Testing the Magma Ocean Model using Distribution of Chromium on Vesta's Surface from Dawn Framing Camera Color Images.

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Introduction: Asteroid (4) Vesta is the largest differentiated asteroid in the main belt that is mostly intact today. NASA's Dawn mission entered orbit around Vesta in July 2011 to begin its year-long mapping mission. The Dawn Framing Cameras (FC) are a pair of identical imagers (one is redundant) that images the surface in seven color filters (0.44-1.0 μm) and a clear at resolutions up to 20 meters/pixel [1]. These filters are sensitive to Vesta's surface mineralogy and help constrain the composition of various color units.

Several models (partial melting, fractional crystalization, magma ocean) [2,3,4] have been proposed for the formation of Vestan crust from the study of HED (howardite, eucrite and diogenite) meteorites that are thought to be derived from Vesta. [5] proposed the use of the 0.6 μm chromium (Cr^{3+}) absorption feature [6] in the spectra of unbrecciated primitive eucrites such as ALHA81001 (Fig. 1) in order to test the magma ocean model for Vesta petrogenesis. ALHA81001 is a quench-textured eucrite that contains Cr^{3+}-rich pyroxenes. This indicates that ALHA81001 formed from a primitive melt because chromium is a compatible element in eucritic pyroxenes and is only enriched in primitive melts. ALHA81001 is also unmetamorphosed suggesting it somehow escaped the global-scale metamorphic alteration [5] by subsequent volcanic flows that equilibrated the majority of the eucrites.

Mayne et al. (2010) suggested the formation of primitive yet unmetamorphosed eucrites such as ALHA81001 could only form as a quench crust or convective lid in the magma ocean model. If this model is correct it would imply that initially material similar to ALHA81001 covered the entire surface of Vesta. However, if the contrasting partial melting model were true then the distribution of ALHA81001-type material on Vestan surface would be limited and this meteorite would represent a late stage primitive melt. While the lack of Cr^{3+}-rich eucrites like ALHA81001 in terrestrial meteorite collections would support the partial melting model, the real test would be to map the global distribution of the 0.6 μm chromium (Cr^{3+}) absorption feature using Dawn FC color filter data (0.44-1.0 μm).

Data Reduction and Analysis: Dawn FC higher level data were processed with a pipeline developed at MPS, named 'Mule', which uses applications from the ISIS [7] software (created by USGS). FC color images were converted to reflectance (I/F) by dividing the observed radiance by the solar irradiance from a normally solar-illuminated Lambertian disk, and photometrically-corrected to standard viewing geometry (30° incidence and 0° emergence and 30° phase angles). Subpixel coregistration was applied to align the seven color frames in order to create color cubes. Analysis was done using our tools 'DawnKey' (IDL based) and 'Asteroid Spectral Analyzer' a Matlab based program for spectral characterization [8].

Detection and quantification of Chromium Band: Cloutis (2002) quantified the amount of Cr^{3+} required for the formation of the 0.6-μm chromium absorption band to be between 0.38 and 0.9 wt%. In the three Cr^{3+}-rich eucrites (ALHA81001, Chervony Kut, PCA 91078) where the 0.6-μm band was detected by [5], the abundance was 0.65 wt%. This suggests that a minor amount of Cr^{3+} is enough to produce the absorption band depth and Cr^{3+} abundance.

Dawn FC Color Filters. Four FC color filters (0.44, 0.55, 0.65 and 0.75 μm) cover the wavelength range of the 0.6 μm Cr^{3+} absorption band (Fig. 2). While the VIR spectrometer has higher spectral resolution in this wavelength range, the FC has four times the spatial resolution enabling detection of small color units that show the chromium band. Confirmation of any Cr^{3+}-rich color units would require the use of complementary data from VIR and GRaND instruments.

Detection of the 0.6 μm Cr^{3+} absorption band using FC color data is accomplished using color ratio maps of various filters that encompass this feature. For instance, ratio of 0.75/0.65 μm filter and/or 0.75/0.55 μm can assess the depth of the chromium band. Another possible method of detecting the chromium feature is by using the 'kink' equation:

$$Cr^{3+}\ \text{Kink} = (0.65\ \mu\text{m Rfl.}/(A * 0.55\ \mu\text{m Rfl.} + B * 0.75\ \mu\text{m Rfl.})) - 1$$

Where the constants A (0.4824) and B (0.5176) correct for the asymmetry in the difference in central band passes of the three FC filters used. For example, a negative kink would suggest a positive identification of Cr^{3+} and vice versa for positive kink.

Preliminary Findings: We analyzed a global FC color mosaic at a resolution of 487 m/pixel in order to search for the Cr band at 0.6 µm. Global color ratio map of 0.75/0.65 µm shows no detectable variation across the surface. However the 0.75/0.55 µm ratio map exhibits an interesting region with higher band depth surrounding the 33-km crater Oppia (Fig. 2). 0.75/0.65 µm band ratio (Fig. 3) and Cr^{3+} kink image (Fig. 4) of the same region are not detecting the band due to Cr^{3+}.. Therefore, the high value observed for the 0.75/0.55-µm ratio could be explained by just a steeper spectral slope rather than evidence for Cr^{3+} on the surface.

This would suggest that ALHA81001-type material does not cover large areas of Vesta on a global/regional scale or such layer if present has been buried/processed into the regolith by impact processes rendering the detection of Cr^{3+} difficult at this spectral and spatial resolution. Further investigation is ongoing.

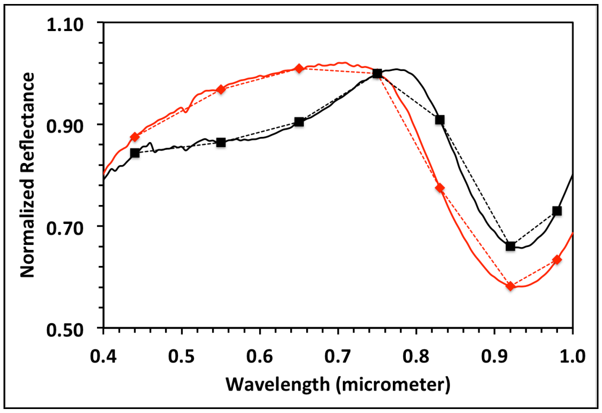

Fig. 1. Laboratory spectra of Serra de Mage (red) and ALHA81001 (black) meteorites showing the presence of 0.6-µm band due to chromium. The 7 data points overlaid are FC color spectra of the meteorites. Spectra are normalized to unity at 0.75 µm.

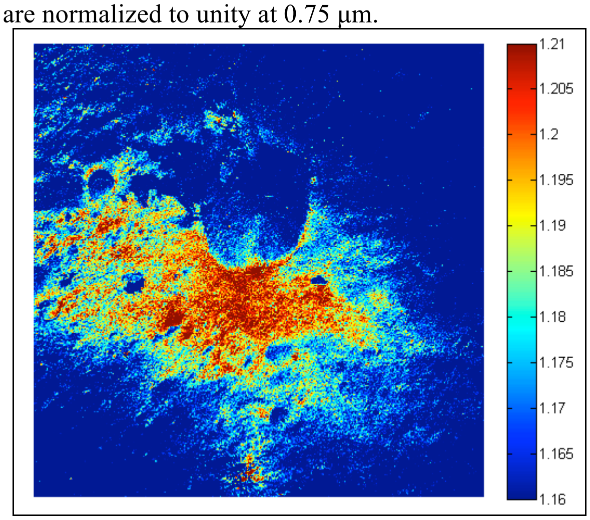

Fig. 2. Band ratio image of 0.75/0.55 µm filters of 33 km crater Oppia showing higher ratios in the ejecta blanket.

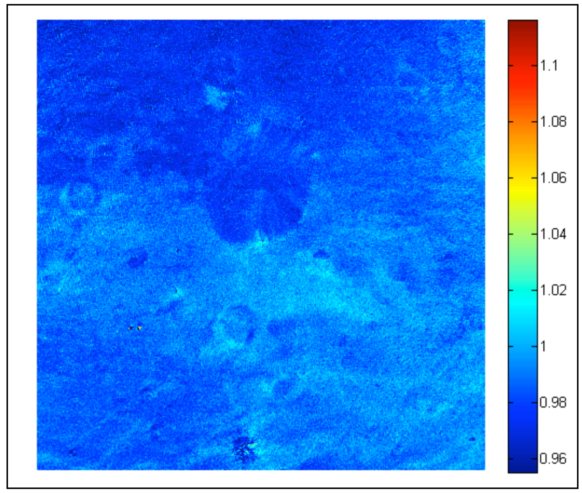

Fig. 3 Band ratio image of 0.75/0.65 µm filters of 33 km crater Oppia showing no variation suggesting a lack of the chromium feature on the surface.

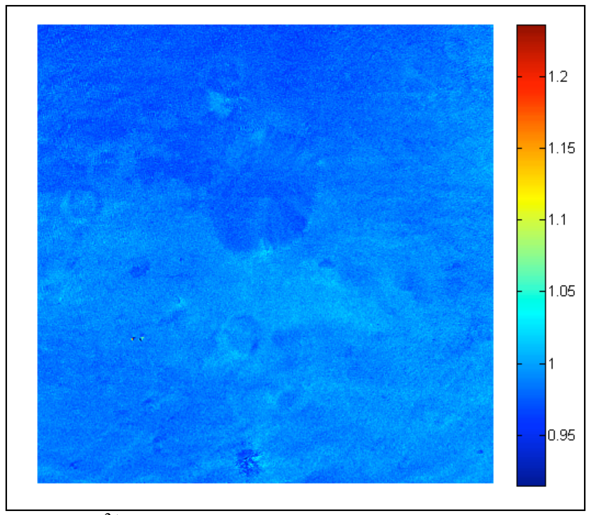

Fig. 4 Cr^{3+} kink image of 33 km crater Oppia showing no variation suggesting a lack of the chromium feature on the surface.

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