MORPHOMETRIC AND SPATIAL ANALYSIS OF MOUNTAIN GEOMORPHOLOGY ON TITAN AND IMPLICATIONS FOR THE TECTONIC HISTORY. T. Morgan[1], J. Radebaugh[1] and E.H Christiansen[1], Department of Geological Sciences, Brigham Young University, Provo Utah, 84602, tlm1998@byu.edu

Introduction: Mountains on Titan are regions that exhibit significant positive relief as compared to the rest of the surface of Titan [1,2,3]. Titan's abundant mountains and erosional morphologies bear record of its structural evolution and the interaction of dynamic internal stress regimes with external erosive processes [4,5,6,7]. Mountain geomorphology was examined in a region near the equator and the future *Dragonfly* landing site to reveal statistics on shape-related parameters for mountains. By conducting a morphometric analysis, we can compare Titan's mountain morphologies with those of similar features on Earth, in hopes of determining a possible tectonic history for Titan's mountains.

Method: The datasets used come from *Cassini* Synthetic Aperture Radar (SAR), Visual and Infrared Mapping Spectrometer (VIMS), and Imaging Science Subsystems (ISS) instruments. Mountain features are isolated blocks or long ridges and are identified through SAR bright and dark pairs of the summit regions (Fig. 1). They bear morphological resemblance to eroded, mountainous features on Earth (Fig. 1) [1].

The study region was located west of the Xanadu region and the Huygens Probe landing site (Fig. 1) and covered 915,000 km^2 of SAR swaths T008, T041, T061, and T095. **Mountain Ridges**, which are individual, isolated mountains with SAR bright/dark pairs indicating presence of a ridge [1], and **Mountain Belts** [1,2,4,5], which are long, linear features with semi-connected Mountain Ridges (Fig. 1) were mapped. A morphometric study was then conducted on parameters including length, width, height, and area. Mountain Belts were also measured for sinuosity (the axial length of a mountain belt divided by its straight end-to-end length), segment orientation and relative assemblage (% ridge versus % valley). Similar parameters have been examined on mountain features on Earth to determine the degree of tectonic deformation [8,9].

Measurements were taken from *Cassini* SAR imagery and SARTopo data (topography based on alignment of adjacent SAR beams) using the geospatial tools in ArcGIS Pro. Measurements were also made on mountains in the contractional Zagros fold belt of Iran and in the extensional Basin and Range province of western North America for comparison. Relative mountain and valley compositions were also studied using *Cassini* VIMS data.

Morphometric Statistics: Within the study area, 269 individual Mountain Ridges were measured along with 50 linear Mountain Belts. Apart from the width of mountain ridges, all morphometric statistics had a right skewed distribution. Because of this skewness, the closest approximation to the center of the distribution is the median, which is what we focus on below

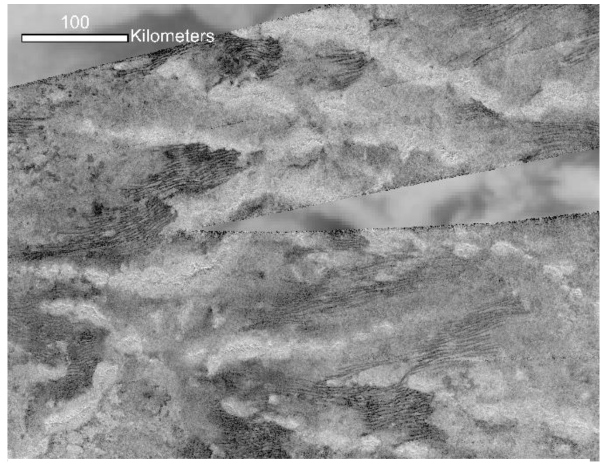

Figure 1. Cassini SAR image mosaic, with separate SAR bright Mountain Ridges and long, linear Mountains Belts visible. Located at the equator west of Xanadu and the Huygens landing site.

The median length of Mountain Ridges was 18 km and the mean width was 14 ±8 km. The total sum of mountain ridge lengths in the study area was 7741 km. Mountain Belt lengths ranged from 40 km to 523 km with a median belt length of 130 km. The total sum of Mountain Belt lengths in the study area was 9458 km. The mean Mountain Belt width was 13.9 ±4.9 km. An average of 4.6 ±2.7 Mountain Ridges were contained within each Mountain Belt, with a maximum of 15 ridge segments. A geospatial analysis of the strike of mountain belts yielded a directional mean 102° from north (ESE), though there is considerable deviation from the mean across the study area. Mountain belts were comprised on average of 67% mountain ridges and 33% inter-ridge valleys.

The median sinuosity of the mountain belts was 1.036. This was compared with the sinuosity of similarly scaled mountain belts on Earth in the Zagros and the Basin and Range. The median sinuosity of 14 Zagros belts was 1.033 and of 20 Basin and Range belts was 1.026. The median area for 269 Mountain Ridges surveyed was 207 km^2. The total area covered by Mountain Ridges was 133,246 km^2, about 15% of the study area (Fig. 2). The high points on 21 mountain ridges were obtained from *Cassini* SARTopo data. Maximum relief ranged to 443 m above the Titan reference sphere, with a median height of 156 m.

Structure and surface materials: An analysis of VIMS data in the region revealed the primary composition of the study area is organic sedimentary rocks (mainly VIMS-white), with some water ice mixed with organics (VIMS-blue), likely stratigraphically lower than the VIMS-white [11]. Much of the inter-ridge valleys have a water ice and organic sedimentary composition with some VIMS-brown regions (organic sand) where aeolian dunes are present. These topographically low regions, generally 73 to -287 m, may act as basins for the accumulation of hydrocarbon sediments. The tops of the Mountain Ridges are largely free from aeolian sediment deposits and are often VIMS-blue, consistent with exposure of deeper bedrock through tectonism and erosion [2,11].

Discussion: Currently several ideas have been put forward for the formation of Titan's mountains. One hypothesis is that these mountain ridges and segmented mountain belts are the heavily eroded remnants of contractional mountain building processes like fold and thrust belts on Earth [4,5]. Our mountain measurements reveal regular sizes and separations of individual ridges within longer belts. Initially thought to result from erosion alone [4], this segmentation could likewise be the result of minor contractional tectonics with overlapping lobate thrusts making the segments, then amplified by erosion. A closer examination of orientations may reveal this en echelon thrusting. While Titan Mountain Belt spacing and semi-parallelism bears resemblance to extensional geomorphologies, as in the Basin and Range, the sinuosity is more similar to contractional features. Titan's Mountain Belts are slightly more sinuous than either the contractional Zagros or the extensional mountains of the Basin and Range, which corroborates a contractional origin for features on Titan. Furthermore, the higher sinuosity may provide evidence for a longer and more complex multistage history of stress and deformation in Titan's lithosphere, with varying stress regimes over time, termed tectonic warping [9]. Finally, the heights of Titan's mountains make them more analogous to wrinkle ridges on Mars or Mercury, to be examined in future studies.

Mountains on Titan may be uplifted and internally deformed blocks of stratified rocks, subject to a range of stress directions and strengths over time. Given the variations in morphologies, orientations, heights and segmentation, there is likely a range of ages and levels of tectonic activity across the Mountain Belts of Titan.

These studies will prepare us for the morphologies to be revealed by the *Dragonfly* mission, which will lead to an even better understanding of the history of Titan's equatorial mountains.

References: [1] Radebaugh, J. et al. (2007), *Icarus 192*, 77-91. [2] Barnes, J.W. et al. (2007), *JGR 112*, E11006. [3] Mitri, G. et al. (2010), *JGR 115*. [4] Liu et al. (2016), *Icarus 270*, 2-13. [5] Cook-Hallett, C. et al. (2016), *JGR 120*, 1220-1236. [6] Solomonidou, A. et al. (2013), *Planetary and Space Science 77*, 104-117. [7] Lalich, D.E. et al. (2022), *Icarus 374*, 114775. [8] Radebaugh, J. et al. (2018) *Geol. Soc. London 440*, 2305. [9] Haji Hosseinlou (2017), *IGES 9*, 105-114. [10] Radebaugh, J. et al. (2016), *LPSC XLVII*, Abstract 2694. [11] Lake, B. et al. (2022), *LPSC XVIII*.

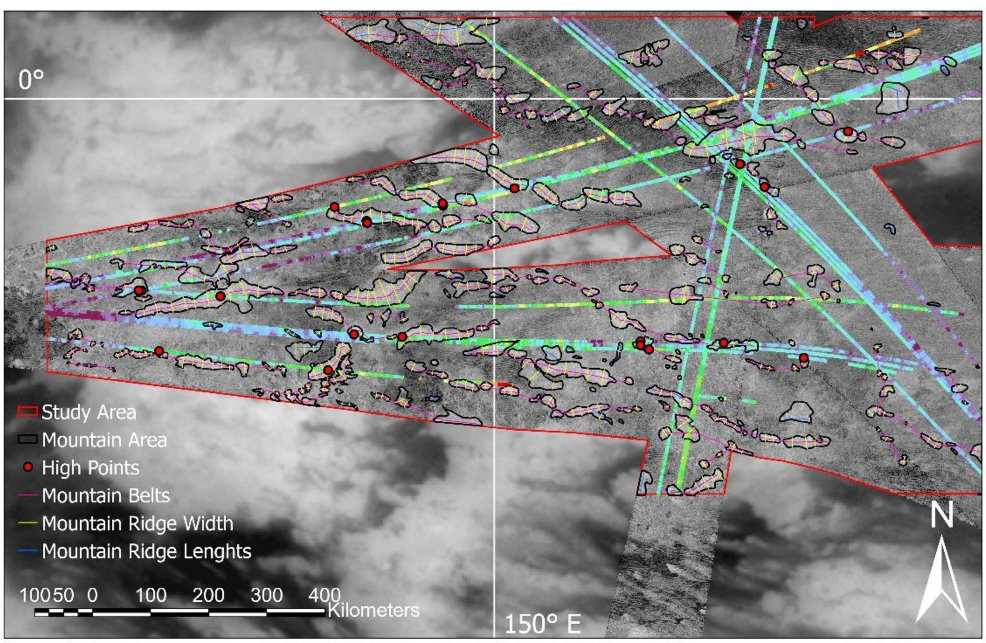

Figure 2. Cassini SAR and SARTopo image mosaic of the study area (in red) with polygon, line and point features.