Characterizing the composition and elastic properties of the near-surface of Ceres: Insights from flexural modeling of the Nar Sulcus fractures. K. H. G. Hughson[1], C. T. Russell[1], H. G. Sizemore[2], B. E. Schmidt[3], D.L. Buczkowski[4], P. Schenk[5], G. Peltzer[1,6], C. A. Raymond[6], [1]Department of Earth, Planetary, and Space Sciences, University of California Los Angeles, 595 Charles E Young Drive E, Los Angeles, CA 90095, USA (p151c@ucla.edu); [2]Planetary Science Institute, Tucson, AZ; [3]Georgia Institute of Technology, Atlanta, GA; [4]Johns Hopkins University Applied Physics Laboratory, Laurel, MD; [9]LPI, Houston, TX; [6]JPL, Pasadena, CA.

Introduction: Since its arrival at Ceres in March 2015 the Dawn spacecraft has observed a number of unique geomorphological features that have no direct analogs on Vesta (Dawn's previous target) or any other large asteroid observed at comparable resolution. One of the most striking of these structures is the large parallel fractured terrain named Nar Sulcus.

Nar Sulcus, centered at 41.86° S, 280.11° E, is located in the southwest quadrant of Yalode crater on Ceres' southern hemisphere. Geological mapping of the fractured terrain (Fig. 1) revealed it is composed of two sets of mutually perpendicular fractures with the larger of these sets trending east-west and the smaller trending north-south. The fractures lie on the north flank of a large (~60 km mean diameter) tholus that rises ~4 km above the floor of Yalode [1]. The eastern end of the east-west trending fractures intersect the north facing slope of this tholus, while the north-south trending fractures run parallel to its east facing slope. The fractures in both sets display en echelon-like incremental vertical displacements that step up in the direction of increasing elevation. Due to this characteristic behavior these fractures have been interpreted as normal faults.

The major east-west trending fracture set is composed of five main faults, each around 40 km in length with vertical displacements ranging from ~100-200 m. The largest of these displacements belongs to the central fault of this set.

We test the hypothesis that the topography and morphology of the Nar Sulcus normal faults are controlled primarily by a thin ice-rich elastic layer. We do this by carefully mapping the structures in Nar Sulcus from Dawn framing camera images, determining characteristic heaves and throws for these faults, by comparing their profiles to a single layer flexural-cantilever model for normal faulting similar to the one developed by [2], and by analyzing their displacement (fault throw): length (lateral extent in plan view) (D/L) ratios using a method similar to the technique described in [3]. This analysis, which is similar to the one conducted on the europan ice shell by [4], estimates the elastic thickness, elastic moduli, and remote stress acting on the faults at Nar Sulcus. Insight into the water ice content of the near surface of Ceres is gained through comparisons of these derived values to laboratory and field measurements of numerous ice-bearing phases.

Methods: In order to estimate the mechanical properties of the faulted material in Nar Sulcus, we fit a single layer flexural-cantilever model of elastic plate bending to characteristic topographic profiles derived from the detailed geological mapping using the Dawn High Altitude Mapping Orbit Based Digital Terrain Model (Fig. 2). The model considers the effects of extension, isostatic uplift, and flexural rigidity.

The remote stresses on the faults in Nar Sulcus are estimated from a D/L ratio model extrapolated from tensile crack growth theory by [3]. This model takes into account the frictional stress on the faults, The elastic constants derived from the flexural-cantilever model were utilized in estimating the remote stress.

Results: Initial results from the flexural-cantilever model indicate that the elastic thickness of the cerean 'crust' is ~700 m, and that its tensile strength is higher than that of pure water ice but much lower than that of even weakly lithified silicate material. The D/L analysis suggests that the remote stress on the Nar Sulcus normal faults is on the order of a few tens of MPa.

Initial model results for the transect in Fig. 1 are depicted in Fig. 3.

Discussion: While the ~700 m eleastic thickness is larger that the ~200 m elastic thickness found by [4] for Europa, it is considerably thinner than what would be expected for a silicate dominated composition. On this basis we interpret the brittle/elastic behavior of the surficial material around Nar Sulcus to be dominated by the effects of a weak ground ice phase: although, much work remains to be done characterizing additional cross-sections across Nar Sulcus to more definitively and quantitatively test this interpretation.

The estimated driving stress of a few tens of MPa at Nar Sulcus is incompatible with a genesis from static loading, and suggests an active source of uplift [5]. This could plausibly be solid-state diapirism (as is the case for salt diapirs on the Earth), or laccolith formation due to cryomagma accumulation sourced from either impact melt or endogenic reservoirs (as is the case for floor fractures craters on the Moon) [6].

References: [1] Sizemore H. G. et al. (2018) *LPSC XLIX.* [2] Kusznir N. J. et al. (1991) *Geological Society, Special Publication 56*, 41-60. [3] Cowie P. A. and Scholz C. H. (1992) *Journal of Structural Geology 14*, 1133-1148. [4] Nimmo F. and Schenk P. (2006) *Journal of Structural Geology 28*, 2194-2203. [5] Bland M. et al. (2018) *LPSC XLIX.* [6] Buczkowski D. L. et al. (2017) *LPSC XLIIX,* Abstract # 2117.

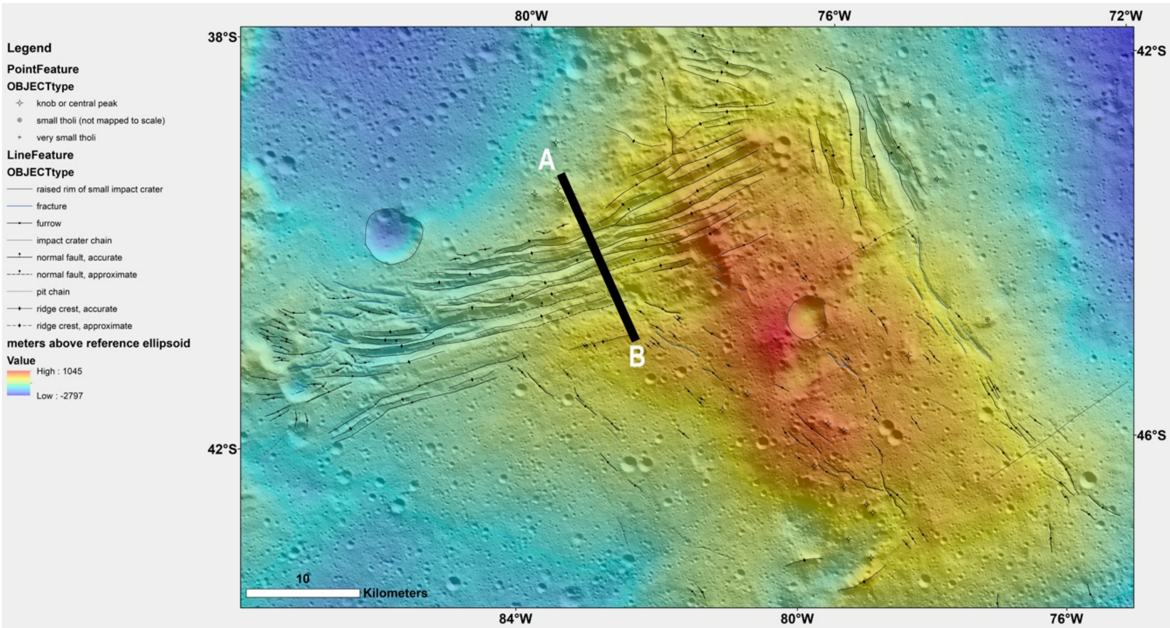

Fig. 1. This map shows the structural elements of Nar Sulcus as well as the local topographic relief. The A-B transect shown is the path of the cross-section in Fig. 3.

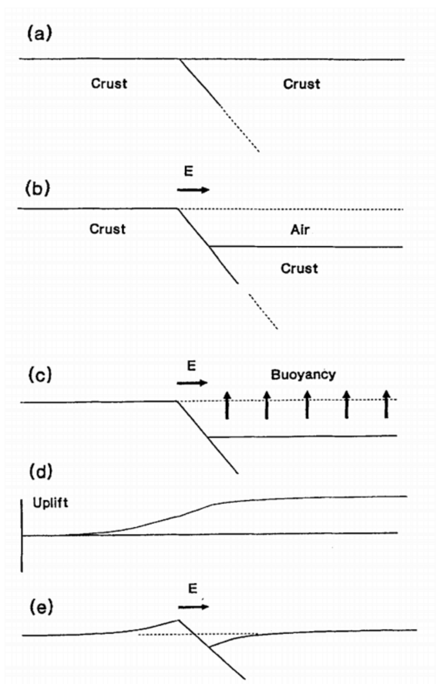

Fig. 2. Procedural sketch of how the flexural-cantilever model is implemented, adapted from Kusznir et al. (1991). a) represents the unfaulted material, b) depicts the initial ideal fault topography, c) indicates the effect of buoyancy on the faulted terrain, d) the model deflection, and e) shows the final topographic profile generated by the model.

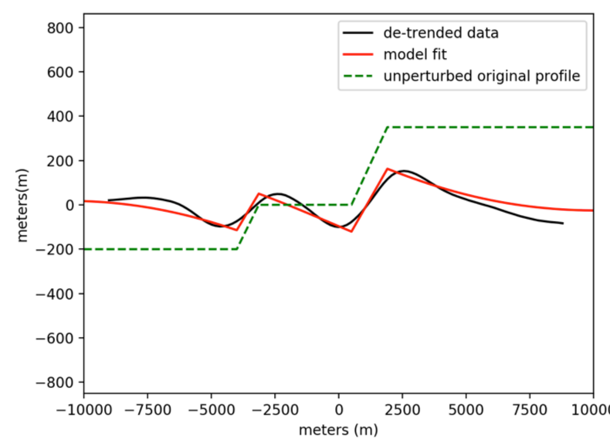

Fig. 3. Preliminary flexural-cantilever model results for the largest faults in the Nar Sulcus region using a Young's modulus of 2 GPa, an elastic thickness of 700 m, and a Poisson's ratio of 0.27. Note how the true topography is well replicated by flexural plate bending. On the transect in Fig. 1 A is the left end of the black line on this figure while B is the right end.