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The Tectonics of Ceres and Vesta

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Abstract

Images of Vesta and Ceres taken by the Dawn spacecraft revealed large-scale linear structural features on the surface of both asteroids. We evaluate the morphology of the Vesta and Ceres structures to determine 1) what processes caused them to form and 2) what implications this has for the history of Vesta and Ceres as planetary bodies.

1. Introduction

The Dawn spacecraft [*1*] approached Vesta in July of 2011, left Vesta in late 2012 and went into orbit around Ceres in March 2015. Framing Camera (FC) [2] data from the Approach, Survey, High Altitude Mapping Orbit (HAMO) and Low Altitude Mapping Orbit (LAMO) orbits, including clear filter and color images and digital terrain models derived from stereo images, enabled a three-dimensional characterization of both asteroids.

2. Vesta

2.1 Divalia Fossae

The most prominent set of large linear structures encircle Vesta roughly aligned with the equator. While most of these structures are wide troughs bounded by steep scarps, extending in a similar orientation are muted troughs, grooves and pit crater chains [3]. Fault plane analysis suggests that the formation of the equatorial troughs was triggered by the impact event that formed Rheasilvia basin, as the poles of the planes described by their fault traces cluster on the Rheasilvia central peak [*4*].

The large equatorial troughs encircle approximately 60% of Vesta [3]. Structures with similar orientation (per fault plane analysis [*4*]) are identified in the remainder of the equatorial region. No equatorial troughs cut the topographically high plateau known as Vestalia Terra, but pit crater chains with a similar orientation were identified and proposed to represent sub-surface faulting below the plateau [*3*].

2.2 Saturnalia Fossae

A second set of linear structures on Vesta extend to the northwest from the equatorial troughs [5]. The primary structure in this group extends into the north polar region. In the region north of Vestalia Terra, there are smaller graben and grooves that are parallel to the primary structure [5]. Fault plane analysis ties the formation of the Saturnalia Fossae to Veneneia basin impact event [*4*].

2.3 Brumalia Tholus

As Albalonga Catena, a pit crater chain located in eastern Vestalia Terra, progresses westward it phases from being a topographically low feature of merged pits into being the topographically high Brumalia Tholus, an elongate hill that is evident in both the photographic and topographic data of Vesta [6]. Assuming that Albalonga Catena represents a buried normal fault, it was hypothesized that the topographic high that emerges along its length could have been formed as a magmatic intrusion utilizing the subsurface fracture as a conduit to the surface, intruding into and deforming the rock above it [6].

If a magmatic intrusion, then the core of Brumalia Tholus should be comprised of diogenite, which is a more plutonic rock than the basaltic eucrites and brecciated howardites that have been observed in the equatorial region of Vesta. Teia crater impacts the northern face of Brumalia Tholus and thus its ejecta is likely sampling Brumalia's core material. Analysis by VIR has shown that these Teia ejecta are more diogenitic than other Vestalia Terra materials [6].

3. Ceres

3.1 Samhain Catenae

Kilometer-scale linear structures - including grooves, pit crater chains, fractures and troughs - cross much of the eastern hemisphere of Ceres [7]. Many of these structures appear to be radial to the large craters Urvara and Yalode, and most likely formed due to impact processes. However, the Samhain Catenae do not have any obvious relationship to impact craters and the lack of raised rims on the merged pits makes it unlikely that these are secondary crater chains. The Samhain Catenae are crosscut by the linear features radial to Urvara and Yalode, indicating they are not fractures formed during those impact events.

Instead, the morphology of these structures more closely resembles that of pit crater chains (buried normal faults). The orientation of the Samhain Catenae relative to each other is suggestive of en echelon fractures. In addition, many of the longer Samhain Catenae are comprised of smaller structures that have linked together; the S-shaped linkages are also suggestive of en echelon fracturing [7].

3.2 Polygonal craters

Polygonal craters, theorized to form when pervasive subsurface fracturing affects crater formation are widespread on Ceres, as they are on icy moons and other asteroids. Those polygonal craters proximal to the Samhain Catenae have straight crater rims aligned with the grooves and troughs. This alignment supports the Samhain Catenae being fracture systems, not ejecta scour or secondary craters [6].

3.3 Floor-fractured craters

Several of the impact craters on Ceres have patterns of fractures on their floors. Geomorphic analyses show that they are similar to lunar floor-fractured craters (FFCs). FFCs on the Moon are hypothesized to be a product of intrusions of magmatic material below the craters uplifting their floors. The Ceres FFCs according to the classification scheme designed for the Moon [8].

Class 1 Ceres FFCs have both radial and concentric fractures at the crater center, and concentric fractures near the crater wall [7]. In the magmatic model these craters represent fully mature magmatic intrusions, with initial doming of the crater center due to laccolith formation resulting in the crater center fractures, while continuing outward uplift of the remaining crater floor results in concentric fracturing adjacent to the crater wall. Other large (>50 km) Ceres FFCs which have only linear or radial fractures at the center of the crater are also classified as Class 1 FFCs [7], but likely represent a less mature magmatic intrusion, with doming of the crater floor but no tabular uplift.

Smaller craters on Ceres are more consistent with Type 4 lunar FFCs [7]. The three Class 4 sub-classes all have a v-shaped moat separating the wall scarp from the crater interior, but different interior morphologies: Class 4a, with both radial and concentric fractures; Class 4b, having a distinct ridge on the interior side of its v-shaped moat and subtle fracturing; Class 4c, with a moat and a hummocky interior, but no obvious fracturing.

A depth vs. diameter analysis shows that, like lunar FFCs, the Ceres FFCs are anomalously shallow [7]. We also observe the d/D trend for the Class 1 FFCs is shallower than that for the Class 4 FFCs. This is consistent with the magmatic intrusion models, which suggest that the increased fracturing of Class 1 FFCs is due to increased uplift.

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