Investigating the Origin of Dark Material on Vesta using Dawn Framing Camera. V. Reddy[1,2], L. Le Corre[1], A. Nathues[1], E. A. Cloutis[3], M. J. Gaffey[2], K. J. Becker[4], T. B. McCord[5], J.-Ph. Combe[5], E. Palomba[6], D. T. Blewett[7], H. McSween[8], C. A. Raymond[9], D. Williams[10], and the Dawn Science Team. [1]Max-Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, reddy@mps.mpg.de, [2]Dept. of Space Studies, Univ. of North Dakota, Grand Forks, USA, [3]Dept. of Geography, Univ. of Winnipeg, Canada, [4]Astrogeology Science Center, USGS, Flagstaff, Arizona, USA, [5]Bear Fight Institute, Winthrop WA 98862 USA, [6]INAF-IAPS, Rome, Italy, [7]Johns Hopkins University APL, Laurel MD USA, [8]U. of Tenn, Knoxville TN USA, [9]Cal. Inst. Tech Jet Prop. Lab. Pasadena CA USA, [10]ASU, Tempe AZ USA.

Introduction: NASA's Dawn spacecraft entered orbit around asteroid (4) Vesta in July 2011 beginning its yearlong mapping mission. The Dawn Framing Cameras (FC) [1] are a pair of identical cameras that acquire images of the asteroid in clear and seven color filters (0.44-1.0 µm) at a resolution of ~20 meter/pixel. These seven filters help identify different geologic units, constrain lithologies and understand Vesta's composition and surface heterogeneity.

Background: Dawn FC images revealed a surface with the most diverse albedo variations of any asteroid observed so far. While ground based observations of Vesta had shown large hemispherical scale dichotomy, regional and local scale albedo variations were unexpected. An enigmatic surface unit in the form of very low albedo material on Vesta was first observed during the approach phase at a resolution of ~487 m/pixel. This dark material is primarily associated with impact craters, topographic high units and dark spots (Fig. 1). Here we present some preliminary results of our investigation into the origin of dark material.

Data Reduction and Analysis: Dawn FC images were processed with a pipeline developed at MPS, named 'Mule', which is using applications from the ISIS 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 [2].

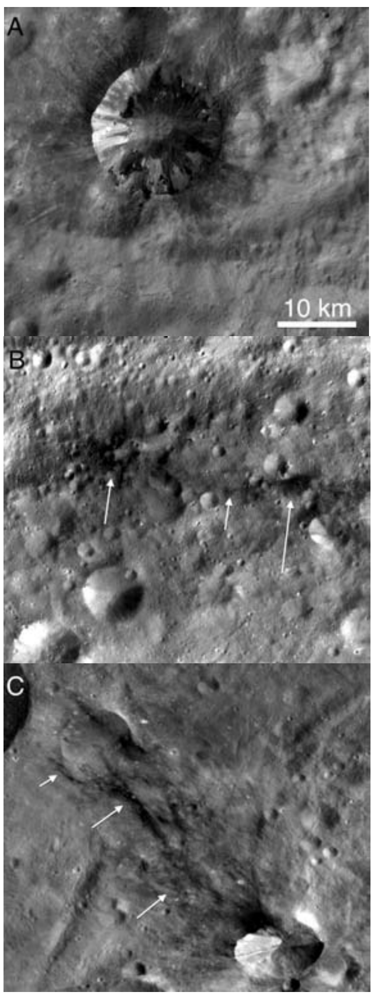
Description of Dark Material: The majority of dark material is found on the walls of impact craters but is also present overlapping the ejecta and crater rims (e.g., 30-km diameter crater called Numisia located at 7.47°S and 112.82°W). Specifically, some fresh impact craters exhibit excavation of mixtures of bright and dark material within the crater walls and the ejecta blanket (Fig. 1A). In the meantime, other dark deposits can be seen in different kind of settings (Fig. 1B, C and D) in more than 25 locations on Vesta. In some cases such as Lucaria Tholus region (13.24°S, 105.38°E), dark material is observed on top of a hill (Fig. 1B). Some flow-like morphology are observed (Fig. 1B, C). Clusters of dark spots can be found in the vicinity of old craters (Fig. 1D) but can also be found scattered, with no specific geologic features. They could be small secondary impact craters. The last example, dark curvilinear features, can be observed on slopes (Fig. 1E).

Quantifying Color Parameters: Dark material has lower reflectance (8-13% in the 0.75-micrometer filter) than the background surface and displays weaker 0.75/0.92 micrometers band ratio suggesting shallower 0.90-micrometer pyroxene absorption band (Fig. 2). In addition, dark material show redder visible spectral slope compared to the background gray material.

Preliminary Results: Clues for the origin and nature of endogenous or exogenous dark material can be derived from HED meteorites. Some unbrecciated eucrites (e.g., MET 01081 and BTN 00300) have higher modal abundances of opaque minerals (chromite, ilmenite, troilite, metal) that reduce spectral contrast and lower the overall albedo [3]. Even without a high abundances of opaque minerals, spectra of unbrecciated eucrites such as ALHA81001 show reduced spectral contrast and albedo, which has been attributed to micron-sized grains of ilmenite interspersed throughout the sample [3].

Our analysis of color ratios of opaque-rich eucrites suggest that their overall albedo at 0.75 micrometer (25-35%) and 0.75/0.92 micrometers band ratio is much higher than dark material on Vesta. Alternative endogenous products could be shocked eucrites/impact melt, which have reduced spectral contrast and lower albedo as well. Our laboratory analysis of shocked polymict eucrite breccia Jiddat Al Harasis 626 (JaH 626) shows that the overall albedo at 0.75 micrometer remains high (40-45%) for small grain size (≤90 micrometers), but is reduced to 14% for grain size ≥250 micrometers. The 0.75/0.92 micrometers band ratio for JaH 626 is 9% lower than average for eucrites but still deeper than the one observed in dark material.

Exogenous material in HEDs have been observed and quantified. A majority of these exogenous materials are in the form of dark hydrous clasts (primarily composed of CM2 and CR carbonaceous chondrite meteorites) in howardites [4]. These clasts typically comprise ≤5 vol.% but more recent Antarctic meteorite finds such as PRA 04401 have up to 60 vol.% dark carbonaceous clasts [5]. Our initial analysis of laboratory mixtures of CM2 carbonaceous chondrite (Murchison) and basaltic eucrite (Millbillillie) suggests that a 60:40 vol.% ratio is required in order to mimic the color parameters observed in dark material [6]. If these findings were true one would expect to see absorption bands due to OH in the 3-micrometer region due to the presence of hydrous phases (6-7 wt.%) in CM2 clasts [4]. Dark material has also been observed on other asteroids visited by spacecraft. Notably, a dark boulder observed on asteroid Itokawa by the Hayabusa spacecraft has been interpreted as a carbonaceous chondrite [7].



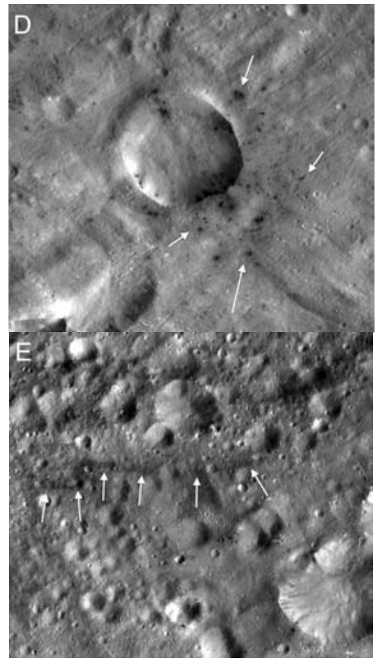


Fig. 1. Examples of dark material at 750 nm (all at the same scale). (A) associated with impact craters (in the ejecta material and/or on the crater wall and rims); (B, C) as flow-like deposits often associated with topographic high units; (D) as dark spots; and (E) as curvilinear features on slopes.

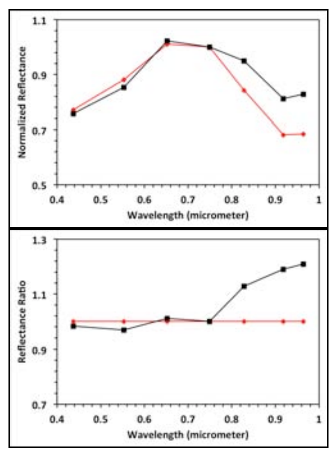


Fig. 2. Color spectra (top) of dark material (black) and global average of Vesta (red). Ratio of dark material spectrum (bottom) to that of global average. Note how the 0.90 micron pyroxene band is shallower than global average for the dark material.

References: [1] Sierks et al., (2011) *Space Science Reviews* [2] Reddy et al. (2011) *Division of Planetary Sciences Meeting, Nantes, France* [3] Mayne et al. (2010) *MAPS* 1-19 [4] Zolensky et al. (1996) *MAPS* 31 [5] Herrin et al. (2011) LPSC 2011. [6] Le Corre et al. (2011) *Icarus 216* [7] Saito et al. (2006) *Science 312*.