THERMOKARST PROCESSES IN TITAN'S LAKES: COMPARISON WITH TERRESTRIAL DATA.

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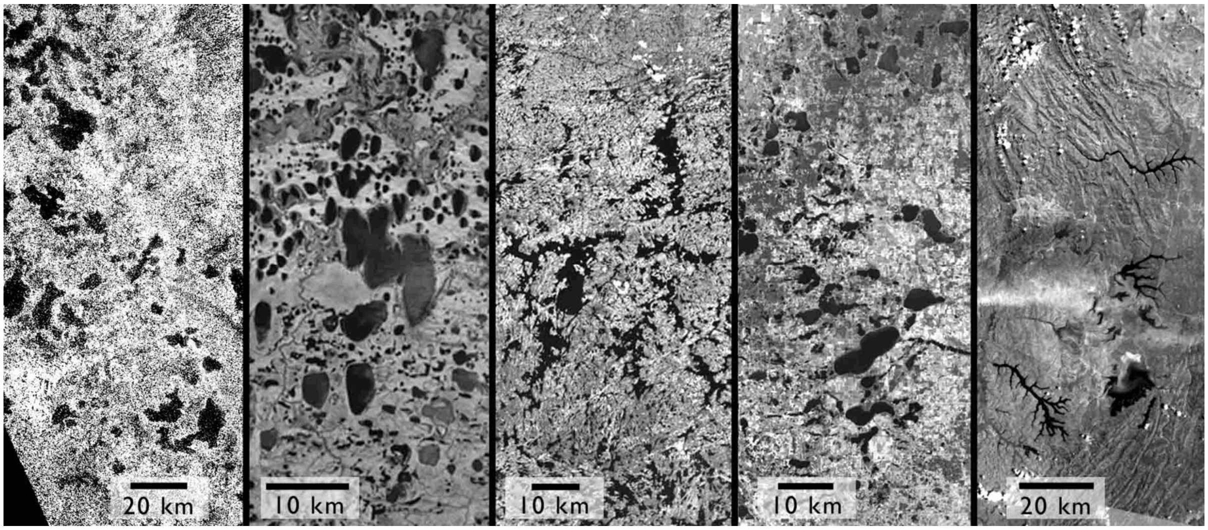

Figure 1. Examples of lakes included in our comparative analysis. (a) Titan, (b) Yakutia (Siberia), (c) Canada, (d) Minnesota (U.S.A.), and (e) the African Great Rift Valley (Rwanda, Burundi, and Tanzania).

Introduction: Thermokarst has been suggested as a possible modification process for Titan's northern lakes [1]. This diagnosis was made on the basis of morphology, particularly the relatively simple, subcircular lake shape, steep littoral regions, and shallow depth. These features are shared by terrestrial alases, periglacial depressions that range from 0.1 to 15 km in length, and 3 to 40 m in depth [2]. These dimensions are comparable to alas-like Titanian lakes, whose mean length we calculate to be 24 ± 16 km, and whose depths are estimated to be a few to a few 10s of m [3].

Thermokarst processes in alases take the form of localized, long term melting of permafrost [2]. The archetypes, found in Yakutia (Siberia), are associated with the Holocene Climatic Optimum (9000 and 5000 B.P.). Given the resemblance between Titanian lakes and terrestrial alases, it is intriguing that surface temperatures at the polar regions of Titan, likely in the range 90 K to 94 K [4], are consistent with an active methane permafrost layer (the melting point of methane under Titanian conditions is 90.7 K).

However, while these preliminary comparisons of Titanian and terrestrial morphologies (and their environments) is promising, there are lakes elsewhere on earth - such as in Minnesota in the U.S. - that exhibit some of the same morphologies without the involvement of thermokarst (Fig. 1). Clearly, then, more information is needed before thermokarst can be accepted as a likely candidate for Titanian lake modification. Here we provide a quantitative comparison of Titanian and terrestrial lake outlines in order to seek the signature of thermokarst processes, if one exists.

Methodology: Our analysis shares some features with that of [5], in which a very general comparison of Titanian and terrestrial shoreline characteristics was made. We use 108 Titanian lakes, 91 Yakutian alas lakes, 20 Minnesotan lakes, 76 Canadian lakes, and 31 African Great Rift Valley lakes (located in Rwanda, Burundi, and Tanzania). Canadian and Rift Valley lakes were chosen as features formed primarily by precipitation in cold and warm environments, respectively, while Minnesotan lakes were chosen because of their morphological similarities to alases.

We obtained outlines of every lake: Titanian outlines were drawn by hand using a polar stereographic basemap of Cassini Radar data; terrestrial lake outlines were extracted from Google Maps. The latter uses a modified Mercator projection which preserves the shape and size of small objects. After [6], we measured the length of lake shorelines by placing virtual rulers of a chosen length end-to-end along the shoreline. This exercise was repeated for a range of ruler lengths, yielding plots of shoreline length vs. ruler length (Fig. 2). Uncertainties were obtained by repeating the analysis with a range of randomly selected starting points for the first ruler.

Unlike [5] and [6], we did not calculate fractal dimension. Instead, we were interested in the shoreline wavelength information contained in the shoreline length plots. Lakes with smooth, scalloped shorelines should exhibit a flattening of the curve as one moves to lower ruler lengths, because no fine details exist to be captured by smaller rulers, resulting in no further increase in the shoreline length estimate.

The final step of our analysis was to measure the approximate curvature of the shoreline length vs. ruler length curves. We first partitioned the data into three bins of equal ruler length range, and computed the mean shoreline and ruler length for each bin. A circle was then fitted to these three data points, and the inverse of the circle's radius was taken as the representative curvature of the data.

Results: Curvature results are shown in Figure 3. As expected for lakes without thermokarst modification, curvature is fairly low regardless of lake size, as is evident in the Canadian and Great Rift Valley data. For these lakes, there are always smaller shoreline features to be captured by smaller rulers. For Titanian and Yakutian lakes, however, curvatures become strongly negative for lakes smaller than about 20 km. This is because shoreline length vs. ruler length curves have strong rollovers (top curve, Fig. 2), implying that short wavelength features are absent from lake outlines. A statistically small number of Minnesotan lakes mirror the Titanian/Yakutian trend, but their curvatures are mostly small.

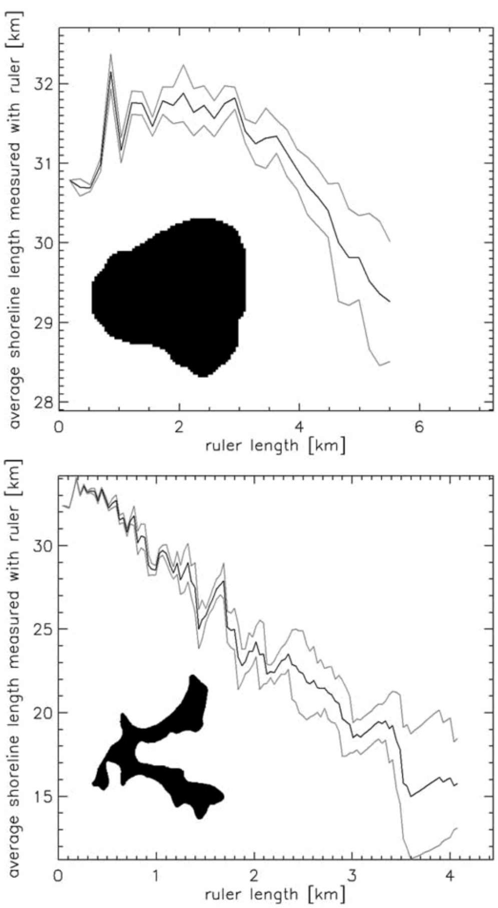

Figure 2. Shoreline length vs. ruler length for a Titanian lake (top) and a Great Rift Valley lake (bottom). Lake shapes are also shown (at approximately the same scale). The curve for the Titan lake is concave, falling off at lower ruler lengths, while the curve for the terrestrial lake is approximately linear.

Conclusions: Our initial analysis indicates that the wavelength structure of Titanian lake outlines follows a similar trend to that of thermokarst alases in Yakutia, a trend that is distinct from other terrestrial lakes. This is consistent with the hypothesis that thermokarst modification of Titan lakes is occurring.

References: [1] Mitchell, K. L. et al. (2007) *LPSC XXXVIII*, Abstract #2064. [2] Gutiérrez, M. (2005) *Climatic Geomorphology*, Elsevier, Amsterdam. [3] Lunine J. I. and Atreya S. K. (2008) *Nat. Geosci.*, *1*, 159-164. [4] Mitri G. et al. (2007) *Icarus*, *186*, 385-394. [5] Sharma P. and Byrne S. (2011) *Geophys. Res. Lett.*, *38*, doi:10.1029/2011GL049577. [6] Mandelbrot B. B. (1967) *Science*, *156*, 636-638.

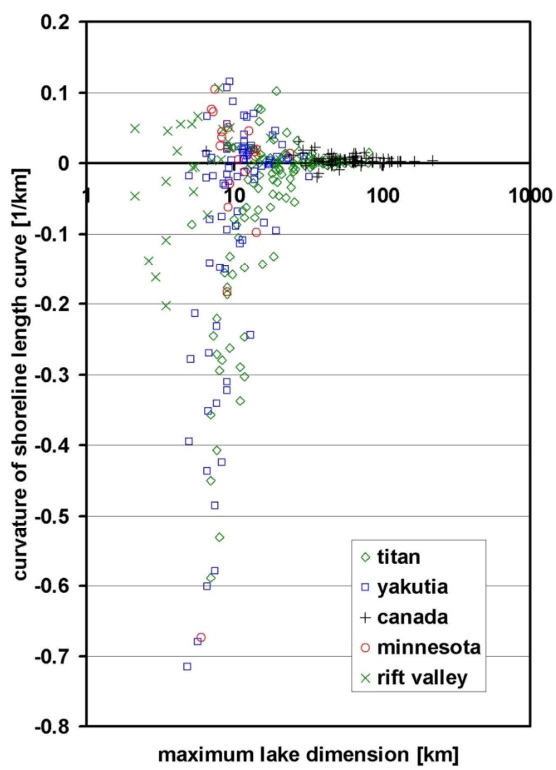

Figure 3. Curvatures of shoreline length curves (as defined in the text) vs. maximum lake dimension. Strongly negative curvatures dominate among small Titanian and Yakutian lakes, a trend that is only weakly mirrored by Minnesotan lakes. Canadian and African lakes of all sizes maintain relatively low curvatures.