The tectonic evolution of (433) Eros

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Introduction: The tectonic evolution of 433 (Eros) can be characterized by several lines of evidence: the observed distribution of tectonic lineaments that cover the asteroid [1,2]; the low porosity of Eros [3]; observations that some tectonic structures have been re-activated [4]; and the localized effects of seismic shaking near the Shoemaker crater (the youngest large crater on the surface of Eros) [5]. These observations are reviewed and interpreted in light of new impact calculations indicating that Eros must have been nearly intact, possessed strength, and had little to no porosity before the largest crater, Himeros, formed.

Tectonic Structures: A range of lineaments is present on the surface of Eros, most of the lineaments being extensional structures [2,4]. The widespread existence of these lineaments implies that Eros today is coherent over most of its surface, with some internal strength. An effort to map these lineaments across the asteroid showed that most are the result of impact events [2]. Indeed, the largest population of lineaments is located circumferentially around Eros, at right angles to the direction of impact for the three large equatorial craters Himeros, Shoemaker, and Psyche. Two sets of surface lineaments exist that do not seem to have any parent craters, including the large tectonic ridge called the Rahe Dorsum, and a possible conjugate set of faults [1,6]. These sets are located on one half of Eros and may have been produced during the original parent body disruption event that formed Eros.

Porosity: The measured shape and mass of Eros, and the identification from remote-sensing data that this asteroid is likely to be an undifferentiated ordinary chondrite, imply that Eros has a porosity of approximately 20–25 % [3]. Such porosity suggests Eros is most likely a fractured shard rather than a true rubble pile.

Crater modification by Tectonic Displacement: In several instances, craters have been modified by tectonic displacements [4]. The shape of these moderate-sized craters (diameter $\sim$1 km) are distorted in unusual ways due to surface movement along the pre-existing faults. The movement was probably moderate given that the overall crater shapes are still apparent, suggesting that the tectonic structures were already present before further displacements along these structures occurred.

Numerical Model Results and Interpretation: We use a numerical approach to look at the consequences of formation of the three largest craters on Eros by modeling failure using a new micromechanics-material-based damage model discussed in [8]. In brief, the micromechanics framework underlying this model assumes that geologic materials fail through the interaction and growth of a distribution of small flaws, which through their collective behavior can lead to large-scale features. Once a critical damage level is reached, the model assumes the material becomes granular, and flows viscoplastically with a pressure-dependent yield strength similar to sand.

We assume Himeros is the oldest large crater on the surface of Eros, followed by Psyche and Shoemaker. The results indicate that much of the porosity seen on Eros, and the damage developed, including the tectonic features observed, are the result of the Himeros impact. The subsequent major impact events cause minor changes to the porosity and create new regional, not global, lineaments surrounding the resulting craters.

The calculations imply Eros must have been nearly intact before Himeros formed, despite having some evidence for pre-existing cracks. It seems difficult to otherwise explain Eros' current porosity. The formation of Himeros also generated the bulk of the lineaments we see today. Moderate-sized craters could have formed without disturbing or being disturbed by the pre-existing structure from Himeros, but were then heavily modified once those cracks were displaced by the large craters Psyche or Shoemaker. The model also helps explain why the most recent large crater Shoemaker, which is similar in size to Himeros, removed small craters in its vicinity and had lesser effects on the shape of some craters farther away [7].

References: [1] Thomas et al. 2002,GRL, 29, 0.1029/2001GL014599, 2002. [2] Buczkowski et al. 2008. Icarus, 193, p.39. [3] Wilkison et al. Icarus 155, 94–103. [4] Prockter et al., 2002. Icarus 155, 75–93. [5] Thomas and Robinson, 2005. Nature 436, 366–369. [6] Buczkowski et al., 2009. LPSC, (abstract) 40, p.1187. [7] Ernst et al., 2012, LPSC 43, 2393. [8] Tonge et al., 2014, ACM (this issue).