before being heated, the sample is set at 373K to release the residual water adsorbed at its surface and in the mesopores of the sample grains.

Impacts on the visible spectral range. We then focus on the visible spectral range to analyze the variations occurring in the Fe²⁺-Fe³⁺ bands at 700 nm and 900 nm. The cell is in the same configuration as during the previous experiment, and in order to detect the temperature at which the variations start to become irreversible, the thermal cycle (29 temperature steps) is set as follow : an increase of 40K, followed by a decrease of 20K, until reaching 523K. A spectrum is acquired at each step of temperature. It is thus measured twice at each temperature, once after an increase in temperature, and another after cooling. The sample is then left to cool down, during which one spectrum is acquired every 50K to detect any spectral variation.

Results: Reflectance spectra of all carbonaceous chondrites show variation due to the imposed temperature changes. All absorption features due to hydration are altered, despite the rather low temperature and short duration of the heating.

Analysis of the 2.7 μm and organics features. During the heating, the 2.7 μm phyllosilicate band weakens and becomes thinner. Meanwhile, the organics features around 3400nm, get sharper and deeper (see Figure 1).

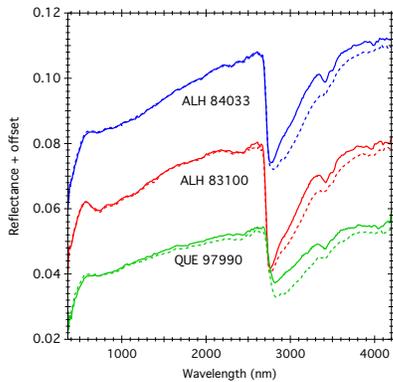


Figure 1: Reflectance spectra before (dotted line) and after heating at 523K (solid line). A vertical offset of 0.02 and 0.04 has been added respectively on Allan Hills 83100 and Allan Hills 84033.

The 2.7 μm absorption feature corresponds to the –OH stretching modes of the terrestrial adsorbed water molecules and of the water of hydrated minerals such as phyllosilicates [9]. As our measurements are performed under vacuum, the contribution of the weakly bonded terrestrial water is excluded, leaving the water of hydration of the minerals as a contribution to the 2.7 μm band. The sharpening and loss of amplitude of the band indicates an irreversible alteration of the phyllosilicates. The faint features around 3.4 and 3.5 μm correspond to C-H stretching modes in –CH₃ and –CH₂– groups in organics. The deepening and sharpening of these bands suggest a permanent reorganization of the organic structures. A comparison between the different samples show that heavily altered chondrites present the smallest spectral variations after the temperature cycle.

Analysis of the visible range. The effect of temperature on the visible range, focused on the iron features, is investigated with the second experiment (see Figure 2).

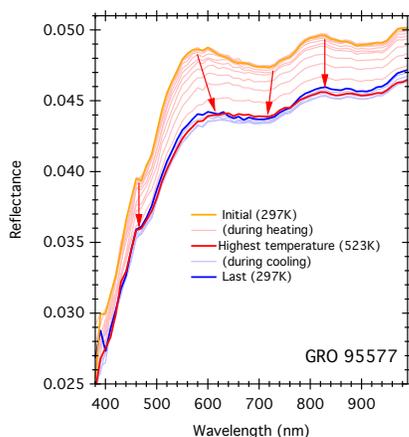


Figure 2: Reflectance spectra of the meteorite Grosvenor Mountains 95577 acquired during the thermal cycle.

Our results show that, along with the absorption features, the continuum slope and the reflectance level of each sample are also altered by the temperature ramp. The near-UV absorption and the 700 nm band are also irreversibly altered, losing depth, width and shifting towards the shorter wavelengths. The 900 nm band is also modified with temperature, but the effects are generally reversible, and the band tends to regain its initial position and shape after the complete cool down of the sample.

The 700 nm and 900 nm bands in the reflectance spectra of CM chondrites are attributed to a charge transfer between Fe²⁺ and Fe³⁺ within a phyllosilicate structure, and Fe³⁺ crystal field transition. Permanent modification of these two bands can be a sign of a redistribution of the Fe²⁺ and Fe³⁺ population on their energy levels.

The progressive darkening is consistent, along with the deepening of the 3.4 μm features, with the transformation of the organics inside the sample.

Conclusion: Irreversible alteration of the hydration spectral features occurs in the time scale of laboratory experiments on meteorites subjected to thermal conditions relevant for NEAs. The effects vary from one sample to another, following a general trend of disappearance of the absorption bands during the increase and decrease of the temperature, except for the organic feature. The succession of thermal cycles on the surface of a rotating asteroid could lead to a weakening or a complete disappearance of the absorption bands on the reflectance spectra of the small body.

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