INVESTIGATING THE ORIGIN OF BRIGHT MATERIALS ON VESTA: SYNTHESIS, CONCLUSIONS, AND IMPLICATIONS. Jian-Yang Li[1], D.W. Mittlefehldt[2], C.M. Pieters[3], M.C. De Sanctis[4], S.E. Schroder[5], H. Hiesinger[6], D.T. Blewett[7], C.T. Russell[8], C.A. Raymond[9], H.U. Keller[10]. [1]Department of Astronomy, University of Maryland, College Park, MD 20742, USA, jyli@astro.umd.edu, [2]Astromaterials Research Office, NASA Johnson Space Center, Houston, TX, USA, [3]Department of Geological Sciences, Brown University, Providence, RI 02912, USA, [4] INAF, Istituto di Astrofisica Spaziale e Planetologia Spaziali, Area di Ricerca di Tor Vergata, Roma, Italy, [5]Max-Planck-Institut für Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany, [6]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Germany, [7]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, USA, [8]Institute of Geophysics and Planetary Physics, Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095, USA, [9]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, [10]Institut für Geophysik und extraterrestrische Physik, Mendelssohnstr. 3, 38106 Braunschweig, Germany.

Introduction: The Dawn spacecraft started orbiting the second largest asteroid (4) Vesta in August 2011, revealing the details of its surface at an unprecedented pixel scale as small as ~70 m in Framing Camera (FC) clear and color filter images and ~180 m in the Visible and Infrared Spectrometer (VIR) data in its first two science orbits, the Survey Orbit and the High Altitude Mapping Orbit (HAMO) [1]. The surface of Vesta displays the greatest diversity in terms of geology and mineralogy of all asteroids studied in detail [2, 3]. While the albedo of Vesta of ~0.38 in the visible wavelengths [4, 5] is one of the highest among all asteroids, the surface of Vesta shows the largest variation of albedos found on a single asteroid, with geometric albedos ranging at least from ~0.10 to ~0.67 in HAMO images [5]. There are many distinctively bright and dark areas observed on Vesta, associated with various geological features and showing remarkably different forms.

Here we report our initial attempt to understand the origin of the areas that are distinctively brighter than their surroundings. The dark materials on Vesta clearly are different in origin from bright materials and are reported in a companion paper [6].

Distribution: A complete survey of all bright materials on Vesta based on HAMO images is reported in [7]. Fig. 1 shows examples of some major types bright materials. The largest concentrations of bright materials are located on the walls and/or in the ejecta of some large craters. But not all large craters have associated bright materials. While most of the craters that are associated with large-scale deposits of bright material appear to be morphologically fresh with sharp rims, there are some craters displaying at least partially rounded rims. Almost all large-scale bright material deposits appear to be located in the mid-southern latitudes between 0º and 60º S, while from longitude ~315º to ~135º there are noticeably fewer instances.

The surface of Vesta also exhibits numerous small distinctive bright spots. At higher resolution, most of these bright spots resolve into small craters with bright annuli or bright ejecta in some cases. These bright spots are possibly ubiquitous across Vesta, but their distribution is probably non-uniform. Some areas associated with large-scale bright material clearly host more concentrated bright spots than others. The Rheasilvia basin has relatively fewer bright spots in it.

Photometry and Visible Colors: The visible photometric properties and colors are reported by [8]. Overall, the albedos of bright material on crater walls and in bright ejecta are ~40% higher than the average albedo of Vesta; bright spots are ~20% brighter. Hapke photometric modeling for some bright areas with limited available geometries does not show distinctively different phase function and macroscopic roughness.

A preliminary analysis of FC color images shows that most bright materials have relatively deeper 1-µm pyroxene band compare to surrounding areas. This might be related to grain size difference, or different space weathering status. A notable exception is one very bright streak on the slope of a crater near the Rhe-

Fig. 1. Examples of bright materials. This image was taken during HAMO with a pixel size of 62 m. The crater is located at (0º, 166.5º)

asilvia basin that has a 1-μm band comparable or shallower than average.

Spectroscopy: [9] reports the preliminary analysis of Vesta bright materials from Dawn spectroscopic data. Compared to background, bright materials in general show deeper and wider absorption in both 1-μm and 2-μm pyroxene bands. Bright areas appear to be dark at thermal wavelengths near 5-μm, confirming that their high brightness is dominated by high albedo rather than topography. The similar band centers of bright materials and surrounding areas suggests similar pyroxene compositions. The deeper absorption is consistent with both different grain sizes and different space weathering status.

Origin of Bright Materials: The surface of Vesta is dominated by howarditic materials with various degrees of eucrite and diogenite mixing [3]. The howardite-eucrite-diogenite (HED) meteorite samples display a large range of albedos. The amount of opaque phases, impact-melt, carbonaceous chondrite clasts, and the inherent grain sizes can have dramatic effects on their albedos. Therefore, the geological history, space weathering process and status, and composition could all be responsible for altering the brightness of Vesta's surface.

We currently have two working hypotheses for the origin of bright materials on Vesta. These working hypotheses are not mutually exclusive, and each may play a role in specific cases.

Lithologic diversity. The association of large-scale bright material with morphologically fresh craters could suggest that these impacts have exposed an inherently high-reflectance lithologic unit. Slumping of crater wall materials exposes the bright lithology and forms the bright slope material. Tiny craters are likely relatively young as the smallest craters will be the first to be obliterated by continuing impacts and ejecta deposition. Not all small craters have light-toned annuli, suggesting that at least some of the bright annuli reflect an intrinsically light-toned lithology. If the bright annuli around tiny craters do represent excavated light-toned lithologies, then this would suggest that those bright deposits are only a few tens of meters below the surface, much shallower than the crater wall materials seen in large craters. The non-uniform distribution of large-scale bright material and small bright spots indicates the presence or absence of bright lithology at a particular depth in a given location. It is not yet established whether such lithology is from crustal rock units or from ejecta from previously formed craters.

Space weathering. On the other hand, the relatively stronger ferrous-iron absorption band [9] and high albedo [8] of bright materials may indicate that they are simply typical vestan lithologies that have been recently exposed and thus unweathered. The space weathering process on Vesta is currently being investigated using Dawn data [10]. There is evidence that mixtures of similar mafic minerals with different featureless bright or dark components are associated with different morphological ages of craters. The fact that many bright materials are associated with relatively fresh craters is consistent with this scenario. For bright slope material, the slumping of weathered materials on crater walls exposes the underlying unweathered materials, and forms bright streaks on crater walls.

It is unlikely that bright deposits could be exogenic materials (impactor residue). The overall albedo of Vesta is relatively high among all asteroids. The north-south hemispherical brightness dichotomy on Vesta appears to be correlated with the formation of the relatively young Rheasilvia basin [2, 5]. Many bright craters appear to be geographically associated, suggesting light-toned layers perhaps several kilometers in lateral extent, and hence unlikely to be the result of accretion of foreign matter.

Discussions: Some craters associated with large-scale bright material do have at least partially rounded rims. If they are geologically old, then this observation might suggest a different origin of the associated bright material, such as composition. However, it appears that many craters formed on steep slopes on Vesta have down-slope rims that are rounded possibly due to slumping of debris [2]. We are still investigating whether there is any relationship between crater age and bright materials.

While the paucity of bright materials in the northern hemisphere of Vesta could be subject to observational selection due to the poor illumination under a subsolar latitude of ~25º S, the lack of relatively bright areas in the Rheasilvia region should be real. This latitudinal heterogeneity is likely related to the formation of Rheasilvia basin, but the detailed process is still under investigation.

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