**OPENING-MODE FRACTURES ARE AN ALTERNATIVE EXPLANATION FOR LARGE-SCALE TROUGHS ON ASTEROID 4 VESTA.** Hiu Ching Jupiter Cheng[1] and Christian Klimczak[1], [1]Structural Geology and Geomechanics Group, Department of Geology, University of Georgia, Athens, GA 30602 (jupiterchc@uga.edu)

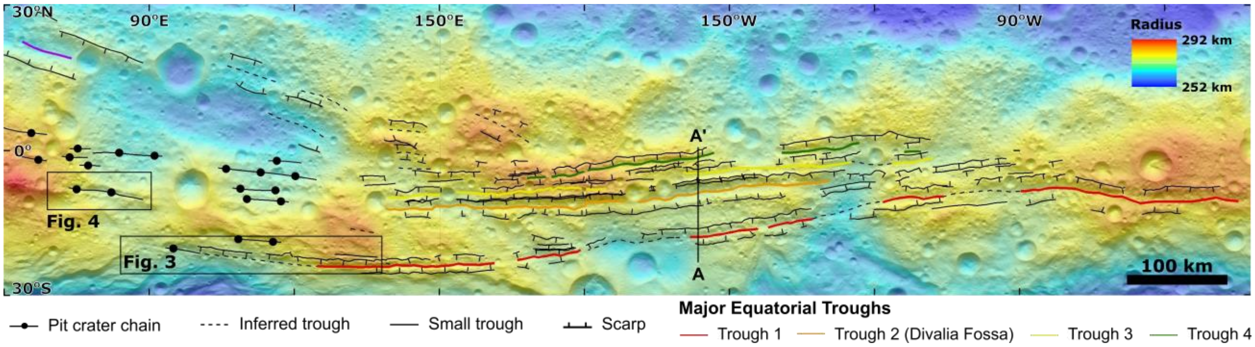


**Figure 1.** *Digital terrain model overlaid on hillshade showing the location and structure map of Vesta's equatorial troughs.*

**Large troughs on Vesta:** The Dawn mission entered orbit around Asteroid 4 Vesta and captured two sets of enormous linear structures, which are thought to be related to the two Veneneia and Rheasilvia impact basins at the south pole [1]. The first set consists of equatorial troughs (Figure 1), whereas the older second set is located in the northern hemisphere [1]. The digital terrain model derived from Dawn images allows detailed mapping and structural analysis of these troughs.

Previous work evaluated the shapes of the troughs and interpreted them to be analogous to grabens on the terrestrial planets [2]. Grabens typically consist of an observable flat floor bounded by two opposite-dipping normal faults. The maximum displacements of both graben-bounding faults should locate near the center of the structure and at a similar position along the fault length. Those geomorphic features are commonly observed to be preserved over billions of years on airless planetary bodies.

**Geological observations:** We mapped and analyzed the geomorphology of the equatorial troughs on Vesta (Figure 1). Our observations show that (1) these troughs have V- and bowl-shaped cross sectional geometries (Figure 2), (2) that the rims of troughs are scalloped (Figure 3), and that (3) troughs narrow and terminate in a pit crater chains, which then align with smaller pits further away from their end (Figure 3). Furthermore, (4) pit crater chains that align with the troughs are observed to have larger pits in the middle and smaller pits at the two ends (Figure 4). We also collected measurements of elevation differences between the trough floor and rim along the length of 4 troughs. Measurements for one such trough were previously interpreted as fault throws [2]. We observe that (5) the maximum elevation differences are located at different locations along the troughs for every structure investigated.

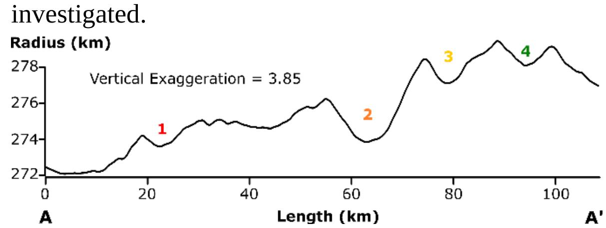


**Figure 2.** *Topographic profiles across A-A' (Figure 1) showing the geometry of four major equatorial troughs.*

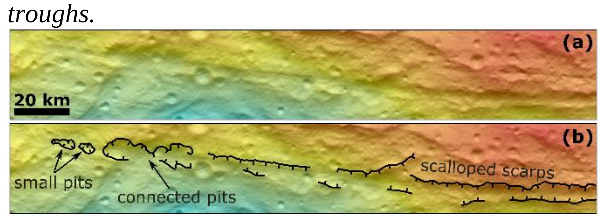


**Figure 3.** *(a) Raw and (b) mapped images showing trough 1 bounded by scalloped scarps narrows and aligns with a pit crater chain and small pits.*

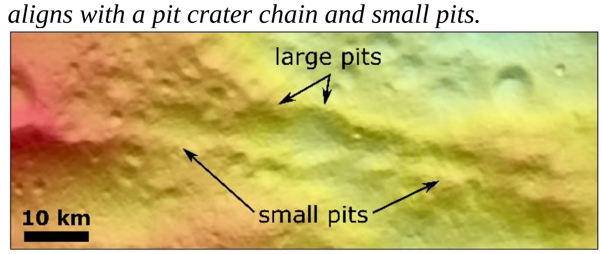


**Figure 4.** *Pit crater chain with larger pits in the middle and smaller pits at the two ends.*

Observations (1), (2), and (5) are inconsistent with the graben formation and distinct flat-floored troughs are not commonly observed. The rims of troughs are too scalloped or degraded to be consistent with interpretation as normal faults, whereas coeval Rheasilvia impact basin terracing scarps (e.g., Matronalia Rupes) appear remarkably fresh. Mismatch in locations of maximum elevation differences between the floor and the two rims of the troughs would imply that the proposed graben-bounding faults originated at different positions, which is unusual for graben formation. Furthermore, the graben interpretation does not explain well the pit crater chain observations (3) and (4).

**Opening-mode fracture interpretation:** Laboratory experiment and numerical modeling have demonstrated that a set of subsurface shear planes are developed after the Rheasilvia-forming event. After that, large regions of the subsurface undergo tensile stresses in addition to shear stresses and propagate the subsurface failure to the surface to create a large set of troughs [3]. The numerical model in [3] simulates extreme tensile stresses of around −400 to −500 MPa, which is well above the observed tensile strength of any jointed basaltic rock [4]. Therefore, it is expected that the material within the body will experience opening-mode fracturing, instead of normal faulting, even at substantial depth and considering the added strengthening effect of the overburden pressure.

We study the individual and cumulative width distribution along the four equatorial troughs (Figure 2). Three out of four mapped troughs have their maximum width occurring at a similar position along the trace (Figure 5a). Trough 1 (in red) is separated into three segments far from each other, which makes it difficult to determine if it is a single trough or multiple troughs. The cumulative width distribution shows one general maximum at the center of the overall length trace (~450 km; Figure 5b). This result is consistent with the prediction of opening-mode fractures, where the displacement distribution profiles display centrally located displacement maxima that taper to zero at the fracture tips [5].

The V-shaped and bowl-shaped troughs are likely to represent different stages of degrading and slumping. This interpretation also provides an explanation for the observed pit craters and their alignment with the troughs. The pit craters are circular depressions that form by the collapse of material into subsurface voids, which may represent subsurface fractures that did not propagate to the surface. In this case, they show similar appearances as opening-mode fractures that the maximum aperture is at the center of the length with smaller apertures near the tips and align with the equatorial trough set.

**Conclusion:** Previous mapping work interpreted the large-scale troughs on Vesta as grabens. Our geological observations and the estimated rock strength [3] are inconsistent with this interpretation but instead point to an opening-mode fracture origin. Continued structural analysis of these troughs will yield further insight into their origin and Vesta's lithospheric evolution.

**References:** [1] Jaumann, R., et al. (2012) *Science, 336: 687−690*. [2] Buczkowski, D. L., et al. (2012) *GRL 39: L18205*. [3] Stickle, A. M., et al. (2015) *Icarus 247: 18−34*. [4] Schultz, R. (1993) *JGR: Planets 98: 10883−10895*. [5] Vermilye, J. M. & Scholz, C. H. (1995) *JSG 17: 423−434*.

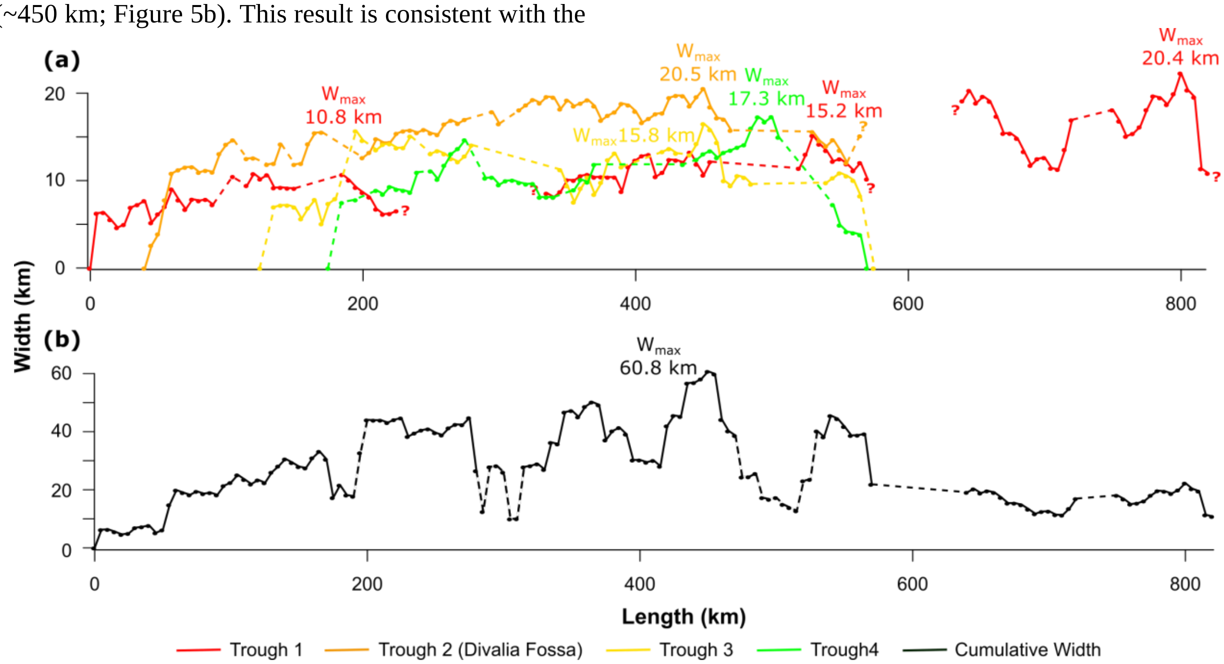


**Figure 5.** *(a) Individual and (b) cumulative width distributions along trough lengths. Note the locations of the maximum width ($W_{max}$) of each mapped trough and the cumulative profile.*