THE TECTONIC RESURFACING OF ARIEL. E. J. Leonard[1], D. A. Patthoff[2], and C. Beddingfield[3,4]
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Introduction: Ariel, a mid-sized icy moon of Uranus, displays a surprisingly young surface in the images returned by Voyager 2 [1]. The lack of impact structures on this remote world (Fig. 1) suggest a period of relatively recent geologic activity (<4 Ga) [2]. Fractures, ridges, scarps, and a relative dearth of craters larger than about 10 km diameter, point to a history of significant tectonic resurfacing. This resurfacing is also evidenced by the chasmata, or large (>5 km wide) canyons (Fig. 2), that extend for 10s of kilometers and are located near the equator of the moon (in the limited images obtained by Voyager). Previous work on the chasmata hypothesizes that they are cryovolcanic features and evidenced by the smooth material that fills these canyons [3]. Here we seek to constrain potential tectonic resurfacing mechanisms for the formation of the chasmata through numerical and analogue models.

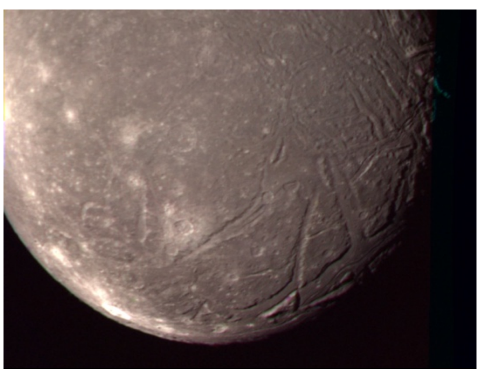

Figure 1: A color image of Ariel from Voyager 2 (PIA00041) illuminating the south polar region.

Specifically, we explore the potential contributions of diurnal and obliquity tidal stresses to create the observed structural features. We use SatStressGUI to calculate the magnitudes and orientations of the resulting stresses [4]. A range of ice shell and ocean thicknesses and orbital eccentricities are modeled to determine which configurations result in stresses large enough to fracture the ice shell. The modeled stress orientations are also compared to observable features to determine potential correlations.

We also simulate an extensional environment on Ariel with a physical analogue model [5, 6]. We use a two-layer model to simulate a cold, brittle outer layer and an inner warmer, ductile layer. The two-layer physical analogue model for the ice shell is directly comparable to the environment used for the numerical models.

Methodology: In order to investigate the formation of the chasmata on Ariel, we combine the results from observations of morphology and topography, a two-layer physical analogue model, and a numerical model.

Observations. There are several morphologic characteristics of the chasmata that we observe in the Voyager image and resulting DEMs, including: (1) The ridges have broad, flat tops, (2) Troughs are also generally broad and appear relatively rectangular in cross-section, (3) Material within the trough appears smoother than the material on the ridges, (4) Ridges and troughs can be systematic or stand-alone, (5) Troughs are linear to curvilinear along their length, and (6) The terminations of chasmata can be ramp-like or abrupt. For the chasmata that are systematic, or alternating ridges and troughs, the spacing ranges from 15-19 km.

Analogue Model. In order to simulate chasmata formation, we develop a two-layer physical analogue experiment, previously developed for ridged plains formation on Europa [4], to simulate an extensional environment on Ariel. We then compare the resulting morphology of the graben produced to observations of the chasmata.

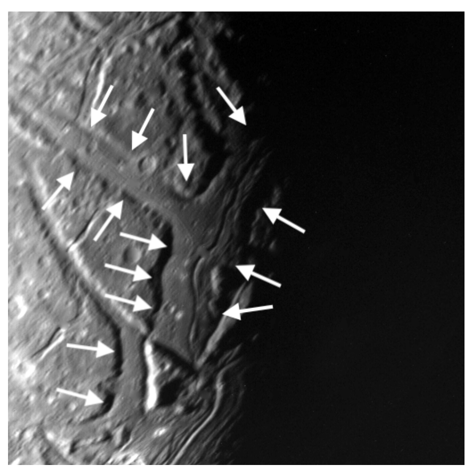

Figure 2: Chasmata (indicated by white arrows) on Ariel's surface (PIA01356, resolution ~ 2.4 km/px).

The analogue model consists of a ductile, lower viscosity layer underlying a Coulomb-material brittle layer. We use therapeutic putty with a measured viscosity of about 10^4 Pa s for our ductile layer and fine-grained sand for the brittle layer. We chose these materials for our experiments because they scale well to conditions on Ariel. For example, if we scale with the cohesive strength of our experimental sand (~60 Pa) and use approximate values for Ariel [1, 3], we obtain a spatial scaling factor of $1{:}10^{-6}$, which means that 1 cm thick sand in our model represents a 10 km thick ice layer on Ariel [5].

To set up an experiment, we first layer the putty into a 90 cm by 90 cm box and let it relax to a flat surface over the course of a few days before adding the desired amount of sand. We also add coffee grounds on top of the sand to act as strain markers. For experiments where we simulate extensional processes, we move one wall outward with a step motor.

When we increase the brittle layer thickness in the model, the spacing of resulting normal faults also increases. The resulting horst and graben system in the experiments have similar morphologies to the chasmata on Ariel (Fig. 3) including: (1) flat-topped ridges, (2) broad troughs, and (3) slight bowing-up of the material within the troughs [3].

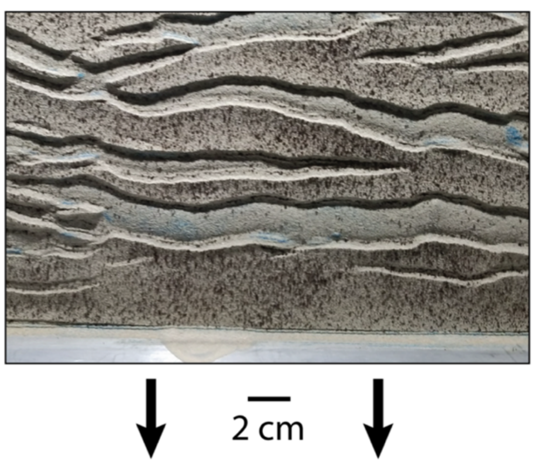

Figure 3: Extension experiment from two-layer analogue model. The resulting horst and graben formations resemble the chasmata on Ariel.

SatStressGUI. To determine if the driving stresses to create the observed features are tidally controlled, we use SatStressGUI [4] to calculate the magnitudes and orientations of the resultant stresses. We perform a range of simulations that vary the ice shell and ocean thicknesses, and eccentricities to determine the magnitude and orientation of potential stresses. We then compare the resultant stresses to mapped features on the surface to determine if there is a correlation. This modelling serves to constrain the brittle and ductile thicknesses used in the analogue modelling aspect of this work. Additionally, the modelling can be used to determine if Ariel had a larger eccentricity in the past that could have resulted in larger stresses.

Initial Results and Future Work: Our initial results from the analogue modeling suggest that at least some of the chasmata were formed in extension. From the scaling of the model, we find that the spacing of the chasmata on Ariel would suggest a brittle layer thickness of ~10-12 km at the time of formation. In order to further validate the model, we will compare the topography generated in the model to the topography of the chasmata covered by a DEM created from stereo and photoclinometry.

The initial results from the stress modeling in SatStressGUI show that tidal stresses show similar orientations to the chasmata. We will do a statistical analysis comparing the stresses with the orientations of the chasmata in order to further quantify this result. Additionally, the tidal stress magnitudes are likely not large enough to form the chasmata, so we also plan on investigating obliquity stresses.

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References: [1] Smith, B. A. et al. (1986). Science, 233, pp. 43–64. [2] Plescia, J. B. (1987) Nature, 327(6119), pp. 201–204. [3] Schenk, P. M. (1991). Solid Earth, 96(B2), 1887-1906. [4] Patthoff, et al (2018) AGU Fall Meeting, abstract P21E-3398. [5] Leonard, E. J., Pappalardo, R. T., & Yin, A. (2018). AGU Fall Meeting Abstracts. [6] Hubbert, M. K. (1937). Bulletin of the Geological Society of America, 48(10), 1459-1520.