STRUCTURE AND TECTONICS OF THE DIVALIA FOSSAE ON 4 VESTA. Hiu Ching Jupiter Cheng[1] and Christian Klimczak[1], [1]Center for Planetary Tectonics, Department of Geology, University of Georgia, Athens, GA 30602, USA (jupiterchc@uga.edu).

Introduction: Asteroid 4 Vesta hosts two sets of large-scale troughs bounded by steep scarps. The Divalia Fossae encircle two-thirds of the equator and vary in width from several hundreds of meters to up to ~20.5 km. The Saturnalia Fossae are oriented northwest-southeast at a 30° angle to the Divalia Fossae and are only exposed in the northern hemisphere with their southern extent truncated by the Divalia Fossae. The origin of troughs has been proposed to be related to the two impact basins near the south pole, the 421-km-diameter Veneneia basin and the 450-km-diameter Rheasilvia impact basin which partially superposes it.

One hypothesis is that the Divalia Fossae and Saturnalia Fossae were grabens directly and simultaneously formed by the impacts that led to the emplacements of the Rheasilvia and Veneneia basins, respectively. These troughs were interpreted as forming by normal faulting based on the trough geomorphology [1]. The analysis by [2] proposed that the poles of vertical planes defined along the Divalia Fossae and Saturnalia Fossae are clustering near the center of Rheasilvia and Veneneia impact basins, respectively, which was interpreted as evidence for an impact-induced origin of these troughs. To date, this scenario is widely accepted as the leading formation hypothesis of the troughs [e.g., 1, 3-5]. Dawn mission data [6,7] allows us to reanalyze the geographic relationship between the troughs and the basin and further testing the nature and origin of the troughs with structural mapping, crater counting, and rock mechanical calculations.

The Divalia Fossae are not grabens but joints: Typical morphologies of grabens include flat-floored troughs bounded by two relatively steep walls with maximum reliefs near the centers of the troughs that decrease toward their ends. The trough morphology of the Divalia Fossae is not flat-floored and the maximum reliefs do not lie at the trough centers [8]. These observations are inconsistent with the previously proposed faulting origin [1, 4]. Instead, the troughs have their maximum widths near the trough center, pointing to an opening-mode fracture origin. Rock-mechanical calculations that account for Vesta's low gravitational acceleration and degree of fracturing reveal that faulting is not favored to be initiated at depths above at least ~3 but as much as 55 km within Vesta's lithosphere. Therefore, opening-mode displacements are more plausible fracturing mechanisms for the Divalia Fossae. These types of fracturing predict that the Divalia Fossae were formed by tensile stresses with north-south orientation.

Divalia Fossae were not directly formed by an impact: While a large impact could generate tensile stresses large enough for fracturing [9], the formation of the Rheasilvia basin did not cause any noticeable antipodal deformation, inconsistent with numerical modeling predictions [10] and observations on other planetary bodies. While several reasons may explain the lack of major antipodal structures (e.g., weakened antipodal constructive interference of seismic waves due to an oblique impact), it is suspicious how Divalia Fossae could have formed at the equator directly by the impact, yet no deformation is observed at the antipode.

The temporal relationship of troughs and basins as derived from crater statistics permit the formation of Divalia Fossae to be well after or before Rheasilvia basin emplacement [11]. Although the crater statistics provide a relatively restrictive age of the Divalia Fossae, there is no consensus on the age of the Rheasilvia basin due to the large uncertainty in cater statistics and disagreement in meaningful count areas. Crater counting does not yield tight constraints of the relative age between the troughs and the basin.

The Divalia Fossae crosscut the Rheasilvia basin, providing direct evidence that the troughs must have formed after the basin emplacement and modification [12]. The emplacement and immediate modification of the Rheasilvia basin were estimated to take place over approximately 2–3 h [13], defined by the formation of basin-bounding scarps. Considering a typical earthquake rupture propagation rate of approximately 3 km/s, the Divalia Fossae should form ~100–150 s after the impact by fracturing deep within Vesta from the Rheasilvia impact that propagated to the surface. Even though seismic shaking could still affect the surface for hours after the impact, the formation of Divalia Fossae, if indeed caused by the Rheasilvia impact, would have to take place before or within the same timeframe of the modification stage of the Rheasilvia basin, which contradicts the observed cross-cutting relationship.

A reassessment of the geographic relationship between the Divalia Fossae and the Rheasilvia basin indicated the troughs are not concentric around the basin center [12]. The geometric mean centers of the Rheasilvia basin and its central mound are not co-located with the poles of the Divalia Fossae with upward of 95% confidence [12]. Instead, the Divalia Fossae are found to be concentric around the south pole and thus to the asteroid's spin axis [12]. This result establishes that the Divalia Fossae do not display a clearly defined geographic relationship with the Rheasilvia basin as previously thought. While there may be reasons (e.g., the interior heterogeneities) explaining why the troughs would not necessarily have to be concentric around the Rheasilvia basin for them to be genetically linked, the lack of a clear collocation of the basin and troughs nullifies the sole argument on which the hypothesis, that the basin forming impact directly triggered the formation of the troughs of Divalia Fossae, is based on.

The origin of Divalia Fossae is spinning-related: To explore the possibility of a spinning-related trough origin, we investigate the geographic relationship of the topographic depression formed by Veneneia and Rheasilvia with Divalia Fossae and the south pole. The Veneneia and Rheasilvia basins together show an enormous depression at the south pole (Fig. 1a). Despite the effect of the Rheasilvia central mound, irregularity of the depression, and other large impact craters on the basin floors, the geometric mean center of the combined Veneneia and Rheasilvia basin-bounding scarps calculated here, coincides with the south pole and the center of the topographic depression (Fig. 1a).

Two methods have been used to define the plane of Divalia Fossae. Method 1 from [2] assumes the planes defined by the troughs are cutting through the center of the asteroid. The orientations of the planes located at the center positions of each of the trough segments are shown as great circles in an equal area stereonet (Fig. 1b). Method 2 determines the planes defined by the troughs without the assumption that they cut through the center of the asteroid [12], and that the trough segments of Divalia Fossae belong to four main structures [8]. These planes are defined as circular best fits to each structure, represented as four small circles on an equal-area stereonet (Fig. 1c). The 95% confidence interval ellipses of the poles of the troughs (Fig. 1b,c shown in grey) describe the uncertainty inherent in the estimate of the pole position, representing the set of acceptable hypotheses. The geometric mean center of both basins and the south pole (spin axis) are co-located with the poles of the planes defined by Divalia Fossae (Fig. 1b,c), which also coincides with the center of the south polar topographic low formed by the Venenea and Rheasilvia basins (Fig 1a). These well-defined geographic relationships point to a formation scenario of the troughs involving changes to the spinning of Vesta.

Conclusion: We presented a list of geologic constraints rejecting the leading hypothesis that the large-scale troughs on Vesta were directly formed by impacts but instead pointing towards a spinning-related origin. Because the troughs are concentric around the south pole and because the center of the depression co-created by Rheasilvia and Veneneia also coincides with the south pole, the troughs likely formed as long-term consequence of the impacts, in which changes in location and/or rate of Vesta's spin axis occurred. A new trough origin hypothesis that is capable of explaining all our listed geologic constraints is needed.

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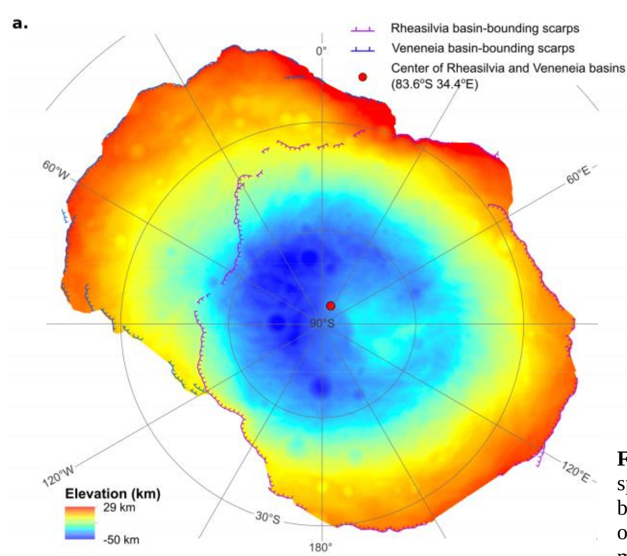

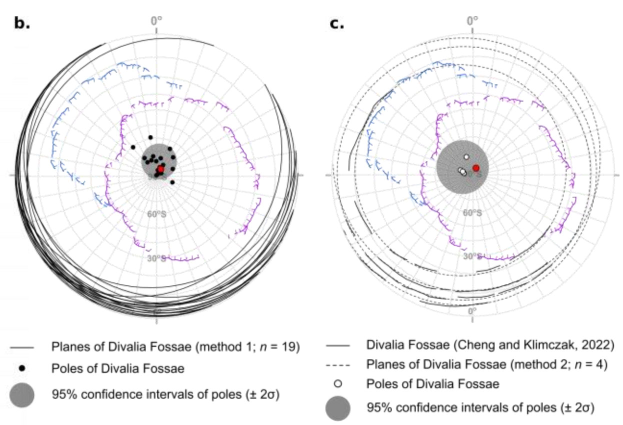

Figure 1. The geographic relationship between the basins, troughs, and spin axis of Vesta. (a) Elevation map within Rheasilvia and Veneneia basins. (b) Equal area south pole projection stereonet showing the center of Rheasilvia and Veneneia basins with the Divalia Fossae defined by (b) method 1 and (c) method 2 (see main text).