MODELING OF TITAN'S SURFACE PROCESSES CONSTRAINED BY SHORELINE FRACTAL ANALYSIS AND COMPARISON WITH TERRESTRIAL ANALOGS.

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Introduction: Titan's north polar hydrocarbon lakes [1] offer a unique opportunity to indirectly characterize the statistical properties of Titan's landscape. A statistical characterization of Titan's topography can be extracted through analysis of the shorelines of its north polar lakes, since the complexity of a shoreline can be related to the complexity of the landscape it is embedded in through fractal theory [2, 3]. Such a statistical analysis can also be directly used to compare Titanian lake shorelines with terrestrial ones and infer the dominant processes responsible for formation of lake basins on Titan. The topographic information gleaned from the statistical analyses of Titan's shorelines, in conjunction with the results from terrestrial analogs, can be used to constrain the spatial distribution of surface process types and perform landscape evolution modeling to infer the dominant surface processes that sculpt the landscape of Titan, including impact cratering, fluvial erosion, mass wasting/landslides, aeolian activity, lacustrine processes, cryovolcanism and tectonics.

Statistical Analysis Of Titan's North Polar Shorelines: Our previous study of Titan's north polar shorelines [2] has revealed them to be closely approximated by fractal shapes, a property also demonstrated by terrestrial lake shorelines [3] i.e. measured lengths of these shorelines increases, as the measuring scale decreases, because smaller measuring scales are sensitive to smaller features of the shoreline. We calculated the ruler and box-counting fractal dimensions of 190 of the north polar Titanian lakes using Cassini Synthetic Aperture Radar (SAR) data [4]. The average ruler and box-counting dimensions are 1.27 and 1.32, at length scales of (1-10) km, resulting in an inferred power-spectral exponent of Titan's topography (β) to be ≤ 2.

Some of the shorelines exhibit multi-fractal behavior, (different fractal dimensions at different scales) which we interpret to signify a transition from one set of dominant surface processes to another. We did not observe any spatial variation in the fractal dimension with latitude; however we do report significant spatial variation of the fractal dimension with longitude (increased fractal dimension in the 0-90°E zone where the largest lakes are located) (Fig. 1). Also, we noted a systematic difference between the dimensions of orthogonal sections of lake shorelines (Fig. 2), which signifies possible anisotropy in Titan's topography.

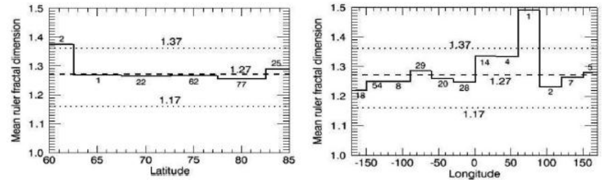

Fig. 1. Spatial variation of fractal dimension of Titanian north polar lake shorelines with latitude and longitude.

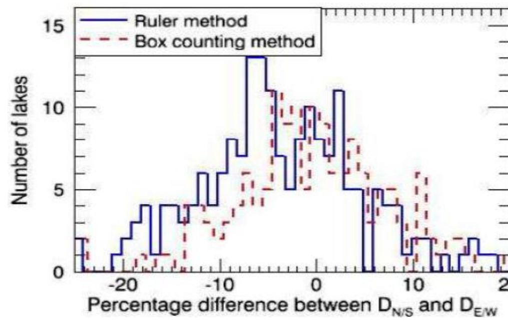

Fig. 2. Anisotropic signature in fractal dimension of Titanian lake shorelines.

Comparison With Terrestrial Analogs: For this statistical comparison, we used C-band (5.66 cm wavelength) Radar backscatter data and a vector database of the outlines of water bodies (SWBD: SRTM Water Body Database) from the Shuttle Radar Topography Mission (SRTM) [5,6]. Formation mechanisms for terrestrial lakes can broadly be classified into nine different types (glacial erosion/deposition, impacts, volcanism (caldera lakes), tectonic uplift/subsidence, fluvial processes (oxbow lakes), aeolian processes (interdune lakes), dissolution of limestone (karst), landslide and periglacial processes (i.e. thermokarst)) [7,8].

Since we do not yet understand which surface processes create the lakes on Titan, we chose to use surface area as the criterion for selecting terrestrial analogs for comparison with Titan's lakes. We chose 114 terrestrial lakes, which include lakes of each process type (excluding thermokarst lakes), as possible analogs to the Titanian lakes for our study. The 114 terrestrial lakes in our database include 20 glacial lakes, 20 volcanic caldera lakes, 6 impact crater lakes, 20 tectonically formed lakes, 20 karst lakes, 10 fluvial oxbow lakes, 10 aeolian interdune lakes and 8 lakes formed by landslides.

Amongst these, we grouped together the 94/114 terrestrial lakes and 184/190 Titanian lakes that have surface areas smaller than 5000 km^2 (we compared the larger lakes separately and had similar findings.)

The statistical parameters that we used for the quantitative comparison are the ruler fractal dimension, shoreline development index (ratio of the shoreline length or perimeter of the lake to the circumference of a circle that has the same area as the lake) and an elongation index (maximum ratio of two perpendicular dimensions). We performed an Analysis-of-Variance (ANOVA) statistical test using these calculated parameters, to determine the probability of the chance occurence of variability between different terrestrial groups. Using the ruler fractal dimensions of the 114 terrestrial lakes, we derive an F-ratio of 5.52, which would occur by chance only 0.002% of the time, indicating that the differences between the lakes formed by various processes are statistically significant. Using the shoreline development indices and the elongation indices, we derive values of F-ratio of 8.59 (which could occur by chance 2.6×10^{-6}% of the time) and 6.47 (which could occur by chance 2.3×10^{-4}% of the time), respectively. Therefore, terrestrial lakes formed by different processes do indeed belong to different statistical populations with different means. Such a statistical analysis can therefore be used to distinguish between groups of terrestrial lakes formed by different processes. Could Titan's lakes be similar to one of these terrestrial sub-populations and not the others?

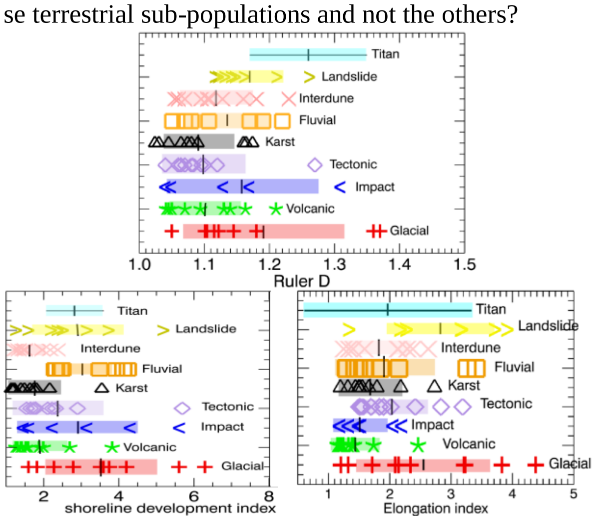

Fig. 3. Comparison of shoreline statistical parameters for Earth and Titan.

In Fig. 3 we compare the fractal dimensions, shoreline development indices and elongation indices for the lakes with surface areas smaller than 5000 km^2. We found overlap between Titan's lakes and terrestrial lakes formed by multiple processes. By performing a Kolmogorov-Smirnov test, we determined that the distribution of Titan's shoreline parameters does not match the distribution of any of the terrestrial process datasets. We thus conclude that there is no one process or set of processes that we can propose, on the basis of shoreline morphology alone, to be responsible for forming the depressions containing the lakes on Titan.

Titan's lakes are thus a set of complex features that have been influenced by many surface processes. In order to further investigate these features we undertake landscape evolution modeling of several simultaneously acting surface processes.

Landscape Evolution Modeling: We are using the results of the statistical analyses of Titanian and terrestrial lake shorelines to constrain the behavior and output of our landscape evolution models for Titan.

Relief in our models is produced by impact cratering and/or simplified models of spatially-variable tectonic uplift. Relief-reducing processes in our models include detachment-limited erosion (i.e. bedrock erosion) as well as transport-limited erosion and deposition (i.e. alluvial channels and fans) [9]. As an initial proof of concept, Fig. 4 shows simulated landscapes depicting the evolution of a cratered landscape (top) and a fractal landscape (bottom) with known power spectrum, modified by bedrock channel erosion (modeled as an advective/erosive process) and mass wasting (landslides) (modeled as a diffusive/smoothing process).

We will report on results of our landscape evolution modeling and provide details of the statistical comparison of Titanian lake shorelines with terrestrial analogs.

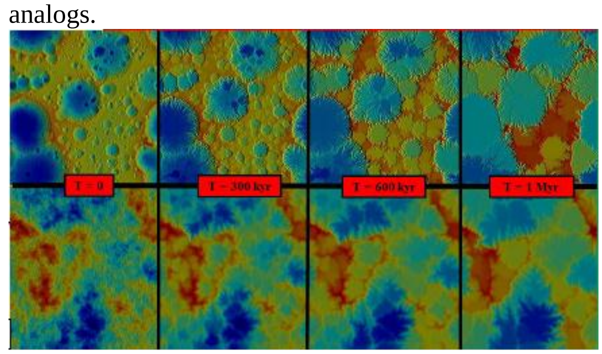

Fig. 4. Synthetic landscapes produced by modifying initial cratered surface (top) and initial fractal surface (bottom) with bedrock channel erosion and mass wasting. Red/Blue colors correspond to high/low elevations.

References: [1]Stofan E.R. et al. (2007) *Nature, 445, 7123,* 61-64. [2] Sharma P. and Byrne S. (2010) *Icarus, 209, 2,* 723-737. [3]Mandelbrot B. (1967) *Science, 156, 3775,* 636-638. [4] Elachi C. et al. (2004). *Space Sc. Rev.,115,* 71-110. [5] Sharma P. and Byrne, S. (2011). *Geophysical Research Letters, 38,* L24203. [6] Farr T.G. et al. (2007) *Rev. of Geophys., 45,* RG2004. [7] Hutchinson G. E. (1957) *John Wiley & Sons, Inc.,* 1015 [8] Cole G.A. (1975) *Textbook of Limnology, 1st Ed.,* 283. [9] Pelletier J.D. (2008) *Cambridge Univ. Press.* 304.