BI-DIRECTIONAL REFLECTANCE SPECTRA OF HED METEORITES: CRYSTAL FIELDS BANDS, THE 3 MICRON REGION AND THE SIGNATURES OF VESTA's MANTLE . P. Beck[1], J-A Barrat[2], E. Quirico[1], F. Grisolle[1], B. Schmitt[1], F. Moynier[3], P. Gillet[4] and C. Beck[5]. [1]UJF-Grenoble 1 / CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) UMR 5274, Grenoble, F-38041, France, beckp@obs.ujf-grenoble.fr.[2]Universite de Bretagne occidentale, IUEM, 29280 Plouzané cedex, France.[3]Washington University, 1 Brookings Dr, Saint-Louis MO, USA.[4]Ecole Polytechnique Fédérale de Lausanne, Switzerland.[5]Institut des Sciences de la Terre, Université de Savoie, France.

Introduction: The howardite-eucrite-diogenite group (or HED) is a major group of achondrites. Eucrites are basaltic or gabbroic rocks that formed as lava flows or intrusions, and are certainly samples of the upper crustal lithologies of their parent body. Diogenites are orthopyroxene-rich ultramafic cumulates whose parental magmas are not well constrained. Most of these rocks were extensively brecciated and locally melted by meteorite impacts. These mafic to ultramafic rocks originate from an early differentiated parent body, possibly the asteroid 4-Vesta. Interest is actually growing for HEDs. In September 2007, the Dawn spacecraft was launched to the asteroid belt and will begin studying Vesta in 2011[1].

Here, we report on the near-IR spectra of 10 HED meteorites that span most of the petrographical and chemical diversity encountered. We report on spectra within the 0.4-4.6 nm range, which is comparable to future measurements by the VIR spectrometer onboard DAWN. For the first time the bi-directional spectra of two HED meteorites was measured in the same spectral range, to constrain the dependence of the various spectral classification parameters on observation geometry. We also report on NIR spectra of olivine diogenites, and we will see how they can be distinguished from other diogenites.

Samples and analytical method:10 meteorite samples were used in this study: 5 eucrites (NWA 5356, Pasamonte, Millbillillie, Dho 007 and NWA 5617), 3 diogenites (Tatahouine, Bilanga and Dhofar 700), and 2 olivine diogenites (NWA 4225 and NWA 5480). Because we were interested in the Fe^{2+} and Fe^{3+} crystal field bands, they were chosen to represent a significant part of the diversity of pyroxene chemistry described in the literature. The main petrographical features, especially the compositions of the phases (plagioclases, pyroxenes and olivines) of most of the meteorites that we have selected for this study have been described in previous studies. Each sample was prepared by grinding within an agate mortar. We paid special attention not to compact the sample in any manner. All individual meteorite spectra shown in Fig 1 were measured under controlled dry atmosphere ($P=10^{-3}$ mbar, T=80°C), to ensure removal of terrestrial water.

Reflectance spectra: The spectra of the studied HED meteorites are presented in Figure 1. All measured spectra show a high average reflectance (typically 0.3-0.4) over the wavelength range studied, which in the case of silicates is characteristic of fine-grained powders. The only exception is NWA 4223, which is much darker and shows a reduced spectral contrast. NWA 4223 is an olivine diogenite which olivine crystal are unusually dark although rich in magnesium, as was previously described for Martian meteorite [4-6]. All spectra reveal the presence of 3-μm band. The presence of hydrated and/or hydroxylated phase is confirmed by observation of 1.5 and 1.9 μm features. The intensity of the 3-μm band is highly variable within our studied sample suite, the two extremes being NWA 5617 for which the 3-μm band is even stronger than the Fe- crystal field absorptions, and Tatahouine for which a 3 μm–band is barely detectable.

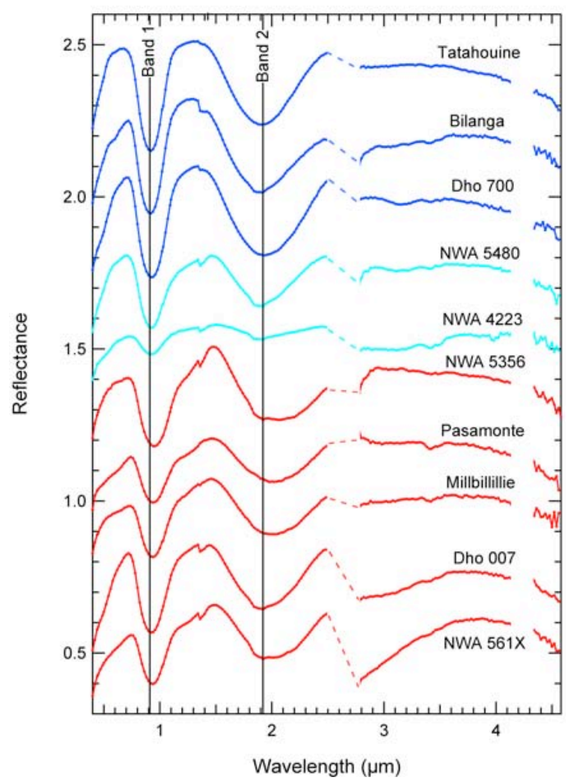

Figure 1: vis-NIR spectra of the HED meteorites studied. The 2.5-2.8 -μm range is removed because strongly perturbed by atmospheric water in the lab.

Bi-directionnal measurements: Two sets of bi-directionnal measurements were acquired on Tatahouine and Millbillillie. The spectra of Millbillillie for incidence angle of 60° are presented for in figure 2.

For both meteorites, the effects of geometry are more moderate for low incidence angle than for high-incidence angle. In the case of Millbillillie, the maximum of reflectance at around 1.5 μm was found to vary between 0.463 to 0.487 (i.e. 5 %) as a function of emergence angle, in the case of the θ_i=0° dataset. The same sample studied at high incidence angle showed much more variability since the maximum of reflectance at around 1.5 μm was found to vary between 0.449 and 0.538 (i.e. 17 %). Similar results were obtained for Tatahouine. Both samples show the same behaviour, a tendency to act as forward scatters, and an increase of the samples appear to be more forward scattering at longer wavelength. A decrease in relative intensity of the two bands with regard to the continuum is observed at high phase angles. The relative intensity of the 1 and 2 μm bands decreases by up to 30% toward high phase angle. We interpret this behaviour by an increase of the contribution of the first external reflection on a grain surfaces at high phase angle, which tends to scatter out of the sample an increasing fraction of light that did not enter any grain. For the 3 μm band, this explanation was validated in Pommerol et al. (2009), by studying the grain size effect on the bidirectional phase function.

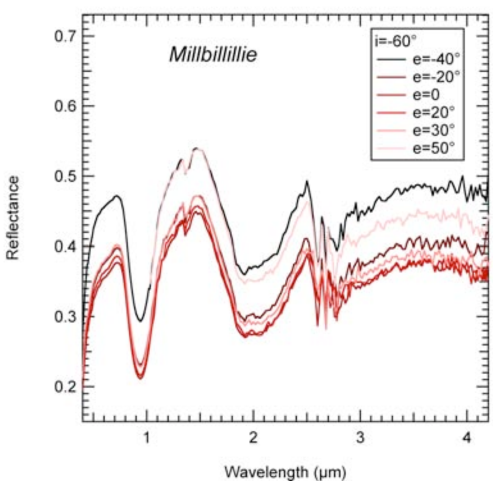

Figure 2: Bidirectionnal reflectance spectra of Millbillillie (60° incidence and 6 observations angles)

The 3 μm region: The 3 μm region has been shown to be very sensitive to the presence of –OH and H_2O bearing phases, and 3 μm features have been observed at the surface of Mars, the Moon or asteroids. If it is related to water, the presence of a 3 μm feature in the studied HED meteorites is at odd with the common idea that these meteorite sample originate from degassed and thus volatile poor asteroidal bodies. Because some meteorites were recovered more than 10 years after their falls (e.g. Millbillillie, Tatahouine) or are finds from hot desert, a possible explanation is the presence of a significant amount of terrestrial weathering. However, some of the meteorites studied are "falls", which are not expected to have experienced significant terrestrial aqueous alteration (Pasamonte, and Bilanga). Although weak, a significant 3 μm feature remains present in these meteorites. The shape and maximum of this feature is located between 2.6 and 2.9 μm, which is suggestive of the presence of some hydroxilated phase [7-8]. The presence of hydroxyls groups within these meteorites could be explained by the presence of some fusion crust with the grinded meteorite chips, that would have incorporated atmospheric water that subsequently dissociated into hydroxyl groups, although special care was taken to avoid the incorporation of fusion crust. If not, the presence of a 3-μm band for these samples implies that water related process occurred on Vesta, for which some evidence have been reported in the literature.

Olivine diogenites: For the first time we have presented NIR spectra of olivine diogenites. Identification of olivine-rich lithologies on Vesta is of great interest because they might be related to particular zones in diogenitic intrusions (e.g., [9-10]) or alternatively, they might be related to the asteroid's mantle. When plotted in the Band 1 vs Band 2 position diagram, olivine diogenites do not appear easily distinguishable from "regular" diogenites. However, a very useful diagram to identify various pyroxene/olivine mixtures is the use of the areal ratio between band 2 and Band 1, the so-called BAR index [11]. Because olivine only displays a band 1, a high value of the BAR suggest a high amount of olivine with regard to pyroxenes. Gaffey et al. (1997)[12] studied the rotational phase dependence of the NIR spectra of 4-Vesta, and found area were a significant decrease of the BAR is present, that they interpret by the presence of some amount of olivine (10%). When representing the BAR index as a function of the band 1 position, it appears that olivine diogenite plot away from the diogenite and eucrite field, because of a low value of the BAR index. This behavior is expected, since addition of olivine tends to decrease the BAR coefficient for a similar value of the band 1 position. If present, olivine-rich lithologies should be readily identified at the surface of Vesta.

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