A GLOBAL SUB-SURFACE ALKANIFER SYSTEM ON TITAN?

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Introduction: Titan's polar lakes contain insufficient methane to buffer the atmosphere against losses over geological time [1]. However, sufficient additional methane may exist in near-surface liquid reservoirs (subsurface alkanofers or buried seas) [e.g. 2], within the pore space of a regolith of water-ice of 100s m [3] to ~10 km [4] depth. Titan's arctic contains 100s of filled lakes [5,6,7] at a range of elevations [8]. Two studies [6,7] propose subsurface fluid transport from higher elevation lakes to the lower-elevation seas, consistent with such a system [7]. We consider the possibility that these processes can occur over a global scale, and that the seas result from intersection of topography with a global liquid alkane layer; hydraulic head driving liquids from the higher elevation low latitude regions towards the poles [9].

A similar scenario may occur on Mars [10], with low latitude outflows and a global hydrologic system recharged by south polar basal melting. Beyond the thermochemical contrast, there are several important differences: (1) The global groundwater layer on Mars is sealed beneath an impermeable ice-filled cryosphere [10], suppressing outflow unless the cryosphere is fractured, possibly resulting in considerable overpressure; (2) Titan's dominantly compressional crust contrast with Mars' extensional tectonics, which facilitate aquifer pressurization, and may significantly enhance discharge rates when fractures occur [11]; and (3) Clathratization is likely where liquid alkanes are in contact with water-ice, and may result in expansion of ice volume by ~20%, possibly closing off pore space [12].

Testing the model: Carr [13] proposed a fundamental, and successfully applied a, test for the Mars polar basal recharge model. If outflow features are below the maximum possible recharge elevation, that is to say the elevation of the surface beneath the south polar cap, they are consistent with the model; Carr [13] found that the floors of all major outflow sources fit this criterion. Recent studies suggest additional local sources of groundwater from snowpack melt at higher elevation Tharsis and Elysium [14,15], but these do not feed the largest channels. Outflow sites may be more difficult to interpret on Titan, but a similar exercise may prove useful, and so in this work we search for sites of comparable or less elevation than the seas, to search for possible outflow sources. Our aim is to check for plausibility as an end-member model, and put in place the framework for later modeling efforts.

Topographic data for Titan are sparse and poorly controlled relative to Mars. The sources include: (1) RADAR altimetry, of limited spatial coverage; (2) SARTopo [16], of improved coverage with the benefit of being registed to imagery; and (3) Stereo [8], of limited coverage at high spatial resolution. All of these data are currently referenced to a sphere, rather than to a gravitational equipotential geoid, hence there may be considerable relative error in elevations particularly over long distances. Simple fits to the radar data [17] reveal that Titan is somewhat oblate, with mean polar elevations being depressed about 500 m relative to the equator. However, this may not represent the true geoid, as depressions at the poles could be real, consistent with the presence of sea/lake basins. Instead, a near-hydrostatic shape (~100 m polar depression relative to equator) may be more realistic. Finally, it could also be somewhere in between, and until this is resolved, an elevation test is error prone.

Our approach uses multiple estimates of the geoid, ranging from an estimated [17] hydrostatic case (pole radius 100 m less than equator) to the best oblate spheroid fit (pole radius 500 m less than equator) [17], with an assumed 0, 100 or 200m tolerance. Sea level is estimated by displaying SARTopo points of the north polar region atop a SAR mosaic until sea shorelines began to appear. A cluster of several hundred points were found that seemed to highlight the shorelines well, and the lowest 50 of these were selected to avoid biasing the data towards "top of cliff" topography. An abstraction of results from this exercise are shown in Fig. 1. Where topography intersects the same elevation of the seas, we look for signs of outflow.

Results: Some arctic locations in the T18 swath appear to be a few 100 m below sea level. Inspection of these data show that the locations are around lakes, some of which appear drained (radar bright) and some filled (radar dark), demonstrating that Titan's hypothetical global alkanofer system is not in hydraulic equilibrium. The three non-arctic sites found that have sub-shoreline elevations are described below:

Ganesa Macula and the associated Winia Fluctus radar-bright flows, stand out as some of the lowest points on the planet. When taken together with the apparent uniqueness of this area and stereo observations [8], that show a shape for Ganesa that is largely inconsistent with a cryovolcanic dome [e.g. 18], we propose revisiting Ganesa as a potential hydrologic feature. Many of the flow features can be interpreted as sedimentary or fluvial in origin, rather than cryovolcanic. One could counter that cryovolcanic flows are likely to flow downhill and therefore occupy topographic lows. However, the source of the flows appears local. It is possible that there is a geophysical explanation as to why cryovolcanism might occur at topographic lows, which we do not speculate about here.

Ksa Crater's interior shows no direct evidence for fluvial processes. However, Ksa has unusually thick ejecta for a Titan impact crater, something which, on Mars, indicates entrainment of water. It also has a pronounced peak with a depression in the middle, like some Mars peaks that are attributed to evaporation of a subsurface water-rich zone leading to peak collapse; similar is seen on Jupiter's satellites. In summary, Ksa is unusual and the presence of liquids in the subsurface may provide an explanation.

Antarctic lows in the T39 swath are not associated with filled lakes. The main cluster is to the south of a feature at ~50° S that as appears to be an escarpment associated with several fluvial channels. The main depression is a radar-bright expanse fed by apparent channels, which we interpret as a playa. This whole area is consistent with our expectations for an outflow site: low elevation, high nearby slopes and lots of evidence for fluvial/sedimentary processes.

Summary: We have shown partial consistency of observation with our end-member hypothesis (the other end being no horizontal subsurface flow), which may provide an explanation for the formation of several features on Titan's surface. Whether it can be rationalized with experimental studies of methane water-ice interactions [19] remains to be seen. Further work will include permeability measurements, development of a global hydrological flow model, and detailed morphological studies.

References: [1] R.D. Lorenz *et al.* (2008a) *PSS* **56**, 1132-1144. [2] D.J. Stevenson (1992) *Symp. Titan*, ESA SP-338, 17-22. [3] L.M. Lara. *et al.* (1994) *PSS* **41**, 5-l4. [4] K. Kossacki & R.D. Lorenz (1996) *PSS* **9**, 1029-1037. [5] E.R. Stofan *et al.* (2007) *Nature* **445**, 61-64. [6] A. Hayes *et al.* (2008) *GRL* **35**, L09204. [7] K.L. Mitchell *et al.* (in review) "Titan's north polar lake district: Insights from Cassini RADAR". Submitted to *Icarus.* [8] R.L. Kirk (this volume) "Three-Dimensional Views of Titanís Diverse Surface Features from Cassini RADAR Stereogrammetry". [9] J. Lunine & S. Atreya (2008) *Nature Geoscience* **1**(3), 159-164. [10] S.M. Clifford (1993) *JGR* **93**, 10973-11016. [11] J.C. Hanna & R.J. Phillips (1995) *JGR* **111**, E03003. [12] O. Mousis *et al.* (2008) *Astr. J.* **677**, L67-L70. [13] M.H. Carr (2002) *JGR* **107**, 5131. [14] M.H. Carr & J.W. Head (2003) *GRL* **30**, 2245. [15] P.S. Russell & J.W. Head (2007) *PSS* **55**, 315-332. [16] B.W. Stiles *et al.* (in prep.) "Estimating Titan surface topography from Cassini SAR data", *Icarus*. [17] H.A. Zebker *et al.* (in prep.) "Size and shape of Saturn's moon Titan from Cassini RADAR Altimeter and SAR Monopulse observations", *Icarus*. [18] R.M.C. Lopes *et al.* (2007) *Icarus* **186**, 395-412. [19] C. Sotin *et al.* (this volume) "Ice-hydrocarbons interactions under Titan's conditions: Implications for the carbon cycle on Titan."

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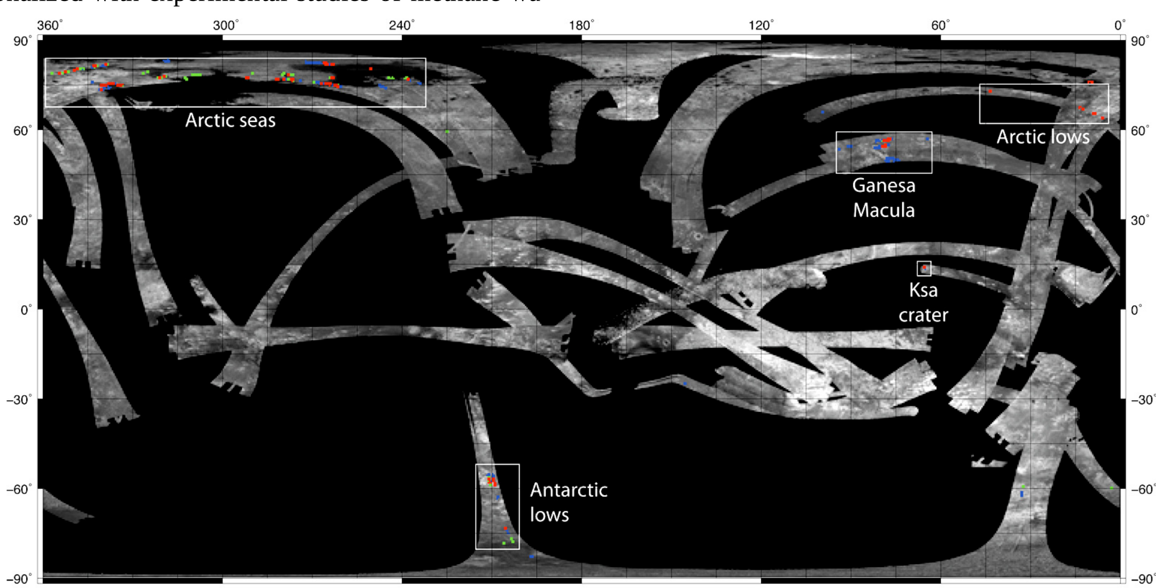

Figure 1: Global mosaic of Cassini Titan Radar Mapper SAR images, with topographic lows relative to sea shores highlighted in red (based on hydrostatic equilibrium; polar radius ~100 m less than equatorial, 0 m tolerance), green (best fit of CTRM topographic data to an oblate ellipsoid; polar radius ~500 m less than equatorial, 0 m tolerance) and blue (as red, 100m tolerance).