GEOMORPHOLOGY AND STRUCTURAL GEOLOGY OF SATURNALIA FOSSAE AND ADJACENT STRUCTURES IN THE NORTHERN HEMISPHERE OF VESTA.

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Introduction: Vesta's size and surface gravity, 0.25 m/s^2, place it in an intermediate category between terrestrial planets and small asteroids [e.g. 1]. Unlike Earth or Mars, Vesta lacks a protective atmosphere and consequently the dominant geologic process is impact cratering [e.g. 1,2,3]. The two most prominent impact features are large impact basins near Vesta's southern pole: Rheasilvia (500 km wide), which partially overlies an older basin, Veneneia (450 km wide) [3].

Previous studies have shown that impact processes not only form numerous craters on Vesta, but also induce the formation of large structural features termed fossae: the Saturnalia Fossae in the northern hemisphere and the Divalia Fossae around the equator [1,4,5]. It is proposed that Vesta's differentiated interior amplified and reoriented the stresses induced by the impacts and allowed the fossae, which are interpreted to be graben, to form [4]. Such amplification and reorientation does not occur on smaller, undifferentiated asteroids, like Lutetia, Eros and Ida, where smaller-scale impact-induced lineaments and grooves form [4].

This work expands upon the link between impact cratering processes and structural features on Vesta by presenting findings of a structural mapping study of the Saturnalia Fossae and a variety of other, smaller-scale, adjacent structural features. These structures are located in the northern hemisphere, primarily in two of Vesta's fifteen quadrangles, Caparronia and Domitia.

Methods: This work mainly uses clear filter Framing Camera images and mosaics from the Low Altitude Mapping Orbit (~20 m/pixel), overlain onto High Altitude Mapping Orbit 2 (~65 m/pixel) data to fill in coverage gaps. Geological mapping was carried out using ESRI ArcMap 10.0 software, the Small Body Mapping Tool [6] and JMARS (for Vesta).

Results: Full geological maps of Caparronia and Domitia quadrangles were produced, along with structural maps of the Saturnalia Fossae in the whole northern hemisphere and of the adjacent structures in Caparronia, Domitia and Floronia quadrangles.

Definition of Map Units. The geologic units in Caparronia and Domitia quadrangles were characterized and ordered from oldest to youngest, based mainly on cross-cutting relationships [further information in 7]: 1) Vestalia Terra unit, 2) cratered highlands unit, 3) Saturnalia Fossae trough unit, 4) Saturnalia Fossae cratered unit, 5) undifferentiated lobate unit, 6) dark lobate unit, 7) dark linear unit and 8) confined lobate unit. All units are either modified by impact cratering processes, directly formed by impact cratering processes or induced by impact-induced processes.

Observation and interpretation of structures.

i. Saturnalia Fossae. The Saturnalia Fossae are the principal structure in Vesta's northern quadrangles. There are a maximum of 5 fossae within the group, of which Saturnalia Fossa A is the largest structure, with a maximum width of ~43 km. In cross section Saturnalia Fossa A is an approximately symmetrical rounded depression, while fossae B–E are more asymmetric rounded depressions. Saturnalia Fossa A is also deeper than fossae B–E, with a maximum depth of ~4.5 km. The mean orientation of the fossae is ESE-WNW (Fig. a).

Tight clustering of the orientations of the fossae suggests a related formation mechanism. It has been previously suggested that Saturnalia Fossa A is a graben [4]. In profile Saturnalia Fossa A is the deepest fossae and is symmetrical, which is interpreted to be due to the presence of two large, symmetrical normal faults on either side, which form a graben. Fossae B-E are asymmetric in profile and significantly shallower than Saturnalia Fossa A and are consequently interpreted to be half-grabens. It is likely that they are formed by synthetic faults that may connect to the southernmost Saturnalia Fossa A fault at depth.

ii. Adjacent structures: minor ridges. The minor ridges are ~2-25 km long, are linear to curvilinear and are shallower than the fossae. Some minor ridges are observed to cross-cut impact craters. The mean orientation of the minor ridges is NE-SW (Fig. d). The orientations of the minor ridges can be divided into two dominant groupings of orientations: E-W, which is approximately parallel to the regional slope and NE-SW and N-S, which is not approximately parallel to regional slope.

The two groupings of minor ridges are interpreted to have two different formation mechanisms. The group of minor ridges aligned approximately parallel to regional slope, E-W, may be accumulations of regolith that piled up as the material flowed under the control of the regional slope. However, this formation mechanism cannot be invoked for the minor ridges approximately aligned NE-SW and N-S. The morphology of the minor ridges closely resembles wrinkle ridges/ thrust scarps observed on the Moon [8], Mercury [9] and Mars [10]. Also, the observation that some minor ridges cross-cut impact craters is interpreted as further evidence that the minor ridges aligned NE-SW and N-S are the surface expression of thrust faults that thrust over older craters.

iii. Adjacent structures: grooves and crater chains. The grooves and crater chains are ~1-25 km long, are linear to curvilinear and are shallower than the fossae. Both have mean orientations of E-W (Figs. b and c). In some locations, a feature begins as a groove and merges into a crater chain and vica versa. Some grooves and crater chains are orientated radially around Calpurnia and Marcia craters. However, there are many other groupings of grooves and crater chains that are not clearly radial to an impact crater.

It is likely that the grooves and crater chains are end-members of the same type of feature. Secondary material from an impact scouring and bouncing across the surface commonly forms ejecta ray systems, which consist of grooves and secondary crater chains [e.g. 11]. Grooves and crater chains radial to Calpurnia and Marcia craters are interpreted to form in this way.

However, many of the E-W trending grooves and crater chains and not oriented radially to an impact crater and may have a tectonic origin. Pit crater chains on Earth and Mars are proposed to form by unconsolidated material draining down into extension fractures and/ or dilational normal faults in a more consolidated material at depth [12,13]. In this scenario the crater chains are pit crater chains and are the surface expression of funnels of down-draining material and the grooves represent a more even distribution of down-drained regolith.

Discussion: The structural features are classified into stages of formation by the scale of impact interpreted to have formed them and by their relative temporal relationships.

Stage 1: Formation of Saturnalia Fossae by the Veneneia impact. The fossae are interpreted to be older than the adjacent structures because of cross-cutting relationships and morphology. As discussed in the Introduction, the Saturnalia Fossae were induced by the large (>100 km wide) Veneneia impact [1,4,5].

Stage 2a: Formation of a sub-set of adjacent structures by the Rheasilvia impact. The minor ridges interpreted as thrust faults are oriented NE-SW and N-S and are approximately orthogonal to the grooves and pit crater chains that also have a structural origin, which are oriented E-W. Thus, since extension fractures form approximately orthogonal to thrust faults in shear zones [14] these structures are oriented as if they formed due to simple shear. Consequently, the shear over most of the surface of Vesta, which was a result of the large (>100 km diameter) Rheasilvia-forming impact [1,4,5], may have formed these adjacent structures.

Stage 2b: Formation of a sub-set of adjacent structures by small- and medium-scale impacts. The formation of the remaining adjacent structures is interpreted to be induced: a) by ejected secondary material forming grooves and secondary crater chains and b) by impact-induced seismic shaking [1] inducing the flow of regolith under the control of the regional slope, which formed E-W minor ridges. Near-by likely source craters are <100 km in diameter, i.e. small and medium scale.

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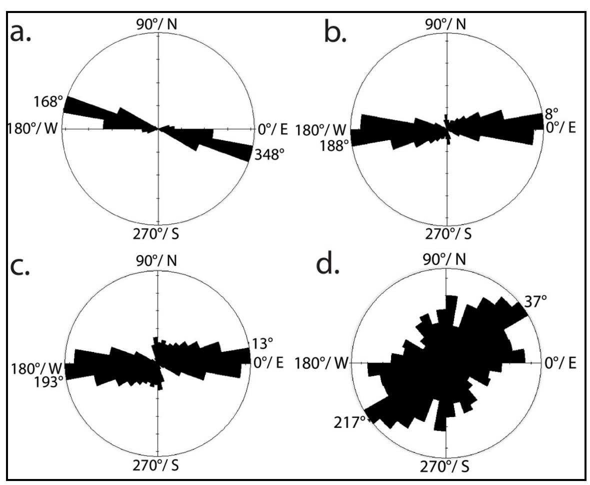

Figures a-d. Rose Diagrams displaying orientations of (a) Saturnalia Fossae, (b) crater chains, (c) grooves and (d) minor ridges.