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The Geology of Ceres and Vesta

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1. Introduction

In 2007 the Dawn spacecraft was launched into space in order to study the two most massive objects of the asteroid belt: Vesta and Ceres. The goal of the mission was to understand the conditions and processes that formed the early solar system on the basis of the geology, elemental and mineralogical composition, topography, shape, and internal structure of Vesta and Ceres. In July 2011 Dawn entered orbit around Vesta and started a complete survey of the south polar and equatorial regions with Survey and High Altitude Mapping (HAMO) data (Russell et al., 2012). The high resolution Low Altitude Mapping (LAMO) data nearly covers the surface of Vesta from 90°S up to 55°N for about 90%. After studying Vesta for 14 months with its Framing Camera (FC) [2], Visible- and Infrared Spectrometer (VIR) [3] and Gamma-Ray and Neutron Detector (GRaND) [4], NASA's Dawn spacecraft departed Vesta in September 2012 and entered orbit around Ceres on March 6, 2015, where it still remains. Dawn recently finished its global mapping at Ceres and continues there with an extended mission. The main geologic results of the two bodies are described below.

2. Geologic features on Vesta

Vesta's surface reveals a multifaceted morphology with impact basins, various forms of impact craters, a variety of ejecta blankets, large troughs extending around the equatorial region, enigmatic dark material, mass wasting features and surface alteration processes [5-7]. The south polar region is dominated by two large impact basins, Veneneia underlying the larger Rheasilvia basin [5,6]. They are strongly correlated with Vesta's global tectonic patterns, the two distinct sets of large trough-and groove terrrains named Saturnalia and Divalia Fossae, respectively, and may have formed them [5,7]. Overall, Vesta shows a complex topography with extreme height differences resulting in steep slopes, locally exceeding 40° [8]. Comparable to the Moon, impact craters on Vesta range from fresh to highly degraded, indicating an intensive cratering history [5,6]. The steep sloped topography of Vesta results in craters with an unusual asymmetrical shape, where a sharp crater rim exists on the uphill side, and a subdued rim on the downhill side [8]. The asymmetrical shape was formed because of the preferential accumulation of ejecta material on the downhill crater rim relative to the uphill rim [8]. Other remarkable features associated with craters or steep slopes on Vests are pitted terrains and gullies. Pitted terrains are found in young craters and are interpreted to be the result of outgassing of volatile-rich material [9]. Linear gullies are interpreted to be formed by flow of dry granular material and curvilinear gullies are possibly formed by transient flow of water [10]. HED meteorites (Howardite-Eucrite-Diogenite) are believed to originate from Vesta [14, and ref's therein].

Most of the Vestan surface is composed of Howardite material with localized enrichments of Eucrite and Diogenite [11,12]. The surface of Vesta consists of thick (100 meters to a few kilometers), multilayered sheets of regolith with different albedos, formed by the accumulation of ejecta from numerous impacts that have resurfaced Vesta over time [5,13]. Deposits of dark material are intermixed into the regolith, and partially were excavated by impacts. They are exposed as dark halos around craters, or blocks and layers out-cropping in crater walls and rims [5,13], indicating material was excavated from the subsurface. The distribution of dark material seems to be correlated with the rim and ejecta of Veneneia, which match with the hypothesis that the dark material is exogenic, from carbon-rich low velocity impactors. Nevertheless, an endogenic origin, from freshly exposed mafic material or impact melt, exposed or produced by impacts is also possible. The correlation between dark material and an OH hydration band, indicate the presence of carbonaceous chondrites [5,13-16]. However, the bright ejecta material found on Vesta´s surface is thought to represent fresh, unweathered surface material [15,17].

3. Geologic features on Ceres

Prior to the Dawn Mission, Ceres, the dwarf planet was anticipated to be dark, wet and at least partially differentiated [18]. The surface of Ceres reveals a wide range of different features which are interpreted to be formed by water ice and/or volatile-rich material, e.g., domes, pits, plains and lobate flows [19-23]. The 4-km- high Ahuna Mons is the most prominent dome on Ceres and thought to be formed by the extrusion of cryolavas [21]. Cryolava is also found within Occator crater. The bright material of the faculae within Occator is thought to consist of liquid brine, rich in carbonates and ammoniated salts. Liquid brines are thought to reach the surface at high velocity, as in a salt-water fountain [24]. Young craters shows a bluish signature in the enhanced FC HAMO color mosaics (956/555/440 nm) [20,25]. The blue material implies a possible relationship to an impact-triggered alteration and/or space weathering processes, that could be linked with blankets of ultrafine grains and partly amorphous phyllosilicates [24]. Ceres´ surface is disrupted by numerous linear features, which are thought to be impact-derived secondary crater chains or fractures and faults [19,26].

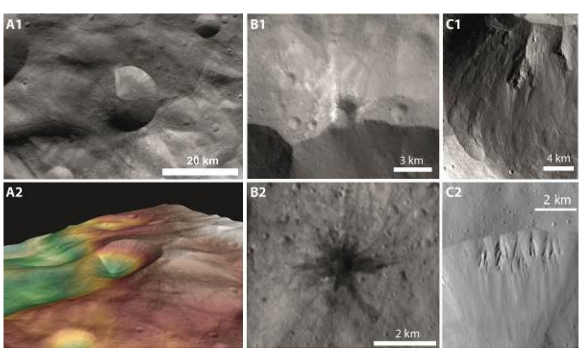

Figure 1: Examples of features on Vesta: A1+2: Asymmetric crater Antonia. B1: Bright material. B2: dark material. C1+2: Spur-and gully morphology.

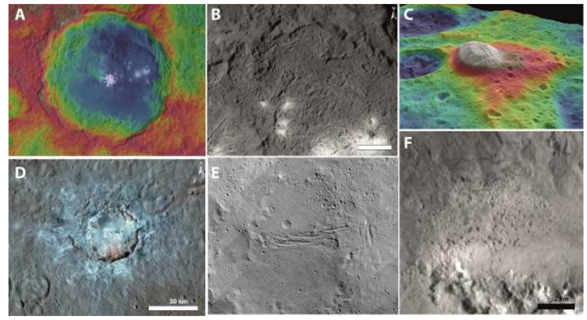

Figure 2: Examples of features on Ceres: A: Occator crater and its faculae. B: Flow features within Occator. C: Ahuna Mons. D: Blue material at Haulani. E: Cracks within Yalode crater. F: Pits within Haulani.

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