SERPENTINE IN EXOGENIC CARBONACEOUS CHONDRITE MATERIAL ON VESTA DETECTED BY DAWN FC.

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Introduction: The Framing Camera (FC) [1] onboard Dawn spacecraft has imaged the entire visible surface of asteroid (4) Vesta from three different orbits at spatial resolutions of ~250 m/pixel, ~60 m/pixel, and ~20 m/pixel. The FC is equipped with one clear and seven color filters, covering the wavelength range between 0.4 and 1.0 µm [1].

The surface of Vesta is unlike any asteroid visited so far. Albedo and color variation are the most diverse among the objects in the asteroid belt [2]. Low albedo features were among the most prominent units appearing during Dawn's approach to Vesta. Subsequently, terrains rich in low albedo material, termed "Dark Material" (DM), have been identified in several geologic settings [3, 4]. FC color spectra [3], and spectra acquired by VIR [5], indicate that DM, which is mixed with materials indigenous to Vesta, is spectrally similar to carbonaceous chondrite meteorites (CC), and thus of exogenic origin, i.e. due to the infall of carbonaceous volatile-rich material [6].

Data Processing: FC images exist in three standard levels from which we use level 1c that is corrected for the "in-field" stray light component [7]. This corrected level 1c I/F data is used for processing in our pipeline based on the ISIS software [8], which performs the photometric correction of the FC color data to standard viewing geometry using Hapke functions. The resulting reflectance data are map-projected in several steps and co-registered to align the color frames, creating global spectral mosaics. For the present analysis, FC color data from HAMO and HAMO2 orbits were used. The color mosaics generated by the ISIS pipeline were analyzed using ENVI and ArcGIS software. For the georeferencing and photometric correction of our FC data and the visualization of the results, we used the Vesta shape model (version of 2013/05/22) derived from FC clear filter images by [9].

Results: Our detailed investigation of the Vestan surface revealed for the first time the presence of an absorption feature at ~0.7 µm for several DM localities, when inspected at high spatial resolution [10]. In order to identify potential sites showing this feature we extracted those that meet the following three criteria: 1) I/F reflectances $R_{(0.653)} \leq 0.09$ are assumed to be caused by carbonaceous chondrite material with minor HED admixtures, 2) $(R_{(0.438)})^2/R_{(0.917)} \leq 0.085$, and 3) $(R_{(0.653)}*R_{(0.749)})/R_{(0.438)} \leq 0.115$; where $R_{(\lambda)}$ is the reflectance in a filter centered at λ µm.

Fig. 1 shows the spatial occurrence of DM sites that meet these criteria. The concentration of DM on the low albedo hemisphere of Vesta, along and inside the crater rim of the Veneneia basin is striking, suggesting that DM was deposited by the Veneneia impactor, which consisted of CC material.

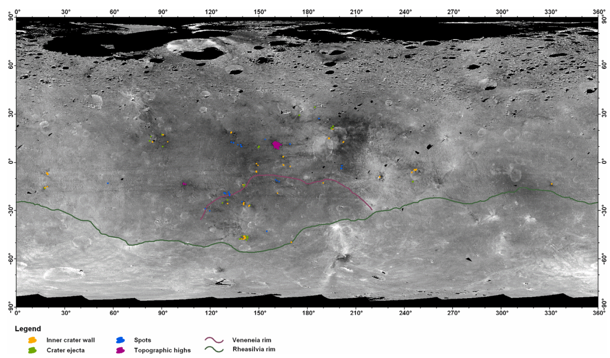

Figure 1: Global distribution map of different geologic DM units on Vesta (Claudia coordinate system). For larger version see http://dawn.signale.de/data/7748.png

Fig. 2 depicts the average color spectrum of the DM (diamonds), as well as the average spectrum (squares) of the remaining Vestan surface from HAMO data. Compared to the HED-dominated average Vesta spectrum, the DM shows lower reflectivity and is generally flatter, with a less pronounced 1 µm absorption band, which is due to the mineral pyroxene.

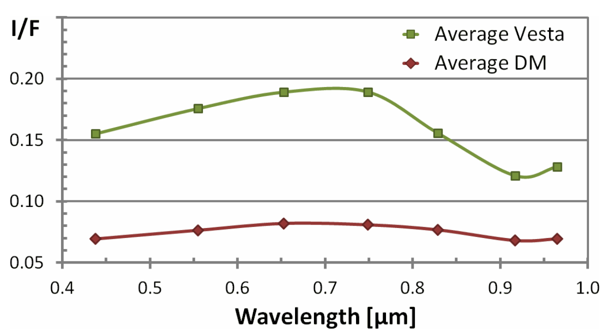

Figure 2: Averaged global FC color spectra of Vesta and average spectra of all DM sites shown in Fig.1.

While the average spectra of the different geologic DM units show no variation among them, higher spatially resolved data of individual sites do. Fig. 3 displays one example at Occia crater, which shows extensive DM deposits in its ejecta and inner walls. While most of the localities show different mixtures of HED and CC material, which is expressed in changes of their albedo and spectral shape, some sites exhibit an absorption feature which can be seen in the 0.749 µm filter (Fig. 3B). By computing the band depth ($R_{(0.653)}+R_{(0.829)})/R_{(0.749)}$ these sites show values greater than 2.0.

Comparisons with VIR data (e.g. Fig. 3B) indicate a band center of the absorption feature around 0.72 µm. Furthermore it can be seen that the FC filter wavelengths are not ideal for its identification. Nevertheless the feature has been found in the first place by using spatially high-resolution color data of the FC.

Discussion: By extensive comparisons with laboratory spectra, the mineral serpentine has been identified as the most likely constituent responsible for the 0.72 µm absorption feature. Three independent clues hint at the nature of this finding:

First, hydrogen has been identified by the GRaND instrument onboard Dawn in areas concurrent with the strongest concentrations of DM [6]. Second, inclusions of CM2 chondrites are known in howardites, which are believed to originate from Vesta [12]. CC meteorites of class CM2 are known to include hydrated minerals such as serpentine [13]. Their spectral signature includes a wide absorption band centered near 0.7 µm. Although hydrated minerals on a differentiated body like Vesta may not be pristine, they may have been delivered by asteroids. As a third clue, this condition is fulfilled by asteroids as large as (19) Fortuna, which shows the same absorption feature. Their taxonomic class [14] is generally identified with surfaces of CC material. For the stability of serpentine against metamorphism on Vesta, low impact velocities are essential [2]. These are enabled by the low gravity and the presence of potential sources in the immediate dynamical environment [2].

Conclusion: Most of the apparent DM on Vesta is located along the rim and inside the Veneneia basin, and it is almost absent in the younger Rheasilvia basin (see Fig. 1), leading to the conclusion that DM was deposited by the Veneneia impact [3]. DM in its purest form exists in sub-surface layers or lenses, which are exposed in larger impact craters as outcrops and DM flows on the inner walls. From these craters, DM is often emanating as rays, or as ejecta blankets. Smaller impacts penetrated the upper brighter surface of HED material at many sites and excavated DM from beneath, creating DM spots. Interestingly, all exposed DM localities are caused by impact craters.

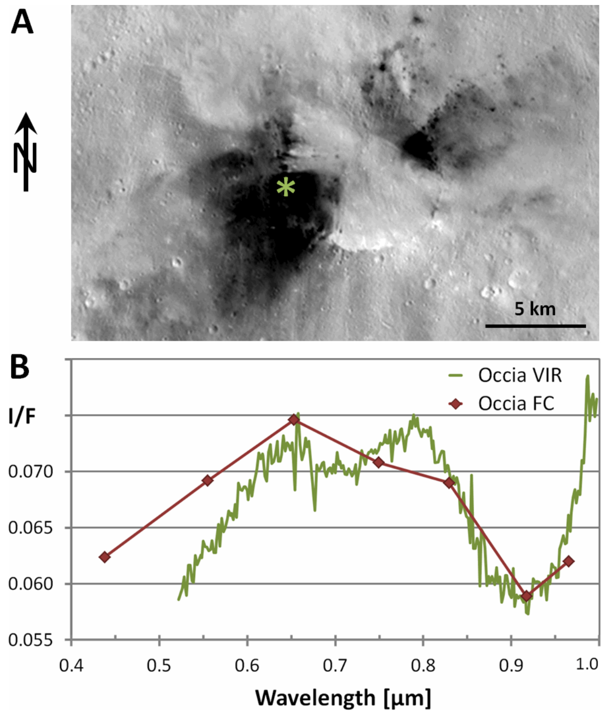

Figure 3: Spatial DM distribution at crater Occia (A) in HAMO data (~60 m/pixel, 0.555 µm filter). Below FC and VIR spectra (B) at the site of the asterisk. The 0.72 µm absorption feature related to serpentine found by FC color data can also clearly be seen by VIR.

Our discovery of an absorption feature that is attributed to a component of CM meteorites, namely serpentine, confirms the theory of an exogenic origin for DM. Other hypotheses, such as DM being basalt flows (dikes/sills) that were shattered and redistributed by impacts, and impact melt produced by large impacts [4, 11], are unlikely.

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