Vesta Surface Colors and Mineralogy. V. Reddy[1], L. Le Corre[1], A. Nathues[2], J.-Y. Li[1], T. B. McCord[3], M. J. Gaffey[4], C. T. Russell[5] and C. A. Raymond[6], [1]Planetary Science Institute, 1700 E. Fort Lowell Road, Tucson, Arizona 85742, reddy@psi.edu; [2]Max-Planck Institute for Solar System Research, Katlenburg-Lindau, Germany; [3]Bear Fight Institute, Washington; [4]University of North Dakota, North Dakota; [5]University of California Los Angeles, California; Jet Propulsion Laboratory, [6]California Institute of Technology, California.

Introduction: Surface colors and mineralogy of Vesta are unique among asteroids visited so far by spacecraft. Dawn Framing Camera observed the asteroids in seven color (0.4-1.0 microns) and a clear filter during its year-long orbital mission mapping the surface at a resolution as high as 16 meters/pixel. These seven filters help identify different geologic units, constrain lithologies and understand Vesta's composition and surface heterogeneity.

Dawn FC images revealed a surface with the most diverse albedo variation 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 [1]. Unlike the Moon, where albedo and topography are intimately correlated with the mineralogy of lower albedo maria and higher albedo highlands, no such relationship was observed on Vesta [1].

Albedo: Li et al. (2013) studied the photometric properties of Vesta in the visible wavelengths using FC data, and found that its photometric properties show weak or no dependence on wavelengths, except for the albedo. At 0.554 microns, the global average geometric albedo of Vesta is 0.38±0.04; the Bond albedo is 0.20±0.02. The bolometric Bond albedo is 0.18±0.01. Vesta's phase function is similar to those of S-type asteroids. Vesta's surface shows a single-peaked albedo distribution with a full-width-half-max ~17% relative to the global average, much smaller than its full range of albedos (from ~0.55× to >2× global average) in localized bright and dark areas of a few tens of km in sizes, and is probably a consequence of significant regolith mixing on the global scale. Rheasilvia basin is ~10% brighter than the global average [2]. Vesta's phase reddening measured from Dawn FC is comparable or slightly stronger than that of Eros as measured by the Near Earth Asteroid Rendezvous mission, but weaker than previous measurements based on ground-based observations of Vesta and laboratory measurements of HED meteorites [2].

Color Units: Ground-based and HST observations of Vesta revealed several color and albedo units that were confirmed by the Dawn spacecraft [3]. The largest of these units include the hemispherical scale dichotomy which has been attributed to 'age-related darkening effect' [4]; "domination by iron-rich and relatively calcium-rich pyroxene" similar to basaltic flows like eucrites [5]; and impact craters/basins filled with dark material similar to lunar mare [6]. Dawn FC and GRaND observations of the dark Western hemisphere shows that it is composed of a mixture of exogenic carbonaceous chondrite material with HEDs [7,8] while the brighter Eastern hemisphere was primarily sculpted by impact processes.

Apart from hemispherical scale dichotomy in albedo and composition, several distinct color units have been identified on Vesta. These include: Dark, Bright, background gray and Orange material.

Dark Material. Dark material has lower albedo (~8%) than average Vesta surface and is found on the walls of impact craters, ejecta, and crater rims (Fig. 1). Color properties of dark material in small craters are similar to lower albedo Western hemisphere. Apart from lower albedo, pyroxene absorption bands in dark material are also weaker. Laboratory mixtures of HED meteorites and carbonaceous chondrites mimic the color properties of dark material on Vesta [7]. Independent observations by VIR spectrometer and GRaND instrument confirmed the exogenous origin on dark material on Vesta [8,9]. The distribution of dark material coincides with the concentration of OH [8]. 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 [7]. An hydration feature associated with dark material has been observed from ground-based telescope prior to arrival of Dawn on Vesta. Hasegawa et al. (2003) noting the presence of a 3-μm absorption suggested contamination from impacting carbonaceous chondrites as possible cause of this feature.

Bright Material: Bright material on Vesta is pristine with little or no contamination from exogenous carbonaceous material or impact melt/shocked material [10]. Composition of bright material is predominantly dictated by its location with more diogenitic material associated with bright material in the South Pole Rheasilvia basin and more howarditic material outside the basin and its associated ejecta [11].

Gray Material: Mixed bright and dark material is the predominant cause of the background gray material on Vesta [1]. Composition of gray material is dependent on the local abundances of eucrite and diogenite components with more diogenitic material closer to the Rheasilvia basin.

Orange Material: While bright, dark and gray material were identified using clear filter images from the Framing Camera, additional color units were identified using color filter ratio images. One such color composite is the Clementine RGB color composite in which CR= R(0.75)/R(0.45), CG= R(0.75)/R(0.92), and CB= R(0.45)/R(0.75); where R(λ) is the reflectance in a filter centered at λ(μm) and CR, CG, CB are the red, green and blue channels respectively. Greener areas in this color ratio have deeper pyroxene absorption bands (typical of diogenites) and redder areas have steeper visible slopes relative to bluer areas. Two large impact craters (Oppia and Octavia) that showed prominent red/orange ejecta in Clementine color ratio. Le Corre et al. (2013) also noted several brighter orange patches around Oppia. The orange/red color of these craters and surrounding patches appears to come from a steeper visible slope (R(0.75)/R(0.45)) compared to surrounding areas.

Ground based observations of Vesta showed a distinct feature on Vesta, which was interpreted to be an olivine-rich unit [4]. This unit corresponds to the location of Oppia (Fig. 2) on Dawn FC Clementine color ratio maps [3]. HST observations of Vesta label this feature as #15 and noted distinct red slope in its color spectrum [12]. Based on this red slope, [12] suggested space weathering as a possible mechanism for explaining it. Detailed compositional analysis using all three instruments on Dawn by [13] suggests that the most probable analog for the orange material on Vesta is impact melt. Orange patches, which seem to be distributed around the South Pole, are thought to be impact melt splash from the formation of the Rheasilvia basin [13]. While the observations of Oppia from ground by [13] and HST by [12] are consistent with those from Dawn FC and VIR spectrometer, the interpretations (olivine vs. space weathering vs. impact melt) are different primarily due to the improved spatial context provided by spacecraft data.

References: [1] Reddy et al. 2012. *Science,* [2] Li et al. 2013. *Icarus,* [3] Reddy et al. 2013. *Icarus,* [4] Gaffey 1997. *Icarus,* [5] Binzel et al. 1997. *Icarus,* [6] Zellner et al. 2005 *Icarus* [7] Reddy et al. 2012. *Icarus,* [8] McCord et al. 2012. *Nature,* [9] Prettyman et al. 2012. *Science,* [10] Li et al., 2012. ACM abstract, [11] Zambon et al. 2014. *Icarus,* Submitted, [12] Li et al., 2010. *Icarus,* [13] Le Corre et al. 2013. *Icarus.*

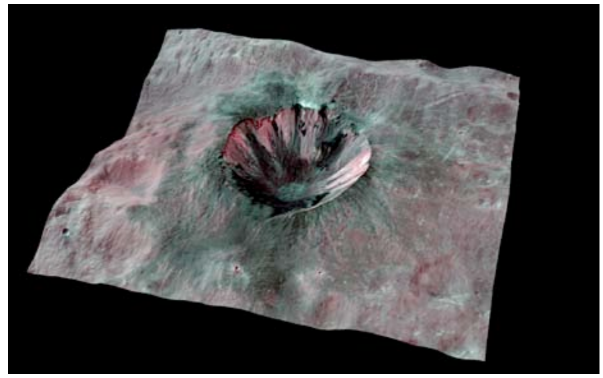

Figure 1. Dark material associated with impact crater Cornelia shown here overlaid on topography.

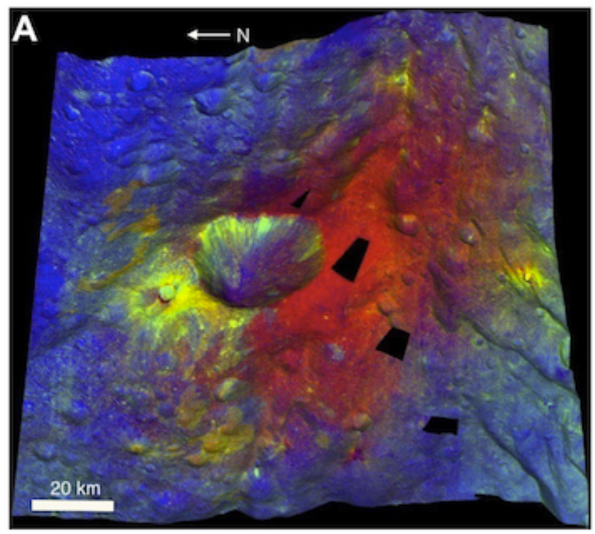

Figure 2. Orange material associated with impact crater Oppia shown in this Clementine color ratio image overlaid on topography.