STRUCTURE AND MORPHOLOGY OF ENCELADUS' CRATERED TERRAINS. M. J. Kinczyk[1], P. K. Byrne[2], and G. W. Patterson[1], [1]The Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, [2]Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO, 63130.

Introduction: Studies of Enceladus' surface geology have primarily focused on the nature and evolution of the South Polar Terrain (SPT). The discovery of active jets emanating from the SPT by the Cassini spacecraft [1] made an even more compelling case for studying Enceladus, especially to determine the nature of this plume material and how it relates to the SPT geology. However, indicators for geological activity are present outside of this region [2,3], which have important implications for understanding Enceladus' surface and interior evolution. Among these indicators are the much older cratered terrains that host myriad crater sizes and morphologies, as well as ancient and relatively recent tectonic deformation [4].

Since the Cassini Imaging Science Subsystem (ISS) returned images of the north polar (and most heavily cratered) region on Enceladus toward the end of the Cassini mission, it has become possible only recently to develop a global picture of Enceladus' geological history. The clear diversity of cratered terrain morphologies, along with the now available global image basemap [5], provide a key motivation to develop detailed evaluations of portions of Enceladus' cratered terrains. We present a quantitative assessment of the distributions of impact craters and tectonic structures in seven morphologically distinct regions of interest (ROI) in the cratered terrains (**Fig. 1**). We found that the tectonic structures in the cratered terrains, including both ancient troughs and very recent young fractures, point to a cratered terrain that not only experienced early tectonic modification but shows evidence supporting recent geological activity.

Methods: We mapped impact craters, narrow fractures, and subdued troughs in each ROI to establish superposition relationships. Impact craters were mapped on a global Enceladus basemap [5], complemented by ancillary flyby mosaics that preserve original color and represent a variety of viewing and illumination geometries. All craters ≥0.5 km in diameter were counted to ensure full coverage of craters at ≥1 km in diameter, from which our crater size–frequency distributions were compiled (**Fig. 2**). Morphologically fresh, narrow fractures were mapped at a maximum scale of 1:125,000, and ancient, more subdued troughs were mapped at a scale of 1:500,000 in a Geographical Information System (GIS). These respective structures were identified by relative morphology and cross-cutting relationships, where ancient troughs were morphologically subdued and disrupted by the more recent narrow fractures with distinct fault faces.

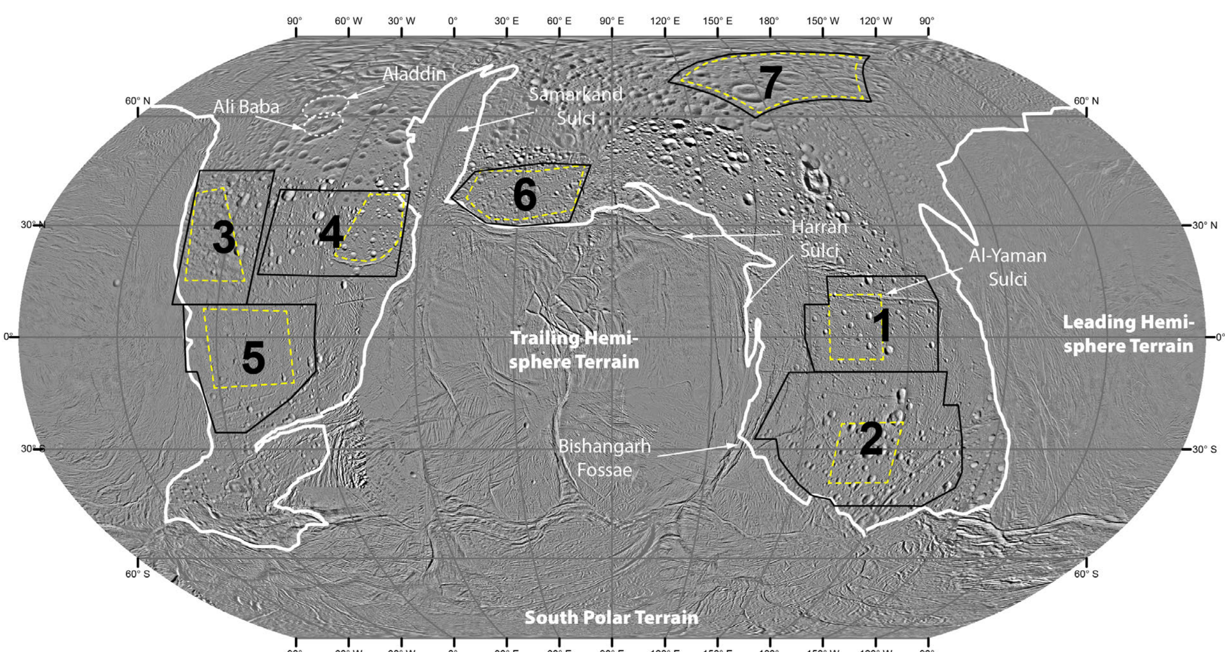

Figure 1. Global monochrome image mosaic of Enceladus (100 m/px) in Robinson projection centered at 0°E. White outlines mark the boundaries of the cratered terrains from previous work [2]. Black sections are the regions of interest in this study, and yellow dashed lines indicate locations where craters were mapped to generate crater size–frequency distributions.

Results: Broader implications for understanding the evolution of Enceladus' surface, drawn from analysis of its older cratered terrain, include:

Ancient Troughs: The ancient troughs span a wide range of orientations across all regions. However, the troughs in the sub- and anti-Saturnian cratered terrains are similar in orientation, and comparable in size, to tectonic fabrics located at the edges of the Leading and Trailing Hemisphere Terrains (LHT and THT respectively), suggesting that the sub- and anti-Saturnian terrains previously underwent similar modes of deformation as the LHT and THT. If the source of activity that caused the formation of the LHT and THT is collocated with the apex and antapex of motion, then these observations together make a strong case for non-synchronous rotation (NSR) of the ice shell having contributed to the present-day configuration of these ancient troughs.

Impact Craters: Crater size–frequency distributions for craters in each ROI are displayed in an R-plot in **Fig. 2**. These data show that, among sub-Saturnian terrains examined, Region 7 near Enceladus' north pole has nearly the highest relative frequency of craters across all regions and all diameters, exceeded only by Region 4 in mid-sized craters (i.e., ~3–5 km diameter). Region 7 also has the highest number of craters >10 km in diameter suggesting that this region is the most ancient and well-preserved of the terrains we investigated. We also found that Regions 1 and 5, which are near Enceladus' sub- and anti-Saturnian points respectively, show statistically significant differences in the presence of craters <3 km in diameter.

Narrow Fractures: The narrow and morphologically fresh extensional fractures observed are pervasive across much of the cratered terrain, and crosscut nearly all other features. In general, most such fractures are oriented approximately N–S. Ice shell thickening has been invoked to form fractures due to secular cooling [6,7]. However, the generally uniform N–S trends of fractures indicate that the differential stress state was oriented ~E–W. It has recently been proposed [8] that an ice shell that is thicker along its tidal axis, coupled with a steep thermal gradient, would encourage melting at the base of the ice shell in the leading and trailing hemispheres. Active thinning of these regions (which would be consistent with recent models of ice shell thickness [9]) of the shell over a global ocean would plausibly lead to subsidence relative to the thicker cratered terrains, resulting in N–S-oriented tensional fractures thus explaining the presence of these structures and their sharp morphology.

Summary: Spatial analysis of impact crater distributions in each ROI reveal that an apparent equatorial dearth of craters does not hold for craters <3 km in diameter in the anti-Saturnian cratered terrains. Preferential burial and/or removal of small craters in the sub-Saturnian cratered terrain is unlikely, indicating that more work is required to determine the source of this disparity.

The similarity in the size and orientation of ancient troughs in the equatorial cratered terrains are similar to those present in the LHT and THT. This similarity suggests that the equatorial cratered terrains underwent similar tectonic deformation to the LHT and THT in Enceladus' geologically recent past, supporting a theory of NSR of the shell. Additionally, the predominant N–S trend of young narrow fractures suggests that the cratered terrains recently underwent extension in the E–W direction. We posit that this E–W surface extension is caused by the subsidence of the surrounding younger (and thinner) LHT, THT, and SPT.

References: [1] Porco, C.C. et al. (2006) *Science, 311,* 1393-1401. [2] Crow-Willard , E.N. & Pappalardo, R.T. (2015) *JGR: Planets, 120,* 928-950. [3] Bland, M.T., et al. (2012) *GRL, 39,* L17204. [4] Martin, E.S., et al. (2017) *Icarus, 294,* 209-217. [5] Bland, M.T., et al. (2018) *Earth & Space Sci., 5,* 604-621. [6] Hemingway, D.J., et al. (2020) *Nat. Astr., 4,* 3, 234-239. [7] Nimmo, F. (2004) *JGR Planets, 109,* E12001. [8] Rhoden, A.R., et al. (2020) *EPSL, 544,* 116389. [9] Hemingway, D.J. & Mittal, T. (2019) *Icarus, 332,* 111-131.

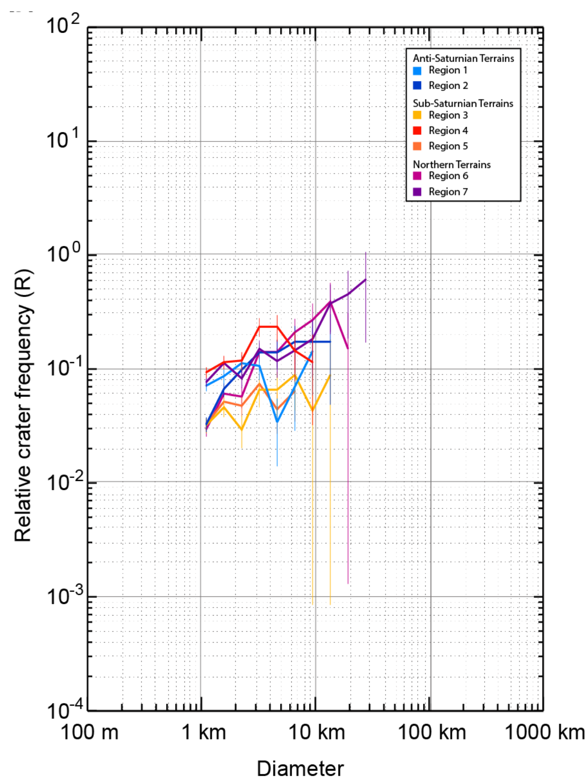

Figure 2. Crater size–frequency distributions for ROI in Enceladus' cratered terrain displayed as an R-plot. Error bars are given as standard $\sqrt{N}$ values.