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Digital Geologic Mapping of Vesta and Ceres from NASA's Dawn Mission

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Abstract

NASA's Dawn mission [1] was designed to orbit the two most massive objects in the Main Asteroid Belt, asteroid 4 Vesta and dwarf planet 1 Ceres. Dawn successfully accomplished her mission at Vesta in 2011-2012 and at Ceres in 2015-2017, including several orbital phases at each object where increasingly higher spatial resolution data were obtained. These data facilitated iterative digital geological mapping of both objects, including production of global geologic maps and a series of quadrangle maps. In this presentation we describe the details of the Vesta and Ceres Mapping Campaigns and key results obtained for both objects.

Approach

1. Geologic mapping is an investigative process that goes beyond photogeologic analysis by organizing planetary features into discrete process-related map units. These units are defined and characterized based on specific physical attributes (albedo, morphology, structure, color, topography) related to the putative geologic processes that produced them (volcanism, tectonism, impact cratering, weathering-erosion-deposition). Application of stratigraphic principles (superposition, lateral continuity, cross-cutting, embayment, intrusion, etc.) are used to determine the chronologic order of emplacement of the map units. The map units can then be grouped into geologic formations, from which a geologic timescale and geologic history is determined. Thus, geologic maps are *tools* to help interpret the geologic history of a planetary surface.

2. The geologic mapping approach was similar for both Vesta and Ceres. The Dawn Science Team requested geologic mapping campaigns with the goals to: a) Identify the variety and stratigraphic correlations of geologic features on these two objects, and b) Provide geologic context for the interpretation of compositional measurements from the Visible and Infrared Spectrometer (VIR) and Gamma Ray and Neutron Detector (GRaND). The geologic mapping was iterative, using increasingly higher spatial resolution Framing Camera (FC) image mosaics obtained by the various orbital phases at each object: Approach, Survey, High Altitude Mapping Orbit (HAMO), Low Altitude Mapping Orbit (LAMO). A global geologic map was produced from the HAMO mosaics, and a series of 15 quadrangle maps were made from the LAMO mosaics. The mosaics, along with corresponding digital terrain models (DTMs, made using stereo photogrammetry) were produced by the German Aerospace Center (DLR) to support Science Team activities. Geologic mapping was done using ArcGIS™ software, and the mapping team met regularly at Team Meetings to correlate geologic units and contacts across quadrangle boundaries. For the Ceres campaign, a dedicated technician with background in ArcGIS was brought onboard to facilitate digital geologic map production.

Vesta Geologic Mapping Campaign

3. The HAMO-based global geologic map of Vesta was published by [2], the LAMO-based quadrangle maps were published in the December 2014 issue of *Icarus* [3] including the vestan chronostratigraphy and geologic timescale [4]. A new unified quadrangle, LAMO global geologic was presented by [5], and currently production of a U.S. Geological Survey-publishable global geologic map of Vesta is underway.

4. Globally, impact cratering has dominated the geologic evolution of Vesta. Ancient impacts have constrained the structure of the surface, and later impacts have influenced the distribution of ejecta and exposure of volatiles. Almost all evidence of the ancient volcanic processes implied by the Howardite-Eucrite-Diogentie (HED) meteorites has been completely destroyed – only one dome-like feature, Brumalia Tholus, interpreted as a laccolith, hints at Vesta's igneous past [6]. Brumalia Tholus occurs on Vestalia Terra, a relatively high-standing terrain which superposition relations suggests is the last remaining part of Vesta's original crust [6] and gravity data suggests might be a fossil mantle plume [7]. The Veneneia and Rheasilvia impact basins at Vesta's south pole produced a set of northern latitude

and equatorial ridge-and-trough systems, respectively, that cover large segments of the surface. These fossae systems are though to be a tectonic response to the formation of the south polar basins [8]. Pitted terrain has been identified in several craters [9], which along with curvilinear gully systems in several crater interiors [10] suggest the presence of volatiles (perhaps water ice) scattered within the vestan crust. Lobate deposits demonstrate the role of mass wasting and impact melt in the modification of the surface.

Ceres Geologic Mapping Campaign

5. The HAMO-based global geologic map of Ceres is completed (**Figure 1**) and a manuscript is in preparation. The LAMO-based quadrangle maps are currently under peer review for publication in a special issue of *Icarus* hopefully for late 2017.

6. Global map units include ancient cratered terrain, smooth material, younger crater materials, lobate materials, rayed crater material, among others. Formations separate the Yalode and Urvara impact units that dominate the southern hemisphere. The 284-km diameter Kerwan basin is the oldest crater on Ceres, and separates Pre-Kerwanan cratered terrain from younger Urvaran and Yalodean units. The youngest materials on Ceres (Azaccan) define the era of rayed craters (as does the Copernican on the Moon), and includes most recognized mass wasting, glacial-like, and cryovolcanic flows.

References:

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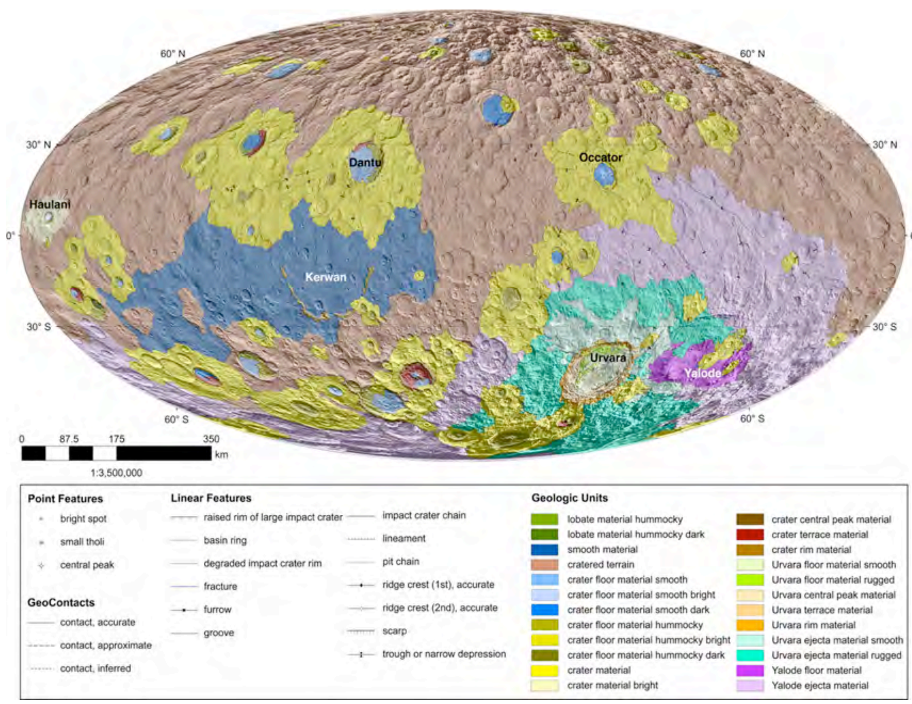

Figure 1. HAMO-based global geologic map of Ceres, scale 1:3.5M. Mapping by Scott Mest, PSI.